Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment:

Study to assess renewal requests for 29 RoHS 2 Annex III exemptions [no. I(a to e -lighting purpose), no. I(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37]

Carl-Otto Gensch, Oeko-Institut

Yifaat Baron, Oeko-Institut

Markus Blepp, Oeko-Institut

Katja Moch, Oeko-Institut

Susanne Moritz, Oeko-Institut

Otmar Deubzer, Fraunhofer Institute for Reliability and Microintegration, IZM

07 June 2016

Report for The European Commission

Prepared by Oeko-Institut e.V., Institute for Applied Ecology and Fraunhofer-Institut IZM for Environmental and Reliability Engineering

Oeko-Institut e.V.

Freiburg Head Office, P.O. Box 1771
79017 Freiburg, Germany

Tel.:+49 (0) 761 – 4 52 95-0
Fax +49 (0) 761 – 4 52 95-288

Web: www.oeko.de

Fraunhofer-Institut IZM

Gustav-Meyer-Allee 25
13355 Berlin, Germany

Tel.: +49 (0)30 / 46403-157
Fax: +49 (0)30 / 46403-131

Web: www.fraunhofer.de

Approved by:

Adrian Gibbs, Eunomia	Carl-Otto Gensch, Oeko Institute e.V
(Peer Review)	(Project Director)
………………………………………………..	………………………………………………..

Eunomia Research & Consulting Ltd
37 Queen Square, Bristol, BS1 4QS, UK

Tel: +44 (0)117 9172250
Fax: +44 (0)8717 142942

Web: www.eunomia.co.uk

Acknowledgements:

We would like to express our gratitude towards stakeholders who have taken an active role in the contribution of information concerning the requests for exemption handled in the course of this project.

Disclaimer:

Eunomia Research & Consulting, Oeko-Institut and Fraunhofer Institute IZM have taken due care in the preparation of this report to ensure that all facts and analysis presented are as accurate as possible within the scope of the project. However no guarantee is provided in respect of the information presented, and Eunomia Research & Consulting, Oeko-Institut and Fraunhofer Institute IZM are not responsible for decisions or actions taken on the basis of the content of this report.

Executive Summary

Under Framework Contract no. ENV.C.2/FRA/2011/0020, a consortium led by Eunomia Research & Consulting was requested by DG Environment of the European Commission to provide technical and scientific support for the evaluation of exemption requests under the new RoHS 2 regime. The work has been undertaken by Oeko-Institut and Fraunhofer Institute IZM, and has been peer reviewed by Eunomia Research & Consulting.

E.1.0 Background and Objectives

The RoHS Directive 2011/65/EU entered into force on 21 July 2011 and led to the repeal of Directive 2002/95/EC on 3 January 2013. The Directive can be considered to have provided for two regimes under which exemptions could be considered, RoHS 1 (the former Directive 2002/95/EC) and RoHS 2 (the current Directive 2011/65/EU).

- The scope covered by the Directive is now broader as it covers all EEE (as referred to in Articles 2(1) and 3(1));
- The former list of exemptions has been transformed in to Annex III and may be valid for all product categories according to the limitations listed in Article 5(2) of the Directive. Annex IV has been added and lists exemptions specific to categories 8 and 9;
- The RoHS 2 Directive includes the provision that applications for exemptions have to be made in accordance with Annex V. However, even if a number of points are already listed therein, Article 5(8) provides that a harmonised format, as well as comprehensive guidance – taking the situation of SMEs into account – shall be adopted by the Commission; and
- The procedure and criteria for the adaptation to scientific and technical progress have changed and now include some additional conditions and points to be considered. These are detailed below.

The new Directive details the various criteria for the adaptation of its Annexes to scientific and technical progress. Article 5(1)(a) details the various criteria and issues that must be considered for justifying the addition of an exemption to Annexes III and IV:

- The first criterion may be seen as a threshold criterion and cross-refers to the REACH Regulation (1907/2006/EC). An exemption may only be granted if it does not weaken the environmental and health protection afforded by REACH;
- Furthermore, a request for exemption must be found justifiable according to one of the following three conditions:

  - Substitution is scientifically or technically impracticable, meaning that a substitute material, or a substitute for the application in which the restricted substance is used, is yet to be discovered, developed and, in some cases, approved for use in the specific application;
  - The reliability of a substitute is not ensured, meaning that the probability that EEE using the substitute will perform the required function without failure for a period of time comparable to that of the application in which the original substance is included, is lower than for the application itself;
  - The negative environmental, health and consumer safety impacts of substitution outweigh the benefits thereof.
- Once one of these conditions is fulfilled, the evaluation of exemptions, including an assessment of the duration needed, shall consider the availability of substitutes and the socio-economic impact of substitution, as well as adverse impacts on innovation, and life cycle analysis concerning the overall impacts of the exemption; and
- A new aspect is that all exemptions now need to have an expiry date and that they can only be renewed upon submission of a new application.

The current study presented here, evaluates a total of 29 exemption renewal requests for existing exemptions approaching their expiry date.

E.2.0 Key Findings – Overview of the Evaluation Results

The exemption requests covered in this project and the applicants concerned, as well as the final recommendations and proposed expiry dates are summarised in Table 1-1. The reader is referred to the corresponding section of this report for more details on the evaluation results.

The – not legally binding – recommendations for the requests for the renewal of exemptions (29 RoHS 2 Annex III exemptions: no. I(a to e - lighting purpose), no. I(f - special purpose), no. 2(a), no. 2(b)(3), no. 2(b)(4), no. 3, no. 4(a), no. 4(b), no. 4(c), no. 4(e), no. 4(f), no. 5(b), no. 6(a), no. 6(b), no. 6(c), no. 7(a), no. 7(c) - I, no. 7(c) - II, no. 7(c) - IV, no. 8(b), no. 9, no. 15, no. 18b, no. 21, no. 24, no. 29, no. 32, no. 34, no. 37) were submitted to the EU Commission by Oeko-Institut and have already been published at the EU CIRCA website on 27 June 2016. So far, the Commission has not adopted any revision of the Annex to Directive 2011/65/EU based on these recommendations.

Table 1-1: Overview of the exemption requests, associated recommendations and expiry dates

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n. 1	Mercury in single-capped (compact) fluorescent lamps not exceeding (per burner):			Mercury in single-capped (compact) fluorescent lamps not exceeding (per burner)		
a to e (lighting)		1(a) For general lighting purposes < 30 W: 5 mg 1(b) For general lighting purposes ≥ 30 W and < 50 W: 5 mg 1(c) For general lighting purposes ≥ 50 W and < 150 W: 5 mg 1(d) For general lighting purposes ≥ 150 W: 15 mg 1(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm: 7 mg	NARVA Lichtquellen GmbH + Co. KG LightingEurope	(a) For general lighting purposes < 30 W: 2.5 mg (b) For general lighting purposes ≥ 30 W and < 50 W: 3.5 mg	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024	The maximum transition period should be granted to other categories (18 months); The COM should consider adopting measures to limit product availability to B2B transactions.
				(c) For general lighting purposes ≥ 50 W and < 150 W: 5 mg (d) For general lighting purposes ≥ 150 W: 15 mg	For Cat. 5: 21 July 2019; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(e) For general lighting purposes with circular or square structural shape and tube diameter ≤ 17 mm	7 mg may be used per burner until 31.12.2019, 5 mg may be used per burner after 31.12.2019 For Cat. 5: 21 July 2019 For Cat. 8 and Cat. 9: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023 For Sub-Cat. 9 industrial: 21 July 2024	
f (special purpose)		1(f) For special purposes: 5 mg	NARVA Lichtquellen GmbH + Co. KG LightingEurope	**Mercury in single-capped (compact) fluorescent lamps not exceeding (per burner)**		
				(f)-I For lamps designed to emit light in the ultra-violet spectrum: 5 mg	For Cat. 5: 21 July 2021	The maximum transition period should be granted for other applications and other categories (18 months); Integrating this entry into a UV lamp exemption should be considered.

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(f)-II For special purposes: 5 mg	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	The COM should consider adopting measures to limit product availability to B2B transactions.
n. 2 (a)	Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp):		NARVA Lichtquellen GmbH + Co. KG LightingEurope	**Mercury in double-capped linear fluorescent lamps for general lighting purposes not exceeding (per lamp)**		
(1-5)		(1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 5 mg		1) Tri-band phosphor with normal lifetime and a tube diameter < 9 mm (e.g. T2): 4 mg	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
		(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 5 mg (3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 5 mg (4) Tri-band phosphor with normal lifetime		(2) Tri-band phosphor with normal lifetime and a tube diameter ≥ 9 mm and ≤ 17 mm (e.g. T5): 3 mg (3) Tri-band phosphor with normal lifetime and a tube diameter > 17 mm and ≤ 28 mm (e.g. T8): 3.5 mg (4) Tri-band phosphor with normal lifetime and a tube diameter > 28 mm (e.g. T12): 3.5 mg	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	The maximum transition period should be granted for other applications and other categories (18 months);

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
		and a tube diameter > 28 mm (e.g. T12): 5 mg (5) Tri-band phosphor with long lifetime (≥ 25 000 h): 8 mg		(5) Tri-band phosphor with long lifetime (≥ 25 000 h): 5 mg	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n. 2 (b) (3)		(3) Non-linear tri-band phosphor lamps with tube diameter > 15 mm (e.g. T9)	NARVA Lichtquellen GmbH + Co. KG LightingEurope	2(b) Mercury in other fluorescent lamps not exceeding (per lamp)		
				(3) Non-linear tri-band phosphor lamps with tube diameter > 17 mm (e.g. T9)	For Cat. 5: 21 July 2019; For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n. 2 (b) (4)		(4) Lamps for other general lighting and special purposes (e.g. induction lamps): 15 mg per lamp	LightingEurope	(I) Lamps for other general lighting and special purposes (e.g. induction lamps); 15 mg may be used per lamp after 31 December 2011	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(II) Lamps emitting light in the non-visible spectrum: 15 mg per lamp	For Cat. 5: 21 July 2021	Integrating this entry into a UV lamp exemption should be considered.
				(III) Emergency lamps: 15 mg per lamp	For Cat. 5: 21 July 2021	
				(IV) Mercury in other fluorescent special purpose lamps not specifically mentioned in this Annex: 15mg per lamp	For Cat. 5: 21 January 2019	
n.3	Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes not exceeding (per lamp):		LightingEurope	Mercury in cold cathode fluorescent lamps and external electrode fluorescent lamps (CCFL and EEFL) for special purposes not exceeding (per lamp):		
		(a) Short length (≤ 500 mm): 3.5 mg per lamp (b) Medium length (> 500 mm and ≤ 1 500 mm): 5 mg per lamp (c) Long length (> 1 500 mm): 13 mg per lamp		(a) Short length (≤ 500 mm), 3,5 mg may be used per lamp; (b) Medium length (> 500 mm and ≤ 1 500 mm), 5 mg may be used per lamp; (c) Long length (> 1 500 mm) 13 mg may be used per lamp	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				(d) Short length (≤ 500 mm), 3,5 mg may be used per lamp in EEE placed on the market before 22 July 2016* (e) Medium length (> 500 mm and ≤ 1 500 mm), 5 mg may be used per lamp in EEE placed on the market before 22 July 2016* (f) Long length (> 1 500 mm) 13 mg may be used per lamp in EEE placed on the market before 22 July 2016*	For Cat. 5: 21 July 2021	*Or before the EC's decision date on this exemptions renewal
				(g) For back-lighting liquid crystal displays, not exceeding 5 mg per lamp, used in industrial monitoring and control instruments placed on the market before 22 July 2017	Alternative a: For Cat. 5: 21 July 2021; or Alternative b: For Sub-Cat. industrial: 21 July 2024	To be considered should Ex. 35 of Annex IV be transferred to Annex III
n.4 (a)	Mercury in other low pressure discharge lamps (per lamp): 15 mg per lamp		NARVA Lichtquellen GmbH + Co. KG LightingEurope	4(a)-I: Mercury in low pressure non-phosphor coated discharge lamps, where the application requires the main range of the lamp-spectral output to be in the UV spectrum; up to 15 mg mercury may be used per lamp.	For Cat. 5: 21 July 2021	The maximum transition period should be granted for other applications and other categories (18 months);

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
				4(a)-II: Mercury in other low pressure discharge lamps (15 mg may be used per lamp)	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.4 (b)	Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60:		LightingEurope	Mercury in High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner) in lamps with improved colour rendering index Ra > 60:		
		I) P ≤ 155 W: 30 mg per burner II) 155 W < P ≤ 405 W: 40 mg per burner III) P > 405 W: 40 mg per burner		(I) P ≤ 155 W; 30 mg may be used per burner (II) 155 W < P ≤ 405 W; 40 mg may be used per burner	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024	
				(III) P > 405 W; 40 mg may be used per burner	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	It is understood that these lamps are no longer placed on the market. Thus the exemption appears to have become obsolete, however is specified for Cat. 8 and Cat. 9 in light of Article 5(2).

Exemption No.	Wording: Main Entry	Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.4 (c)	Mercury in other High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner)		LightingEurope	Mercury in other High Pressure Sodium (vapour) lamps for general lighting purposes not exceeding (per burner):		
		I) P ≤ 155 W: 25 mg per burner II) 155 W < P ≤ 405 W: 30 mg per burner III) P > 405 W: 40 mg per burner		(I) P ≤ 155 W; 25 mg may be used per burner after 31 December 2011 (II) 155 W < P ≤ 405 W; 30 mg may be used per burner after 31 December 2011 (III) P > 405 W; 40 mg may be used per burner after 31 December 2011	For Cat. 5: 31 August 2018; For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
				(IV) P ≤ 405 W; 20 mg may be used per burner (V) P > 405 W; 25 mg may be used per burner	For Cat. 5: from 1 September 2018 until 21 July 2021	
n.4(e)	Mercury in metal halide lamps (MH)		LightingEurope	Mercury in metal halide lamps (MH)	For Cat. 5, 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.4(f)	Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex	VskE Lighting Europe VDMA	(I) Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex	For Cat. 8 & 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. industrial: 21 July 2024	
			(II) Mercury in high pressure mercury vapour lamps used in projectors where an output ≥2000 lumen ANSI is required	For Cat. 5: 21 July 2021	
			(III) Mercury in high pressure sodium vapour lamps used for horticulture lighting	For Cat. 5: 21 July 2021	
			(IV) Mercury in lamps emitting light in the ultraviolet spectrum for curing and disinfection	For Cat. 5: 21 July 2021	
n.5(b)	Lead in glass of fluorescent tubes not exceeding 0,2 % by weight	LightingEurope	Lead in glass of fluorescent tubes not exceeding 0,2 % by weight	For Cat. 5: 21 July 2021; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.6(a)	Lead as an alloying element in steel for machining purposes and in galvanised steel containing up to 0,35 % lead by weight	Dunkermotoren; The European Steel Association (EUROFER) and European General Galvanizers Association (EGGA) Sensata Technologies	I) Lead as an alloying element in steel for machining purposes containing up to 0,35 % lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2019	
			II) Lead in batch hot dip galvanized steel components containing up to 0.2% lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2021	
			III) Lead as an alloying element in steel for machining purposes and in galvanized steel containing up to 0,35 % lead by weight	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.6(b)	Lead as an alloying element in aluminium containing up to 0,4 % lead by weight	AISBL - EAA Sensata Technologies Dunkermotoren	Lead as an alloying element in aluminium		
			I) with a lead content up to 0.4 % by weight, used for the production of parts not machined with shape cutting chipping technologies	For Cat. 1-7 and 10 and 11: 21 July 2021	
			II) for machining purposes with a lead content up to 0.4 % by weight	For Cat. 1-11: 21 July 2021	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			III) Lead as an alloying element in aluminium containing up to 0,4 % lead by weight	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.6(c)	Copper alloy containing up to 4 % lead by weight	Bourns Inc. Dunkermotoren Framo Morat Group Sensata Technologies Phoenix Contact GmbH &Co KG; Harting KGaA Lighting Europe	Copper alloy containing up to 4% lead by weight	For Cat. 1-7 and 10 and 11: 21 July 2019; For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.7(a)	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	Bourns Inc. IXYS Semiconductor GmbH Chenmko Enterprise Co., Ltd Yeashin Technology Co., Ltd Freescale Semiconductor Formosa Microsemi Co., Ltd.	I) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
			Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)		
			II) in all applications not addressed in items III and IV,	For categories 1 to 7 and 10: 21 July 2021	See exemption report for alternative

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			but excluding applications in the scope of exemption 24		wording proposal for 7(a)(II-IV).
			III) for die attach	For categories 1 to 7 and 10: 21 July 2019	
			IV) for electrical connections on or near the voice coil in power transducers		
n.7(c)-I	Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	Bourns Inc. Sensata Technologies YAGEO Corporation RALEC TECHNOLOGY (KUNSHAN) CO. BANDELN electronic GmbH&Co.KG RALEC TECHNOLOGY (KUNSHAN) CO. Japan Electronics & Information Technology Industries Association Murata Elektronik GmbH EPCOS AG VISHAY BC	7(c)-I: Electrical and electronic components containing lead in a ceramic other than dielectric ceramic in discrete capacitor components, e.g. piezoelectronic devices	For categories 1-7 and 10: 21 July 2019	See exemption report for alternative wording proposal for 7(c)-I
			7(c)-V: Electrical and electronic components containing lead in a glass or in a glass or ceramic matrix compound. This exemption does not cover the use of lead in the scope of exemption 34 (cermet-based trimmer potentiometers).	For categories 1-7 and 10: 21 July 2021	See exemption report for alternative wording proposal for 7(c)-I

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
		components BEYSCHLAG GmbH SCHOTT AG	7(d): Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	See exemption report for alternative wording proposal for 7(c)-I
n.7(c)-II	Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher	Murata Elektronik GmbH EPCOS AG VISHAY BC components BEYSCHLAG GmbH JEITA(Japan Electronics & Information Technology Industries Association)	Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
			Lead in dielectric ceramic in discrete capacitor components for a rated voltage of 125 V AC or higher, or for a rated voltage of 250 V DC or higher	For Cat. 1-7 and 10: 21 July 2019	
n.7(c)-III	Recommended modified wording		Lead in dielectric ceramic in discrete capacitor components for a rated voltage of less than 125 V AC, or for a rated voltage of less than 250 V DC	1 January 2013 and after that date may be used in spare parts for EEE placed on the market before 1 January 2013	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.7(c)-IV	Lead in PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors	ST Microelectronics	Lead in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors	For Cat. 1-7 and 10: 21 July 2019; For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
n.8(b)	Cadmium and its compounds in electrical contacts	Sensata Technologies National Electrical Manufacturers Association	8(b) Cadmium and its compounds in electrical contacts	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	
			8(c): Cadmium and its compounds in electrical contacts of (I) circuit breakers (II) thermal motor protectors excluding hermetically sealed thermal motor protectors	For Cat. 1-7 and 10: 21 July 2021	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			(III) thermal sensing controls	For Cat. 1-7 and 10: 21 July 2019	
			(IV) AC switches rated at 6 A and more in combination with 250 V AC and more (V) AC switches rated at 12 A and more in combination with 125 V AC and more	Applies to *EEE* in Cat. 1 to 5, 7 and 10 For Cat. 1 to 5, 7 and 10: 21 July 2019	
			(VI) AC switches for corded tools rated at 6 A and more in combination with 250 V AC and more (VII) AC switches for corded tools rated at 12 A and more in combination with 125 V AC and more (VIII) DC switches for cordless tools with a rated current of 20 A and more in combination with at a rated voltage of 18 V DC and more (IX) switches for tools conceived to be used with power supplies of 200 Hz and more	Applies to Cat. 6 EEE: 21 July 2021	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.9	Hexavalent chromium as an anticorrosion agent of the carbon steel cooling system in absorption refrigerators up to 0,75 % by weight in the cooling solution	Dometic	Hexavalent chromium as an anticorrosion agent applied in carbon steel cooling systems of absorption refrigerators of applications: (I) designed to operate with electrical heater only, with up to 0,75 % by weight in the cooling solution		
			(II) designed to operate with variable energy sources (III) designed to operate with other than an electrical heater	For Cat. 1: 21.7.2019 (three years)	
n.15	Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	Intel Corporation	I) Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			II) Lead in solders to complete a viable electrical connection between semiconductor die and the carrier within integrated circuit flip chip packages where one of the below criteria applies:		
			a) A semiconductor technology node of 90 nm or larger	For categories 1-7 and 10: 21 July 2019	
			b) A single die of 300 mm^2 or larger in any semiconductor technology node	For categories 1-7 and 10: 21 July 2021	
			c) Stacked die packages with dies of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger	For categories 1-7 and 10: 21 July 2021	
			d) Flip chip on lead frame (FCOL) packages with a rated current of 3 A or higher and dies smaller than 300 mm^2		The exemption cannot be recommended but is added here in case the Commission would decide that it should be granted

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.18(b)	Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps when used as sun tanning lamps containing phosphors such as BSP (BaSi 2 O 5 :Pb)	NARVA Lichtquellen GmbH + Co. KG Lighting Europe	Lead as activator in the fluorescent powder (1 % lead by weight or less) of discharge lamps containing phosphors such as BSP (BaSi2O5 :Pb), when used: I. in tanning equipment; or II. in Annex I category 8 medical phototherapy equipment - excluding applications falling under point 34 of Annex IV	For Cat. 5: 21 July 2021	
n.21	Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses	Lighting Europe	I. Cd when used in colour printed glass to provide filtering functions, used as a component in lighting applications installed in displays and control panels of EEE	For Cat. 1-7 and 10: 21 July 2021	The EU Commission should consider if it would not be more beneficial to add this entry to Ex. 13b.
			II. **Alternative A:** Cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, when used to comply with harmonised standards specifying the use of	For Cat. 1-7 and 10: 21 July 2021	The EU Commission could consider providing a shorter validity period so as to promote the supply chain to develop a strategy for research and

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			particular hues for safety applications. **Alternative B:** Cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses, excluding Cd used in colour printed glass to provide filtering functions.		development of alternatives for Cd-based inks.
			III. Lead in printing inks for the application of enamels on other than borosilicate glasses.	For Cat. 1-4, 6,7 and 10: 21 July 2019	The recommended period should suffice to establish the reliability of Pb-free substitutes in other than borosilicate glasses.

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
			IV. Lead and cadmium in printing inks for the application of enamels on glasses, such as borosilicate and soda lime glasses	For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;	As it can be understood that the exemption duration may vary for various categories on the basis of Article 5(2), expiration dates have been specified here on the basis of the validity periods specified in Article 5(2) for categories, which are newly in scope.
n.24	Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	Knowles	Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	For Cat. 1-7 and 10: 21 January 2019; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.29	Lead bound in crystal glass as defined in Annex I (Categories 1, 2, 3 and 4) of Council Directive 69/493/EEC (1)	EUROPEAN DOMESTIC GLASS and LightingEurope	Lead bound in crystal glass as defined in Directive 69/493/EEC	For Cat. 1-10: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023 For Sub-Cat. industrial: 21 July 2024	
n.32	Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes	Coherent Inc. JDSU	Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes	For Cat. 1-10: 21 July 2021 For Sub-Cat. 8 in-vitro: 21 July 2023 For Sub-Cat. industrial: 21 July 2024	
n.34	Lead in cermet-based trimmer potentiometer elements	General Electric	Lead in cermet-based trimmer potentiometers	For Cat. 1-7 and 10: 21 July 2019; For Cat. 8 and Cat. 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024;	

Exemption No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration	Comments
n.37	Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body	IXYS Semiconductor GmbH General Electric	Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body	For categories 1-7 and 10: 21 July 2019; For Cat. 8 and 9: 21 July 2021; For Sub-Cat. 8 in-vitro: 21 July 2023; For Sub-Cat. 9 industrial: 21 July 2024	

The report includes the following sections:

Section 1.0: Project Set-up

Section 2.0: Scope

Section 3.0: Links from the Directive to the REACH Regulation

Sections 4.0 through 34.0: Evaluation of the requested exemptions handled in the course of this project.

Contents

List of Tables and Figures

1.0 Project Set-up

Assignment of project tasks to Oeko-Institut, started 29 December 2014. The overall project has been led by Carl-Otto Gensch. At Fraunhofer IZM the contact person is Otmar Deubzer. The project team at Oeko-Institut consists of the technical experts Yifaat Baron and Katja Moch. Eunomia, represented by Adrian Gibbs, have the role of ensuring quality management.

2.0 Scope

The scope of the project covers the evaluation of twenty-nine exemptions for which requests for renewal have been submitted to the European Commission. An overview of the exemption requests is given in Table 1-1 below.

In the course of the project, a stakeholder consultation was conducted. The stakeholder consultation was launched on 21 August 2015 and held for a period of 8 weeks, thus concluding on 16 October 2015.

The specific project website was used in order to keep stakeholders informed on the progress of work: http://rohs.exemptions.oeko.info. The consultation held during the project was carried out according to the principles and requirements of the European Commission. Stakeholders who had registered at the website were informed through email notifications about new steps within the project.

Information concerning the consultation was provided on the project website, including a general guidance document, the applicants' documents for each of the exemption requests, results of earlier evaluations where relevant, a specific questionnaire and a link to the EU CIRCA website. All non-confidential stakeholder comments, submitted during the consultation, were made available on the RoHS Evaluation website and on the EU CIRCABC website (Communication and Information Resource Centre for Administrations, Businesses and Citizens).[1]

The evaluation of the stakeholder contributions led to further consultation including, inter alia, engaging with stakeholders in further discussion, further exchanges in order to clarify remaining questions, cross-checking with regard to the accuracy of technical arguments, and checks in respect of confidentiality issues. Meetings held in the context of the exemptions are detailed in the specific exemption reports.

[1] EU CIRCABC website: https://circabc.europa.eu (Browse categories > European Commission > Environment > RoHS 2014 Evaluations Review, at top left, click on "Library")

The exemptions requested for renewal were evaluated according to the various criteria (Cf. Section E.1.0 for details). The evaluations of each exemption appear in the following chapters. The information provided by the applicants and by stakeholders is summarised in the first sections. This includes a general description of the application and requested exemption (requested renewal or proposed amendment), a summary of the arguments made for justifying the exemption, information provided concerning possible alternatives and additional aspects raised by the applicants and other stakeholders. In some cases, reference is also made to information submitted by applicants and stakeholders in previous evaluations, in cases where a similar request has been reviewed or where a renewal has been requested of a request reviewed in the past. The Critical Review follows these sections, in which the submitted information is discussed, to clarify how the consultants evaluate the various information and what conclusions and recommendations have been made. For more detail, the general requirements for the evaluation of exemption requests may be found in the technical specifications of the project.[2]

[2] Cf. under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_8/RoHS_Pack8_Technical_specifications.pdf

3.0 Links from the Directive to the REACH Regulation

Article 5 of the RoHS 2 Directive 2011/65/EU on "Adaptation of the Annexes to scientific and technical progress" provides for the:

> "*inclusion of materials and components of EEE for specific applications in the lists in Annexes III and IV, provided that such inclusion does not weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006*".

RoHS 2 does not further elaborate the meaning of this clause.

Regulation (EC) No 1907/2006 regulates the safe use of chemical substances, and is commonly referred to as the REACH Regulation since it deals with **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances. REACH, for its part, addresses substances of concern through processes of authorisation and restriction:

- Substances that may have serious and often irreversible effects on human health and the environment can be added to the candidate list to be identified as Substances of Very High Concern (SVHCs). Following the identification as SVHC, a substance may be included in the Authorisation list, available under Annex XIV of the REACH Regulation: "List of Substances Subject to Authorisation". If a SVHC is placed on the Authorisation list, companies (manufacturers and importers) that wish to continue using it, or continue placing it on the market, must apply for an authorisation for a specified use. Article 22 of the REACH Regulation states that: *"Authorisations for the placing on the market and use should be granted by the Commission only if the risks arising from their use are adequately controlled, where this is possible, or the use can be justified for socio-economic reasons and no suitable alternatives are available, which are economically and technically viable."*
- If the use of a substance (or compound) in specific articles, or its placement on the market in a certain form, poses an unacceptable risk to human health and/or to the environment that is not adequately controlled, the European Chemical Agency (ECHA) may restrict its use, or placement on the market. These restrictions are laid down in Annex XVII of the REACH Regulation: "Restrictions on the Manufacture, Placing on the Market and Use of Certain Dangerous Substances, Mixtures and Articles". The provisions of the restriction may be made subject to total or partial bans, or other restrictions, based on an assessment of those risks.

The approach adopted in this report is that once a substance has been included into the regulation related to authorization or restriction of substances and articles under REACH, the environmental and health protection afforded by REACH may be weakened in cases where, an exemption would be granted for these uses under the provisions of RoHS. This is essentially the same approach as has already been adopted for the re-evaluation of some existing RoHS exemptions 7(c)-IV, 30, 31 and 40,[3] as well as for the evaluation of a range of requests assessed through previous projects in respect of RoHS 2.[4] Furthermore, substances for which an authorisation or restriction process is already underway are also reviewed, so that future developments may be considered where relevant.

When evaluating the exemption requests, with regard to REACH compliance, we have checked whether the substance / or its substitutes are:

- on the list of substances proposed for the adoption to the Candidate List (the Registry of Intentions);
- on the list of substances of very high concern (SVHCs- the Candidate List);
- in the recommendations of substances for Annex XIV (recommended to be added to the Authorisation List);
- listed in REACH Annex XIV itself (The Authorization List); or
- listed in REACH Annex XVII (the List of Restrictions).

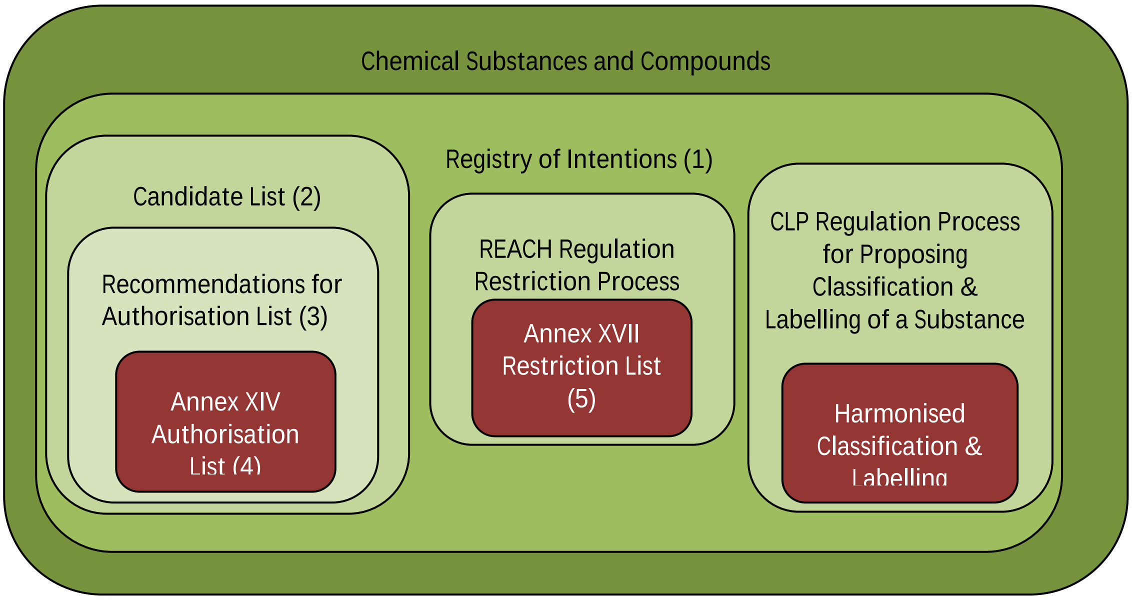
As the European Chemicals Agency (ECHA) is the driving force among regulatory authorities in implementing the EU's chemicals legislation, the ECHA website has been used as the reference point for the aforementioned lists, as well as for the exhaustive register of the Amendments to the REACH Legal Text.

Figure 3-1 shows the relationship between the two processes and categories. Substances included in the red areas may only be used when certain specifications and or conditions are fulfilled.

[3] See Zangl, S.; Blepp, M.; Deubzer, O. (2012) Adaptation to Scientific and Technical Progress under Directive 2011/65/EU - Transferability of previously reviewed exemptions to Annex III of Directive 2011/65/EU, Final Report, Oeko-Institut e. V. and Fraunhofer IZM, February 17, 2012, http://rohs.exemptions.oeko.info/fileadmin/user_upload/Rohs_V/Re-evaluations_transfer_RoHS_I_RoHS_II_final.pdf

[4] Gensch, C., Baron, Y., Blepp, M., Deubzer, O., Manhart, A. & Moch, K. (2012) Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive), Final Report, Oeko-Institut e. V. and Fraunhofer IZM, 21.12.2012 http://rohs.exemptions.oeko.info/fileadmin/user_upload/Rohs_V/RoHS_V_Final_report_12_Dec_2012_final.pdf

Figure 3-1: Relation of REACH categories and lists to other chemical substances



The following bullet points explain in detail the above mentioned lists and where they can be accessed:

- Member States Competent Authorities (MSCAs) / the European Chemicals Agency (ECHA), on request by the Commission, may prepare Annex XV dossiers for identification of Substances of Very High Concern (SVHC), Annex XV dossiers for proposing a harmonised Classification and Labelling, or Annex XV dossiers proposing restrictions. The aim of the public Registry of Intentions is to allow interested parties to be aware of the substances for which the authorities intend to submit Annex XV dossiers and, therefore, facilitates timely preparation of the interested parties for commenting later in the process. It is also important to avoid duplication of work and encourage co-operation between Member States when preparing dossiers. Note that the Registry of Intentions is divided into three separate sections: listing new intentions; intentions still subject to the decision making process; and withdrawn intentions. The registry of intentions is available at the ECHA website at: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/registry-of-intentions;
- The identification of a substance as a Substance of Very High Concern and its inclusion in the Candidate List is the first step in the authorisation procedure. The Candidate List is available at the ECHA website at http://echa.europa.eu/web/guest/candidate-list-table;
- The last step of the procedure, prior to inclusion of a substance into Annex XIV (the Authorisation list), involves ECHA issuing a Recommendation of substances for Annex XIV. The ECHA recommendations for inclusion in the Authorisation List are available at the ECHA website at

http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list;

- Once a decision is made, substances may be added to the Authorisation List available under Annex XIV of the REACH Regulation. The use of substances appearing on this list is prohibited unless an Authorisation for use in a specific application has been approved. The Annex can be found in the consolidated version of the REACH Legal Text (see below);
- In parallel, if a decision is made concerning the Restriction on the use of a substance in a specific article, or concerning the restriction of its provision on the European market, then a restriction is formulated to address the specific terms, and this shall be added to Annex XVII of the REACH Regulation. The Annex can be found in the consolidated version of the REACH Legal Text (see below); and
- As of the 28 of September, 2015, the last amendment of the REACH Legal Text was dated from 28 May 2015 (Commission Regulation (EU) No 2015/830) and so the updated consolidated version of the REACH Legal Text, dated 01.06.2015, was used to check Annex XIV and XVII: The consolidated version is presented at the ECHA website: http://echa.europa.eu/web/guest/regulations/reach/legislation.

Relevant annexes and processes related to the REACH Regulation have been cross-checked to clarify:

- In what cases granting an exemption could "weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006" (Article 5(1)(a), pg.1)
- Where processes related to the REACH regulation should be followed to understand where such cases may become relevant in the future;

In this respect, restrictions and authorisations as well as processes that may lead to their initiation, have been reviewed, in respect of where RoHS Annex II substances are mentioned (i.e. lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).[5]

Compiled information in this respect has been included, with short clarifications where relevant, in Tables A.1-5, which appear in Appendix A.1.0.

The information has further been cross-checked in relation to the various exemptions evaluated in the course of this project. This has been done to clarify that the Article 5(1)(a) pg.1 threshold-criteria quoted above is complied with in cases where an

[5] This review currently does not address the 4 phthalates, DEHP, BBP, DBP and DIBP, which according to Commission Delegated Directive (EU) 2015/863 of 31 March 2015, have been added to the Annex. Information regarding these substances shall be added in future reviews.

exemption is to be granted / its duration renewed/ its formulation amended/ or where it is to be revoked and subsequently to expire as an exemption. The considerations in this regard are addressed in each of the separate chapters in which the exemption evaluations are documented (Chapters 4.0 through 34.0) under the relevant section titled “*REACH Compliance – Relation to the REACH Regulation*” (Sections 4.5.1 through 34.4.1).

21.0 Exemption 7a

Declaration

In the sections that precede the "Critical Review" the phrasings and wordings of stakeholders' explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms

CTE	Coefficient of thermal expansion; measure for the thermal mismatch between two materials bonded together
DA5	'Die Attach 5' – a partnership between Bosch, Infineon, Freescale, STM and NXP
DCB	Direct copper bonding
DBC	Direct-bonded copper, like DCB
EEE	Electrical and electronic equipment
HMP	High melting point
HMPS	high melting point solders
LHMPS	Lead-containing high melting point solders with at least 85 % of lead content
RoHS 1	Directive 2002/95/EC
RoHS (Directive)	Directive 2011/65/EU (recast RoHS Directive, RoHS 2) if not specified otherwise
SAC	Tin-silver-copper (solders)
SMT	Surface mount technology
TFCB	Thick film copper bonding
THT	Through hole technology

21.1 Description of the Requested Exemption

21.1.1 Overview of the Submitted Exemption Requests

Table 21-1 gives an overview of the various applications for the continuation of exemption 7(a).

IXYS apply for the continuation of exemption 7(a) with limited scope. This scope restrictionis related to the applicants' product portfolio and does not imply that IXYS have RoHS-compliant solutions for all other uses of lead-containing high melting point solders (LHMPS) in the scope of the current exemption 7(a). Bosch contributed to the stakeholder consultation in supporting the continuation of exemption 7(a) without changes, but alternatively proposed a specific exemption for their own specific use of LHMPS.

Table 21-1: Overview of applications and stakeholder inputs related to exemption 7(a)

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Bourns[791]	Continuation of exemption without changes	5 years	-
Bosch[792]	Support for renewal without change, otherwise *"Lead in high melting temperature type solders used in high-power transducers (loudspeakers)"*	Not indicated	Submitted during public stakeholder consultation as answers to the consultation questionnaire
Chenmko	Unclear	Unclear	Application disqualified for formal reasons as lacking even most basic information
Formosa	Continuation of exemption without changes	5 years	Application disqualified for formal reasons as lacking even most basic information

[791] Bourns Inc. 2015a "Exemption Request Exemption 7a: Document "7a_Exemption_extension_ap_7a.pdf"," Bourns Inc., http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/7a_Exemption_extension_ap_7a.pdf

[792] Bosch Security Systems GmbH 2015 "Document "Bosch-Stakeholder-contribution-Exemption-request-7a.pdf", submitted during the online stakeholder consultation," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bosch-Stakeholder-contribution-Exemption-request-7a.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Freescale et al.[793]	Continuation without change	Maximum validity period (5 years)	-
IXYS[794]	Lead in soft solder alloys used in power semiconductor devices containing more than 90 % lead	Maximum validity period (5 years)	Applicant mentions alternative technology (DCB, direct copper bonding)
Yea Shin Technology	Unclear	Unclear	Application disqualified for formal reasons as lacking even most basic information

21.1.2 Background and History of the Exemption

Exemption 7(a) "Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)" was already listed in the annex of Directive 2002/95/EC (RoHS 1)[795], when it was officially published in 2003. In 2008/2009, the exemption was reviewed for the first time.[796] The evaluators found that exemption 7(a) allowing the use of lead-containing high melting point solders (LHMPS) is still required. However, exemption 7(a) is material specific, while most other RoHS exemptions are application specific. LHMPS can therefore be used in each application as long as it contains at least 85 % of lead, even if lead-free alternatives are available. In the course of the exemption evaluation in 2008/2009, the reviewers stated that:

> *"[...]HMP solders are used where alternative solutions reducing the amounts of lead are available* [797]

---

[793] Freescale Semiconductors/NXP et al. 2015a "Request for Continuation of Exemption 7a, document "Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf": Exemption request form," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf

[794] IXYS Semiconductor GmbH 2015a "Request for continuation of exemption 7a with limited scope, document "7a_IXYS_RoHS_V_Application_Form.pdf": Exemption request form," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/7a_IXYS_RoHS_V_Application_Form.pdf

[795] Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, RoHS 1, European Union (13 February 2003)

[796] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[797] Ibid., page 86

1) *The current general exemption for lead in HMP solders offers a loophole to bypass the use of lead-free solders or to avoid searching for other RoHS-compliant solutions that do not require the use of lead. Manufacturers use leaded HMP solders in applications, for which others offer lead-free solutions.*[798]

2) *The current general exemption unnecessarily increases the use of lead in applications, where lead-free solutions are technically impracticable and an exemption for the use of lower lead content solders would be possible or is already in place."*[799]
A component manufacturer stated that "It has become more apparent that some of our customers are tending towards using higher lead alloys (typically 95 % lead rather than 50 % lead) '....]". [we] have actively encouraged switching to the lower lead content In/Pb solder alloys allowed by exemption 24."
Instead of using available or applying for a new exemption for the use of lead in low lead-content solders like e.g. the tin-lead solder with 37 % lead (SnPb37), manufacturers may shift to HMP solders with high lead contents of 85 % and more.[800]*"*

In 2009, the reviewers therefore recommended transferring exemption 7(a) into an application specific exemption:

> *"[...] in line with the latest Commission decisions on exemptions which are application and technology oriented and thus are use specific. [...] It cannot be assumed that [the] stakeholder comments cover all uses, in which the use of lead in HMP solders needs to be exempted [...]. Parts of the electronics industry thus might suddenly see themselves producing non-RoHS-compliant products if the general exemption would be changed into an application specific based on the available information from the stakeholder consultation for this review process. A new stakeholder consultation is required to give industry worldwide the opportunity to apply for the necessary application and technology specific exemptions. [...]*
>
> *The reviewers propose leaving the exemption unchanged for now, but giving it an expiry date, which allows industry a reasonable time frame to apply for specific exemptions for the use of lead in HMP solders, where they are justifiable by the requirements set out in Art. 5(1)(b). [...] The consultants propose 30 June 2013 as the expiry date for exemption 7(a)."*[801]

798 Ibid., page 86
799 Ibid., page 86
800 Ibid., page 86
801 Ibid., page 87

The Commission did not set an expiry date. In 2011, exemption 7(a) was transferred to Annex III of the recast directive 2011/65/EU[802] (RoHS 2) without changes, and the maximum period to the next review or the expiry of the exemption was respectively extended from July 2014 under RoHS 1 to July 2016 under RoHS 2 for use in all electrical and electronic equipment (EEE) in the scope of the RoHS Directive other than EEE in categories 8 and 9.

As the RoHS Directive requires that *"Exemptions from the restriction for certain specific materials or components should be limited in their scope [...]"*, and in order to avoid abuse of exemption 7(a), the scope specification of exemption 7(a) is in the focus of the present review as far as such exemptions would be in line with the conditions for exemptions laid down in Art. 5(1)(b).

21.1.3 Technical Description of the Requested Exemption

The technical background of exemption 7(a) was described in detail in the report of the last review of this exemption in 2009.[803] This chapter therefore only presents the most relevant technical facts and information that is of relevance for this review.

The technical background of the Bourns[804] and IXYS[805] exemption requests are technically equivalent to the technical description submitted by Freescale/NXP et al.[806] They are therefore not specifically explained in this chapter.

According to Freescale et al.[807] the most important property for lead (Pb) HMP solders (LHMPS) is the high melting point, which is solely managed by the lead composition. Other practical properties, such as electrical conductivity, thermal conductivity, ductility, corrosion-resistivity, appropriate oxidation nature, and wettability are also inherent in lead. Lead is the only known element which gives all these properties. Table 21-2 sums up the properties of lead required in LHMPS.

21.1.3.1 Specific Properties of Lead in LHMPS

In Table 21-2 and in the subsequent figures, Freescale et al.[808] present the required properties of lead in HMPS. It is the physical and chemical properties of the alloys that are important. Some combinations of elements (e.g. AuSn) will meet some criteria, but the essential requirement is the unique combination of essential properties of HMP solders with lead, not any single property.

---

[802] Recital 19 of the Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast), RoHS 2, European Union (1 July 2011)
[803] Op. cit. Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009, p. 76 et seqq.
[804] dddOp. cit. Bourns Inc. 2015a
[805] Op. cit. IXYS Semiconductor GmbH 2015a
[806] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[807] Ibid.
[808] Ibid.

Table 21-2: Required performance of HMPS solder and specific properties of lead

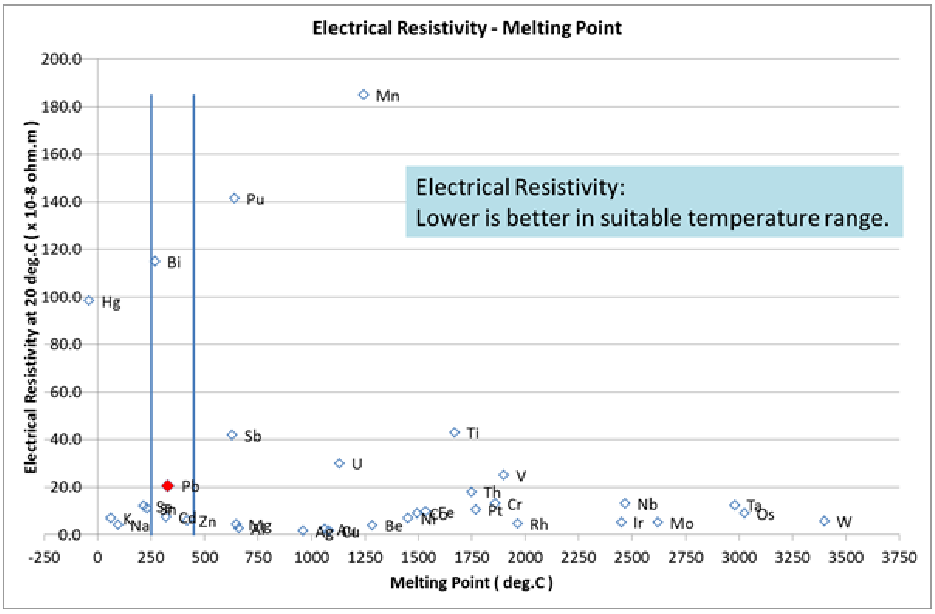
Performance requirements	Reasons for the requirements	Function of lead	Data
High melting points	Not to be melted during secondary assembly steps including soldering. Functionality of electrical parts not to deteriorate.	While HMPS applications require minimum melting points above 250°C, solder processes have an upper limit defined as 450 °C. Few elements have melting points in this range. 250°C is a critical limit, and in reality for most applications the melting point for the HMPS in specific applications is higher. Lead is the least hazardous among these elements such as tellurium, cadmium or thallium.	Melting points, cf. Figure 21-1 to Figure 21-11 below
Electrical connection	Electrical functionality	Lead is the unique element which has practical qualities of melting point, electrical conductivity, thermal conductivity, mechanical reliability and chemical stability with an ideal balance.	Electrical resistivity, cf. Figure 21-1 and Figure 21-2 below
Thermal conduction	To ensure the reliability of electronic components due to the heat dissipation		Thermal conductivity, cf. Figure 21-3and Figure 21-4 below
Ductility	To join the materials having the different coefficients of expansion together (To ensure mechanical reliability)		Young's modulus, cf. Figure 21-5 and Figure 21-6 below
Corrosion-resistivity	To ensure the reliability		Ionization tendency (very low next to hydrogen, it means difficult to oxidize), cf. Figure 21-7 and Figure 21-8 below
Oxidation nature	To prevent oxidation at the secondary mounting; To ensure the reliability		Standard electrode potential, cf. Figure 21-9 and Figure 21-10 below

Source: Freescale et al.[809]

[809] Ibid.

The below figures illustrate the properties of lead for wide and narrow temperature ranges respectively. Freescale et al.[810] plotted as many different metallic elements as possible in the ‘wide temperature’ range figures to show that elements present in the high melting point solder domain are extremely limited. The ‘narrow temperature range’ graphs are presented by enlarging the illustrations in order to make it easier to understand the properties of lead in the melting domain of high melting point solders. The narrow temperature range is necessary from the processability and usability points of view.

Figure 21-1: Electrical resistivity and melting points of elements (wide temperature range)

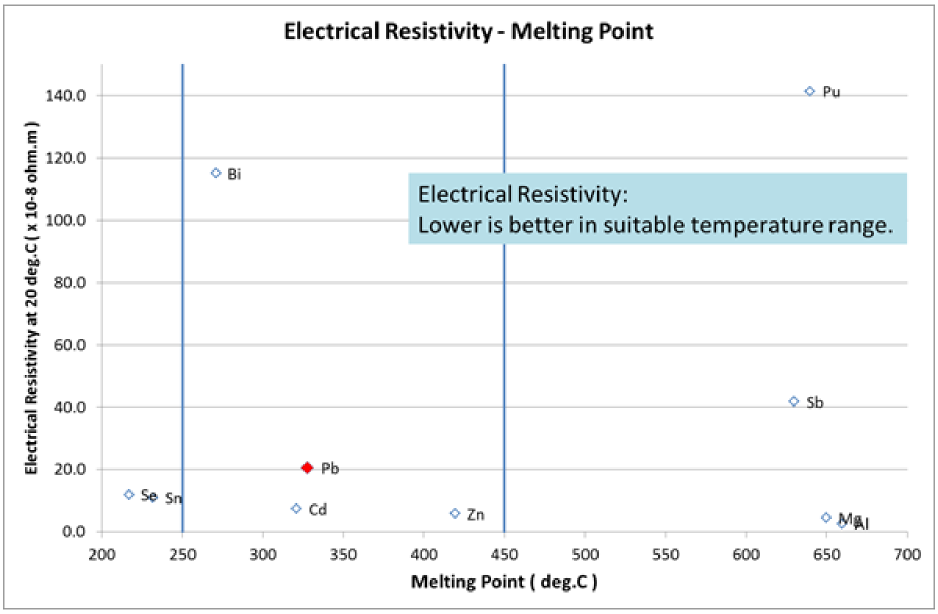


Source: Freescale et al.[811]

[810] Freescale Semiconductors/NXP et al. 2016a: “Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Freescale_Response_2016-01-28.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, Freescale (NXP) et al., on 28 January 2016” unpublished manuscript,

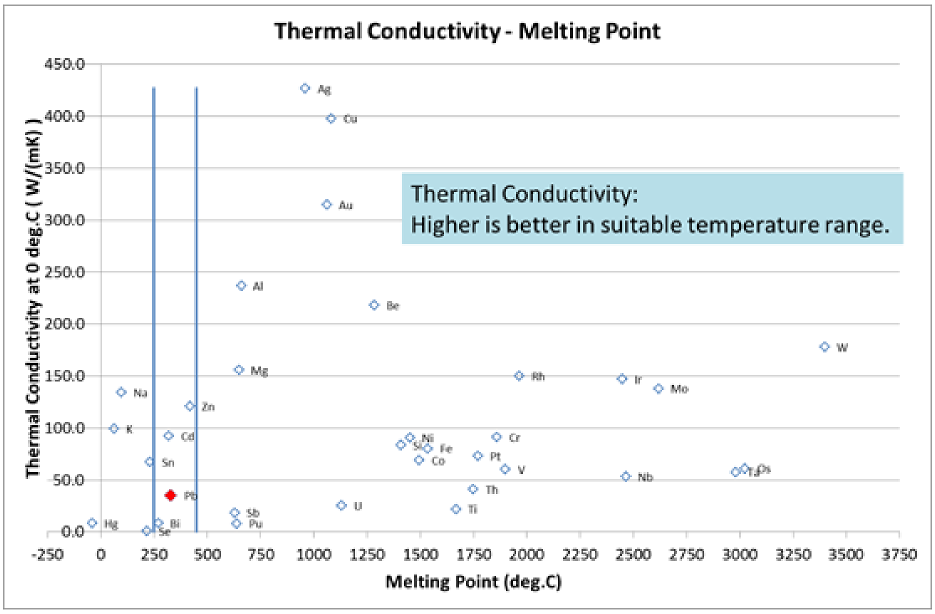
[811] Op. cit. Freescale Semiconductors/NXP et al. 2015a

Figure 21-2: Electrical resistivity and melting points by element (narrow temperature range)



Source: Freescale et al.[812]

Figure 21-3: Thermal conductivity and melting points by element (wide temperature range)

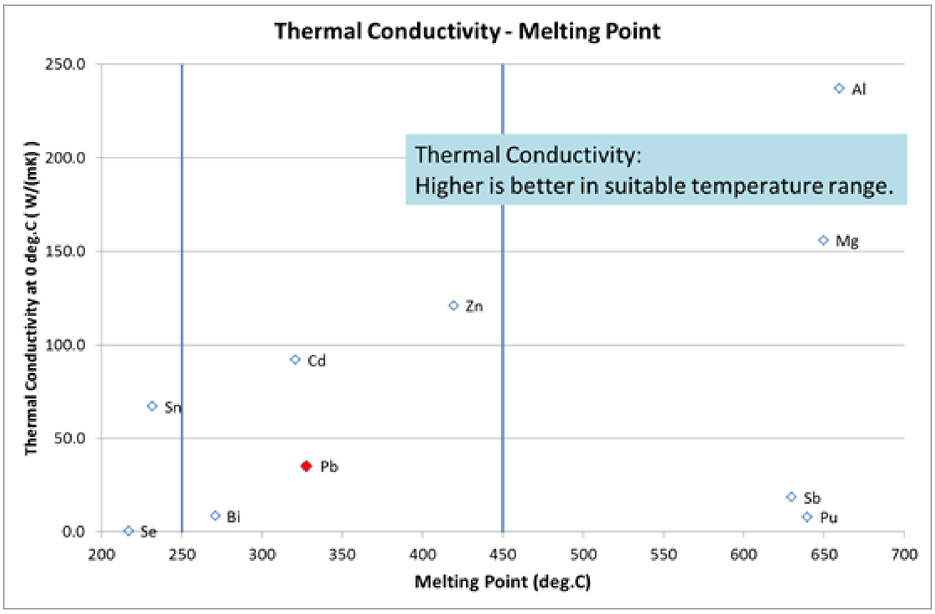


Source: Freescale et al.[813]

---

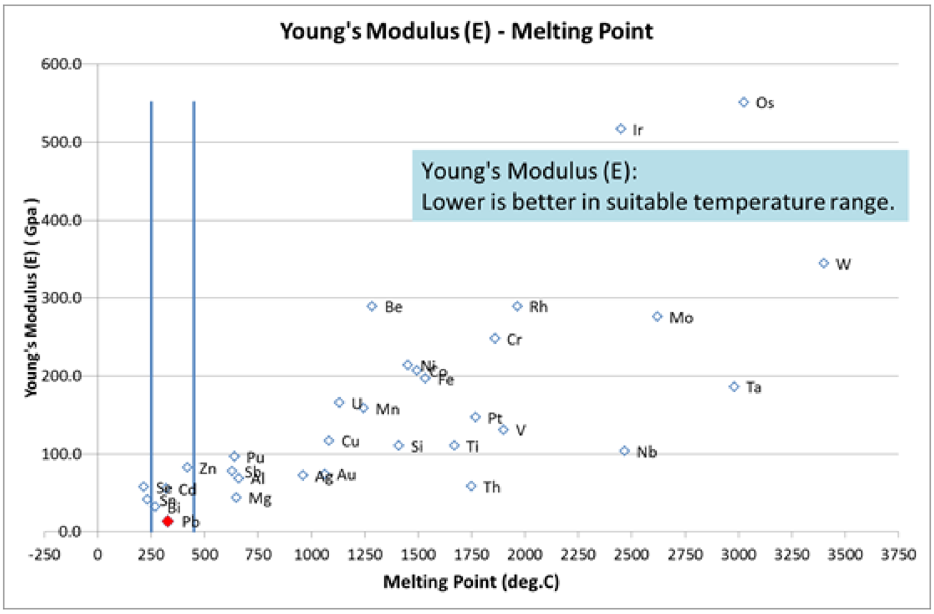
[812] Ibid.

Figure 21-4: Thermal conductivity and melting points by element (narrow temperature range)



Source: Freescale et al.[814]

Figure 21-5: Young's modulus (E) by melting points (wide temperature range)

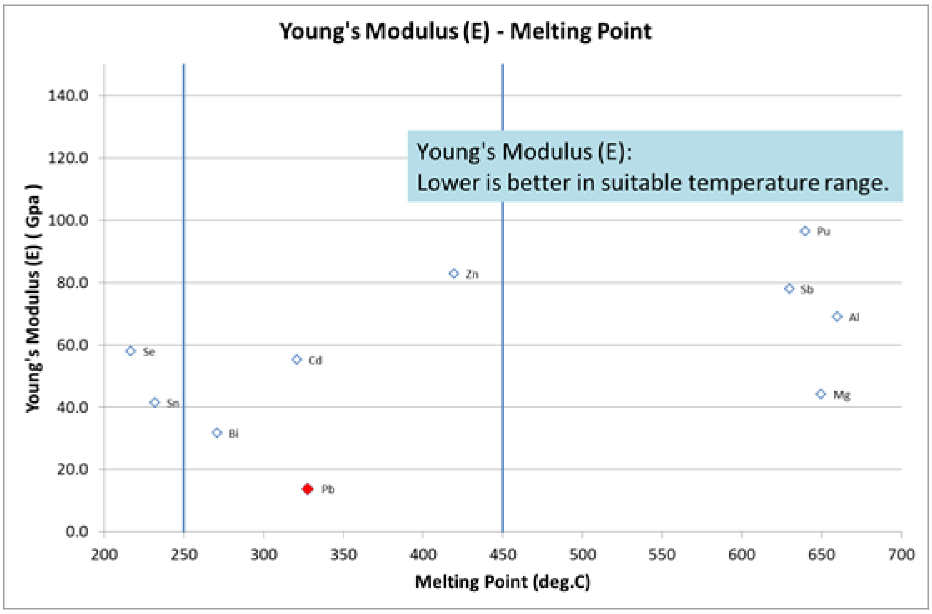


Source: Freescale et al.[815]

---

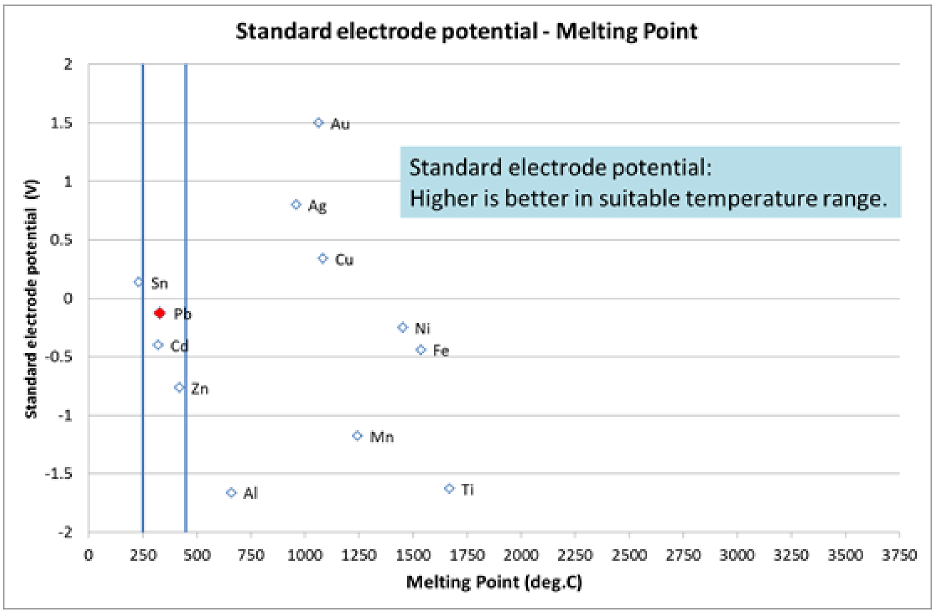
[813] Ibid.
[814] Ibid.

Figure 21-6: Young's modulus (E) by melting points (narrow temperature range)



Source: Freescale et al.[816]

Figure 21-7: Standard electrode and melting points of elements (wide temperature range)

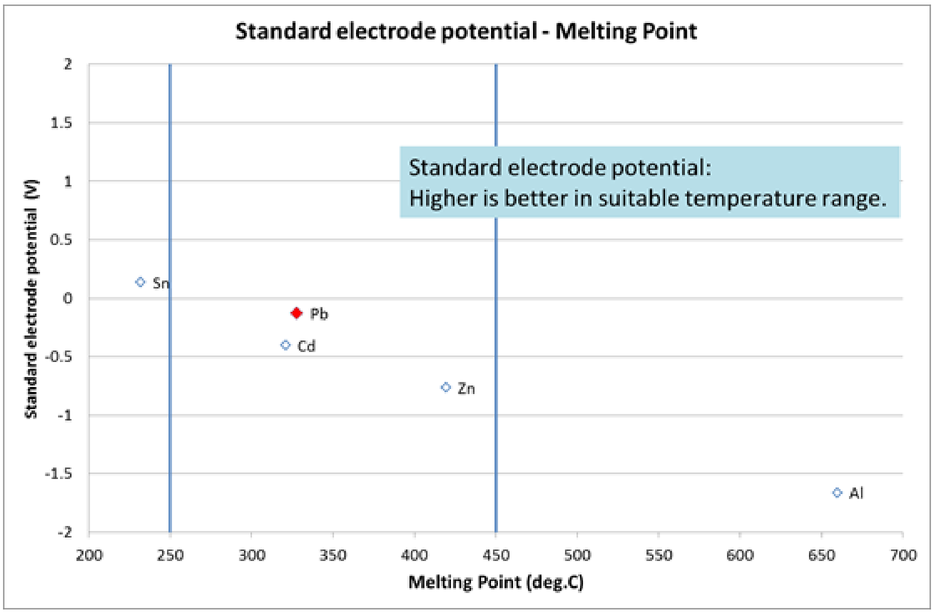


Source: Freescale et al.[817]

---

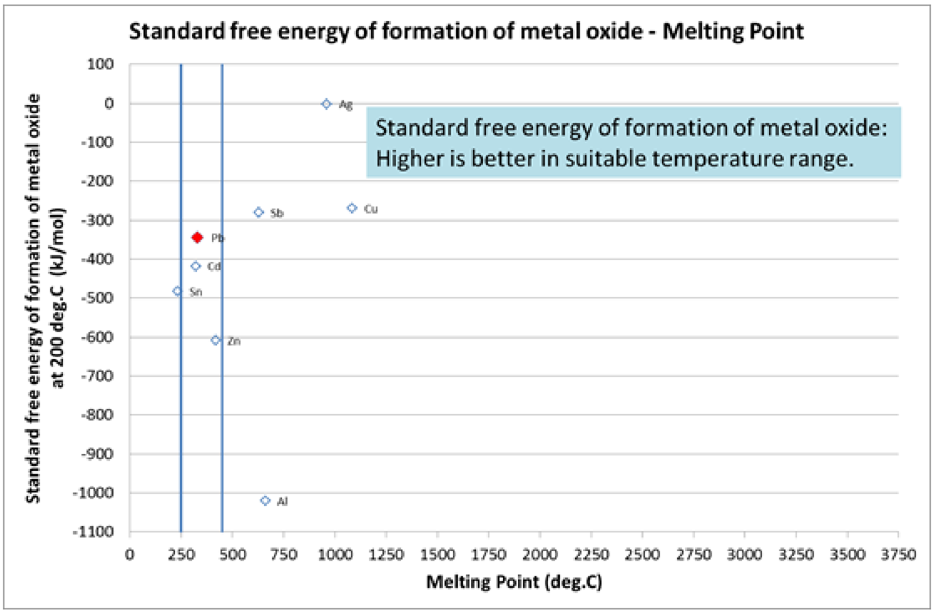
[815] Ibid.
[816] Ibid.

Figure 21-8: Standard electrode and melting points of elements (narrow temperature range)



Source: Freescale et al.[818]

Figure 21-9: Standard free energy of metal oxide formation and melting points of elements (wide temperature range)

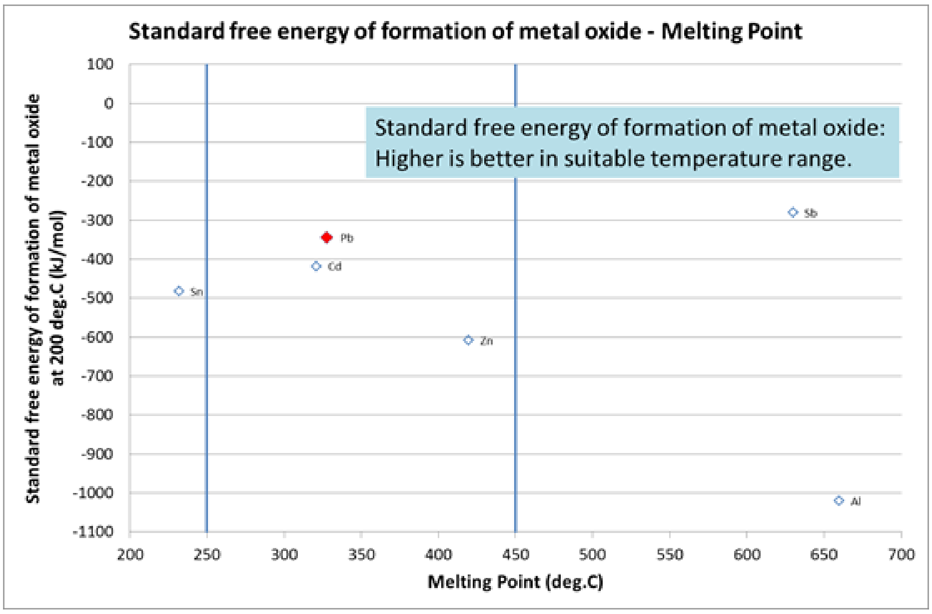


Source: Freescale et al.[819]

---

[817] Ibid.
[818] Ibid.

Figure 21-10: Standard free energy of metal oxide formation and melting points of elements (narrow temperature range)



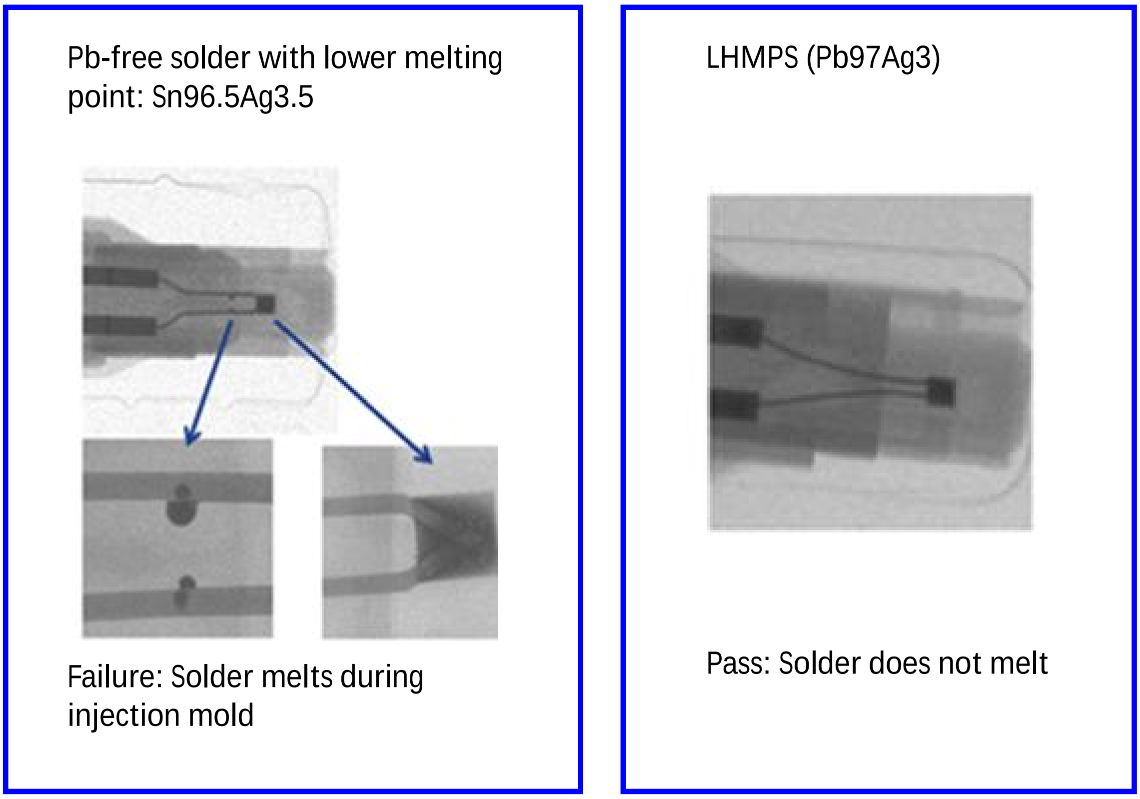
Source: Freescale et al.[820]

With Figure 21-11, Freescale et al.[821] explain why a thermistor requires high HMPS. Thermistor devices are used in high temperature / harsh environment applications. This requires plastic over-moulding with materials having a working temperature of ~ 260 ^{o}C. High temperature solder is required to avoid any reflows which weaken the connecting lead[822]-to-thermistor adhesion. The left picture in Figure 21-11 details the solder reflow from plastic over-moulding with lead-free type solders. The picture on the right depicts high temperature lead-based solder in the same over-moulding operation.

---

[819] Ibid.
[820] Ibid.
[821] Ibid.
[822] not Pb

Figure 21-11: Thermistor requirement for LHMPS



Source: Freescale et al.[823]

Freescale et al.[824] explain that similar circumstances are relevant with current limiting thermistor products. Current limiting thermistors can reach temperatures up to 240 °C during normal operating conditions in the field. In order to stay above the plastic and solder melting point for this application, LHMPS are the only commercial solution available at this time.

---

[823] Ibid.
[824] Ibid.

21.1.3.2 Uses of LHMPS

Table 21-3 lists the uses of LHMPS, which are illustrated with examples in the figures below the table.

Table 21-3: Uses of LHMPS

LHMP solder use	Examples of related products	Reasons for necessity
For combining elements integral to an electrical or electronic component: - **a functional element with a functional element; or,** - **a functional element with wire/terminal/heat sink/substrate, etc.**	· Resistors, capacitors, chip coil, resistor networks, capacitor networks, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, chip EMI, chip beads, chip inductors, chip transformers, power transformers, lamps, etc.; · see examples in Figure 21-12to Figure 21-17 below	· Stress relaxation characteristic with materials and metal materials at the time of assembly is needed. · When it is incorporated in products, it needs heatproof characteristics to temperatures higher than 250 to 260°C. · It is needed to achieve electrical characteristic and thermal characteristic during operation, due to electric conductivity, heat conductivity / high thermal dissipation, etc. · It is needed to gain high reliability for temperature cycles, power cycles, etc.
For mounting electronic components onto sub-assembled modules or sub-circuit boards	· Hybrid IC, modules, optical modules, etc. · See example in Figure 21-18 below	
As a sealing material between a ceramic package or plug and a metal case	· SAW (Surface Acoustic Wave) filter, crystal resonators, crystal oscillators, crystal filters, etc. · See example in Figure 21-19 below	

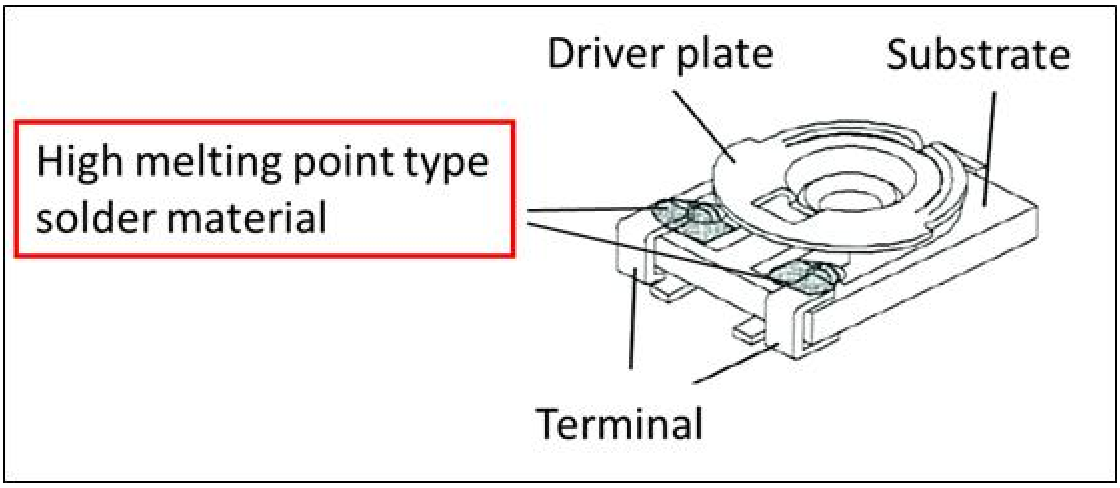
Source: Freescale et al.[825]

LHMPS uses for combining elements integral to an electrical or electronic component

Freescale et al.[826] provide five examples in the below figures for how LHMPS are used to combine elements integral to an electrical or electronic component – either a functional element with a functional element, or a functional element with wire/terminal/heat sink/substrate, etc.

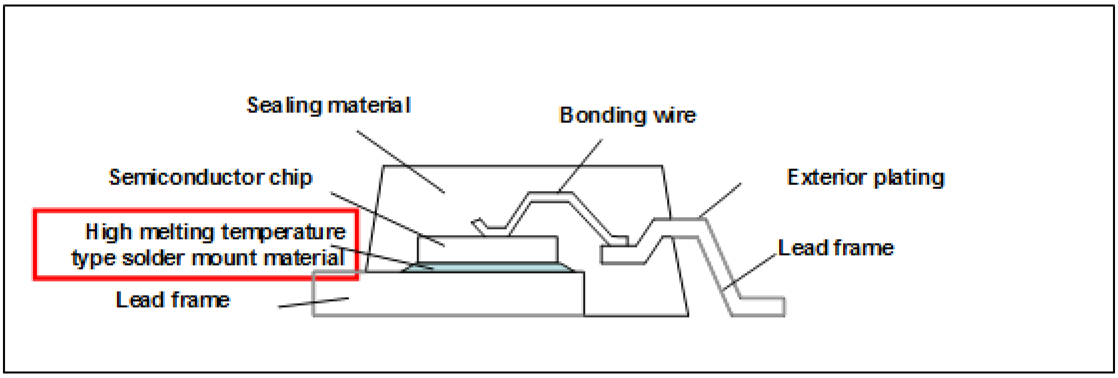
[825] Ibid.
[826] Ibid.

Figure 21-12: Schematic view of potentiometer with HMP lead (Pb) solder visible from the outside



Source: Freescale et al.[827]

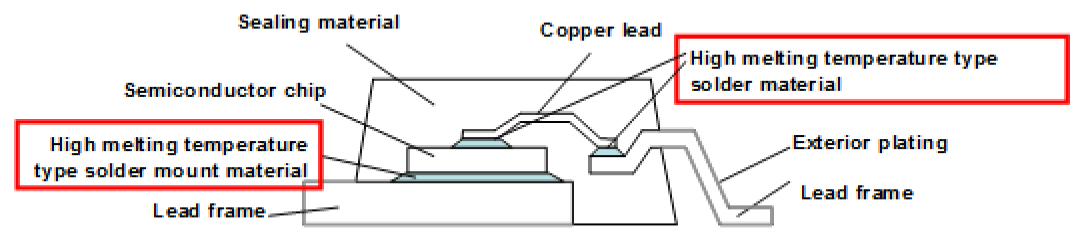
Figure 21-13: Schematic cross sectional view of a power semiconductor



Source: Freescale et al.[828]

[827] Ibid.
[828] Ibid.

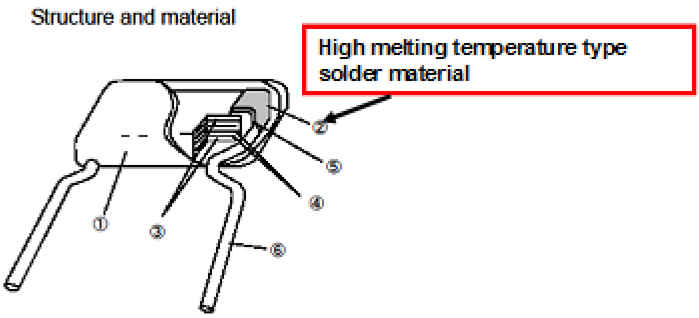
Figure 21-14: Schematic cross sectional view of internal connection of semiconductor



Source: Freescale et al.[829]

Figure 21-15: Schematic view of a capacitor with lead wire

1. Structure



2. Material and Description

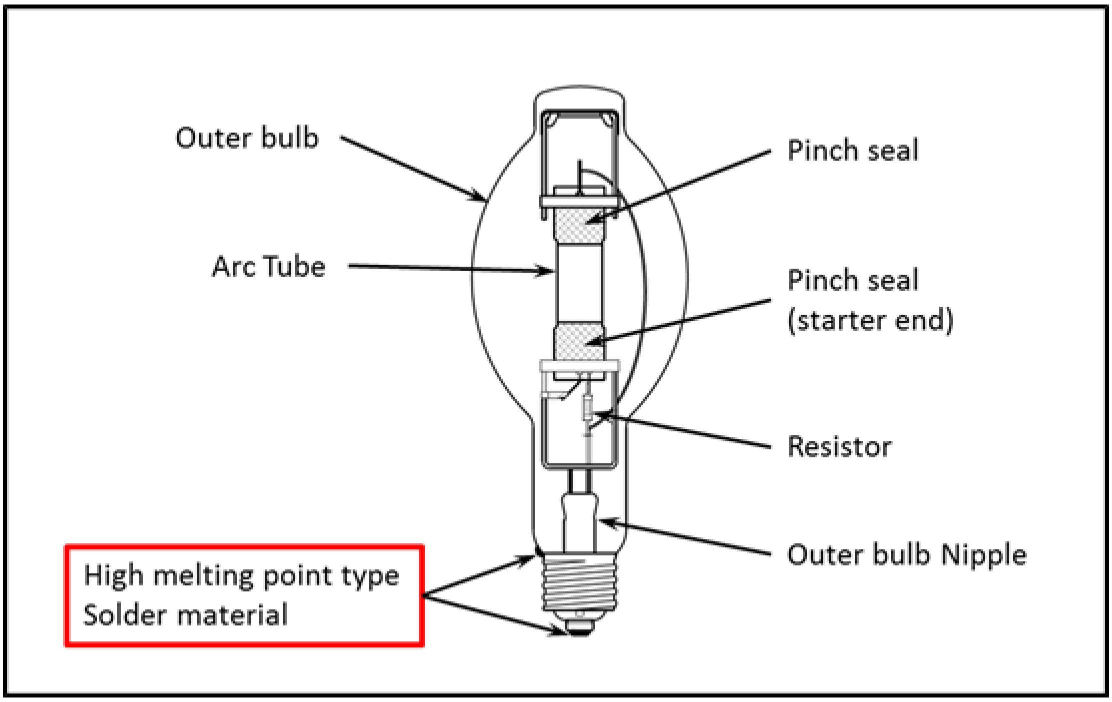
No.	Material	Description
①	Enclosure	Epoxy resin
②	Inner solder	Sn-Pb type solder *1
③	Dielectric	Ceramic
④	Inner electrode	Ni or Pd or Ag/Pd
⑤	Outer electrode	1)Ag/Pd or 2) Ag or Ag/Pd or Cu + Ni plating + Sn plating
⑥	Lead wire	Solder(Sn-2.5Cu) coated copper wire or Solder(Sn-2.5Cu) coated CP wire

*1 Lead in high melting temperature type solders (Pb:85% or more) are exempted from the requirements of RoHS.

Source: Freescale et al.[830]

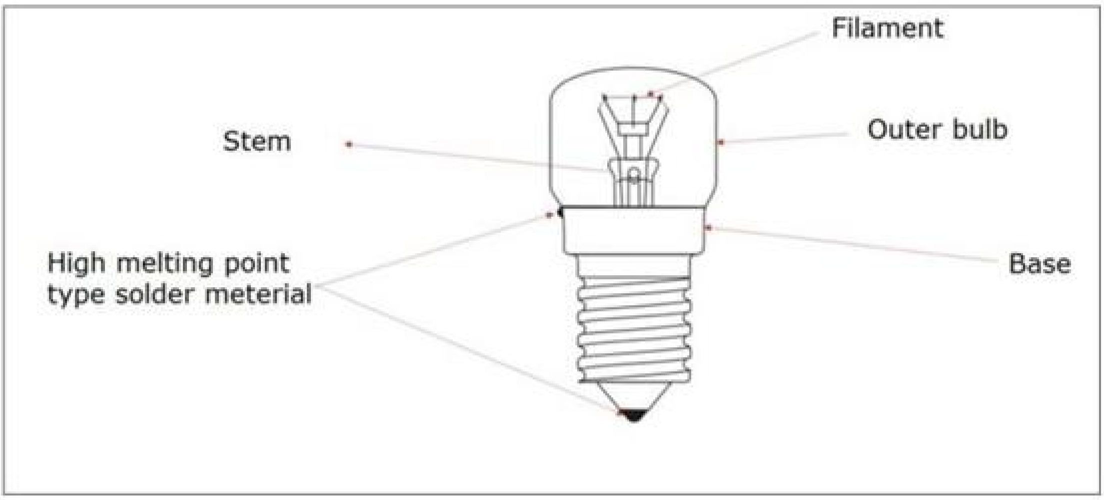
829 Ibid.
830 Ibid.

Figure 21-16: Schematic view of a HID lamp



Source: Freescale et al.[831]

Figure 21-17: Oven lamp with LHMPS



Source: Freescale et al.[832]

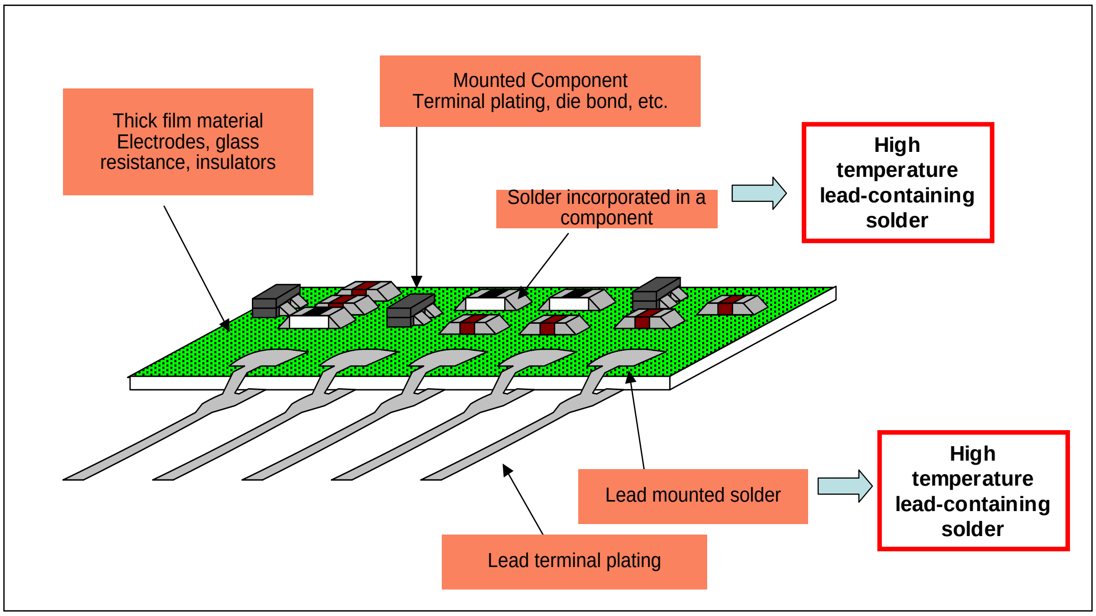
---

[831] Ibid.
[832] Ibid.

Examples for mounting electronic components onto sub-assembled modules or sub-circuit boards with LHMPS

Figure 21-18 shows examples for how LHMPS are used to mount electronic components onto sub-assembled modules or sub-circuit boards.

Figure 21-18: Schematic view of a circuit module component



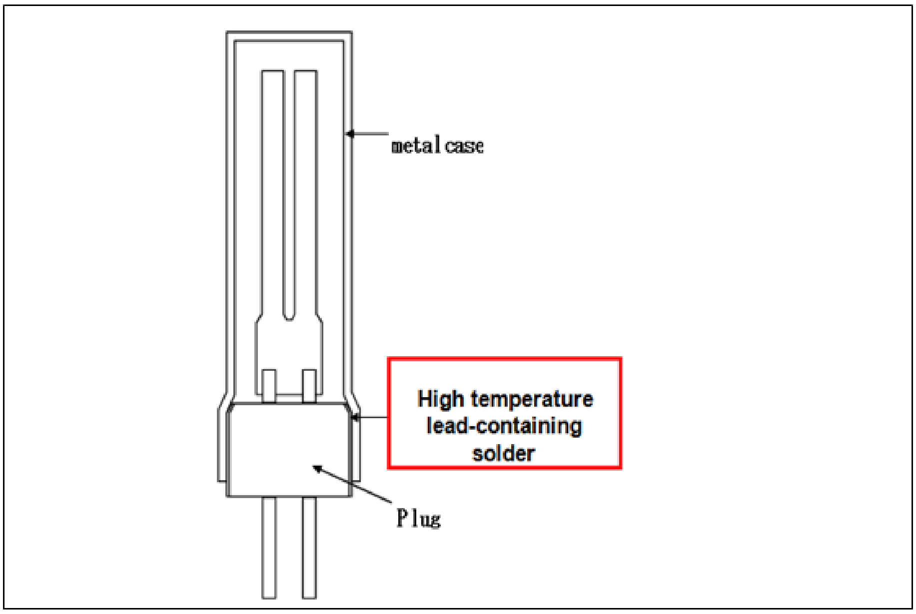
Source: Freescale et al.[833]

LHMPS uses as sealing material between a ceramic package or plug and a metal case

In Figure 21-19, Freescale et al.[834] illustrate the use of LHMPS for sealings between a ceramic package or plug and a metal case.

[833] Ibid.
[834] Ibid.

Figure 21-19: Schematic view of a crystal resonator



Source: Freescale et al.[835]

LHMPS in High PowerTransducers (Bosch)

Bosch[836] describes that high power transducers (both low and high frequency in professional sound applications) are used with power amplifiers capable of producing output greater than 200 V and 30 A. This amount of energy creates a significant amount of heat dissipated in the voice coil. The temperatures for low frequency transducers exceed the melting point of lead-free solders in less than 100 seconds, resulting in catastrophic failures. In addition, the solder used must be compatible with copper and aluminium wire.

In Bosch's[837] high power loudspeaker designs it is necessary to transition between a high flexibility, high cross sectional area conductor, down to the very fine gauge wire used to make the coil of wire that provides the electromotive force to drive the transducer. These solder joints must be made in close proximity to the magnet wire coil for a variety of reasons.

A primary reason for the proximity is structural integrity. The fine gauge magnet wire is often not able to withstand the high amounts of vibrational energy in the coil structure. This magnet wire can be aluminium, copper-clad aluminium, or copper. All of these magnet wires experience bending fatigue. If the solder joint is too far from the coil of magnet wire, this conjoining section of wire will mechanically fail due to highly

[835] Ibid.
[836] Op. cit. Bosch Security Systems GmbH 2015
[837] Ibid.

repetitious bending modes. These fractures can create an electrical arc across the break in the wire that can ignite nearby materials.[838]

This proximity of the solder joint to the magnet wire coil in conjunction with the high temperatures of the magnet wire in the coil, make HMP solder a necessity.[839] Figure 21-20 and Figure 21-21 describe the situation.

Figure 21-20: Inner diameter of a typical high power woofer voice coil

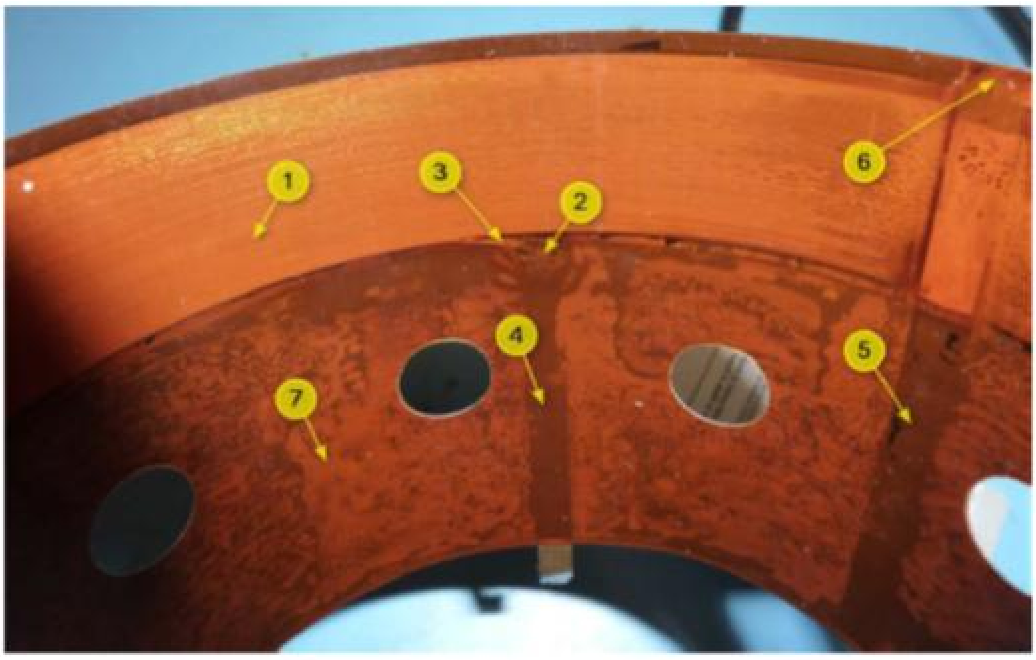


Image of the inner diameter of a typical high power woofer voice coil.

In this image;

1) Shows the coil of magnet wire. Visible through the coil bobbin (item 7).
2) The Upper solder joint. This joint is layered between the bobbin (7) and another high temperature resistance electrically insulating polymer. The magnet wire (3) is soldered to the flexible conductor (4) with HMP solder.
3) The magnet wire splitting off the coil (1) to go to the upper solder joint (2)
4) .1mm x 6mm flexible conductor (e.g. Phosphor Bronze.)
5) Same as 4 but extending under the coil of wire to make Lower Solder Joint (6)
6) The Lower Solder joint. This joint is layered between the bobbin (7) and a high temperature resistance adhesive. The magnet wire (3) is soldered to the flexible conductor (5) with HMP solder.
7) Bobbin – High temperature resistance polymer (e.g. Polyimide film)

Source: Bosch[840]

---

[838] Ibid.
[839] Ibid.
[840] Ibid.

Figure 21-21: Outer diameter of a typical high power woofer voice coil

Source: Bosch[841]

Figure 21-21 shows the black area which is the high temperature adhesive that overcoats the Lower Solder Joint and the magnet wire as it splits away from the coil of wire.

Although Bosch[842] started research two years prior to RoHS being required they have not discovered an alternative to LHMPS. Bosch[843] sells several products using these transducers in Europe. They are used in large installations including stadiums (e.g. World Cup stadiums), they have EN54 certifications for life safety applications.[844]

According to Bosch[845], these large installations are not large scale fixed installations, which would be excluded from the scope of the RoHS Directive.

21.1.4 Amount of Lead Used Under Exemption 7(a)

In 2000, the annual worldwide use of LHMPS in the scope of exemption 7(a) was investigated to be around 11,000 t corresponding to around 9,400 t based on the minimum lead content of 85 % mentioned in exemption 7(a).[846] In the 2008/2009 review, JBCE estimated the amount of LHMPS put on the EU market with 3,600 t/year,

---

841 Ibid.
842 Ibid.
843 Ibid.
844 For product examples c.f. http://www.electrovoice.com/family.php?id=117; source as referenced by Bosch
845 Bosch Security Systems GmbH 2016a "Answers to first questionnaire, document "Exe_7a_Questionnaire-1_Bosch_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Erich Pudelko, Bosch, on 23 March 2016" unpublished manuscript,
846 Otmar Deubzer 2007 Explorative study into the sustainable use and substitution of soldering metals in electronics: Ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future, Design for Sustainability Program publication 15 ([S.l.]: [s.n.]), http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/; page 73 et seqq.

corresponding to at least 3,100 t of lead. This figure did not include the HMP solders contained in products imported into the EU market.[847]

In the current review, Freescale/NXP et al. [848] estimate the amount of LHMPS put on the EU market with around 2,700 t, which corresponds to at least 2,300 t of lead. The calculation below shows that this figure does not contain the lead from LHMPS in products imported into the EU.

Figure 21-22: Calculation of LHMPS solders in the EU

1,590,000 tonnes / year =	Electrolytic Pb consumption in Europe
X 1.3%	Ratio of Pb used in Pb solder applications
X 12.9%	HMP lead (Pb) solder ration of all solders
2,667 tonnes / year =	HMP lead (Pb) solder entering EU market

Source: Freescale/NXP et al.[849]

Bourns estimates the worldwide amount of lead from LHPMS based on some of its products with around 960 kg.[850]

IXYS[851] indicates the annual amount of LHMPS in power semiconductor devices containing more than 90% of lead with around 50 t/a for the EU market.

Bosch[852] estimates that they will place a mass of less than 15 kg of lead into the field per year in their high power loudspeaker products, less than 40 % of that quantity, around 6kg, will be used in the EU. This figure does not include lead that other manufacturers would use as LHMPS in high power transducers.

Overall, the figures differ depending on the applied calculation base and depending on the data quality and the product spectrum taken into account. The figures of JEITA et al.853 and of Deubzer854 have the broadest product scope and can therefore be assumed to be closest to the actual magnitude of HMPS solder use and related lead on the global and EU level, even though the data of Deubzer should be considered to reflect the magnitude of lead rather than the actual amounts since this data is now 16 years old.

[847] Op. cit. Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009
[848] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[849] Ibid.
[850] Bourns Inc. 2015b "1st Questionnaire (Clarification Questionnaire) Exemption 7a: Document "20150815_Ex_7a_Bourns_1st-Questionnaire_2015-07-14.pdf"," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/20150815_Ex_7a_Bourns_1st-Questionnaire_2015-07-14.pdf
[851] Op. cit. IXYS Semiconductor GmbH 2015a
[852] Op. cit. (Bosch Security Systems GmbH 2016a)
[853] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[854] Otmar Deubzer 2007 Explorative study into the sustainable use and substitution of soldering metals in electronics: Ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future, Design for Sustainability Program publication 15 (Delft: TU Delft), http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/

The actual use of lead thus is probably in the lower range of several thousand tonnes in the EU.

21.2 Applicants' Justification for the Continuation or Repealment of the Exemption

Freescale et al.[855] are requesting the renewal of exemption 7(a) in its current wording for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. They state that alternative technologies with similar ductility and strength as lead (Pb) that can survive one or several standard reflow processes with either leaded or unleaded solders are unavailable for the following uses:

- For combining elements integral to an electrical or electronic component:
  - a functional element with a functional element; or,
  - a functional element with wire/terminal/heat sink/substrate, etc.;
- For mounting electronic components onto sub-assembled modules or sub-circuit boards;
- As sealing materials between a ceramic package or plug and a metal case.

21.2.1 Substitution of LHMPS by Lead-free Solders and Conductive Adhesives

Freescale et al.[856] state that the RoHS Directive has encouraged the transition from lead solders to lead-free solders for external terminations and board attachment. Due to the higher melting points of lead-free solders, soldering temperatures in production processes have risen to between 250 °C and 260 °C for lead-free solders mainly composed of Sn-Ag-Cu. Soldering temperatures in production processes for solder joints were 230 °C to 250 °C for lead-containing solder joints. The increased processing temperature for lead-free solder joints expanded the requirement for HMP lead (Pb) solder. These high melting temperature solders typically contain more than 85 % lead.

Freescale et al.[857] present the Table 21-4, showing the current commercially available lead-free solders and their melting points.

The solders with a solidus line of less than 250 °C are not appropriate. In Table 21-5, Freescale et al.[858] explain the advantages and disadvantages of lead-free solders with a solidus line temperature of 250 °C or higher and electrically conductive adhesives. Those are the candidates for the replacement of high temperature type lead-containing solders.

[855] Op. cit. Freescale Semiconductors/NXP et al. 2015a
[856] Ibid.
[857] Ibid.
[858] Ibid.

Table 21-4: Composition and melting temperatures of main lead-free solders

Category	Solder Type	Alloy Composition [wt %]	Melting Temperatures (Solidus Line / Liquidus Line)
Lead-free solders (Solidus Line 250°C or lower)	Sn-Zn (-Bi)	Sn-8.0Zn-3.0Bi	190~197 °C
	Sn-Bi	Sn-58Bi	139 °C
	Sn-Ag-Bi-In	Sn-3.5Ag-0.5Bi-8.0In	196~206 °C
	Sn-Ag-Cu-Bi	Sn96Ag2.5Bi1Cu0.5	213~218 °C
	Sn-Ag-Cu	Sn-3.0Ag-0.5Cu	217~220 °C
		Sn-3.5Ag-0.7Cu	217~218 °C
		Sn-4Ag-0.5Cu	217~229 °C
	Sn-Cu	Sn-0.7Cu	227 °C
	Sn-low Sb	Sn-5.0Sb	235~240 °C
Lead-free solders (Solidus Line more than 250°C)	Bi system	Bi-2.5Ag	263 °C
	Au-Sn system	Au-20Sn	280 °C
	Sn-high Sb	Sn->43Sb	325~>420 °C
	Zn-Al system	Zn-(4-6)Al(Ga,Ge,Mg)	About 350~380 °C
	Sn system & high melting temperature type metal	Sn+(Cu, Ni, etc.)	≧about 230~ >400 °C

Source: Freescale et al.[859]

[859] Ibid.

Table 21-5: Properties of lead-free solders with solidus line temperatures of 250 °C or higher

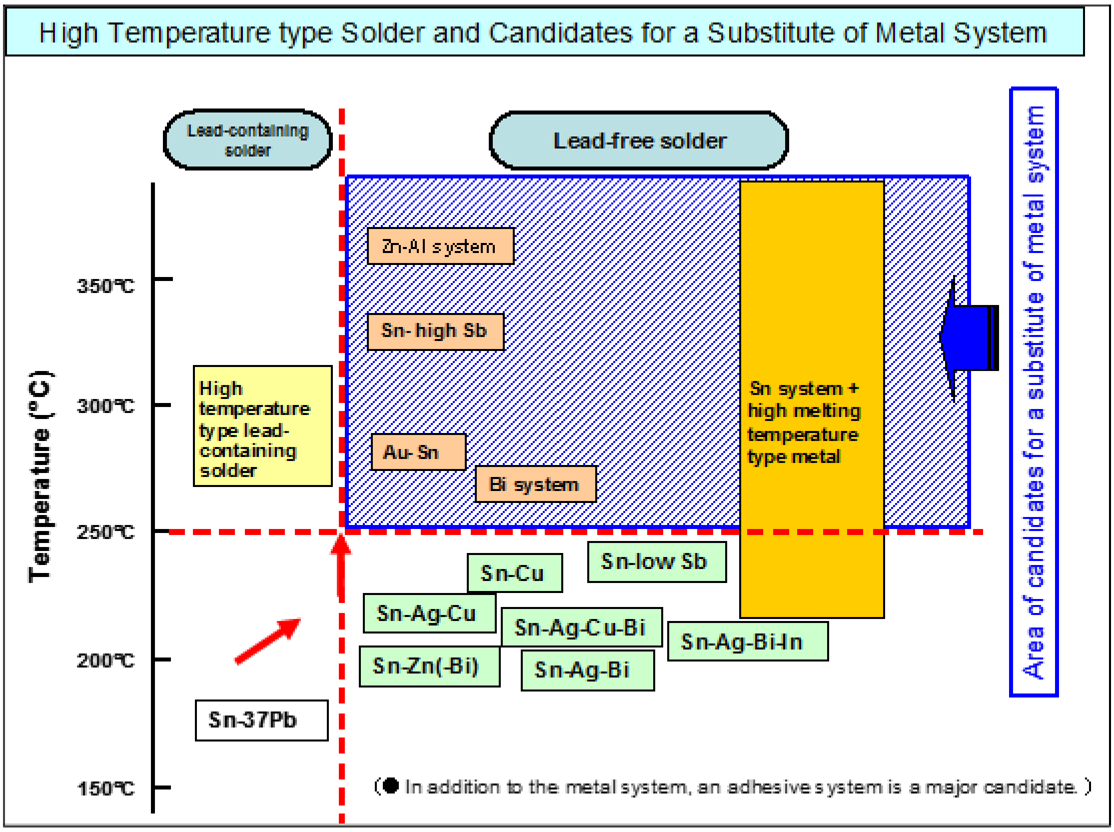
Candidate for Substitution		Advantages	Disadvantages
Metal System	**Bi system**	· Solidus line is high · Joint operating temperature is comparable with conventional high temperature type solders · Relatively low-cost	· Low ductility · Low strength · High electrical resistivity
	Au-Sn	· Solidus line is high · Joint operating temperature is comparable with conventional high temperature type solders · Strength is high	· Low ductility · Low melting point compared to LHMPS
	Sn-high Sb	· Solidus line is high	· Low ductility · Concern of Sb toxicity · Temperature required to solder is ~50 oC higher than Pb-based solder and is too hot for some processes
	Zn-Al system	· Solidus line is high	· Brittle or low ductility · Susceptible to corrosion and early failure · Temperature required to solder is significantly higher than Pb-based solder and is too hot for some processes.
	Sn system + High melting temperature type metal	· It is still retentive even if it is remelted. The joint operating temperature is comparable with that of conventional high temperature type solder, depending on a combination of remelting. · Solidus line is high if all can be made inter-metal compounds.	· For a resin mold, there is fear that a molten part may exude to outside of a component. · Joint operating temperature is high, extending solder duration, which might lead to high intermetallic growth which is often brittle and leads to a reliability issue. · Fragile or low ductility because joint is mainly made by inter-metal compounds.
Electrically conductive adhesive system		· No concern of remelting due to thermal hardening.	· Poor heat conductivity · Poor electrical conductivity which can deteriorate with age · Susceptible to humidity · Difficult to repair

Source: Freescale et al.[860]

[860] Ibid.

As a synopsis of Table 21-3and Table 21-4, Freescale et al.[861] show the relationship of types and melting temperatures of lead-containing and lead-free solders in Figure 21-23.

Figure 21-23: Relationship diagram of solders and melting temperatures



Source: ACEA, referenced in Freescale et al.[862]

Freescale et al.[863] conclude that both lead-free solders with solidus line temperatures of 250 °C or higher as well as electrically conductive adhesives presented in Table 21-5 have important disadvantages which do not qualify them for substituting LHMPS. No lead-free materials currently on the market meet or exceed the required functionality and reliability of LHMPS. Yet the materials industry continues to develop potential future alternatives in conjunction with component manufacturers.

Freescale et al.[864] state that additionally the proceeding trend of miniaturization of components and structures increases the thermal and mechanical load on components. The unique properties of LHMPS described on page 373 et seqq. ensure less defects

[861] Ibid.
[862] Ibid.
[863] Ibid.
[864] Ibid.

during manufacturing and high reliability throughout the life of the component, thereby also resulting in longer life of components and reduced waste[865].

In addition, Freescale et al.[866] claim a very careful scrutiny to be required in the event that a substitute production technology becomes available, so as to maintain the required high quality of components in the process, to avoid failure in the field, so that such new technology can be adopted.

The justifications of Bourns[867] and IXYS[868] for their uses of LHMPS follow the same rationale like Freescale/NXP et al. and are therefore not specifically explained.

21.2.2 Elimination of LHMPS

Besides for die attach, Freescale et al.[869, 870] do not mention any efforts or possibilities to eliminate the use of LHMPS with bonding technologies others than soldering.

21.2.2.1 Alternative bonding technologies without LHMPS use

Compression-bonded contact systems

IXYS[871] mentions that for very high power semiconductor systems, compression bonded contact systems are in use. Packaging is mostly realized as voluminous ceramic cases as illustrated in Figure 21-24. Alternatively, the ceramic was tried to be replaced by plastic cases, but still with compression bond technology,[872] which was, however, not successful because it is not reliable due to humidity leakages of the plastic housing.

---

865 Freescale et al. 2015b reference the document by the UK's BERR (now UK's BIS) at http://www.berr.gov.uk/files/file40576.pdf on page 18
866 Ibid.
867 dddOp. cit. Bourns Inc. 2015a
868 Op. cit. IXYS Semiconductor GmbH 2015a
869 Op. cit. Freescale Semiconductors/NXP et al. 2015a
870 Freescale Semiconductors/NXP et al. 2015b "1st Questionnaire (Clarfication Questionnaire) Exemption 7a, document "Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf": Questionnaire 1 (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf
871 Op. cit. IXYS Semiconductor GmbH 2015a
872 For details see patent DE2825682C2; referenced by IXYS 2015b

Figure 21-24: Compression bonded contact systems for very high power semiconductor systems

Source: IXYS Semiconductor GmbH[873]

According to IXYS[874], this technology is an alternative to LHMPS-bonded die components in "hockey pucks", where steady state currents of more than 500 A, surge currents of at least 50 kA and silicon die diameters of more than 25 mm occur. IXYS[875] describes typical applications to be "hockey puck" stacks for high-voltage direct current (DC) transmission of electricity, which are used in the range between 200V/2,900A and 6,500V/3,000A.

Upon further request, IXYS[876] states that they are not aware of any other applications of such compression-bonded contact systems that are clearly within the scope of the RoHS Directive, and where these types of components can replace components that use LHMPS for die attach.

The compression bonding technology therefore will not be followed up further in the review.

[873] Ibid.
[874] Op. cit. Freescale Semiconductors/NXP et al. 2015b
[875] IXYS Semiconductor GmbH 2016b "Answers to questionnaire 2, document "Exe-7a_Questionnaire-2_IXYS.docx", received via e-mail from Markus Bickel, IXYS, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 January 2016" unpublished manuscript,
[876] Ibid.

Direct Copper Bonding

IXYS[877] explains that the combination of larger power dies with copper plates is a root cause for the use of LHMPS. The more expensive electrically isolated package versions in DCB technology with metal bonded alumina or AlN ceramic isolator substrates have better CTE (coefficient of thermal expansion) matches, and more and more lead-free tin-silver-copper type solders are used. IXYS Germany[878] (formerly BBC, ABB) claims to be a pioneer to offer an alternative based on DCB technology, which has been under strong dispute among competitors in the past, but which now most competitors[879] have adopted. IXYS[880] already introduced such products in the 1980s, for example the wide range of lead-free standard power semiconductor modules with screw connectors.[881]

The DCB technology is more costly, however, it includes the electrical insulation.[882] IXYS[883]mentions in this context, however, that their ISOPLUS devices incorporating the DCB technology for applications in the SMT (**s**urface **m**ount **t**echnology) need LHMPS for internal connections while THT (through hole technology) components can be wire bonded. This is due to the fact that during SMT processing the devices have to survive temperatures exceeding the lead-free SAC (tin-silver-copper alloy) melting point[884]. Otherwise the internal lead-free solder connections in the plastic moulded devices would remelt and degrade their quality. THT uses LHMPS for internal die attach because subsequent wave soldering process is with lead-free SAC.

IXYS[885] [886] state that DCB with Au-Si eutectics are applicable for die edge sizes smaller than 3 mm, and presents an example of such a product. IXYS has such products in its portfolio. LHMPS is especially important when combining larger power dies with copper base plates (headers).

---

[877] Op. cit. IXYS Semiconductor GmbH 2015a

[878] IXYS Semiconductor GmbH 2015b "1st Questionnaire (Clarification Questionnaire) Exemption 7a, document document "20150804_Ex_7a_Ixys_Questions_answered_amended.pdf": Questionnaire 1, clarification questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/20150804_Ex_7a_Ixys_Questions_answered_amended.pdf

[879] http://www.semikron.com/dl/service-support/downloads/download/semikron-flyer-semitop-2015-04-22 see under key features – "No baseplate design"; source as referenced by IXYS 2016b

[880] Op. cit. (IXYS Semiconductor GmbH 2016b)

[881] IXYS Semiconductor GmbH, http://ixapps.ixys.com/DataSheet/MCC95-08io1B.pdf; source as referenced by IXYS

[882] For more information see http://www.ixys.com/SearchResults.aspx?search=ISOPLUS&SearchSubmit=Go, and for fully isolated TO-220 special packages https://de.wikipedia.org/wiki/Liste_von_Halbleitergeh%C3%A4usen#Plastikgeh.C3.A4use_mit_und_ohne_K.C3.BChlfahne; source as referenced in Op. cit. IXYS Semiconductor GmbH 2015b

[883] Ibid.

[884] For details see IEC 60749-20, table 6 and Fig. B.9 as well as IEC61190-1-3, table B.2; source referenced by IXYS Semiconductor 2015b

[885] Op. cit. Freescale Semiconductors/NXP et al. 2015b

[886] Op. cit. IXYS Semiconductor GmbH 2015a

According to IXYS,[887] the DCB process includes an alumina carrier plus chemical and high temperature process and is therefore more costly compared to LHMPS use.

21.2.3 Substitution and Elimination of Lead in High Power Transducers (Bosch)

Bosch[888, 889] states that they need LHMPS because they can only solder the magnet wire close to the coil where it is exposed to high temperatures. Although Bosch started research two years prior to 2006, when the substance restrictions in the RoHS Directive started to apply, and they search for new solders at least 3 times per year, to date they have not found any new high melting point solders introduced into the market that do not contain lead.

In new designs for low frequency transducers, Bosch[890] will move the wire solder joints away from high temperature areas where lead-free solders can probably be used, but this approach has not been proven and is not applicable for high frequency transducers since high frequency designs have high temperatures at much lower power levels already. In previous attempts to move the solder joint further away from the heat source Bosch[891] have found that the fine gauge magnet wire can fatigue from the high vibrational energy and fracture. When the wire fractures it can cause enough heat, due to electrical arcing, to start neighbouring parts on fire. Further investigation of this has shown that aluminium and copper clad aluminium wires are more subject to this failure. In their newest designs, Bosch[892] use pure copper magnet wires and the joints can be moved far enough away to use a lead-free solder. Unfortunately this would not be possible for all designs.

In a recent low frequency transducer introduction, Bosch[893] attempted the new technique but in the length of magnet wire leading from the voice coil windings to the top of the voice coil bobbin the wire would stress fatigue and fracture. This was due to standing waves that formed in the wire at frequencies in the 800 to 900 Hz range. They tried many ways to reinforce the area but could not stop the fractures from occurring without making the acoustic performance unusable.

Bosch[894] claims that modifying most of their existing designs is not possible because they use aluminium-based wires. The mass and resistance differences make an acoustically/electrically backwards compatible redesign impossible. This is why Bosch's

---

[887] Op. cit. (IXYS Semiconductor GmbH 2016b)
[888] Op. cit. Bosch Security Systems GmbH 2015
[889] Op. cit. (Bosch Security Systems GmbH 2016a)
[890] Op. cit. Bosch Security Systems GmbH 2015
[891] Op. cit. (Bosch Security Systems GmbH 2016a)
[892] Ibid.
[893] Bosch Security Systems GmbH 2016c "E-mail communication, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript,
[894] Op. cit. (Bosch Security Systems GmbH 2016a)

newest designs use pure copper magnet wires and the joints can be moved far enough away to use a lead-free solder.

Bosch[895] cannot put the new design into high frequency compression drivers because of mechanical reasons. The magnet wire cannot withstand the millions of cycles of flexing that occur in the suspension of the driver. This forces the transition from magnet wire to something that can withstand the flexing. This transition must be made very close to the source of heat and so it requires LHMPS.

Bosch[896] continues exploring possible solutions to resolve the issues that keep them from initiating new designs in all new low frequency transducers. The new design is not only better for the environment but it is easier to produce and less costly. Bosch has a financial incentive, besides the environmental one. This is a very strong motivator to resolve these issues. Even with that incentive Bosch has not been able to resolve all the issues. They will continue to use the new design in every application possible while they continue their investigations. Bosch expect to find techniques and materials that ultimately allow to no longer use the exemption in low frequency transducers, but they do not know when that solution will come. They also have strong doubts that they will find a solution that works in compression drivers in the near future as this would require an inventive step that cannot be predicted.

21.2.4 Other Stakeholder Contributions

21.2.4.1 TT Microelectronics/AB Mikroelektronik GmbH (AB)

AB[897] submitted information after the public stakeholder consultation on thick film copper bonding (TFCB) in the context of die attach where it could partially replace LHMPS and thus eliminate the use of lead. According to AB[898], thick film substrates are sintered structures so there is more flexibility in comparison to the laminated DCB substrates. This flexibility reduces stresses in the die attach materials as well as the large area soldering joint needed to contact to the heatsink or baseplates. In general, the thick film substrates can be directly substituted for a DCB for instance, when higher current applications demand thicker copper conductors electrically and thermally.

AB[899] has successfully tested TFCB on AlN (aluminium nitride ceramic) and Al_2O_3 (aluminium oxide ceramic) substrates. Organic substrates such as FR4 have not been tested as of yet, but the processing requires high temperatures of more than 800 °C.

---

[895] Op. cit. (Bosch Security Systems GmbH 2016c)
[896] Ibid.
[897] TT Electronics/AB Mikroelektronik GmbH 2015a “Information on TFC, document "AB-Mikro_TFC.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 8 January 2016” unpublished manuscript,
[898] TT Electronics/AB Mikroelektronik GmbH 2015b “E-mail communication, document "E-Mail-Communication_AB-Mikro.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 14 March 2016” unpublished manuscript,
[899] Ibid.

AB[900] are a supplier to the automotive industry, and they have a sister company working in the aerospace industry, where TFCB has proven to be more effective concerning lifetime between zero and 350 °C.

The company's TFCB technology would require an in-depth review including a consultation with other stakeholders to evaluate whether and how far TFCB can eliminate the use of lead in applications under exemption 7(a) for EEE in the scope of the RoHS Directive. Given the considerable efforts undertaken already for the review of exemption 7(a) and the limited time and resources available, this in-depth review could not be performed in the course of this review process.

The stakeholder was, however, recommended to submit a separate exemption request applying for the partial revoke of exemption 7(a), where the company should explain where and how TFCB can be used in EEE in the scope of the RoHS Directive to eliminate the use of lead. This request can then be subjected to a public online stakeholder consultation and a subsequent review taking into account the applicant's and other information collected during the consultation. As the use of lead is also restricted in Directive 2000/53/EC (ELV Directive), AB Mikroelektronik can also apply the revoke of exemption 8(e) in Annex II of the ELV Directive, which is analogous to RoHS exemption 7(a).

21.2.4.2 Ministry of Environment, Finland

The Ministry of Environment in Finland and Finnish Safety and Chemicals Agency (Tukes)[901] contributed to the stakeholder consultation expressing concerns about purely material specific character of the exemption. They believe that the wording of exemption 7(a) is too wide and can be interpreted to cover all product categories. This may create problems for the enforcement of the RoHS Directive in Member States. In some applications there are already lead-free alternatives available so the wide use of exemption 7(a) is not consistent with aims of the RoHS Directive. From their point of view the exemption should be granted only for those applications and technologies where it is deemed necessary and where no lead-free alternatives are available.

The Finnish Ministry[902] demands that, if the exemption is needed in some applications or technologies and a more precise wording is not feasible at this stage, an end (i.e. an expiration date – consultants comment) should be set for the exemption as required in Article 5 (2) of the RoHS Directive.

---

[900] Ibid.

[901] Ministry of the Environment, Finland 2015 "Document "Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf" submitted during the online stakeholder consultation," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf

[902] Ibid.

21.2.5 Environmental Impacts

Freescale et al.[903] estimate the amount of Pb in HMPS for EEE to be less than 0.2 % of the total Pb placed on the market per year. A research paper from AIST concludes that substitution of Pb in solders has a very small impact concerning risk to ecosystems.[904] Freescale et al.[905] consider the paper to be a useful reference, notwithstanding the fact that research is limited to the recycling of four types of consumer electronics (household air conditioning, TV, electric refrigerators / electric freezer, electric washing machines / clothes dryers) in Japan.

21.3 Roadmap for Substitution or Elimination of Lead

Freescale et al.[906] report that the "Die Attach 5" (DA5 – a partnership between Bosch, Infineon, Freescale, STM and NXP) have been working with suppliers for several years to identify and evaluate alternatives to LHMPS. They have evaluated a variety of new materials from leading global suppliers of solders, adhesives, silver sintering and transient liquid phase sintering (TLPS) materials. The DA5 evaluations recognize continuous improvement in the evaluated materials over the past five years, but even the best of these materials do not meet the DA5 requirements for quality, reliability and manufacturability. They are not at least as good as the traditional LHMPS. Many solutions are still under development, constantly being revised and strictly guarded by suppliers under non-disclosure agreements. They are not available for mass production. Details on the assessed materials and test results are provided in Appendix A.5.1.

Freescale et al.[907] offer International Rectifiers' information for its evaluation of promising Ag epoxy materials from four different suppliers and five different partial melt solders (SnCu, SnAgSb, SAC, SnCuSbCo and SnAgCuSb). The Ag epoxy materials each suffered unacceptable reliability failures due to package delamination causing shifts in Rds(on) (MOSFET "On-state" Drain Source Resistance). The partial melt solders failed industry criteria for MSL (Moisture Sensitivity Level) preconditioning prior to reliability testing; those solders partially melted during 260 °C reflow and caused massive package delamination and solder squirt. Details are available in Appendix A.5.2.

Concerning whether, once the DA5 or International Rectifiers have identified one or more practicable solutions for lead-free die attach, such solutions would be applicable to all the other LHMPS applications as well, Freescale/NXP et al.[908] state that industry

---

[903] Op. cit. Freescale Semiconductors/NXP et al. 2015a

[904] National Institute of Advanced Industrial Science and Technology (AIST): http://www.aist-riss.jp/main/modules/product/RTA_cleaners_J_downloadform.html?ml_lang=en; referenced in Freescale et al 2015a

[905] Ibid.
[906] Ibid.
[907] Ibid.
[908] Op. cit. (Freescale Semiconductors/NXP et al. 2016a:)

cannot test solutions that are not available on the market. Market availability for alternatives to LHMPS requires extensive research, development of manufacturing processes and equipment, and verification of functionality and reliability. These steps must occur sequentially for the raw material supplier, for the component manufacturers, and for EEE manufacturers. Freescale/NXP et al. hope to find a single solution that might be applicable to all LHMPS uses, but years of research have found no such perfect solution.

According to Freescale/NXP et al.[909], LHMPS manufacturers have invested significant resources into developing potential alternative solutions. The DA5 continues to work with these suppliers to modify the formulations to develop or improve the manufacturability and reliability. Some solutions look promising for die attach, especially for very small die sizes. The example applications of LHMPS identified by Oeko have unique thermal, mechanical and reliability requirements. Every Pb-free solutions eventually found for DA5 die-attach will subsequently require qualification for other LHMPS applications based upon their unique specifications. While 1:1 usability for a DA5 die-attach solution within other LHMPS applications cannot be guaranteed and is not likely, the anticipated future DA5 solutions will require further investigation into the feasibility of adoption for other applications.

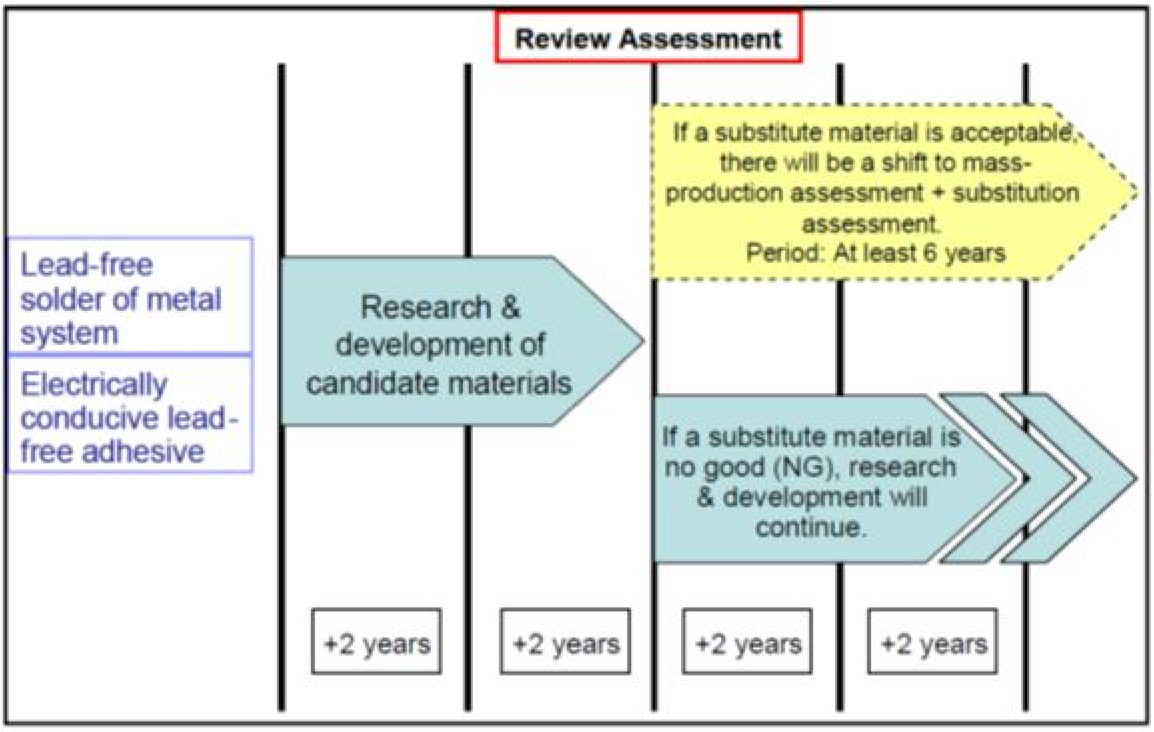
Freescale/NXP et al.[910] report further on that the DA5 has concentrated on finding a proof of concept for high reliability Pb-free replacements to LHMPS die attach materials. Once available, the resulting materials *could* be useful for many applications. The initial research will not qualify material for other applications, but will help to develop materials that *might* work in different applications. The alternatives will require testing and verification for each industry application. In this sense, Freescale/NXP et al.[911] agree that different alternatives may be necessary for different LHMPS applications. Freescale/NXP et al.[912] claim the electronics industry will continuously research for alternatives, however, currently no lead-free alternative technology can be predicted for the future. If a possible substitute is identified for evaluation, widespread conversion from use of high temperature type lead-containing solders in related applications will require time for the appropriate EEE qualifications based on the long term reliability requirements. Conversions cannot begin until lead-free alternatives are developed and perfected by solder manufacturers; processes and equipment are installed and implemented within component manufacturing lines; components are qualified, and those components are made available to EEE manufacturers for:

- development,
- assessment, and
- replacement with alternative products.

---

909 Ibid.
910 Ibid.
911 Ibid.
912 Ibid.

Figure 21-25: Material transition process

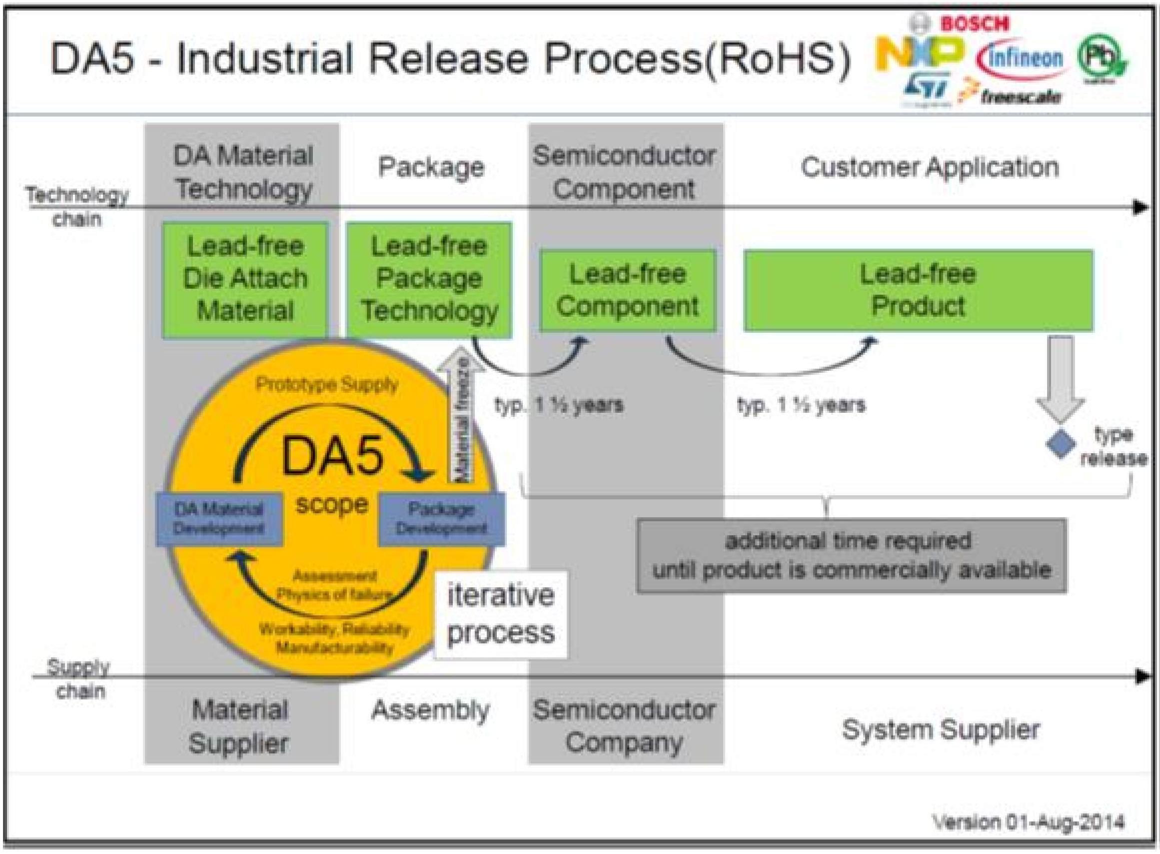


Source: Freescale/NXP et al.[913]

Looking at high-lead solder for attaching die to semiconductor packages, the DA5 consortium is working with selected material suppliers on the development of an appropriate replacement for lead solder (DA5 scope). The properties of the needed die-attach material is specified by the DA5 (material requirement specification) and provided to the material suppliers. Selected material suppliers offer their materials, which are evaluated by one of the DA5 companies together with the supplier. The detailed results are discussed with the material suppliers and all DA5 companies on a regular basis in face-to-face meetings. The results lead to further optimizations of the materials (development loop). The combined results are published by DA5 (c.f. Appendix A.5.1)[914]

[913] Ibid.
[914] Ibid.

Figure 21-26: Cycle time to conversion



Source: Freescale/NXP et al.[915]

After a material is chosen and material development is frozen, another 3 to 5 years will be required to qualify the new material through the whole supply chain. Based on current status, DA5 cannot predict a date for customer sampling as no suitable materials have yet been identified.[916]

Concerning further plans and steps in the next five years to substitute or eliminate lead in the various other types of LHMPS applications mentioned in their exemption request, Freescale/NXP et al.[917] want to support the overall RoHS objective of contributing to the protection of human health and the environment, including the environmentally sound recovery and disposal of waste electrical and electronic equipment. They remain committed to supporting the procedure for the adaptation to scientific and technical progress, and will continue developing, requesting the development and/or applying

---

[915] Ibid.
[916] Ibid.
[917] Freescale Semiconductors/NXP et al. 2016d "Answers to questionnaire 3a, document "Exe_7a_Questionnaire-3a_Freescale_2016-03-28.pdf", received via e-mail from Griffin Teggeman, NXP, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016" unpublished manuscript,

possible alternatives taking into account the practicability, reliability or environmental, health and consumer safety impacts of substitution.

21.4 Critical Review

21.4.1 REACH Compliance - Relation to the REACH Regulation

The exemption allows the use of lead. Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substance nor as substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists entry 28 and entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under entry 28 and entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

- *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
  This restriction does, however, not apply to crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Council Directive 69/493/EEC (*), and to internal components of watch timepieces inaccessible to consumers
- *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and*

those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."
This restriction does, however, not apply to articles within the scope of Directive 2011/65/EU (RoHS 2)

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

21.4.2 Substitution and Elimination of Lead in High Power Transducers (Bosch)

Bosch contributed to the public stakeholder consultation stating that exemption 7(a) should stay unchanged or alternatively this specification should be added:

"Lead in high melting temperature type solders used in high-power transducers (loudspeakers)"

As the RoHS Directive requires exemptions to be as specific as possible, the consultants reviewed the proposed specific wording in light of the requirements of Art. 5(1)(a). Bosch states that they have to use LHMPS because they can only solder the fine magnet wire close to the coil where high temperatures occur, which would melt lead-free solders. While this basic fact is plausible and clear, several questions remained open in the further discussions with the stakeholder.[918, 919, 920]

Moving away the solder joint from the coil reduces the temperature the solder joint is exposed to and may facilitate the use of lead-free solders instead of LHMPS. It is understood that Bosch has verified this approach at least in some newer low frequency high power transducer designs. This approach seems to be viable in low and possibly in mid frequency, but not in high frequency transducers, whereas it is not clear whether it would make the substitution of lead practicable in all low and mid frequency power transducers.

Bosch states that they cannot modify their old designs so that lead-free solders could be used. A complete redesign is required, which raises the question whether this redesign would in all cases allow the substitution of lead, and why this redesign has not been performed already. Bosch also mentions that other manufacturers of high power

---

[918] Op. cit. (Bosch Security Systems GmbH 2016a)
[919] Bosch Security Systems GmbH 2016b "Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript,
[920] Op. cit. (Bosch Security Systems GmbH 2016c)

loudspeakers have new designs on the market, but it is unclear whether these new designs are actually produced without lead.

It was attempted[921, 922, 923] to narrow the scope of the exemption by demarcating "power" transducer from other transducers, which then would not require the use of LHMPS. The consultants and Bosch agreed on the below wording of the exemption to better describe the actual use of LHMPS in high power transducers:

Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) for electrical connections on or near the voice coil in power transducers.

Bosch's information suggests that LHMPS is actually required where solder joints in high power transducers have to be exposed to high temperatures that exclude the use of lead-free solders. It remains unclear how far a redesign can help to avoid the higher temperatures enabling the use of lead-free solders, but the information submitted plausibly explains that this is currently not yet possible in all power transducers.

Taking into account the available information and in the absence of contrary information, the consultants recommend granting this exemption appraising the situation that LHMPS is required in high power transducers, justifying an exemption according to Art. 5(1)(a). However, it is recommended to grant the exemption for three years only as to further specify the scope of the exemption. This would still leave sufficient time for stakeholders to apply for the renewal should the exemption still be required in three years.

Granting the exemption would also allow splitting this use of LHMPS from the presently material specific exemption 7(a). Vice versa, the use of LHMPS in the high power transducers could still be permitted under exemption 7(a) even though there are prospects of eliminating or substituting lead.

21.4.3 Substitution and Elimination of Lead Die Attach

The information submitted by Bourns, Freescale/NXP et al. and IXYS suggests that generally, the substitution or elimination of lead is scientifically and technically still impracticable. IXYS provided, however, examples of components where alternative technologies such as direct copper bonding (DCP) eliminate the use of lead.

Freescale/NXP et al.[924] comment on IXYS' statements and achievements:

---

[921] Op. cit. (Bosch Security Systems GmbH 2016a)
[922] Op. cit. (Bosch Security Systems GmbH 2016b)
[923] Op. cit. (Bosch Security Systems GmbH 2016c)
[924] Freescale Semiconductors/NXP et al. 2015c "Document "7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf", submitted during the stakeholder consultation: Consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf

- DBC solution with AuSi die attach material does not address any LHMPS applications besides die attach. AuSi eutectic die attach on a bare copper leadframe may become brittle and unreliable.
- The IXYS solution addresses only THT (through hole technology), but not SMT (surface mount technology) packages.
- Operating power: IXYS only suggests converting LHMPS customers to their DBC alternative in low and medium power ranges, but Freescale/NXP et al. are not aware of a standard industry definition for low, medium and high power products. The IXYS power definition may be specific to their technologies.
- Freescale/NXP et al. agree that the IXYS solution may be reliable for certain applications with very small die size. The 3 x 3 mm die size lacks industry consensus. Vishay tested a gold-silicon solder process and determined the maximum reliable die size to be 0.5 x 0.5 mm rather than 3 x 3mm as indicated by IXYS. Reliable die size for DCB may vary by manufacturing process, equipment, materials and/or power range. Failure points for power and die size are not known.

Freescale/NXP et al.[925] conclude that exemption 7(a) has broad usage for critical applications, but the DCB bonding method can only be adapted to limited applications. It is not obvious that these applications are easily categorized or that they represent a substantial volume of LHMPS reduction. More important, it is very difficult to determine whether a narrowed exemption scope would affect the applications, which really require LHMPS. Freescale/NXP et al. thus contend that the exemption wording should be kept in its present form.

IXYS was asked to comment the above statements. IXYS[926] agrees that gold-silicon DCB is useful for die attach only. There is also risk of brittleness. Concerning the die sizes that can accommodate DCB die attach, IXYS specifies that they spoke of die sizes less than 3 mm, and not sizes equal to 3 mm, which includes the 0.5 mm x 0.5 mm size which Freescale/NXP et al.[927] mention as a reliability limit for DCB.

IXYS' information and product examples show that at least in specific cases, DCB can eliminate the use of lead in LHMPS, but these are restricted to ceramic substrates, and SMT components require LHMPS in the internal interconnects. The discussion between Freescale/NXP et al. and IXYS remains inconclusive with respect to a clear definition of criteria for die attach where DCB can eliminate the use of lead from other die attach cases, where the use of LHMPS is still scientifically and technically impracticable.

[925] Ibid.
[926] Op. cit. (IXYS Semiconductor GmbH 2016b)
[927] Op. cit. Freescale Semiconductors/NXP et al. 2015b

Nevertheless, the consultants proposed a wording for a more specific scope for die attach with LHMPS in the context of a further specification of exemption 7(a) in order to start an in-depth discussion. Since Freescale et al. as well as IXYS speak of power semiconductors in the context of LHMPS required for die attach, an attempt was made to specify the scope of LHMPS in die attach to power semiconductors. IXYS[928] state that power devices should be capable to sustain steady state currents of more than 1 A and/or blocking voltages beyond 200 V with no upper limit. Additionally, Freescale et al.[929] mention Vishay's test results that the maximum reliable die size for DCB is 0.5 mm x 0.5 mm. These criteria were integrated into a wording proposal for die attach for a future exemption 7(a):

> *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used for die attach in power semiconductors with steady state currents of more than 1 A and/or blocking voltages beyond 200 V and die edge sizes larger than 0.5 mm.*

Freescale/NXP[930] et al. expressed their principal disagreement with splitting exemption 7(a), but did not comment directly on the wording proposal related to die attach. IXYS[931] agreed to the proposed wording, but Bourns[932] commented that the above wording would exclude several components that require LHMPS for die attach. Bourns was therefore asked to propose a wording that would include all their components where the use of LHMPS is still technically indispensable and came back with a modified proposal[933], which was sent out to all applicants for commenting:

> *Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used for die attach in power semiconductors with steady state or transient/impulse currents of 1 A or greater and/or blocking voltages beyond 200 V, or die edge sizes larger than 0.5 mm*

Only Freescale/NXP et al.[934] reacted, this time including technical comments directly related to die attach. The core arguments were that the wording mentions

---

928 Op. cit. IXYS Semiconductor GmbH 2015b
929 Op. cit. Freescale Semiconductors/NXP et al. 2015c
930 Freescale Semiconductors/NXP et al. 2016b "Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_2016-02-16_NXP-et-al.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 25 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders
931 IXYS Semiconductor GmbH 2016a "Answers to the first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1-All-Stakeholders_Reply-Ixys_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickl, Ixys Semiconductor GmbH, on 26 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders
932 Bourns Inc. 2016a "Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Bourns_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns Inc., on 7 March 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders
933 Ibid.
934 Freescale Semiconductors/NXP et al. 2016c "Answers to second questionnaire to all stakeholders,

transient/impulse currents. The inclusion of IMPULSE improves the wording compared to the previous one, but still does not capture all the key criteria driving the LHMPS. Other criteria would include peak transient currents, resistance and the size of the power region within the die. The wording still appears to exclude some products that require LHMPS. The immediately identified indicative examples include Zener diodes with die sizes less than 0.5mm; clip bonded diodes and other products with currents less than 1 A and 200 V and more; SMD diodes or axial diodes with less than 1 A and more than 200 V; SMD or axial diodes with less than 0.5 mm; some triodes for alternating currents or silicon controlled rectifiers with 1 A; and transient suppressors.

Freescale/NXP et al. [935] did not explain why LHMPS would be required in components with die sizes less than 0.5 mm x 0.5 mm despite Vishay's findings, and they did not provide any alternative formulation that would include those components claimed to be excluded in the current wording, nor did they provide information to show that the use of LHMPS in such components could not be avoided.

Based on the above feedback to the wording proposals and the other available information, the consultants conclude that it is currently possible to define criteria for a few individual companies, where the substitution and elimination of lead in LHMPS for die attach is scientifically and technically practicable depending on their product portfolio. It was however not possible to perform this exercise within the available time and resources of the current evaluation due to the multitude and high variety of components and criteria.

For LHMPS used in die attach, Freescale/NXP et al. present past research (DA5, International Rectifier) to substitute or eliminate lead and ongoing efforts planned for the next years. So far, even though progress has been made, no possibilities for elimination or substitution of lead have been reported, so that granting an exemption would be in line with Art. 5(1)(a). This was also the result when these efforts were evaluated in 2015 in the course of the review of exemption 8(e)[936] (the equivalent of RoHS exemption 7(a)) in the Annex of Directive 2000/53/EC (ELV Directive).[937]

The information provided suggests that all research efforts are focused on finding a drop-in solution for LHMPS in die attach, i.e. a lead-free material that can replace LHMPS 1:1. Besides searching for one single solution to accommodate all needs of die attach, research for replacements of LHMPS avoiding the use of lead in specific die attach

---

document "Exe_7a Questionnaire-2-All-Applicants_2016-02-16_NXP.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 22 March 2016: NXP answers to questionnaire to all stakeholders" unpublished manuscript,

[935] Ibid.

[936] Gensch et al. 2015 "7th Adaptation to Scientific and Technical Progress of Exemptions 8(e), 8(f), 8(g), 8(h), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV): Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020"

[937] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, ELV Directive, European Union (21 October 2000)

applications could be a further option for progress. The at least partial viability of lead-free solutions like the IXYS DCB-based products show that specific solutions should be taken into account as well, including integrated approaches aligning die attach materials and the overall component design. Further research and new approaches may open possibilities for elimination or substitution of lead, possibly, if applicable also taking into account technologies like TFCB presented by AB Mikroelektronik.[938]

The accessible information suggests that the substitution or elimination of lead is still scientifically and technically impracticable so that granting an exemption would be in line with the requirements of Art. 5(1)(a). The applicants did not provide substantiated information that would have allowed clarifying where and under which conditions DCB is scientifically and technically practicable to replace lead, or why this should not be possible. It can thus not be excluded that the substitution of lead generally is scientifically and technicaly practicable within less than five years. The consultants therefore recommend granting the exemption for three years only, which on the one hand would allow to narrow the scope in order to gradually phase out the use of lead or otherwise clarify why this is scientifically and technically impracticable, and on the other hand still leave sufficient time for industry to apply for the continuation of the exemption should it still be required.

21.4.4 Substitution and Elimination of Lead in Other Applications of LHMPS

The applicants claim that the applications of LHMPS are numerous, and they explain this for various examples in their exemption request. They claim that once the DA5 have identified a solution, which should be a drop-in solution, they will transfer and adapt this solution into other applications using LHMPS (see Section 21.3 – Roadmap for Substitution or Elimination of Lead from page 401).

LHMPS offers the advantage to accommodate all needs of various applications by adapting the lead content of the LHMPS solder. In the consultants' understanding, however, it cannot be concluded that all applications of LHMPS will have a lead-free solution based on the same basic material and technology. The requirements in the various LHMPS applications are different, even though they all use LHMPS at present. For the various applications, different individual or combined properties of LHMPS are relevant to a different degree, and it is reasonable to assume that this requires different alternative solutions and thus also application-specific research to substitute or eliminate lead.

The applicants do not present specific future efforts towards the replacement of LHMPS in the provided example applications of LHMPS besides die attach. They state that they cannot test materials that are not available. In the consultants' opinion, however, this

[938] Op. cit. (TT Electronics/AB Mikroelektronik GmbH 2015a)

situation will continue if no research is started to find materials that can specifically accommodate the needs of particular LHMPS applications.

Based on the information made accessible, elimination or substitution of lead are still scientifically and technically impracticable for LHMPS applications as well as possibly for die attach. As there are no prospects that this situation will change within the next five years, it is recommended to continue the exemption for five years. The applicants will then, however, have to present clear and dedicated research efforts to find specific lead-free solutions for the various applications of LHMPS.

21.4.5 Specification of Exemption 7(a)

According to the RoHS Directive[939] "Exemptions from the restriction for certain specific materials or components should be limited in their scope and duration, in order to achieve a gradual phase-out of hazardous substances in EEE, given that the use of those substances in such applications should become avoidable."

Exemption 7(a) in its current wording has a purely material-specific scope. It allows the use of lead in high melting point solders regardless of where and how these lead-containing high melting point solders (LHMPS) are used. It is thus a priority within RoHS that the scope of both exemptions should be reduced now, where possible, and further in future exemption review rounds through the promotion of research and development of lead-free solutions, as well as through improvements in exemption wording specifications.

21.4.5.1 Consultant's Proposed Rewording of Exemption 7(a)

Based on information provided by the applicants in this review and in previous exemption reviews, the consultants formulated a wording, targeting a scope, which is as narrow as possible to exclude the abuse of the exemption and promote specific research into lead-free solutions. In parallel, the same proposed wording is as wide as necessary to ensure all applications are covered where substitution and elimination of lead is still impracticable. Following two rounds of discussions with the stakeholders[940, 941, 942, 943], the consultants modified their original proposal to the below wording.

---

[939] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast), RoHS 2, European Union (1 July 2011), recital clause (19)

[940] Freescale Semiconductors/NXP et al. 2016b "Answers to first questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1_All-Applicants_2016-02-16_NXP-et-al.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 25 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[941] Knowles et al. 2016a "Answers to first questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 25 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[942] IXYS Semiconductor GmbH 2016b "Answers to questionnaire 2, document "Exe-7(a)_Questionnaire-

Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used

- *a) for internal interconnections in electrical and electronic components, i.e.*
  - *i) for die attach in power semiconductors with steady state or transient/impulse currents of 1 A or greater and/or blocking voltages beyond 200 V, or die edge sizes larger than 0.5 mm*
  - *ii) in components with steady state currents of more than 1 A and/or blocking voltages beyond 200 V other than die attach*
  - *iii) for other internal interconnections in electrical and electronic components excluding those in the scope of exemption 24*
  - *iv) in HID lamps and oven lamps*
- *b) in solder balls for the attachment of ceramic BGA to the printed circuit board (second level interconnect)*
- *c) for the attachment of components to printed circuit boards (second level interconnect) in high temperature plastic overmouldings (> 220 °C)*
- *d) for mounting electronic components onto subassemblies (first level interconnect), i.e. modules or sub-circuit boards*
- *e) as a hermetic sealing material between a ceramic package or plug and a metal case*
- *f) other applications; expires on 1 January 2021 for EEE in cat. 1-7 and 10*

In a final round, this proposal was discussed with the stakeholders[944, 945, 946, 947] again. The following summarizes the applicants' comments.

2_IXYS.docx", received via e-mail from Markus Bickel, IXYS, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 January 2016" unpublished manuscript,

943 IXYS Semiconductor GmbH 2016a "Answers to the first questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1-All-Stakeholders_Reply-Ixys_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickl, Ixys Semiconductor GmbH, on 26 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

944 Freescale Semiconductors/NXP et al. 2016c "Answers to second questionnaire to all stakeholders, document "Exe_7(a) Questionnaire-2-All-Applicants_2016-02-16_NXP.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 22 March 2016: NXP answers to questionnaire to all stakeholders" unpublished manuscript,

945 Knowles et al. 2016b "Answers to second questionnaire to all stakeholders, document "Exe_7(a)_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, on 21 March 2016" unpublished manuscript,

946 Knowles et al. 2016c "Answers to third questionnaire, document "Exe_7(a)_Questionnaire-2_Knowles_2016-03-29.pdf", received via e-mail from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript,

947 Bourns Inc. 2016a "Answers to first questionnaire to all stakeholders, document

The applicants[948] disagree with the proposed rewording of RoHS Exemption 7(a). Further, they disagree with the need to reword the existing RoHS-2 exemption 7(a) and they voiced concerns with splitting the exemption into multiple sub-sections. In order to maintain a simple exemption renewal process, they also object to the proposed inclusion of an expiry date for any application that is less than the 5 years allowed under RoHS 2. They further urge Oeko-Institut and Fraunhofer IZM to recommend to maintain consistent wording for RoHS exemption 7(a) and ELV exemption 8(e) based upon the wording included in the related European Commission's draft legislative proposal to amend ELV's Annex II currently under scrutiny by the European Parliament and the Council of the EU.[949]

Freescale/NXP et al. [950] are concerned about the technical complexity to determine, which sub-exemption applies to each homogeneous material, and the lack of incremental environmental, health and consumer benefits resulting from this delineation since alternative Pb-free solutions are not available on the market. Furthermore, they do not believe that any one company or group of companies can currently adequately define the revised wording for a more detailed application and ensure that the new wording accounts for all required uses for LHMPS.

21.4.5.2 Applicants' Alternative Wording Proposals

Below, the applicants[951] attempt to enumerate the primary arguments related to the infeasibility of interpreting and applying the proposed exemption wording as given above:

- The 7(A)a)i structure is STATEMENT1 or STATEMENT2 and/or STATEMENT3 or STATEMENT4. The AND creates logic problems. [952]
- 7(A)a)i mentions "*transient/impulse currents*". The inclusion of "*impulse*" improves the wording in comparison to the prior questionnaire, but still does not capture all the key criteria driving the LHMPS. Other criteria would include *'peak transient currents'*, *'resistance'* and the *'size'* of the power region within the die.[953]
- 7(A)a)i and 7(A)a)ii appear to exclude some products that required LHMPS. The immediately identified indicative examples include Zener diodes with die sizes < 0.5mm; clip bonded diodes and other products with currents ≤ 1 A &

"Exe_7(a)_Questionnaire-1_All-Applicants_Bourns_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns Inc., on 7 March 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[948] Op. cit. (Freescale Semiconductors/NXP et al. 2016c)

[949] Ibid.

[950] Ibid.

[951] Ibid.

[952] Ibid.

[953] Ibid.

≤ 200 V; SMD diodes or Axial diodes < 1 A and < 200 V; SMD or Axial diodes < 0.5 mm; some triacs or SCRs < 1 A; and transient suppressors.[954]

- 7(A)a)iii must cover LHMPS for all connections within a component, whether they are electrical or nonelectrical. The definition of internal connection does not provide this certainty. Some connections require LHMPS for electrical and / or electronic functions, others for thermal functions, and others for reliability under harsh conditions. As one example, it is not clear that this definition includes a heat shield that is attached to a component with LHMPS to allow subsequent Pb-free step soldering for mounting the component. This heat shield is part of the component when sold.[955]

  Knowles et al.[956] add that from some points of view, an 'interconnect' is only an electrical connection so that the consultants' rewording proposal does not cover a non-electrical connection such as heat sink attachment. They would suggest that 'interconnect' is replaced with 'connection' or simply 'joint'. Knowles et al. ask, whether with regards to the definition of 'internal' – it is meant to include all connections within the space envelope of a single component, or if it only means connections that are hidden internally in the design. They also stress the example of the shielding cover and heatsink assembled onto the top of a ceramic substrate as part of an electronic filter. As the finished component will be surface mounted to a circuit board using Pb free alloys, the cover is soldered in place using LHMP solder alloy with the resulting joint being visible on the outside of the component. The connection to shield the device is made as part of the component manufacture and as such is part of the component and internal to its design, but as the joint is on the outside of the component the term 'internal' for a connection like this could be disputed. Knowles et al. in this case suggest that the reference to 'internal' could possibly be removed or changed to 'integral', covering all joints made as part of the component manufacture.

- 7(A)c) appears to exclude second level interconnections for lead frame products where molding occurs at temperatures ≥ 180°C but ≤ 220°C. [957]

Freescale et al. [958] state that also at the consultants' urging, they reluctantly considered and shared the below preliminary suggestions for a more detailed and functional wording. *None* of the proposals is acceptable to all members of the Freescale/NXP et al. working group. The differences between these proposals indicate a variety of subtle issues that arise when changing the exemption wording.

[954] Ibid.
[955] Ibid.
[956] Op. cit. (Knowles et al. 2016b)
[957] Op. cit. (Freescale Semiconductors/NXP et al. 2016c)
[958] Ibid.

- 7(a) LHMPS used for internal or external interconnections in or to electrical and electronic components, HID lamps, oven lamps, hermetic sealing materials between a ceramic package or plug and a metal case, or other applications.
- 7(a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used:
  - for combining elements integral to an electrical and electronic component, including a functional element with a functional element; or, a functional element with wire/terminal/heat sink/substrate, etc.;
  - for mounting electronic components onto sub-assembled modules or sub-circuit boards;
  - as a sealing material between a ceramic package or plug and a metal case;
  - other applications.
- 7(a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used for:
  - internal interconnections within electrical and electronic components;
  - die attach;
  - plastic overmoulding;
  - ceramic BGA;
  - high power applications;
  - solders for mounting electrical and electronic components onto sub-assembled modules or sub-circuit boards;
  - solders used as a hermetic sealing material between a ceramic package or plug and a metal case;
  - HID lamps and oven lamps.
- 7(a) Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead) used:
  - for internal interconnections in electrical and electronic components;
  - in HID lamps and oven lamps;
  - in solder balls for the attachment of ceramic BGA to the printed circuit board;
  - for the attachment of components to printed circuit boards in high temperature plastic overmouldings;
  - for mounting electrical and electronic components onto subassemblies;
  - as a hermetic sealing material between a ceramic package or plug and a metal case; or
  - in other applications.

21.4.6 Conclusions

21.4.6.1 Continuation of Exemption 7(a)

The information made available to the consultants suggests that the substitution and elimination of lead in LHMPS generally is still scientifically and technically impracticable so that granting an exemption could be justified by Art. 5(1)(a).

The applicants present future efforts towards the substitution or elimination of lead in die attach. Such clear perspectives for future efforts are missing for other application examples of LHMPS, which the applicants present in their exemption request. Lead-free solutions for die attach are, however, available at least for some smaller die sizes where the applicants did not provide a sound justification as to why these lead-free solutions may or may not be generally practicable to a degree that would allow narrowing the scope of the exemption for the use of LHMPS in die attach.

The consultants therefore recommend explicitly mentioning die attach in the wording of Exemption 7(a) and to renew the exemption for die attach for three years.

For the use of LHMPS in high power transducers, the consultants can understand that substitution of lead via design changes is possible in some cases but not in others. In this application, the information submitted plausibly explains that LHMPS is currently still required, but the actual status of the redesign efforts remains unclear, and the substitution and elimination of lead may become scientifically and technically practicable within less than five years. Granting the exemption for five years would therefore not be in line with the stipulations of Art. 5(1)(a), and it is consequently recommended to re-evaluate the situation in three years.

To cover the manifold other uses of LHMPS that could not yet be specified, the consultants recommend adding a third clause exempting the use of LHMPS in all applications others than die attach and high power transducers.

Exemption 24 covers the use of lead-containing solders including LHMPS for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors. This application of LHMPS should be excluded from exemption 7(a) to avoid overlapping scopes of exemptions. The consultants propose different options for the wording of exemption 7(a) depending on whether or not the Commission decides to renew exemption 24 as recommended or to include it within the scope of exemption 7(a) (for details please refer to the review of exemption 24).

21.4.6.2 Further Specification of Exemption 7(a)

The discussion related to the consultants' rewording proposal for exemption 7(a) shows that a consensus on the technical details of such a rewording proposal requires further exchange with the various stakeholders to clarify the architecture and the definitions of terms. Obviously, the alternative proposals of Freescale/NXP et al. and the contributions of Knowles et al. also require further discussions to achieve a technical consensus among the stakeholders. The limited time and resources available for the review of this exemption did not allow further discussions with the applicants and other stakeholders. The above proposals and discussions can however, be a basis to a further specification of

Exemption 7(a) in a future review taking into account the then achieved status of elimination and substitution of lead.

In the consultants opinion, the slightly modified rewording proposal recommended in Section 21.5 for the time being is a first step towards a specification of exemption 7(a) maintaining the clarity of the wording, taking into account the applicant's current and future research efforts and narrowing the scope to phase out the use of lead.

In case the Commission would like to follow the stakeholders' principal arguments against any rewording of Exemption 7(a), it is recommended to grant the exemption in its current wording for three years.

21.5 Recommendation

21.5.1 Wording of Exemption 7(a)

The information made available to the consultants suggests that the substitution and elimination of lead in LHMPS generally is still scientifically and technically impracticable so that granting an exemption could be justified by Art. 5(1)(a).

For die attach, the applicants do not provide a sound justification why available lead-free solutions for small dies may or may not be generally practicable.

The use of LHMPS in high power transducers can at least partially be avoided via design changes. While the applicant plausibly explains that LHMPS is currently still required, the actual status of the redesign efforts remains unclear. It is consequently recommended to re-evaluate the situation in three years.

The consultants therefore recommend granting Exemption 7(a) for die attach and for the use of LHMPS in power transducers for three years. A period of five years would not be in line with Art. 5(1)(a) since substitution or elimination of lead at least partially may become scientifically and technicaly practicable within the next five years.

A further specification of Exemption 7(a) to better reflect the broad range of LHMPS applications and to exclude abuse of the exemption is currently not yet possible. The consultants therefore recommend to add a general clause allowing the use of LHMPS in all applications others than in die attach and in high power transducers, and to grant this part of the exemption for five years because there is no prospect that lead-free solutions will become available within the next five years. The applicants should by then present dedicated research efforts to find specific lead-free solutions for the various applications of LHMPS.

The use of LHMPS in Exemption 24 should be excluded from exemption 7(a) to avoid overlapping scopes of exemptions. The consultants propose the below wording options of exemption 7(a) depending on whether or not the Commission decides to renew exemption 24 as recommended or to include it within the scope of exemption 7(a) (for details please refer to the review of exemption 24).

	Exemption 7(a)	Expires on
I)	*Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)*	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9* *21 July 2023 for in vitro diagnostic medical devices in category 8* *21 July 2024 for industrial monitoring and control instruments in category 9*
	Lead in high melting temperature type solders (i.e. lead-based alloys containing 85 % by weight or more lead)	
	Recommended wording if the Commission decides to renew exemption 24 as recommended:	
II)	*in all applications not addressed in items III and IV, but excluding applications in the scope of exemption 24*	*21 July 2021 for categories 1 to 7 and 10*
III)	*for die attach*	*21 July 2019 for categories 1 to 7 and 10*
IV)	*for electrical connections on or near the voice coil in power transducers*	
	Alternative wording, if exemption 24 is not renewed:	
II)	*in all applications not addressed in items III, III and IV*	*21 July 2021 for categories 1 to 7 and 10*
III)	*for die attach*	*21 July 2019 for categories 1 to 7 and 10*
IV)	*for electrical connections on or near the voice coil in power transducers*	
V)	*in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors*	*21 July 2021 for categories 1 to 7 and 10*

21.5.2 Applicants' Statements Concerning the Split of Exemption 7(a)

Bourns, Freescale/NXP et al. and Knowles et al. raised concerns on a splitting of exemption 7(a). These arguments refer to the proposed rewording with a more detailed split presented in chapter 21.4.5412. The consultants would like to nevertheless present those arguments, as they may also apply to the above proposed moderate rewording of exemption 7(a), as the split proposed above was not subject to further discussion in light of the lacking time and resources. The arguments of Freescale/NXP et al. are listed below as representatively reflecting the applicants' concerns.

Bourns, Bosch, Freescale/NXP et al. and Knowles et al. advocate the renewal of exemption 7(a) with its current wording. Freescale/NXP et al.[959] mention that the EEE industry and automotive industry have an extensive overlap in their supply chains. They

[959] Op. cit. (Freescale Semiconductors/NXP et al. 2015a)

would recommend that the EU maintain consistent wording between RoHS exemption 7(a) and ELV exemption 8(e) where feasible. [960]

According to Freescale/NXP et al.[961], splitting the exemption will not eliminate existing functional requirements for LHMPS, nor will it improve the availability of Pb-free alternatives. They are not aware of readily available and manufacturable Pb-free HMPS with the required melting points, conductivity, ductility and reliable performance. The proposed changes to the wording would likely divert resources to rework the existing EEE material content reports and conformity declarations in support of CE certifications. This might reduce resources investigating technical solutions.[962]

Furthermore, they[963] believe an application list of OEM EEE end-uses for LHMPS is not feasible. The supply chain cannot link LHMPS to all EEE applications or intended uses. Freescale/NXP et al.[964] do not understand the benefit of increasing the complexity of this exemption. They see no evidence that the language change will reduce the amount of lead placed on the EU market in the coming five years. LHMPS is a lead solder. LHMPS already represents a tangible application. They believe the existing wording already defines an application for upstream users (i.e. LHMPS). The proposed changes to the wording would increase the complexity for certifying and verifying compliance, resulting in increased errors. It would create challenges for regulatory compliance. [965] [966]

In case the Commission would like to follow the applicants' arguments, it is recommended to continue the current exemption for a minimum of three years period.

21.6 References Exemption 7(a)

Bosch Security Systems GmbH 2015 Document "Bosch-Stakeholder-contribution-Exemption-request-7a.pdf", submitted during the online stakeholder consultation. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bosch-Stakeholder-contribution-Exemption-request-7a.pdf.

Bosch Security Systems GmbH 2016a Answers to first questionnaire, document "Exe_7a_Questionnaire-1_Bosch_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Erich Pudelko, Bosch, on 23 March 2016.

Bosch Security Systems GmbH 2016b Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

960 Op. cit. (Freescale Semiconductors/NXP et al. 2015a)
961 Op. cit. (Freescale Semiconductors/NXP et al. 2016b)
962 Op. cit. (Freescale Semiconductors/NXP et al. 2016b)
963 Ibid.
964 Ibid.
965 Ibid.
966 Ibid.

Bosch Security Systems GmbH 2016c E-mail communication, document "Exe_7a_Questionnaire-2_Bosch_2016-03-24.docx", received via e-mail from Erich Pudelko, Bosch, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

Bourns Inc. 2015a Exemption Request Exemption 7a. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/7a_Exemption_extension_ap_7a.pdf.

Bourns Inc. 2015b 1st Questionnaire (Clarification Questionnaire) Exemption 7a. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Bourns/20150815_Ex_7a_Bourns_1st-Questionnaire_2015-07-14.pdf.

Bourns Inc. 2016a Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Bourns_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns Inc., on 7 March 2016.

Deubzer, Otmar 2007 Explorative study into the sustainable use and substitution of soldering metals in electronics: Ecological and economical consequences of the ban of lead in electronics and lessons to be learned for the future. Design for Sustainability Program publication 15. [S.l.]: [s.n.]. http://repository.tudelft.nl/view/ir/uuid%3Af9a776cf-57c3-4815-a989-fe89ed59046e/.

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELV DirectiveEuropean Union. October 21, 2000.

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. RoHS 1European Union. February 13, 2003.

Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast). RoHS 2European Union. July 1, 2011.

Freescale Semiconductors/NXP et al. Document "7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf", submitted during the stakeholder consultation 2015c. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/7aEx__RoHS_Freescale_Consultation_Response_2015_1015_Final_to_Oeko.pdf.

Freescale Semiconductors/NXP et al. 2015a Request for Continuation of Exemption 7a, document "Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Ex_Renewal_Dossier_2015_0723_v20_revised.pdf.

Freescale Semiconductors/NXP et al. 2015b 1st Questionnaire (Clarfication Questionnaire) Exemption 7a, document "Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf".

http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Freescale_Semiconductor/Ex_7a_Freescale_Response_to_Clarification_questions_2015_0817_Final_to_Oko_Questions_of_2015_0716.pdf.

Freescale Semiconductors/NXP et al. 2016a: Answers to second questionnaire, document "Exe_7a_Questionnaire-2_Freescale_Response_2016-01-28.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, Freescale (NXP) et al., on 28 January 2016.

Freescale Semiconductors/NXP et al. 2016b Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_2016-02-16_NXP-et-al.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 25 February 2016.

Freescale Semiconductors/NXP et al. 2016c Answers to second questionnaire to all stakeholders, document "Exe_7a Questionnaire-2-All-Applicants_2016-02-16_NXP.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Griffin Teggeman, NXP, on 22 March 2016.

Freescale Semiconductors/NXP et al. 2016d Answers to questionnaire 3a, document "Exe_7a_Questionnaire-3a_Freescale_2016-03-28.pdf", received via e-mail from Griffin Teggeman, NXP, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016.

Gensch et al. 7th Adaptation to Scientific and Technical Progress of Exemptions 8(e), 8(f), 8(g), 8(h), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV) 2015.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

IXYS Semiconductor GmbH 2015a Request for continuation of exemption 7a with limited scope, document "7a_IXYS_RoHS_V_Application_Form.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/7a_IXYS_RoHS_V_Application_Form.pdf.

IXYS Semiconductor GmbH 2015b 1st Questionnaire (Clarification Questionnaire) Exemption 7a, document document "20150804_Ex_7a_Ixys_Questions_answered_amended.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/IXYS/20150804_Ex_7a_Ixys_Questions_answered_amended.pdf.

IXYS Semiconductor GmbH 2016a Answers to the first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1-All-Stakeholders_Reply-Ixys_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickl, Ixys Semiconductor GmbH, on 26 February 2016.

IXYS Semiconductor GmbH 2016b Answers to questionnaire 2, document "Exe-7a_Questionnaire-2_IXYS.docx", received via e-mail from Markus Bickel, IXYS, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 January 2016.

Knowles et al. 2016a Answers to first questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 25 February 2016.

Knowles et al. 2016b Answers to second questionnaire to all stakeholders, document "Exe_7a_Questionnaire-1_All-Applicants_Knowles-et-al_2016-02-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, on 21 March 2016.

Knowles et al. 2016c Answers to third questionnaire, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received via e-mail from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

Ministry of the Environment, Finland Document "Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf" submitted during the online stakeholder consultation 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_a_/Ex_7a_Finnish_Safety_and_Chemicals_Agency-comment_161015.pdf.

TT Electronics/AB Mikroelektronik GmbH 2015a Information on TFC, document "AB-Mikro_TFC.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 8 January 2016.

TT Electronics/AB Mikroelektronik GmbH 2015b E-mail communication, document "E-Mail-Communication_AB-Mikro.pdf", received via e-mail from Chris Burns, AB Mikroelektronik, by Dr. Otmar Deubzer, Fraunhofer IZM, on 14 March 2016.

22.0 Exemption 7c-I: “Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

Curie temperature	Temperature at which piezoelectric ceramics lose their piezoelectric properties; *Source: Zangl et al. 2010*[967]
Electro Mechanical Coupling Coefficient (k) of piezoelectric ceramics	Coefficient to show the efficiency to transform and communicate electric alteration into the energy of mechanical alteration (or vice versa) due to the piezoelectric effect $k = \sqrt{\frac{\text{mechanical energy stored}}{\text{electrical energy applied}}}$ or

[967] Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010a “Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS): Final report - revised version,” Final Report Oeko-Institut e. V. und Fraunhofer IZM, accessed August 4, 2015, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf

	$k = \sqrt{\frac{\text{electrical energy stored}}{\text{mechanical energy applied}}}$ In order to gain filter characteristics, materials with high values in this category are essential; *Source: Zangl et al. 2010*[968]
Mechanical Quality Factor Coefficient of piezoelectric ceramics	Shows the extent of mechanical loss near frequencies where the piezoelectric substance resonates; in resonators and oscillators, as the value becomes higher, the oscillator becomes more efficient and the fluctuation in the resonance frequency decreases; *Source: Zangl et al. 2010*[969]
NTC	Negative Temperature Coefficient, materials decreasing their electrical resistance with increasing temperature; *Source: Zangl et al. 2010*[970]
Piezoelectric Strain Coefficient (d constant) (Piezoelectric material constant)	Indicates how efficient an electric field can generate strain of the piezoelectric material, or vice versa how efficient a strain applied on the ceramic can generate an electrical field. Higher values indicate higher efficiency. d=strain / applied electrical field If the value is high, the piezoceramic can generate displacement efficiently from a low electric field. Also, the output is larger for sensors and it can be used as a good sensor material with high sensitivity *Source: Zangl et al. 2010*[971]
PTC	Positive Temperature Coefficient, materials increasing their electrical resistance with increasing temperature *Source: Zangl et al. 2010*[972]
PTCR	Positive temperature coefficient of resistance
PZT ceramics	Ceramics consisting of a mixture of $PbZrO_3$ and $PbTiO_3$ *Source: Zangl et al. 2010*[973]
Saturation polarization	Highest practically achievable magnetic polarization of a material when exposed to a sufficiently strong magnetic field *Source: Zangl et al. 2010*[974]

[968] Ibid.
[969] Ibid.
[970] Ibid.
[971] Ibid.
[972] Ibid.
[973] Ibid.

22.1 Background and History of the Exemption

The current wording of exemption 7c-I in Annex III of Directive 2011/65/EC (RoHS 2), is:

"Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound"

When Directive 2002/96/EC (RoHS 1) (EuropeanUnion) was published in 2003, the above exemption did not yet exist in this form. The use of lead in glass and ceramics was covered by two different exemptions with a different wording: Exemption 5 allowed the use of lead in glass:

"Lead in glass of cathode ray tubes, electronic components and fluorescent tubes"

Exemption 7d covered the use of lead in ceramics of electronic components:

"Lead in electronic ceramic parts (e.g. piezoelectronic devices)"

In 2007, the Commission received an application for exemption of

"Lead in cermet-based trimmer potentiometer elements"

The applicant requested this exemption claiming that exemptions 5 and 7 in the annex of directive 2002/95/EC (RoHS 1) in the status of 2006/2007 did not cover the use of lead in these cermet-based trimmer potentiometers. The applicant said that this resistive layer in the cermet-based trimmer potentiometer is a homogeneous material, as it can be mechanically separated from the ceramic base. This homogeneous material, the thick-film layer containing the lead, in itself is neither a glass nor a ceramic material. The exemption request was reviewed[975] and the Commission granted the exemption as exemption 34 in the annex of RoHS 1.

Exemption 11 of Annex II in Directive 2000/53/EC (ELV Directive), the equivalent to exemption 7c-I of RoHS Annex III, was reviewed in 2007/2008[976]. The stakeholders decided that the wording in the ELV Directive covers applications like lead in cermet-based trimmer potentiometers. To avoid insecurities whether and how far similar uses of lead like in the cermet-based trimmer potentiometers are exempted, it was decided in the review of RoHS exemption 7d in 2008/2009[977] to take over the wording of ELV

---

[974] Ibid.

[975] For details see report of Gensch, Carl-Otto, Stéphanie Zangl, and Otmar Deubzer 2007 "Adaptation to scientific and technical progress under Directive 2002/95/EC: Final report." Accessed August 11, 2015. http://ec.europa.eu/enviro nment/waste/weee/pdf/rohs.pdf., page 18 et sqq.

[976] Lohse, Joachim; Gensch, Carl-Otto; Groß, Rita; Zangl, Stéphanie, Oeko-Institut e.V.; Deubzer, Otmar, Fraunhofer IZM (2008): Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC. Final Report - Amended Final. https://circabc.europa.eu/sd/a/f5d79a51-2e5a-47eb-85d3-7b491ae6a4b3/Final_report_ELV_2008_Annex_II_revision.pdf; page 65 et sqq.

[977] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM.

exemption 11 with further slight adaptations, resulting in the current wording of exemption 7c-I.

The exemption was transferred from the annex of RoHS 1 into annex III of RoHS 2 without changes and has become due for review as stakeholders have requested its continuation prior to its expiry in July 2016.

22.2 Description of the Requested Exemption

22.2.1 Overview of the Submitted Exemption Requests

Several stakeholders have requested the continuation of exemption 7c-I. Table 22-1 gives an overview of the submitted requests.

Pyreos' request for exemption[978] had actually been submitted as part of pack 8 of the RoHS exemption reviews[979]. Since the applicant asks for the application-specific renewal of exemption 7c-I, Pyreos[980] agreed that its exemption request will be evaluated in the broader context of exemption 7c-I in this review round.

---

http://ec.europa.eu/enviro nment/waste/weee/pdf/final_reportl_rohs1_en.pdf; http://ec.europa.eu/enviro nment/waste/weee/pdf/report_2009.pdf; page 98 et sqq.

[978] Pyreos Ltd. 2015a "Document "Questionnaire-1_Clarification_Exe-Req-Pyreos_cg130415 final - publication.pdf": 1st questionnaire (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015_1/Questionnaire-1_Clarification_Exe-Req-Pyreos_cg130415_final_-_publication.pdf

[979] C.f. reviews of pack 8 and 9 RoHS exemption requests, http://rohs.exemptions.oeko.info/index.php?id=221

[980] Pyreos Ltd. 2015b "Document "Pyreos_Suspension-of-Request-with-Conditions.pdf", sent via e-mail to Dr. Otmar Deubzer, Fraunhhofer IZM, by Torben Nørlem, Intertek, on 20 July 2015,"

Table 22-1: Overview of requests for the continuation of exemption 7c-I and application-specific wordings

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Bandelin[981]	Annex III: Continuation with specification: **Piezoelectric hard PZT containing lead for high performance ultrasonic and** electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound Annex IV: Lead in single crystal piezoelectric materials for ultrasonic transducers and in **piezoelectric hard PZT containing lead for high performance ultrasonic transducers**	Maximum validity period (5 years)	Applicant additionally requests amendment of exemption 14 in Annex IV
Bourns[982]	Continuation of exemption without changes	Maximum validity period (5 years)	Applicant mentions lead-free glasses applied in some components
IXYS	Lead in coatings of high voltage diodes	Maximum validity period	IXYS had applied for this exemption under Exemption 37; it was agreed with the applicant that the exemption is related to glass coatings of high voltage diodes, and not to lead in the platings of such diodes. The exemption request therefore was shifted to Exemption 7c-I.

[981] Bandelin Electronic GmbH 2015a "Request for continuation of exemption 7c-I with addition, document "Ex_7c_I_Application_Bandelin.pdf: Exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/BANDELN/Ex_7c_I_Application_Bandelin.pdf

[982] Bourns Inc. 2015a "Exemption request, document "7c-I_Exemption_extension_ap_7c-I.pdf": Request for continuation of exemption 7c-I," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Bourns/7c-I_Exemption_extension_ap_7c-I.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
JEITA et al.[983]	Continuation of exemption with clarification of scope: “Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in **discrete** capacitor **components**, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound”	Maximum validity period (5 years)	Request almost identical to that of Murata et al.
Murata et al.[984]	Continuation of exemption with clarification of scope: “Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in **discrete** capacitor **components**, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound”	Maximum validity period (5 years)	Request almost identical to that of JEITA et al.
Ralec[985]	Continuation of exemption without changes	Maximum validity period (5 years)	Applicant did not reply timely to clarification questionnaire; application has therefore not been followed up

[983] JEITA et al. 2015a “Exemption request, document "JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf
[984] Murata et al. 2015a “Original exemption request, document "Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf
[985] Ralec Technology 2015 “Exemption request, document "7c-I_RoHS_V_Application_Form_to_RoHS.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/RALEC/7c-I_RoHS_V_Application_Form_to_RoHS.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Pyreos[986 987]	Add following exemption to Annex III and Annex IV: Lead in thin film electronic sensor elements such as pyroelectric sensors or piezoelectric sensors	7 years	Sensors currently used in monitoring and control instruments (category 9) for both industrial and non-industrial use, but can possibly expand to other product groups of RoHS Directive;
Schott[988]	Continuation of exemption without changes	Maximum validity period (5 years)	Schott specifies the application of lead in "solder glasses" to attach optical elements like windows or lenses into metal components for high quality hermetic package for optoelectronic devices
Sensata[989]	Continuation of exemption without changes	Not specified	Request for lead in glasses to manufacture sensors and to bond sensors to other materials like e.g. metals

[986] Pyreos Ltd. 2014 “Original exempiton request for renewal of exemption 7c-I with new wording, document "RoHS_V_Application_Form-Pyreos_final 14112014 -publication.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015_1/RoHS_V_Application_Form-Pyreos_final_14112014_-_publication.pdf

[987] Op. cit. Pyreos Ltd. 2015a

[988] Schott AG 2015a “Exemption request document "20150820_Ex_7c-I_Schott_Application_Revised_A.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/SCHOTT/20150820_Ex_7c-I_Schott_Application_Revised_A.pdf

[989] Sensata Technologies 2015a “Request for continuation of exemption 7c-I, document "7c-I_RoHS-Exemptions_Application-Format_Ex_7cI_Pb_in_glass_20150115.pdf": Exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Sensata/7c-I_RoHS-Exemptions_Application-Format_Ex_7cI_Pb_in_glass_20150115.pdf

Applicant	Requested Exemption	Requested Expiry Date/ Continuation	Remarks
Vishay[990] [991]	Continuation of exemption without changes; provides application examples with below wordings in support of the unchanged continuation of exemption 7c-I: “Wire wound resistors with enamel coatings containing lead (Pb) as lead-oxide (Pb3O4) in glass” “Lead in glass of the Ag top and bottom electrode of NTC chips”	Maximum validity period (5 years)	Member of the consortium of Murata et al.[992] (Annexed to exemption request document)
YAGEO Corporation [993]	Continuation of exemption without changes		Applicant did not reply to clarification questionnaire; application has therefore not been followed up

[990] Vishay 2015a 2015 “Document "RoHS-Exe-7c-I_Pb-in-glass-Enamel-Coating_Wirewound_Resistors.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a: Document referenced in the exemption request of Murata et al. 2015a” (January 2015) unpublished manuscript,

[991] Vishay 2015c “Document "Request for exemption 7c-I NTC chips update dec15.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a: Document referenced in the exemption request of Murata et al. 2015a” unpublished manuscript,

[992] Op. cit. Murata et al. 2015a

[993] Yageo Corporation 2015 “Exemption request, document "7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf",” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/YAGEA/7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf

22.2.2 Technical Background of the Requests for Renewal of Exemption 7c-I (Murata/JEITA et al.)

Murata/JEITA et al.[994] [995] request the renewal of the exemption for five years, but ask for a slight modification of the exemption wording to clarify its scope without extending it:

> *"Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in* ***discrete*** *capacitor* ***components****, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound"*

The background of this proposed change is explained in detail in the review of exemption 7c-II, see Chapter 23.0.

The technical background for the use of lead in glass[996] and in ceramics[997] under exemption 7c-I was explained in detail in the report of the 2008/2009 review. The exemption is used in all types of electrical and electronic equipment (EEE) listed in Annex I of the RoHS Directive. The description of the exemption is therefore limited to the main aspects.

Murata et al.[998] state that the applications of lead in ceramic and glass are too numerous and that it is impossible to list all of them. They provide illustrative examples, reproduced in Table 22-2, which they claim not to constitute a comprehensive list of the uses of lead in ceramics and in glass used in electronic components.

Murata et al.[999] explain that lead is used to obtain appropriate physical characteristics in glass and/or ceramic. In ceramics, lead provides particular dielectric, piezoelectric, pyroelectric, ferroelectric, semiconductor, magnetic properties over a wide use ranges in terms of temperatures, voltages and/or frequencies.

---

[994] Op. cit. Murata et al. 2015a
[995] Op. cit. JEITA et al. 2015a
[996] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf, page 52 et seqq.
[997] Ibid., page 98 et seqq.
[998] Op. cit. Murata et al. 2015a
[999] Ibid.

Table 22-2: Example applications of lead in exemption 7c(I)

Application	Function	Product examples
Ceramic (including applications using thick film & thin film technology)		
PZT in piezoelectric ceramic	Piezoelectric effect	Transformer, filter, resonator, buzzer, actuator, sensors (pressure, shock)
Semiconductor ceramic (PTC)	Temperature dependent resistance	PTC resistor / thermistor, heater
Pyroelectric ceramic	Pyroelectric effect	Infrared sensor, temperature sensor
Ferroelectric /magnetic ceramic	Ferroelectric / Magnetic effect	Ferroelectric memories, ferrite core
Dielectric ceramic	Energy storage by polarization effect	Capacitive layers in electronic components (discrete capacitor components are in scope of 7c(II) and 7c(III))
Glass and glass-ceramic matrix compounds (including applications using thick film & thin film technology)		
Glass and/or glass frits for amorphous isolating solid or interconnection	Protection, Insulating	Discrete Semiconductors
		Glass passivation of semiconductor chips
		Glass sleeve diodes (various sizes)
		Thick film resistors
		Wire wound resistors
		NTC – Glass coating
		Metal pressure sensors
	Adhesives / Bonding	MEMS
		SMD Components
		Capacitive pressure sensing element
		Resistive pressure sensing element
	Hermetic sealing	Electronic components with hermetically sealed ceramic package
Glass-ceramic matrix compound	Functional glass compound, resistance	Thick film resistors coating, resistance and conductor layer
		High voltage resistors
		Outer electrode of ceramic components
Glass-ceramic material	Functional glass	Glass-ceramic cooking field

Source: Murata et al.[1000]

22.2.2.1 Electrical and Electronic Components Containing Lead in Ceramic

Murata et al.[1001] explain that ceramic constituted by oxides of tetravalent cations of Group 4 elements and divalent cations of lead (Pb) have the outstanding special characteristics of stably bringing out electrical properties (dielectric, piezoelectric,

[1000] Murata et al. 2015b "Questionnaire 1 (clarification questionnaire), document "RoHS_7c-I_Murata__1st_Questionnaire_answers_final_20Aug.pdf"," Clarification questionnaire, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/RoHS_7c-I_Murata__1st_Questionnaire_answers_final_20Aug.pdf

[1001] Op. cit. Murata et al. 2015a

pyroelectric, ferroelectric, semiconductor, magnetic properties) over a wide use range (temperature, voltage, frequency).

According to Murata et al.,[1002] these lead-containing ceramics are widely used as main constituent materials of electrical and electronic components and as important additives for controlling and enlarging the usable environment range (temperature, voltage) of other ceramic. Moreover, lead-containing ceramic has characteristics of densely sintering throughout a wide range of sintering conditions, low energy consumption in manufacturing and high electrical and mechanical durability of the product after sintering. By controlling the sintering conditions, a fine layered structure can be internally formed and the functionality of the electronic components can be largely improved.

The specific examples of various types of ceramics containing lead and the status of substitution or elimination are explained in Section 22.3.1 (General Status of Lead Substitution in Ceramics of Electrical and Electronic Components from page 444).

22.2.2.2 Electrical and Electronic Components Containing Lead in Glass or Ceramic Matrix Compounds

According to Murata et al.[1003] glass for electronic components is an amorphous isolating solid. In electrical and electronic components, together with making use of the various properties exhibited by glass, the desired function is obtained by the combination of glass with other materials such as metal, ceramic, etc. Lead as a constituent element of glass:[1004]

- Lowers the melting and softening points;
- Improves workability and machinability;
- Increases wettability with metal and ceramic and improves the bonding strength with other materials;
- Facilitates controlling electrical properties like conductivity, resistance values in combination with other materials over a wide range and thus provides excellent functionality; and
- Improves the chemical stability and mechanical strength of glass and helps to achieve excellent reliability;

Murata et al.[1005] state that lead-containing glass can be used over a wide range of applications. It is used for insulating, protection, resistance, adhesives, bonding, hermetic sealing and other uses. Table 22-3 provides examples.

[1002] Ibid.
[1003] Ibid.
[1004] Ibid.
[1005] Ibid.

Table 22-3: Example applications of glass containing lead

Example#	Functional group	Product and Parts example
# 1.1	Protection & Insulating	Discrete Semiconductors
# 1.2		Glass sleeve diodes (various sizes)
# 1.3		Thick film resistors
#1.4		Wire wound resistors
#1.5		NTC – Glass coating
#1.6		Metal pressure sensors
#2.1	Functional glass compound/Resistance	Thick film resistors coating and/or contact layer
#2.2		High ohmic / high voltage resistors materials
#2.3		NTC – Inner electrode
#3.1	Adhesives / Bonding	MEMS
#3.2		SMD Components
#3.3	Hermetic sealing	Electronic components with hermetically sealed ceramic package

Source: Murata et al.[1006]

Murata et al.[1007] [1008] highlight that in the above list neither the functional groups nor the product examples are exhaustive. The list serves to explain why lead in glass is needed and lead-free substitutes are not technically suitable. The examples for the various functional groups and the prospects to substitute or eliminate lead are explained in more detail in Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds from page 460).

[1006] Ibid.
[1007] Ibid.
[1008] Murata et al. 2016a “Answers to second questionnaire, document "Exe_7c-I_Questionnaire-2_Murata-JEITA_2015-12-30_answers_final.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Wolfgang Werner, Vishay, on 29 January 2016” unpublished manuscript, Second questionnaire

22.2.3 Technical Background of the Bandelin Application-specific Exemption Request

Bandelin[1009] requests an addendum to the current exemption wording:

> ***Piezoelectric hard PZT containing lead for high-performance ultrasonic transducers and*** *electrical and electronic components containing lead in glass or ceramic materials other than dielectric ceramic in capacitors*

Bandelin[1010] claims that the wording of exemption 7c-I does not clearly describe the applied use, as no differentiation is made between soft PZT and hard PZT. Only hard PZT is suitable for high-performance applications. Soft PZT is used for actuators and sensors.

Bandelin[1011] explains that they use piezoceramic material, which is used as lead zirconium titanate (PZT) in great quantities and various forms to create high-performance piezoelectric transducers, which are a major part of equipment such as ultrasonic cleaning systems and homogenisers. Piezoceramic “hard PZT” in the form of perforated discs is the exclusive material used for these high-performance transducers worldwide. In Europe, it bears the designation PZT 4 or PZT 8, and it contains more than 0.1 % by weight of lead.

Bandelin[1012] considers itself a leading manufacturer of high-performance ultrasound equipment with a wide range of devices for cleaning technology and ultrasound technology for industrial, medical and laboratory applications. They install roughly 70,000 perforated discs made of hard PZT 4 and PZT 8 in their high-performance ultrasonic transducers every year.

The development of high-performance piezoceramic ultrasonic transducers began in the 1950s and has undergone an enormous upswing since the invention of lead zirconium titanate materials – especially in the overall field of cleaning technology. Among other things, this led to chlorinated hydrocarbons and chlorofluorocarbons being replaced by water-based ultrasonic cleaning processes.[1013]

As an equipment manufacturer, Bandelin[1014] absolutely relies on purchasing high-performance piezoelectric ceramics made of hard PZT for the construction of high-performance ultrasonic transducers.

[1009] Op. cit. Bandelin Electronic GmbH 2015a
[1010] Bandelin Electronic GmbH 2015b “Questionnaire 1 (clarification questionnaire), document "Ex_7c-I_Bandelin_1st_Questionnairie_and_Answers.pdf",” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/BANDELN/Ex_7c-I_Bandelin_1st_Questionnairie_and_Answers.pdf
[1011] Op. cit. Bandelin Electronic GmbH 2015a
[1012] Ibid.
[1013] Ibid.
[1014] Ibid.

22.2.4 Technical Description of the Bourns Exemption Request

Bourns[1015] uses lead in thick films, which are resistive and conductive films greater than 0.0001 inches thick, resulting from firing a paste or ink that has been deposited on a ceramic substrate. These thick film inks typically contain a glass material that includes lead.

Bourns[1016] also uses lead-containing glass frits that have several applications including barrier layers for stopping the migration of silver and a sealing material for hermetic packages. Glasses are typically part of a thick film formulation. Various oxides are melted together to form a glass matrix. It is also used as a sealant in hermetic ceramic and metal electronic (semiconductor and hybrid) component packages. The lead oxide is used to lower melting temperature and viscosity for processing below 550 °C and to raise the dielectric strength. The lead oxide content of the glass can be adjusted controlling the coefficient of thermal expansion which is favourable for high sintering temperature operations.

Components using lead-glass include chip arrays, chip resistors, ESD protectors, transient voltage suppressor diodes, encoders, fuel cards, ceramic PTC resettable fuses, thick film moulded dips, panel controls, power resistors, trimming potentiometers. These electronic components are typically used on circuit boards and other internal electronics in products of all RoHS categories in Annex I by Bourns' customers.[1017]

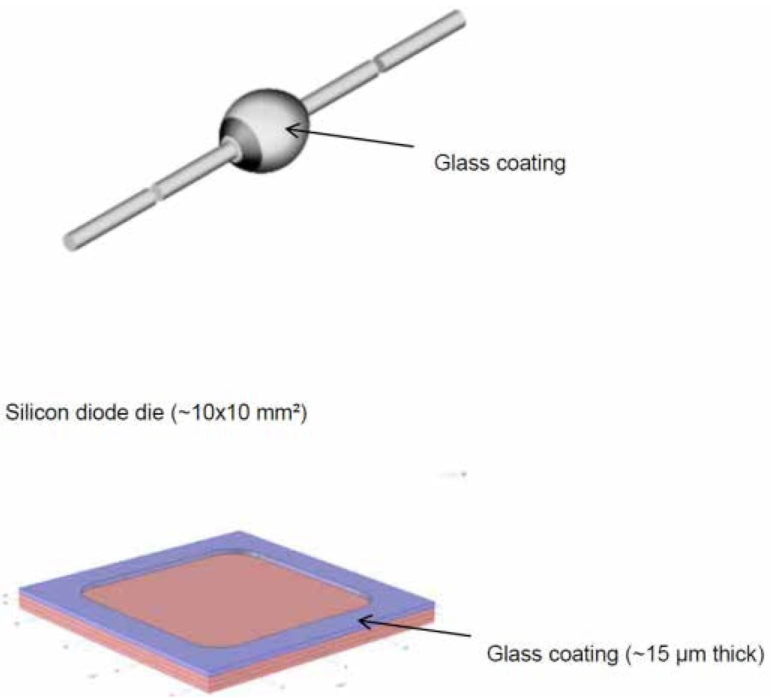
The homogeneous material is the glass included in the thick film ink or encapsulation, which is then fired on a substrate. The lead content will vary and can range from 1-75 % in the glass only. The total ink/encapsulation including the glass is generally less than 1 % of the finished part.[1018]

22.2.5 Technical Description of the IXYS Application-specific Exemption Request

IXYS[1019] request an exemption for lead in coatings of high voltage diodes. The glass coatings used for high reliability semiconductor power device passivation and packaging contain lead. Lead-based glasses are used because they have unique combinations and characteristics that cannot be achieved by other materials or methods. Zinc borosilicate glasses with lead are used to prevent degradation of high reliability semiconductor devices in applications at or above 100 V AC for rectification and other electric power converters.

[1015] Op. cit. Bourns Inc. 2015a
[1016] Ibid.
[1017] Ibid.
[1018] Ibid.
[1019] IXYS Semiconductor GmbH 2014 2014 "Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf

Figure 22-1: Lead glass in high voltage diodes and on silicon diode dies



Source: IXYS[1020]

Examples are provided by IXYS of lead glass used in high voltage diodes and on silicon diode dies in Figure 22-1. According to IXYS,[1021] these components are used in transportation, automotive, and in high power equipment in the industry, from which only the latter is in the scope of the RoHS Directive.

IXYS[1022] explains that lead provides good physical properties in combination with pure silicon crystals and a good ability to withstand high electric fields in the range of 200,000 V/cm in alternate and direct current power semiconductor devices.

[1020] Ibid.
[1021] Ibid.
[1022] Ibid.

22.2.6 Technical Background of the Pyreos Application-specific Exemption Request

Pyreos[1023] requested to add an exemption with the following wording to both RoHS Annex III and Annex IV with a maximum validity of seven years:

> *"Lead in thin film electronic sensor elements such as pyroelectric sensors or piezoelectric sensors"*

Pyreos[1024] explains the request to relate to lead in thin film $PbZrTiO_3$ (PZT) sensors for pyroelectric or piezoelectric applications. The sensors are currently used in monitoring and control instruments but the future use could expand to other product groups under RoHS.

According to Pyreos[1025], lead in the sensing elements of thin film PZT sensors is used for pyroelectric applications such as:

- low power gesture / proximity detection;
- gas detection;
- safety and security applications such as gas detection and intruder alarms;
- Infrared spectroscopy for industrial and consumer applications; or
- piezoelectric applications such as piezo actuators or transducers.

Pyreos[1026] states the lead atoms are fundamental to the unique properties of the PZT material system and it is the special electronic structure of lead together with its weight that gives the PZT material system its unique properties. Present lead-free alternatives are not commercially viable and the substitution of lead may potentially adversely impact the performance of monitoring and control equipment relying on the PZT thin film sensors whereby consumer and worker safety may be impaired.

Pyreos[1027] explain that there are a total of 32 crystal configurations of which 10 are polar showing a pyroelectric effect. Ferroelectric materials form a sub-class of the polar materials, and some ferroelectric materials are characterised by a very high pyroelectric effect. Figure 22-2 shows the technically most relevant material groups including some key performance parameters.

[1023] Op. cit. Pyreos Ltd. 2015a
[1024] Op. cit. Pyreos Ltd. 2014
[1025] Ibid.
[1026] Ibid.
[1027] Ibid.

Figure 22-2: Ferrocelectric materials and pyroelectric effects

Material	Example	$\varepsilon/\varepsilon_o$	tanδ	p $10^{-4}C/m^2K$	F_D $10^{-5}/\sqrt{Pa}$
Ferroelectric single crystals	$LiTaO_3$	45	0.005	2.0	4.4
Modified ferroelectric ceramics	$PbTiO_3$	250	0.007	4.2	4.3
Ferroelectric thin films on silicon	PZT	250	0.006	2.2	2.4
Ferroelectric polymers	PVDF	12	0.015	0.3	0.9

Source: Pyreos[1028]

Pyreos[1029] states that for most applications it is not only important to have a large pyroelectric effect, but other factors, such as temperature dependence of the pyroelectric material, its Curie temperature and the manufacturing costs are also important factors that will ultimately determine the commercial success of a sensor material.

Pyreos[1030] claim that they can realise all of the above mentioned requirements with thin-film, ferroelectric lead zircon titanate (PZT) layers on silicon (line 4 in the above table). This is compared to the most commonly used ceramic pyroelectric infrared sensors based on PZT and lead titanate ($PbTi0_3$, line 2 of the table above), for which a RoHS exemption is required. The sensors with thin-film PZT layers on silicon contain only about 1/3000 of lead.

The PZT layers, which are the homogeneous material, contain around 80 % of lead resulting in only around 1 g of lead annually that would be used in the EU under this requested exemption.

[1028] Ibid.
[1029] Ibid.
[1030] Ibid.

Pyreos[1031] concludes that it requests the new exemption as the quantity of lead and the technology used for thin film sensors is fundamentally different from the conventional technology covered by the existing exemption 7c-I.

22.2.7 Technical Background of the Schott Exemption Request

Schott[1032, 1033] supports the continuation of exemption 7c-I in its current wording and scope, but specifically lead-oxide-based glasses, so called “solder glasses”, to attach optical elements like windows or lenses into metal components to achieve a glass-to-metal sealing for the hermetic packaging of electronic devices. This assembly is part of a hermetic package (“Cap”) for optoelectronic devices like laser diodes, photo detectors etc.

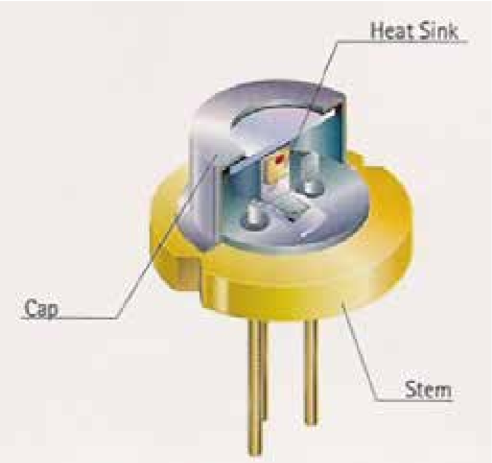
SCHOTT AG produces components for many types of EEE. Applications of these components are[1034]:

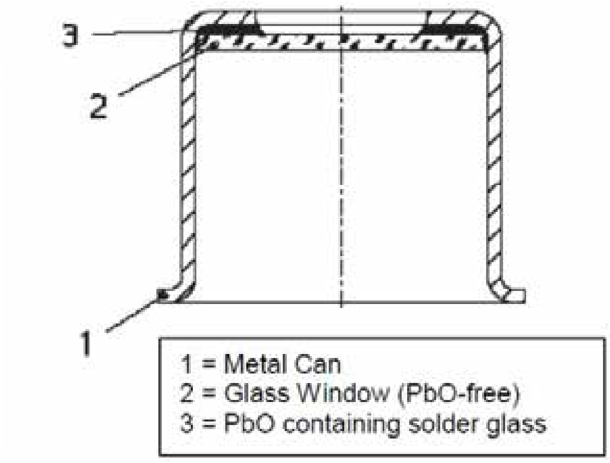
- Fibre Optic Data Communication Components:
  - Laser Diodes for Transmit Modules; and
  - Photodiodes and Avalanche Photo Diodes for Receive Components;
- Laser Packaging;
- Optical Sensor Devices:
  - Laser Diode-based Gas Sensors;
  - Infrared Sensors;
  - Photodiodes and photoresistors;
- Optical micro-electromechanical systems (MEMS) Packaging;
- High Power light emitting diode (LED) Packaging;

The “solder” glass contains around 75 % of lead to achieve a sufficiently low working temperature.

[1031] Op. cit. Pyreos Ltd. 2015a
[1032] Op. cit. Schott AG 2015a
[1033] Schott AG 2015b “Questionnaire 1 (clarification questionnaire), document "20150820_Ex_7c-I_Schott_Ans_Questionnaire-1_Schott_2015-07-30.pdf": Questionnaire 1 (clarification questionnaire),” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/SCHOTT/20150820_Ex_7c-I_Schott_Ans_Questionnaire-1_Schott_2015-07-30.pdf
[1034] Op. cit. Schott AG 2015a

Figure 22-3: Laser diode package (left) and cross section of its window cap (right)





Source: Schott[1035]

22.2.8 Technical Background of the Sensata Exemption Request

Sensata applies for the renewal of exemption 7c-I in its current scope and wording. Sensata[1036] uses lead in glass to obtain good bonding, sealing and encapsulation properties in for example: [1037]

- Bonding ceramic to ceramic to form a pressure sensing element;
- Bonding diverse sensing elements on steel including sealing; or
- Encapsulating electronic components, like thick film paste for hybrid integrated circuits, resistors, capacitors, etc..

The use of lead in bonding glasses results in lowering the softening point, lowering the viscosity, matching the coefficient of thermal expansion (CTE), improving affinity and strengthening environmental resistance of parts to be bonded, sealed and/or encapsulated.[1038]

The lead glass is used in sensors for measuring for example pressure and temperature to improve safety, increase energy efficiency, reduce emissions etc.[1039] The lead in the glass helps to achieve the following glass properties:

- Lead in the glass lowers the softening point. The glass is used to bond for example silicon strain gages with aluminium bond pads on stainless steel

---

1035 Ibid.
1036 Op. cit. Sensata Technologies 2015a
1037 Ibid.
1038 Ibid.
1039 Ibid.

diaphragm. The firing temperature (at which the silicon is bonded to the stainless steel) must not exceed the (eutectic) temperature of the aluminium, potentially causing junction spiking and other reliability issues in the aluminium on silicon. Firing temperature is normally in the 850 °C range.[1040]

- Lead glass also has a low viscosity needed to flow well during the bonding process. Bad flow potentially causes pin holes and other (surface) imperfections which makes the glass sensitive to cracks and other mechanical damages when subjected to mechanical stresses which will occur during normal operation (= pressure exerted on steel and ceramic diaphragm). Cracks cause unacceptable sensor drift and potential sensor failure. Lead-free glasses have much higher viscosity (in the order of 100).[1041]
- Match the coefficient of thermal expansion of parts to be bonded. The coefficient of thermal expansion (CTE) of the glass should be within a specific range and compatible with stainless steel and alumina. Too low values cause a too high compressive stress in the glass, too high values can cause tensile stress. Both may result in glass cracks and, consequently, sensor failure.
- Improve affinity - to guarantee a sufficient adhesion between ceramic element and metal electrode or between semiconductor device and glass.
- Increase the resistance against adverse environmental conditions.

There is a growing need in for example household and industrial applications for mission critical sensors as made by Sensata, to make applications safer, more energy efficient and less emissive.[1042]

22.2.9 Amount of Lead Used Under the Exemption

Murata/JEITA et al.[1043, 1044] quantify the amount of lead used under the exemption in the EU with around 350 tonnes annually.

Murata/JEITA et al.[1045, 1046] base their estimate on 2013 data from the below companies, which represent the major players on the EU market:

- Ceram Tec;
- Emerson;
- EPCOS;
- Freescale;

[1040] Ibid.
[1041] Ibid.
[1042] Ibid.
[1043] Op. cit. Murata et al. 2015a
[1044] Op. cit. JEITA et al. 2015a
[1045] Op. cit. Murata et al. 2015a
[1046] Op. cit. JEITA et al. 2015a

- Johnson Matthey Piezo ProductsMeggitt DK;
- Morgan Advanced Materials;
- Murata;
- PI Ceramic.

Murata/JEITA et al.[1047, 1048] state that electrical and electronic components are used in a wide range of final products and markets, it is impossible to provide a precise figure of the amount of lead included in glass and ceramic components in the EU for EEE. The electronic equipment industry is engaged in the reduction of lead and environmental burdens within its powers, although it is impossible to completely cease the use of lead under the scope of 7(c)-I. They present the above estimate based on company figures. It should be noticed that there may be components with lead-containing ceramic and companies which are not included in this estimation. For this reason, the values presented here are given for reference purposes only.

22.3 Applicants' Justifications for the Exemption

Murata et al.[1049] state that our society requires the best health care and safety technology. Many components containing lead in a glass and/or ceramic matrix compound provide high security performance in EEE or save lives like, for example, overcurrent or over-temperature protection.

Murata et al.[1050] investigated the substitution of lead in glass and/or ceramic used in electrical and electronic components prior to the last review and have continued the investigation after 2009 as well; however, they have not found any substitution technology up to the present day, and extensive research has shown that there are no prospects of finding substitutes in the next five years. Consequently, they claim that it is necessary to extend exemption 7(c)-I for an additional validity period of 5 years for categories 1 – 7 and 10 equipment.

22.3.1 General Status of Lead Substitution in Ceramics of Electrical and Electronic Components

According to Murata et al.[1051] numerous potential compositions have been investigated for ceramic in the last 10 years and the main task is still the development of reliable technical solutions on an industrial scale. However up to the present moment, substitution technology has not been found and there is no prospect of finding it at least until the maximum validity period. No lead-free substitute with equivalent electrical properties, environmental adaptability range, reliability, workability and productivity has been found. Consequently, lead-containing glass and/or ceramic are indispensable for

[1047] Op. cit. Murata et al. 2015a
[1048] Op. cit. JEITA et al. 2015a
[1049] Op. cit. Murata et al. 2015a
[1050] Ibid.
[1051] Ibid.

bringing out the required functionality and properties of the electrical and electronic components applicable to exemption 7(c)-I.

For piezoelectric ceramics, according to Murata et al.,[1052] niobium, tantalum, antimony, lithium, rare earth elements etc. have been investigated as elements for substituting lead as a constituent element of ceramic. However, the electrical (piezoelectric) properties are inferior when compared with lead-containing ceramic and cannot be stably achieved throughout a wide temperature range. Moreover, the properties described in research papers were obtained in the laboratory and experience has shown that these cannot generally be achieved stably at a mass production scale. There are still many remaining technical issues needing to be solved in order to achieve mass production of practical products. Adding to that, even in the case that mass production technology is achieved; the research has shown that the required properties for substituting almost all of the applications cannot be obtained.

Murata et al.[1053] claim that replacing PTC even in a certain resistance-Tc range only at the moment would need an overall change in powders conception used in the production of PTC. This is because not just one powder is used in production of a certain product but usually a mixture of two or more powders. With the alternative materials examined up until now, because of the strong limitations in regard to certain properties, only ceramic for applications with low Curie temperatures might be meaningful to undergo further investigation and development. Also for these low Tc applications, several constraints still exist.

22.3.1.1 Principle Elements for Lead Substitution in Ceramics

Murata et al.[1054] state that electrical properties of ceramic strongly depend on their crystal structure. According to Pauling's rule, in order to form the same crystal structure, constituent elements of ceramic, which can substitute lead are restricted to ions with a divalent valence and an ionic radius of 0.93-1.81 Å. On a purely scientific basis the elements which meet these conditions are limited to the following four:

- Cadmium;
- Calcium;
- Strontium; and
- Barium.

Cadmium is much more toxic than lead and is already restricted by the RoHS Directive, and thus is not appropriate even for consideration as a substitute material. "Lead-free" ceramics formed from alkaline-earth metals and titanium and zirconium, etc. have electrical properties strongly dependent on the operating environment temperature and voltage, and as they lack stability throughout a wide use environment range, i.e.

[1052] Ibid.
[1053] Ibid.
[1054] Ibid.

temperatures, voltages, frequencies, the alkaline-earth metals cannot be used as substitute materials of lead.

22.3.1.2 New Ceramics

Murata et al.[1055] report about the alternative approach of ceramics having a completely different composition than those using lead, as a substitute material for lead-containing ceramics. In spite of that, up to the present moment it has not been possible to achieve mass production of electrical and electronic components using substitute materials and having the same level of functionality. The electrical properties (piezoelectric properties) of (K, Na)NbO_3-type ceramics constituted of potassium, sodium and niobium are inferior when compared with lead-containing ceramic and cannot be stably achieved throughout a wide temperature range. [1056] Moreover, the properties obtained in the laboratory cannot generally be stably achieved at a mass production scale. There are still many remaining issues needing to be solved in order to achieve mass production of practical products. Adding to that, even in the case that mass production technology is achieved; the required properties for substituting almost all of the applications cannot be obtained.

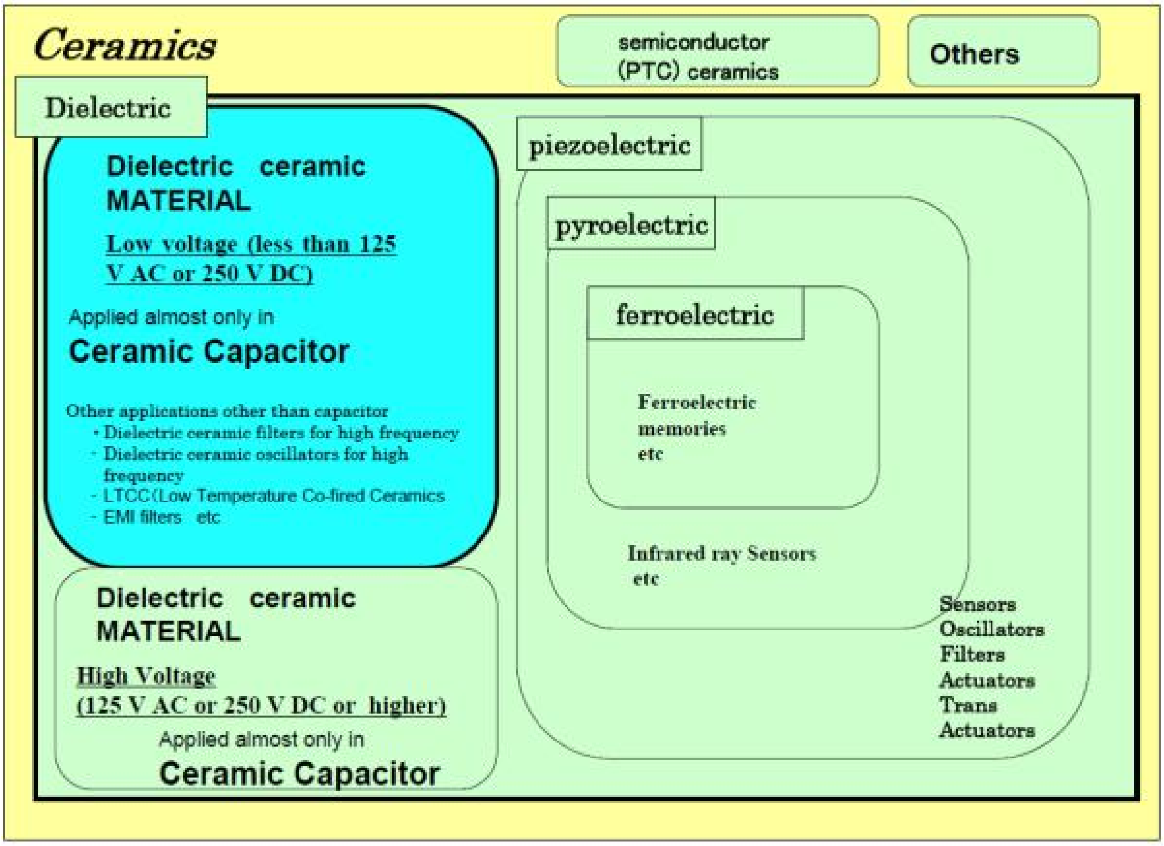
22.3.1.3 General Conclusion for Substitution or Elimination of Lead in Ceramics

Murata et al.[1057] conclude that for lead-containing ceramic falling into the technical scope of exemption 7(c)-I it is not possible to substitute lead by simply replacing it by another element. Moreover, attempts to obtain equivalent electrical properties from a completely different perspective have not progressed beyond ultimately obtaining similar results at best for a small part of the properties at laboratory level, and there are absolutely no technical perspectives to comprehensively eliminate lead from ceramic as of now.

Figure 22-4 gives an overview on the main types of ceramics in the scope of exemption 7c-I.

[1055] Ibid.
[1056] Jing-Feng Li, Ke Wang, Fang-Yuan Zhu, Li-Qian Cheng and Fang-Zhou Yao. “(K, Na) NbO3-Based Lead-Free Piezoceramics: Fundamental Aspects, Processing Technologies and Remaining Challenges”, J. Am. Ceram. Soc., 1-20 (2013); source referenced in Murata et al. 2015a
[1057] Ibid.

Figure 22-4: Classification of ceramic materials and their main uses



Source: JEITA et al. in Zangl et al. (2010 [1058])

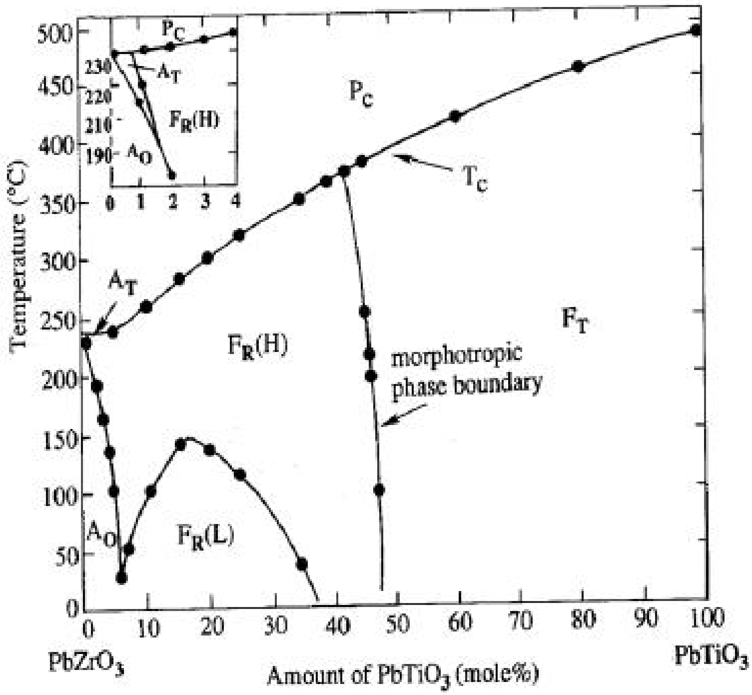
The following applicants present justifications for the continued use of lead in piezoelectric and PTC ceramics. The use of lead in dielectric ceramics in ceramic capacitors is covered by exemptions 7c-II, 7c-III and 7c-IV.

22.3.2 Substitution of Lead in PZT Ceramics

Murata e al.[1059] explain that Lead Titanium Zirconium Oxide abbreviated as PZT is the main material for piezoelectric devices. Lead (Pb^{2+}) is the main constituent in the solid solution of Lead Titanium Oxide with a tetragonal crystal structure and lead zirconium oxide with a rhombohedral crystal structure. Lead titanium oxide and lead zirconium oxide form a unique morphotropic phase boundary which is vertical above temperature as shown in the following phase diagram.

[1058] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010a
[1059] Op. cit. Murata et al. 2015a

Figure 22-5: Phase diagram with morphotropic phase boundary of PZT



Source: Jaffe, Cook Jaffe: Piezoelectric ceramics, referenced by Murata et al.[1060]

According to Murata et al.[1061], this special perovskite structure in combination with the unique electron structure of Pb brings out the unique combination of piezoelectric properties over a wide temperature range, like:

- High Curie temperatures;
- High piezoelectric charge constants;
- High electromechanical coupling factors;
- High quality factors and low losses for ultrasonic devices;
- High stability under different driving and environmental conditions, especially temperature;
- High reliability.

Murata et al.[1062] put forward that those properties are required for the applications. To aid the understanding of the applicant's justification, Table 22-4 explains essential parameters of PZT ceramics.

[1060] Ibid.
[1061] Ibid.
[1062] Ibid.

Table 22-4: Essential characteristics of PZT ceramics

Curie temperature	Temperature at which piezoelectric ceramics lose their piezoelectric properties.
Electro Mechanical Coupling Coefficient (k) of piezoelectric ceramics	Coefficient to show the efficiency to transform and communicate electric alteration into the energy of mechanical alteration (or vice versa) due to the piezoelectric effect: $k = \sqrt{\frac{\text{mechanical energy stored}}{\text{electrical energy applied}}}$ or $k = \sqrt{\frac{\text{electrical energy stored}}{\text{mechanical energy applied}}}$ In order to gain filter characteristics, materials with high values in this category are essential.
Mechanical Quality Factor Coefficient of piezoelectric ceramics	Shows the extent of mechanical loss near frequencies where the piezoelectric substance resonates. In resonators and oscillators, as the value becomes higher, the oscillator becomes more efficient and the fluctuation in the resonance frequency decreases.
Piezoelectric Strain Coefficient (d constant) (Piezoelectric material constant)	Indicates how efficient an electric field can generate strain of the piezoelectric material, or vice versa how efficient a strain applied on the ceramic can generate an electrical field. Higher values indicate higher efficiency. d=strain / applied electrical field If the value is high, the piezoceramic can generate displacement efficiently from a low electric field. Also, the output is larger for sensors and it can be used as good sensor material with high sensitivity.
PZT ceramics	Ceramics consisting of a mixture of $PbZrO_3$ and $PbTiO_3$.
Saturation polarization	Highest practically achievable magnetic polarization of a material when exposed to a sufficiently strong magnetic field.

Source: Zangl et al. 2010[1063]

Murata et al.[1064] inform that intensive work has been done in the past to identify alternatives for PZT resulting in more than 2,500 patent publications[1065]. Most of them go back to the known base compositions and indicate the development effort to improve the piezoelectric properties related to the base lead-free compositions. Murata et al.[1066] claim to continuously review the possibility of using alternative lead-free piezoelectric materials and have done internal and external developments towards lead-

[1063] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010a
[1064] Op. cit. Murata et al. 2015a
[1065] C.f. http://www.geocities.jp/kusumotokeiji/wadi.htm, source as referenced by Murata et al.
[1066] Ibid.

free materials, e.g. in the REALMAK[1067] and DELLEAD[1068] projects funded by the German Government, and in the sfb 595 at TU Darmstadt[1069], Germany.

Based on the state of the art in the development of lead-free alternatives for PZT, Murata et al.[1070] list three main groups of compositions as potential lead-free piezoceramic candidates:

- Barium titanate-based;
- Bismuth sodium titanate (BNT)-based; and
- Potassium sodium niobate (KNN)-based.

According to Murata et al.[1071], none of the above materials can be considered as a suitable overall lead-free substitute for PZT applications in the scope of the RoHS Directive. Figure 22-6 presents a comparison of basic physical properties of PZT and lead-free ceramics.

[1067] RealMAK - Technische Informationsbibliothek (TIB); Link: https://www.tib.eu/de/suchen/?id=198&tx_tibsearch_search%5Bquery%5D=RealMAK&tx_tibsearch_search%5Bsearchspace%5D=portal&tx_tibsearch_search%5Bsrt%5D=rk&tx_tibsearch_search%5Bcnt%5D=20; source as referenced by Murata et al./JEITA et al. 2016b

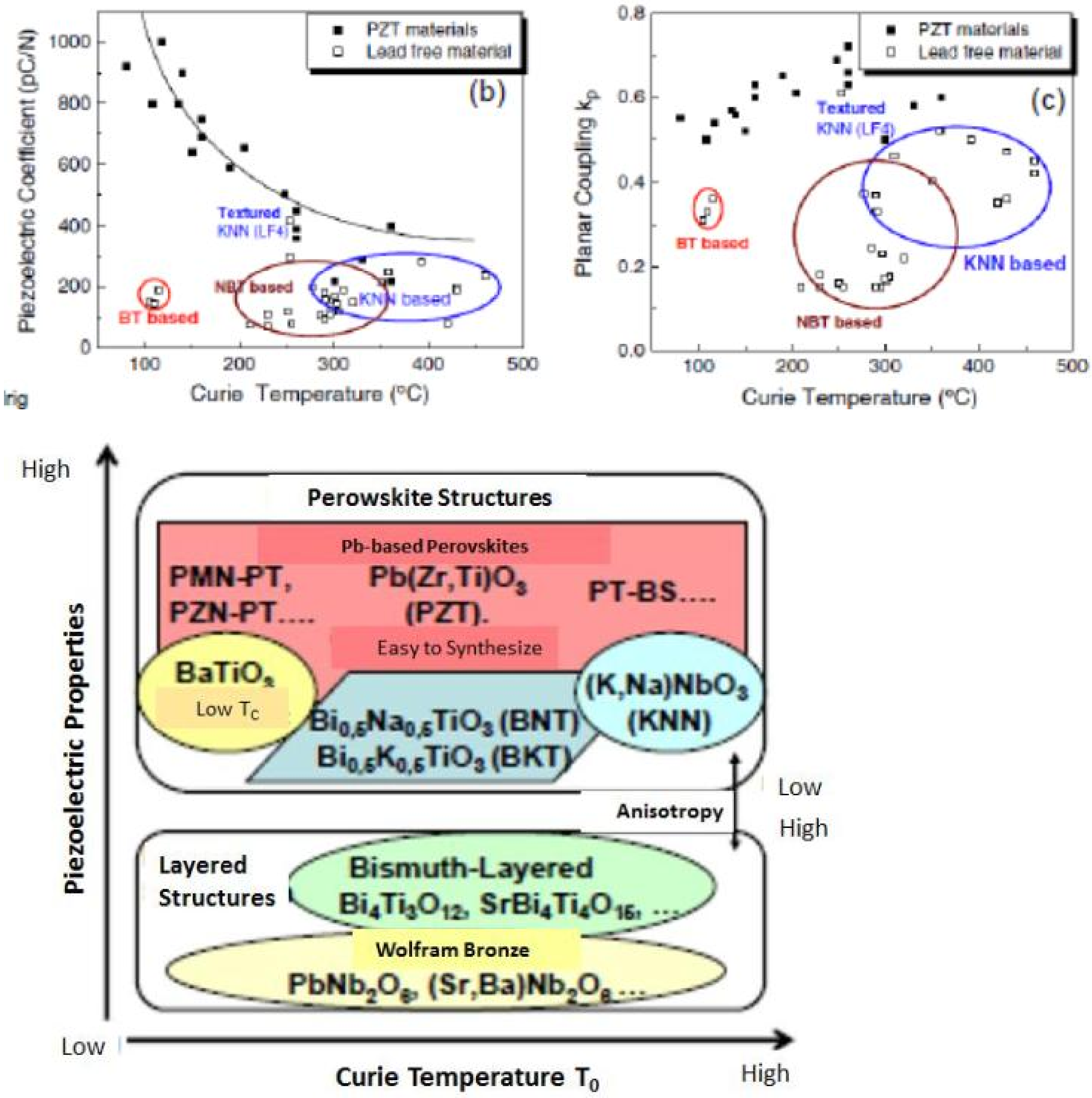
[1068] DelLead Bleifreie Piezokeramik für die Aktorik DelLead - Technische Informationsbibliothek (TIB); Link: https://www.tib.eu/en/search/id/TIBKAT%3A577111779/; source as referenced by Murata et al./JEITA et al. 2016b

[1069] Sfb595 – Technische Universität Darmstadt; Link: http://www.sfb595.tu-darmstadt.de/sfb595/sfb595_1.de.jsp; source as referenced by Murata et al./JEITA et al. 2016b

[1070] Ibid.

[1071] Ibid.

Figure 22-6: Performance comparison of lead-free and PZT ceramics



Source: M. Matsubara[1072], T.R. Shrout et al.[1073], referenced in Murata et al.[1074]

According to Murata/JEITA et al.[1075], the two top figures in Figure 22-6 show that the piezoelectric characteristics of piezoelectric ceramics largely fluctuate in a domain close

---

[1072] M. Matsubara 2005: Processing and piezoelectric properties of lead-free (K, Na)NbO³; dissertation department of applied chemistry, Graduate School of Engineering, Nagoya University

[1073] T.R. Shrout, S.J.Zhang: Lead-free piezoelectric ceramics: Alternatives for PZT?, in: Journal of Electroceramics 19, 2007, page 113 - 126

[1074] Murata et al. 2015c "Addendum to original exemption request, document "Leadfree_PZT_comparison.pdf","

[1075] Murata et al./Jeita et al. 2016b "Answers to third questionnaire (ceramics), document "Exe_7c-I_Questionnaire-3_Murata-JEITA_2016-03-03_ceramics.pdf", received via e-mail by Dr. Otmar Deubzer, to the Curie temperature, and when exceeding the Curie temperature the functionality of the ceramics is lost through depolarization. In order to use piezoelectric ceramics in practice, it is necessary that the piezoelectric characteristics be stable, therefore when considering the use environment and manufacturing conditions of general EEE, the Curie temperature needs to be 200 °C or more as a minimum, and preferably 250 °C or more.

22.3.2.1 Barium Titanate-Based Ceramics as PZT Substitute

Murata et al.[1076 1077] state that lead-free barium titanate ($BaTiO_3$), the first piezoceramic ever, to their best knowledge for historic reasons is still used for niche military applications, specifically for naval underwater acoustics, which are outside the scope of the RoHS Directive. In the lead-free versions the working temperature is limited to the low Curie temperature of about 120 °C.

According to Murata et al.[1078 1079], all other $BaTiO_3$ materials are modified with up to 10 % lead titanate to increase the Curie temperature. These materials are not used as a replacement for PZT, but are used due to other properties, e.g. density, where PZT cannot be used. Murata/JEITA et al.[1080] to the best of their knowledge, however, do not know applications for which such $BaTiO_3$ can be used, but PZT cannot. Upon further request, Murata/JEITA[1081] reaffirm that they do not know other properties besides density that would qualify the use of the $BaTiO_3$-based ceramics with up to 10 % of lead and that they do not know applications where they could be used where PZT cannot be used.

In principle, the $BaTiO_3$ materials with up to 10 % of lead titanate could be used to replace PZT ceramics, which contain 50 % of lead and more, in order to reduce the total amount of lead where its material properties are sufficient. Murata/JEITA et al.[1082] explain that the modification of $BaTiO_3$ with up to 10 % $PbTiO_3$ is a compromise to increase T_c from ~120 °C to ~150 °C. But with increasing lead content, the piezoelectric properties decrease. Therefore, $BaTiO_3$ with a lower lead content still have piezoelectric properties which are inferior compared to PZT. It is actually inferior even compared to other lead-free compounds.[1083] Moreover, in almost all applications, heat is applied in manufacturing processes or use environments, therefore higher Curie temperatures (200 °C or more, preferably 250 °C or more) are required. Even by partially substituting $BaTiO_3$

Fraunhofer IZM, from Klaus Kelm, Murata, on 22 March 2016” unpublished manuscript,
[1076] Op. cit. Murata et al. 2015a
[1077] Op. cit. (Murata et al. 2016a)
[1078] Op. cit. Murata et al. 2015a
[1079] Op. cit. (Murata et al. 2016a)
[1080] Op. cit. (Murata et al./Jeita et al. 2016b)
[1081] Murata et al./JEITA et al. 2016d “Answers to questionnaire 5a, document "Exe_7c-I_Questionnaire-5a_Murata-JEITA_2016-03-28_Ceramics_final.pdf", received via e-mail from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016” unpublished manuscript,
[1082] Op. cit. (Murata et al./Jeita et al. 2016b)
[1083] Jaffe, Cook, Jaffe; Piezoelectric Ceramics; Academic Press Ltd.; 1971; source as referenced by Murata/JEITA et al. 2016b

by lead titanate, the Curie temperatures will increase to levels of not more than 20-30 °C, which is insufficient.

22.3.2.2 Bismuth Sodium Titanate (BNT) as PZT Substitute

BNT-based compositions are characterized by so called depolarization temperatures, at which the macroscopic piezoelectric properties are lost within a very narrow temperature range, which is much lower than the Curie temperature. Therefore, the usable working temperature range is limited to about 200 °C. BNT-based compositions show a strong anisotropic behaviour, which means that these materials have a low planar mode but a high thickness mode piezoelectric coupling with low piezoelectric charge coefficients, a low dielectric permittivity and moderate dielectric losses. Sometimes a high normalized charge coefficient d_{33}, i.e. induced strain / applied electric field strength, is mentioned in the literature suggesting a strong piezoelectric effect. At this point it must be clarified that this so called "giant piezoelectric effect" is caused by a field induced phase transition and it is not a linear piezoelectric effect. For PZT or similar components field induced phase transitions or domain switching processes lead to reliability issues due to crack propagation in the grains. Nonetheless, no reliability study is currently available according to Murata et al.[1084]

22.3.2.3 Potassium Sodium Niobate (KNN) as PZT Substitute

KNN-based compositions, textured or non-textured, have the highest potential to be an alternative to PZT because the Curie-temperatures are comparable to the PZT family and piezoelectric coefficients are between the BNT-based materials and PZT. But it must be pointed out that this strong piezoelectric coupling is found around polymorphic phase transitions and therefore shows a remarkable temperature dependence.

Murata et al.[1085] state that besides the dielectric and piezoelectric properties for the possible alternatives for PZT, the technological requirements for production on an industrial scale must be considered. The safe mass production of PZT materials based on conventional ceramic processes, including water-based mixing and milling processes as well as sintering in normal atmosphere, is well established. In contrast, for BNT-based materials as well as for KNN-based materials, different processes must be developed to bring out the properties obtained in the laboratory to mass production. In particular the KNN-based materials are the most challenging with respect to the synthesis. It is well known that the properties are strongly dependent on real stoichiometric composition, which can hardly be controlled because of the volatility of the alkaline metals. For both KNN and BNT materials, especially the mixing and milling play a crucial role. Because of the water solubility of most of the raw materials, processes must be switched from water- to solvent-based ones, with a high impact on health and environment protection.

[1084] Op. cit. Murata et al. 2015a
[1085] Ibid.

Murata/JEITA et al.[1086] state that new technological routes for a stable mass production must be developed. At the moment this is not yet achieved, and it is not foreseeable when a breakthrough can be achieved. In summary, Murata et al.[1087] conclude, none of the known lead-free piezoelectric materials is a suitable overall substitute for PZT.

22.3.2.4 Bandelin's Application-specific Exemption Request for use of PZT Ceramics in High Power Transducers

Bandelin[1088] claims they are in constant contact with the manufacturers Ceram Tec and Pi Ceramic in Germany in order to develop potential alternatives to substitute lead in high-performance piezoelectric ceramics, especially for the early testing of lead-free perforated discs in high-performance ultrasonic transducers. Bandelin has already conducted such tests with samples from Honda/JP, but the results were quite negative. It is not possible to substitute PZT by changing the construction of high-performance ultrasonic transducers and substituting the material with a lead-free ceramic has not been conceivable to date.

High-performance applications with hard PZT basically employ the inverse piezoelectric effect to produce high dynamic alternating oscillations in high-frequency resonant operation, with amplitudes of up to 10 µm per ceramic element in continuous operation without cooling.[1089]

The known material threshold values also yield clear evidence of the unsuitability of lead-free BNT and KNN piezo ceramics for high-performance applications. Table 22-7 compares the mean values for core performance parameters of various ceramics.[1090]

Table 22-7: Comparison of material properties of ceramics

Material	tanδ (10^{-3}) (electrical loss angle)	Qm (mechanical Q)	Tc/Td Curie/depolarisation temperature
Soft PZT	20	70	260 °C (Tc)
Hard PZT	4	800	320 °C (Tc)
BNT ceramic	30	200	200 °C (Td)
KNN ceramic	30	unknown	290 °C (Tc)

Source: Bandelin[1091]

Due to the higher internal losses in lead-free piezo ceramics, a higher proportion of the supplied electric power is converted into heat, leading to significantly lower energy

[1086] Op. cit. (Murata et al./Jeita et al. 2016b)
[1087] Op. cit. Murata et al. 2015a
[1088] Op. cit. Bandelin Electronic GmbH 2015a
[1089] Op. cit. Bandelin Electronic GmbH 2015b
[1090] Ibid.
[1091] Ibid.

efficiency in the products. For instance, high-performance ultrasonic transducers are pre-stressed by the sonication liquid by up to 80 °C in ultrasonic baths, so the remaining permitted range for the piezo ceramic operating temperature is extremely limited (a continuous operation temperature of only 120 °C is generally prescribed by the manufacturers), and thus the piezo ceramic must have high efficiency rates or low losses.[1092]

To Bandelin's knowledge, no commercial technology is available for manufacturing adequate piezoelectric components from BNT/KNN, which could replace PZT material. Moreover, there is still no reliable evidence of the reliability, long-term stability or availability of piezoelectric components made from these materials.

Bandelin[1093] used lead-free BNT piezo ceramic material from HONDA ELECTRONICS, Japan, with the same geometrical dimensions as their own hard PZT ceramics. This permitted direct comparison with high-performance ultrasonic transducers of identical construction. The results showed that, due to the lower Q and higher loss factor, the necessary amplitude and performance range in the analogue HF operating voltage range for hard PZT could not be achieved. Even in the ordinary continuous operation test, the transducers constructed with BNT discs heated up so strongly as to preclude their use in Bandelin's products. Due to the low losses, cooling of their high-performance transducers with hard PZT is unnecessary, and, in fact, functionally impossible.

Bandelin[1094] does not expect any alternative materials to substitute the PZT ceramics in the next 10 years. PZT is the only material that can be used in high-performance ultrasonic transducers. PZT in a finished component is said by Bandelin to be neither harmful to the health nor hazardous to the environment and can be disposed of properly.

Bandelin[1095] fulfil their duties in the disposal of electronic waste (including piezo materials) in the scope of their electronic waste registration and annual verification thereof. In light of these facts, they apply for the amendment of exemption 7c-I.

22.3.2.5 Pyreos'Application-specific Exemption Request for Lead in Ceramics

Pyreos[1096] claims it has spent considerable resources to reduce the content of lead in the sensors resulting in a lead reduction compared to the incumbent pyroelectric sensor technology by about a factor 1,000. As a result, the amount of lead in the sensors already implemented by Pyreos today is extremely low. In order to reduce the amount of lead in the sensors, Pyreos[1097] used PZT materials with the same lead-content like other

---

[1092] Ibid.
[1093] Ibid.
[1094] Op. cit. Bandelin Electronic GmbH 2015a
[1095] Ibid.
[1096] Op. cit. Pyreos Ltd. 2014
[1097] Pyreos Ltd. 2016a "Answers to questionnaire 2, document "Questionnaire-2_Pyreos_2016-03-06.pdf",

manufacturers, but the PZT thinfilm on the silicon decreases the total amount of PZT in the sensors and as a consequence the amount of lead.

In a next step, Pyreos[1098] wants to develop an infrared absorption layer that will allow to further reduce the thickness and the pixel area of the pyroelectric sensor by a factor of 10-100 within an intended timescale until 2018, and a lead-free infrared absorption layer until 2020. Pyreos[1099] recently located a new partner for the absorption layer implementation with superior performance and is evaluating manufacturability. With the lead-free infrared sensor they have just started as partners of a government funded project to further investigate and establish the production of useful lead-free pyroelectric thin films. If successful, it would in principle enable lead-free thin film sensors, but it will take considerable time for it to mature to be industrially accepted at a cost effective price.

22.3.3 Substitution of Lead in PTC Semiconductor Ceramics

Murata et al.[1100] explain that PTC ceramics (Positive Temperature Coefficient) increase their electrical resistance with increasing temperature. Examples of material compositions are doped barium (BT) and lead titanate (PT) mixtures. The basic PTC material barium-strontium-lead-titanate is a perovskite which undergoes a phase transition from ferro- to paraelectric at the Curie temperature. If properly processed and slightly donor doped (< 1 mol%) such materials are PTCR active so to speak, i.e. semiconductive at low temperatures and quite highly resistive at temperatures above the Curie temperature. It is possible with dopants and some changes in proportions of components and additives to tune the properties of a composition to a specific targeted application.

22.3.3.1 Classification of PTC Ceramics

Murata et al.[1101] divide the active PTCR materials into four sections based on resistivity and Curie temperature, in which each individual section contains hundreds of material recipes based on BT and PT:

- **Materials with Curie temperatures below 120 °C and resistivity values below 1,000 ohm.cm:**
  These materials serve applications like overload protection, inrush current limitation, heating, telecom line protection, motor protection, motor start and temperature sensing. Lead titanate is added to the recipes to decrease the resistivity and increase performance because lead increases the ferroelectricity in the ceramic material.

---

received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Torben Norlem, Intertek, on 23 March 2016: Second questionnaire" unpublished manuscript,

1098 Op. cit. Pyreos Ltd. 2014

1099 Op. cit. (Pyreos Ltd. 2016a)

1100 Op. cit. Murata et al. 2015a

1101 Ibid.

Lead-free materials are available for this region but the performance and durability that can be achieved is significantly lower and for most applications, such materials can therefore not be used. Based on the current state of the art, breakdown voltages are lower by approximately 30 % for lead-free ceramics. As a result, the present situation is that no lead replacement with sufficient performance has been found yet to produce a PTC with a Curie temperature below 120 °C and low resistance values.

- **Materials with high Curie temperatures above 120 °C and resistivity values below 1,000 ohm.cm:**
  This is the most commonly used material type. It serves applications like overload protection, inrush current limitation, telecom line protection, motor protection, motor start, temperature sensing and heating. Lead is added to the recipes to achieve both higher Curie temperatures and lower resistance.
  A lead-free bismuth-based perovskite material was the main material investigated as a substitute in the literature. It exhibits higher Curie temperatures and can therefore be used to increase the Curie temperature of a solid solution with barium titanate. However, it has been demonstrated that such components as BNT (bismuth sodium titanate) have limited solubility in barium titanate and can increase the Curie temperature only to regions around 160 °C. At the same time electrical parameters including important ones like steepness of resistance change and breakdown voltage strength deteriorate dramatically. Especially the energy efficiency for switching applications like motor starters will be influenced strongly. The break down voltage for typical motor start elements would be reduced by approximately 30 % and the resistance stability during application would decrease as well. The performance in terms of reliability is affected most. Tests according to the industry standard IEC 60738-1 like electrical endurance, electrical cycling, temperature storage, show higher resistance changes by an order of magnitude, compared to the current standard. In the IEC 60738-1 test procedure for humidity even higher changes of up to two orders of magnitudes are observed.
- **Materials with low Curie temperature and resistivity values of 1,000 ohm.cm and more:**
  This section is one of the most critical ones in regard to material development. It mainly serves applications like overload protection, inrush current limitation, temperature sensing and heating. Nevertheless, Industry has started some further investigations in this direction. The reduction of lead would reduce the breakdown voltage performance by approximately 30 %. Additionally, materials with reduced or no lead are especially problematic in terms of reproducibility of the resistance and resistance spread.
- **Materials with high Curie temperature and resistivity values of 1,000 ohm.cm and more**:
  They serve applications like overload protection, inrush current limitation and especially heating. These materials require lead titanate compounds in the

ceramic because of the high Curie temperature of up to 300 °C. So far no material system beside BT and PT has been developed that achieves Curie temperatures above 200 °C. Adding lead to the barium titanate matrix of the PTC ceramic is the only known procedure to raise the Curie temperature of the basic barium titanate without loss of important properties and functionality.

22.3.3.2 Substitution of Lead in Ceramic Materials with Curie Temperatures below 120 °C

Murata et al.[1102] explain that adapting strontium titanate generally may achieve certain temperature ranges for applications with Curie temperatures Tc < 120 °C.

In the low ohmic section at Tc<120°C, Murata et al.[1103] report that the reduction of lead reduces the ferroelectricity (permittivity, polarization) of the material involved. BNT and BKT are reported to have a relative permittivity of less than 5,000 where lead titanate shows a relative permittivity of around 10,000. The effectiveness of the charge compensation, which appears at temperatures below Tc, is due to the magnitude of the ferroelectric material involved. According to Heywang[1104], the mechanism which causes the PTC effect decreases if relative permittivity at the grain boundary is reduced.

According to Murata et al.[1105], the replacement of lead will decrease the lifespan of the product as well as its voltage breakdown strength for around 30 % depending on the material type in question. Even if PTC materials are produced without lead for Tc lower than 120°C, it will come at the cost of reduced performance.[1106] Hence, increased dimensions, more material and energy need to be used to produce the individual product. Furthermore, lead-free materials cannot serve all applications and functions. This demonstrates the still many problems need to be solved before a "lead-free" material can be produced in practice.

Murata et al.[1107] see a major challenge in substituting lead in ceramic materials with low Tc and high resistance because of the difficulties with reproducibility and resistance spread.

[1102] Ibid.
[1103] Ibid.
[1104] W.Heywang. Semiconducting Barium Titanate. J Mater Sci 1971; 6:1214-1226; source as referenced by Murata et al.
[1105] Ibid.
[1106] H. Takeda et.al.: Fabrication and operation limit of Lead -Free PTCR ceramics using BT-BNT; Journal of Electroceramics (2009) 22, 263-269; source as referenced by Murata et al.
[1107] Ibid.

22.3.3.3 Substitution of Pb in Ceramics with Curie Temperatures of 120 °C and Higher

For high temperature sections, Murata et al.[1108] consider BNT (bismuth sodium titanate) and BKT (bismuth potassium titanate) to be the most promising materials to push the lead-free limit. Those materials work best at higher resistances above 1,000 ohm-cm. In this high ohmic section above 120°C, a Tc could be reached up to 200°C according to Takeda et al.[1109]. This limitation is mainly caused by the volatility of Bi which changes the composition and incorporation mechanism and thereby the sintering characteristics and achievable resistance, respectively. Wei et al.[1110] suggest a limit at 160 °C because above that temperature the ceramic becomes highly resistive. The best performances were reported at Curie temperatures below 150 °C, which are, however, still distinctly inferior to the traditional materials containing lead titanate.

Murata et al.[1111] expect the breakthrough voltage to be rather low due to the fact that the PTCR steepness α [%/C] around Tc is below 10 %/C, which influences the maximum resistance that is directly related to the break down voltage. For comparison, values of 60 %/C can be achieved with the standard lead titanate material. At the moment it is not possible to make a reliable statement about the Tc reproducibility. However, due to the volatility of Bi a poor Tc reproducibility and predictability is expected.

Murata et al.[1112] point out that the results obtained so far are at laboratory (research) level, and reliability and mass production technology have not been ensured. Consequently, there are no prospects for actual mass production supply being provided, and the current situation does not allow the substitution in the next few years.

According to Murata et al.[1113], the low ohmic section above 120°C, which is the economically most important section, is even more challenging. Naturally, the PTC effect is weaker than for higher resistances due to the very basic principles involved. The drawback of the new BNT- and BKT-based materials in terms of steepness; break down voltage and so on, becomes even more dominant than at high ohmic quarters. B.Y. Wu et.al.[1114] assessed the limit at Tc=160°C for BT PTC materials doped with BNT. Higher additions of BNT to BT in order to increase the Tc to higher temperatures would lead to high resistivity well above 1,000 ohm-cm in the PTCs, which Murata et al.[1115] deem

---

[1108] Ibid.

[1109] H. Takeda et.al.: BaTiO 3–(Bi 1/2 Na 1/2) TiO 3 Solid-Solution Semiconducting Ceramics with Tc> 130 C; Appl. Phys. Lett. 87 (2005) 102104; source as referenced by Murata et al.

[1110] J. Wei et.al.: Effects of BNT Addition on the Microstructure and PTC Properties of La-Doped $BaTiO_3$-Based PTCR Ceramics; Ferroelectrics, 403; 91-96, (2010); source as referenced by Murata et al.

[1111] Ibid.

[1112] Ibid.

[1113] Ibid.

[1114] B.Y. Wu et.al.: A Study of PTC Ceramics Based on (V1-x, Crx)2 O3 Electroceramics; British Ceramic Proceedings No.41 Stoke-on-Trent, 1989, p.195-203 Institute of Ceramics; referenced by Murata et al.

[1115] Ibid.

unacceptable. According to Wei et al.[1116], the limited solubility of BNT in BT causes the effect due to which Bi^{3+} as an acceptor would occupy Ti^{4+} positions, which would lead to a reduction of free charge carriers.

According to Leng et al.[1117], the use of BKT-doped BT induces a similar limitation. Although there are reports of BNT and BKT-containing materials as an additive to BT replacing lead titanate in the range up to 160 °C for low voltage applications, Murata et al.[1118] explain that it is most important that the lowest resistance that is achievable is in the range of 100 Ohm-cm. This is still well above the limit of 2 Ohm-cm for lead-containing materials (traditional technique).

Murata et al.[1119] conclude that material studies on BNT reveal the lower performance and lower reliability of these lead-free PTC materials compared to the standard lead-containing materials. Actual results show 30 % lower breakdown voltage, 30 % lower steepness of the RT-curve and more than 1,000 % less stability at temperatures above 160 °C.

22.3.4 Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds

Murata et al.[1120] claim manufacturers have investigated boron, phosphorus, zinc, tin, bismuth, etc. as potential elements for substitution of lead as a constituent element of glass. “Lead-free” glasses using these elements can partially promote machining efficiency (ability to minimize energy consumed to apply heat, mechanical pressure, etc. in manufacturing processes) and affinity (ability for mutually wetting and bonding different materials such as metal and ceramic) which are necessary properties for achieving the required functionality of electrical and electronic components. However, when compared with lead-containing glasses, chemical stability and mechanical strength of the glasses are insufficient and do not meet the required functionality.

Murata et al.[1121] state that boron, phosphorus, zinc, bismuth, etc. are, in a general manner, inadequate for substituting lead as constituent elements of glass and as of now there are absolutely no technical perspectives for comprehensively eliminating lead from glass of electrical and electronic components.

[1116] J. Wei et.al.: Effects of BNT Addition on the Microstructure and PTC Properties of La-Doped BaTiO3-Based PTCR Ceramics; Ferroelectrics, 403; 91-96, (2010); source as referenced by Murata et al.

[1116] Ibid.

[1117] [2] S. Leng et.al.: Synthesis of Y doped BT-BKT Lead-Free Positive Temperature Coefficient of resistivity ceramic and their PTC effects; Journal of American Ceramic Soc. (2009) 92 [11], 2772-2775; source as referenced by Murata et al.

[1118] Ibid.

[1119] Ibid.

[1120] Ibid.

[1121] Ibid.

Murata et al.[1122] conclude that no substitution technology is available that can provide the high functionality required for electrical and electronic components. Only lead glass can bring out the necessary characteristics such as integrity of the layer, step coverage, delamination resistance, hermetic sealing, charge balance etc. and reliability to ensure public safety and avoid additional waste from premature failure, simultaneously satisfying high reliability requirements and usability over a wide range of applications. Lead glass is used for insulating, protection, resistance, adhesives, bonding, hermetic sealing and other uses.

Murata et al.[1123] state they cannot set a technical goal for a comprehensive substitution of lead glass concerning the technical scope of exemption 7(c)-I, and there are no perspectives for such in the foreseeable future. Therefore Murata et al. request the renewal of the exemption at least until the maximum validity period. Otherwise, Murata et al.[1124] fear accidents originating from crucial failures in EEE incorporating electrical and electronic components composed of glass with lead substituted by these elements due to their insufficient reliability and quick deterioration.

Bourns[1125], Murata et al.[1126], Schott[1127], Sensata[1128] and Vishay[1129] present specific and exemplary applications where lead in glass and glass ceramic matrices cannot be fully replaced. The below presentation of the application examples follows the system of Murata et al.[1130] presented in Table 22-3 on page 435.

22.3.4.1 Lead Glass for Protection and Insulation

Example 1.1 – Lead Glass Frits to Hermetically Seal Semiconductor Devices

Murata et al.[1131] explain that semiconductor device circuitries are susceptible to corrosion. They are protected by depositing a thin layer of glass to form a hermetic seal. This passivation glass layer must not impose stresses to the silicon or circuitry so its physical characteristics must be precisely controlled and its chemical composition is

---

[1122] Ibid.
[1123] Ibid.
[1124] Ibid.
[1125] Bourns Inc. 2015b "Request for continuation of exemption 7c-I, document "20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf", clarification questionnaire: Clarification questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf
[1126] Op. cit. Murata et al. 2015a
[1127] Op. cit. Schott AG 2015a
[1128] Op. cit. Sensata Technologies 2015a
[1129] Op. cit. (Vishay 2015a January 2015)
[1130] Op. cit. Murata et al. 2015a
[1131] Ibid.

important to avoid interactions with dopants or with subsequent process step chemicals. The glass must have the following properties and processability:[1132]

- Temperature of the annealing process > 800 °C to better flow glass into the silicon groove / step coverage integrity of the layer (to avoid cracks);
- Chemical compatibility with the further steps of the process, and the back end: dicing and assembly integrity of the layer (holes);
- Compatibility of the thermal expansion coefficient with the silicon for mechanical behaviour to control stress resistance (delamination); and
- Electric charges in the glass balanced with the dopants in the junctions, for electrical stability in temperature and electrical stress (leakage current drift under high voltage stress).

According to Murata et al.[1133], the glass passivation is needed to protect the junction and to guarantee the proper behaviour of the semiconductor under high reverse voltage and the reliability of the component. The glass layer must not impose stresses on the silicon and must be compatible with the chemical process integration. The electrical insulation capability of glass is very high: it helps to achieve high voltage devices with a limited periphery area.

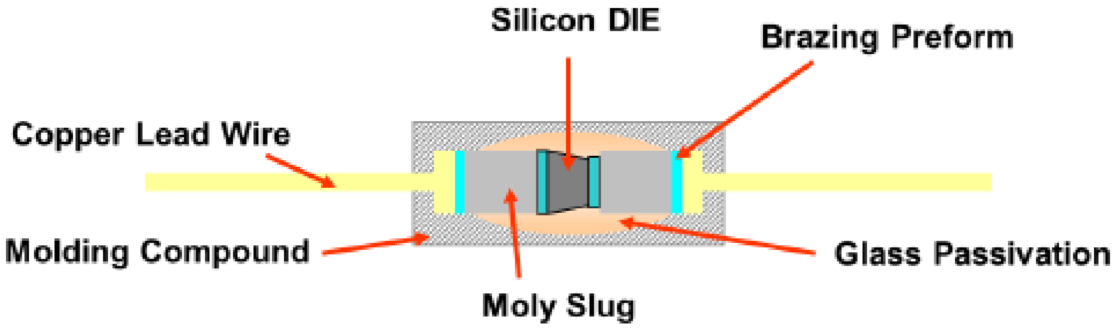
Murata et al.[1134] do not mention any specific research or efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, page 460).

Example 1.2 – Glass for Hermetical Sealings of Diode Chips

According to Murata et al.,[1135] glass sleeve diodes in various sizes like in DO-35, DO-41, SOD-80 MELF (Metal Electrode Leadless[1136] Faces) packages, glass bead diodes, super-rectifiers etc., use glass to hermetically seal the diode chip. The advantage of packages with glass as the body or part of the body is the ability to hermetically seal the chip. This has technological advantages like better reliability, moisture-resistance, etc. over non-glass packages. Lead is needed in the glass to lower the melting point and reduce the viscosity, which together provides good hermetic sealing and adhesion to the adjacent metal plugs. Figure 22-8 shows an example.

[1132] Ibid.
[1133] Ibid.
[1134] Ibid.
[1135] Ibid.
[1136] "Lead" does not stand for the chemical element Pb, but for the carrying structure of the component

Figure 22-8: Schematic view of a high voltage "Superectifier ®" diode with glass as part of the package



Source: Murata et al.[1137]

Murata et al.[1138] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 1.3 – Lead Glass for Insulation and Protection in Thick Film Resistors

Glass passivation layers block or help to block the sulfur, e.g. from traces of atmospheric hydrogen sulphide, from reaching the silver in the inner electrodes of thick film resistors, which might cause open circuit failures. The lead makes the glass pliable in the manufacturing process of the chip resistor to form a hermetic seal. The lead addition allows for lower oven temperatures, better quality and higher yields.

Murata et al.[1139] do not mention any specific research or efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 1.4 – Lead in Enamel Coatings of Wire Wound Resistors

Vishay[1140] requests an exemption for wire wound resistors with enamel coatings containing lead (Pb) as lead-oxide (Pb_3O_4) in glass. In order to limit thermal stresses and gain long term stability and high reliability, the applicant claims that exemption 7(c)-I is needed to reach:

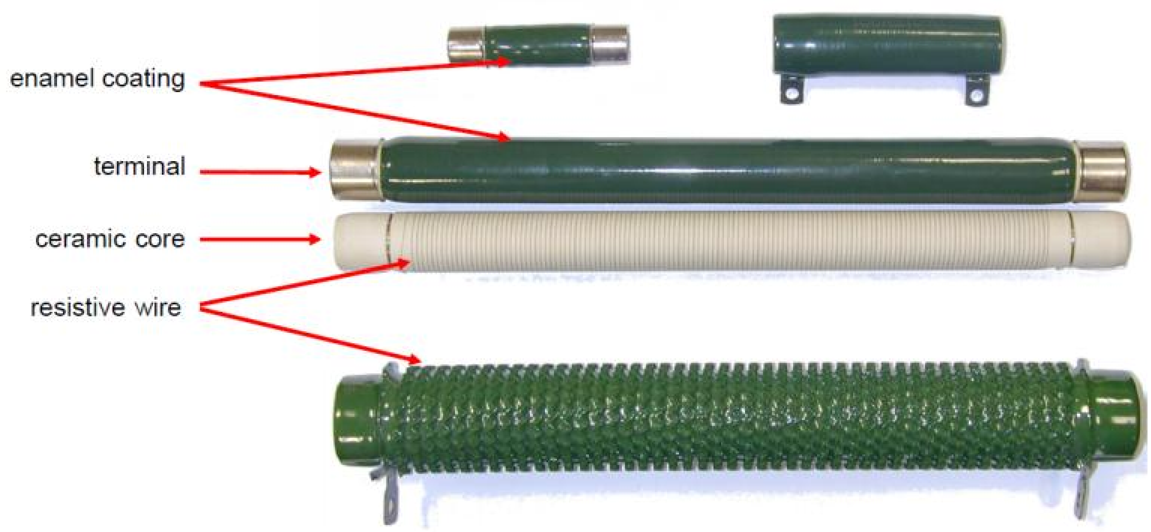
- Good flow conditions of the molten glass during production;

[1137] Ibid.
[1138] Ibid.
[1139] Ibid.
[1140] Op. cit. (Vishay 2015a January 2015)

- Virtually void free coverage of resistive metal wire and ceramic core; and
- Thermal expansion well matched to the resistive metal wire and ceramic core.

Vishay [1141] explains that wire wound resistors are made long-lasting and reliable by protecting the resistive wire from detrimental ambient conditions such as high humidity by virtually impenetrable enamel coatings (glass) that contain lead. Examples provided are shown in Figure 22-9.

Figure 22-9: Wire wound resistors



Source: Vishay[1142]

Vishay[1143] states that the thermal expansion of the different materials (ceramic, metal and glass) must match each other in order to limit destructive thermal stresses. The enamel coating (glass) otherwise cracks and can delaminate from the ceramic core and/or the metal wire, as Figure 22-10 illustrates.

[1141] Ibid.
[1142] Ibid.
[1143] Ibid.

Figure 22-10: Cracks (left) and delamination (right) in enamel wire wound resistor coatings

Source: Vishay [1144]

Vishay[1145] describes that cracks allow humidity to penetrate and reach the metal wire. This can lead to detrimental corrosion of the wire. Delamination reduces the effectiveness of heat transport away from the resistive wire. This can lead to hot spots and over-heating. Both effects can destroy the resistor within a fraction of the usual lifetime even under standard operating conditions.

According to Vishay[1146], wire wound resistors are used in many applications in the industry and transportation sector because of their unrivalled high pulse load capability. The load, continuous or pulse, leads to an excess temperature of the resistor of up to 600 °C. Therefore, the thermal expansion of the different materials (ceramic, metal and glass) must match each other in order to limit destructive thermal stresses. The enamel coating is non-flammable too, making the durable wire wound resistors an excellent choice for relevant “safety” applications.

Vishay[1147] takes significant effort to eliminate lead (Pb) in the enamel coating of wire wound resistors, but so far no technically equivalent solution is available to allow for the present quality standard under usual operating conditions. Vishay[1148] had carried out a first project to use lead-free enamel coating on wire wound power resistors from 1999 to 2002, and was not successful. A following project has been started in December 2014. An enamel coating has to comply with the following requirements like, to name some:[1149]

- Melting temperature;

[1144] Ibid.
[1145] Ibid.
[1146] Ibid.
[1147] Ibid.
[1148] Op. cit. Murata et al. 2015b
[1149] Ibid.

- Viscosity;
- Surface tension;
- Coefficient of thermal expansion; and
- Alkaline ions.

According to Vishay[1150], typical lead (Pb) free enamel coatings usually have too high melting temperatures, and the viscosity, surface tension, and the coefficient of thermal expansion do not meet specifications for suitable processing. From today's viewpoint the most likely replacement of lead is bismuth (Bi).The melting temperature of the lead-free enamel coating can be lowered to some extent by adding considerable amounts of bismuth. However, this may pose unforeseeable health risks due to the lack of knowledge about the level of toxicity of bismuth. Other materials than lead containing glass, such as cement or epoxy, do furthermore not fulfil the specifications of long term stability or non-flammability, respectively. Only the present mix of glass frits with special additives fulfils all of the technical/physical requirements to meet customers' specifications concerning reliability and long term stability.

Example 1.5 – Glass Coatings for Insulation in Negative Temperature Coefficient (NTC) SMD Resistors

Vishay[1151] uses lead-containing glass in two series of NTC surface mount device (SMD) thermistors illustrated in Figure 22-11. The thermistors cover a size range of 0402 to 1206 and a large resistance range from 2 kΩ to 470 kΩ.

Figure 22-11: NTCS and NTHS SMD thermistors

Source: Vishay[1152]

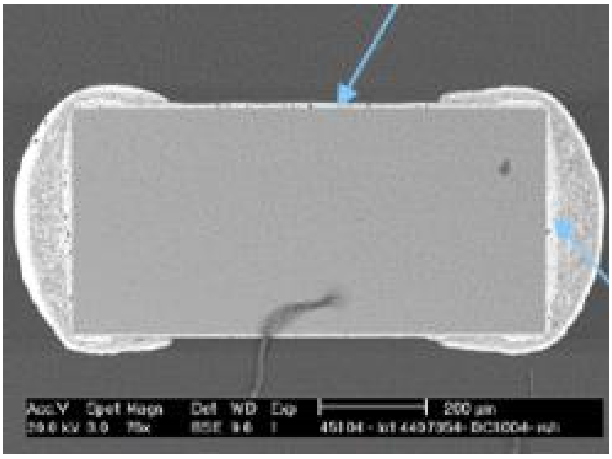
As shown in Figure 22-12, the thermistors contain lead silicate glass on four sides (upper arrow) and a lead silicate glass frit in Ag wrapped around the termination (lower / right hand arrow).

[1150] Ibid.

[1151] Vishay 2015b 2015 "Document "NTC – Glass coating for insulation.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a: Document referenced in the exemption request of Murata et al. 2015a" (January 2015) unpublished manuscript,

[1152] Ibid.

Figure 22-12: Lead-silicate class in thermistors



Source: Vishay[1153]

Vishay [1154] reports that NTC SMD (Surface Mounted Devices) resistors need lead-containing glass coatings for several reasons:

- **High accuracy:**
  The distance between the two terminations does not influence the R value as the glass layer insulates the ceramic body.
- **Insulation of the ceramic body during the plating process**:
  Without the glass coating, Sn and Ni metals are deposited as well on the ceramic body modifying the electrical properties.
- **Variety of ceramics compositions:**
  Each resistance value has a specific ceramic composition. More than 60 different ceramic compositions are used with thermal expansion coefficient going from 6 ppm/K to 14 ppm/K. So it is very difficult to find one glass that can be used for the complete resistance range.
- **Firing temperature:**
  The firing temperature of the glass must be high enough to sustain the firing of the silver termination in the subsequent process.
- **Purity and stability of the glass**:
  The glass is deposited onto the ceramic body by electrophoretic deposition. Therefore a stable glass suspension must be achieved. Very pure glass (free of alkali) and a narrow particle size distribution are needed.
- **Adhesion of the silver layer (Ag) to the ceramic:**
  Glass frits with Ag paste are used to achieve good adherence of the Ag layer

[1153] Ibid.
[1154] Op. cit. (Vishay 2015a January 2015)

onto the ceramic. During firing, the glass diffuses into the ceramic and reacts with it creating an interface between ceramic material, glass and silver. Again here, it is very difficult to find a lead-free glass reacting properly with the complete ceramic range keeping all the performances: ohmic contact, no cracks, good adherence, good reliability in thermal cycling, damp heat, endurance tests. Furthermore, the interface must be resistant to the acidic plating bath solutions entering the porous terminations during plating. It is known that Pb free glasses are not well resistant to those solutions. The chemical attack of the interface by plating solutions has a dramatic effect on the reliability of the parts as the termination is coming lose from the ceramic body.

Vishay[1155] claims to undertake significant efforts to eliminate lead in the glass coating and silver termination of the NTC SMD but so far, no technical mature solution is available. As each resistance value has a specific ceramic composition, more than 60 different ceramic compositions are used with thermal expansion coefficient going from 6 ppm/K to 14 ppm/K. So Vishay[1156] states that it is very difficult to find one glass that can be used for the complete resistance range.

Example 1.6 - Metal Pressure Sensors

Murata et al.[1157] report the use of lead oxide glass in glass metal pressure sensors. The glass provides a seal and an electrically insulating surface for a capacitor plate.

Murata et al.[1158] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

22.3.4.2 Lead in Functional Glass Compounds/Resistance

Example 2.1 - Pastes with Lead in Glass

According to Murata et al.[1159], pastes with lead in glass are generally used as functional (resistive) material, glass coating and/or contact layer.

Murata et al.[1160] claim that substitutes are unreliable as current product specifications or stability requirements cannot be fulfilled. In substitutes, lead is replaced by bismuth (Bi) with possible environmental concerns, c.f. Section 22.3.5 from page 478.

[1155] Op. cit. (Vishay 2015b January 2015)
[1156] Ibid.
[1157] Op. cit. Murata et al. 2015a
[1158] Ibid.
[1159] Ibid.
[1160] Ibid.

Example 2.2 - Pastes With Lead In Glass And Lead Containing Functional Complex Oxides For High Ohmic Resistive Materials

According to Murata et al.[1161], pastes for high ohmic resistive layers require lead in glass and lead containing functional complex oxides in order to meet required specifications:

- No reaction with the glass matrix and no decomposition;
- Sufficiently high sheet resistivity;
- Low TCRs (Temperature Coefficient of Resistance);
- Low temperature sensitivity;
- Low moisture sensitivity – this alters resistance;
- Low humidity sensitivity – this changes the resistance value;
- Low process sensitivity;
- High resistance deviation after soldering processes used in surface mount processes.

Murata et al.[1162] claim lead-free resistor pigments in combination with the lead-free glasses showed:

- A reaction with the glass matrix and decomposition;
- Too low sheet resistivity;
- Too high TCRs (Temperature Coefficient of Resistance);
- Too high temperature sensitivity;
- Too high moisture sensitivity – this alters resistance;
- Too high humidity sensitivity – this changes the resistance value;
- Too high process sensitivity;
- Too high resistance deviation after soldering processes used in surface mount processes.

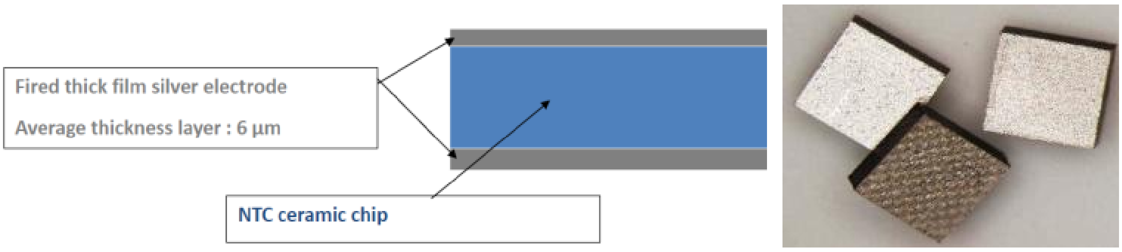
Murata et al.[1163] conclude that substitutes are technically impracticable and/or unreliable so that these materials cannot yet replace lead-containing glasses in this function.

Example 2.3 - Lead in Glass of the Silver Top and Bottom Electrode of NTC Chips

Vishay[1164] requests an exemption for NTC (negative temperature coefficient) chips with a silver top and bottom electrode that contains 4.5 ± 0.3% lead silicate glass as illustrated in Figure 22-13.

1161 Ibid.
1162 Ibid.
1163 Ibid.
1164 Op. cit. (Vishay 2015c)

Figure 22-13: NTC ceramic chips with thick film silver electrodes



Source: Vishay[1165]

Vishay[1166] applies the thick film silver paste electrode, a low firing Ag paste with lead containing glass frit, by screen printing and firing. The lead glass serves as interface for good adherence properties, electrical characteristics and reliability of the electrode, for which the lead in the glass is indispensable. The whole product range of NTC chips is produced with more than 60 different ceramic compositions. The actual silver electrode is compatible with all ceramic compositions and excellent in reliability tests and electrical behaviour.

According to Vishay[1167], these NTC chips are mainly used for accurate temperature sensing or compensation mainly in automotive, medical, and domestic applications. The total number of manufactured NTC chips accounts for 60,000,000 pieces per year.

Vishay[1168] mentions that Ag pastes with lead-free glass frits are available on the market, but claims there is no single one fitting to Vishay's wide variety of ceramics. Since one product series requires this many ceramics, it is impossible to change to a lead-free Ag paste for practical purposes.

Vishay[1169] claims to undertake significant efforts to eliminate lead in glass frit of the Ag electrode of the NTC chip, but so far no technical mature solution is available. A study is being started up to develop an NTC chip with a Pb free glass frit.

22.3.4.3 Lead Glass Used as Adhesive/Bonding Material

Example 3.1 - Micro Electro Mechanical Systems (MEMS)

According to Murata et al.[1170], lead-based glasses are used in MEMS devices for low temperature compatibility with aluminium pads in a glass frit wafer-to-wafer bonding process. Such devices are used in e.g. accelerometers, gyroscopes, etc.

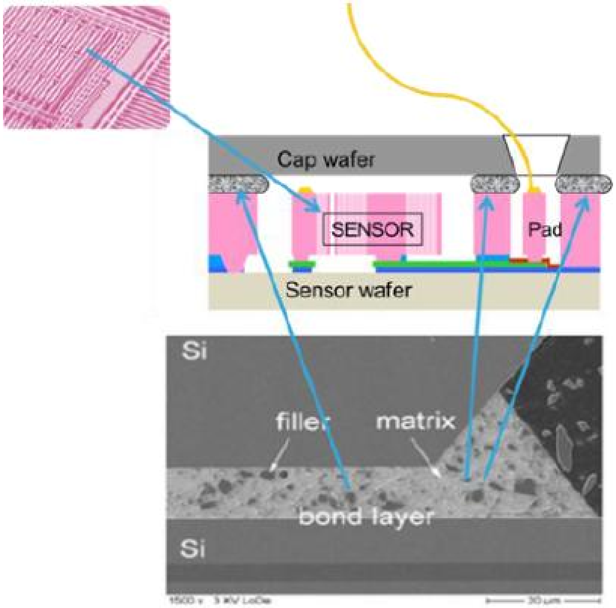
According to Murata et al.[1171], only lead glass can achieve the low process temperature of less than 450 °C. Moreover, the lead glass frit is compatible with a wide variety of

---

[1165] Ibid.
[1166] Ibid.
[1167] Ibid.
[1168] Ibid.
[1169] Ibid.
[1170] Op. cit. Murata et al. 2015a

substrates, not only silicon, and can adapt to different types of surfaces and topology (rough, smooth, with steps), which are typical of MEMS devices. Lead-glass frit bonding ensures a strong bond between different substrates, and ensures a stable and hermetic sealing of the device, unlike with lead-free glass frits.

Figure 22-14: MEMS device with lead-containing glass (Arrows)



Source: Murata et al.[1172]

According to Murata et al.[1173] glass frit wafer bonding is the most commonly used process for MEMS devices, where fully processed wafers have to be bonded at wafer level. This end-of-line wafer level bonding process must fulfil stringent requirements, and must not affect the final yield of bonded wafers. Specifically, the process temperature (i.e. the bonding temperature) must be below 450 °C in order to be compatible with the aluminium pads of the device and to avoid thermal stress on the wafer. This low melting temperature can be obtained only by adding lead to the glass. Moreover, the glass frit is compatible with a wide variety of substrates, not only silicon, and can adapt to different types of surfaces and topology (rough, smooth, with steps), which are typical of MEMS devices. Lead-glass frit bonding ensures a strong bond between different substrates, and ensures a stable and hermetic sealing of the device, unlike with lead-free glass frits.

Murata et al.[1174] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under

---

[1171] Ibid.
[1172] Ibid.
[1173] Ibid.
[1174] Ibid.

Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 3.2 – Lead Glass in SMD Components

Murata et al. report that SMD components are being used to control operating conditions in power semiconductor modules. To achieve a useful temperature signal, the SMD temperature sensors should be placed as close as possible to the silicon dies. To guarantee customers' reliability conditions the assembly processes - usually soldering processes - are being operated by temperature profiles that are far away from JEDEC profiles for standard SMD dies. SMD components, which are available on the global market, and which ride out increased process temperatures are MELF dies (Metal Electrode Leadless Faces) whose glass insulator contains lead oxide (PbO) in addition to quartz.

Murata et al.[1175] report that no lead-free dies are available on the global market that provide a comparable (or better) reliability and which are approved for the required or even higher process temperatures than those assembled with lead-containing glass. Lead-free dies would not ride out the high temperatures of the soldering process.

Murata et al.[1176] do not mention any specific research or other efforts to substitute or eliminate lead in this application besides the general justification directly under Section 22.3.4 (Substitution of Lead in Glass and Glass/Ceramic Matrix Compounds, from page 460).

Example 3.3 - Electronic Components with Hermetically Sealed Ceramic Package

According to Murata et al.[1177], electronic component packages with hermetic sealings using a ceramic body with a ceramic or glass lid require lead glass as sealing material between the two parts of the package. The lead in the glass reduces the melting temperature enough to not harm the functional element itself. At the same time, the temperature is still sufficiently high to withstand the reflow soldering temperatures without losing its strength and sealing properties. Even a temporary loss of the sealing properties would be fatal as in many cases the inside of the hermetically sealed package is under vacuum.

Murata et al.[1178] state that many materials have been tested to replace the Pb in glass in this function, but failed either due to a too high melting point (i.e. $Bi2O_3$-100 °C or higher and V_2O_5-50 °C or higher) or extreme sensitivity to moisture and humidity (i.e. P_2O_5-based materials), which destroys the vacuum and causes corrosion of the internal circuitry. The use of Au-Sn-based sealings leads to failures, especially in applications which need to cover wide operating temperature ranges. This is because the thermal expansion coefficient of ceramic ($7.1*10^{-6}$/°C) is vastly different to that of Au-Sn

---

[1175] Ibid.
[1176] Ibid.
[1177] Ibid.
[1178] Ibid.

($17.5*10^{-6}/°C$), thus generating extensive mechanical stress inside the sealing, resulting in reliability problems and finally yielding in component failures (cracks).

22.3.4.4 Bourns Exemption Request for Lead in Glass

Bourns[1179] have developed lead-free glasses internally. These glass formulations are proprietary. These limited solutions do not solve the lead-glass issue in all applications. Obviously, any successful substitution will be used to eliminate lead in glass when possible. The majority of applications are still in the research stage. It is a lengthy process to identify potential solutions, test on a small scale basis, test on a larger scale, and qualify with reliability checks. The test phase is trial and error taking an unspecified amount of time. To date, Bourns' internal analysis as well as published information clarifies that more time is needed to find suitable substitutes.[1180]

There is no drop-in solution or a one-size-fits-all solution. Any change will take research, testing, final qualification, process changes, etc. for each specific application. Potential substitutes in these articles do not yet meet all the positive characteristics of lead-based glasses that are also cost-effective. There may be one or more alternatives to address each individual application. It appears that at this time there may be solutions; however, most likely the solutions will not be identified, tested, qualified and adapted to the process in the mid-2016 time frame when the exemption is set to expire.[1181]

Bourns[1182] references the below research papers:

- *Review of High-Lead Solder and Lead-Glass RoHS Exemptions*, http://rohs.exemptions.oeko.info/fileadmin/user_upload/Stakeholder_comments/Exemption-7a_5_Pecht_Uni_Maryland_25_March_2008.pdf
- *REACH Dossier: Exemption from registration for glass under REACH regulation n. 1907/2006/EC.*, http://www.glassallianceeurope.eu/images/cont/dossier-glass-alliance-europe-on-glass-exemption-under-reach_1_file.pdf
- *Position paper concerning the status of the raw materials for the production of glass, as intermediates, under the EU REACH regulation*, http://www.glassallianceeurope.eu/images/cont/glass-alliance-europe-statement-for-intermediates-revision-may-2012_1_file.pdf

1179 Op. cit. Bourns Inc. 2015a
1180 Ibid.
1181 Ibid.
1182 Ibid.

22.3.4.5 IXYS' Application-Specific Exemption Request for Lead in Coatings of High Voltage Diodes

IXYS[1183] requests the renewal of the exemption for the use of lead in **coatings of high voltage diodes.** Lead-based glasses are used because they have unique combinations and characteristics that cannot be achieved by other materials or methods. Lead is required in combination with pure silicon crystals for good withstandability against high electric fields in the range of 200,000 V/cm in alternate and direct current power semiconductor devices. The justification follows the same rationale like that of Murata/JEITA et al.

IXYS[1184] mentions, however, new passivation systems under development, i.e. diamond-like carbon coatings or amorphous silicon-oxide layers (SIPOS, semi-insulating polycrystalline silicon). Their long term stability in various environments, workability, and the fabrication equipment are still under research and development. These developments could replace the use of lead glass in the high voltage components.

IXYS[1185,1186] states that the diamond like carbon coating method very much depends on equipment design and manufacture – where IXYS has minimum influence. SIPOS (semi-insulating polycrystalline silicon) is under development at IXYS in several lower voltage applications.

As mostly with new developments and technologies, IXYS[1187] states that there is no guarantee on when there will be a breakthrough on the whole front of this kind of power semiconductors.

22.3.4.6 Schott Request for Renewal of the Exemption

To ensure the production of high quality hermetic packages for opt-electronic devices it is crucial to use lead-oxide-based glasses. These so called "solder glasses" are necessary to attach optical elements like windows or lenses into metal components.[1188]

SCHOTT[1189] started a PbO substitution project for solder glasses in the year 2000. New glass systems have been developed for replacement of PbO containing solder glasses. These new glasses were based on the following substitutes:

[1183] Op. cit. IXYS Semiconductor GmbH 2014

[1184] IXYS Semiconductor GmbH 2014 "Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf

[1185] IXYS Semiconductor GmbH 2016a "Answers to questionnaire 1 (clarification questionnaire), sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Markus Bickel, Ixys Semiconductor GmbH, on 27 January 2016,"

[1186] Ibid.

[1187] Ibid.

[1188] Op. cit. Schott AG 2015a

[1189] Ibid.

- Bismuth-oxide, Bi_2O_3;
- Phosphate glasses P_2O_5.

The development for these glasses was mainly done for glass to glass or glass to ceramic joints. In a separate project, which was launched 2004, Schott tested all these new systems for usability for metal to glass joints.[1190]

The substitute glass has to meet the following requirements:

- Gas tight seal: hermeticity better than 1x10-8 mbar*l/s; must remain unchanged after 15 cycles of thermal shock liquid to liquid (-65°C <> 150°C);
- No outgassing;
- Mechanically strong bond: the assembly has to pass stringent shock, typically 1500 g gravitational acceleration and vibration testing;
- Chemical resistance: No performance change after 1000 h at 85°C and 85 % relative humidity;
- Low cost, which excludes the usage of metalized windows and metal solder;
- Working temperature less than 500 °C;
- Mechanically stable up to 260 °C.

Table 22-5 shows the test results. The metal solders used with the metalized windows were gold/tin solders with 80 % (weight) of gold (AuSn 80/20) to achieve a melting point of more than 260 °C, which is higher than the conventional lead-free and lead-solders. This solution is only applicable to window caps. Moreover, these products will not fit Schott's customers´ requirements because they have to accept that the counterpart is gold-plated. [1191]

[1190] Ibid.
[1191] Op. cit. Schott AG 2015b

Table 22-5: Test results of lead-free alternatives to leaded solder glass

Glass System	Weaknesses	Positive Findings	Further conclusion
Bi_2O_3	• Sealing Temperature 550-570°C (dependant on Cap geometry) • Optical elements damaged by high sealing temperature • Metal surface requirement cannot be met (Damp Heat, Bellcore Spec GR468)	• Mechanically good bonding to metal and glass • Chemical resistance of solder glass improved compared to PbO	• Launch of new project for improved Bi_2O_3 glass with lower sealing temp (see next line)
Bi_2O_3 Next Gen. Glasses	• Sealing Temperature only reduced to 530-550°C No glass composition identified with lower seal temp. (appr. 50 new glass compositions tested)	• See above	• No Solution found with Bi_2O_3 system
P_2O_5	• No bond to suitable metal surfaces • Chemical resistance no adequate for Cap application	• None	• No further activities
SnO_2-P_2O_5	• Environmental Stability not adequate	• Sealing Temperature requirement <500°C met • Bond between Solder glass and metal achieved	• No further activities
Metalized Windows & Metal Solder	• Metallization process is too costly for this application (costs are about 5-10x too high) • Not applicable to all products (i.e. ball lenses)		• No further activities

Source: Schott[1192]

Lead oxide as a glass constituent is responsible for the low working temperature of the glass, yet maintaining an acceptable level of environmental resistance. Higher working temperatures will damage the optical elements of the components. Without using lead containing solder glasses Schott will no longer be able to produce their huge variety of high level electronic components.[1193]

Regarding the small amount of lead containing solder glass needed for Schott's purposes and the fact that glass is an inert and stable material, which does not pose any danger to human health and environment along the lifecycle, Schott applies for the extension of the existing exemption in Annex III, no. 7(c)-I.[1194]

[1192] Ibid.
[1193] Op. cit. Schott AG 2015a
[1194] Ibid.

As no substitutes are available or foreseeable in the near future, Schott[1195] requests the continuation of Exemption 7(c)-I for the maximum five year period.

22.3.4.7 Sensata's Request for the Renewal of the Exemption

Alternative lead-free glasses meeting the requirement of matching coefficient of thermal expansion of parts to be bonded are available, but these materials do not fulfil other requirements as shown in Table 22-6. Experiments on alternative materials are conducted but with marginal results. The material match and process profiles are not fulfilling the requirements. Lead glasses are superior in the combination of characteristics versus for example Zn, P-S and Na-Al-P-B glasses.

Table 22-6: Test results of lead-free glasses

Characteristics	Pb glass	Zn glass	P-Sn glass	Na-Al-P-B
Affinity	Good	Not good	Not good	Good
Low melting point	Yes	No	Yes	Yes
Coefficient to thermal expansion	Good	Good	Good	Not good
Weather resistance	Good	Good	Not good	Not good

Source: Sensata[1196]

Sensata[1197] claims there are no applications where not all of the characteristics listed in Table 22-6 are required, so that neither lead-free glasses nor alternative technologies like lead-free solders can be applied.

Sensata[1198] states that beyond the above arguments, the rationale of its exemption request is based on the justifications of Murata/JEITA et al. [1199] [1200]

[1195] Ibid.
[1196] Sensata Technologies 2015b "Questionnaire 1 (clarification questionnaire), document "7c-I_Questionnaire_Sensata_20150901.pdf": Questionnaire 1 (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Sensata/7c-I_Questionnaire_Sensata_20150901.pdf
[1197] Ibid.
[1198] Ibid.
[1199] Op. cit. JEITA et al. 2015a
[1200] Op. cit. Murata et al. 2015a

22.3.5 Impacts on Environment, Health and Resources

Murata et al.[1201] claim that so far no substitution technology has been found, but many potential compositions have been investigated in order to develop reliable technical solutions on industrial scale, however below are further examples of environmental and health and production impacts of major candidates:[1202]

- Potential future candidates under investigation are expected to have more difficult raw materials and processes, even under mass production considerations;
- Niobium and bismuth-based substitutes have a higher impact on environment during extraction and purification than lead, as lead is already recycled with high recovery and is relatively abundant in nature (10 to 70 times more than Bi and 3 times more than niobium).

The environmental impact of lead in ceramic and glass is low, because of the low water solubility of lead contained in ceramic and glass, therefore, leakages into the environment are very low. Current PZT production is based on water; potential substitutes would require alternative technology based on organic solvents (e.g. isopropyl alcohol, ethanol, acetone). Such solvent-based technologies and the requirement to meet ATEX regulations would result in higher efforts and risks in health and environment protection, e.g. to avoid emission of solvents (Isopropyl alcohol, Ethanol, Acetone) that are VOCs (volatile organic carbon) which also need to be minimized in the EU due to the Industrial Emissions Directive 2010/75/EU.

PZT is used in industry for processing of ceramic for many years under controlled worker conditions. Health impacts have been well investigated.

Murata et al.[1203] provide the following references to support their environmental statements:

- Worker Exposure to Lead Titanate Zirconate in an Ontario Company M.L. Roy, MD, PhD; S.Siu, Md; W.Waddell, MD; P.Kennedy, BSc, J Occup Med. 1989 Dec;31(12):986-9.

- Comments on an Annex XV Dossier for Identification of a Substance as SVHC and Responses to these Comments, http://echa.europa.eu/documents/10162/25b4427f-1c53-4497-8ca2-29d24a55f4b5

Murata et al.[1204] also present the EU critical raw materials from the 2013 list (reproduced in Figure 22-15).

[1201] Ibid.
[1202] Ibid.
[1203] Ibid.
[1204] Ibid.

Figure 22-15: EU critical raw materials 2013

Antimony	Beryllium	Borates	Chromium	Cobalt	Coking coal	Fluorspar
Gallium	Germanium	Indium	Magnesite	Magnesium	Natural Graphite	Niobium
PGMs	Phosphate Rock	REEs (Heavy)	REEs (Light)	Silicon Metal	Tungsten	

Niobium, one of the potential candidates used in lead-free ceramics, is listed as a critical raw material. Additionally, Murata et al.[1205] state that tantalum was on the EU's critical material list prior to the 2013 one.

22.4 Roadmap for Substitution or Elimination of Lead

22.4.1 Substitution and Elimination of Lead in Piezoelectric and PTC Ceramics

According to Murata et al.,[1206] there are still many remaining technical issues to be solved in order to achieve mass production of practical products. Adding to that, even in the case that mass production technology is achieved, the research has shown that the required properties for substitutes in the various applications of ceramics cannot be obtained.

For ceramics, Murata et al. indicate the following steps towards the substitution or elimination of lead:

- Achievable material properties are known;
- First demonstrations of applications published;
- Technologies for industrial production must be developed;
- Simple replacement of PZT components have already been shown not to be possible;
- Adaption or new development of EEE, reliability investigations;
- Certain replacements: time frame >5 years, overall replacement not foreseeable;

Murata et al.[1207] states that introducing new chemical compounds and materials in order to replace PTC ceramics even in a certain resistance-Tc range would need an overall change in powders conception used in the production of PTC at the moment. This is because not just one powder is used in production of a certain product but usually a mixture of two or more powders is used. With the alternative materials examined up to now, only ceramic for applications with low Curie temperatures might be meaningful to

[1205] Ibid.
[1206] Ibid.
[1207] Ibid.

undergo further investigation and development because of the strong limitations in regard to certain properties as mentioned above. Furthermore, for these low Tc applications there still exist several constraints as explained in the justification of the exemption for PTC ceramics.

Overall, Murata et al.[1208] do not see any perspectives for a comprehensive transition to ceramic in the next five years and therefore claim they cannot set a technical goal.

Murata/JEITA et al.[1209] were asked again about their plans and the steps they want to undertake in the next five years towards the substitution and/or elimination of lead for the various types of ceramics (roadmap) described in their exemption request. They replied they will continue developing, requesting development and/or applying possible alternatives taking into account the practicability, reliability or environmental, health and consumer safety impacts of substitution. However, as this involves individual company policies, unpredictable technical and scientific findings and market and consumer developments it is impossible to draw any serious roadmap under the present circumstances.

22.4.2 Substitution and Elimination of Lead in Glass and Glass or Ceramic Matrix Compounds

Murata/JEITA et al.[1210] [1211] claim that there are no prospects concerning the technical scope of exemption 7(c)-I for a comprehensive substitution to “lead-free” glass and/or ceramic at least until the next revision (21 July, 2021)

Murata et al.[1212] report that boron, phosphorus, zinc, tin, bismuth, etc. as elements for substituting lead as a constituent element of glass, have been investigated. However, when compared with lead-containing glasses, chemical stability and mechanical strength of the glasses are insufficient (to meet the required functionality). As a result, there are concerns of accidents originating from crucial failures in EEE incorporating electrical and electronic components composed of glass with lead substituted by these elements due to their insufficient reliability and quick deterioration.

Murata/JEITA et al.[1213] remain committed to supporting the procedure for the adaptation to scientific and technical progress, and will continue developing, requesting the development and/or applying possible alternatives taking into account the practicability, reliability or environmental, health and consumer safety impacts of substitution.

[1208] Ibid.
[1209] Op. cit. (Murata et al./JEITA et al. 2016d)
[1210] Op. cit. Murata et al. 2015a
[1211] Op. cit. JEITA et al. 2015a
[1212] Op. cit. Murata et al. 2015a
[1213] Murataet al./JEITA et al. 2016e “Answers to questionnaire 6a, document"Exe_7c-I_Questionnaire-6a_Murata-JEITA_2016-03-2.pdf", received from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016” unpublished manuscript,

However as this involves individual company policies, unpredictable technical and scientific findings and market and consumer developments it is impossible to draw any serious roadmap under the present circumstances.

Schott[1214] states that after spending 5.5 person years of research, and thorough testing of substitute systems, Schott sees no adequate replacement for PbO to attach optical elements like windows or lenses into metal components. Therefore, no substitutes are likely to be developed in the foreseeable future and so the maximum validity period is required for this exemption.

IXYS[1215] wants to continue with the development of new passivation systems, i.e. diamond-like carbon coatings or amorphous silicon-oxide layers (SIPOS, semi-insulating polycrystalline silicon). As mostly with new developments and technologies, IXYS[1216] states that there is no guarantee on when there will be a breakthrough on the whole front of this kind of power semiconductors.

Bourns[1217] will continue to work with their suppliers, explore possible solutions, and experiment with possible alternatives. It is a slow process with research, experimentation, testing, scale-up, qualification & reliability testing. If there is a failure along the way, the process starts over.

22.5 Critical Review

22.5.1 REACH Compliance - Relation to the REACH Regulation

Lead is used in glass in the scope of Exemption 7c-I. Barium titanate (BT), lead titanate (PT), lead zirconium titanate (PZT) as well as barium strontium lead titanate are used in the ceramics in the scope of this exemption according to the applicants. These ceramics and their constituents therefore need to be evaluated whether their use weakens the environmental and health protection afforded by Regulation (EC) No 1907/2006 (REACH Regulation). There are, however, hundreds of material recipes for each of the ceramics, which could not be addressed and mentioned in this review and which may be even proprietary knowledge. They cannot be taken into account.

Since no substitutes have been identified in the review process that would result in the restriction of the exemption scope, the various substances used in lead-free ceramics were not specifically taken into account. As, however, lead-free lithium tantalate sensors have been identified as a potential future alternative to PZT-based sensors, lithium tantalate will be evaluated as well.

[1214] Op. cit. Schott AG 2015a

[1215] Op. cit. IXYS Semiconductor GmbH 2014

[1216] Op. cit. IXYS Semiconductor GmbH 2016a

[1217] Bourns Inc. 2016a “Request for continuation of exemption 7c-I, document "20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf": Answers to second questionnaire” unpublished manuscript,

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 28 and 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
  This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
- *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."*
  This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption. Should the ceramics in the scope of the exemption actually be used in watch timepieces, this use of lead would be allowed.

Various entries in the REACH Regulation annexes restrict the use of barium and strontium compounds in several articles and uses. Nickel barium titanium primrose priderite and strontium chromate are specified for Annex XVII entry 28. These compounds are, however, not relevant for the ceramics in the scope of Exemption 7c-I. The same applies to strontium chromate, which is also listed in Annex XIV under Entry 29.

No other entries for the above mentioned ceramics and their compounds relevant for the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

Lithium nickel dioxide, cobalt lithium nickel oxide, lithium perfluorooctane sulfonate and lithium heptadecafluorooctanesulfonate are also listed under Entry 28 and Entry 30 in Annex XVII of the REACH Regulation so that the same conditions apply to these substances like for lead and its compounds. These substances and compounds are not relevant for the use of lithium tantalate in sensors, which may be a potential and commercially available alternative to PZT-based sensors. No other entries relevant for the use of lithium tantalate in these sensors could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the use of lithium tantalate to substitute or eliminate lead would not weaken the environmental and health protection afforded by the REACH Regulation.

22.5.2 Substitution and Elimination of Lead in Ceramics

The applicants argue that none of the known lead-free piezoelectric materials is a suitable overall substitute for PZT. Art. 5(1)(a) would, however, require to apply lead-free solutions if they were available for specific application fields. Not all applications of PZT-containing components may require the all properties of PZT to the highest level at the same time, these being:

- High Curie temperatures;
- High piezoelectric charge constants;
- High electromechanical coupling factors;
- High quality factors and low losses for ultrasonic devices;
- High stability under different driving and environmental conditions, especially temperature; and
- High reliability.

22.5.2.1 Use of Lower Performing Ceramics in Less Demanding Applications

Murata et al.[1218] explain that the functions and properties (e.g. Curie temperature, breakdown voltage, etc.) required for ceramic of electrical and electronic components and the usage environment are not only diverse but also change during use due to changes in the usage environment. For example, a high voltage of a few tens of thousands of volts may be instantly applied over electrical/electronic equipment, or temperature loads exceeding the expectations may occur, etc. In order to use these items with safety it is necessary that they can withstand such conditions. Since lead-containing ceramics, which are stable and show excellent functionality over a wide range of usage environments, are essential for compatibility with the required functionality and usage environment, the decision on whether substitution by "lead-free" ceramics is possible or not will vary with the equipment type and subpart on a case-by-case basis and it is not possible to identify applications, which can be substituted.

Murata et al.[1219] furthermore state that electrical and electronic components have to withstand conditions in manufacturing that are different from those during use so that it is impossible to decide on the use of lead-free PTC only by application. For example, in the manufacturing of electrical and electronic equipment the components can be heated to 150 °C so that ceramic that breaks down or deteriorates at this temperature cannot be used. $BaTiO_3$ with a T_C of 120 °C would, for instance, simply depole during such processes.

Murata et al.[1220] also point out that piezoelectric materials are selected based on a combination of properties. Even if a given lead-free composition fits the sensitivity criteria, it does not necessarily mean that it will be stable over a given temperature range or have the required dielectric or mechanical properties. In addition to this, lead-free materials are known to have different and generally more complex temperature characteristics such as additional phase transitions within the operating temperature range. Moreover, the reproducibility of lead-free piezoceramics' properties is significantly lower due to the fact that their production is considerably more sensitive to process parameters.

Overall, the information provided by the applicants explains that currently the substitution of lead in the ceramics in the scope of exemption 7c-I is scientifically and technically still impracticable. The available information suggests that lead-free ceramics are still inferior in performance, and their manufacturing in industrial scale is not yet achieved. The submitted information also suggests that such lead-free ceramics cannot be used in components that could be applied where not all of the properties of lead-containing ceramics are required.

[1218] Op. cit. (Murata et al. 2016a)
[1219] Ibid.
[1220] Ibid.

The applicants' exemption requests and the answers to the clarification questionnaire were made available through the online consultation to the public, i.e. to industry, governments, NGOs and other stakeholders, and a consultation questionnaire had been prepared for the public online consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received, and there were no hints that lead-free solutions would be foreseeable for the near future.

22.5.2.2 Commercial Availability of Lead-free Sensors

In the last questionnaire received on 1 April 2016, Pyreos [1221] mentions that Panasonic commercially offers lead-free lithium tantalate sensors for specific applications. A short internet investigation actually showed that there are scientific publications on lithium tantalate sensors[1222] and examples of commercial sensor products[1223] where it is explicitly stated that these pyroelectric elements "*[...] contain lithium tantalate and are lead-free. Typical PIR sensing elements are ferroelectric ceramic (PZT) containing lead*."

According to Pyreos,[1224] lithium tantalate can substitute thick film PZT-based sensors in applications, which have lower performance requirements and are not so robust, such as low operating temperatures (-20 to +85 °C). Lithium tantalate cannot so easily substitute thin film PZT as there are even more different performance requirements such as temperature shock response etc. In general, litihium tantalate cannot substitute thin film PZT in applications where higher cost, reproducibility and superior performance are a consideration.

The Panasonic data sheet[1223] lists commercial / residential equipment (including lighting fixtures, sensor switches, video intercoms, vending machines, home automation control panels) and home appliances (including television and PC monitors, air conditioners and air purifiers) as applications for the lead-free pyroelectric sensors.

Thus, the substitution or elimination of lead is viable at least in pyroelectric sensors even though they might not have the properties that would allow covering the whole range of applications where PZT ceramics are used. In the consultants' understanding, the results of the internet investigation are at least an indication that contrary to the statements in particular of Murata et al., substitution or elimination of lead may be scientifically and technically practicable to a certain degree. The considerable efforts already spent on the

[1221] Pyreos Ltd. 2016b "Answers to third questionnaire, document "Exe_7c-I_Questionnaire-3_Pyreos_2016-03-30_final.pdf", received via e-mail from Torben Norlem, Intertek, by Dr. Otmar Deubzer, Fraunhofer IZM, on 31 March 2016" unpublished manuscript,

[1222] Vincent Stenger, Michael Shnider and Sri Sriram, SRICO, Inc.; Donald Dooley and Mark Stout, Gentec-EO USA, Inc.: Thin Film Lithium Tantalate (TFLT™) Pyroelectric Detectors; SPIE Photonics West 2012, Optoelectronic Materials and Devices THz Technology and Applications V – OE107, Paper Number 8261-27 http://www.srico.com/files/PW2012_TFLT%20Pyro%20Detectors.pdf

[1223] Panasonic: PaPIRS Passive Infrared Motion Sensor, http://datasheet.octopart.com/EKMC1601111-Panasonic-datasheet-43724067.pdf

[1224] Ibid.

review of exemption 7c-I and the time restrictions did not allow a further clarification with Murata et al.

Adding to the above, Murata et al. provide only very general and unspecific information on their future efforts to substitute or eliminate lead in ceramics. They justify this with confidentiality, but the consultants believe that even though the members of the industry consortium are competitors, there should be possibilities to describe in more details future steps, which should also be related to the various types of ceramics and their application-specific requirements to find specific solutions where general drop-in alternatives are not viable.

22.5.2.3 Bandelin

Bandelin requests to add a specific application (identified by the bold addition) to the current wording of exemption 7c-I, and to add this exemption to Annex IV as well:

> ***"Piezoelectric hard PZT containing lead for high-performance ultrasonic transducers and*** *electrical and electronic components containing lead in glass or ceramic materials other than dielectric ceramic in capacitors"*

The principle rationale of the exemption request follows the arguments of the other stakeholders that the substitution or elimination of lead is currently scientifically and technically not possible, and Bandelin explains this plausibly for the PZT used in high performance ultrasonic transducers.

Based on this information and in the absence of contrary information, granting the exemption would be in line with the requirements of Art. 5(1)(a).

Technically, the use of lead in the applicant's transducers is fully covered by the current exemption 7c-I, and it shall be decided in the context of the future wording of this exemption 7c-I whether and how to take into account this specific exemption in RoHS Annex III.

The applicant applies to adopt the same exemption wording to RoHS Annex IV. It is the consultants' understanding that, to avoid the proliferation and overlapping of exemptions, Annex IV should only list exemptions that are exclusively required for EEE in categories 8 and 9 of RoHS Annex I, which according to Bandelin[1225] is not the case for their high power transducers. The consultants therefore recommend not to adopt this exemption to Annex IV as long as an exemption in Annex III covers the use of lead in this application and consequently allows the uses of lead in the scope of the exemption for all categories of EEE.

[1225] Op. cit. Bandelin Electronic GmbH 2015a

22.5.2.4 Pyreos

Pyreos asks to add the following exemption to Annexes III and IV of the RoHS Directive:

> *"Lead in thin film electronic sensor elements such as pyroelectric sensors or piezoelectric sensors"*

The information submitted by Pyreos suggests that the company uses lead zirconium titanate (PZT) as thin films instead of thicker films and thus has successfully reduced the amount of lead in its sensors. They are not lead-free at the current state of development, and despite further investigation[1226], it could not be clarified whether they would actually become lead-free in the next development step in the sense of the RoHS Directive, i.e. containing less than 0.1 % of lead in any homogeneous material applied.

Pyreos[1227] explains its motivation for its request that a specific exemption focused on lead in thin film PZT sensors will significantly reduce the quantity of lead used in PZT sensors sold on the market today when compared to conventional technology using other types of PZT sensors not falling within the scope of the specific exemption.

This effect will, however, not be achieved if the proposed exemption is adopted as a specific exemption, or if the current wording is amended accordingly. It would then allow the use of lead in thin film PZT sensors – which is already the case in the current exemption 7c-I – but it would not restrict the use of lead in any other sensors.

It was pointed out to the applicant[1228] that the only way to achieve their intention would be to exclude other types of sensors than PZT thin film sensors from the scope of the future exemption 7c-I allowing the use of lead in ceramics. This would require a detailed technical specification, where other sensors can be replaced, and it will also require feedback and discussions from other stakeholders, and it would best have been discussed in the online stakeholder consultation. Such an intention of Pyreos' exemption request was not obvious based on the documents submitted.

Pyreos[1229] stated thereupon that in line with the purpose of the RoHS legislation as far as possible, they would like to seek support for this specific exemption by:

- Specifically exempting the use of lead in thin PZT film (e.g. total thickness cannot exceed 10 microns) in applications where thin PZT film can replace other PZT (e.g. thickness greater than 10 microns) sensors with an equivalent or superior cost effectiveness, performance and reliability.
- Specifically allowing the use of lead in thin film PZT sensors until a lead-free thin film pyroelectric (or sensor) material with an equivalent or superior cost effectiveness, performance and reliability, is available.

[1226] Op. cit. (Pyreos Ltd. 2016b)
[1227] Op. cit. (Pyreos Ltd. 2016a)
[1228] Op. cit. (Pyreos Ltd. 2016b)
[1229] Ibid.

The consultants agree that the reduction of lead is an important contribution to the objectives of the RoHS Directive and as such the applicant's approach is worthy of support. The approach the applicant chose does not allow to actually restrict the use of lead in the sensors in the scope of Pyreos' request for the reasons explained above. It actually required some time and discussion[1230, 1231, 1232] with the applicant to fully understand the intention. Restriction criteria in the applicant's answer to the last questionnaire[1233] are examples, and there was no further time to discuss whether these criteria are sufficient and clear with the applicant and other stakeholders.

Technically, the use of lead in the applicant's sensors is fully covered by the current exemption 7c-I, and it remains to be seen in the total context of the future wording of this exemption whether it makes sense to add an explicit exemption to Annex III as the applicant requested. In any case, the applicant can explicitly apply for the restriction of the scope of the future exemption 7c-I, and the request can then undergo the public online stakeholder consultation and subsequent review of the stakeholder information to find out how the scope of the exemption could actually be narrowed. It will then also have to be clarified whether and how far lead-free pyroelectric sensors[1223] can actually replace PZT-based pyroelectric sensors.

The applicant applies to adopt the same exemption wording to RoHS Annex IV. According to Pyreos,[1234] the exemption would be relevant for all categories of EEE. For the same reasons like explained for Bandelin's request, the consultants recommend not to follow the applicant's request.

22.5.3 Substitution and Elimination of Lead in Glass and Glass or Ceramic Matrix Compounds

22.5.3.1 Bourns and IXYS

Bourns' and IXYS' arguments for the use of lead glass and lead in glass/ceramic matrix compounds are plausible, and no information has been received during the stakeholder consultation or later discrediting the applicant's arguments. They follow the rationale of the justification of Murata/JEITA et al. for the use of lead in glass.

Bourns have developed some proprietary lead-free solutions. These, however, are not drop-in solutions and are said to only work on a case by case basis for certain components. Consequently, no rule can be accordingly deduced to demarcate applications where lead-free glass can be used to specify the exemption. Some of these components are trimmer potentiometers. The situation is therefore described in more

[1230] Op. cit. Pyreos Ltd. 2015b
[1231] Op. cit. (Pyreos Ltd. 2016a)
[1232] Op. cit. (Pyreos Ltd. 2016b)
[1233] Ibid.
[1234] Op. cit. Pyreos Ltd. 2014

detail in the review of exemption 34 (trimmer potentiometers), but also applies to other Bourns components.

IXYS is working on passivation systems that would allow substituting lead in the glass of high voltage diodes. The development still requires time and, according to the applicant, it is not foreseeable that lead can be replaced in the near future.

The situation shows, however, that the elimination or substitution of lead in glass and glass/ceramic matrix compounds is obviously scientifically and technically practicable in some cases. As such it may be possible to restrict the scope of the exemption at a future time, and hence setting a short expiry on a renewed exemption 7c-I may bring forward the potential for this to occur in the next exemption review.

22.5.3.2 Schott

Schott present research on lead-free alternatives to the lead-containing glass they use to attach optical components into metal components. The results show that there is currently no lead-free glass that can replace the lead-containing glass. The tested gold-tin metal solder seems to be viable in principle for some window caps, but Schott says it is too expensive and requires gold contacts on the customers' side as well so that their customers cannot accept this solution. Thus, technically, the substitution and elimination of lead is not yet practicale and granting an exemptin for this application would be in line with the requirements of Art. 5(1)(a).

The cost argument as raised by the applicant cannot justify an exemption in accordance with the stipulations of RoHS Art. 5(1)(a) unless the availability of the substitutes or the socioeconomic impacts would make the manufacturing of such components impossible so that the products depending on these components could no longer be produced, or similarly severe impacts. The applicant does not provide substantiated information that would suggest such severe impacts.

Schott also justifies its exemption request with the small amounts of lead used and the fact that the glass is inert and thus not hazardous along the life cycle. This is, however, only partially true as the lead has to be mined and refined, where it is not inert but emissions into the environment do occur, and the same applies to processing and disposal at end of life. Furthermore, RoHS Art. 5(1)(a) would only justify an exemption if the negative impacts from the use of lead-free alternatives are likely to outweigh the positive effects of lead substitution. The applicant does not provide information showing that this might be the case. The small amount of lead used cannot be accepted as a justification for an exemption either, as RoHS Art. 5(1)(a) does not set a threshold for minimum amounts of restricted substances that would justify granting an exemption.

Technically, the applicant's information suggests that, currently and in the foreseeable future, the substitution of lead is scientifically and technically not yet practical and granting an exemption for five years would thus be justified in line with Art. 5(1)(a).

22.5.3.3 Sensata

Sensata[1235] shows test results suggesting that there have been tests of lead-free glass, which showed that they are not a viable substitute. They claim that all properties of lead glass are required in all their applications so that lead-free glasses, which do not exhibit this combination of materials, cannot be used. There is no information available to the consultants that disproves this statement.

Beyond this specific information, Sensata's justification follows the rationale of Murata/JEITA et al. and is therefore not further discussed separately, the more as Sensata's information does not allow to deduce a specific wording for their uses of lead in glass.

22.5.4 Specification of the 7c-series Exemptions

Exemption 7(c) is related to lead in glass and ceramic type materials which may be used in electrical and electronic components. Given the broad range of ceramic and glass materials, and their multiple uses and functionalities in components, the scope of this exemption is wide so that it may hinder the gradual phase-out of lead. Following the same rationale like for exemption 7(a), it was tried to specifiy the scope of exemption 7(c)-I.

Based on information provided by the applicants in this review and in previous exemption reviews, the consultants formulated a wording targeting a scope which is as narrow as possible to exclude the abuse of the exemption and promotes specific research into lead-free solutions. In parallel, the same proposed wording is as wide as necessary to ensure all applications are covered where substitution and elimination of lead is still impracticable.

A specification of Exemption 7(c)-I in the current numbering and wording is not viable. The exemption was therefore split into two specific wordings for ceramics on the one hand, and glass and glass ceramic matrix compounds on the other hand.

22.5.4.1 Lead in Ceramics of Electrical and Electronic Components

The consultants proposed the below wording for the ceramic-part of exemption 7(c)-I. Exemptions 7(c)-II, 7(c)-III and 7(c)-IV were integrated into this wording proposal:

Lead in

i) *piezoelectric ceramics in electrical and electronic components, i.e.*
   - o *ferroelectric ceramics*
   - o *pyroelectric ceramics*
   - o *other piezoelectric ceramics*

[1235] Op. cit. Sensata Technologies 2015b *ii) positive temperature coefficient (PTC) ceramics in electrical and electronic components*

- *with T_C < 120 °C (T_C: Curie temperature) and resistivity of less than < 1000 Ωcm*
- *with T_C < 120 °C and resistivity of 1,000 Ωcm and more*
- *with $T_C \geq$ 120 °C and resistivity of less than 1,000 Ωcm*
- *with $T_C \geq$ 120 °C and resistivity of 1,000 Ωcm and more*

iii) dielectric ceramics in discrete capacitor components for a rated voltage of 125 V AC or higher, or for a rated voltage of 250 V DC or higher

iv) dielectric ceramic in discrete capacitor components for a rated voltage of less than 125 V AC, or for a rated voltage of less than 250 V DC; for use in spare parts of EEE placed on the market before 1 January 2013

v) PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors

vi) other ceramics

Murata/JEITA et al.[1236] [1237] recommend keeping the current wording with slight modifications (see review of exemption 7c-II). They claim that the exemption scope cannot be correctly understood in the above proposed wording and fear that the effectiveness of the legal enforcement will be damaged. They strongly assert that a wording to be adopted should summarize a wide knowledge of Industry, and be carefully examined in order to not cause any misinterpretation of the legal text to avoid any unnecessary misunderstanding, misinterpretation and/or wrong usage of lead in the supply chain. Therefore, they strongly insist a wording should remain as proposed in the original application form of Murata/JEITA et al.[1238] [1239]

[1236] Murata et al./Jeita et al. 2016b "Answers to third questionnaire (ceramics), document "Exe_7c-I_Questionnaire-3_Murata-JEITA_2016-03-03_ceramics.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Kelm, Murata, on 22 March 2016" unpublished manuscript,

[1237] Murataet al./JEITA et al. 2016f "Answers to questionnaire 5b, document "Exe_7c-I_Questionnaire-5b_Murata-JEITA_2016-03-2.pdf", received via e-mail from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 5 April 2016" unpublished manuscript,

[1238] Murata et al. 2015a "Original exemption request, document "Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf": Exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf

[1239] JEITA et al. 2015a "Exemption request, document "JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf": Exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf

Murata/JEITA et al.[1240] put forward the following more specific justifications for their position:

- Splitting further the exemption will not eliminate existing functional requirements for lead in glass and ceramic, nor will it improve the availability for Pb-free alternatives because different functions are combined for each individual product application.
- Part i) and part ii) of the wording proposal are not based on physical laws, being simply a classification for convenience based on end-use applications in EEE. For this reason they consider that unless they prepare an application list of end-uses for all OEM/EEEs identifying the scope, it is impossible to define the exemption scope from the wording proposal.
- It is believed that a comprehensive application list of OEM EEE end-uses for lead in glass and ceramic is not currently feasible because the applications are extremely numerous and thus impossible to quantify, requiring different and complex parameters for their specification (definition).
- It is believed that the division of RoHS Ex. 7(c) into eleven applications, intended uses or components is not necessary and would be confusing.
- The proposed wording would misalign with the ELV exemption 10(a) wording included in ELV's Annex II.
- If the wording is so deeply changed, how would customers interpret this complex definition to determine how it applies?
- The application-specific wording proposals are too ambiguous, which may result in interpretation issues. It is impossible to define all end-use applications. Many of these component devices have unique characteristics, which may be excluded with the current application-based proposals. Trying to develop categories under the 7(c) exemptions that will cover all current components/devices is extremely difficult. Some products will ultimately be left out creating a compliance and economic issue for those component companies affected.
- Additionally from a technical point of view the categorization proposed above by Oeko-Institut and Fraunhofer IZM has some technical problems as well. From the point of view of properties, ferroelectric materials are a subgroup of pyroelectric materials that are a subgroup of piezoelectric materials and all should be considered as dielectrics etc. However, when this categorization is used to distinguish between applications as it seems to be the case here, it leads to ambiguity, since all piezoelectric ceramics need to be ferroelectric and thus also pyroelectric. This also leads to undesired side effects for many

[1240] Op. cit. (Murata et al./Jeita et al. 2016b) piezoelectric applications: the ferroelectric character may lead to depoling (loss of polarisation) due to an external electric field in actuators and transducers, and the pyroelectric character may give rise to pyroelectric charges in sensors due to a temperature change. It will be extremely difficult to make exhaustive lists of applications of piezoelectric ceramics covering all present and future uses, and Murata/JEITA et al. foresee that in practice it will not be possible for customers to clearly identify a category in cases where their application relies on a number of properties.

The discussion related to the consultants' rewording proposal for exemption 7(c)-I shows that a consensus on the technical details of such a rewording proposal requires further exchange with the various stakeholders to agree on the architecture and the definitions of terms. The limited time and resources available for the review of this exemption did not allow further discussions with the applicants and other stakeholders. The consultants therefore recommend to continue the exemption as proposed in the review of Exemption 7(c)-I. The above proposals and discussions can, however, be a basis to a further specification of Exemption 7(a) in a future review taking into account the new status of elimination and substitution of lead.

22.5.4.2 Lead in Glass and Glass or Ceramic Matrix Compounds in Electrical and Electronic Components

The consultants proposed the below wording related to lead in glass and glass/ceramic matrix compounds in exemption 7c-I. Exemption 34 (Lead in cermet-based trimmer potentiometers) was integrated into this wording as well as the glass beads of high voltage diodes where the use of lead glass is the root cause for contaminations in the plating, which is in the scope of exemption 37).

Lead in glass or in a glass or ceramic matrix compound

- *used for protection and electrical insulation*
  - *in glass beads of high voltage diodes on the basis of a zinc-borate glass body*
  - *in other electrical and electronic components*
- *used as resistance material*
  - *in cermet-based trimmer potentiometers*
  - *other electrical and electronic components*
- *used for bonding purposes in electrical and electronic components*
- *for hermetic sealings between ceramic packages and glass or ceramic lids in electrical and electronic components*
- *used for any other purposes in electrical and electronic components*

Murata/JEITA et al.[1241] state that the time available was not enough to allow a cross-industry association discussion. They principally disagree with the splitting of the exemption for the same reasons as mentioned above in the ceramic part of the proposed rewording.

More specifically, Murata/JEITA et al. [1242] [1243] put forward that attempting to develop categories under the 7(c) exemptions that will cover all current components/devices is extremely difficult. Some products will ultimately be left out creating a compliance and economic issue for those component companies affected.

The consultants do not share this argument. The last clause of the proposed wording should cover all those cases, which are out of the scope of the previous clauses. It is, however, crucial that the other clauses actually address specific uses of glass and glass and ceramic matrix compounds containing lead as otherwise the specification of the exemption would not make sense. The replies of Murata/JEITA et al. are not detailed enough to allow clear insights on the viability of the proposed specific uses.

Murata/JEITA et al.[1244] state that there is not just one type of lead glass but there are different glasses for different functions/applications. Even though lead in glass material used today might be rather similar in their chemical composition, potential alternative materials will not likely be the same for the different applications. Based on previous investigations and studies it does not seem likely that one material compound could be found which fulfills the specific requirements for all the variety of applications.

This statement supports in principle the specification of the exemption to gradually phase out the use of lead, as stated in recital 19 of the RoHS Directive. [1245]

In the consultants' understanding, a clear consensus should be achieved with the applicants that the exemption technically covers all applications of glass and glass ceramic materials correctly, so as to avoid that misunderstandings and misinterpretations, which had occurred in the discussion process, result in an inappropriate wording. The limited time and resources available for the review of this exemption did not allow more time for further discussion. The above wording proposal should, however, be a good basis for a specification of the exemption in the next review.

[1241] Murata et al./Jeita et al. 2016c "Answer to questionnaire 4 (glass), document "Exe_7c-I_Questionnaire-4_Murata-JEITA_2016-03-09_glass.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Wolfgang Werner, Vishay, on 22 March 2016" unpublished manuscript,

[1242] Ibid.

[1243] Murataet al./JEITA et al. 2016g "Answers to questionnaire 6b, document "Exe_7c-I_Questionnaire-6b_Murata-JEITA_2016-03-3.pdf", received via e-mail from Wolfgang Werner, Vishay, on 5 April 2016" unpublished manuscript,

[1244] Ibid.

[1245] *Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast)*, recital clause (19)

22.5.5 Conclusions

22.5.5.1 Lead in Ceramics of Electrical and Electronic Components

The accessible information suggests that the substitution of lead in ceramics is scientifically and technically still impractical in the majority of applications. Contrary to the statements in particular of Murata et al., substitution or elimination of lead may be scientifically and technically practical to a certain degree even though it could not be clarified whether this would justify and enable narrowing the scope of the exemption.

Appraising the overall situation, Art. 5(1)(a) would justify renewing the exemption for lead in ceramics, taking into account the fact that the substitution or elimination of lead scientifically and technically is still impractical at least in the majority of cases. It can, however, not be excluded that lead-free solutions are or shall become available in the nearer future. Granting the exemption for five years would thus not be justifiable according to Art. 5(1)(a). The consultants hence recommend a validity period of three years, which would allow restricting the scope of the exemption, while still leaving enough time to for the stakeholders to apply for the renewal of the exemption 18 months prior to its expiry, should it still be required at that time. The applicants would then also have to show dedicated efforts to achieve the substitution and elimination of lead.

22.5.5.2 Lead in Glass or in Glass or Ceramic Matrix Compounds in Electrical and Electronic Components

The information provided by the applicants suggests that currently the substitution of lead in glass and in glass/ceramic matrix compounds in the scope of exemption 7c-I is scientifically and technically still impracticable. Bourns and IXYS are both continuing to work on lead-free solutions, though at present, these are understood not to be sufficiently mature to allow narrowing the scope of Exemption 7c-I in the foreseeable future.

The applicants' exemption requests and the answers to the clarification questionnaire were made available through the online consultation to the public, i.e. to industry, governments, NGOs and other stakeholders, and a consultation questionnaire had been prepared for the public online consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received, and there were no hints that lead-free solutions would be foreseeable for the near future.

Murata et al. provide only very general and unspecific information on their future efforts to substitute or eliminate lead in ceramics. They justify this with confidentiality, but the consultants believe that even though the members of the industry consortium are competitors, there should be possibilities to describe in more detail the future steps to be taken. These efforts should also be related to the various types of glass and glass/ceramic matrix compounds and their application-specific requirements to find specific solutions where general drop-in alternatives are not viable.

Taking into account the overall situation, the consultants recommend granting the exemption given the fact that lead is still required in glass and glass and ceramics matrix compounds. As no substitutes are foreseeable in the near future, Art. 5(1)(a) would justify renewing the exemption for the maximum validity period of five years. It will, however, be essential that the applicants will have undertaken dedicated efforts in the coming five years to find application-specific solutions for the various types of glass applications should they apply for another renewal of this exemption.

22.5.5.3 Specification of Exemption 7(c)-I

The discussion related to the consultants' rewording proposal for exemption 7(c)-I shows that a consensus on the technical details of such a rewording proposal requires further exchange with the various stakeholders to agree on the architecture and the definitions of terms. The above wording proposal should, however, be a good basis for further efforts to specificy the exemption in the next review.

22.6 Recommendation

The applicants' information suggests that the substitution and elimination of lead generally is still scientifically and technically impracticable in the applications in the scope of Exemption 7c-I. Art. 5(1)(a) thus would allow renewing the exemption. While for lead in glass and glass or ceramic matrix compounds no possibilities for substitution or elimination of lead are foreseeable, the information available does not allow excluding that lead-free solutions for ceramics are or will become available within less than five years.

The consultants therefore recommend renewing the exemption for five years for lead in glass or glass or ceramic matrix compounds, and for three years only for lead in ceramics of electrical and electronic components.

It should also be noted here that the exemption for lead in glass or glass or ceramic matrix compounds of electrical and electronic components technically covers the use of lead in cermet-based trimmer potentiometers, which is in the scope of Exemption 34. To avoid overlapping scopes of exemptions, Exemption 34 should be excluded from this part of the exemption.

Exemption 7(c)-I	**Expires on**
Electrical and electronic components containing lead in a ceramic other than dielectric ceramic in discrete capacitor components, e.g. piezoelectronic devices	*21 July 2019 for categories 1-7 and 10*
Exemption 7(c)-V	**Expires on**
Electrical and electronic components containing lead in a glass or in a glass or ceramic matrix compound. *This exemption does not cover the use of lead in the scope of exemption 34 (cermet-based trimmer potentiometers).*	*21 July 2021 for categories 1-7 and 10*

Exemption 7(d)	Expires on
Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9* *21 July 2023 for in vitro diagnostic medical devices in category 8*
	21 July 2024 for industrial monitoring and control instruments in category 9

Exemptions 7(c)-II, 7(c)-III and 7(c)-IV can be integrated into the above table.

In order to keep the purely ceramic-related exemptions together, it is recommended above to give the exemption valid for cat. 8 and 9 a new number and to list all ceramic-related exemptions under 7c-I. This numbering would also prevent that exemptions 7(c)-II, 7(c)-III and 7(c)-IV have to be renumbered, which overall reduces the administrative burden.

If the Commission decides not to change the numbering of the part of the exemption that covers Cat. 8 and 9, the consultants recommend the below wording and numbering for Exemption 7c-I.

Exemption 7(c)-I	Expires on
Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9* *21 July 2023 for in vitro diagnostic medical devices in category 8* *21 July 2024 for industrial monitoring and control instruments in category 9*
Exemption 7(c)-V	**Expires on**
Electrical and electronic components containing lead in a glass or in a glass or ceramic matrix compound. *This exemption does not cover the use of lead in the scope of exemption 34 (cermet-based trimmer potentiometers).*	*21 July 2021 for categories 1-7 and 10*
Exemption 7(d)	**Expires on**
Electrical and electronic components containing lead in a ceramic other than dielectric ceramic in discrete capacitor components, e.g. piezoelectronic devices	*21 July 2019 for categories 1-7 and 10*

Exemptions 7(c)-II, 7(c)-III and 7(c)-IV can be integrated into the above table.

22.7 References Exemption 7c-I

Bandelin Electronic GmbH 2015a Request for continuation of exemption 7c-I with addition, document "Ex_7c_I_Application_Bandelin.pdf. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/BANDELN/Ex_7c_I_Application_Bandelin.pdf.

Bandelin Electronic GmbH 2015b Questionnaire 1 (clarification questionnaire), document "Ex_7c-I_Bandelin_1st_Questionnairie_and_Answers.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/BANDELN/Ex_7c-I_Bandelin_1st_Questionnairie_and_Answers.pdf.

Bourns Inc. 2015a Exemption request, document "7c-I_Exemption_extension_ap_7c-I.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Bourns/7c-I_Exemption_extension_ap_7c-I.pdf.

Bourns Inc. 2015b Request for continuation of exemption 7c-I, document "20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf", clarification questionnaire. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf.

Bourns Inc. 2016a Request for continuation of exemption 7c-I, document "20150818_Ex_7c-I_Bourns_Questionnaire-1_2015-07-28.pdf".

Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment. RoHS 1European Union. February 13, 2003.

Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast). RoHS 2European Union. July 1, 2011.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

IXYS Semiconductor GmbH 2014 Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf.

IXYS Semiconductor GmbH 2016a Answers to questionnaire 1 (clarification questionnaire), sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Markus Bickel, Ixys Semiconductor GmbH, on 27 January 2016.

JEITA et al. 2015a Exemption request, document "JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7 _c_-I/JEITA/7c-IandII_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf.

Murata et al. 2015a Original exemption request, document "Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/7c-I_RoHS_V_Application_Form_7c1_20140116_combined_final.pdf.

Murata et al. 2015b Questionnaire 1 (clarification questionnaire), document "RoHS_7c-I_Murata__1st_Questionnaire_answers_final_20Aug.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Murata/RoHS_7c-I_Murata__1st_Questionnaire_answers_final_20Aug.pdf.

Murata et al. 2015c Addendum to original exemption request, document "Leadfree_PZT_comparison.pdf".

Murata et al. 2016a Answers to second questionnaire, document "Exe_7c-I_Questionnaire-2_Murata-JEITA_2015-12-30_answers_final.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Wolfgang Werner, Vishay, on 29 January 2016.

Murata et al./Jeita et al. 2016b Answers to third questionnaire (ceramics), document "Exe_7c-I_Questionnaire-3_Murata-JEITA_2016-03-03_ceramics.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Kelm, Murata, on 22 March 2016.

Murata et al./Jeita et al. 2016c Answer to questionnaire 4 (glass), document "Exe_7c-I_Questionnaire-4_Murata-JEITA_2016-03-09_glass.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Wolfgang Werner, Vishay, on 22 March 2016.

Murata et al./JEITA et al. 2016d Answers to questionnaire 5a, document "Exe_7c-I_Questionnaire-5a_Murata-JEITA_2016-03-28_Ceramics_final.pdf", received via e-mail from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016.

Murataet al./JEITA et al. 2016e Answers to questionnaire 6a, document"Exe_7c-I_Questionnaire-6a_Murata-JEITA_2016-03-2.pdf", received from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016.

Murataet al./JEITA et al. 2016f Answers to questionnaire 5b, document "Exe_7c-I_Questionnaire-5b_Murata-JEITA_2016-03-2.pdf", received via e-mail from Klaus Kelm, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 5 April 2016.

Murataet al./JEITA et al. 2016g Answers to questionnaire 6b, document "Exe_7c-I_Questionnaire-6b_Murata-JEITA_2016-03-3.pdf", received via e-mail from Wolfgang Werner, Vishay, on 5 April 2016.

Pyreos Ltd. 2014 Original exempiton request for renewal of exemption 7c-I with new wording, document "RoHS_V_Application_Form-Pyreos_final 14112014 - publication.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015_1/RoHS_V_Application_Form-Pyreos_final_14112014_-_publication.pdf.

Pyreos Ltd. 2015a Document "Questionnaire-1_Clarification_Exe-Req-Pyreos_cg130415 final - publication.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_7/2015_1/Questionnaire-1_Clarification_Exe-Req-Pyreos_cg130415_final_-_publication.pdf.

Pyreos Ltd. 2015b Document "Pyreos_Suspension-of-Request-with-Conditions.pdf", sent via e-mail to Dr. Otmar Deubzer, Fraunhhofer IZM, by Torben Nørlem, Intertek, on 20 July 2015.

Pyreos Ltd. 2016a Answers to questionnaire 2, document "Questionnaire-2_Pyreos_2016-03-06.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Torben Norlem, Intertek, on 23 March 2016.

Pyreos Ltd. 2016b Answers to third questionnaire, document "Exe_7c-I_Questionnaire-3_Pyreos_2016-03-30_final.pdf", received via e-mail from Torben Norlem, Intertek, by Dr. Otmar Deubzer, Fraunhofer IZM, on 31 March 2016.

Ralec Technology 2015 Exemption request, document "7c-I_RoHS_V_Application_Form_to_RoHS.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/RALEC/7c-I_RoHS_V_Application_Form_to_RoHS.pdf.

Schott AG 2015a Exemption request document "20150820_Ex_7c-I_Schott_Application_Revised_A.pdf" 2015a. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/SCHOTT/20150820_Ex_7c-I_Schott_Application_Revised_A.pdf.

Schott AG 2015b Questionnaire 1 (clarification questionnaire), document "20150820_Ex_7c-I_Schott_Ans_Questionnaire-1_Schott_2015-07-30.pdf" 2015b. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/SCHOTT/20150820_Ex_7c-I_Schott_Ans_Questionnaire-1_Schott_2015-07-30.pdf.

Sensata Technologies 2015a Request for continuation of exemption 7c-I, document "7c-I_RoHS-Exemptions_Application-Format_Ex_7cI_Pb_in_glass_20150115.pdf" 2015a. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Sensata/7c-I_RoHS-Exemptions_Application-Format_Ex_7cI_Pb_in_glass_20150115.pdf.

Sensata Technologies 2015b Questionnaire 1 (clarification questionnaire), document "7c-I_Questionnaire_Sensata_20150901.pdf" 2015b. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/Sensata/7c-I_Questionnaire_Sensata_20150901.pdf.

Vishay 2015a Document "RoHS-Exe-7c-I_Pb-in-glass-Enamel-Coating_Wirewound_Resistors.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a 2015.

Vishay 2015b Document "NTC – Glass coating for insulation.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a 2015.

Vishay 2015c Document "Request for exemption 7c-I NTC chips update dec15.pdf", submitted as additional reference for the exemption request of Murata et al. 2015a.

Yageo Corporation 2015 Exemption request, document "7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/YAGEA/7c-I_RoHS_V_Application_Form_YAGEO_2015-01-19.pdf.

Zangl, Stéphanie [Oeko-Institut e.V.] et al. Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS) 2010. http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf.

23.0 Exemption 7c-II “Lead in Dielectric Ceramic in Capacitors for a Rated Voltage of 125 V AC or 250 V DC or Higher”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

HVC	high voltage capacitor(s), capacitor(s) with rated voltage of 125 V AC or 250 V DC or higher

23.1 Description of the Requested Exemption

The current wording of exemption 7c-II in Annex III of the RoHS Directive is:

> *“Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher”*

Murata et al.[1246] apply for the renewal of Exemption 7c-II for five years with a modified wording to clarify the scope:

> *“Lead in dielectric ceramic in **discrete** capacitor **components** for a rated voltage of 125 V AC **or higher**, or **for a rated voltage of** 250 V DC or higher**”***

[1246] Murata et al. 2015a “Request for Renewal of Exemption 7c-II from 16 January 2015,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_V_Application_Form_7c2_20140115_final.pdf

23.1.1 Background and History of the Exemption

When Directive 2002/96/EC (RoHS 1)[1247] was published in 2003, Exemption 7d covered the use of lead in ceramics of electronic components:

"Lead in electronic ceramic parts (e.g. piezoelectronic devices)"

In the 2008/2009 review[1248] of this exemption it was found that the substitution of lead is scientifically and technically practicable in the low voltage area and the wording detailed below was thereupon recommended and adopted to the Annex of RoHS 1 demarcating the lead-free ceramic low voltage ceramic capacitors from the high voltage ones that still required the use of lead:

> *"7(c)-II Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher*
>
> *7(c)-III Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC"*

Exemption 7c-III was transferred without changes from the Annex of RoHS 1 to Annex III of RoHS 2 and expired on 1 January 2013.

Exemption 7c-II was also transferred without changes from the Annex of RoHS 1 to Annex III of RoHS 2 and would expire on 21 July 2016 if application for renewal had not been received.

23.1.2 Technical Description of the Exemption

Murata et al.[1249] explain that discrete ceramic capacitors for a rated voltage of 125 V AC or 250 V DC or higher (high voltage capacitors, HVD) bear the capability of storing and releasing electric charges (electrostatic capacitance) and are incorporated into high voltage circuits in a wide variety of electrical and electronic equipment. They are used in all types of markets and applications, for example: [1250]

- Social infrastructure systems;
- Industry automation;
- Oil and mineral exploration;
- Power conversion;
- High power supplies;

[1247] Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment, RoHS 1, European Union (13 February 2003)

[1248] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[1249] Op. cit. Murata et al. 2015a

[1250] Ibid.

- Telecommunication;
- Medical.

Typical applications are: [1251]

- Power electronic inverters;
- Pulsed power electronics and pulse forming networks;
- Capacitive discharge units;
- Transient high voltage suppression;
- Magnetization/demagnetization devices;
- Plasma generators;
- High-energy flashes;
- Lamps;
- Radio frequency interference suppression and electrical safety.

Murata et al.[1252] say that the above are nothing more than representative examples only partially showing markets and applications in which the exemption is used.

Murata et al.[1253] state that even though the major trend is miniaturization with low voltage rating and low power, other optimization parameters are often required for HVC, for example the need for high capacitance at high voltage and high power. The function of lead in the dielectric ceramic is to obtain:[1254]

a. High dielectric constant at high operating voltage;
b. High energy storage capability (also at high temperatures);
c. Low leakage at high voltage and high temperatures; and
d. Low loss at high current, frequency, and temperatures.

Murata et al.[1255] indicate that design engineers frequently call upon these parameters to meet technical requirements. Lead-containing dielectric ceramic has the outstanding feature of stably bringing out the above functions.

23.1.3 Amount of Lead Used under the Exemption

In Table 23-1, Murata et al.[1256] present a rough estimate of the total amount of lead included in glass/ceramic of the main electrical and electronic components. These figures were estimated from the production and sales results of electrical and electronic component manufacturing companies from Japan and Europe.

[1251] Ibid.
[1252] Ibid.
[1253] Ibid.
[1254] Ibid.
[1255] Ibid.
[1256] Ibid.

Table 23-1: Estimated amount of lead used in HVC

2007					2013				
Number of pieces placed on the market (G*5 pcs)		Lead use amount*2 — Per piece unit (mg)	Lead use amount (t) — Total amount placed on the market		Number of pieces placed on the market (G*5 pcs)		Lead use amount*2 — Per piece unit (mg)	Lead use amount (t) — Total amount placed on the market	
World*1	Europe*4		World*3	Europe*4	World*1	Europe*4		World*3	Europe*4
1.3	0.39	78	100	30	1.6	0.38	30	50	11.9

Source: Murata et al.[1257]

**1: Estimate by JEITA.*
**2: There are components with several different shapes and masses. We have estimated the lead use amount of an average component.*
**3: Rough estimate from *1 and *2.*
**4: Estimated from the EU/World GDP ratio.*
**5: G = 10^9 pieces.*

Murata et al.[1258] state that HVC are used in large quantities in a wide range of final products. It is impossible to provide an actual estimate of the amount of lead included in dielectric ceramic entering the EU. The above presented numbers result from an estimate concerning HVC for which production figures are comparatively easy to obtain by JEITA. It should also be noted that there may be capacitors for high voltage applications with lead-containing dielectric ceramic which are not included in the calculation. For this reason, although the estimates were done in good faith with the data resources available, the values shown here are provided strictly for reference purposes, and Murata et al.[1259] shall bear no responsibility concerning their accuracy or enforceability.

The around 12 t of lead indicated by the applicants should be considered as a minimum and the actual amount could be much higher given the fact that high volumes of EEE are imported into the EU.

[1257] Ibid.
[1258] Ibid.
[1259] Ibid.

23.2 Applicants' Justification for the Renewal of the Exemption

23.2.1 Clarification of the Exemption Scope

Murata et al.[1260] and JEITA et al.[1261] clarify that in the existing wording electronic components expressed as "capacitors" are precisely speaking "discrete capacitor components". They propose the underlined additions to the current wording for clarification of the technical scope of 7(c)-II.

> *Lead in dielectric ceramic in <u>discrete</u> capacitor <u>components</u> for a rated voltage of 125 V AC <u>or higher</u>, or <u>for a rated voltage of</u> 250 V DC or higher*

Murata[1262] and JEITA et al.[1263] explain that the current wording may be understood as also covering lead-containing dielectric ceramic in other components aside from discrete capacitor components, e.g. lead containing dielectric ceramic incorporated in ICs, boards, etc. These dielectric ceramic materials as well can store and release electricity, which is technically determined as capacitance. Those materials are, however, already in the technical scope of exemption 7(c)-I.

In the applicants' opinion[1264, 1265] the rated voltage limits in the current wording do not clearly determine the limits with respect to 125 V AC and 250 V DC resulting in an ambiguous wording. The proposed additions would clearly determine those limits.

Murata[1266] and JEITA et al.[1267] assure that their proposal only targets a more precise and less ambiguous wording and does not intend to enlarge the technical scope of Ex. 7(c)-II.

23.2.2 Substitution of Lead

Murata et al.[1268] claim that they had investigated the substitution of lead in lead-containing dielectric ceramic in discrete ceramic capacitor components for a rated voltage of 125V AC or higher, or for a rated voltage of 250 V DC or higher before the last review and continued the investigation after 2009 as well. Nevertheless, no substitution technology has been found up to the present day and there are no prospects of finding it within the foreseeable future. The reasons for the exemption presented by the

[1260] Ibid.
[1261] JEITA et al. (Japan 4EEE) 2015 "Request for renewal of exemption 7c-II" unpublished manuscript, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf
[1262] Op. cit. Murata et al. 2015a
[1263] Op. cit. (JEITA et al. (Japan 4EEE) 2015)
[1264] Op. cit. Murata et al. 2015a
[1265] Op. cit. (JEITA et al. (Japan 4EEE) 2015)
[1266] Op. cit. Murata et al. 2015a
[1267] Op. cit. (JEITA et al. (Japan 4EEE) 2015)
[1268] Op. cit. Murata et al. 2015a

stakeholders in 2009 are still valid. Consequently, it is necessary to extend the exemption.

Of central importance, as stated above, according to Murata et al.[1269] lead-containing dielectric ceramic has the outstanding feature of stably bringing out all of the below functions:

a. High dielectric constant at high operating voltage;
b. High energy storage capability (also at high temperatures);
c. Low leakage at high voltage and high temperatures; and
d. Low loss at high current, frequency, and temperatures.

Design engineers frequently call upon these parameters to meet technical requirements. Even for use at the condition of a rated voltage of 125 V AC or higher, or 250 V DC or higher, lead elimination can be achieved in practice for some partial applications, nevertheless in applications requiring all of the functions (a)-(d) the addition of lead is indispensable.

For example, in ceramic capacitors composed of barium titanate, which is known for its high dielectric constant and, which is used in lower voltage capacitors, these functions cannot be achieved without the addition of lead. If high voltage is applied to electrical and electronic equipment containing barium titanate capacitors, the equipment becomes unstable and even breaks down in the worst cases due to heat dissipation through energy loss and mechanical distortion due to electrostriction, the conversion of electric energy into mechanical distortion. Lead is added to suppress energy loss and electrostriction at the time when high voltage is applied. [1270]

Murata et al.[1271] report that ceramic capacitors having a material composed of strontium titanate show low energy loss and low electrostriction characteristics when high voltage is applied, meaning that functions (b)-(d) can be achieved. In spite of that, function (a) cannot be achieved due to a small dielectric constant, and so addition of lead becomes indispensable in order to increase the dielectric constant and have such capacitors operable in practice.

Murata et al.[1272] state that according to Pauling's rules, in order to form the same crystal structure, the constituent elements of ceramic, which can substitute lead, are restricted to those having a divalent valence and an ionic radius of 0.93-1.81 Å. The elements, which meet these conditions, are restricted to cadmium and alkaline-earth metals. Among those, cadmium has a higher toxicity than lead, and thus is not appropriate as a substitute material. In the case of alkaline-earth metals other than strontium (calcium, barium) are added, energy loss and electrostriction increase and therefore they cannot be used as substitute materials.

[1269] Ibid.
[1270] Ibid.
[1271] Ibid.
[1272] Ibid.

Murata et al.[1273] report that for particular use conditions, the required functions can be achieved with lead-free dielectric ceramic, however lead-containing dielectric ceramic is indispensable in applications for which it is necessary that multiple parameters coexist. It is required that the lead-containing dielectric ceramic used in ceramic capacitors for utilization at the condition of rated voltages of 125 V AC or higher, or 250 V DC or higher, must have a high dielectric constant capable to produce the required electrical capacitance in circuits of electrical and electronic equipment, as well as low energy loss and low electrostriction characteristics when high voltages are applied.[1274]

Lead is indispensable for the stable achievement of excellent functionality (high dielectric constant, low energy loss) over a wide range of use conditions (temperature, voltage, frequency). Moreover, as these use conditions vary during the use of electrical and electronic equipment, it is impossible to specify a technical range for elimination of lead with values based on a single condition. Consequently, there are no technical prospects for the general elimination of lead from dielectric ceramic materials in high voltage capacitor applications.[1275]

For further information, Murata et al. reference the 2008/2009 review report[1276] and the input from JBCE[1277] to the 2008/2009 review.

23.2.3 Elimination of Lead

Murata et al.[1278] explain that there are cases when substitution is possible in specific fields, as for example, film capacitors. There may exist other cases as well. However, to their knowledge, no product exists, which can substitute the advantages obtained in practice by lead-containing ceramic capacitors.

23.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

Murata et al.[1279] report about technical advances to reduce the amount of lead. The electrical and electronic equipment industry has enhanced the performance of discrete ceramic capacitors for high voltage applications in relation to their size. This has been achieved by improving the dielectric constant through the addition of lead, by using the multilayer technology, which takes advantage of the characteristic that lead-containing

---

1273 Ibid.
1274 Ibid.
1275 Ibid.
1276 Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), in particular page 104 et sqq.
1277 C.f. JBCE, http://rohs.exemptions.oeko.info/fileadmin/user_upload/Stakeholder_comments/Exemption-7c_JBCE_1_April_2008.pdf
1278 Murata et al. 2015b “Answers to questionnaire 1 (clarification questionnaire)” unpublished manuscript, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_Questionnaire-1_ZVEI-et-al_2015-09-06_final.pdf
1279 Op. cit. (Murata et al. 2015a)

ceramic can be densely sintered over a wide range of sintering conditions and by promoting miniaturization.

At the same time, with the advance of IT/wireless technology in recent years and the increase of high-frequency equipment associated with it, the number of electrical and electronic components per unit of electrical and electronic equipment has drastically increased. Overall, industry has nevertheless been successful in reducing the total amount of lead included in the ceramic of discrete ceramic capacitors for high voltage applications placed on the world market, including Europe.[1280] Table 23-1 on page 505 shows the detailed figures calculated by Murata et al.[1281]

Murata et al.[1282] conclude that although it is impossible to completely cease the use of lead under the scope of exemption 7(c)-II, improvements concerning its use have been implemented within their power, and industry is engaged in the reduction of the environmental burden as well as the amount of lead brought into the EU.

Concerning further stages for establishing possible substitutes and respective time frames needed for their completion, Murata et al.[1283] claim there are no prospects for substitution for the foreseeable future because of the technical reasons explained in their request for the renewal of exemption 7c-II.

23.4 Critical Review

23.4.1 REACH Compliance - Relation to the REACH Regulation

Barium titanate, strontium titanate and lead are used in the ceramics according to the applicants and therefore need to be evaluated whether their use weakens the environmental and health protection afforded by Regulation (EC) No 1907/2006 (REACH Regulation).

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is

---

[1280] Ibid.
[1281] Ibid.
[1282] Ibid.
[1283] Ibid.

relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 28 and 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
   This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."*
   This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption. Should HVC actually be used in watch timepieces, this use of lead would be allowed.

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of barium, strontium and compounds in various articles and uses.

Nickel barium titanium primrose priderite is specified for Annex XVII entry 28. This barium-containing substance is, however, not relevant for the ceramics in the scope of Exemption 7c-II. The same applies to strontium chromate, which is listed in Annex XIV.

No other entries, relevant for the use of substances relevant for the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

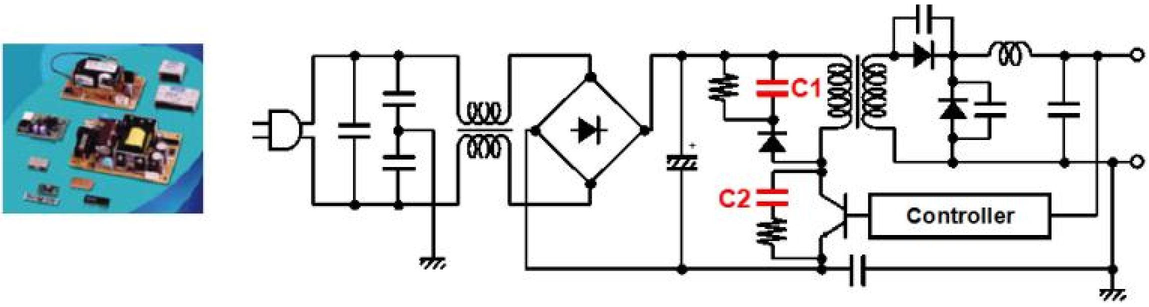
23.4.2 Substitution and Elimination of Lead

Murata et al.[1284] stated that HVC applied at a rated voltage of 125 V AC or higher, or 250 V DC or higher, lead elimination can be achieved in practice for some partial applications. They were asked to explain this in more detail with respect to applications that do not require the full range of properties that lead-containing dielectric ceramics can provide:

1) High dielectric constant at high operating voltage;
2) High energy storage capability (also at high temperatures);
3) Low leakage at high voltage and high temperatures;
4) Low loss at high current, frequency, and temperatures.

Only upon repeated requests[1285] [1286] [1287] Murata et al finally presented two examples of lead-free HVC snubber capacitors that are used in switching power supplies (C1, C2 in Figure 23-1).

Figure 23-1: Switching power supply



Source: Murata et al.[1288]

Murata et al.[1289] explain that the lead-free HVC C1 and C2 in the above figure eliminate high-frequency noise, for which ceramic HVC are generally used. C1 and C2 are operated

[1284] Ibid.
[1285] Op. cit. (Murata et al. 2015b)
[1286] Murata et al. 2016a “Answers to second questionnaire, document "Exe_7c-II_Questionnaire-2_ZVEI-et-al_2015-01-25_answers_final.pdf", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 February 2016” unpublished manuscript,
[1287] Murata et al. 2016b “Answers to third questionnaire, document "Exe_7c-II_Questionnaire-3_ZVEI-et-al_2016-03-14.DOCX", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 24 March 2016” unpublished manuscript,
[1288] Ibid.

with high frequencies and high voltages. However, in case “lead-free” HVCs are used, there is the possibility of a short circuit failure occurring over a short period of time depending on the voltage conditions of the equipment and use conditions in the market. In practice, according to Murata et al., equipment using “lead-free” HVCs have recently caused short failure accidents in the market. The applicants did not provide further information substantiating this statement.

Murata et al.[1290] state that in recent years, as voltage and use conditions become more severe, high reliability and longer longevity of the equipment are being required by society in order to promote accident prevention in the market and reduce maintenance burdens including environmental aspects. “Lead-free” HVCs cannot fulfill the requirements of high reliability and longevity, thus there is the risk that they may cause serious accidents in the market.

Murata et al.[1291] ask to note that the use conditions required by equipment applications utilizing snubber capacitors C1 and C2 stretch over a very wide range as shown below, and moreover, there are applications requiring compatibility to further high frequency trends and high voltage.

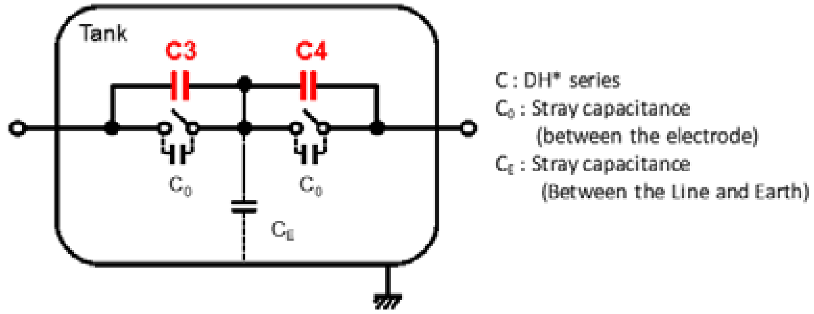
- Frequency: Generally 50 - 150kHz; there are market trends of shifting to higher frequencies.
- Voltage: Generally 150Vp-p - 1000Vp-p, however there are cases exceeding 1000Vp-p depending on the input voltage to the equipment and noise conditions.
  Vp-p = Volt peak to peak (electrical potential difference between minimum and maximum values of AC voltage).

Murata et al.[1292] indicate that in order to fulfill these use conditions, capacitance (electrostatic capacity) and nominal voltage are listed as performance parameters required for C1 and C2, however neither of them can be specified. The capacitance changes according to the noise frequency to be eliminated, so that the capacitance range cannot be specified. Besides requirements that change depending on the input voltage and noise conditions, safety design conditions of equipment are diverse. As there are cases where higher nominal voltages are (also) required, it is not possible to specify the voltage range.

As a second example of lead-free HVC uses, Murata et al.[1293] present circuit breakers of power (C3 and C4 in Figure 23-2).

[1289] Ibid.
[1290] Ibid.
[1291] Ibid.
[1292] Ibid.
[1293] Ibid.

Figure 23-2: Circuit breaker



Source: Murata et al.[1294]

Murata et al.[1295] explain that C3 and C4 are capacitors used dividing voltage and reducing restriking voltage. The voltage of these subparts is some hundreds of kilovolts AC at 50/60Hz with multiple capacitors being used in series. Therefore, the applied voltage onto individual capacitors is a high voltage (maximum AC40kV) at 50/60 Hz.

However, as high voltage noise is generated when switching the circuit breaker, high resistance to surge (impulse) voltage performance is required. There are cases when “lead-free” HVCs are used in this subpart. As impulse (surge) resistance performance of “lead-free” HVCs is low compared to lead-containing HVC, it is necessary to increase the thickness of the ceramic element or to increase the number of serial HVC in order to adopt those “lead-free” HVC. This results in the upsizing of the equipment as a whole. In order to reduce the environmental load, including the amount of lead used, and promote the downsizing of the entire equipment, lead-containing ceramic materials, which have excellent surge (impulse) resistance performance, are indispensable.

Murata et al.[1296] summarize the use conditions required by the equipment application concerning C3 and C4 listing capacitance, nominal voltage and surge (impulse) resistance as performance parameters required for C3 and C4. However, regardless of the parameters it is not possible to specify a technical scope for which “lead-free” HVC may be utilized.[1297]

- **Frequency**: 50/60Hz
- **Voltage**: some hundreds kV AC as a circuit
  As multiple capacitors are used connected in series, the applied voltage changes according to the circuit design and thus cannot be specified.
- **Capacitance**
  As capacitors are used as multiple units in a series, the capacitance of the equipment is the total sum of those capacitances. Consequently, it is not

---

[1294] Ibid.
[1295] Ibid.
[1296] Ibid.
[1297] Ibid.

possible to specify the capacitance values required by each individual capacitor.

- **Nominal Voltage**

  As capacitors are used as multiple units in a series, the required nominal voltage changes with the circuit design. The safety design conditions of the equipment are diverse, and as there are also cases when higher nominal voltages are required it is not possible to specify them. For this reason, it is not possible to specify the nominal voltage of the individual capacitor units.
- **Surge (Impulse) Resistance Performance**

  There is a correlation between surge (impulse) resistance performance and nominal voltage, and as the safety design conditions of equipment are set for surge (impulse) performance and nominal voltage respectively, it is not possible to determine a specification for surge (impulse) performance individually.

There are cases when it is not possible to fulfill the required performance of the product with "lead-free" HVC depending on the applied voltage conditions. For this reason, it is impossible to comprehensively substitute specific applications by "lead-free" HVC.[1298]

23.4.3 Rewording of the Exemption

Murata/JEITA et al.[1299] [1300] propose a slight modification of the exemption wording (c.f. Section 23.2.1 on page 506) to clarify that actually the discrete capacitor components are in the scope and not other dielectric ceramic materials that may also have a capacitance, but that are covered by exemption 7c-I. As this was actually the intended scope of exemption 7c-II, the consultants recommend to adopt the proposed wording based on the applicants' assertion that these modifications clarify, but do not change the technical scope of the exemption.

According to the applicants, such dielectric ceramic materials are not only used in discrete ceramic capacitors. The consultants therefore wonder whether in the low voltage area below 125 V AC or 250 V DC the substitution of lead would not be scientifically and technically practicable in all dielectric ceramic materials with capacitance or where the capacitance is the reason for their use. As this question arose, however, at the very end of the review process, it could not be discussed with the stakeholders and shall need to be followed up in the next evaluation.

23.4.4 Conclusions

The applicants provide plausible information that the substitution of lead is scientifically and technically impracticable in HVC for applications that require all of the properties which currently only lead-containing dielectric ceramics can deliver. In the absence of

[1298] Ibid.
[1299] Op. cit. (Murata et al. 2015a)
[1300] Op. cit. (JEITA et al. (Japan 4EEE) 2015)

contrary information, granting an exemption would therefore be in line with RoHS Art. 5(1)(a).

In the light of the stipulations for exemptions in Art. 5(1)(a) the core criterion is, however, where the substitution or elimination of lead is scientifically and technically practicable. This raises the question whether all ceramic capacitors in all applications in the high voltage area actually need the combination of all properties of the leaded dielectric ceramics.

The applicants did not provide information on lead-free HVC or possible other alternatives to substitute or eliminate the use of lead, e.g. where not all of the leaded ceramics' properties are required. Only upon repeated request[1301, 1302, 1303] did they submit two examples of lead-free HVC and where they are used. The declaration as "examples" suggests that there are other lead-free HVC as well.

It is comprehensible that the applicability of such lead-free HVC depends on multiple parameters that may be difficult to be linked to criteria, which would allow a clear demarcation of application fields, where such lead-free HVC can be used. It can be assumed that such lead-free HVC have certain performance parameters such as rated voltages, temperature and frequency ranges, which circuit designers need to know in order to decide about their usability to verify certain requirements. Furthermore, electronic circuits could at least in part be redesigned to better accommodate the limits of such lead-free HVC and allow their use to thus reduce the amount of lead-containing HVC. The applicants did not provide information to clarify these questions.

Murata et al.[1304] also mention film capacitors as another example to substitute or eliminate lead and mention that there may be other options as well, but do not provide more comprehensive information about the properties of such devices.

Appraising the overall situation against the criteria stipulated in Art. 5(1)(a), the consultants recommend granting the exemption. The information available shows that lead-free alternatives are available for some applications, even though it was not possible to clarify with the available resources and time whether these lead-free alternatives would allow restricting the scope of the exemption. Substitution or elimination of lead thus may be scientifically and technically practicable in some cases within the maximum five years validity period. According to Art. 5(1)(a), it would not be justified to grant the maximum validity period of five years. The consultants propose to continue the exemption for three years only. This would on the one hand accommodate the scientific and technical impracticability to substitute or eliminate lead in HVC and give the applicants sufficient time to apply for the renewal of the exemption 18 months

[1301] Op. cit. (Murata et al. 2015b)
[1302] Op. cit. (Murata et al. 2016a)
[1303] Op. cit. (Murata et al. 2016b)
[1304] Op. cit. (Murata et al. 2015b)

prior to its expiry. On the other hand it would facilitate a further clarification of those areas where lead can already be substituted or eliminated.

23.5 Recommendation

The information which the applicants submitted suggests that many if not most applications require HVC containing lead in the dielectric ceramic material so that the substitution or elimination of lead in those HVC is scientifically and technically impracticable. In the absence of contrary information, granting an exemption would therefore be justified in line with Art. 5(1)(a). For some applications, alternative components such as lead-free HVC are, however, available on the market. The applicants did not provide comprehensive information about these components. In light of the lacking data related to availability of alternatives, the consultants would recommend a short term renewal, restricting the validity period of the exemption to three years. Should industry fail then again to provide substantiated information about specific research and available lead-free HVC in the future, the consultants recommend cancelling the exemption in the next review.

Exemption 7c-II	Expires on
Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher	*21 July 2021 for medical equipment in category 8 monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9
Lead in dielectric ceramic in discrete capacitor components for a rated voltage of 125 V AC or higher, or for a rated voltage of 250 V DC or higher	*21 July 2019 for categories 1-7 and 10*

The modified wording to clarify the scope of exemption 7c-II should also be reflected in exemption 7c-III, whose current wording is:

> *"Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC"*

The table below proposes a modified wording for exemption 7c-III.

Exemption 7c-III	Expires on
Lead in dielectric ceramic in discrete capacitor components for a rated voltage of less than 125 V AC, or for a rated voltage of less than 250 V DC	*1 January 2013 and after that date may be used in spare parts for EEE placed on the market before 1 January 2013*

23.6 References Exemption 7c-II

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

JEITA et al. (Japan 4EEE) 2015 Request for renewal of exemption 7c-II. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_Exemption_Renewal_Request_7_c_I_Japan4EEEassociations.pdf.

Murata et al. 2015a Request for Renewal of Exemption 7c-II from 16 January 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_RoHS_V_Application_Form_7c2_20140115_final.pdf.

Murata et al. 2015b Answers to questionnaire 1 (clarification questionnaire). http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-II/7c-II_Questionnaire-1_ZVEI-et-al_2015-09-06_final.pdf.

Murata et al. 2016a Answers to second questionnaire, document "Exe_7c-II_Questionnaire-2_ZVEI-et-al_2015-01-25_answers_final.pdf", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 February 2016.

Murata et al. 2016b Answers to third questionnaire, document "Exe_7c-II_Questionnaire-3_ZVEI-et-al_2016-03-14.DOCX", received via e-mail from Walter Huck, Murata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 24 March 2016.

24.0 Exemption 7c-IV “Lead in PZT based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

ADSL	Asymmetric Digital Subscriber Line, a communication technology
BST	Barium-Strontium-Titanate (ceramic)
F	Farad, unit for electrical capacitance
FRAM	Ferroelectric random access memory (or memories)
IC	Integrated circuit
IPD	Integrated passive device(s)
MEMS	Micro-Electro-Mechanical Systems
MFIS FeFET	Metal-ferroelectric-insulator-semiconductor Fe-Field Effect Transistor
MIM capacitor	Metal/insulator/metal type capacitor
MIS capacitor	Metal/insulator/semiconductor type capacitor
MOS capacitor	Metal oxide/silicon type capacitor
SBT	Strontium bismuth tantalite
SST	Strontium bismuth tantalite (ceramic)
STM	ST Microelectronics
PZT	Lead-Zirconium-Titanate (ceramic)

24.1 Description of the Requested Exemption

STMicroelectronics (STM) et al.[1305] request the continuation of exemption 7c-IV in Annex III of the RoHS Directive with the current scope and wording.

> "*Lead in PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors*"

24.1.1 Background and History of the Exemption

Exemption 7c was reviewed during the last adaptation of the Annex to the scientific and technical progress in 2008/2009.[1306] The Commission adopted the consultants' recommendation and adopted the following exemption wording:

- ***"7(c)-I** Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound*
- ***7(c)-II** Lead in dielectric ceramic in capacitors for a rated voltage of 125 V AC or 250 V DC or higher*
- ***7(c)-III** Lead in dielectric ceramic in capacitors for a rated voltage of less than 125 V AC or 250 V DC until 1 January 2013, and after that date may be used in spare parts for EEE placed on the market before 1 January 2013."*

Exemption 10 in Annex II of the ELV Directive exempted the use of lead in ceramics and glass as well. The background of this exemption technically is the same as exemption 7c in the RoHS Directive. Exemption 10 of the ELV Directive was reviewed[1307] in 2009/2010 and it was recommended to restrict the use of lead in dielectric ceramic materials of capacitors following the example in the RoHS Directive.

During the review of exemption 10 in the Annex of the ELV Directive, stakeholders informed the consultants that ceramic capacitors being part of integrated circuits or discrete semiconductors use dielectric ceramic materials based on PZT ceramics. These ceramics require the use of lead. As these capacitors are conceived for rated voltages of less than 125 V DC or 250 V AC, the use of lead in these components would no longer be allowed after December 2012.

[1305] STMicroelectronics et al. 2015a "Request for continuation of exemption 7c-IV, document "7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf

[1306] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, page 194 et sqq.

[1307] Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010 "Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS): Final report - revised version," Final Report Oeko-Institut e. V. und Fraunhofer IZM; page 194 et sqq.

The stakeholders at that time could plausibly justify the need for this exemption and the Commission followed the contractors' recommendation[1308] to grant the exemption in the ELV Directive with the following wording as exemption 10(a)(iv) in the Annex of the ELV Directive[1309]:

> *"Lead in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors"*

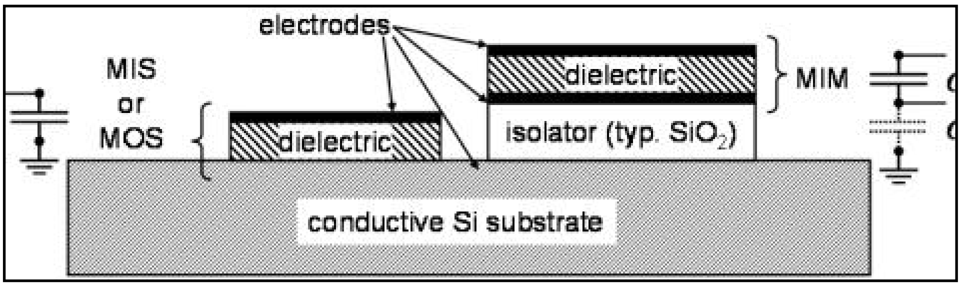
The stakeholders requested an identical exemption under the RoHS Directive (RoHS 1) in 2011 which was granted with the same wording like above and adopted to the annex of RoHS 1. The exemption was later transferred to Annex III of RoHS 2 and would have expired in July 2016 if no applications for renewal had been submitted.

24.1.2 Technical Description of the Requested Exemption

The technical background of the exemption was described in detail in the review report of this exemption[1310] under the scope of the ELV Directive in 2010. Capacitors store electrical energy in dielectric materials. Two electrodes are used to conduct the energy to and from the capacitor.

Figure 24-1 illustrates the two common capacitor types for integrated capacitors. The silicon substrate can be used as electrode (MIS or MOS). In this case, all capacitors share the substrate as ground electrode. MIM capacitors can be used in any configuration.[1311]

Figure 24-1: Typical thin film capacitor configurations



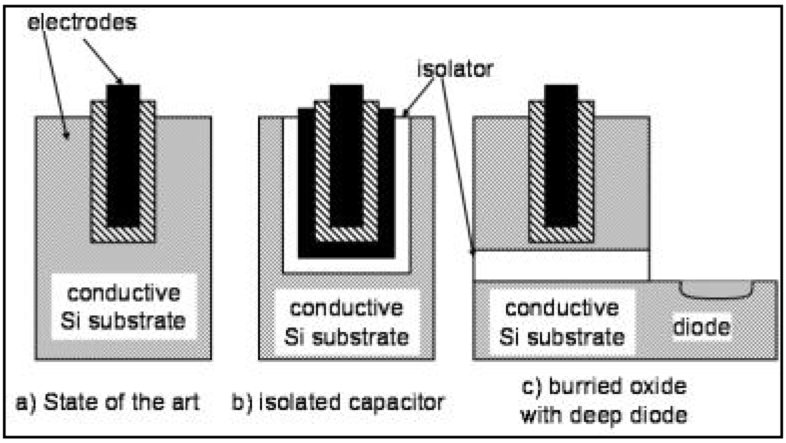
MIM *metal/insulator/metal type capacitor*
MIS *metal/insulator/semiconductor type capacitor*
MOS *metal oxide/silicon type capacitor*

Source: NXP in Zangl et al.[1312]

[1308] Ibid.
[1309] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, ELV Directive, European Union (21 October 2000), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT
[1310] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.
[1311] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.
[1312] Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010 "Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC

Trench (MOS) capacitors could be a potential alternative to high-density silicon integrated capacitors, as illustrated in Figure 24-2.[1313]

Figure 24-2: Trench capacitors



Source: NXP in Zangl et al.[1314]

Trench capacitors have disadvantages compared to PZT capacitors as they offer:[1315]

- Much lower capacitance density; and
- Significantly lower breakdown voltage (only 30 V, compared to 100 V for PZT-based materials).

The disadvantage of the lower capacitance density can partially be compensated by using the 3rd dimension making the capacitors larger. However, the breakdown voltage of PZT-based capacitors cannot be reached.[1316]

PZT offers:[1317]

- A high piezoelectric effect;
- A high dielectric constant, especially large at the morphotropic phase boundary;

(RoHS): Final report - revised version," Final Report Oeko-Institut e. V. und Fraunhofer IZM, accessed August 4, 2015, http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf

1313 Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.

1314 Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010

1315 Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010, page 194 et sqq.

1316 Ibid.

1317 STMicroelectronics et al. 2015b 2015 "Answers to questionnaire 1 (clarification questionnaire), document "Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf": Questionnaire 1 (clarification questionnaire)," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf

- Pyroelectric behaviour;
- Ferroelectric properties.

STM et al.[1318] highlight that lead-zirconium-titanate (PZT) material has the highest known dielectric constant (εr = 1000 – 1200) and thus can be used as a planar Metal/Insulator/Metal (MIM) capacitor with a breakdown voltage of more than 100 V. No alternative to PZT is currently known for thin film capacitors and Ferroelectric Random Access Memory (FRAM) that achieves the same combination of high dielectric constant, high breakdown field and temperature stability of 20 % in a temperature range from -25 to +85 °C. This combination of properties is indispensable to realize capacitors as parts of integrated circuits and discrete semiconductors.

According to STM et al.,[1319] integrated circuits or discrete semiconductors involving PZT-based dielectric ceramic materials for capacitors are used in:

- **IPD**[1320]
  Integrated passive devices (IPD) include functional blocks such as impedance matching circuits, harmonic filters, couplers, baluns and power combiner/divider, generally fabricated using standard wafer fab technologies such as thin film and photolithography processing, realized on thin substrates like silicon, alumina or glass. The IPD technology enables high-density capacitors, MIM capacitors, resistors, high-Q inductors, PIN diodes or Zener diodes to be integrated on the same silicon. These passives combined with active functions in one component respond to the high integration and low power consumption featured by high performing wireless devices.
- **FRAM**[1321]
  Ferroelectric Random Access Memories use a ferroelectric layer to achieve non-volatility. FRAM is one of a growing number of alternative non-volatile random-access memory technologies that offer advantages over flash memories including lower power usage, faster write performance and a much greater maximum number of write-erase cycles. FRAM products are found in a variety of sectors including, but not limited to, electricity meters, automotive electronics, business machines, instrumentation, medical equipment, industrial microcontrollers, and radio frequency identification tags.
- **Other uses**[1322]
  MEMS (Micro-Electro-Mechanical Systems) as integrated circuits or discrete semiconductors involving PZT-based dielectric ceramic materials. There may

---

[1318] Op. cit. STMicroelectronics et al. 2015a
[1319] Op. cit. STMicroelectronics et al. 2015b 2015
[1320] Ibid.
[1321] Ibid.
[1322] STMicroelectronics et al. 2016a "Answers to second questionnaire, document "Exe_7c-IV_Questionnaire-2_STM_2016-01-17.pdf", received via e-mail from Frederic Chapuis, STMicroelectronis, by Dr. Otmar Deubzer, Fraunhofer IZM, on 3 March 2016" unpublished manuscript,

also be applications where it is needed to implement decoupling or bypass capacitors. In such cases, the IPD technology would not be the only one which uses PZT material. It could be of interest also to build decoupling capacitors above integrated circuits (IC's) or MEMS's core technologies.

The use of PZT-based thin-film technologies includes, but is not limited to capacitors embedded in filters for wireless devices and other applications as shown in Figure 24-3.[1323]

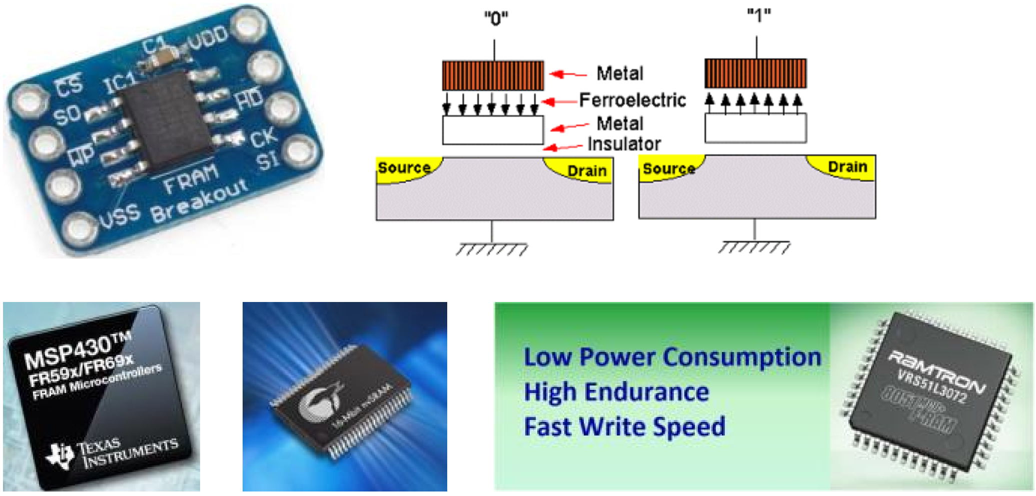
Figure 24-3: Use of PZT-based thin-film technologies in wireless and other devices

Source: Yole referenced in STM et al.[1324]

Pb is also present in PZT thin-film used for FRAMs memories as shown in Figure 24-4.[1325]

[1323] Op. cit. STMicroelectronics et al. 2015a
[1324] Ibid.
[1325] Ibid.

Figure 24-4: PZT thin-film in FRAM



	SRAM/DRAM	FLASH E²PROM	FUJITSU FRAM
Fast Unlimited Read/Write Access	Fast Unlimited R/W Access	Slow Block Access ROM	Fast Unlimited R/W Access
Non-Volatile	Volatile – Power Required	Non-Volatile	Non-Volatile

Source: Switch Science, Egloos, Texas Instruments, Cypress Semiconductor, Fujitsu (Internet); referenced in STM et al.[1326]

24.1.3 Amounts of Lead Used under Exemption 7c-IV

STM et al.[1327] reference the Yole production forecast 2012-2018 for IPDs, FRAMs and MEMS combined, where the number of 6 inch equivalent wafers shipped for the thin film PZT market was 578,000 (6'' eq.) in 2012 and is estimated to be 533,700 (6'' eq.) wafers by 2018. Based on this forecast, a yearly worldwide average estimation over 2014-2020 can be set at 550,000 wfs (6'' eq.) /annum, including MEMS.

The estimated weight of Pb in 6" wafers: 50 mg maximum[1328]

Estimated weight of Pb in devices annually sold on the market: 550,000 x 50 mg, which is equivalent to around 27.5 kg for the worldwide market.[1329]

The amount of substance entering the EU market annually through application for which the exemption is requested is thus below 27.5 kg.[1330]

[1326] Ibid.
[1327] Ibid.
[1328] Ibid.
[1329] Ibid.

24.2 Applicants' Justification for the Continuation of the Exemption

STM et al.[1331] claim that alternatives to PZT-based dielectric ceramic capacitors are not available. Trench capacitors have a breakdown of less than 30 V, compared to more than 100 V for PZT-based MIM capacitors.

Potential alternative materials such as Barium-Strontium-Titanate (BST) have only half the dielectric constant, which results in much larger devices that do not meet the size dimensions of semiconductor applications. Performance characteristics with alternatives – trench or BST capacitors – are severely degraded. These potential alternative techniques are not able to fulfil the electric requirements that are needed for such applications, i.e. a high breakdown voltage and low internal resistance at low leakage currents and high capacitance values. New materials without Pb will have to be invented. [1332]

24.2.1 Alternatives to PZT-based Integrated Passive Devices in Thin Film High Density Capacitors

24.2.1.1 Barium Strontium Titanate as Substitute for PZT

Thin film high density capacitor integrated passive devices (IPD) are made with PZT. STM et al.[1333] state that for these PZT in thin film high density capacitors since 2010-2011, basic research has not evidenced a new material which could be a substitute so that no alternative to PZT is currently known that achieves the same combination of high dielectric constant, high breakdown field and temperature stability in a temperature range from -25 to +85 °C, this combination of properties being indispensable to realize capacitors as parts of integrated circuits and discrete semiconductors.

STM et al.[1334, 1335] conducted a study after 2011 on Barium Strontium Titanate (BST), from which publications are available as well.[1336] STM[1337] interpret the results of the study as follows:

- At equal thickness of the dielectric, BST has a much lower capacity density than PZT;

[1330] Ibid.
[1331] Ibid.
[1332] Ibid.
[1333] Op. cit. STMicroelectronics et al. 2015b 2015
[1334] Ibid.
[1335] Op. cit. (STMicroelectronics et al. 2016a)
[1336] Comparison of Paraelectric and Ferroelectric Materials for Applications as Dielectrics in Thin Film Integrated Capacitors; http://www.imaps.org/journal/2000/q2/ulrich.pdf; source as referenced by STM 2016a; contact for the study: CEA – LETI (Commissariat à l'Energie Atomique et aux Energies Alternatives)

[1337] Op. cit. STMicroelectronics et al. 2015b 2015

- When the BST thickness is reduced at its minimum, it is possible to catch up with PZT in terms of capacitance density, but the reliability is then much below what is expected for the targeted electronic applications;
- In combination with trench capacitances, e.g. a 3-dimensional structure, it is possible to obtain comparable densities, but with two parameters affected:
    - higher series resistance:
      for density lower than 45 nF/mm² (nF: Nano-Farad), PZT and 3D capacitors have almost the same series resistance, but from around 45 nF/mm² on, dielectrics must be stacked into the trenches in the case of 3D capacitors. This stacking induces an increase of the series resistance from x 2 up to x 10 depending on the layout, which can be very damaging for the frequency answer of the device. It can increase the current going through the capacitor during an electrostatic discharge pulse leading to an earlier fuse or breakdown of the device.
    - lower breakdown voltage: for capacitance with medium density (~ 30 nF/mm²), the breakdown voltage is around 2 or 3 times lower for 3D capacitors than for PZT capacitors (30V versus 70V). For applications using DC voltage like ADSL (Asymmetric Digital Subscriber Line), PZT capacitors do not require very low voltage ESD clamping diodes in parallel to being correctly protected, contrary to 3D capacitors. If required, a basic protection diode can then be integrated on the same die as the PZT capacitance, improving the frequency answer at reduced cost.

STM et al.[1338] conclude from the above that the use 3D/trench capacitors leads to a quite different parametric compromise than PZT, requiring the re-design of the complete electronic functions. STM et al.[1339] estimate that the re-design would take a three to five year minimum timeframe to get validation and adoption of such alternatives.

STM et al.[1340] state that most electronic needs tend to be compatible with 3D capacitances when the acceptable breakdown voltage is low and the series resistance high. According to STM et al.[1341], this is valid for applications in which the DC (direct current) supply nominal voltage is a few tens of volts, for instance in computers, telecom equipment, industrial electronics and automotive applications. The use of PZT cannot be restricted to those types of electrical and electronic equipment since low and high voltage DC supplies can be found in the same application type so that both technologies can be useful on the same electronic board. Other applications like for example ADSL decoupling capacitors and analogic microphones demanding high voltage or low

[1338] Ibid.
[1339] Op. cit. (STMicroelectronics et al. 2016a)
[1340] Op. cit. STMicroelectronics et al. 2015b 2015
[1341] Op. cit. (STMicroelectronics et al. 2016a)

resistance require the use of PZT. For those applications, a new material without lead will have to be invented.

24.2.1.2 New Materials and Technologies to Replace PZT

STM et al.[1342] claim that previous extensive research has ruled out the use of the early-touted lead-free strontium bismuth tantalite (SST), but they closely monitor the current investigations of the alternative lead-free ferroelectric material hafnium oxide, as reported in 2011 by the combined groups of NaMLab, Fraunhofer CNT and Global Foundries in Dresden.[1343] A Taiwan group is reporting ferroelectricity in a similar system of materials in a MFIS FeFET (Metal-ferroelectric-insulator-semiconductor Fe-Field Effect Transistor) structure with similar results.[1344]

STM et al.[1345] deems that the Dresden team has an evident embodiment with a memory window. Although $Si0_2$:$Hf0_2$ may be a ferroelectric, there is no evidence to show it will be ferroelectric in other than a gate stack. This would need to be accomplished before full productisation. Table 24-1 summarizes the performance of the hafnia-based FeFET.

Table 24-1: Overview of Hafnia-based FeFET (red) performance

	Endurance	Retention	Speed	
			Program /Erase	Read
FRAM (130nm) FM22LDI6, 4Mbit, parallel	10^{14} cycles	10 yrs/85° C	55-ns access time	55-ns access time, 110-ns 4 Mbit
FeFET (Desden) (32 mm)	10^4 cycles	10 yrs/25° C	100 ns?	<50ns?
FeFET (Expect)	Same as FRAM ?	Same as FRAM ?	100 ns?	<50ns?

Source: STM et al.[1346]

STM et al.[1347] comment the properties in Table 24-1 in more detail:

[1342] Op. cit. STMicroelectronics et al. 2015b 2015
[1343] Ferroelectricity in hafnium oxide: CMOS compatible ferroelectric field effect transistors, Electron Devices Meeting (IEDM), 2011 IEEE International P24.5.1 - 24.5.4; source as referenced by STM et al.2015a
[1344] Low-Leakage-Current DRAM-Like Memory Using a One-Transistor Ferroelectric MOSFET with an Hf-Based Gate Dielectric, Cheng and Chin, IEEE Electron Device letters, Vol. 35, No. I, January 2014
[1345] Ibid.
[1346] Ibid.

- **Retention**
  The confidence level of the extrapolated 10 year data retention is low because it is based on 240 hours at room temperature. Extended bakes at higher temperatures will help to increase the confidence level and verify that the extrapolation is indeed linear with log time. The Dresden lead technologist[1348] agrees with this evaluation that retention is limited.
- **Endurance**
  This FeFET technology will not replace the FRAM performance as most applications require very high endurance. The endurance is clearly inferior to current FRAM. This FeFET would be far too slow and malfunction almost instantly in most applications. The characterization of the present FeFET devices is interesting but more work needs to be done. The distribution of individual devices would be very interesting and, if anything like typical memory weak bit issues, could require a significant amount of work to control. The anomalous behaviour seen on the 32 nm devices may be a side effect of the channel implants; so more work is needed to prove there is not a fundamental limitation of ferroelectric hafnia-based FeFET at these geometries. STM et al. expects and hopes the Dresden group proceeds on this issue.
- It is not sure that a higher coercive voltage is advantageous as claimed. To compete with existing floating gate technology, the required ferroelectric layer for the FeFET is so thin that the applied electrical field will be very high. This will limit the endurance performance of the IT FRAM due to polarization fatigue, which is demonstrated by this paper. The current Dresden films require ~2.5 V to fully switch the ferroelectric polarization while the PZT FRAM films saturate polarization at less than 1.35 V. In addition, the Dresden films' polarization saturation behaviour does not improve at thinner films making it currently impossible to achieve the same low voltage behaviour of the PZT.
- The Dresden group continues to publish based on the original work and good progress is indicated.

Upon request, STM et al.[1349] provide information about more recent publications than the 2011 Dresden Group report:

- Impact of Scaling on the Performance of HfO-based Ferroelectric Field Effect Transistors, Ekaterina Yurchuk et al, IEEE Transaction Devices VOL.61 No.11 November 2014, Page 3699

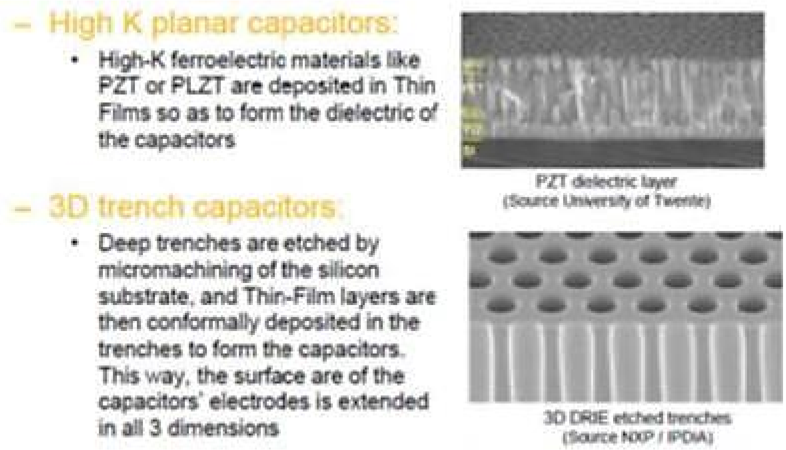
[1347] Ibid.
[1348] Stefan Müller (Stefan.mueller@namlab.com); contact provided by STM et al. 2016a
[1349] Op. cit. (STMicroelectronics et al. 2016a)

- Origin of the Endurance Degradation in the Novel HfO2-based 1T Ferroelectric Nonvolatile Memories, Ekaterina Yurchuk et al, IEEE Proceedings 978-1-4799-3317-4/14, 2014, page 2E.5.1

STM et al.[1350] report that a start-up company (Ferroelectric Memory Company), a spin-off from NaMlab, formed in 2015, based on the Dresden Group's study results. A 100 bit array of 28 nm FeFET was demonstrated in May 2015. According to STM et al., the company is not ready for production of lead-free products at this time, but indications are that sometime in the future there will be commercial lead-free offerings. The product specifications are yet to be determined, however.

STM et al.[1351] reference a Yole report[1352] from 2013 identifying a new material and a new technology which would, however, only further improve the capacitance density, but still contain lead. STM et al.[1353] explain that the new material is "high K planar PZT capacitors" as one of the two alternative technology tracks typically followed to integrate high density decoupling capacitors. STM et al. provide Figure 24-5 in this respect.

Figure 24-5: New material and new technology for integration of high density decoupling factors



Source: Yole[1352] referenced in STM et al.[1354]

According to the referenced Yole report, in both approaches the thin film deposition of the dielectric layer (PZT or PLTZ (lead lanthanum zirconate titanate)) allows for the making of thin capacitor dielectrics. The optimal dielectric thickness is a trade-off

---

[1350] Ibid.
[1351] Op. cit. STMicroelectronics et al. 2015a
[1352] Yole: "Thin Film PZT for Semiconductor - Application trends &Technology update (FRAM, IPDs and MEMS)" – 2013; source as referenced by STM et al.2015a
[1353] Op. cit. (STMicroelectronics et al. 2016a)
[1354] Op. cit. STMicroelectronics et al. 2015a

between capacitance density and the breakdown voltage. STM et al.[1355] explain that the highest values of capacitance density will not be reached without PZT, but possibly combined with Trench capacitors in applications.

STM et al.[1356] conclude that since 2011, the situation of fundamental research in the world has not allowed the research and development departments of companies, which design electronic components requiring exemption 7(c)-IV, to progress towards the substitution or the elimination of lead, while thanks to the unique properties of PZT-based capacitors in ICs or discrete semiconductors, many applications could feature higher integration, extended performance and lower power consumption. Those features are real advantages expected in the development of new electronic devices and, considering the extremely low quantity of lead involved in those components, call for the renewal of the 7(c)-IV exemption.

24.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

The Semiconductor Industry is working independently with selected material suppliers on the selection of an appropriate replacement for PZT. The properties of the needed capacitance and piezoelectricity material are specified by the industry (material requirement specification) and provided to the material suppliers. Selected suppliers offer their materials, which are evaluated by one of the companies together with the suppliers. The combined results are evaluated by the industry. After a material is chosen and material development is frozen, a minimum of 6 years will be required to qualify the new material through the whole supply chain. Based on current status, the Semiconductor Industry cannot predict a date for customer sampling. However the Semiconductor industry is already engaged in evaluating different alternative materials and evaluating other in-house material synthesis as well.[1357]

Development of BST - barium strontium titanate (Ba1-xSrxTiO3) - and SBT - strontium bismuth tantalite (SrBi2Ta2O9) - materials in order to solve the RoHS issues with Pb in PZT is considered, but no fixed timeline can be defined. However, SBT and BST have a 2x lower performance than PZT so there is a reluctance to switch to SBT and BST.[1358] Elaborating on this, STM et al.[1359] provide the data and general requirements in Table 24-2.

[1355] STMicroelectronics et al. 2016b “Answers to third questionnaire, document "Exe_7c-IV_Questionnaire-3_STM_2016-03-14.pdf", received via e-mail from Frederic Chapuis, STMicrelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016” unpublished manuscript,
[1356] Op. cit. STMicroelectronics et al. 2015b 2015
[1357] Op. cit. STMicroelectronics et al. 2015a
[1358] Ibid.
[1359] Ibid.

Table 24-2: Comparative table between PZT- and BST-based capacitors

	PZT	BST	Requirements
Operating Temperature	-40C to +125C	-10C to +85C	-40C to +125C
Longevity	≥ 40 years	~10 years	>40 years
Endurance	1E12 r/w [1] cycles	1E9 r/w cycles	Unlimited cycles
Relative dielectric K	1700 [2]	500 [3]	Highest Possible

[1] r/w = read/write
[2] MEMS,Dec 1995,Vol.4,No.4, p.234
[3] Scott, J.F., "High-dielectric Constant Thin Films for Dynamic Random Access Memories (DRAM)," Annu. Rev. Mater. Sci. 1998. 28:79–100

Source: Texas Instruments referenced in STM et al.[1360]

24.4 Critical Review

24.4.1 REACH Compliance - Relation to the REACH Regulation

PZT (lead zirconium titanate) and possibly PLZT (PZT containing lanthanum) are used in the PZT-based ceramics in the scope of exemption 7c-IV. No lead-free ceramic material can currently replace the PZT-based ceramic.

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

[1360] Ibid.

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."*
  This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
- *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."*
  This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

Various entries are listed in the REACH Regulation Annex XVII, restricting the use of titanium and zirconium compounds.

As titanium-related compounds, nickel barium titanium primrose priderite, nickel titanium trioxide and nickel titanium oxide are specified for Annex XVII entry 28, and nickel zirconium trioxide is specified as zirconium-related compound. These compounds are, however, not relevant for the PZT ceramics used in exemption 7c-IV.

No other entries, relevant for the use of substances relevant for the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

24.4.2 Substitution and Elimination of Lead - Specification of the Exemption

STM et al.[1361] justify their exemption request in considerable parts citing the reviewers' conclusions from the 2010[1362] and 2011[1363] exemption review reports. Those conclusions can, however, no longer justify the exemption after five years and more, as the core objective of this review process is to assess the scientific and technical progress. The applicants were therefore asked to show the efforts they have undertaken since the last reviews to find lead-free alternatives. The applicants provide additional information related to the two main application fields, thin film high density capacitors and FRAMs. This information was integrated into the applicant's justification of the exemption.

From the applicants' submitted information, the consultants understand that 3D capacitances (trench capacitors) can be used as a lead-free alternative where the acceptable breakdown voltage is low and the series resistance high. STM et al.[1364] state that "*[…] most electronic needs tend to be compatible with 3D capacitances when the acceptable breakdown voltage is low and the series resistance high*." According to STM et al.[1365], this is valid for applications in which the DC (direct current) supply nominal voltage is a few tens of volts, for instance in computers, telecom equipment, industrial electronics and automotive applications. Since low and high voltages can occur in the same applications/devices, the use of PZT dielectric ceramics integrated circuits and semiconductors cannot be restricted to certain applications/devices. The consultants therefore proposed to restrict the use of PZT ceramics on the component level taking into account the above-mentioned limits of use:

> *Lead in PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors with a nominal voltage of 30 V DC or less and a series resistance of yy Ω or more*

The applicants were asked to comment on the proposed wording and to suggest limits for the series resistance and the voltage limit, which in the above version reflects the status of some years ago.

STM et al.[1366] expressed their disagreement "*with splitting RoHS Exemption No. 7c-IV into multiple sub-sections*." They stated that no possible alternative substance matching PZT dielectric properties can be found at present in the current state of material physics

---

[1361] Ibid.

[1362] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010

[1363] Zangl, Stéphanie, Oeko-Institut e.V. 2011 "Adaptation to Scientific and Technical Progress under Directive 2002/95/EC: Evaluation of New Requests for Exemptions and/or Review of Existing Exemptions," Final Report Oeko-Institut e. V. und Fraunhofer IZM, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IV/RoHS_final_report_May_2011_final.pdf

[1364] Op. cit. STMicroelectronics et al. 2015b 2015

[1365] Op. cit. (STMicroelectronics et al. 2016a)

[1366] Op. cit. (STMicroelectronics et al. 2016b) knowledge. STM et al.[1367] say that they extracted this information from the Oeko Institute Final report - revised version - Freiburg, 28 July 2010: "*Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS)*"[1368] and from Yole: "*Thin Film PZT for Semiconductor - Application trends &Technology update (FRAM, IPDs and MEMS)" – 2013*". They also state that the works led by the Semiconductor Industry are relying on selected materials offered by suppliers, which are evaluated by one of the companies together with the suppliers. The combined results are then evaluated by the industry and after a material is chosen and material development is frozen, a minimum of six years are required to qualify the new material through the whole supply chain.

At the present date, no alternative material has been identified to substitute PZT with equivalent physical properties, even for partial replacement in the involved product portfolio of the IC and discrete semiconductor manufacturers. STM et al. are still six years minimum ahead of any viable substitutive material, without consideration of cost.

STM et al.[1369] put forward that splitting the ICs or discrete semiconductor devices, which include lead in PZT-based dielectric ceramic materials for capacitors into categories defined by a specified voltage or a series resistance value is currently too early, the risk of choosing wrong values by lack of R&D supporting such a split being much too high. STM et al. recall that the Oeko-Institut stakeholder 28/07/2010 report was concluding that "*technically there are no alternatives for integrated MIM like PZT capacitors. PZT is the only material to integrate highest capacitance density with high breakdown voltages on silicon to ensure best filter- and ESD-performance at low leakage current levels. 3d (trench) and BST capacitors cannot fulfil the requirements*."

STM et al.[1370] further assert that the amount of lead entering the EU market annually through applications for which the exemption is requested is much less than 27.5 kg, which applies to the global market, including the MEMS (this value being deduced from the mass of PZT deposited on the wafers). Splitting the exemption into multiple sub-sections would just lead to divide the above mass at planetary level into fragments of a few kg each, with extremely low incremental environmental, health and consumer benefits resulting from such a split.

STM et al.[1371] put into perspective that what was expressed with respect to IPDs, in the Second Questionnaire Exemption No. 7c-IV with response to Oeko sent on February 2, 2016, is only the perspective of a tendency of the application needs to be compatible with 3D (trench) capacitances when the acceptable breakdown voltage is low and the series resistance high. "*In other words, we know for sure that 3D capacitances cannot be*

[1367] Ibid.
[1368] Op. cit. Zangl, Stéphanie [Oeko-Institut e.V.] et al. 2010
[1369] Op. cit. (STMicroelectronics et al. 2016b)
[1370] Ibid.
[1371] Ibid.

used in applications in which the DC supply nominal voltage is several tens volts, without being able to precise a significant voltage threshold at the present time". [1372]

Finally, STM et al.[1373] do not believe that any one company or group of companies can currently define a revised wording splitting the exempted products and ensure that the new wording would account for all required uses of PZT-based dielectric ceramic materials in capacitors which are part of ICs or discrete semiconductors.

24.4.3 Conclusions

The above information in the consultants' view is not plausible. On the one hand, the applicants' information suggests that trench capacitors can be an alternative for low voltage and low series resistance areas even though it is clear that they cannot replace PZT completely at the current state of science and technology. On the other hand they state that they cannot indicate any voltage or resistance limits as it is too early and more research is needed. However, the applicants do not mention any research related to lead-free trench capacitors besides the reference to the Yole report and yet it should be noted that this source does not refer to lead-free alternatives, only to materials with improved capacitance density yet still containing lead. They just mention that a redesign of EEE and components would be required, which would take three to five years.

STM et al. were again asked whether the statement that most electronic needs tend to be compatible with 3D capacitances after such a redesign actually refers to lead-free trench capacitors. STM et al.[1374] confirm that the statement actually is related to the lead-free trench capacitors.

The applicants' information thus suggests that there are areas where lead-free alternatives are possible. The applicants did, however, not provide substantiated and plausible information that would allow either identifying those physical and electrical parameters where lead-free alternatives could be used, or that would otherwise plausibly explain why this is impossible.

Besides the above case, the information submitted by the stakeholders plausibly explains that PZT-based capacitors are actually required in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors. The applicants' exemption request and the answers to the clarification questionnaire were made available through the public online consultation to industry, governments, NGOs and other stakeholders. A questionnaire had been prepared for the public stakeholder consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received. Based on the available

---

[1372] Ibid.
[1373] Ibid.
[1374] STMicroelectronics et al. 2016c "E-mail communication, document "E-mail-Communication_STM_2016-04-01.pdf", received via e-mail from Frederic Chapuis, STMicroelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, until 1 April 2016" unpublished manuscript,

information, the consultants conclude that the complete substitution or elimination of lead is still scientifically and technically impracticable and granting an exemption could therefore be justified by Art. 5(1)(a).

Taking into account the overall situation, the consultants recommend renewing the exemption for three years. As the applicants' information does not allow excluding that the substitution or elimination of lead is scientifically and technically practicable within less than five years, Art. 5(1)(a) would not allow granting the exemption for the maximum five years. A three year validity period would make sure there is sufficient time to apply for the renewal of the exemption on the one hand, and on the other hand to clarify the applicability range of eliminating lead with the trench capacitors, and to take into account recent research results of researchers such as the above-mentioned Dresden Group which according to the applicants has made good progress.

24.5 Recommendation

The applicant's information substantiates that overall the ~~complete~~substitution and elimination of lead is scientifically and technically still impracticable in PZT-based dielectric ceramic materials of capacitors that are part of integrated circuits or discrete semiconductors.

Nevertheless, the applicants' information also suggests that lead-free alternatives may already be available for some components in particular applications. The applicants neither defined those possibilities nor could they plausibly explain why the elimination or substitution is scientifically and technically still impracticable in these cases. Additionally, upon request the applicants report about progress in the research of lead-free dielectric ceramic materials that may allow further progress towards the substitution of lead prior to the next five years.

Appraising the overall situation, Art. 5(1)(a) would allow renewing the exemption. The exemption should, however, only be granted for a maximum of three years since the information provided clarifies that substitution or elimination of lead could be implemented in some cases in a period shorter than five years. This period should suffice to allow clarifying the scope of applications in which substitutes could eliminate the need for lead as well as whether the exemption is still needed for other applications.

<table>
<tr><th>Exemption 7c-IV</th><th>Expires on</th></tr>
<tr><td rowspan="4">Lead in PZT-based dielectric ceramic materials of capacitors being part of integrated circuits or discrete semiconductors</td><td>21 July 2019 for categories 1-7 and 10</td></tr>
<tr><td>21 July 2021 for
· medical equipment in category 8
· monitoring and control instruments in category 9</td></tr>
<tr><td>21 July 2023 for in vitro diagnostic medical devices in category 8</td></tr>
<tr><td>21 July 2024 for industrial monitoring and control instruments in category 9</td></tr>
</table>

24.6 References Exemption 7c-IV

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELV DirectiveEuropean Union. October 21, 2000. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

STMicroelectronics et al. 2015a Request for continuation of exemption 7c-IV, document "7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/7c-IV_RoHS_V_Application_Form_7c-IV_Final.pdf.

STMicroelectronics et al. 2015b Answers to questionnaire 1 (clarification questionnaire), document "Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-IV/Ex_7c-IV_STM_Answer_to_Oeko_questionnaire_2015-09-15_final2.pdf.

STMicroelectronics et al. 2016a Answers to second questionnaire, document "Exe_7c-IV_Questionnaire-2_STM_2016-01-17.pdf", received via e-mail from Frederic Chapuis, STMicroelectronis, by Dr. Otmar Deubzer, Fraunhofer IZM, on 3 March 2016.

STMicroelectronics et al. 2016b Answers to third questionnaire, document "Exe_7c-IV_Questionnaire-3_STM_2016-03-14.pdf", received via e-mail from Frederic Chapuis, STMicrelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016.

STMicroelectronics et al. 2016c E-mail communication, document "E-mail-Communication_STM_2016-04-01.pdf", received via e-mail from Frederic Chapuis, STMicroelectronics, by Dr. Otmar Deubzer, Fraunhofer IZM, until 1 April 2016.

Zangl, Stéphanie [Oeko-Institut e.V.] et al. Adaptation to scientific and technical progress of Annex II to Directive Adaptation Directive2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS) 2010. http://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3_2010_Review_Final_report_ELV_RoHS_28_07_2010.pdf; or https://circabc.europa.eu/sd/d/a4bca0a9-b6de-401d-beff-6d15bf423915/Corr_Final%20report_ELV_RoHS_28_07_2010.pdf.

Zangl, Stéphanie, Oeko-Institut e.V. Adaptation to Scientific and Technical Progress under Directive 2002/95/EC 2011. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IV/RoHS_final_report_May_2011_final.pdf.

25.0 Exemption 8b: “Cadmium and its Compounds in Electrical Contacts”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders unless otherwise stated, and the views presented should not be taken to represent the views of the consultants (authors of this report).

Acronyms and Definitions

AC	Alternating current
Cd	Cadmium
DC	Direct current
EEE	Electrical and electronic equipment
NEMA	National Electrical Manufacturers Association

25.1 Description of the Requested Exemption

The current wording of exemption 8b in RoHS Annex III is

> *“Cadmium and its compounds in electrical contacts”*

Sensata[1375] and the National Electrical Manufacturers Association (NEMA)[1376] et al. apply for the continuation of exemption 8b. While NEMA et al. call for the unchanged

[1375] Sensata Technologies Inc. 2015a “Request for Continuation of Exemption 8b, document "RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf" and document "Sensata_Cd-Exemption-Request_Jan-2015.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf

[1376] NEMA et al. 2015a 2015 “Request for continuation of exemtion 8b, document "8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf": Original exemption request,” National Electrical Manufacturers Association, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf continuation of the exemption, Sensata[1377] proposes the following wording with a specification of the scope[1378]:

> *"Cadmium and its compounds electrical contacts for temperature sensing controls, thermal motor protectors and motor starter relays applied in various end applications"*

In the course of the review process, Sensata[1379] changed their exemption request to:

> *"Cadmium and its compounds in electrical contacts for circuit breakers, thermal sensing controls, and thermal motor protectors"*

Marquardt[1380] contributed to the stakeholder consultation supporting NEMA's exemption request, but proposing the following reformulation of the exemption in case it should not be continued with the current scope and wording:

> *"Cadmium and its compounds in switches of*

- *cordless power tools rated 20 A at 18 V DC and more*
- *corded power tools rated with 1,500 W and more (6A 250VAC, 12A 125VAC)*
- *specialised heavy duty power tools used with high frequency power supplies (200 Hz and more)"*

In the course of the review, a stakeholder, Ubukata submitted information that they shifted their product portfolio of thermal sensing controls and thermal motor protectors to cadmium-free contacts and will have implemented these cadmium-free devices in their customers' products in the course of 2016.

25.1.1 Background and History of the Exemption

The use of cadmium in electrical contacts was already exempted under exemption no 8 in the annex of Directive 2002/95/EC (RoHS 1) when RoHS 1 entered into force in 2003:

> *"8. Cadmium plating except for applications banned under Directive 91/338/EEC amending Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations."*

[1377] Sensata Technologies Inc. 2016a "Answers to questionnaire 2, document "Exe-8b_Questionnaire-2_Sensata_Response_2016-01-22.docx", sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Albert van der Kuji, Sensata: Answers to second questionnaire" unpublished manuscript,

[1378] Sensata had proposed a different wording in its original exemption request, but corrected it in the course of the review.

[1379] Sensata Technologies Inc. 2016c "Answers to third questionnaire, document "Exe-8b_Questionnaire-3_Response_Sensata_2016-02-11.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 11 February 2016" unpublished manuscript,

[1380] Marquardt GmbH 2016a "Contribution to the stakeholder consultation, answers to the consultation questionnaire," Consultation questionnaire, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Marquardt_Questionnaire_Exemption_8b__with_table__4_Publication.pdf

With the Commission Decision 2005/747/EC in October 2005, the exemption wording was changed to:

> *"8. Cadmium and its compounds in electrical contacts and cadmium plating except for applications banned under Directive 91/338/EEC amending Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations."*

The exemption was first reviewed in 2005/2006[1381], and again in 2008/2009[1382] and thus gradually transferred into its current status with a split into exemption 8a and 8b:

> *"8(a) Cadmium and its compounds in one shot pellet type thermal cut-offs Expires on 1 January 2012 and after that date may be used in spare parts for EEE placed on the market before 1 January 2012*
>
> *8(b) Cadmium and its compounds in electrical contacts"*

In the 2009 report, the expiry date 31 July 2014 was recommended for exemption 8b, which was the maximum possible under RoHS Directive 2002/95/EC (RoHS 1) (four years from 2010 on). It was clear that cadmium-free contact materials are available for applications under exemption 8b), but that there are no drop-in replacements. Industry therefore required time to adapt the cadmium-free solutions to their applications and to test them to make sure the cadmium-free contacts suffice in terms of safety and other requirements. The five years from 2009 to 2014 were deemed appropriate to cope with this task, and to ask for specific exemptions should cadmium-free solutions not be feasible in defined cases.

The exemptions in the Annex of RoHS 1 were transferred into the recast RoHS Directive 2011/65/EU (RoHS 2). In the course of that process, the expiry dates of all exemptions with maximum validity duration of four years were systematically extended to five years, but from July 2011 on. This gave industry a total of seven years from 2009 on to substitute or eliminate cadmium in contacts.

25.1.2 Amount of Lead Used Under the Exemption

Sensata[1383] used 920 kg of cadmium in electrical contacts in 2013 and wants to bring down this amount to 350 kg in 2016. NEMA et al.[1384] indicate the amount of cadmium entering the EU market in electrical contacts at less than 10 tonnes and claim the actual

[1381] Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 "Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version"; http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf, page 25 et seqq.

[1382] For details see report of Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 114 sqq.

[1383] Op. cit. Sensata Technologies Inc. 2015a

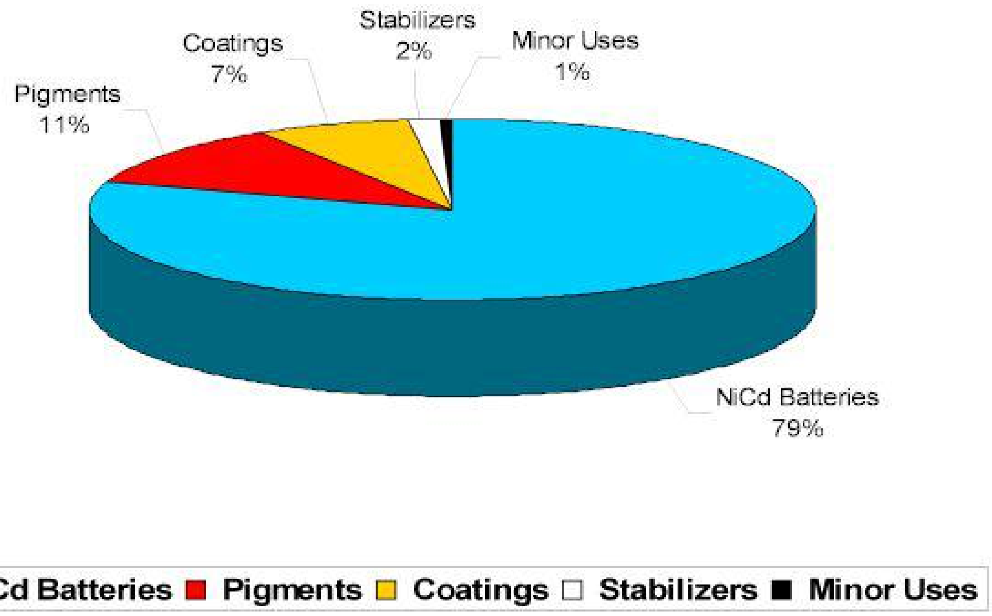
[1384] Op. cit. NEMA et al. 2015a 2015

amount will be much lower as the current estimate is based on worst case, taking into account:[1385]

- The maximum of the tonnage band in the REACH registration dossier; and
- The relative use of cadmium for minor uses, including but not limited to cadmium in electric contact alloys.

NEMA et al.[1386] reference the REACH registration information[1387] for cadmium where the total tonnage band is 1 000 – 10 000 tonnes (17 February 2013). The International Cadmium Association (ICdA) presents relative data on the use of cadmium in applications as follows:[1388]

Figure 25-1: Uses of cadmium



Source: International Cadmium Association, referenced by NEMA et al.[1389]

Cadmium in electrical contacts is considered one of the applications identified under the group of "Minor uses". Considering the maximum values of these data NEMA et al. conclude that 10 tonnes of Cadmium are the maximum amount, which would enter the EU market under the requested exemption.

[1385] Ibid.
[1386] Ibid.
[1387] REACH registration information on cadmium: http://echa.europa.eu/documents/10162/13641/annex_xv_cd_in_artist_paints_en.pdf, ("B.2.1 Manufacture, import and export of cadmium", p. 15); source as referenced by NEMA et al.

[1388] The International Cadmium Association – Cadmium applications: http://www.cadmium.org/pg_n.php?id_menu=9; source as referenced by NEMA et al.
[1389] Ibid.

25.1.3 Technical Description of the Requested Exemption

The technical background of the exemption was described in detail in the report[1390] of the 2008/2009 review of exemption 8b. In the following, only the applicants' main arguments are detailed.

NEMA et al.[1391] explain that cadmium (Cd) is being used in electrical contacts in the form of silver cadmium oxide (AgCdO). Electrical contact materials are used in many electromechanical devices as components, which can carry current intermittently through contact surfaces. In particular, the exemption request is relevant to various EEE making use of electrical contacts, in particular:[1392]

- Electrical contacts used in power switching of electric motors, specifically thermal protectors and switches;
- Electrical contacts used in relays and contactors;
- Electrical contacts in switches for power tools and appliance switches;
- Electrical contacts in circuit breakers for switching equipment; and
- Electrical contacts in power packs, occupancy/time delay sensors, lighting control panels, line voltage switching control devices (1A-20A, 120V AC-480V AC).

The basic properties required for the contact materials are that they should possess high electrical and thermal conductivity, high melting point and good oxidation resistance. The high melting point is required to avoid any accidental overheating because of fusion of the contact points whereas high thermal conductivity helps to dissipate heat effectively. In order to keep the contacts clean and free of insulating oxides, it is essential that the material possesses good oxidation resistance.

NEMA et al.[1393] state that electrical arc erosion plays a crucial role in the reliability and life of power switching devices. Depending on the contact material's behaviour in response to an electrical arc, surface damage can induce severe changes in contact material properties that will impact the power switching device's functioning. Consequently, electrical arc effects and consequences on the contact material surface are of first importance. Welding of contacts could present a safety concern if the contactor cannot open the circuit. Cadmium prevents tack welding, both under severe operation conditions and when the product nears end-of-life. The following characteristics have made cadmium an essential element for contact materials[1394]:

- Superior performance – lasts longer;

[1390] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf, page 114 et sqq.

[1391] Op. cit. NEMA et al. 2015a 2015

[1392] Ibid.

[1393] Ibid.

[1394] Ibid.

- Quenches arcs – resists contact welding;
- Higher conductivity – smaller size of contacts;
- Less contact erosion – essential for critical and safety applications ; and
- Relatively easy to manufacture compared to alternatives.
- According to Sensata,[1395] the following standards govern the requirements for thermal sensing controls, thermal motor protectors and circuit breakers:
- EN/IEC60730-1 Automatic electrical controls - Part 1: General requirements.
- EN/IEC60730-2-2 Particular requirements for thermal motor protectors.
- EN/IEC60730-2-4 Particular requirements for thermal motor protectors for motor-compressors of hermetic and semi-hermetic type.
- EN/EN60730-2-9 Particular requirements for temperature sensing controls.
- EN/IEC60947-1 Low-Voltage Switchgear and Controlgear - General rules.
- EN/IEC60947-2 Circuit-breakers.

25.2 Applicants' Justification for the Continuation of the Exemption

25.2.1 NEMA et al.

NEMA et al.[1396] explain that they have not yet found substitutes offering the same reliability as the exempted application for a number of applications. A number of alternative substances are suggested, of which $AgSnO_2$ is considered the most suitable alternative, particularly for higher switching currents.

NEMA et al.[1397] state that there are no alternative substances for which the capability to extend life and reduce tack welding is as good as cadmium. In addition, typically the entire contactor will need major redesign in order to perform with the alternative substances. Replacement contacts built with alternative contact materials would be larger, requiring larger contactors that may not fit in the space of the original contactor. This could result in disposal and replacement of the entire end-product increasing the volume of products disposed into the waste stream. A drop-in replacement of cadmium with other materials alone is therefore not feasible.

According to NEMA et al.[1398], exemption 8b is still relevant to various EEE making use of electrical contacts, in particular:

- Electrical contacts used in power switching of electric motors, specifically thermal protectors and switches;
- Electrical contacts used in relays and contactors;
- Electrical contacts in switches for power tools and appliance switches;

[1395] Op. cit. (Sensata Technologies Inc. 2016c)
[1396] Op. cit. NEMA et al. 2015a 2015
[1397] Ibid.
[1398] Ibid.

- Electrical contacts in circuit breakers for switching equipment; and
- Electrical contacts in power packs, occupancy/time delay sensors, lighting control panels, line voltage switching control devices (1A-20 A, 120 V AC-480 V AC).

NEMA et al.[1399] state that $AgSnO_2$ semi-refractory tin oxide particles potentially could provide performance properties, especially resistance to contact welding and arc erosion, comparable to those of cadmium oxide. Particular advantages would be: [1400]

- Superior corrosion resistance; and
- Better anti-welding properties;

While disadvantages would be: [1401]

- Rate of contact erosion;
- Higher contact resistance;
- Higher bulk resistance;
- Higher temperature rise; and
- No standard composition.

NEMA et al. [1402] report that in general, the 10 %, 12 % and 15 % (weight) of cadmium oxide grades are replaced with 8, 10 and 12 % tin oxide. To improve the electrical characteristics of the $AgSnO_2$, a range of additional oxides (dopants) can be added, e.g. tungsten oxide, molybdenum oxide, bismuth oxide. Dopants improve the arc-quenching characteristics and prevent the formation of high resistance oxide layers on the surface of the contacts. The particular dopants required depend on the type of switching application of the electrical contact.

NEMA et al.[1403] explain that higher SnO_2 shares increase the welding resistance, contact resistance and hardness, but decrease the conductivity and ductility. Individual manufacturers have tested various alternatives with little success. In the case where substitution is possible the nature of the alternative materials will, however, require redesign of the coils, magnets, armatures and contact springs.

NEMA e al.[1404] admit that Cd-free substitutes are available for some applications. Nevertheless, there remain applications, for which no material other than AgCdO can perform to the necessary safety and performance standards. In NEMA motor control

---

[1399] Ibid.
[1400] Ibid.
[1401] Ibid.
[1402] Ibid.
[1403] Ibid.
[1404] NEMA et al. 2015b “Questionnaire 1 (clarification questionnaire), document" "http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf": Clarification questionnaire,” National Electrical Manufacturers Association, http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf

products (sizes 00-9), transfer switching products, motor hermetic overload relays, bypass contactors, and general purpose power switches for less than 30 A AC or greater than 600 V DC at 600 A, efforts to find a suitable replacement for AgCdO have been largely unsuccessful.

So, NEMA et al.[1405] conclude that, while research regarding Cd-free formulations has led to advances consistent with the goals of the RoHS Directive, this should not be viewed as evidence that viable substitutes for Cd contacts are – or will soon be - commercially available for electrical contacts in all circumstances. The suitability of alternative materials is affected by a range of factors such as voltage, current range, and the required number of cycles associated with the application. This multiplicity of factors leads to a substantial amount of trial-and-error by manufacturers and their suppliers during product development. It also makes it highly impractical to specify with precision the conditions, under which alternative formulations offered by material suppliers are suitable for a particular application. That being the case, Exemption 8(b) should be renewed in its current broadly stated form to allow manufacturers maximum flexibility in product design. Renewing the exemption as it stands will not impede the continued search for Cd-free substitutes.

25.2.2 Sensata

Sensata[1406] [1407] has been aggressively eliminating the use of cadmium oxide in contact systems since 2000 to remain fully committed to the intent of the RoHS directive. Where suitable alternatives have been found to provide comparable cycle reliability and product performance, the contact system is converted to a cadmium-free alternative. Sensata conducts the development of all new products without the use of cadmium oxide contacts. Significant progress has been made finding Cd free alternatives. Nevertheless, the exemption remains necessary for Sensata products which are applied as circuit breakers, temperature sensing controls and thermal motor protectors. Sensata[1408] puts forward that its testing results with substitute materials and design changes has shown that elimination of Cd in contacts in these applications reduces the cycle life, thermal stability, and product performance. This could lead to safety issues for consumers employing safety related products. Therefore it is Sensata’s position that exemption number 8(b) needs to be extended for an additional period with respect to circuit breakers, temperature sensing controls and thermal motor protectors.

Sensata[1409] stated that it has made good progress in its portfolio as illustrated in the below below table.

[1405] Ibid.
[1406] Op. cit. Sensata Technologies Inc. 2015a
[1407] Op. cit. (Sensata Technologies Inc. 2016a)
[1408] Op. cit. Sensata Technologies Inc. 2015a
[1409] Op. cit. (Sensata Technologies Inc. 2016a)

Table 25-1: Sensata substitution of cadmium product history

Sensata Technologies Cadmium Free History Products Effected by EU RoHS					
	2000	2005	2008	2014	2016
No. of Sensata Products that fall under EU RoHS for Cadmium Contacts	73	73	77	73	73
Products with Cadmium Free Contacts	27	39	47	45	62
Products with Contacts containing Cadmium	46	34	30	28	11
Estimated kg of Cadmium in Products Sold Worldwide	1,538	1,456	979	920	350
	Summary of Changes				
No. of Cadmium Free Products	37%	53%	61%	62%	85%
Converted to Cadmium Free		12	4	2	17

Source: Sensata[1410]

However, for certain safety controls using high capacity electrical contact systems, Sensata[1411] still needs cadmium for the reliability of the safety function. Sensata[1412] explains that high capacity is defined, among other criteria, by:

- voltage,
- current,
- type of load (resistive/inductive),
- number of cycles,
- contact pressure, and
- switch velocity, etc.

According to Sensata[1413], it is hard to define criteria limiting the scope of the RoHS 8b exemption due to these multiple criteria, and for this reason it also takes time to find proper alternatives for cadmium replacement. Sensata therefore supports the continuation of exemption 8b) for thermal sensing controls and motor starter relays in its exemption request to provide additional time to make design modifications as required and to qualify silver cadmium oxide replacements with comparable cycle

---

[1410] Op. cit. NEMA et al. 2015a 2015
[1411] Ibid.
[1412] Op. cit. (Sensata Technologies Inc. 2016a)
[1413] Ibid.

reliability, thermal stability, and performance. The additional time is necessary to also obtain approvals in the many different end applications that utilize these temperature sensing control safety products and motor starter relays.

Sensata[1414] reports they have been involved in testing and evaluating silver nickel and silver tin oxide materials as alternatives for the past ten years and has achieved a high number of successful conversions to cadmium-free as shown in Table 25-1 showing that over 85 % of Sensata's portfolio is forecasted to be Cadmium free in 2016. This required a significant amount of product testing that has occurred to reach this conversion rate, which is illustrated as an example for the thermal sensing controls between 2007 and 2014. Executing qualification test plans on over 500 product lots has involved considerable Sensata resources.

Table 25-2: Temperature sensing control product test summary 2007 to 2014

Product Family	Products Tested	No. Qual Builds	Cd Free Materials	Contact Suppliers	Electrical Perf		Cycle Life	
					Groups	No. Pcs	Tests	No Pcs
1 Ø External	6	26	5	5	124	4,092	88	700
1 Ø Internal	7	34	6	5	128	4,174	120	1160
3 Ø Internal	9	77	5	3	286	6,921	282	1692
Total	**22**	**137**			**538**	**15,187**	**490**	**3,552**

Source: Sensata[1415]

Sensata[1416] explains that despite the effort and success, there remain significant hurdles to convert the remainder 15 % of their portfolio:[1417]

5) Only a few suppliers are capable of producing Cd free contacts with the multilayer contact construction required for Sensata's product designs. Each material supplier's $AgSnO_2$ has unique chemistries which cause variations in performance and reliability. This drives the need to test each supplier's custom material and prevents product approvals by material type. Considering the 30 products on the 2008 conversion list, this has created a heavy burden on Sensata's test capacity. The test volume has limited the number of qualification iterations per product.
6) Many of Sensata's products are applied as safety devices and certified by global standard agencies. Besides the relevant European Norm standards (see list of standards in Section 25.1.3) there are similar standards published by agencies such as Underwriter Laboratories (UL) and the Canadian Standards Agency (CSA). Agency standards associated with temperature sensing controls require cycle lifes up to 10,000 cycles minimum with a maximum temperature drift of + 5 °C.

[1414] Op. cit. NEMA et al. 2015a 2015
[1415] Ibid.
[1416] Ibid.
[1417] Ibid.

Cadmium free contacts are faced with increased levels of temperature drift and decreased cycle life creating an obstacle to agency approval.

7) Sensata products also receive agency approval as thermal motor protectors. These are not subjected to specific standard test specifications but must be evaluated by OEM's in the application to verify system safety performance. OEM testing has not been performed for the products that are the reason for this exemption continuation request. There may be specific application conditions, which will be a challenge for Cd free options, but will not be known until products are submitted for OEM approval.

Sensata presents the below high level planning for follow up on phasing out of cadmium in electrical contacts for circuit breakers, temperature sensing controls and thermal motor protectors.

Table 25-3: Time plan for the phase out of cadmium

	circuit breakers	protective controls such as thermal cut-outs and thermal ballast protectors	thermal motor protectors excluding hermetically sealed THERMAL motor protectors
Qualification of Cd-Free Solutions by Sensata	January-2018	January-2018	January-2019
Qualification by Customers of Sensata	July-2018	July-2018	July-2019
Sensata Depletion of Inventory of Cd Contacts	January-2019	January-2019	January-2020
Final Shipment to Customers of Sensata Product Containing Cd in Contacts*	July-2019	July-2019	July-2020
Last European-Market Entry Date**	July-2020	July-2020	July-2021
*For European market.			
**Estimated Last European-Market Entry Date of Goods Manufactured with Sensata Product Containing Cadmium Contacts (not controlled by Sensata).			

Source: Sensata[1418]; products in the third column are thermal sensing controls

25.2.3 Marquardt

Marquardt[1419] manufactures switches for many applications such as household appliances. Only a small portion of the Marquardt power tool switches still need cadmium, for which Marquardt[1420] presents its conversion plan towards cadmium-free power tool switches in Table 25-4.

[1418] Sensata Technologies Inc. 2016d "Answers to fourth questionnaire, document "Exe-8b_Questionnaire-4_Sensata_2016-04-01.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016" unpublished manuscript,

[1419] Marquardt GmbH 2016c "Answer to the first questionnaire to all stakeholders, document"Exe_8b_Questionnaire-1_All-Stakeholders_Marquardt_2016-03-07.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 7 March 2016" unpublished manuscript,

[1420] Op. cit. Marquardt GmbH 2016a

Table 25-4: Conversion plan for cadmium-free switches in Marquardt tools

History: Marquardt cadmium-free contacts used in Powertool Switches						Target		
Affected Powertool Switches								
	2007	2008	2010	2012	2014	2016	2018	2020
Annual number of Powertool Switches sold	29.400.000	28.500.000	27.200.000	29.960.000	30.460.000	30.500.000	32.000.000	33.500.000
Powertool Switches with Cadmium-Free Contacts	27.500.000	26.900.000	26.400.000	29.460.000	29.910.000	30.050.000	31.775.000	33.475.000
Powertool Switches with Contacts containing Cadmium, including spare parts for product repairs	1.900.000	1.600.000	800.000	500.000	550.000	450.000	225.000	25.000
New introduced switch families with AgCdO Contacts	0	0	0	0	0	0	0	0
Estimated Mass (Kg) of CdO in the affected Powertool Switches	16,4	13,8	6,9	4,3	4,7	3,9	2,9	0,9
Ratio of Cadmium Free Powertool Switches	93,5%	94,4%	97,1%	98,3%	98,2%	98,5%	99,3%	99,9%

Source: Marquardt[1421]

Based on the above conversion program, Marquardt[1422] proposes to restrict the scope of exemption 8b for the use of cadmium in power tool switches:

"Cadmium and its compounds in switches of

- *cordless power tools rated 20 A at 18 V DC and more;*
- *corded power tools rated with 1,500 W and more (6 A 250 V AC, 12 A 125 V AC);*
- *specialized heavy duty power tools used with high frequency power supplies (200 Hz and more)"*

Marquardt[1423] states that the exemption is no longer required for most switches in power tools, but that they need five more years to actually implement the more challenging high voltage, high current and high frequency cadmium-free switches in their customers' product portfolios.

Marquardt[1424] claims it needs up to two years for an individual customer with a specific application and a specific switch family. This includes:

- The preparation of testing samples for the customer and qualification of the switch internally at Marquardt;
- Testing of the switch at the customer including testing under real life conditions;

[1421] Marquardt "Answers to consultation questionnaire: Consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Marquardt_Questionnaire_Exemption_8b__with_table__4_Publication.pdf
[1422] Op. cit. Marquardt GmbH 2016a
[1423] Ibid.
[1424] Ibid.

- Optimization with subsequent further testing; and
- After the customers' approval, the preparation of the required documentation and possibly adaptations of the production process.

Marquardt[1425] needs the five additional years to actually implement the cadmium-free solutions for around 200 switch variants from 27 switch families for around 100 different customers worldwide.

25.2.4 Ubukata

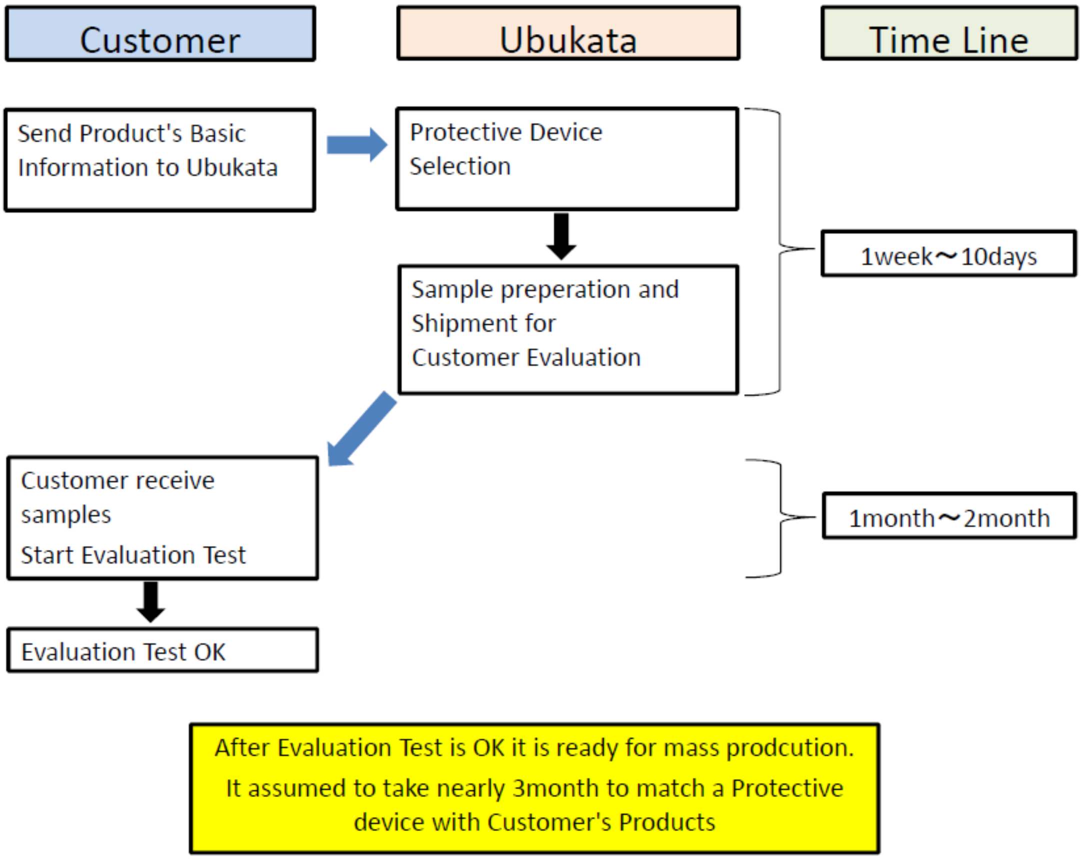
In the course of their investigations, Ubukata Industries, a manufacturer of thermal motor protectors and thermal sensing controls, contacted the consultants. Ubukata[1426] claim they can offer cadmium-free thermal motor protectors and thermal sensing controls that satisfy the IEC/EN60730 safety standards which govern the requirements for these safety-relevant devices (c.f. chapter Technical Description of the Requested Exemption in Section 25.1.3 from page 542). Ubukata[1427] presents an example certificate for a thermal sensing control.

Ubukata[1428] also states that their cadmium-free thermal motor protectors and thermal sensing controls can cover the whole spectrum of market requirements according to those standards as well as all customers' technical requirements. By the end of 2016, Ubukata wants to have implemented its cadmium-free products in its customers' products.

Thermal motor protectors and thermal sensing control need a certificate according to the above mentioned standards. Ubukata[1429] says that depending on the certifying body, it may take up to several months to obtain these certificates, but some certification bodies are faster than others. After that, Ubukata[1430] states it takes around another 3 months to qualify the device with the customers for their products. Figure 25-2 illustrates the various steps and the approximately required times.

[1425] Marquardt GmbH 2016b "E-mail communication, document "E-mail_Marquardt_5-Year-Conversion.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Fiederer, Marquardt, on 18 February 2016" unpublished manuscript,
[1426] Ubukata Industries 2016b "Answers to first questionnaire, document "Exe_8b_Questionnaire-1_Ubukata_2016-02-05.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from A.K. Morshad, Ubukata Industries, on 17 February 2016" unpublished manuscript,
[1427] Ubukata Industries 2016c "Example certificate thermal sensing controls, document"Ubukata_Certificate_Thermal-Sensing-Control.pdf", received via e-mail from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016" unpublished manuscript,
[1428] Op. cit. (Ubukata Industries 2016b)
[1429] Ubukata Industries 2016d "E-mail communication, document "E-mail-communication_Ubukata_Thermal-Sensing-Controls_2016-03-29.pdf", received from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, until 29 March 2016" unpublished manuscript,
[1430] Ubukata Industries 2016e "E-mail communication, document "Time_Protective-Device-Development.pdf", received from A.K. Morshad, Ubukata Technologies, by Dr. Otmar Deubzer, Fraunhofer IZM, on 26 February 2016" unpublished manuscript,

Figure 25-2: Time plan for customer qualification of thermal sensing controls and thermal motor protectors



Source: Ubukata[1431]

Ubukata states that customer qualifications are expected to be finalized in 2016 for the thermal motor protectors as well as for the thermal sensing controls.

25.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

25.3.1 NEMA et al.

NEMA et al.[1432] claim that the methods for manufacture, proprietary or otherwise, of cadmium-free contact materials vary significantly among suppliers, and these methods influence such properties as arc erosion, contact resistance and tendency to weld in service. As part of the qualification on initial samples it is recommended that the user electrically test the materials in a functional manner for all devices applicable to the

[1431] Ibid.
[1432] Op. cit. NEMA et al. 2015a 2015

material's use. Discrete contact parts produced under this guide shall be sampled and tested on a lot basis. This means that extensive testing will be necessary for each supplier in relation to:[1433]

- Voltage;
- Switching current;
- Steady current;
- Switching speed;
- Life cycle;
- Mechanical wear; and
- Environmental;

Because of the potential significant variation in properties from lot to lot, from supplier to supplier, NEMA et al.[1434] state that much more extensive testing will be required as compared to AgCdO. In the process of substitution they distinguish between the following steps:[1435]

- Materials research;
- Testing; and
- Implementation;

NEMA et al.[1436] put forward that the process of substitution will take more time when potential substitutes are found not to be suitable to replace the exempted substance. On the one hand a substitute may fail tests before reaching any stage of implementation. On the other hand substitutes may be successfully implemented at one or more levels in the value chain, but fail when further being integrated in specific equipment or equipment being used under specific conditions. In either case the process of looking into suitable alternative substances shall need to start all over again. As a consequence it may take several years before substitution at the material level will lead to successful implementation in final equipment.

25.3.2 Sensata

Sensata[1437] presents a conversion table (c.f. Figure 25-2 on page 551) for the further substitution of cadmium in electrical contacts, and will continue to examine:

8) Additional potential material sources of supply;
9) Additional material alloys and additives;
10) Contact mating with dissimilar alloys;
11) Alternate contact attachment processes where feasible;
12) Product design modifications where feasible;

[1433] Ibid.
[1434] Ibid.
[1435] Ibid.
[1436] Ibid.
[1437] Ibid.

13) Alternate device series which will require customer re-application and agency re-certification.

25.3.3 Ubukata and Marquardt

Ubukata have converted their thermal sensing controls and the thermal motor protectors to cadmium-free versions. Marquardt presented a plan how to achieve RoHS compliance for its last cadmium-containing switches in power tools (category 6 of RoHS Annex I) until around 2020 (c.f. Section 25.2.3 on page 548) and states that the other switches in their product portfolio are already cadmium-free and qualified for use in all their customers' products.

25.4 Critical Review

25.4.1 REACH

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of cadmium in various articles and uses.

Entry 23 of Annex XVII of REACH restricts the use of Cd in applications. Paragraph 1 regards various materials that can be summarised as plastic materials, thus not relevant for this exemption, which relates to the use of Cd in electrical contacts. Use in metal plating, in brazing fillers and in metal parts (jewellery, beads) is also restricted in later paragraphs, but understood not to be relevant to the application at hand.

Entry 28 and entry 30 in Annex XVII of the REACH Regulation, stipulate that various cadmium compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of cadmium in this application. Cd used in electrical contacts, in the consultants' point of view is not a supply of cadmium and its compounds as a substance, mixture or constituent of other mixtures to the general public. Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would thus not apply.

No other entries, relevant for the use of cadmium in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016).

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. The exemption could thus be granted for this use of Cd if other criteria of Art. 5(1)(a) apply.

25.4.2 Substitution and Elimination of Cadmium

The last review[1438] of this exemption in 2008/2009 showed that cadmium-free materials for electrical contacts at that time had been available already on the market for a while. However, these cadmium-free materials were not drop-in replacements for the cadmium-containing contacts. On the contact manufacturers and the equipment manufacturers' side, it was understood that it required comprehensive testing and evaluation, of the cadmium-free contacts and geometrical adaptations and other redesigns in the contacts and in the EEE, to decide on a case-by-case base, whether and how they are appropriate for the intended application. Cadmium-free switches and relays were on the market and used in EEE for switching medium to moderately high currents. For safety and durability/reliability reasons, the applicants in 2008/2009 stated that AgCdO could not be replaced in most types of electrical switches and circuit breakers. Despite numerous tests over years, it has not been possible so far to replace all cadmium-containing electrical contacts.

The findings from 2009 imply that the transition to cadmium-free contacts on the one hand requires time to implement solutions on the contact level and to realize these solutions in the electrical and electronic equipment of their customers. On the other hand, in particular the higher voltage and higher current area as well as the safety relevant applications of electrical contacts are understood to be the most challenging. They may require even more time, and possibly no solutions might be available for specific cases.

Looking at each applicant's and stakeholder's information individually, Sensata's exemption request is in line with these findings of the last review and as such technically plausible. Sensata showed that they have successfully converted a large portion of their product portfolio and present a conversion plan when to replace cadmium in circuit breakers, thermal sensing controls and thermal motor protectors until 2021.

The same applies for Marquardt who ask to continue the exemption for high current, high voltage and high frequency switches in tools (cat. 6) only, as they have already achieved the full conversion for their other switches.

NEMA et al. request the continuation of Exemption 8b in its current wording for another five years. The technical arguments and the status they describe more or less represents the status and arguments of the last review in 2008/2009. It was clear at that time that cadmium-free alternative materials do not provide the same functions and that they are not drop-in replacements. NEMA et al. do not present any more specific information such as conversion achievements or plans. Thus it is plausible that the transition to cadmium-free contacts may require more time and possibly might be scientifically and technically not yet practicable in particular for high current and high voltage contacts. The applicants' arguments do, however, not justify the general continuation of the exemption request in its current wording for another five years, all the more as other

---

[1438] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009) stakeholders present cadmium-free solutions that may allow the specification of the exemption.

25.4.3 Conclusions

Through the consultation process, the consultants developed the below wording for a tightening of the scope of the current exemption in discussions with NEMA et al.,[1439] [1440] [1441] Sensata,[1442] [1443] [1444] [1445] [1446] Marquardt[1447] [1448] [1449] [1450] and Ubukata[1451] [1452] [1453]:

Cadmium and its compounds in electrical contacts of

a) *circuit breakers*

b) *thermal sensing controls; expires on 21 July 2019*

c) *thermal motor protectors excluding hermetically sealed thermal motor protectors*

d) *switches for electrical and electronic equipment in categories 1 to 5, 7 and 10 of Annex I, i.e.*

[1439] NEMA et al. 2016a "Answers to second questionnaire, document "Exe-8b_Questionnaire-2_Response_NEMA_2016-01-22.pdf", sent via e-mail on 1 February 2016 to Dr. Otmar Deubzer, Fraunhofer IZM, by Mark Kohorst, NEMAS: Answers to second questionnaire" unpublished manuscript,

[1440] NEMA et al. 2016b "Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_NEMA_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Mark Kohorst, NEMA, on 26 February 2016" unpublished manuscript, Answers to first questionnaire to all stakeholders

[1441] NEMA et al. 2016c "Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_NEMA.pdf", received via e-mail from Mark Kohorst, NEMA, by Dr. Otmar Deubzer, Fraunhofer IZM, on 22 March 2016" unpublished manuscript,

[1442] Op. cit. (Sensata Technologies Inc. 2016a)

[1443] Sensata Technologies Inc. 2016b "Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_Sensata_2016-02-26.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 26 February 2016"

[1444] Op. cit. (Sensata Technologies Inc. 2016c)

[1445] Op. cit. (Sensata Technologies Inc. 2016d)

[1446] Sensata Technologies Inc. 2016e "Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-21 SENSATA.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 March 2016" unpublished manuscript,

[1447] Op. cit. (Marquardt GmbH 2016a)

[1448] Op. cit. (Marquardt GmbH 2016b)

[1449] Op. cit. (Marquardt GmbH 2016c)

[1450] Marquardt GmbH 2016d "Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-15_MQ.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 17 March 2016" unpublished manuscript,

[1451] Op. cit. (Ubukata Industries 2016b)

[1452] Op. cit. (Ubukata Industries 2016d)

[1453] Op. cit. (Ubukata Industries 2016e)

i) *AC switches rated at 6 A and more in combination with 250 V AC and more; expires on 21 July 2019*

ii) *AC switches rated at 12 A and more in combination with 125 V AC and more;
expires on 21 July 2019*

iii) *[DC switches rated at 20 A and more in combination with 18 V DC and more]*

iv) *[switches for electrical and electronic equipment conceived to be used with power supplies of 200 Hz and more]*

e) *switches for tools in category 6 of Annex I, i.e.*

i) *AC switches for corded tools rated at 6 A and more in combination with 250 V AC and more,*

ii) *AC switches for corded tools rated at 12 A and more in combination with 125 V AC and more*

iii) *DC switches for cordless tools with a rated current of 20 A and more in combination with at a rated voltage of 18 V DC and more*

iv) *switches for tools conceived to be used with power supplies of 200 Hz and more*

Based on the information submitted and on the technical background from the previous review, the substitution or elimination of cadmium in electrical contacts is in principle scientifically and technically practicable. The applicants' information suggests, however, that substituting cadmium is most challenging in circuit breakers, thermal sensing controls and high power and high frequency switches. More time is needed for adapting designs, to find contact materials, and for qualifying cadmium-free solutions in the supply chain and in the EEE manufacturers' products, since the cadmium-free contact materials are not drop-in replacements. The time for qualification of substitutes according to the qualification procedures applied in specific sectors has been taken into account in the past review rounds of exemptions in line with Art. 5(1)(a) to ensure the reliability of the substitutes.

Generally, Art. 5(1)(a) does not justify granting exemptions to make sure each company has converted its product portfolio to cadmium-free contacts in cases where the substitution or elimination of cadmium in contacts is scientifically and technically practicable. Art. 5(1)(a) allows, however, granting exemptions if more time is required to ensure the reliability of substitutes even in cases where the substitution or elimination of cadmium is scientifically and technically practicable under two conditions: Applicants prove that they are undertaking reasonable efforts to find and implement cadmium-free solutions as soon as possible, and that there are no other producers that can supply and implement reliable cadmium-free solutions. These aspects are considered separately for each type of electrical contact application in the following subsections.

25.4.3.1 Circuit Breakers and Thermal Sensing Controls

The consultants conclude from the applicants' information and in the absence of contrary information that the renewal of the exemption could still be justified for another five years in line with the requirements of Art. 5(1)(a) for circuit breakers in part a) of the above wording proposal.

Ubukata can offer cadmium-free alternatives for thermal sensing controls in part b) of the above exemption wording. The consultants had proposed to exclude the thermal sensing controls covered by the standards EN/IEC60730-1 (Automatic electrical controls - Part 1: General requirements) and EN/EN60730-2-9 (Particular requirements for temperature sensing controls) from an exemption, for thermal sensing controls, possibly with a transition period based on the fact that Ubukata can offer cadmium-free alternatives for these thermal sensing controls. There was, however, an ongoing technical discussion between the applicants[1454] whether and how thermal sensing controls should be differentiated into operating and protective thermal sensing controls. The consultants additionally raised the question, which other thermal sensing controls are in the market besides the ones covered by the standards EN/IEC60730-1 and EN/EN60730-2-9. The stakeholders could not provide clear information on this aspect. Given the considerable efforts undertaken already to restrict the exemption and the limited time and resources available, the consultants could not conclude the technical discussions. Instead, the consultants recommend granting part b) of the exemption for three years. This approach offers the advantage to set an expiry date for all types of thermal sensing controls and leaves time to apply for the renewal of the exemption in specific cases where the substitution or elimination of cadmium would scientifically and technically still be impracticable.

25.4.3.2 Thermal Motor Protectors

Ubukata offers cadmium-free thermal motor protectors, whereas NEMA et al. and Sensata request the renewal of the exemption for these devices for another five years. Several rounds of discussions[1455, 1456, 1457, 1458, 1459, 1460] were held aimed at clarifying the exemption wording. Taking into account the technical situation of cadmium-substitution in thermal motor protectors, the stakeholders, and the consultants agreed on the wording as proposed in part c) of the rewording proposal of NEMA et al.[1461]

1454 Op. cit. (Ubukata Industries 2016d)
1455 Op. cit. (NEMA et al. 2016b)
1456 Op. cit. (Sensata Technologies Inc. 2016b)
1457 Op. cit. (Sensata Technologies Inc. 2016e)
1458 Op. cit. (Ubukata Industries 2016d)
1459 Sensata Technologies/Ubukata Industries "E-mail communication with Sensata and Ubukata, document E-mail-communication_Sensata-Ubukata_2016-03-14.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Sensata and Ubukata on 14 March 2016" unpublished manuscript,
1460 Op. cit. (NEMA et al. 2016c)
1461 Ibid.

This wording proposal takes into account that Ubukata's cadmium-free thermal sensing controls are all hermetically sealed and can therefore be excluded from the exemption, while there is no evidence that other thermal motor protectors have been fully converted to cadmium-free, i.e. ones that are not hermetically sealed.

25.4.3.3 Switches

NEMA et al. requested the continuation of Exemption 8b) in its current wording whereas Marquardt has converted its switches to cadmium-free and states that the exemption is only required for another five years in tools with the specifications listed in part e) of the exemption wording. The consultants therefore propose this wording, which was agreed upon with Marquardt to make sure it adequately covers those applications where more time is required to implement the cadmium-free solutions into the customers' EEE in order to ensure the reliability of the substitutes, which justifies granting an exemption in line with Art. 5(1)(a).

Besides switches for power tools, Marquardt produces a broad range of switches for other applications where exemption 8b) is no longer required. Marquardt[1462] puts this situation into perspective stating that there are definitely other switch applications in the market, which are not covered by the Marquardt product range, but cannot specify them.

Technically, the challenges related to switches in high voltage, high current and high frequency applications are the same for tools and for other applications. In agreement with Marquardt[1463], the consultants therefore propose part d) in the new exemption wording transferring the situation in the power tool sector to other switches. Upon request, Marquardt[1464] provided, however, cadmium-free AC-switches with ratings exceeding the limits of 6 A at 250 V AC or 12 A at 125 V AC where Marquardt no longer requires Exemption 8b).

Taking into account that Marquardt cannot cover the full spectrum of switches outside Cat. 6, the consultants nevertheless recommend a three year transition period for the AC switches in part c), which would leave sufficient time to apply for specific exemptions in case the use of cadmium would still be required for some specific switches.

Marquardt[1465] states that the high power DC switches and the high frequency switches may only be relevant for tools in Cat. 6, but not for EEE in other categories of RoHS Annex I. NEMA et al. were presented Marquardt's examples of high voltage/high current AC switches and asked to comment, and to clarify whether the respective AC and high

---

[1462] Op. cit. (Marquardt GmbH 2016d)
[1463] Op. cit. (Marquardt GmbH 2016b)
[1464] Marquardt GmbH 2016e "E-mail communication, document "E-mail_Marquardt_Cd-free-Switches.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 15 March 2016" unpublished manuscript,
[1465] Ibid.

frequency switches are actually relevant outside category 6. NEMA et al. replied[1466] on 22 March 2016 that there was not enough time to acquire the data needed to respond to the question whether the DC switches in part d) are actually relevant, but "That may change and if so, I will forward any relevant information to you immediately." Until 3 April 2016, there was no further input from NEMA et al. For this part of the exemption there is thus no justification, or it is actually irrelevant. Thus, the consultants recommend to delete this part of the exemption.

25.5 Recommendation

25.5.1 Rewording of the Exemption

Based on the information submitted in the exemption requests, during the online stakeholder consultation and the subsequent review, the substitution or elimination of lead is still scientifically and technically impracticable in several types of devices with electrical contacts, or requires more time to ensure the reliability of the substitutes. Granting an exemption for these cases would thus be in line with the requirements of Art. 5(1)(a). The consultants recommend the renewal of Exemption 8b with the following wording that reflects the current situation of substitution and time requirements for the qualification of cadmium-free contacts noting that this modifies the wording as listed in Section 25.4.2 in line with the judgements made in Section 25.4.3

Exemption 8 (b)	**Expires on**
8(b) Cadmium and its compounds in electrical contacts	*21 July 2021 for medical equipment in category 8 and monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9
8(c) Cadmium and its compounds in electrical contacts of	
I) circuit breakers *II) thermal motor protectors excluding hermetically sealed thermal motor protectors*	*21 July 2021 for categories 1-7 and 10*
III) thermal sensing controls	*21 July 2019 for categories 1-7 and 10*
IV) AC switches rated at 6 A and more in combination with 250 V AC and more *V) AC switches rated at 12 A and more in combination with 125 V AC and more*	*Applies to EEE in* categories 1 to 5, 7 and 10 21 July 2019 for categories 1 to 5, 7 and 10

[1466] Op. cit. (NEMA et al. 2016c)

Exemption 8 (b)	**Expires on**
VI) AC switches for corded tools rated at 6 A and more in combination with 250 V AC and more, *VII) AC switches for corded tools rated at 12 A and more in combination with 125 V AC and more* *VIII) DC switches for cordless tools with a rated current of 20 A and more in combination with at a rated voltage of 18 V DC and more* *IX) switches for tools conceived to be used with power supplies of 200 Hz and more*	*Applies to category 6 EEE* *21 July 2021 for category 6*

25.5.2 Stakeholders' Comments on the Rewording Proposal

Even though the proposal was worked out with the applicants, Sensata[1467] and NEMA et al.[1468] prefer the following alternative rewording:

Cadmium and its compounds in electrical contacts of circuit breakers, thermal sensing controls, thermal motor protectors (excluding hermetic thermal motor protectors), DC switches rated at 20 A at 18 V DC and more, AC switches rated at 6 A 250 V AC - 12 A 125 V AC and more, and switches used at voltage supply frequencies of 200 Hz and more

They are afraid the consultants' rewording worked out with the stakeholders may cause high administrative burdens on their side and foresee further difficulties for market surveillance.

Marquardt agree with the new wording, but "*[...] understand that the use of sub-clauses [...] might increase unnecessarily the related administrative efforts for all stakeholders. Therefore we would recommend to use simple indents or bullet points indicating the various application cases like:*

- *circuit breakers*
- *thermal sensing controls...*"[1469]

[1467] Op. cit. (Sensata Technologies Inc. 2016e)
[1468] Op. cit. (NEMA et al. 2016c)
[1469] Marquardt GmbH 2016f "E-mail communication, document "Marquardt_Drop-Subclauses.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 7 March 2016" unpublished manuscript,

25.6 References Exemption 8b

Carl-Otto Gensch, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

Gensch, Carl-Otto [Oeko-Institut e.V.], et al. Adaptation to scientific and Technical progress under Directive 2002/95/EC 2006.

Marquardt GmbH 2016a Contribution to the stakeholder consultation, answers to the consultation questionnaire. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Marquardt_Questionnaire_Exemption_8b__with_table__4_Publication.pdf.

Marquardt GmbH 2016b E-mail communication, document "E-mail_Marquardt_5-Year-Conversion.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Klaus Fiederer, Marquardt, on 18 February 2016.

Marquardt GmbH 2016c Answer to the first questionnaire to all stakeholders, document"Exe_8b_Questionnaire-1_All-Stakeholders_Marquardt_2016-03-07.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 7 March 2016.

Marquardt GmbH 2016d Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-15_MQ.docx", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, on 17 March 2016.

Marquardt GmbH 2016e E-mail communication, document "E-mail_Marquardt_Cd-free-Switches.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 15 March 2016.

Marquardt GmbH 2016f E-mail communication, document "Marquardt_Drop-Subclauses.pdf", received via e-mail from Klaus Fiederer, Marquardt, by Dr. Otmar Deubzer, Fraunhofer IZM, until 7 March 2016.

NEMA et al. 2015a Request for continuation of exemtion 8b, document "8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/8b_Final_RoHS_Exemption_Renewal_Dossier_2015_01_16.pdf.

NEMA et al. 2015b Questionnaire 1 (clarification questionnaire), document" "http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf" . http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/Ex_8b_NEMA_renewal_response_to_questions_MODIFIED_23_Sept_2015.pdf.

NEMA et al. 2016a Answers to second questionnaire, document "Exe-8b_Questionnaire-2_Response_NEMA_2016-01-22.pdf", sent via e-mail on 1 February 2016 to Dr. Otmar Deubzer, Fraunhofer IZM, by Mark Kohorst, NEMAS.

NEMA et al. 2016b Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_NEMA_2016-02-26.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Mark Kohorst, NEMA, on 26 February 2016.

NEMA et al. 2016c Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_NEMA.pdf", received via e-mail from Mark Kohorst, NEMA, by Dr. Otmar Deubzer, Fraunhofer IZM, on 22 March 2016.

Sensata Technologies Inc. 2015a Request for Continuation of Exemption 8b, document "RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf" and document "Sensata_Cd-Exemption-Request_Jan-2015.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_8_b_/RoHS-Exemptions_Application-Format_Cd_Sensata_20150115.pdf.

Sensata Technologies Inc. 2016a Answers to questionnaire 2, document "Exe-8b_Questionnaire-2_Sensata_Response_2016-01-22.docx", sent via e-mail to Dr. Otmar Deubzer, Fraunhofer IZM, by Albert van der Kuji, Sensata.

Sensata Technologies Inc. 2016b Answers to questionnaire 1 to all stakeholders, document "Exe_8b_Questionnaire-1_All-Stakeholders_Sensata_2016-02-26.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 26 February 2016.

Sensata Technologies Inc. 2016c Answers to third questionnaire, document "Exe-8b_Questionnaire-3_Response_Sensata_2016-02-11.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Albert van der Kuij, Sensata Technologies, on 11 February 2016.

Sensata Technologies Inc. 2016d Answers to fourth questionnaire, document "Exe-8b_Questionnaire-4_Sensata_2016-04-01.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 1 April 2016.

Sensata Technologies Inc. 2016e Answers to second questionnaire to all stakeholders, document "Exe_8b_Questionnaire-2_All-Stakeholders_2016-03-21 SENSATA.docx", received via e-mail from Albert van der Kuij, Sensata, by Dr. Otmar Deubzer, Fraunhofer IZM, on 21 March 2016.

Sensata Technologies/Ubukata Industries E-mail communication with Sensata and Ubukata, document E-mail-communication_Sensata-Ubukata_2016-03-14.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Sensata and Ubukata on 14 March 2016.

Ubukata Industries 2016b Answers to first qustionnaire, document "Exe_8b_Questionnaire-1_Ubukata_2016-02-05.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from A.K. Morshad, Ubukata Industries, on 17 February 2016.

Ubukata Industries 2016c Example certificate thermal sensing controls, document"Ubukata_Certificate_Thermal-Sensing-Control.pdf", received via e-mail from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, on 23 March 2016.

Ubukata Industries 2016d E-mail communication, document "E-mail-communication_Ubukata_Thermal-Sensing-Controls_2016-03-29.pdf", received from A.K. Morshad, Ubukata Industries, by Dr. Otmar Deubzer, Fraunhofer IZM, until 29 March 2016.

Ubukata Industries 2016e E-mail communication, document "Time_Protective-Device-Development.pdf", received from A.K. Morshad, Ubukata Technologies, by Dr. Otmar Deubzer, Fraunhofer IZM, on 26 February 2016.

27.0 Exemption 15“Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages”

Declaration

In the sections that precede the “Critical Review”, the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

ASIC	Application specific integrated circuit
BGA	Ball Grid Array
C4 wafer bumps	Controlled collapse chip connection wafer bumps
DNP	Distance from neutral point
DSP	Digital signal processing (or processor(s))
FCOL	Flip chip on lead (frame)
FCP	(Integrated) flip chip packages
FPGA	Field programmable gate array
FTEOS	Fluorinated tetraethyl orthosilicate
ILD	Interlayer dielectric
PC CPU	Personal computer central processing unit
RoHS 1	Directive 2002/95/EC
RoHS, RoHS 2	Directive 2011/65/EU (recast RoHS Directive)
UBM	Under bump metallization

27.1 Description of the Requested Exemption

Exemption 15 is currently listed in Annex I of the RoHS Directive with the following wording:

> *"Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages"*

Intel et al.[1522], a consortium including producers and users of semiconductors and their associations, apply for the continuation of exemption 15 with restricted scope for the maximum five year validity period with the following wording:

> *"Lead in solders to complete a viable electrical connection between active component(s) and the carrier within integrated circuit flip chip packages with at least one of the following characteristics:*
>
> - *Greater than or equal to 90 nm semiconductor technology node*
> - *Die size greater than or equal to 300 mm² in any semiconductor technology / node (including stacked die)*
> - *Stacked Die Packages using interposers greater than or equal to 300mm²*
> - *High current products (Rated at greater than or equal to 3amps) that use smaller package designs (With die sizes less than 300mm²) incorporating the flip chip on lead frame (FCOL) interconnect."*

27.1.1 Background and History of the Exemption

The exemption was added to the Annex of RoHS 1 in 2005 after a review of the related exemption request[1523] with an expiry date in 2010. The exemption was reviewed in 2008/2009 again, under RoHS 1. The consultants recommended to extend the exemption's validity until 2014, the maximum allowed validity period for exemptions under RoHS 1. Exemption 15 was transferred to Annex I of RoHS 2, and the maximum validity period was extended until July 2016. Since Intel et al.[1524] applied for the renewal of the exemption, it has become due for review again.

[1522] Intel et al. 2015a "Request for continuation of exemption 15, document "15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf": Original exemption request," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf

[1523] (Paul Goodman December 2004) *Technical adaptation under Directive 2002/95/EC (RoHS) - Investigation of exemptions: Final Report*, with the assistance of Philip Strudwick, Robert Skipper, ERA Report 2004-0603, http://ec.europa.eu/environment/waste/weee/pdf/era_technology_study_12_2004.pdf

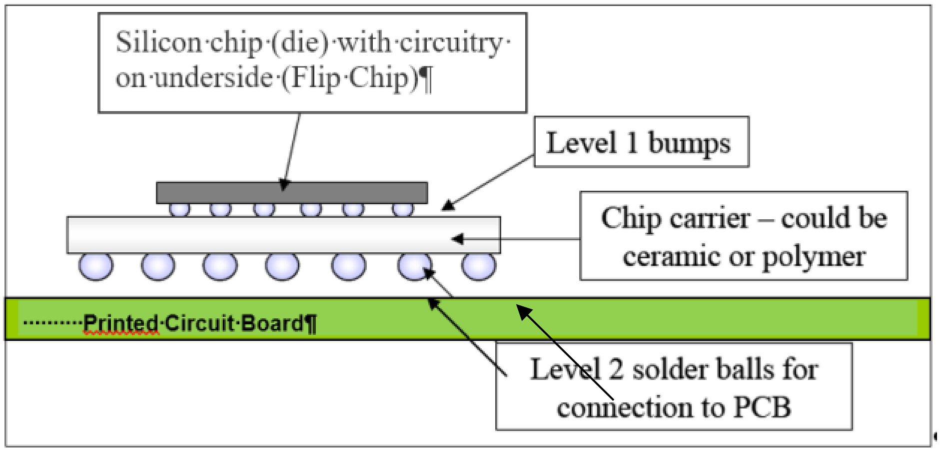
[1524] Op. cit. Intel et al. 2015a

27.1.2 Technical Description of the Requested Exemption

The technical background of the exemption was described in detail in the 2008/2009 review[1525], from which the most important aspects are copied below.

The exemption in its current wording allows the use of leaded solders for level 1 interconnects: the bumps and the solders used to attach the die to the chip carrier.

Figure 27-1: Outline of a flip chip package

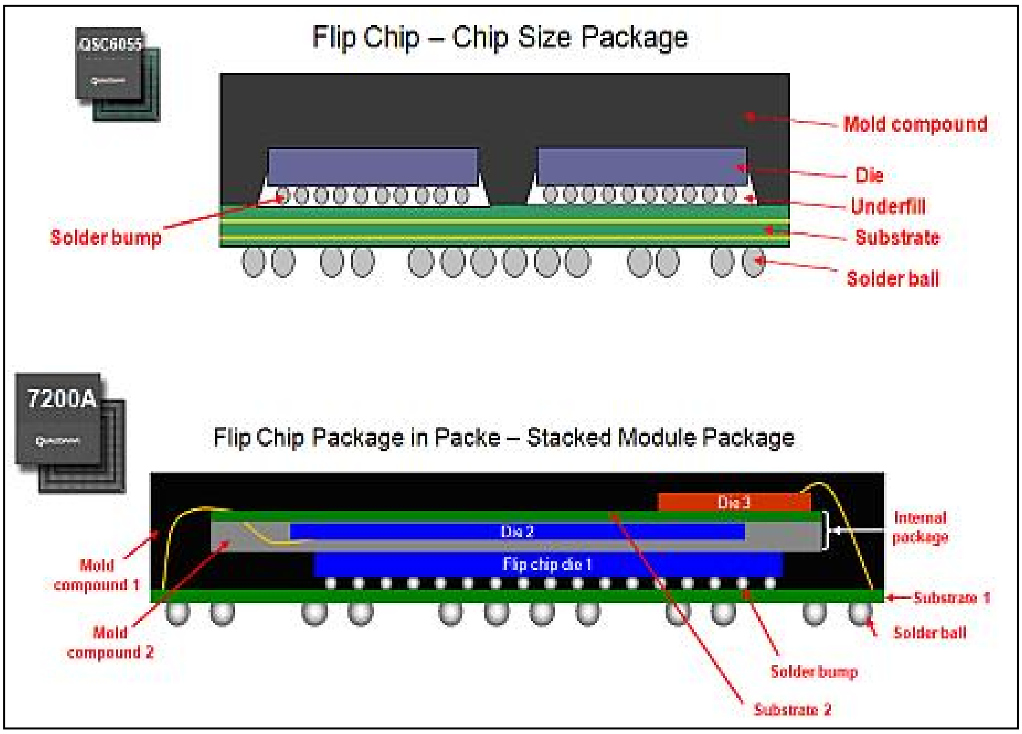


Source: Paul Goodman et al. in Gensch et al.[1526], modified

[1525] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[1526] Ibid.

Figure 27-2: Schematic views of complex flip chip packages



Source: Qualcomm in Gensch et al.[1527]

The flip chip and the chip carrier together form the flip chip package (FCP), as shown in Figure 27-1. These FCPs can be very complex, as shown in Figure 27-2, with different die sizes and die thicknesses.

For the level 2 interconnects, lead-free solders can be used. For level 1 interconnects, different solders are applied:

- High melting point solders with 85% and more of lead (e. g. 97%Pb3Sn, 90%Pb10%Sn);
- Lead-free solders, such as SnAg, Sn3.5%Ag0.7%Cu (SAC);
- gold, copper or gold tin; or
- eutectic solder (63%Sn37%Pb).

The solders used on level 1 in the flip chip connections must be:

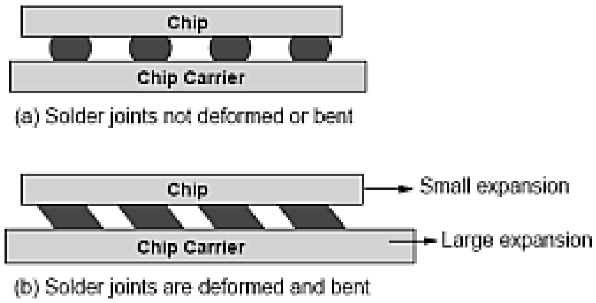
- resistant to electromigration failure at the extremely high current densities required;
- able to create a solder hierarchy that allows staged assembly and rework of components in the manufacture process; and

[1527] Ibid.

- have high ductility to reduce thermo-mechanical stress (Figure 27-3) in under bump metallurgy (UBM) structures in particular in larger dies.

Figure 27-3: Effects of thermomechanical stress in FCP

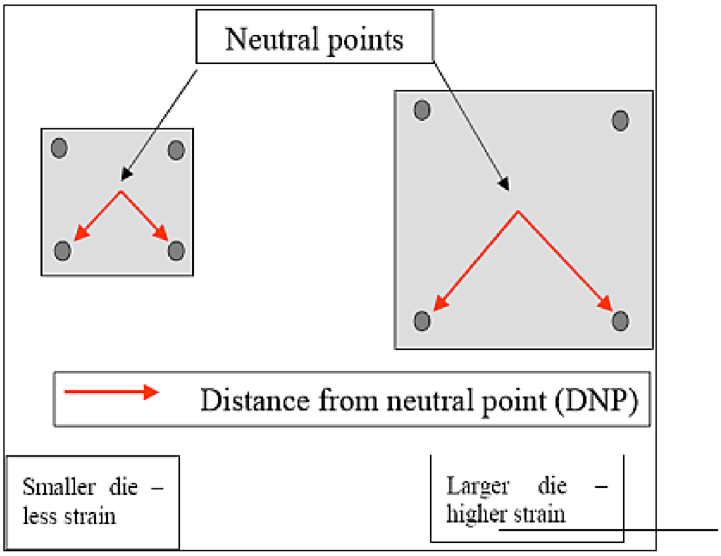
Material	TCE ppm/°C
Silicon	~ 2.5
Ceramics	~ 7
Polymer carriers and PCBs	~ 14



Source: Paul Goodman et al. in Gensch et al.[1528]

The thermal mismatch due to differences in the coefficient of thermal expansion (TCE) of the various materials increases with growing die diagonals. The effects of the TCE become more effective in larger packages. The thermal stress increases with increasing distance of the bumps from the centre of the die (distance to neutral point, DNP), and the most distant bumps thus contribute most to the mechanical stress on the die as illustrated in Figure 27-4.

Figure 27-4: Increasing thermomechanical stress with increasing DNP



Source: Intel et al.[1529]

[1528] Ibid.
[1529] Op. cit. Intel et al. 2015a

A more detailed technical description of the exemption is also available in the 2008/2009 review report[1530] and in the applicant's exemption request.[1531]

Intel et al.[1532] state that currently lead solders are still required for those FCP listed in their new wording proposal for exemption 15.

27.1.3 Amount of Lead Used Under Exemption 15

Intel et al.[1533] estimate the current amounts of lead entering the EU due to exemption 15 at around 900 kg per year. Table 27-1 details the type of devices, worldwide (WW) shipments, and calculated lead placed on the EU market in 2014. The 2008 lead usage estimates are included for reference.

Table 27-1: Shipments of FCP in various types of EEE

Device type	Average Bumps per device in 2014	WW shipments (Million Devices)		Mass of Pb(kg) into EU Markets	
		2008	**2014**	**2008**	**2014**
Server/ Mainframe	10,000	64	40	335	349
PC CPU	3,000	277	0	725	0
Games	3,500	53	0	162	0
DSP	450	23	2.5	10	1
ASIC/ Switch mix	2,000	162	22	353	38
FPGA	2,000	17	2.9	59	5
Graphics Processor	2,000	174	258	607	450
Routers	4000	36	15	63	52
TOTAL				**2315**	**896**

Source: Intel et al.[1534]

Intel et al.[1535] based the lead usage calculation on the following assumptions:

[1530] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 176 et sqq.
[1531] Op. cit. Intel et al. 2015a
[1532] Ibid.
[1533] Ibid.
[1534] Ibid.
[1535] Ibid.

14) An average bump pitch (distance between the bumps) of 150 um;
15) Eutectic tin/lead solder bumps (high Pb bumps, negligible volume);
16) Average bump diameter of 50um;
17) 30% of worldwide shipments are placed on the EU;
18) Volume estimates as obtained from Techsearch International.

Intel et al.[1536] claim that the overall lead usage for this exemption is estimated to have decreased by 61 % since 2008, and it can be seen that PC processors and gaming devices have successfully eliminated leaded solders. The predominant remaining uses of leaded flip chip devices are in servers and graphics processors. Within these devices there is a trend of decreasing dependence on the use of leaded solder. Graphics processor volume increased between 2008 to 2014 from 174 million to 258 million units, while lead usage decreased from 607 kg to 450 kg. The number of server devices using lead FCP is estimated to have decreased from 64 million devices to 40 million devices. Despite the decreased component count, there was a small increase in lead usage in server products due to a 67 % increase in the number of level 1 lead-containing bumps in these devices. The remaining devices using leaded flip chip attach are typically very large chips and/or long lived older integrated circuit technologies for which lead-free designs could not be reliably produced.

Intel et al.[1537] highlight that the electronics industry has demonstrated a strong commitment to develop new lead-free flip chip devices as new technologies with adequate reliability become available. The remaining devices manufactured with lead solders for flip chip attach are expected to continue to decline over the next five years as those products are replaced with newer technology.

Intel et al.[1538] add that, excluding the Flip Chips On Lead frame (FCOL), only a limited number of Pb containing components are in production today, and the volume is in a sharp decline. Even though exact numbers are proprietary, Table 27-2 lists total amounts of lead in 2012, and projected for 2014 and 2015, assuming 2012 volumes of 1,000,000 components containing in average 1.25 mg of lead in flip chips.

[1536] Ibid.
[1537] Ibid.
[1538] Ibid.

Table 27-2: Amount of Lead in FCP other than FCOL

Year	# of Units	Total Amount of Lead
2012	1,000,000	1.25 Kg
2014	200,000	0.25Kg
2015	150,000	0.19Kg

Source: Intel et al.[1539]

Intel et al.[1540] fully expect these volumes to continue to drop as the need to support legacy end products decreases to end of life. As can be seen from the indicative numbers in Table 27-2 the total amount of lead in kilogram for all components is very small. These products are only being supported to meet strict customer design and safety requirements already in place before 2016.[1541]

27.2 Stakeholders' Justification for the Continuation of the Exemption

According to Intel et al.[1542], the following flip chip products cannot meet the long-term reliability requirements with lead-free solder bumps on the dies and therefore need to remain in the scope of the continued exemption 15:

- Flip chip products with transistor gate lengths of 90 nm and longer (older FCP);
- Flip chip products with die sizes of 300 mm² or larger (large FCP);
- Flip chip products with interposers for stacked dies with sizes of 300 mm² or larger (large interposers);
- Flip chips on lead frame packages (FCOL) with rated currents of 3 A or more (high current FCP).

FCOL, according to Intel et al.[1543,1544], consist of products with leads[1545], leadless[1545] and laminate products. Leadless products can be built with lead frames, but the lead frame does not project outside of the package, similar to a ball grid array package.

[1539] Ibid.
[1540] Ibid.
[1541] Ibid.
[1542] Ibid.
[1543] Ibid.
[1544] Intel et al. 2016a “Answers to questionnaire 2, document "Exe-15_Questionnaire-2_Intel-et-al_2016-01-18 Final Response.docx", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel,

Intel et al.[1546] [1547] put forward that flip chips are commonly used in long life, high reliability applications that remain in the field for over 20 years and require continuous availability for replacement parts. Examples are server farms and telecommunication infrastructure. Legacy flip chip devices and many large die devices are older products that have declining volumes year-on-year making it difficult to justify an all-layer and material redesign. Removing these products from the market would create long supply gaps with minimal impact on the amount of lead in the EU market. Pin-for-pin compatibility replacements with devices on more recent silicon technology nodes are not available, potentially resulting in premature replacement of EEE due to lack of repair parts. The elimination of the flip chip lead solder exemption for the applications in this request would result in non-availability of mission critical components.

27.2.1 Lead in Solders of FCP with Large Technology Nodes

27.2.1.1 Technical Practicability of Lead-free Solder Use in FCP

Intel et al.[1548] present Figure 27-5 to explain the persisting problems with lead-free solders in FCP with technology nodes larger than 90 nm.

---

on 6 February 2016: Answers to second questionnaire" unpublished manuscript, Answers to second questionnaire

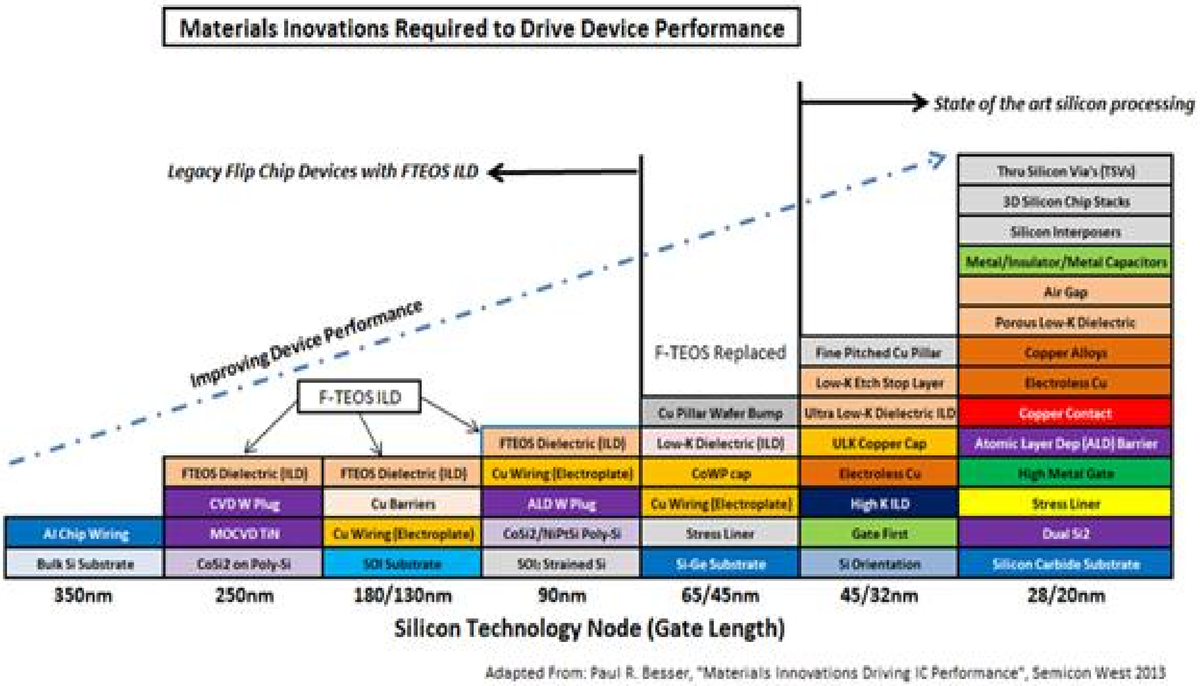
1545 „lead“ does not refer to the chemical element Pb, but to the carrying structure

1546 Op. cit. Intel et al. 2015a

1547 Op. cit. (Intel et al. 2016a)

1548 Op. cit. Intel et al. 2015a

Figure 27-5: Overview of the development of FCP



Source: Intel et al.[1549]

Intel et al.[1550] report that silicon technology nodes with transistor gate lengths longer than 250 nm historically used aluminium interconnects in the wafer processing backend. With further technological advancement, industry had to migrate to copper interconnects due to device performance expectations and increased circuit densities. Devices on the 250 nm to 90 nm technology nodes converted to a common low dielectric constant film (low-k) fluorinated tetraethyl orthosilicate (FTEOS). FTEOS made copper interconnects possible. At the time, FTEOS was a breakthrough in materials engineering and from an electrical perspective it reduced capacitance in the silicon wafer backend dielectric stack. Reducing the resistance of interconnect wiring and the capacitance of the interlayer dielectric (ILD) allows for higher device clock speeds. Dielectric capacitance was significantly reduced with FTEOS when compared to the dielectrics used earlier in the semiconductor industry. The porous nature of the film is what reduces the capacitance. FTEOS offered improved electrical performance, however, at the expense of film mechanical strength.

Intel et al.[1551] state that the low mechanical strength of FTEOS makes it susceptible to dielectric fracturing beneath the under bump metallization (UBM) on the silicon chip

---

[1549] Ibid.
[1550] Ibid.
[1551] Ibid.

(die) with lead-free wafer bumps. This does not occur with lead-containing C4 (controlled collapse chip connection) wafer bumps as illustrated in Table 27-3.

Table 27-3: Failure rates of lead-free and lead C4 bumps in tests

Accelerated Stress	Process	Cycles	Temp Range (°C)	Rate of Temp Change °C/Min (Arbitrary Units)	Control Group Leaded C4 White Bumps (% Fail Units)	Pb-free C4 White Bumps (% Fail Units)
Level 0	After Die Attach	1	STD Pb-free C4 Reflow Temp	2.0 x "Y"	0%	0%
Level 1	MSL3 Reflow	3	STD Pb-free C4 Reflow Temp	3.5 x "Y"	0%	15%
Level 2	Air-to-Air Temperature Cycling (AATC)	*5	Covers Industrial and Commercial Requirements	"Y"	0%	100%

Source: Intel et al. [1552]

Intel et al. [1553] explain that lead-free wafer bumps are significantly less ductile than those containing lead, and the observed failure mode mechanism is driven by mismatch in the coefficients of thermal expansion between the lead-free bump and the FTEOS dielectric. Fracturing of the dielectric with Pb-free wafer bumps is commonly referred to as “ghost” or “white” bumps due to the way they appear in acoustic imaging. Not only can the failure mode reduce assembly yields, it can also adversely impact product reliability. The failure mechanism may not be caught when a unit goes through component assembly and final test. Compromised units that ship are at high risk of failing during the customer’s board level assembly process or in the field. This failure mode does not occur with wafer bumps that contain lead because leaded bumps can absorb the stress associated with the coefficient of thermal expansion mismatch between the silicon chip and the substrate to which the solder attaches.

Intel et al.[1554] explain that more advanced silicon technology nodes, with transistor gate lengths of 65 nm and smaller, completely replaced FTEOS. These replacement technologies are designed to address the stress levels associated with lead-free die solders so that lead solders are no longer required for those FCP unless they use large dies or large interposers of 300 mm² size or larger.

27.2.1.2 Redesign of Older FCP

Intel et al.[1555] focused their lead-free efforts on package redesigns that have increased the overall component’s diameter, thickness and/or ultimate mass compared to the previous Pb containing packages. Since the newer package solutions cannot maintain the form, fit and function of these older FCP, they are not drop in replacements. To maintain form, fit and function, changes cannot be ones that:

- modify the devices height, width or length;

[1552] Ibid.
[1553] Ibid.
[1554] Ibid.
[1555] Ibid.

- change how the connections from the device to the printed circuit board fit together;
- imply significant material changes that can affect the functionality of the device in its current package design.

Going from lead to a non-lead solution is a major material change, and it would also have severe implications on the related processes. Intel et al.[1556] explain that replacing the FTEOS film with another dielectric film in older FCP to enable the substitution of lead would require the entire backend wafer process integration to be re-engineered (e.g. dry etch; photolithography; film deposition; dielectric and copper polishes). Any change in the existing process architecture and materials, however, would cause shifts in electrical characteristics that would force the device to have to be redesigned. Old FCP are, however, products that have declining volume year-on-year making it difficult to justify an all-layer and material redesign.

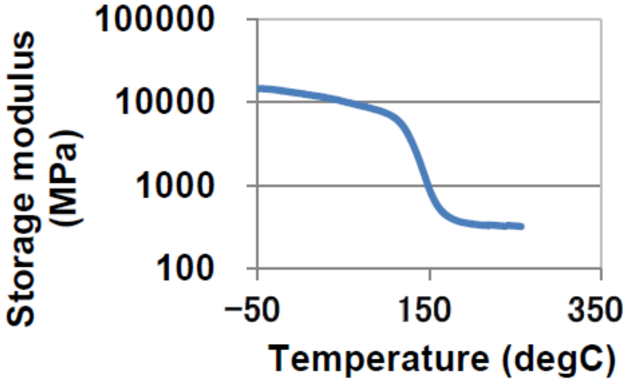
27.2.2 Use of Lead Solders in FCP with Large Dies and/or Large Interposers

27.2.2.1 Use of Lead Solders in FCP with Large Dies

Intel et al.[1557] state that even the advanced silicon technology nodes with 65 nm technology nodes and smaller cannot accommodate the stress levels associated with lead-free die solders when the die size is 300 mm² or larger. According to Intel et al. [1558] such large dies are also still used in the advanced technology nodes. Intel et al. [1559] explain that the package size increases with die size and larger packages impart significantly more strain energy onto the die and solder bump (c.f. Section 27.1.2 on page 585). Large dies with lead-free bumps require a high glass transition temperature (T_g > 120 °C) underfill to prevent solder bumps from cracking during stress tests. Figure 27-6 shows a typical high T_g underfill with a large modulus (> 10 GPa) at low temperature (< 0 °C).

[1556] Ibid.
[1557] Ibid.
[1558] Op. cit. (Intel et al. 2016a)
[1559] Op. cit. Intel et al. 2015a

Figure 27-6: Dynamic mechanical analyses of underfiller with high glass transition temperature



Source: Intel et al.[1560]

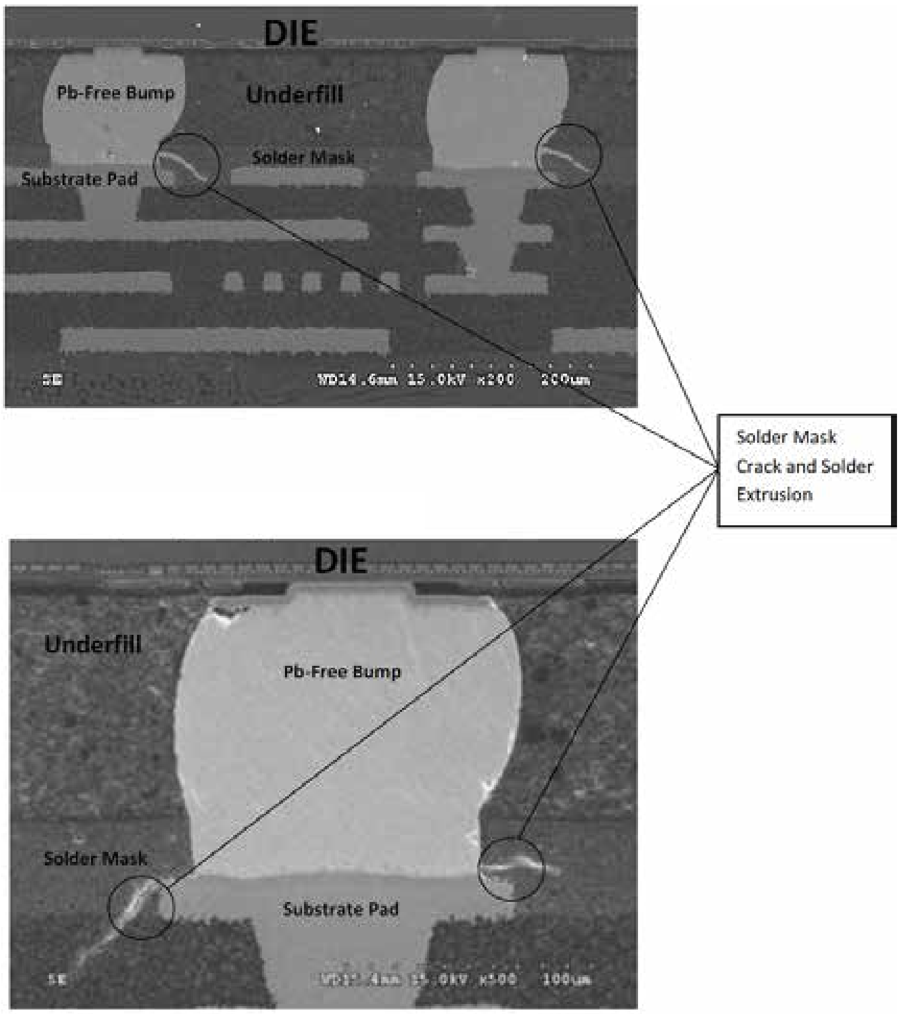
Intel et al. [1561] interpret from the Figure 27-6 stress-strain curve that the storage modulus increases as the temperature decreases, which means that the high Tg underfill becomes very rigid at lower temperatures. The loss of flexibility places strain on the substrate solder mask. The solder mask layer is an organic polymer used for its insulating properties to prevent solder migration. The solder mask ensures a proper connection is made between the solder bump and substrate pad. Figure 27-7 shows that during reliability temperature cycling from -40 °C to -50 °C for large die the solder mask will crack due to the high stress imposed by the high Tg underfill.

Intel et al[1562]. conclude that the failures shown in Figure 27-7 demonstrate that the additional strain from large die increased the failure rate for the solder mask, which adds another variable to the equation in developing a solution to use lead-free solders or any substitute interconnection technology for large dies. Research is still ongoing and more time is needed to find a reliable lead-free solution.

Consequently, lead-free die solder bumps are not compatible with large die sizes even in the most advanced silicon technologies. Large dies with lead-free die solder bumps near the edges and corners will deflect much more thermal and mechanical stress during fatigue cycling which can cause brittle fracture in lead-free bump alloys.

[1560] Ibid.
[1561] Ibid.
[1562] Ibid.

Figure 27-7: Solder mask cracks and solder extrusion in large die FCP



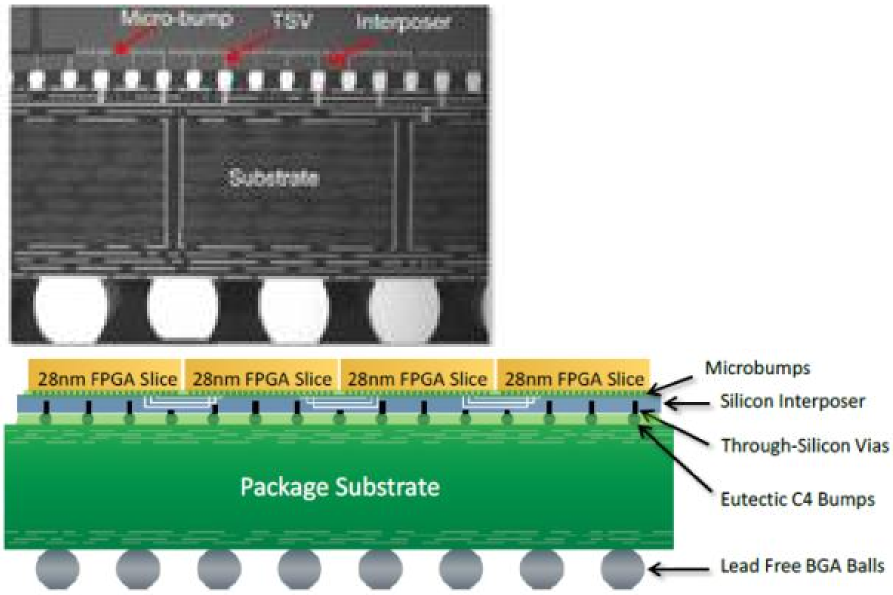
Source: Intel et al.[1563]

27.2.2.2 Use of Lead in Stacked Die Packages with Large Interposers

Interposers are used in stacked die flip chip packages as illustrated in Figure 27-8.

[1563] Ibid.

Figure 27-8: Stacked die FCP



Source: Intel et al.[1564]; TSV: through silicon via

Intel et al. [1565] explain that the schematic side view of a stacked silicon flip chip package, in Figure 27-8, contains four active silicon dies connected to each other through a passive interposer with through silicon via (TSV) using micro-bumps. In this type of package, any number of active dies can be assembled on the interposer and can then be connected to an organic package with C4 bumps. A capillary underfill is used to fill the gap between the micro-bumps and interposer, which helps in reducing the stress in micro-bumps. C4 bumps are created on the interposer backside, which are connected to a package substrate. A second layer of C4 bump capillary underfill is used to fill the gap between the interposer, C4 bumps and the organic package.

Intel et al.[1566] claim that lead-free solders cannot be used with interposers of 300 mm² size and larger. Upon further investigation whether the use of alternative interposers could solve or mitigate this problem, Intel et al.[1567] specify that there are two types of interposers in use:[1568]

- **Silicon interposers**: Silicon interposers are made with standard un-doped wafers, which have extremely high density of connectivity, i.e. more than

---

[1564] Ibid.
[1565] Intel et al. 2016d "Answers to questionnaire 4, document "Exe_15_Questionnaire-4_Intel-et-al_Answers_2016-02-29.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, on 9 March 2016: Fourth questionnaire" unpublished manuscript,
[1566] Ibid.
[1567] Ibid.
[1568] Ibid.

200,000 connections across two adjacent dies. The silicon interposers are thinned and use through silicon vias (c.f. Figure 27-8).

- **Plastic interposers** of many types: Plastic interposers tend to be high density (few hundreds to thousand connections between the dies) and higher cost plastic packages or board technology. They are used as a space transformer to connect to a much lower density and lower cost package board material.

Intel et al.[1569] say that plastic interposers are not suitable for products that require high bandwidth and extremely large connectivity (>10,000 connections) between the two adjacent dies, like for example in flip chip grid array products. The use of interposer materials other than silicon is not feasible because only the silicon processing techniques enable such a high connectivity between the dies.

According to Intel et al.[1570], interposers other than silicon may be used to manage the mechanical stress risk from thermal expansion mismatches between a silicon die product and the plastic package. While lead solders may be used to mitigate the mechanical stress, there are alternative solutions as well. The comprehensive co-optimization of design, materials, assembly process, system integration, handling and assessment of the use environment facilitate the use of lead-free solders even with larger plastics interposers while silicon interposers of 300 mm² and more still require the use of lead solders like the larger silicon dies.

Intel et al.[1571] therefore confine that the exemption is only required for stacked die FCP with silicon interposers of 300 mm² and larger.

27.2.3 Lead in Solders of High Current FCOL

Intel et al.[1572] explain that FCP with high currents of 3 A and more may use dies smaller than 300 mm² incorporating the flip chip on the lead frame (FCOL). The FCOL design moved from traditional wire bond material sets to flip chip package types. Benefits according to Intel et al.[1573] are

1. Reduced package size;
2. Decreased package parasitic current, which is a direct gain in electrical performance;
3. Higher current capabilities.

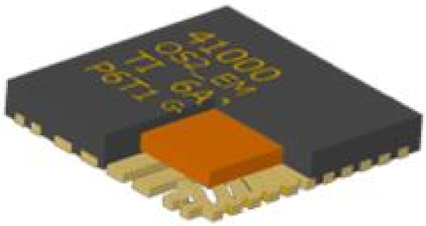
The higher current capabilities of the FCOL packaged products expand the range of applications originally designed for cell phones and mobile devices to applications such

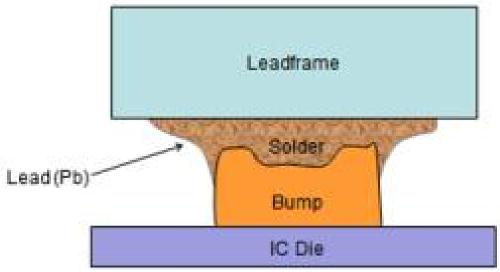
---

[1569] Ibid.
[1570] Ibid.
[1571] Intel et al. 2016e "Answers to questionnaire 5, document "Exe_15_Questionnaire-5_Intel-et-al_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel et al., on 19 March 2016: Answers questionnaire 5" unpublished manuscript,
[1572] Op. cit. Intel et al. 2015a
[1573] Ibid.

as automotive and electronics in general. Figure 27-9 illustrates principle designs of FCOL.

Figure 27-9: Example of FCOL





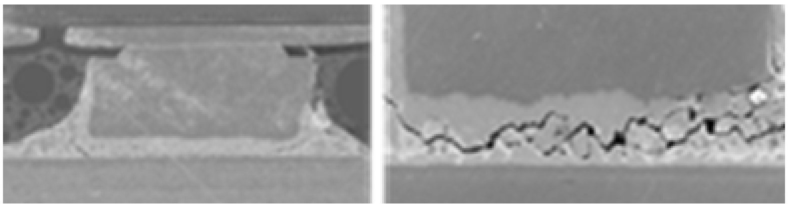
Source: Intel et al.1574

Intel et al.[1575] [1576] state that FCOL packages can be made with the lead[1577] in a ball grid array package or in a lead[1577] frame package. Both require lead (Pb) usage for the same technical reasons such as mechanical integrity, current carrying capability and stability during high temperature reflow. FCOL packages are assembled on a Pb-free profile and the Pb internal solder joint using a 60 % Pb solder does not melt during the secondary 260 °C assembly process. By using the Pb internal solder joint, fatigue resistance to thermal cycling is much greater and resists cracking where Pb-free solutions currently fail. The high current on the bumps that connect the die to the lead frame and the mechanical stress from the CTE mismatch between silicon and copper require the use of lead solders. Lead handles higher mechanical stress better than Pb-free solutions. For the mechanical stress induced within the FCOL package between the copper pillars and the lead frame, the Pb solder solution remains the one capable of meeting the minimal thermal stress requirements.

According to Intel et al.,[1578] working with Pb-free solutions in FCOL products with large copper posts results in fractured joints created during thermal cycling reliability testing, as shown in Figure 27-10.

[1574] Op. cit. (Intel et al. 2016a)
[1575] Ibid.
[1576] Op. cit. (Intel et al. 2016e)
[1577] The "lead" does not refer to the chemical element lead (Pb), but to the carrying and connecting structure in the FCP
[1578] Ibid.

Figure 27-10: Fractured solder joints in FCOL FCP



According to Bastow,[1579] tin, the main constituent of most solders and in particular in lead-free solders, has a strong affinity for alloying with precious metals such as gold. Studies indicate that 63Sn/37Pb at 200 °C (392°F) will dissolve one micron (~40 micro-inches) of gold. As tin reacts with gold, a brittle Au/Sn intermetallic forms. When the concentration is high enough, these intermetallics have a deleterious effect on the thermal fatigue characteristics of the joint, and make it susceptible to fracture during thermal cycling.

Bastow[1580] advises for tin-bearing solders in applications with gold-plated materials to keep the gold layer thin, < 0.38µ (15 micro-inches), thereby reducing the concentration of Au/Sn intermetallics that can form. However, many applications such as optoelectronics packages and defense/space electronics call for thicker gold metallizations. In such scenarios, in which the need for reliability is high, tin-bearing solders are not appropriate.

Bastow[1581] states that unlike tin, indium has a much lower affinity for precious metals and dissolves gold at a rate 13 to 14 times slower than tin. Also, in devices with operational temperatures below 125 °C (257°F), the intermetallic phase that forms between indium and gold is of a much more compliant and ductile nature, and is not susceptible to embrittlement. Therefore, the family of In/Pb solders is beneficial when soldering against thick gold film metallisations. The In/Pb alloys are a solid solution system in which the liquidus and solidus temperatures are close for all compositions (near-eutectic at all compositions). The indium-lead system offers alloys of varying melting points, with indium-rich compositions having a lower melting range, and the lead-rich compositions having a higher melting range. For example, 70In/30Pb has a melting range of 165 to 175 °C (329 to 347°F), and 81Pb/19In has a melting range of 260 to 275 °C (500 to 527°F).

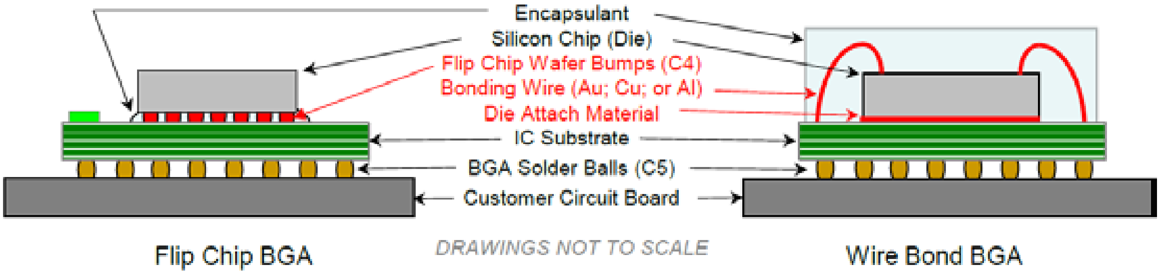
[1579] Eric Bastow, Indium Corp. of America, Utica, New York "Solder Families and How They Work, e-mail: ebastow@indium.com; document referenced by Intel et al. 2015e" unpublished manuscript,
[1580] Ibid.
[1581] Ibid.

Intel et al.[1582] conclude that Pb-based solders have both the creep properties with the highest ability to manage stress as well as achieving the needed current density in high current FCP.

27.2.4 Elimination of Lead in FCP

Intel et al.[1583] explain that FCP were developed from wire bonded BGA. Figure 27-11 shows a comparison between a FCP and a wire bonded BGA.

Figure 27-11: Comparison of FCP and wire-bonded BGA



Source: Intel et al.[1584]

According to Intel et al.,[1585] the lead-containing flip chip bumps replace the bonding wires, but also the die attach material, which is a lead-containing solder (high melting point solder with at least 85 % of lead as exempted in the current exemption 7a). Even if wired bonded components could replace FCP, such a replacement would actually not eliminate the requirement to use lead.

In terms of performance, Intel et al.[1586] state that consumers have expected improvements in both computing power and processing speed (i.e. higher clock rates) over time. Transistor miniaturization and reductions in electrical resistance within semiconductor chips were required to accomplish this. Reduced electrical resistance was achieved in part by minimizing the interconnect wire length between the chip and the package. A repercussion of higher clock rates is increased power consumption by the chip, which the packaged device must dissipate. Flip chip packaging was implemented to facilitate higher clock rates and heat dissipation. For instance, microprocessors that clock between 1.4 GHz and 3.8 GHz must dissipate between 50 and 165 Watts of power over a very small area. Achieving device performance like this is not possible with wire bonding.

1582 Op. cit. Intel et al. 2015a
1583 Ibid.
1584 Ibid.
1585 Ibid.
1586 Ibid.

27.2.5 Other Stakeholder's Contribution

Infinera[1587], a provider of Intelligent Transport Networks (long life and high reliability infrastructure equipment, RoHS Cat. 3) contributed to the stakeholder consultation. Infinera states two key issues that challenge manufacturers of long-lived, high reliability Category 3 infrastructure equipment (like Infinera):

- Relatively short production lifecycles of leading edge semiconductor process technology; and
- Relatively low volume of semiconductor devices designed and built on such process technology.

Infinera's end-to-end packet-optical portfolio is designed for long haul, subsea, datacenter interconnect and metro applications. Infinera state that thier unique large-scale photonic integrated circuits enable innovative optical networking solutions for the most demanding networks.

Infinera[1587] would prefer to keep the current wording of Exemption 15 but, should the wording of Exemption 15 be changed, recommends the exemption expiration "grace period" be extended from the 12-18 months as defined in Directive 2011/65/EU, Article 5, paragraph 6, to a minimum of 36 months.

Ultimately, Infinera[1587] believes there will be little actual difference in terms of direct environmental impact between the original wording and the technically justifiable proposed revision as recommended by the dossier, given the amount of lead contained in typical application specific integrated circuits (ASICs). However, the financial and time impact on the customers of the semiconductor industry will be significant as manufacturers with end of life inventories are suddenly unable to use them unless the Commission extends the expiration date from 12 to 18 months after the date of the decision to at least 36 months after the date of the decision, as recommended above. This will enable a smoother ramp-down of volume production and enable customers to qualify and transition to replacement technologies.

Infinera[1587] believes that 36 months is a far more reasonable timeframe for manufacturers to assess, justify, and fund a project to re-design/re-engineer an ASIC, receive first silicon, test and evaluate it in products, evaluate its reliability, go through customer acceptance qualifications and cut it into volume production. Risk assessments of ASICs and other sole-sourced components always lead to extraordinary redesign costs or difficulties with resource allocation, and tend to result in timeline requirements as set forth here:[1587]

[1587] Infinera 2015 Corp. 2015 "Answer to consultation questionnaire, document "Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf": Answer to consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf

1) Assessment of alternatives: 2 months – this requires obtaining design engineering resources, taking them off current projects, and thereby delaying, new product development (which has a time-to-market cost to the manufacturer). It can therefore take longer than 2 months based on resource availability;
2) Developing and justifying a budget and resource allocation: 1 month;
3) Engineering to tape-out (i.e. design, design verification, sending the design to the foundry): 3-6 months;
4) Receipt of first Silicon: 3-4 months;
5) Functional evaluation and testing: 1-2 months;
6) Reliability evaluation: 3-4 months (may be simultaneous with functional evaluation and testing);
7) Customer review and acceptance: 3-5 months;
8) New component ramp to volume: 3-5 months;
9) Cut-in to revised finished good equipment, ramp to volume: 1-3 months.

Infinera[1587] believes [...] *"a minimum 36-month post-decision timeframe will enable an adequate reduction of business and reliability risks of either transitioning an ASIC or other active device from an existing technology to a replacement technology or customer transition from an existing product to a new product which does not incorporate components using Exemption 15."*

27.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

According to Intel et al.,[1588] the use of lead-free solder bumps in flip chip interconnects continues to be a challenge. Reliability concerns are well documented with the use of lead-free solders because they are less ductile than lead solders. This causes the lead-free solders to crack under stress and increases the likelihood for failures during the product life cycle. Preventing lead-free solder cracks requires additional engineering to improve the thermal and mechanical fatigue life of the solder joints. The primary solution is a load-transfer from the solder to an underfill encapsulant. The residual stress from the underfill can cause other material failures, which most commonly include dielectric crack, delamination, or die crack. Each component must be redesigned and tested several times to obtain the correct formulation needed to protect each layer and the solder joints.

Intel et al.[1589] state that alternatives are readily available for new silicon wafer fabrication technologies and small die sizes. These alternatives typically use copper studs on the die and tin-silver or tin-silver-copper solder on the substrate. These lead-free solders are more rigid than the lead-containing flip chip solder, introducing more stress on the

---

[1588] Ibid.
[1589] Ibid.

products. For older technologies, large die sizes, and large interposers for flip chip stacked die this additional stress ultimately results in an unacceptably high product failure rates. Also for FCOL, industry is working on lead-free solutions, but none have been able to pass the same form / fit / function requirements met by the current Pb flip chip solution.

27.4 Critical Review

27.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The applicants mention indium-lead solders that may be used in the context with FCOL so that Annexes XIV and XVII need to be checked for entries regarding lead and indium.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as a directly added substance nor as a substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds and indium phosphide shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of lead and indium in this application. The use of lead and indium in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead and indium are part of an article and as such, Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

- "shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight." This restriction, however, does not apply to internal components of watch timepieces inaccessible to consumers;
- "shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead or indium in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

27.4.2 Rewording of the Exemption

To simplify and specify the wording, the consultants and the applicant agreed on the below wording[1590] [1591] [1592] including a further restriction of the exemption to large silicon interposers by excluding plastics interposers:

15) Lead in solders to complete a viable electrical connection between the semiconductor die and the carrier within integrated circuit flip chip packages where one of the below criteria applies:

a) A semiconductor technology node of 90 nm or larger

b) A single die of 300 mm^2 or larger in any semiconductor technology node

c) Stacked die packages with a die of 300 mm^2 or larger, or silicon interposers of 300 mm^2 or larger

[1590] Op. cit. (Intel et al. 2016a)
[1591] Op. cit. (Intel et al. 2016d)
[1592] Intel et al. 2016f "E-mail communication, document "E-mail-Communication_Intel-et-al_2016-03-22.pdf", reveived via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, until 22 March 2016: E-mail communication" unpublished manuscript,

d) *Flip chip on lead frame (FCOL) packages with a rated current of 3 A or higher and dies smaller than 300 mm²*

27.4.3 Substitution and Elimination of Lead

The applicants explain plausibly that the substitution or elimination of lead at the current state of the art is not viable for FCP in the scope of exemption parts a), b) and c) as listed in the rewording in Section 27.4.2. The root cause is the mechanical stress due to different coefficients of thermal expansion of the various materials in the FCP resulting in damages of the components. It is plausible that this effect is stronger for larger dies. The dies are made of silicon like the silicon interposers so that the same thermal mismatch issues apply. While larger plastic interposers can be used in combination with lead-free solders, they cannot replace the silicon interposers as only the silicon interposers facilitate very high connectivity rates. It is also plausible that the older FCP with technology nodes of 90 nm and larger cannot be redesigned in order to enable the use of lead-free solders in such FCP.

Differently from the justifications of the other exemption parts, Intel et al. did not provide a proper justification why the use of lead is still necessary in FCOL in part d) of the exemption. It was clearly pointed out to the stakeholders that the justification available in the original exemption request[1593] is not sufficient to justify the requested exemption. Intel et al. were asked three times to provide a sound justification[1594] [1595] [1596]. The applicants were requested to take into account in their answer that "*The justifications for the use of lead in parts 15 b) and c) of the exemption are based on the CTE issues related to large dies or interposers where 300 mm² are a critical size beyond which the use of lead-free solders is currently not possible. Exemption part 15d) would, however, explicitly allow the use of lead with smaller dies. Please justify the use of lead also with respect to the die size. It will otherwise raise questions concerning the plausibility of the technical justification.*"[1597]

"Please make sure you provide a sound overall explanation why lead is required in 15d) despite dies smaller than 300 mm², and take into account the current issue and any other relevant aspects. While the need for the use of lead is plausibly justified in detail for the other parts of exemption 15 related to die sizes, so far we only have a few lines of explanation with a few keywords like CTE, copper lead, current carrying capacity, for 15d). This is not sufficiently detailed and clear to justify the use of lead in 15d) […]. Should we have overlooked any more detailed information, we apologize, but still ask you to answer the above questions."[1598]

[1593] Op. cit. Intel et al. 2015a
[1594] Op. cit. (Intel et al. 2016a)
[1595] Op. cit. (Intel et al. 2016d)
[1596] Op. cit. (Intel et al. 2016e)
[1597] Ibid.
[1598] Ibid.

No information was provided besides what is described in Section 27.2.3 on page 598, which in the consultants' point of view is not sufficiently substantiated to justify the use of lead in this part of the requested exemption.

From the information provided, it is not clear why FCOL actually require the use of lead solders also with dies smaller than 300 mm². It can be concluded that it has to do with the lead frames which makes these components different from the other FCP, but the root causes and context are not further explained. Furthermore, the role of the high currents requiring the use of lead is not explained either. Overall, crucial information is missing that would allow understanding the technical background sufficiently to justify the use of lead in this part of the exemption.

27.4.4 Expiry Date for Older FCP

Based on the information submitted, FCP with technology nodes of 90 nm and larger cannot be designed to lead-free solder use and hence still need lead solders. However, the question arises why such older FCP are still applied in products and whether they cannot be replaced by modern lead-free FCP. On this basis, the extension of the exemption for older FCP is difficult to justify in line with RoHS Art. 5(1)(a) for another five years.

27.4.4.1 Applicants' Arguments for a Five Year Extension

Intel et al.[1599] report that the transition to lead-free on technology nodes of less than 90 nm has been realized between 2008 and 2014 by various suppliers they are aware of. As not all suppliers are on the same timetable for new technology introductions, it is impossible to pick a date that would denote complete conversion by all suppliers. That is not to say that some products did not transition beyond 2014 as well, but that increasing numbers of products were being produced on newer technology nodes by more and more suppliers, and these were being placed on the market with lead-free technology during that timeframe.

The applicants were asked when the big producers (e.g. Intel etc.) started placing lead-free FCP with technology nodes smaller than 90 nm on the market. Intel et al.[1600] replied that the better question is 'what' the companies converted. Just because a company offered Pb-free FC products, this does not equate to them offering replacement products for all existing Pb FC products. Companies had different dates for different die sizes, wafer fabrication processes, reliability requirements, sensitivity to stress, etc. The FC technology is typically used on complex chips that may each provide unique functions or sets of functions. Not all chips have alternatives available on the market – whether Pb or Pb-free.

[1599] Op. cit. (Intel et al. 2016f)
[1600] Ibid.

Intel et al.[1601] continue that it is very difficult to determine conversion timelines for, or among competitors. Companies often announce an initial market entry date for major products, but they tightly guard other roadmap information, such as the date that their very first product was qualified or that their last product converted or will convert from Pb to Pb-free. As part of an industry work-group they have been cautioned against asking these types of questions lest they are accused of collusion. Intel et al. can only ask whether a company is currently using an exemption. They can only assume that they know who will continue to use it based upon those interested in the extension.

According to Intel et al.,[1602, 1603] FCP are used in long life and high reliability products, and older FCP are used in various markets, categories of products listed in RoHS Annex I and component types:[1604]

- Markets:
  - Consumer;
  - Industrial;
  - Automotive and aerospace (out of scope for RoHS).
- Product Types In Scope (Categories 1-7 and 10):
  - Network infrastructure equipment;
  - Telecom equipment, older technology nodes, but with longer product life cycles;
  - Networking and communications equipment;
  - Communications systems;
  - Wireless infrastructure;
  - Storage array systems: both disk and tape systems;
  - Building Control and HVAC;
  - Digital imaging and data storage;
  - Factory automation and drives;
  - Televisual and multimedia equipment;
  - Other undetermined uses within end-products.
- Component types:
  - Microprocessors;
  - Integrated circuits;
  - Chips and memory devices;
  - Controllers.

Intel et al. state that lead-free FCP can provide *most* required electronic functions for *most* products, but put forward that the general availability of the newer technology

[1601] Ibid.
[1602] Op. cit. Intel et al. 2015a
[1603] Intel et al. 2016c "Answers to questionnaire 3, document "Exe_15_Questionnaire-3_Intel-et-al_2016-02-18.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale on 26 February 2016" unpublished manuscript, Answers to third questionnaire
[1604] Ibid.

nodes does not necessarily line up with the design cycles required for many of the above products still utilizing the 90 nm and greater technology nodes. If in a particular application, e.g. the network infrastructure technology, modern FCP were not available until 2012 in the newer technology nodes, the companies providing those finished products into the market would already have been into at least two additional design cycles based on the older technology. This means those finished products (infrastructure equipment) would not be placed on the market until 2015 / 2016 and would continue to be sold for at least five to seven years and for some applications ten to fifteen years beyond introduction.

27.4.4.2 Critical Review of the Stakeholders' Arguments in Relation to Expiry Date

The applicants' above arguments need to be evaluated against the stipulations for exemptions in RoHS Art. 5(1)(a) and the review practices applied in the past in alignment with the European Commission.

- **Use of FCP in long life and high reliability electrical and electronic equipment**
  Intel et al. claim that FCP are used in long life and high reliability products. However, they mention products like mobile phones that use FCP, and consumer products as a general category of electrical and electronic equipment (EEE) that uses FCP. Consumer products can thus be assumed to at least be one part of the market for FCP, where most EEE are neither long life nor high reliability products. Concerning automotive applications, these are not in the scope of the RoHS Directive but are separately governed by the End of Life Vehicle Directive. Intel et al.[1605] insisted that there are many applications such as server farms and telecommunication infrastructure that utilize flip chip technologies and these are both long life and high reliability. Though the information submitted suggests that FCP certainly are also used in high reliability and long life products, it can also be understood that there are many other products with shorter life cycles that use FCP. It can be assumed that these markets are the mass markets for FCP not excluding that some specific FCP are mainly applied in long life and high reliability applications, which would, however, justify a specific extension of the exemption for certain products rather than a general renewal for all EEE in the scope of the RoHS Directive.

- **Technical practicability of using modern FCP to substitute old FCP**
  Intel et al.[1606] state that lead-free FCP can provide *most* required electronic functions for *most* products. In the consultants' point of view, this statement

[1605] Op. cit. (Intel et al. 2016a)
[1606] Ibid.

of Intel et al. is correct for the current product designs still using old FCP, but modern FCP must be applicable in all products, even though not as a drop-in solution, but after a redesign to accommodate the geometrical, mechanical, electronic requirements related to the use of such modern FCP. If modern FCP could not provide all required functions for all products, the volumes could not decline from year to year until they finally disappear from the market, but continuous further production of such old FCP would be required until the products they serve would no longer be needed.

- **Availability of Modern FCP and Redesign of EEE to Enable the Substitution of Lead**

The applicants indicate that the various FCP manufacturers transitioned to lead-free technology nodes of less than 90 nm between 2008 and 2014, and that some products might have transitioned beyond 2014 as well. In light of RoHS Art. 5(1)(a) and the past review practices, the crucial question is not when the last supplier had transitioned to lead-free FCP, but when the substitution of lead became scientifically and technically practicable. This had been the case from 2008 on. It is the applicants' obligation to provide all information substantiating the exemption request. The applicants did not provide any specific information on specific FCP that had not been available on the market. The reviewers therefore act on the assumption that after 2008 and before 2014 modern FCP were sufficiently available on the market to allow the replacement of older FCP, even though only after a redesign of the EEE into which they are applied.

RoHS Art. 5(1)(a) requires producers to change product designs if this enables the substitution or elimination of lead, where this is scientifically or technically practicable. Two to eight years have passed since modern FCP have become available on the market. While the applicants argue that this time line does not fit their product cycles for some of their products, the question arising from the RoHS perspective is whether and how far manufacturers can adapt their product cycles to the availability of lead-free alternatives. FCP producers and their customers should exchange information about when lead-free alternatives become available and the EEE producer could, within certain limits, postpone the next redesign cycle accordingly. In case another supplier offers lead-free FCP earlier than their supplier, they can also be expected to change to the other supplier. Besides technical practicability, the substitution of lead in applications covered by exemptions is also a competitive issue. The example EEE producer mentioned by the applicants being in two product redesign circles already when lead-free FCP became available in 2012 could have possibly better aligned the timing of the redesign cycle and thus have avoided redesigning the EEE with FCP that have to rely on the renewal of exemption 15.

Furthermore, the applicants put forward that this example EEE producer would continue to sell this equipment with old FCP for at least five or seven years or even up to 15 years beyond introduction. In the past exemption review rounds, manufacturers of EEE were allowed sufficient transition time to implement RoHS-compliant solutions in their products once such solutions became available. This transition time is, however, aligned with the time to redesign products and to qualify such RoHS compliant solutions according to the state of the art standard qualification procedures of the respective sectors. Transition times have not been recommended to allow EEE producers to place EEE on the market benefitting from an exemption in the presence of RoHS-compliant solutions that show that the substitution or elimination of the restricted substance in the scope of the exemption is scientifically and technically practicable.

27.4.4.3 Expiry Date

The information available clearly suggests that modern FCP are available to replace old FCP. There has been sufficient time since at the latest 2014 and most probably much longer for most products to be redesigned and replaced with new products and thus to switch to lead-free FCP. In this situation, continuing the exemption for five years would not be in line with RoHS Art. 5(1)(a). Nevertheless, the consultants are aware that some products might require more time than others. The consultants therefore recommend the expiry of that part of the exemption covering the old FCP on 21 July 2019. Should there be need for specific products in the scope of the RoHS Directive to renew the exemption for older FCP beyond 21 July 2019, there is time until 20 January 2018 to request the renewal of the exemption for such specific cases.

Intel et al.[1607] say they understand this approach, but do not agree stating that there are too many variations of products across varying market segments that require this older technology so that the industry will most surely be requesting extensions for the broader industry and not on an application specific basis.

Intel et al.[1608] mention that since many FCP products are used in high reliability applications, even if the exemption is limited to large die size and older technologies, those FCP small die in new technology applications no longer under the exemption would need at least 36 months for customer qualification and supply chain transition. To eliminate this exemption for all devices prematurely would have significant socioeconomic risks associated with early retirement of critical technologies, placing EU countries at a competitive disadvantage. In the consultants' opinion, this early retirement of critical technologies cannot occur as on the one hand the old FCP can still be used for repair and upgrade of EEE placed on the market prior to the expiry of the

[1607] Op. cit. (Intel et al. 2016c)
[1608] Op. cit. (Intel et al. 2015a)

exemption. On the other hand, granting an appropriate transition period should enable producers of EEE to prepare their products for the use of modern FCP.

Infinera[1609], a provider of Intelligent Transport Networks (long life and high reliability infrastructure equipment, RoHS Cat. 3) supports this 36 month transition period as described in Section 27.2.5 on page 602 stating that 36 months will enable the transition to RoHS compliant product.

The consultants conclude from these statements that a 36 month transition period until July 2019 is realistic and reasonable to accommodate the needs of long life high reliability equipment. Any longer period would require a sound justification taking into account why the producers that need more time have not started the transition earlier already when the modern lead-free FCP have become available.

27.4.5 Expiry Date for FCP with Large Dies and Large Silicon Interposers

Based on the information available, it is plausible that lead is still required in those FCP in the scope of parts b) and c) of the requested exemption. The applicants indicate that further research is needed to make the use of lead-free solders scientifically and technically practicable. The applicants' exemption request and the answers to the clarification questionnaire were made available through the online consultation to the public (i.e. to industry, governments, NGOs and other stakeholders) and a consultation questionnaire had been prepared with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received, and there were no hints that lead-free solutions would be foreseeable for the FCP with large dies and large interposers. It is therefore recommended to grant the exemption for another five years. Granting the exemption for another five years would therefore be in line with the requirements of Art. 5(1)(a).

27.4.6 Lead Solders in High Current FCOL

Despite several requests to do so, the applicants did not provide a substantiated justification why the use of lead is required for the high current FCOL in part d) of the proposed new exemption wording. The consultants can therefore not recommend to grant the requested exemption for these FCP. RoHS Art. 5(6) requires providing a transition period of 12 to 18 months in this case.

In the absence of a sound justification, the consultants cannot conclude that an exemption would be justified according to the criteria specified in Article 5(1)(a). The

[1609] Infinera 2015 Corp. 2015 "Answer to consultation questionnaire, document "Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf": Answer to consultation questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf transition period is left to the COMs decision. Should the exemption actually still be required, a 12 to 18 month transition period might not be sufficient.

27.4.7 Conclusions

The applicants showed that FCP with technology nodes of 90 nm and larger cannot be designed to accommodate the properties of lead-free solders. They can, however, be replaced by modern FCP with technology nodes of less than 90 nm, in which lead can be substituted. It is therefore recommended to renew the exemption until 21 July 2019 to allow industry time to adapt to using FCP with smaller nodes.

For FCP involving large dies or silicon interposers of 300 mm^2 and more, it is recommended to renew the exemption for the maximum period of five years as no alternatives are foreseeable to substitute or eliminate the use of lead.

For FCOL, the stakeholders did not adequately substantiate their exemption request to justify the continued use of lead despite several requests to do so. In the absence of a sound justification, the consultants cannot conclude that an exemption would be justified according to the criteria specified in Article 5(1)(a). In cases where exemptions are not renewed even though the renewal has been requested, RoHS Art. 5(6) foresees a transition period of 12 to 18 months. The transition period is left to the Commission's decision. Should the exemption actually still be required, a 12 to 18 month transition period might not be sufficient. The FCOL-related exemption is added to the below recommendation for exemption 15 with the wording as agreed upon with the stakeholders, but without an expiry date.

27.5 Recommendation

Based on the available information, the reviewers recommend the renewal of the exemption with an amended wording and with the following expiry dates:

Exemption 15	Expires on	Comments
I) Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages	*21 July 2021 for medical equipment in category 8 and monitoring and control instruments in category 9*	
	21 July 2023 for in vitro diagnostic medical devices in category 8	
	21 July 2024 for industrial monitoring and control instruments in category 9	
II) Lead in solders to complete a viable electrical connection between the semiconductor die and the carrier within integrated circuit flip chip packages where one of the below criteria applies:		
a) *A semiconductor technology node of 90 nm or larger*	*21 July 2019 for categories 1-7 and 10*	
b) *A single die of 300 mm² or larger in any semiconductor technology node*	*21 July 2021 for categories 1-7 and 10*	
c) *Stacked die packages with dies of 300 mm² or larger, or silicon interposers of 300 mm² or larger*	*21 July 2021 for categories 1-7 and 10*	
d) *Flip chip on lead frame (FCOL) packages with a rated current of 3 A or higher and dies smaller than 300 mm²*		The exemption cannot be recommended but is added here in case the Commission would decide that it should be granted

27.6 References Exemption 15

Eric Bastow, Indium Corp. of America, Utica, New York Solder Families and How They Work, e-mail: ebastow@indium.com; document referenced by Intel et al. 2015e.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

Goodman, Paul 2004 Technical adaptation under Directive 2002/95/EC (RoHS) - Investigation of exemptions: Final Report. With the assistance of Philip Strudwick, Robert Skipper. ERA Report 2004-0603. http://ec.europa.eu/environment/waste/weee/pdf/era_technology_study_12_2004.pdf.

Infinera 2015 Corp. Answer to consultation questionnaire, document "Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/Ex_15_Infinera_Comments_on_Extension_10-15-2015.pdf.

Intel et al. 2015a Request for continuation of exemption 15, document "15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_15/15_12-01-15_WG15_Exemption_Extension_Dossier_-_Final.pdf.

Intel et al. 2016a Answers to questionnaire 2, document "Exe-15_Questionnaire-2_Intel-et-al_2016-01-18 Final Response.docx", received by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, on 6 February 2016.

Intel et al. 2016c Answers to questionnaire 3, document "Exe_15_Questionnaire-3_Intel-et-al_2016-02-18.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale on 26 February 2016.

Intel et al. 2016d Answers to questionnaire 4, document "Exe_15_Questionnaire-4_Intel-et-al_Answers_2016-02-29.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, on 9 March 2016.

Intel et al. 2016e Answers to questionnaire 5, document "Exe_15_Questionnaire-5_Intel-et-al_2016-03-13.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel et al., on 19 March 2016.

Intel et al. 2016f E-mail communication, document "E-mail-Communication_Intel-et-al_2016-03-22.pdf, reveived via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Tisdale, Intel, until 22 March 2016.

30.0 Exemption 24 “Pb in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

CTE	coefficient of thermal expansion
CCTV	closed circuit television, video surveillance systems
EMI	electromagnetic interference
HMPS	high melting point solders
LHMPS	lead-containing high melting point solder(s)
MLCC	multi-layer ceramic capacitors

30.1 Description of the Requested Exemption

Knowles et al. [1693] apply for the continuation of Exemption 24 in its current wording and scope. The current wording of Exemption 24 is

> *“Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors”*

[1693] Knowles Capacitors et al. 2015a: 2015 “Request for continuation of exemption 24, document "24_RoHS_V_Application_Form_E24_final_160115.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/24_RoHS_V_Application_Form_E24_final_160115.pdf

30.1.1 Background and History of the Exemption

The exemption was not yet listed in the Annex of RoHS 1 when it was published in 2003. The exemption was requested and reviewed in 2005/2006, and the Commission followed the reviewers' recommendation[1694] to grant the exemption with the same wording and scope as still valid in the current exemption. The exemption was renewed without changes after the next review in 2008/2009[1695], and was adopted into Annex III of RoHS 2 in 2011. Its foreseen expiry date would have been July 2016 if no requests for renewal had been submitted.

30.1.2 Technical Description of the Exemption

Knowles et al.[1696] use indium-lead solders with 40 % to 50 % lead content (In60Pb or In50Pb, the latter being the preferred alloy), which provides the combination of a suitable melting point and ductility. The ductility of this solder avoids cracking of the ceramic layer during and after soldering due to thermal mismatch between the ceramic capacitor and the copper pin.

Knowles et al.[1697] explain that discoidal and planar array capacitors are derivations of MLCC's (multi-layer ceramic capacitors) with the opposing terminations made to the outside periphery and the inside diameter of holes drilled through the ceramic body. They are specialist capacitors used in EMI (electromagnetic interference) filters and EMI filtered connectors for high end applications, where the elimination of electrical interference is critical. Typical applications for assemblies incorporating these components and covered by the RoHS directive include professional audio equipment, maritime monitoring (coastguard radar) and CCTV (closed circuit television, video surveillance) systems. In application, signal carrying feedthrough pins are passed through the ceramic element and connected to the internal bore to make a mechanical and electrical connection. This connection must have low electrical resistance and inductance for optimum performance, as high resistance / inductance will inhibit the high frequency electrical path to ground through the filtering capacitor. Traditionally this connection is made by lead solder, as lead-free solders cause cracks in the ceramic element.

[1694] Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 "Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version, RoHS I," http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf page 14 et sqq.

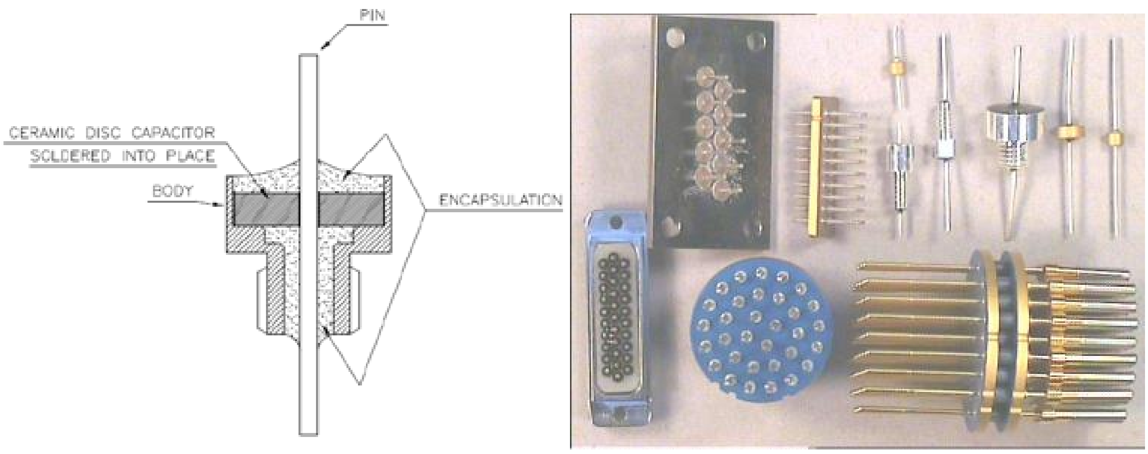
[1695] Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009) Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III, with the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V., and Otmar Deubzer, Fraunhofer IZM, http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf

[1696] Knowles Capacitors et al. 2016a "Answers to Second Questionnaire, document "Exe_24_Questionnaire-2_Knowles-et-al_Response_2016-02-09.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Stephen Hopwood, Knowles Capacitors, on 9 February 2016" unpublished manuscript,

[1697] Op. cit. Knowles Capacitors et al. 2015a, page 214 et sqq.

Knowles et al.[1698] as component suppliers are not aware of all applications where this product is used, but in general it is for high end applications where performance is more important than cost. They are not generally used in low cost consumer electronics. Knowles et al. include category 11 to cover unknown applications. Figure 30-1 shows EMI filters as one typical application in the scope of exemption 34.

Figure 30-1: EMI filter outline (left) and examples of EMI filters and assemblies



Source: Knowles et al.[1699]

A detailed description of the technical background can be found in the report of the last review in 2008/2009.[1700]

30.1.3 Amounts of Lead Used under the Exemption

According to Knowles et al.[1701], the lead content varies with filter design, but typically is 5 mg to 10 mg per solder joint, equating to ~1.0 % of the total component weight (maximum). More complex designs such as filter connectors will be proportionally less as a percentage of the total weight. The total amount of lead put on the EU market under the exemption is estimated to be less than 50 kg as quantified from the information in the following paragraphs.

1698 Ibid.
1699 Knowles Capacitors et al. 2015b: “Addendum to request for continuation of exemption 24, document "Application Note AN0011 Solder Alloy Choice for Through Hole Ceramic Discoidal & Planar Array Capacitors.pdf": Addendum to request for continuation of exemption 24,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Application_Note_AN0011_Solder_Alloy_Choice_for_Through_Hole_Ceramic_Discoidal__Planar_Array_Capacitors.pdf
1700 Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009)
1701 Op. cit. Knowles Capacitors et al. 2015a

Knowles et al.[1702] have no accurate data available to indicate the amount of lead entering the EU in this type of application, however most applications of these components are not covered by the RoHS directive. There are two major players in the supply of planar arrays for EMI filtered connectors, and customers informed Knowles et al. that they account for ~60 % of the market. The average manufacturing of Knowles et al.[1703] is 357,000 capacitive holes per week, amounting to 18.6 million capacitive holes per year, indicating the market is around 31 million capacitive holes per year. The nature of these components is such that they are mainly used for high end applications such as aerospace and military, where technical performance outweighs cost. Knowles et al.[1704] estimate from feedback that only around 4 % of parts are supplied into applications covered by the RoHS directive, corresponding to around 1.25 million capacitive holes. Each hole takes up to 10 mg of lead in a typical solder joint, the total lead from filtered connectors entering RoHS applications per year thus being around 12.5kg maximum

With regard to EMI single line filters, Knowles et al.[1705] estimate the global market at $70 million with a typical selling price of $1.50 per line. From this, using the same 4 % estimate of parts shipping to RoHS applications, indicates the number of lines soldered would be ~1.9 million per year. Again, based on the same lead weight per solder joint of 10mg, this equates to around 19 kg of lead maximum.

Adding the two figures together gives the estimate of 32kg per year supplied into applications covered by the RoHS directive. Allowing for errors and assumptions, Knowles et al.[1706] apply a figure of less than 50 kg.

According to Knowles et al.[1707], these calculations take into account feedthrough lines (unsoldered) and filtered connectors making use of spring clip technology. They do not take into account filters manufactured using high melting point solders with a lead content of at least 85 % where the high melting point solder is needed to allow step soldering of the finished article or during final assembly of the finished article. This application is covered by exemption 7a.

Knowles et al. [1708] state that lead-containing high melting point solder (LHMPS) have the same ductility benefits as indium-lead alloys, but obviously the higher lead content and high processing temperatures (high energy usage) mean this is not a sensible substitution to make on the basis of environmental concerns.

Without exemption 24, the amount of lead used for soldering to machined through hole discoidal and planar array ceramic multilayer capacitors would increase, as the LHMPS

[1702] Ibid.
[1703] Ibid.
[1704] Ibid.
[1705] Ibid.
[1706] Ibid.
[1707] Ibid.
[1708] Ibid.

with at least 85 % of lead content would have to be used instead of the indium-lead solders used under exemption 24 which have a maximum weight share of 50 % lead.

30.2 Applicants' Justification for the Continuation of the Exemption

30.2.1 Elimination of Lead

According to Knowles et al.,[1709] [1710] where it is technically necessary to use solder, there are no known replacements for lead containing alloys. In some cases it has, however, been possible to replace solder with mechanical connections, i.e. spring clips and canted coil springs. Canted coil springs fulfil the same function as spring clips. There are no other purely mechanical methods of connecting to the smooth plated inside bore of the ceramic capacitor and the plated surface of the through lead. The spring clip/coil technology allows making solderless connections.

According to Knowles et al.[1711], the clips and coils have been used in EMI filtered connector applications to make the contact between the planar capacitor array and the through connector pin where they were suitable based on the product requirements. They are the ultimate in reducing stress on the ceramic, but there are limits to their use:[1712, 1713]

1) The technique takes up more physical space, reducing available capacitance and reducing the electrical performance of the device. For this reason the use is limited to larger size filtered connectors with wide contact pitch and lower filtering requirements.
2) The technique does not provide a 100 % grounding ring, so can reduce EMI performance and allow high frequency noise to pass through.

Knowles et al.[1714] claim that the usability of spring clips depends on many factors which may interact:

- Component size;
- Contact (pin) size;

[1709] Ibid.

[1710] Knowles Capacitors et al. 2015c: 2015 "Answers to first questionnaire (clarification questionnaire), document "Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf": Clarification questionnaire," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf

[1711] Knowles Capacitors et al. 2016c "E-mail communication, document "E-mail-communication_Knowles.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, until 16 March 2016" unpublished manuscript,

[1712] Op. cit. Knowles Capacitors et al. 2015a

[1713] Op. cit. Knowles Capacitors et al. 2015c

[1714] Ibid.

- Working voltage;
- Pin pitch;
- Required capacitance / filtering performance; and
- Whether the clip can be isolated from any sealants, epoxies or coatings that are required to achieve the desired performance within the available size envelope.

Knowles et al.[1715] state that single line filters are not made using clips as the dimensions of the units do not allow it. Single line filters also do not allow for isolation of the clip from sealing resins and are too small to allow use of a clip whilst maintaining the necessary capacitance values. Larger filtered units, for example multiway filtered connectors, may use mechanical connections if the mechanical and electrical requirements allow it. However there is a general trend for smaller connectors with tighter pitches that precludes the use of mechanical connections due to the physical and electrical requirements. The clip technique takes up more physical space, reducing available capacitance and the electrical performance of the device. For this reason the use is limited to larger size filtered connectors with wide contact pitch and lower filtering requirements. Additionally, the clip technology can reduce EMI performance and allow high frequency noise to pass through.

Knowles et al.[1716] claim that the evaluation where clips/coils can be used is complex to a degree that it cannot be governed down to a set of rules as there are too many parameters that need to be considered.

Knowles et al. [1717] claim that the evaluation where clips/coils can be used is based on the many parameters listed above making it a complex task. For example, assuming a required level of filtering, it can easily be translated into a necessary capacitance value, and the voltage rating and diameter of the pin can also be defined. In a multi-element connector, the pin-pitch is also known. With this, the available mechanical area can be defined in which the capacitance must be achieved. In the available mechanical area allowance must be made for the joint area. A mechanical clip takes up much more of this area than does a solder joint. Solder has the ability to wet and flow into small gaps – typically 0.1 mm or so – between the pin and the inside bore of the capacitor. Clips will typically need to have around 0.35 mm gap between the capacitor and the pin, so around 0.7 mm per joint around the diameter of the pin. This can dramatically reduce the available area to achieve the capacitance required. In some cases it would make it impossible to fit a capacitor at all in the area that remains.

[1715] Knowles Capacitors et al. 2016b “Answers to third questionnaire, document "Exe_24_Questionnaire-3_Knowles-et-al_2016-03-01.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 8 March 2016: Answers third questionnaire” unpublished manuscript,
[1716] Ibid.
[1717] Ibid.

Knowles et al.[1718] say that the spring/clip must be isolated from sealants or resins to prevent them breaking the electrical contact between the pin and the capacitor. Barrier boards are required which again increase the length of the unit so that it can be impossible to fit the required capacitance into the available space envelope.

Finally, according to Knowles et al.[1719] there is the issue of vibration resistance which can preclude the use of a clip as the contact can be lost increasing the resistance and adversely affecting the functionality of the device. A solder joint provides a guaranteed connection at all times.

Knowles et al.[1720] conclude that each case will be different, with so many variables as listed above so that they cannot provide general criteria to define where clips can replace the lead-containing solders.

30.2.2 Substitution of Lead by Lead-free Solders

Knowles et al.[1721] claim that when lead-free solder is used to connect the feedthrough pins to the internal bore to make a mechanical and electrical connection, the shrinkage of the solder and pin assembly within the bore exerts a tension force on the inside of the bore, sufficient to form micro-cracks in the ceramic element. These cracks have a recognisable shape and form. If the crack propagates through the electrically active portion of the design, where electrodes of opposing polarities overlap each other, then the result can be a low resistance path or an electrical short circuit, resulting in failure of the electrical system and potentially health and safety risks to operators. Knowles et al.[1722] tested the alloys listed in Table 30-1.

30.2.2.1 Tests of Lead-free Solders

According to Knowles et al.[1723], the tested solders specified in Table 30-1, represent the solders currently in use for the assembly of EMI filters, conventional tin lead solders and samples of proposed lead-free replacement solders. In each case, except for the two LHMPS alloys, two sample sets of filters were assembled and reflowed using a five zone hot air reflow furnace. Sample 1 had a standard solder profile with forced cooling by air blowers after zone 5. Sample 2 was reflowed using the same soldering profile but with the cooling air blowers turned off to allow gradual cooling, so as to reduce the stresses on the ceramic.

Knowles et al. [1724] explain that 95Pb/5In solder has a high melting point of between 300 °C and 313 °C, and 93.5Pb/5Sn/1.5Ag a high melting point of between 296 °C and

[1718] Ibid.
[1719] Ibid.
[1720] Ibid.
[1721] Op. cit. Knowles Capacitors et al. 2015a
[1722] Knowles Capacitors et al. 2015b
[1723] Knowles Capacitors et al. 2015b
[1724] Knowles Capacitors et al. 2015b

301 °C, so neither could be soldered using the available hot air furnace. Instead samples of these were assembled using a hot plate at 425 °C. Preheat was not used. Sample 1 parts were force cooled by placing directly in front of a desk fan. Sample 2 parts were allowed to gradually cool. The samples were then sectioned, allowing the capacitor structure around the solder joints to be inspected for cracking.

Table 30-1: Tested solders and results

Alloy Type		Cooling	Defective 'Longbow' (%)	Defective Total (%)
62Sn/36Pb/2Ag	Traditional low melting point lead solder	forced	80	100
		gradual	20	60
60Sn/40Pb	Traditional low melting point lead solder	forced	100	100
		gradual	60	80
99.3Sn/0.7Cu	Lead free 'plumbers' solder	forced	100	100
		gradual	100	100
95.5Sn/3.8Ag/0.7	Lead free solder recommended for PCB assembly	forced	100	100
		gradual	40	80
50Pb/50In	Ductile stress relieving solder	forced	0	0
		gradual	0	0
95Pb/5In (LHMPS)	Ductile stress relieving high melting point solder	forced	0	0
		gradual	0	0
93.5Pb/5Sn/1.5Ag (LHMPS)	Ductile stress relieving high melting point solder	forced	10	10
		gradual	0	0

Source: Knowles et al.[1725]*, modified*

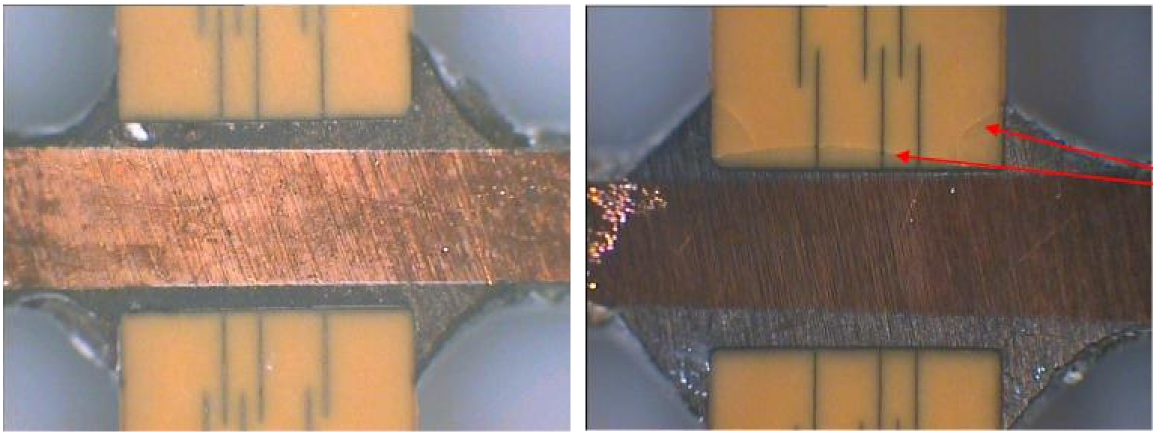
Knowles et al.[1726] that the LHMPS joints were made using capacitors without solder pads as available jigging did not allow padded parts to be assembled. This eliminated corner

[1725] Knowles Capacitors et al. 2015b

cracking and may have slightly shifted the results towards a too positive result for the LHMPS. However, the very low level of longbow cracking found in HMP-soldered parts (10% of force cooled 93.5Pb/5Sn/1.5Ag joints only) still indicates the improved performance of these alloys.

Figure 30-2 shows the example of a test sample without cracks (50Pb/50In with gradual cooling) and a gradually cooled test sample soldered with SnAgCu solder.

Figure 30-2: Test sample without cracks (50Pb/50In, left) and sample with long bow and corner cracks (SnAgCu, arrows, right)



Source: Knowles et al.[1727]

Knowles et al.[1728] conclude that lead containing solders, often in conjunction with other metals such as indium, impart a degree of ductility to the solder joint, allowing stress release within the joint and absorbing the forces applied to the ceramic. Alternative solder alloys, such as tin-based lead-free alloys and SnPb alloys, do not have sufficient ductility to prevent stress damage to the ceramic and can represent a reliability / safety risk during the operating life of the component.

30.2.2.2 Use of Alternative Materials with Less Difference in CTE

Knowles et al.[1729] explain that dielectric ceramic - the same material as used by chip capacitor MLCC - is a sintered brittle material selected primarily for its electrical properties. All ceramic dielectrics are liable to mechanical stress cracking. There are no ceramic dielectric materials currently available with sufficient ductility or crack resistance.

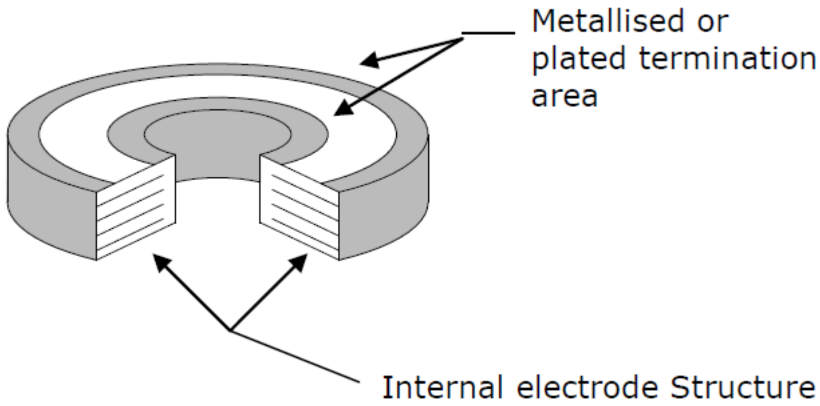
According to Knowles et al.,[1730] the pin material used in this type of component is copper, brass and very occasionally steel, chosen for its machinability and electrical

[1726] Knowles Capacitors et al. 2015b
[1727] Knowles Capacitors et al. 2015b
[1728] Ibid.
[1729] Op. cit. Knowles Capacitors et al. 2015c
[1730] Ibid.

conductivity. The lead-free soldering tests (c.f. Table 30-1) were conducted with silver-plated copper pins, which is the most malleable of the pin materials normally used. The use of other pins and platings would thus even aggravate the crack problem.

In combination with palladium-silver (PdAg) platings, as an alternative approach to enable lead-free soldering, lead-free solders cause failures as well, even though different ones.

Figure 30-3: Typical stray capacitor discoidal construction



Source: Knowles et al.[1731]

Knowles et al.[1732] describe that PdAg platings reduce the bond strength between the termination and the ceramic, compared to gold plating. The effect of this is that the contraction forces tend to stress relieve the assembly at the termination / ceramic interface rather than inside the ceramic structure in the form of a crack. Tests were carried out using capacitor arrays with the electrical design shown above and terminated with PdAg termination material. The advantage with this type of construction is that any failure of the internal termination or ceramic cracking is demonstrated by a drop in the capacitance. This is because of the introduction of an alternative dielectric material – air – in the area of the failure. Prior to assembly, the capacitance of the holes with this design was recorded. The assembly was soldered using 95.5Sn/3.8Ag/0.7Cu lead-free solder and hot air reflow. After assembly, the capacitance was re-measured. Table 30-2 shows the results of the tests undertaken. Knowles et al.[1733] state the drop in capacitance for both soldered arrays indicates failures in all assemblies. Details about the failure mechanism are explained in Knowles et al. 2015b.[1734]

[1731] Op. cit. Knowles Capacitors et al. 2015b
[1732] Ibid.
[1733] Ibid.
[1734] Ibid.

Table 30-2: Test results of PdAg-plated discoidal MLCC soldered with lead-free solders

Array No. 1			Array No. 2		
Start Capacitance (pF)	Capacitance after Soldering (pF)	Change (%)	Start Capacitance	Capacitance after Soldering	Change (%)
551	296	-46.3	539	331	-38.6
550	242	-56.0	540	256	-52.6
550	300	-45.5	535	196	-63.4
552	249	-54.9	536	189	-64.7
553	244	-55.9	532	323	-39.3
546	474	-13.2	538	151	-71.9
544	351	-35.5	536	91	-83.0
543	418	-23.0	539	175	-67.5
551	339	-38.5	544	353	-35.1
551	520	-5.6	536	168	-68.7
546	368	-32.6	536	176	-67.2
550	289	-47.5	534	317	-40.6
544	451	-17.1	544	173	-68.2
544	443	-18.6	543	153	-71.8
550	242	-56.0	543	285	-47.5

Source: Knowles et al.[1735]

Knowles et al. conclude that the use of lead solders is currently still required and ask for the continuation of exemption 24.

30.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

Knowles et al.[1736] see no scope for replacing solder as the primary method of making electrical and mechanical connection between the capacitor and the through conductor pin. They continue to monitor the solder industry through web searches and in conjunction with their partner solder supplier Indium Corporation, but they claim no viable alternatives to lead containing alloys to be available at the present time.

30.4 Critical Review

30.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead and cadmium in various articles and uses.

[1735] Ibid.

[1736] Op. cit. Knowles Capacitors et al. 2015a, page 17 et sqq.

The exemption reduces the amount of lead used in some of the applications in the scope of Exemption 24. Indium replaces part of the share of lead in the lead-containing solder so that Annexes XIV and XVII need to be checked for entries regarding lead and indium.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as a directly added substance nor as a substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds and indium phosphide shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restriction for substances under Entry 28 and Entry 30 of Annex XVII does not apply to the use of lead and indium in this application. The use of lead and indium in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead and indium are part of an article and as such, Entry 28 and Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds…

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."* This restriction, however, does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable*

conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

30.4.2 Elimination of Lead

Knowles et al. explain that the usability of spring clips depends on multiple parameters. Neither during the stakeholder consultation, nor at a later stage of the review process, have other sources of information or contrary information become available disproving the statement of Knowles et al. While it is possible to eliminate the use of lead in some cases, the consultants conclude, based on the available information, that it is not possible to define an exemption wording with a clear-cut demarcation of applications where these clips can be used.

30.4.3 Substitution of Lead

30.4.3.1 Use of Lead-free Solders

The applicant plausibly shows that lead-free solders currently cannot replace the lead-containing solders. One key reason for this is the higher ductility of lead-solder, which thus can better balance the different coefficients of thermal expansion (CTE) between the pin and the ceramics.

One possible approach could thus be to use a different material for the pin with a CTE closer to the other materials involved. Knowles et al.[1737] claim that the pin materials are fixed as copper alloys by application. No other material is acceptable to the industry as offering the appropriate combination of physical and electrical characteristics. Alternative pin materials are thus not considered an option.

30.4.3.2 Replacement of Lead-containing High Melting Point Solders

In the 2008/2009 review[1738], Knowles – at that time named "Syfer" – said that some of its customers are tending towards using higher lead alloys typically containing 95 % of lead rather than 50 % as preferred by Syfer/Knowles to overcome the limitations of the RoHS Directive. Knowles/Syfer at that time considered this solution to represent a negative environmental impact. Lead-containing high melting point lead solders (LHMPS, as currently still exempted under Exemption 7a) with Pb content > 90 % also tend to

[1737] Op. cit. Knowles Capacitors et al. 2015c: 2015

[1738] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009) have the ductility demanded, 92.5Pb/5In/2.5Ag or 95Pb/5In being the most likely solutions. However, alloys with this content of lead have much higher reflow temperatures - 92.5Pb/5In/2.5Ag has a liquidus temperature of 310 °C compared with 210 °C for 50Pb/50In alloy. This will demand new equipment capable of reaching much higher temperatures. Trials have shown that an inert atmosphere will also be necessary to prevent oxidisation problems. The use of these LHMPS would increase the use of lead as well as the energy consumption due to the higher soldering temperatures and for the production of the inert gas. Syfer/Knowles state, however, that some applications require the use of LHMPS in such capacitors.

The applicants were asked whether the above statement is still correct. Knowles et al.[1739] replied that they recommend their customers always to use indium-lead solders where possible, with LHMPS being used where the technical demands require a higher melting point alloy. They believe that customers they are in regular contact with generally follow this advice. The comments regarding the processing limitations for LHMPS, i.e. high process temperatures, higher energy consumption and inert atmospheres, still hold true.

Exemption 24 thus offers an alternative to LHMPS with less use of lead involved. Vice versa, the use of lead in this application would increase without exemption 24 because LHMPS with higher lead contents as exempted in the current exemption 7a may remain as the only alternative.

Exemption 24 thus offers an alternative to reduce the use of lead. LHMPS contains at least 85 % of lead and typically even more than 90 % in the application in the scope of exemption 24, while the alternative indium-based solders apply a maximum of 50 % of lead. The use of lead in this application would therefore increase without exemption 24 because LHMPS with higher lead contents as exempted in the current exemption 7a remains as the only alternative.

Knowles et al.[1740] use indium-lead solders with melting points of around 210 °C. This means that the components within existing designs would not survive a standard soldering process with the most frequently used lead-free solders, which have melting points above 210 °C. Knowles was therefore asked how they can use these indium-lead solders without problems in subsequent soldering processes, in which the component is, for example, bonded onto a printed circuit board.

Knowles et al.[1741] [1742] explain that the types of MLCC covered by exemption 24 are chiefly used in applications where subsequent assembly is by selective soldering, usually

[1739] Op. cit. (Knowles Capacitors et al. 2016a)
[1740] Op. cit. (Knowles Capacitors et al. 2015a)
[1741] Op. cit. (Knowles Capacitors et al. 2016a)
[1742] Knowles Capacitors et al. 2016d "Answers to questionnaire 2 related to exemption 7a, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016" unpublished manuscript

by hand and only to the end pin of the filter/connector. Where a low melting point alloy such as Pb50In50 is used for the assembly of the component, it is preferable from both a lead content and a process point of view. In such cases, the finished component or connector would not be expected to be processed through a standard reflow soldering practice. Otherwise, where a component is designed to be subsequently mounted using standard reflow soldering techniques, it will be assembled using LHMPS. This type of component would then be rated for assembly using conventional lead-free solders, in contrast to those assembled with for example with Pb50In50. The current scope of Exemption 24 covers both of these cases, thus allowing the use of high melting point solders with 85 % and more of lead as well as other solders with lower lead contents.

The consultants tried to clarify[1743] why not all capacitors in the scope of exemption 24 can be soldered selectively so that the use of LHMPS would no longer be required, but this information was not available until the end of the review process. Given the considerable efforts undertaken and the limited time and resources available, it was not possible to follow this technical discussion further.

30.4.4 Conclusions

30.4.4.1 Substitution and Elimination of Lead

The applicants plausibly explain that lead-solders are required to solder the pins into discoidal and planar array multilayer capacitors. Lead-free solders are not sufficiently reliable. Alternative approaches to enable the use of lead-free solders, i.e. the use of different pin materials with more appropriate coefficients of thermal expansion, and alternative plating's, in order to allow the use of lead-free solders, are not technically viable either.

Elimination of soldering via the use of spring clips is an option in some cases, but such cases cannot be clearly demarcated from those areas, which require the use of lead-solders as already determined in the 2008/2009 review[1744]. The situation remains that it is not possible to define a functional exemption wording with a clear-cut demarcation of applications where spring clips can be used.

In the absence of Exemption 24, LHMPS with at least 85 % of lead would have to replace the indium-lead solders with a maximum of 50 % of lead. Exemption 24 thus contributes to reduce the amount of lead as long as the situation persists that lead-free solutions are not available. Based on the available information, the reviewers conclude that renewing Exemption 24 would be in line with the requirements of Art. 5(1)(a).

The current scope of the exemption covers both the use of high melting point solders with 85 % and more of lead as well as other solders with lower lead contents such as Pb50In50. As it has not been possible to detail why the selective soldering of the components in the scope of Exemption 24 could not be generally applied to avoid the

[1743] Ibid.
[1744] Op. cit. (Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009), page 214 et sqq.

use of LHMPS, a rewording targeting a reduction of the maximum content of lead in the solders to less than 85 % could not be proposed.

Even though lead cannot yet be fully substituted, restricting the scope of Exemption 24 to exclude the use of LHMPS would at least reduce the amounts of lead used. Granting the continuation for the maximum of five years would not be justified in line with the requirements of Art. 5(1)(a). To further clarify the scope of the exemption, the consultants recommend granting the exemption for 30 months. As a sound justification why selective soldering cannot be used for all capacitors in the scope of this exemption to avoid the use of LHMPS, in the consultants' opinion does not require further research and development, 30 months should be sufficient time to apply for the renewal of the exemption in time 18 months prior to its expiry.

30.4.4.2 Avoiding Overlaps with Exemption 7(a)

Exemption 7(a) currently covers the use of LHMPS in electrical and electronic equipment so that there is a scope overlap with Exemption 24. The use of LHMPS in the capacitors in the scope of Exemption 24 should therefore be excluded from the scope of Exemption 7(a) to avoid that the use of solders in these capacitors is covered by two different exemptions. In the course of a future scope refinement of Exemption 24, the lead-content of the solder used under Exemption 24 could be reduced to a level below 85 % thus excluding the use of LHMPS provided this is scientifically and technically practicable. In this case, the references to Exemption 24 could be removed from Exemption 7(a).

In principle, the use of LHMPS in the capacitors in the scope of Exemption 24 could also be exempted in Exemption 7(a), which would, however, require adding another entry under Exemption 7(a) for these capacitors. This part of Exemption 7(a) would then have to be revoked should it be practicable to exclude the use of LHMPS in Exemption 24, which generates an additional entry under exemption 7(a) that would have to be maintained to enable repair and reuse. Compliance may also become more difficult for industry if the soldering for a specific component is regulated in two different exemptions. Additionally, regulating the use of LHMPS in the MLCC capacitors would require restricting the lead content in the solders in Exemption 24 to a level below 85 % to avoid an overlap with Exemption 7(a). Such a restriction should be discussed with the applicants and stakeholders to ensure the concentration of lead is high enough to cover all uses of solders other than LHMPS.

Concerning the lead substitutes, the European Commission[1745] lists indium as one of 20 critical raw materials for the European Union, which calls for the substitution of indium, while in the case of Exemption 24, indium replaces lead, which the EU Commission has

[1745] European Commission: 2014 "On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions," http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0297&from=EN, page 5 et sqq.

not listed as a critical material. In this respect, Exemption 24 contravenes the strategy of the Critical Raw Materials Initiative to substitute critical materials and to reduce their use, while it is in line with the requirement of the RoHS Directive to substitute lead.

RoHS Art. 5(1)(a) stipulates that decisions on exemptions shall take into account the availability of substitutes, meaning *"[…] the ability of a substitute to be manufactured and delivered within a reasonable period of time as compared with the time required for manufacturing and delivering the substances listed in Annex II"*, i.e. the list of restricted substances. Hence, if the use of indium would cause delays in the manufacturing of components due to the limited availability of indium, Art. 5(1)(a) would allow cancelling the exemption based on the lacking availability of indium and thus moving industry to alternatively use high melting point solders with at least 85 % lead content under the current exemption 7a. Such indium shortages were not, however, identified by stakeholders, and the fact that the applicants plea for the renewal of Exemption 24 implying the use of indium can be seen as evidence that indium is sufficiently available for these applications.

It should be stressed that it is beyond the consultants' mandate to recommend the continuation or revocation of exemptions based on criteria other than those stipulated in RoHS Art. 5(1)(a). The consultants therefore recommend renewing the exemption based on Art. 5(1)(a). Any other recommendations on whether and how far to take into account strategies or requirements resulting from the Commission's Raw Material Initiative must be considered separately from this review, and such decisions should be made by the competent European Authorities.

Should the Commission prioritize the conservation of indium resources over the reduction of lead use, then Exemption 24 should not be renewed. This would require exempting the use of LHMPS as the substitution or elimination of lead in the capacitors in the scope of Exemption 24 is currently impracticable. In this case, the consultants recommend

A) to take no further action should the Commission decide to keep the current wording of Exemption 7(a).
B) adding a clause in the proposed rewording of Exemption 7(a) allowing the use of LHMPS in the capacitors in the scope of Exemption 24 with a validity period of five years. A validity period shorter than five years would not be justified as no lead-free solutions to replace LHMPS are foreseeable within the next five years.

The above option B will be addressed in an alternative rewording proposal for Exemption 7(a).

30.5 Recommendation

The applicants plausibly explain that neither the elimination nor the substitution of lead is viable to a degree that would allow the revocation or the restricting of scope of Exemption 24. Doing so would prevent the use of indium-lead solders with a maximum of 50 % of lead and instead require the use of high melting point solders with at least 85 % of lead content due to the absence of lead-free solutions.

Based on the available information, renewing the exemption with its current wording would be in line with Art. 5(1)(a). The consultants recommend granting the exemption for 30 months in order to clarify whether the scope of the exemption can be restricted to exclude the use of high melting point solders, which would reduce the amount of lead used under this exemption:

Exemption 24	Expires on
Lead in solders for the soldering to machined through hole discoidal and planar array ceramic multilayer capacitors	*21 January 2019 for categories 1-7 and 10*
	21 July 2021 for · *medical equipment in category 8* · *monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9

The European Commission lists indium as a critical material for the European Union.[1746] Recommendations on exemptions taking into account criteria beyond Art. 5(1)(a), are beyond the consultants' mandate. Taking into consideration strategies and requirements resulting from the Commission's Raw Material Initiative in the context of this exemption should be made by the competent European Authorities.

30.6 References Exemption Request 24

European Commission: On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative 2014. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0297&from=EN.

Gensch, Carl-Otto [Oeko-Institut e.V.], et al.: Adaptation to scientific and Technical progress under Directive 2002/95/EC 2006. http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf.

Gensch, Carl-Otto, Oeko-Institut e. V., et al. 20 February 2009 Adaptation to scientific and technical progress under Directive 2002/95/EC: Final Report, RoHS III. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf.

[1746] Ibid., page 5 et sqq.

Knowles Capacitors et al. 2015a: Request for continuation of exemption 24, document "24_RoHS_V_Application_Form_E24_final_160115.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/24_RoHS_V_Application_Form_E24_final_160115.pdf.

Knowles Capacitors et al. 2015b: Addendum to request for continuation of exemption 24, document "Application Note AN0011 Solder Alloy Choice for Through Hole Ceramic Discoidal & Planar Array Capacitors.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Application_Note_AN0011_Solder_Alloy_Choice_for_Through_Hole_Ceramic_Discoidal__Planar_Array_Capacitors.pdf.

Knowles Capacitors et al. 2015c: Answers to first questionnaire (clarification questionnaire), document "Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_24/Ex_24_Knowles-et-al_Questionnaire-1_2015-08-10_response.pdf.

Knowles Capacitors et al. 2016a: Answers to Second Questionnaire, document "Exe_24_Questionnaire-2_Knowles-et-al_Response_2016-02-09.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Stephen Hopwood, Knowles Capacitors, on 9 February 2016.

Knowles Capacitors et al. 2016b Answers to third questionnaire, document "Exe_24_Questionnaire-3_Knowles-et-al_2016-03-01.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Stephen Hopwood, Knowles Capacitors, on 8 March 2016.

Knowles Capacitors et al. 2016c E-mail communication, document "E-mail-communication_Knowles.pdf, received by Dr. Otmar Deubzer, Fraunhofer IZM, from Steve Hopwood, Knowles Capacitors, until 16 March 2016.

Knowles Capacitors et al. 2016d Answers to questionnaire 2 related to exemption 7a, document "Exe_7a_Questionnaire-2_Knowles_2016-03-29.pdf", received from Steve Hopwood, Knowles, by Dr. Otmar Deubzer, Fraunhofer IZM, on 4 April 2016.

32.0 Exemption 32 “Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

Ion lasers	Gas lasers, i.e. argon and krypton lasers
SSL	Solid state laser(s)

32.1 Description of the Requested Exemption

Coherent[1808] and Lumentum[1809] (formerly JDSU) requested the renewal of Exemption 32 without changes for another five years:

> *Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes*

32.1.1 Background and History of the Exemption

The exemption was first reviewed[1810] in 2006, whereupon the Commission granted the exemption, and once again[1811] in 2010/2011. The exemption was renewed for the

---

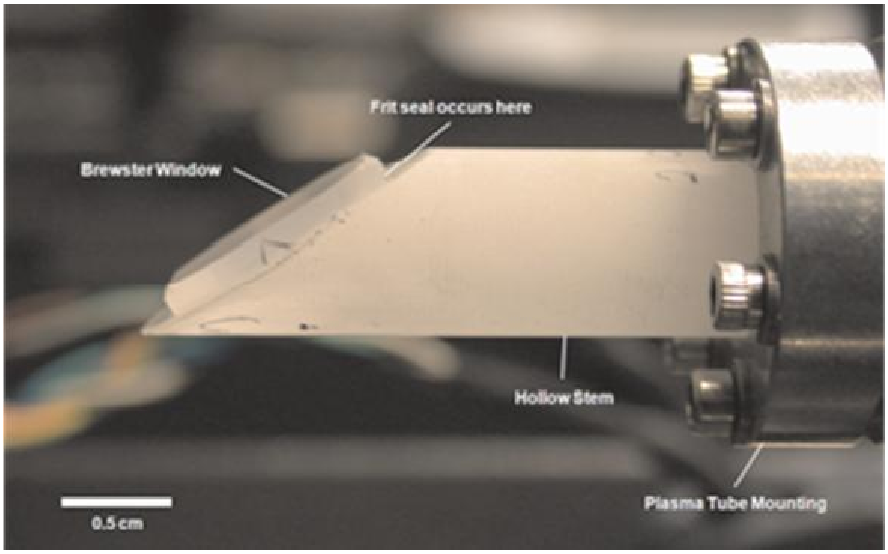
[1808] Coherent 2015a “Request for continuation of exemption 32, document "BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf

[1809] Lumentum 2015a 2015 “Request for continuation of exemption 32, document "32_JDSU_RoHS_Application_Exemption_32.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/32_JDSU_RoHS_Application_Exemption_32.pdf maximum four years allowed under Directive 2002/95/EC (RoHS 1) until 31 July 2014. This expiry date was systematically postponed to July 2016 when the exemption was transferred to Annex III of the recast Directive 2011/65/EU (RoHS 2).

32.1.2 Technical Description of the Exemption

According to Coherent[1812], as illustrated in Figure 32-1 the lead oxide in the seal frit is located in a Brewster window assembly, i.e. an optomechanical assembly that provides a vacuum-tight seal and is optically transparent to the laser radiation.

Figure 32-1: Location of the seal frit in the laser tube assembly



Source: Coherent[1813]

Coherent[1814] classifies the Brewster window with the lead-containing seal frits as a critical optical interface that significantly affects the performance of the laser. A plasma tube can have either one or two of these assemblies based on its type. Lumentum[1815] explains that the lead oxide-based material in Argon and Krypton laser products provides a critical thermo-mechanically-stable and vacuum-tight seal between the optics and

---

1810 Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006 “Adaptation to scientific and Technical progress under Directive 2002/95/EC: Final Report - final version,”; http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf; page 127 et seqq.

1811 For details see report of Zangl, Stéphanie, Oeko-Institut e.V. 30 May 2011 Adaptation to Scientific and Technical Progress under Directive 2002/95/EC: Evaluation of New Requests for Exemptions and/or Review of Existing Exemptions. With the assistance of Otmar Deubzer, Fraunhofer IZM, and Ran Liu, Katja Moch, Oeko-Institut e.V., page 83 et sqq.

1812 Op. cit. Lumentum 2015a

1813 Op. cit. Coherent 2015a

1814 Op. cit. Coherent 2015a

1815 Op. cit. Lumentum 2015a

laser tube. The softening point of the lead-oxide material occurs at a narrow temperature range around 420 °C, and does not thermally damage the nearby fragile components being joined. Additionally the material has a coefficient of thermal expansion closely matched to the components for stress-free sealing. Lead-free glasses are not available for this application, and the continuation of exemption 32 is therefore required.

Coherent [1816] states that ion lasers are unique in that they generate a variety of wavelengths in the ultraviolet, visible and infrared regions of the electromagnetic spectrum. These lasers are capable of producing ultrapure spatial and temporal output. Lumentum[1817] explains that its Argon laser products are used as coherent light sources in a broad range of critical applications, a majority of which are in research, bioinstrumentation and semiconductor manufacturing. Coherent[1818] lists the following primarily scientific and light industrial applications for Argon and Krypton ion lasers in use in the EU today:

- Spectroscopy, e.g. examination of molecules or atoms by measuring effects of laser beam exposure;
- Microscopy, e.g. magnification of samples and objects using laser as light source; non-medical uses include examination of geologic materials; and
- Holography, e.g. using lasers to record and/or view optically stored information for applications such as data storage, security, art, engineering and communications.

Lumentum[1819] states that leading manufacturers of flow cytometers, DNA sequencers, and haematology equipment, incorporate Argon lasers into their products in both new production and in service of a large worldwide installed base. Instruments are used internationally by both government and private sector agencies for health care, drug discovery, and research applications. In semiconductor manufacturing, Argon lasers are used in inspection equipment, again for both new installations and service business.

Further technical details related to Exemption 32 are available in the reports of the previous reviews.[1820, 1821]

[1816] Op. cit. Coherent 2015a
[1817] Op. cit. Lumentum 2015a
[1818] Op. cit. Coherent 2015a
[1819] Op. cit. Lumentum 2015a
[1820] Op. cit. Gensch, Carl-Otto [Oeko-Institut e.V.], et al. 2006; http://ec.europa.eu/environment/waste/weee/pdf/rohs_report.pdf; page 127 et seqq.

[1821] For details see report of (Zangl, Stéphanie, Oeko-Institut e.V. 30 May 2011) Adaptation to Scientific and Technical Progress under Directive 2002/95/EC: Evaluation of New Requests for Exemptions and/or Review of Existing Exemptions. With the assistance of Otmar Deubzer, Fraunhofer IZM, and Ran Liu and Katja Moch, Oeko-Institut e.V., page 83 et sqq.

32.1.3 Amount of Lead Used Under the Exemption

Coherent's[1822] 2014 shipments of replacement plasma tubes and new systems containing plasma tubes, in all non-exempt applications, EU-wide, contain less than 1g of lead, and the number of ion lasers in use for all applications is flat to declining, both in the EU and globally. There is no potential for emerging applications that would employ ion laser technology, and thus, the amount of Pb introduced per annum would be generally flat to declining in subsequent years. Lumentum[1823] indicates its total annual usage of PbO in the sealing glass in its lasers to be 230g, and with only 17g of PbO thereof entering the EU market direct shipments of argon lasers.

Even though exact figures concerning the total amount of lead used under this exemption are not available, the consultants assume it is safe to say that less than 1 kg of lead is used in the EU under this exemption.

32.2 Applicants' Justification for the Continuation of the Exemption

32.2.1 Substitution of Lead

Lumentum[1824] mentions bismuth-based glass as an alternative to the lead-based sealing glass. The bismuth-based glasses have a significantly higher (540°C) melting temperatures than the lead-based glass (420°C). Lumentum has tested the initial suitability of bismuth-based alternatives. While the published melting temperature is 540°C, in trial builds processing temperatures in excess of 560°C did not produce good flow of the frit material. The coverage of the frit material should be complete as in the photo on the left in Figure 32-2. As seen in the photo on the right, the lead-free material did not flow to provide a complete seal (red arrow).

[1822] Op. cit. Coherent 2015a
[1823] Op. cit. Lumentum 2015a
[1824] Ibid.

Figure 32-2: Lead-based (left) and bismuth-based frit (right) after processing

Source: Lumentum[1825]

Lumentum[1826] says the potential of damage to the components, primarily the optics, restricts the processing temperatures. Because the optics utilize complex multilayer coatings (> 30 layers), the suppliers of the optics discourage the use of higher temperatures or longer processing times. The coating fabrication process only allows for stabilization of the key optical properties up to 500°C. Processing at temperatures above 500°C will cause failure of the coatings.

Lumentum[1827] concludes that bismuth oxide material is not considered a viable alternative at this time. The optics are not designed to be subjected to temperatures beyond 500°C. Testing of the bismuth oxide material even above the specified sealing times and temperatures did not provide the complete sealing needed.

Coherent[1828] as well considers bismuth- or phosphorous-based glasses as potential substitutes, which are, however, not sufficiently developed technically or commercially to be viable for Coherent; there is no experience or working history in industry with those materials and Coherentdoes not believe that such materials satisfy the exact technical requirements to form the window bonds. Coherent believes there are a

---

[1825] Ibid.
[1826] Ibid.
[1827] Lumentum 2015b 2015 “Answers to clarification questionnaire, document "Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf": Clarification questionnaire (questionnaire 1),” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf
[1828] Coherent 2015b “Answers to questionnaire 1, document "Coherent_Resp_August_2015_Exem_32_NC.pdf",” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/Coherent_Resp_August_2015_Exem_32_NC.pdf

number of fundamental unresolved difficulties with respect to the viability of lead-free alternatives for the fabrication of Brewster window assemblies: [1829]

- **Yield**

  The manufacturing process of the window bonds is multifaceted and complex. It has evolved incrementally over 40 years. There are extraordinarily stringent requirements for mechanical and optical performance. Despite Coherent's experience with the established process, current yields are only borderline acceptable. Any change to the established process will drive yield even lower. No lead-free frit exists that would allow Coherent to utilise its established processing envelope. Alternative frit materials have melting temperatures of 550°C. This is 125°C higher than the material used in the current processes with lead glass. These higher temperatures will place extreme stresses on both raw materials in the assembly, and the production tooling. A reduction in yield will severely compromise Coherent's ability to provide sufficient product for mission-critical applications in the semiconductor and microelectronics markets.

- **Performance**

  The performance of Coherent's plasma tubes are determined to a significant extent by their capability to resist optical degradation by vacuum ultraviolet (VUV) radiation emanating from the gas plasma. A proprietary optical coating on the vacuum side of the Brewster window confers this distinguishing characteristic. Deposition of this unique optical coating on the Brewster window occurs prior to fritting the window to the stem. The dimensions of the assembly and limitations of the coating process preclude the application of the coating after the window fritting process. Because of this process limitation, the coating must endure the high temperatures required to bring the frit to liquid state. The higher temperatures required by the lead-free material will compromise the integrity of this coating. Manifestations of this degradation are yield loss and premature field failure. Coherent is not aware of a coating that provides the required performance and confers resistance to the higher processing temperatures.

- **Usable lifetime**

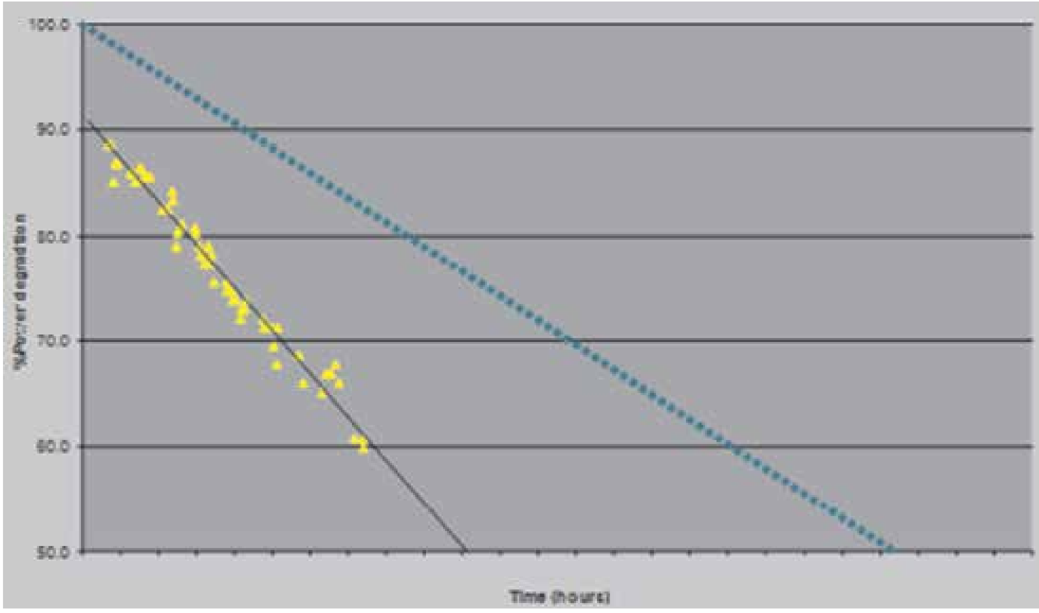
  In highly accelerated testing, lead-free alternatives performed very poorly when compared to the currently used process. Figure 32-3 is illustrative of the significant differences Coherent encountered. The yellow data points represent the lead-free test. The blue line is the current process. (Due to the

[1829] Coherent 2015b "Answers to questionnaire 1, document "Coherent_Resp_August_2015_Exem_32_NC.pdf"," http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/Coherent_Resp_August_2015_Exem_32_NC.pdf sensitive nature of the data, Coherent has removed the x-axis (hours) values). Coherent[1830] finds two things in the lead-free sample remarkable:

- there was an output power (usable light) reduction at the onset, and;
- it takes less than half the time to a 50 % drop in output.

The 10 % initial output loss notwithstanding, just a 10 % reduction in performance would be significant to Coherent's end-users. A 50 % reduction would be catastrophic. Coherent has neither a clear technology path nor a projected timetable that would allow to mitigate performance gaps of this magnitude.

Figure 32-3: Power degradation of lead-free plasma tubes (yellow) vs. historical average with lead (blue dotted line)



Source: Coherent[1831]

Coherent[1832] and Lumentum[1833] conclude that krypton and argon lasers cannot be manufactured without the use of lead oxide in seal frit of the window assembly, and without these lasers many applications would not be possible. That includes instruments used in healthcare and research like flow cytometers, DNA sequencers, haematology equipment as well as equipment for bioinstrumentation and semiconductor manufacturing.

[1830] Ibid.
[1831] Op. cit. Coherent 2015a
[1832] Ibid.
[1833] Op. cit. Lumentum 2015a

32.2.2 Elimination of Lead

Coherent[1834] explains that solid state laser technologies are replacing the argon and krypton type of lasers (ion lasers) that require the above requested exemption. New system shipments of such ion lasers have been in steady decline for five years. Ion lasers are, however, unique in that they generate a variety of wavelengths in the ultraviolet, visible and infrared regions of the electromagnetic spectrum. These lasers are capable of producing ultrapure spatial and temporal output. According to Coherent1835, the use of argon and krypton ion lasers will therefore persist only in those applications where their unique multi-wavelength performance is a necessity.

Lumentum[1836] adds that solid-state lasers are usually well suited for modern instrumentation designed specifically to accommodate their characteristic electrical and optical performance. For some applications, modern solid-state lasers do not provide the required optical characteristics necessary to achieve required results, e.g. specific wavelengths or groups of wavelengths combined with narrow linewidth. As an example, for some DNA sequencing and flow cytometry applications, three or more exotic (uncommon) wavelengths, often ultraviolet, are necessary. Solid-state sources may not be available for these wavelengths or are otherwise unreliable. Substituting solid-state sources for these applications would require several solid state lasers in place of a single gas laser and thus significantly increase the use of natural resources and the environmental impact of the equipment manufacturing in order to perform the same analyses with solid state lasers.

Coherent[1837] states that the use of ion lasers has been in steady and quite significant decline since well before the inception of RoHS. New installations of ion lasers came to a zenith in 2000, after which the markets for ion lasers collapsed rapidly and nearly completely. The applications declined, among others due to alternative laser technologies becoming available. Coherent[1838] thinks it is safe to say that ion lasers are in use today only in those applications that cannot apply a substitute, based on one or more of the following requirements:

- A specific, process-driven wavelength;
- Continuous wave radiation;
- Deep UV, 257 nm and less;
- Single longitudinal mode;
- Transverse mode quality that is not available in an alternative;
- Discrete tuning at a number of visible and/or UV wavelengths;
- Higher output power than is available with a substitute;

[1834] Op. cit. Coherent 2015a
[1835] Ibid.
[1836] Op. cit. Lumentum 2015b
[1837] Op. cit. Coherent 2015b
[1838] Ibid.

- Low output noise which is not available in an alternative;
- Known cost in an established market—in other words, the alternative is more than the market will bear; or
- A 'copy-exactly' process where the cost of risk retirement for any substitute would be prohibitive.

Coherent[1839] lists the following applications where, among others, ion lasers are still used due to the above described unique properties of ion lasers compared to alternatives (Coherent notes this is not a complete list):

- Photomask direct imaging;
- Flat panel display direct imaging;
- Photomask inspection;
- Patterned wafer inspection;
- Spectroscopy;
- Holography;
- Some types of computer-to-plate imaging;
- Some types of particle imaging velocimetry.

Coherent[1840] states there is no market growth today for ion lasers of any type. Many more ion lasers come out of service each year than go into service. The global market for ion lasers with an output of more than 500 mW is less than 75 per year, with nearly all of the demand in Asia. There is no market scenario, real or imagined, which will alter this trajectory. New installations in the EU are rare, and as is the case globally, many more ion lasers come out of service each year than are installed in the EU.

32.2.3 Environmental Arguments

Coherent[1841] claims that in the full calendar year 2014, ion lasers introduced less than 1 g of lead in all shipments to the EU, new devices or serviced devices, exempt, or non-exempt. The amount of new ion laser installations will continue to drop worldwide. Every year, the Pb mass shipped globally under Exemption 32 will decrease.

Coherent[1842] concludes that ion lasers make only a miniscule contribution to lead contamination, as the atmospheric Pb contamination in the EU already stood at around 1,200 tonnes/year in 2012, for industrial sources alone. Other sources such as transport, commercial, institutional, and household fuel combustion accounted for at least as much on top of that.[1843]

[1839] Ibid.
[1840] Ibid.
[1841] Ibid.
[1842] Ibid.
[1843] "Air Quality in Europe, 2014 Report", EEA Report No5/2014, ESSN 1977-8499; source as referenced by Coherent

32.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

32.4 Critical Review

32.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The exemption allows the use of lead.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substance nor as substance that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight. This restriction does not apply to internal components of watch timepieces inaccessible to consumers

- shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children. This restriction does, however, not apply to articles within the scope of Directive 2011/65/EU (RoHS 2)

The restrictions of lead and its compounds listed under Entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

32.4.2 Environmental Arguments

The stakeholders' environmental arguments focus on the very small amounts of lead used under this exemption. Since the RoHS Directive does not specify minimum amounts of restricted substances as a criterion for an exemption, granting an exemption based on these environmental arguments would not be in line with RoHS Art. 5(1)(a).

32.4.3 Substitution and Elimination of Lead

The information submitted to the reviewers suggests that lead cannot be substituted in the seal frit used for making window assemblies for Argon and Krypton laser tubes. Solid state lasers can, however, replace krypton and argon lasers unless their unique characteristics are required. This would eliminate the use of lead. The applicants were therefore asked whether the scope of the exemption cannot be restricted to those applications where these ion lasers' unique properties are required so that solid state lasers cannot replace them.

Coherent[1844] answered that ion lasers are by their very nature the technology of last resort. They are most certainly powerful tools, but they are dinosaurs of the laser industry. They are bulky, inefficient at conversion of electrical energy to light output, and require dedicated infrastructure. Further, because they are relatively complex electro-optical devices, they typically require specialized training to install, maintain, and operate. That they remain in use today is a testament not only to their unique characteristics, and to the variety of performance improvements incorporated over four decades of use in science and industry, but more importantly, the lack of a complete suite of alternative technologies that sufficiently supplant the ion laser solution.

[1844] Ibid.

As a result, Coherent[1845] claims nobody buys an ion laser unless it is necessary. Ion lasers are massive, bulky, inefficient, and generally somewhat troublesome to operate relative to their solid-state alternatives. Moreover, they are expensive. The only customers for ion lasers today are those that require one or more of the unique attributes of the ion laser that are unavailable in a substitute, such as:[1846]

- One or more of the unique wavelengths that can only be obtained from Argon or Krypton plasma;
- The ability to tune between several of these unique wavelengths in a single laser platform;
- Continuous wave radiation;
- Many watts of output light;
- Spectral purity which cannot be matched by the alternative;
- Extreme coherence on the order of 10s of meters, which cannot be achieved by the alternative;
- Spatial characteristics of the output beam to deliver a nearly perfect circular beam cross-section, with a near perfect Gaussian distribution of intensity across the beam diameter (TEM_{00}, M_2<1.2);
- Extremely low output noise, typically <1%;
- Accessibility into the 351 to 413.1 nm range with multiple watts of output;
- Accessibility into the deep UV, specifically the wavelengths between 299nm and 257nm, that are provided by frequency-doubling of argon lasers;
- Proven longevity in commercial applications of more than 10,000 operating hours.

Lumentum[1847] confirms that due to the specific characteristics of ion lasers, it is unmanageable to replace them by solid state lasers where their characteristic properties are required. For example, most of diode laser-based products exhibit a linewidth that is substantially broader than a linewidth of a gas laser. Narrow linewidth is needed to achieve the required sensitivity of the equipment. Another example is the ability of one gas laser source to generate several specific wavelengths at the same time (i.e. 488 nm, 514 nm and 558 nm) critical for some applications. Equipment that requires a multi-line ion laser cannot be replaced with a single solid state laser. Several solid state lasers would be required to perform the same function.

[1845] Coherent Inc. 2016: “Stakeholder document "Letter to O_Deubzer02092016.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Paul Ginouves, Coherent Inc., on 10 February 2016” unpublished manuscript,

[1846] Ibid.

[1847] Lumentum 2016 “Answers to questionnaire 2, document "Exe_32_Questionnaire-2_Lumentum_2016-02-01.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Gabriela Janusz-Renault, Lumentum Inc., on 13 February 2016”

According to Coherent[1848], some of the strongest incentives to choose any alternative to an ion laser are electrical and water consumption. The average mid-power ion laser consumes 25 kW and three gallons (around 11.4 liters) of water per minute for cooling. A high-output device consumes 50 kW and 6 gallons (around 22.7 liters) of cooling water per minute. Ion lasers are inefficient. They convert just 0.1 % of the incoming power to light. The rest is converted to waste heat. A solid-state alternative will be roughly two orders of magnitude more efficient.

Coherent states[1849] that with every passing year, there are more varied alternatives for ion lasers. In addition, every year, the sales of ion lasers decline as a result. The ion laser has become, by its very nature, the laser of last resort. The few remaining customers resign themselves to the purchase, knowing that they truly have no alternative, while hoping for a different solution in the future.

32.4.4 Conclusions

Solid state lasers can in principle replace ion lasers. The above information suggests that for economic and technological reasons, krypton and argon lasers are only used where their unique properties are required, whereas otherwise solid state lasers will be used.

Working out the characteristic features of ion lasers that require their use instead of solid state lasers would result in a complex exemption wording with more than 10 criteria due to the various unique properties of ion lasers, which may have to be further specified and quantified to clearly demarcate the application fields of ion lasers from those of solid state lasers.

In this situation, the reviewers recommend to renew exemption 32 without changes for another five years.

32.5 Recommendation

The information submitted by the stakeholders suggests that substitution of lead in exemption 32 is technically impracticable. While the elimination using solid state lasers instead of ion lasers is possible in some cases, the applicants plausibly explain that argon and krypton lasers for technical and economic reasons are only used where their unique properties are required so that solid state lasers cannot replace them. In this situation, RoHS Art. 5(1)(a) in the reviewers opinion justifies the renewal of the exemption.

The reviewers therefore recommend continuing the exemption for another five years with its current scope and wording:

[1848] Op. cit. (Coherent Inc. 2016)
[1849] Ibid.

Exemption n. 32	Expires on
Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes	*21 July 2021 for* · *EEE of categories 1-7 and 10* · *medical equipment in category 8, and* · *monitoring and control instruments in category 9 of Annex I*
	21 July 2023 for in vitro diagnostic medical devices in category 8 of Annex I
	21 July 2024 for industrial monitoring and control instruments in category 9 of Annex I

32.6 References Exemption 32

Coherent 2015a Request for continuation of exemption 32, document "BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/BR-_9849983-v3-Coherent_Exemption_request_form_update_after_comments___PG_with_redaction.pdf.

Coherent 2015b Answers to questionnaire 1, document "Coherent_Resp_August_2015_Exem_32_NC.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/Coherent/Coherent_Resp_August_2015_Exem_32_NC.pdf.

Coherent Inc. 2016: Stakeholder document "Letter to O_Deubzer02092016.pdf", received by Dr. Otmar Deubzer, Fraunhofer IZM, via e-mail from Paul Ginouves, Coherent Inc., on 10 February 2016.

Gensch, Carl-Otto [Oeko-Institut e.V.], et al. Adaptation to scientific and Technical progress under Directive 2002/95/EC 2006.

Lumentum 2015a Request for continuation of exemption 32, document "32_JDSU_RoHS_Application_Exemption_32.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/32_JDSU_RoHS_Application_Exemption_32.pdf.

Lumentum 2015b Answers to clarification questionnaire, document "Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_32/JDSU/Exe_32_Questionnaire-1_JDSU_2015-08-31.pdf.

Lumentum 2016 Answers to questionnaire 2, document "Exe_32_Questionnaire-2_Lumentum_2016-02-01.docx", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Gabriela Janusz-Renault, Lumentum Inc., on 13 February 2016.

33.0 Exemption 34 “Pb in cermet-based trimmer potentiometer elements”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

Cermet	Heat resistant material made of ceramic and sintered metal; here the resistive layer and the ceramic body onto which it is sintered
EEE	Electrical and Electronic Equipment
GE	General Electric

33.1 Description of the Requested Exemption

GE et al.[1850] request the renewal of exemption 34 in RoHS Annex I with its current wording:

“Lead in cermet-based trimmer potentiometer elements”

In the course of the review of exemption 7(c)-I, it was found that Bourns’ application[1851] for renewal of exemption 7(c)-I covers aspects that are relevant for cermet-based trimmer potentiometer elements as well, in particular concerning the status of lead-free alternatives.

[1850] General Electric et al. 2015a “Request for continuation of exemption 34, document "34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf

[1851] Bourns Inc. 2015 “Answers to first questionnaire (clarification questionnaire), document "20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf": First questionnaire (clarification questionnaire),” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf

33.1.1 Background and History of the Exemption

The exemption was reviewed once in 2007[1852]. The applicant requested this exemption claiming that exemptions 5 and 7 listed in the annex of directive 2002/95/EC (RoHS 1) as they were formulated in 2006/2007 did not cover the use of lead in these cermet-based trimmer potentiometers:

- *"No. 5: Lead in glass of cathode ray tubes, electronic components and fluorescent tubes",*
  and
- *"No. 7: Lead in electronic ceramic parts (e.g. piezoelectronic devices)"*

The manufacturer said that this resistive layer in the cermet-based trimmer potentiometer is a homogeneous material, as it can be mechanically separated from the ceramic base. This homogeneous material, the thick film layer containing the lead, is neither a glass nor a ceramic material and thus would not be covered by the above exemptions. As a consequence, exemption 34 was adopted to the annex of RoHS 1 with its current wording:

> *"Lead in cermet-based trimmer potentiometer elements"*

Exemption 34 was transferred to annex II of RoHS 2 with an expiry date in July 2016.

To avoid confusion about the scope of exemption 5 and 7, and to make sure these exemptions actually cover those uses of lead where it cannot be substituted or eliminated, the consultants aspired to improve exemptions 5 and 7, and to align them with the exemption wording of parallel exemptions within the ELV Directive as far as possible.

Exemption 11 of annex II in directive 2000/53/EC (ELV Directive[1853]), the equivalent to exemption 7(c)-I of RoHS Annex III, was reviewed in 2007/2008[1854]. The stakeholders decided that the wording in the ELV Directive covers applications like lead in cermet-based trimmer potentiometers.

[1852] Carl-Otto Gensch, Stéphanie Zangl, and Otmar Deubzer 2007 "Adaptation to scientific and technical progress under Directive 2002/95/EC: Final report," Oeko-Institut e.V., http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf, page 18 et sqq.

[1853] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, ELV Directive, European Union (21 October 2000), http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT

[1854] Lohse, Joachim; Gensch, Carl-Otto; Groß, Rita; Zangl, Stéphanie; [Oeko-Institut e.V.]; Deubzer, Otmar, Fraunhofer IZM (2008): Adaptation to Scientific and Technical Progress of Annex II Directive 2000/53/EC. Final Report - Amended Final. Oeko-Institut e. V., Fraunhofer IZM. https://circabc.europa.eu/sd/a/f5d79a51-2e5a-47eb-85d3-7b491ae6a4b3/Final_report_ELV_2008_Annex_II_revision.pdf; page 65 et seqq.

In the subsequent review[1855] of RoHS exemption 7c in 2008/2009, it was therefore decided to adopt the wording formulation of ELV exemption 11 with some slight adaptations, which are reflected in the current wording of RoHS exemption 7(c)-I:

> *"Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound"*

Exemptions 5 and 7 were integrated into the above new exemption, and in principle the use of lead in trimmer potentiometers in the scope of exemption 34 is now already covered by exemption 7(c)-I.

33.1.2 Technical Description of the Exemption

The technical background of the exemption was described in detail in the last review report[1856] from 2007.

33.1.3 Amount of Lead Used Under the Exemption

GE et al.[1857] quantify the content of lead in homogeneous material (% weight) with around 40 to 50 % of PbO in glass. The amount of lead entering the EU market annually through applications for which the exemption is requested is, according to GE et al.[1858], a small fraction of the ~ 350 tonnes related to exemption 7(c)-I.

GE et al.[1859] base their estimations on 2013 data from the companies listed below, who represent the major players on the EU market:

- Ceram Tec;
- Emerson;
- EPCOS;
- Freescale;
- Johnson;
- Matthey Catalysts (Germany);
- Meggitt DK;
- Morgan Advanced Materials;
- Murata; and
- PI Ceramic.

[1855] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. und Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.
[1856] Op. cit. Gensch, Zangl and Deubzer 2007, page 18 et sqq.
[1857] Op. cit. General Electric et al. 2015a
[1858] Ibid.
[1859] Ibid.

GE et al.[1860] note that the list is not exhaustive. Electrical and electronic components are used in a wide range of final products and markets, it is impossible to provide a precise figure of the amount of lead included in glass and ceramic components in the EU for electrical and electronic equipment (EEE). For this reason, although the estimates were done in good faith with the data resources available, the values shown here are provided strictly for reference purposes, and GE et al. do not want to bear responsibility concerning their accuracy or enforceability.

GE et al. were asked to provide a more detailed estimate or calculation for the use of lead in exemption 34. GE et al.[1861] stated that their figures are based on one company's estimate of 5.5kg/annum lead used in their products annually. They claim that the overall amount should not exceed 46 kg/annum.

In the 2007 review[1862] of this exemption, the amount of lead-oxide (PbO) used in cermet-based trimmer potentiometers worldwide was indicated to be around 1,600 kg. Around 93 % of the total weight of PbO being lead, the total amount of lead would be around 1,500 kg. The consultants therefore cannot exclude that the share used in the EU, which the applicant could not calculate in 2007, would be much higher than around 50 kg indicated by GE et al.

The actual lead consumption is thus not clear, but in the consultants view it could well be considerably more than 50 kg per year in the EU.

33.2 Applicants' Justification for the Continuation of the Exemption

33.2.1 Substitution of Lead

GE et al.[1863] state that this exemption follows the same justification criteria as exemption 7(c)-I "*Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound*". Alternative technologies have been evaluated, but so far no substitution technology is available for resistive inks in glass which ensures the needed properties such as mechanical endurance and contact resistance variation. Therefore they apply for the renewal of the exemption.

Stated already in the first review[1864] of this exemption in 2007, lead-free solutions were available for certain resistance ranges and applications, but it was at that time not

---

[1860] Ibid.
[1861] General Electric et al. 2015b "Answers to first questionnaire (clarification questionnaire, document "Exe_34_Questionnaire-1_GE-Health-et-al_2015-09-15 - reply.pdf", received via e-mail by Otmar Deubzer, Fraunhofer IZM, from James Vetro, GE Healthcare, on 15 September 2015,"
[1862] Op. cit. Gensch, Zangl and Deubzer 2007, page 19
[1863] Op. cit. General Electric et al. 2015a
[1864] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber,

possible to clearly define resistance ranges and detailed performance parameters of these products, nor the applications where these trimmer potentiometers would be suitable.

GE et al.[1865] claim that since the 2007 review[1866] of the exemption, they analysed several different lead-free cermet inks from several manufacturers. According to GE et al.[1867] there are no dedicated lead-free inks available for potentiometers but it is the target to qualify available inks for resistors applications. GE et al.[1868] mention boron, phosphorus, zinc, tin, bismuth glass/inks, etc. as potential principal lead-free alternatives. GE et al.[1869] tested mainly two types of lead-free inks from vendor A with sheet resistance from 15mΩ/sq to 5Ω/sq and vendor B with sheet resistance from 10 Ω/sq to 100 MΩ/sq. GE et al.[1870, 1871] say they were processed and their performances were measured by running qualification tests. At present no alternative solutions have similar or acceptable results compared to the leaded inks, especially in life tests. The critical point is the surface roughness of the ink after firing, degrading quickly the sliding contact (wiper) or creating unacceptable electric noise. The experiments showed a more rapid wear on the sliding contact as well as electrical noise, resulting in a life expectancy of only 50 % compared to the lead bearing paste.

GE et al.[1872] et al. conclude that based on these results, a continuation of the exemption is necessary to keep the performances of the products.

Within its trimming potentiometer product line, Bourns'[1873] research team has developed lead-free inks for low to mid-range resistance values for some cermet-based trimmer potentiometers. These proprietary lead-free substitutes are a form of calcium silicate borate glass. These ink systems are used on the trimming potentiometer products only. They work for some specific Bourns' parts, but are not a solution for all Bourns' trimming potentiometers, depending on the specific potentiometer models. Another remaining challenge is the higher end resistance values for which the company is still trying to find a suitable solution.

Oeko-Institut e. V. und Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.

1865 Op. cit. General Electric et al. 2015b

1866 Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. und Otmar Deubzer, Fraunhofer IZM. http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.

1867 General Electric et al. 2016a "Answers to second questionnaire, document "Exe_34_Questionnaire-2_GE-Health-et-al_2016-3-11 reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016: Second questionnaire" unpublished manuscript,

1868 Op. cit. (General Electric et al. 2015a)

1869 Op. cit. (General Electric et al. 2016a)

1870 Op. cit. (General Electric et al. 2015b)

1871 Op. cit. (General Electric et al. 2016a)

1872 Op. cit. (General Electric et al. 2015a)

1873 Op. cit. (Bourns Inc. 2015)

With respect to a quantification of the resistance range in which lead can be substituted, Bourns[1874] state that the resistance range varies in relation to specific potentiometer models and their applications. Some of the inks developed are specifically for a certain model. Currently, a typical upper limit for one specific lead-free ink model is 24 kΩ, and 51 kΩ for another one. Bourns[1875] highlights, however, that these models are examples of successful substitutions only. Bourns[1876] still has many models where the substitution of lead in the ead-containing glasses in all resistances – low, mid and high ranges – is scientifically and technically not yet practicable. So for many other models, there has not yet been a successful resolution, and a lot of research is still to be done as it is not a one-size fits all solution.

Bourns[1877] explain that the lead-free trimmer potentiometers can potentially be used in a variety of applications, but does not claim they can be used in all applications. Their usability depends on the end user's need and the form, fit and function of their end products. Bourns[1878] continues to work with its suppliers, to explore possible solutions through experimenting with possible alternatives. It is a slow process with research, experimentation, testing, scale-up, qualification and reliability testing. If there is a failure along the way, the process has to be started over.

33.2.2 Elimination of Lead

Bakelite-based potentiometers were identified in the 2007 review[1879] of the exemption as a potential way to eliminate the use of lead, but have proven to be no adequate replacement at that time.

GE et al.[1880] report that there are several alternative technologies to cermet trimmer potentiometers, for example:

- Conductive plastic inks;
- Other technologies (optic, magnetic, digital).

GE et al.[1881] say that for replacement the following issues have to be taken into account, as cermet trimmers:

[1874] Bourns Inc. 2016a "Answers to second questionnaire, document "Exe_7(c)-I_Questionnaire-2_Bourns_2015-12-21.pdf", sent via e-mail to Otmar Deubzer, Fraunhofer IZM, by Cathy Godfrey, Bourns Inc., on 4 January 2016: Second questionnaire" unpublished manuscript,
[1875] Bourns Inc. 2016b "Answer to second questionnaire, document "Exe_34_Questionnaire-2_Bourns_2016-03-16.pdf, received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns, on 22 March 2016: Second questionnaire" unpublished manuscript,
[1876] Ibid.
[1877] Op. cit. (Bourns Inc. 2016a)
[1878] Ibid.
[1879] Carl-Otto Gensch, Oeko-Institut e. V., et al. (2009): Adaptation to scientific and technical progress under Directive 2002/95/EC. Final Report. With the assistance of Stéphanie Zangl, Rita Groß, Anna Weber, Oeko-Institut e. V. and Otmar Deubzer, Fraunhofer IZM.
http://ec.europa.eu/environment/waste/weee/pdf/final_reportl_rohs1_en.pdf; page 98 et seqq.
[1880] Op. cit. (General Electric et al. 2016a)

- Can be of a very small size;
- Are not sensitive to electrostatical discharge (ESD);
- Do not need reverse polarity or surge protections;
- Can work at high temperature without Ohm value drift, contrarily to bakelite.

Bourns[1882] explain that bakelite is a phenolic resin material typically blended with a carbon powder to create a carbon-based film. Bourns screen prints this conductive plastic ink on a ceramic substrate. It is used for potentiometers, but not trimming potentiometers. Conductive plastic potentiometers are generally lower cost, less precise, used in environments where moisture or humidity is not a factor and resistance drift is not a concern.

GE et al.[1883] detail that cermet-based trimmer potentiometers have no drift for hundreds of hours at 150 °C. With Bakelite inks, several percentages of drift for every 96 hours of testing at 125°C were observed. Cermet is robust enough to support the force of the wiper. In small dimensions, the control of the force is not easy. For cermet wipers a force from 10 cN up to 150 cN can be used. Bakelite pots are of a poorer quality than cermet. The wear of the inks used on Bakelite is quicker than the Cermet ones. Cermet potentiometers can work up to 125 °C and some up to 210 °C.

Bourns[1884] confirm that for more precision in more demanding environmental conditions, where drift is not acceptable, cermets are used. These materials do not include phenolic resins or carbon. They generally have a precious metal-based ink (e.g. silver or gold for conductors; palladium, platinum, ruthenium for resistors). The cermet material is used for trimming potentiometers. One example is a trimming potentiometer used in medical equipment. The demand is for a precise potentiometer that will not drift from the desired setting. The choice here would be a cermet-based trimmer.

33.2.3 Roadmap towards Substitution or Elimination of Lead

GE et al. were asked about their plans and ideas for the future to achieve RoHS compliance. GE et al.[1885] answered that a possible time frame would be at least 3 years: one year for evaluation, one for internal qualification, and one for qualification at customers especially for specific applications.

Still there are some trimming potentiometers that no solution has yet been found for all resistance values. It varies based on the application of the part. Some termination inks still use lead-containing glass.

[1881] Op. cit. (General Electric et al. 2016a)
[1882] Op. cit. (Bourns Inc. 2016b)
[1883] Op. cit. (General Electric et al. 2016a)
[1884] Op. cit. (Bourns Inc. 2016b)
[1885] Op. cit. (General Electric et al. 2016a)

Bourns[1886] states it will continue work with its suppliers, explore possible solutions, and experiment with possible alternatives. It is a slow process with research, experimentation, testing, scale-up, qualification & reliability testing. If there is a failure along the way, the process starts over. Each product line using lead-based thick film inks is unique so a one-size-fits-all application does not work.

33.3 Critical Review

33.3.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The exemption allows the use of lead.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate
- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance,

---

[1886] Op. cit. Bourns Inc. 2015

mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

1) *"shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight."* This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
2) *"shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children."* This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

33.3.2 Substitution and Elimination of Lead

Potentiometers can be made from bakelite with lead-free plastic inks and could be a potential means to eliminate the use of lead. The applicants both explain that the performance as well as the endurance of such bakelite potentiometers is inferior to the cermet-based trimmer potentiometers so that they cannot replace them.

Bourns mention that they have lead-free alternatives for cermet-based trimmer potentiometers; however, these are said to be applicable on a case by case basis and for some low to mid resistance range trimmer potentiometers only. On request, Bourns[1887, 1888] explained that it is not possible to classify and demarcate resistance and application areas where such lead-free alternatives can be applied from others where the use of lead is still indispensable.

GE et al.[1889] mention optic, magnetic, and digital technologies as approaches to eliminate the use of lead. However, they do not provide further information so it remains an open question whether and how far such technologies could eliminate the use of lead.

1887 Op. cit. (Bourns Inc. 2016a)
1888 Op. cit. (Bourns Inc. 2016b)
1889 Op. cit. (General Electric et al. 2016a)

In order to substitute lead, GE et al. report about various experiments in Section 33.2.1 (from page 727). The consultants asked GE et al. who conducted these tests, and when, in order to obtain insights into the applicants' activities since the last review of this exemption in 2007. GE et al.[1890] answered that for potentiometers it is difficult to answer this question, as typically commercially available standard resistor inks are being used. They are printed and then tested regarding their performances to specification and limits.

The consultants consider that it is not plausible for GE et al. on the one hand to present these results, and on the other hand not to know who did these experiments and when.

While Bourns shows clear efforts and successful substitutions, the information provided and the way it is presented raise concerns about the motivation and willingness of GE et al. to actually research for and find alternatives to substitute or eliminate the use of lead. The answer of GE et al. to the question about their future ideas and plans to achieve RoHS compliance in the last questionnaire[1891] fuels these concerns:

> *"A possible time frame would be at least 3 years, one for evaluation, one for internal qualification, one for qualification at customers especially for specific applications."*[1892]

The applicants' exemption requests and the answers to the clarification questionnaire were made available through the online public consultation, i.e. to industry, governments, NGOs and other stakeholders, and a consultation questionnaire had been prepared with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received.

33.3.3 Conclusions

Overall, the information submitted suggests that lead is actually still required in cermet-based trimmer potentiometers, even though for some low and mid range resistance applications lead-free trimmer potentiometers are available. At this current time, these alternatives are not able to be clearly demarcated and specified in order to restrict the exemption's scope. No information is available concerning the status of optic, magnetic, and digital technologies mentioned by GE et al. as approaches to eliminate the use of lead in the application in the scope of Exemption 24.

Granting an exemption would thus be in line with the requirements of RoHS Art. 5(1)(b). The exemption should, however, be granted for a maximum of three years until 21 July 2019 only. Given the fact that the applicants did not provide information, whether lead could at least partially be eliminated within less than five years, a maximum of five years validity period in the consultants' understanding of Art. 5(1)(a) would not be justified. In

---

[1890] Ibid.
[1891] Ibid.
[1892] Op. cit. (Bourns Inc. 2016a)

case the exemption is still required, the applicants can apply for its renewal prior to 21 January 2018.

33.3.4 Integration of Exemption 34 into Exemption 7(c)-I

Technically, exemption 7(c)-I covers the use of lead in cermet-based trimmer potentiometers so that exemption 34 could in principle be included into the scope of exemption 7(c)-I. As exemption 7(c)-I is, however, recommended to be continued with the current wording without further specifications of the scope, the consultants recommend maintaining exemption 34 as a specific exemption for the time being so as to avoid any possible confusion, but to consider its integration into a future exemption 7(c)-I should the specification of that exemption 7(c)-I be successful in the next review.

Vice versa, the use of lead in cermet-based trimmer potentiometers in the scope of Exemption 34 should be excluded from the scope of exemption 7(c)-I to avoid that exempted uses of lead are covered by more than one exemption.

33.4 Recommendation

The information available to the consultants suggests that the substitution and elimination of lead is scientifically and technically impracticable to a degree that justifies the renewal of the exemption in line with the criteria for exemptions in Art. 5(1)(a). The exemption should, however, only be granted for a maximum of three years since the information provided and the way it is presented does not clearly demonstrate that lead cannot be eliminated within the next five years.

The reviewers recommend the renewal of exemption 34 with the identical wording, but an expiry date latest on 21 July 2019.

Exemption 34	Expires on
Lead in cermet-based trimmer potentiometers	*21 July 2019 for categories 1-7 and 10*
	21 July 2021 for · *medical equipment in category 8* · *monitoring and control instruments in category 9*
	21 July 2023 for in vitro diagnostic medical devices in category 8
	21 July 2024 for industrial monitoring and control instruments in category 9

33.5 References Exemption Request 34

Bourns Inc. 2015 Answers to first questionnaire (clarification questionnaire), document "20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_7_c_-I/20150818_Ex_7(c)-I_Bourns_Questionnaire-1_2015-07-28.pdf.

Bourns Inc. 2016a Answers to second questionnaire, document "Exe_7(c)-I_Questionnaire-2_Bourns_2015-12-21.pdf", sent via e-mail to Otmar Deubzer, Fraunhofer IZM, by Cathy Godfrey, Bourns Inc., on 4 January 2016.

Bourns Inc. 2016b Answer to second questionnaire, document "Exe_34_Questionnaire-2_Bourns_2016-03-16.pdf, received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Cathy Godfrey, Bourns, on 22 March 2016.

Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles. ELV DirectiveEuropean Union. October 21, 2000. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0053:EN:NOT.

General Electric et al. 2015a Request for continuation of exemption 34, document "34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf". http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf.

General Electric et al. 2015b Answers to first questionnaire (clarification questionnaire, document "Exe_34_Questionnaire-1_GE-Health-et-al_2015-09-15 - reply.pdf", received via e-mail by Otmar Deubzer, Fraunhofer IZM, from James Vetro, GE Healthcare, on 15 September 2015.

General Electric et al. 2016a Answers to second questionnaire, document "Exe_34_Questionnaire-2_GE-Health-et-al_2016-3-11 reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016.

General Electric et al. 2016b E-mail communication, document "E-Mail-Communication_GE-et-al_2016-03-01.pdf" sent via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, to James Vetro, General Electric, on 1 March 2016.

Gensch, Carl-Otto, Stéphanie Zangl, and Otmar Deubzer Adaptation to scientific and technical progress under Directive 2002/95/EC 2007. http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf.

JEITA and JBMIA 2015 Contribution to stakeholder consultation, document "Ex_34_Jeita_et_al_Japan_4EEE_Answers_to_Public_Consultation20151015.pdf" 2015. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/Ex_34_Jeita_et_al_Japan_4EEE_Answers_to_Public_Consultation20151015.pdf.

34.0 Exemption 37 “Pb in the plating of high voltage diodes on the basis of a zinc borate glass body”

Declaration

In the sections that precede the “Critical Review” the phrasings and wordings of stakeholders’ explanations and arguments have been adopted from the documents provided by the stakeholders as far as required and reasonable in the context of the evaluation at hand. Formulations have been altered in cases where it was necessary to maintain the readability and comprehensibility of the text. These sections are based exclusively on information provided by applicants and stakeholders, unless otherwise stated.

Acronyms and Definitions

AC	alternate current
DC	direct current
HVD	high voltage diode(s)

34.1 Description of the Requested Exemption

IXYS[1893] and GE et al.[1894] apply for the continuation of Exemption 37 in its current wording:

> *“Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body”*

In the course of the review, it became clear that IXYS actually applies for the use of lead in glass, which is covered by exemption 7c-I, and not for the continuation of Exemption 37, which exempts lead in the plating layer of zinc-borate glass high voltage diodes

[1893] IXYS Semiconductor GmbH 2014 2014 “Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf

[1894] General Electric et al. 2015a 2015b “Request for continuation of exemption 37, document "37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/general_elcetric/37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf

(HVD). It was thus agreed with the applicant[1895] to take its exemption application into account in the review of Exemption 7c-I.

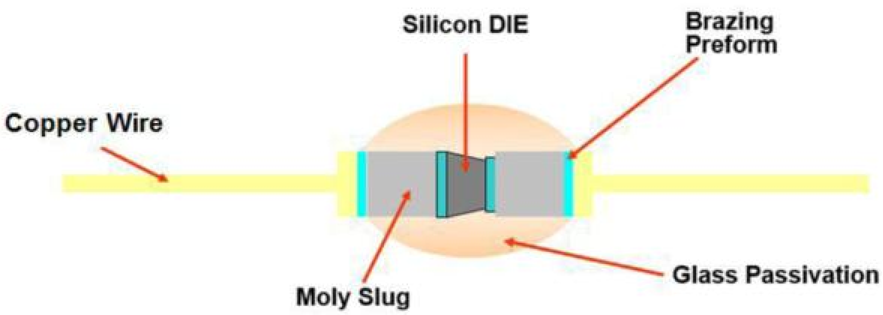
34.1.1 Background and History of the Exemption

The exemption was applied for and reviewed[1896] once in 2007. It was adopted as Exemption 37 to the annex of RoHS 1 and later transferred to Annex III of RoHS 2. The exemption would have expired in July 2016 if no applications for renewal had been submitted.

34.1.2 Technical Description of the Exemption

Figure 34-1 shows an outline of a HVD.

Figure 34-1: Sketch of a high voltage diode based on zinc borate glass



Source: GE et al.[1897]

GE et al.[1898] explain that the difference that sets HVD apart from "conventional" diodes is the special "glass bead design". The glass bead serves as both package and passivation. "Conventional" diode layout is a diode chip soldered between plugs or lead frames embedded in a moulded package.

GE et al.[1899] describe the major features of such HVD:

[1895] IXYS Semiconductor GmbH 2016b "Agreement to shift exemption request to exemption 7c-I, document "IXYS_Shift-to-exe.-7c-I.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickel, IXYS Semiconductor GmbH, on 5 February 2016" unpublished manuscript,

[1896] Carl-Otto Gensch, Stéphanie Zangl, and Otmar Deubzer 2007 "Adaptation to scientific and technical progress under Directive 2002/95/EC: Final report," RoHS II Oeko-Institut e.V., http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf, page 58 et sqq.

[1898] General Electric et al. 2015b 2015 "Answers to first questionnaire (clarification questionnaire, document "Exe_34_Questionnaire-1_GE-Health-et-al_2015-09-15 - reply.pdf", received via e-mail by Otmar Deubzer, Fraunhofer IZM, from James Vetro, GE Healthcare, on 15 September 2015,"

[1899] Ibid.

- They can be built up to breakdown voltages of several kilovolts which cannot be achieved using “conventional” diode packages;
- The special “glass bead” design of those diodes provides hermetical sealing of the chip i.e. that package;

According to the GE et al.[1900], the diodes are used in all categories of electrical and electronic equipment in the scope of RoHS 2. Their main uses are in external power supplies of IT and telecommunication equipment and for automotive applications. The total number of HVD accounts for 100,000,000 pieces per year.

GE et al.[1901] explain that the manufacturing process starts with a silicon chip that is alloyed between two molybdenum (moly) slugs, which are brazed to copper wires. A glass bead is formed around the chip and the moly slugs. Finally the wires are plated. According to GE et al.[1902], during the terminal plating process of the sintered glass diodes, lead from the glass dissolves into the plating solution, which results in around 2.5 % of lead content in the plating layer. Thus, the lead glass is the root cause of the lead content in the wire plating. As such the lead is not added intentionally to the plating layer but is the result of contamination from the lead-containing glass in the manufacturing process.

34.1.3 Amount of Lead Used Under the Exemption

GE et al. [1903] state that the plating layer of the HVD contains 2.5 % of lead and claim that the total amount of lead is a small fraction of the around 350 tonnes of lead that is estimated to be used under exemption 7c-I.

Upon request, GE et al.[1904] present a more substantiated estimate stating that the weight of the plating of HVD is about 3 mg and the lead content in this plating around 2,000 ppm. According to GE et al.[1905] this accounts for about 6×10^{-3} mg of lead, equal to 6×10^{-9} kg lead in the terminal finish per diode.

[1900] General Electric et al. 2015a 2015a “Request for continuation of exemption 34, document "34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf": Original exemption request,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_34/34_RoHS_V_Application_Form_-_Exemption_34_lead_in_trimmer_potentiometers-final.pdf

[1901] Op. cit. General Electric et al. 2015b

[1902] Op. cit. General Electric et al. 2015a

[1903] Op. cit. General Electric et al. 2015a

[1904] General Electric et al. 2015b “Answers to first questionnaire (clarification questionnaire): Clarification questionnaire,” http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/Exe_37_GE_et_al_Questionnaire-1_2015-09-15_reply.pdf

[1905] Ibid.

Based on the known run-rate of a component manufacturer and its estimated share of world market, GE et al.[1906] assume 60 million pieces of HVD annually and present the following overall calculation:

$$60,000,000 \times 6 \times 10^{-9} \sim 0.36 \text{ kg}$$

As a result of this calculation, GE et al.[1907] estimate the overall amount of lead in the plating of HVD in the scope of Exemption 37 to be less than 0.4 kg per year worldwide.

The 2,000 ppm GE et al.[1908] indicate as the lead content in the plating layer of the HVD are equal to 0.2 %, which contradicts the 2.5 % of lead GE et al. [1909] had initially indicated in their exemption request. Assuming a lead content of 2.5 % in the platings of the HVD, the total amount of lead under Exemption 37 would be 4.5 kg. The source of the discrepancy is not known, however the total amount of lead in both cases can be assumed to be in the lower kilogram range.

GE et al.[1910] state that electrical and electronic components are used in a wide range of final products and markets, it is impossible to provide a precise figure of the amount of lead included in glass and ceramic components in the EU for Electrical and Electronic Equipment [EEE]. The electronic equipment industry is engaged in the reduction of lead and environmental burdens within its powers, although it is impossible to completely cease the use of lead under the scope of exemption 37.

The results presented above are an estimate based on company figures. It is possible that there are companies, which are not included in this estimation. It should thus be noted, that the values presented are for reference purposes only.

34.2 Applicants' Justification for the Continuation of the Exemption

GE et al.[1911] state their exemption request follows the same justification criteria as exemption 7(c)-I "Electrical and electronic components containing lead in a glass or ceramic other than dielectric ceramic in capacitors, e.g. piezoelectronic devices, or in a glass or ceramic matrix compound". GE et al.[1912] request to keep the numbering and wording the same to avoid confusion and maintain the initial intention of scope of Exemption 37. They claim that alternative technologies are under evaluation but so far

---

[1906] Ibid.
[1907] Ibid.
[1908] Ibid.
[1909] Op. cit. General Electric et al. 2015a
[1910] Ibid.
[1911] Op. cit. General Electric et al. 2015a
[1912] Ibid.

no substitution technology is available and therefore the renewal of the exemption is requested.

34.2.1 Substitution of Lead in the Glass Bead

The use of lead-free glass in the zinc borat HVD would at the same time solve the lead contamination of the plating layer.

According to GE et al.[1913], lead in zinc borate glass (Exemption 7c-I) is needed to reach similar thermal expansion as the touched metal pins. In addition, the change of the glass type is technically not possible, as the electrical loading of the glass type must be identical with the silicon-type being used within the die (p-Si). Also, with the distance between the Si-blocks only amounting to 180 µm, materials other than glass do not fulfill the specific surface conditions necessary to avoid flashovers at 1,800 V. Furthermore, the expansion of all other materials within the diode (such as the molybdenum slug etc.) is adjusted to this zinc borate glass. Only this kind of glass fulfils all of the technical/physical requirements.

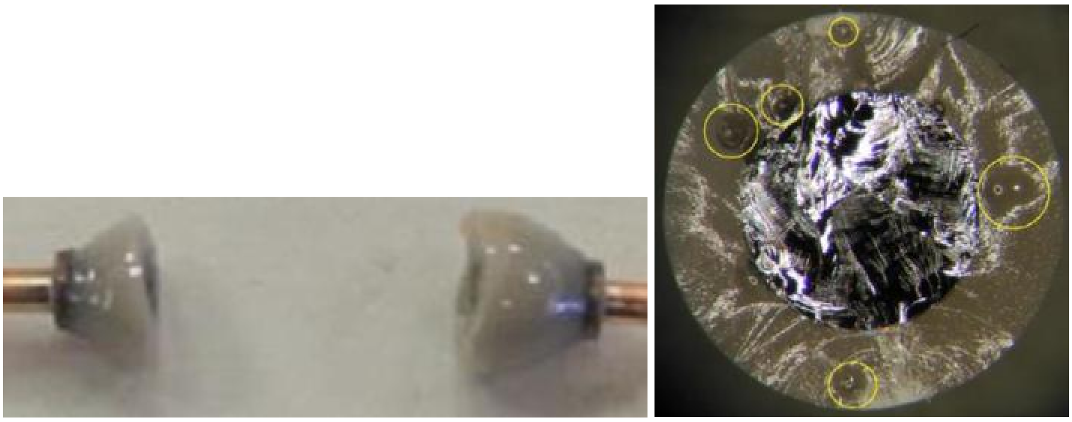
GE et al.[1914] report that latest experiments representing the current technical status have been conducted in 2014 and throughout 2015. Lead-free glass powders from suppliers Schott and NEG were used; precise specifications cannot be provided , with GE et al. citing company-confidential reasons. GE et al.[1915] claim that all attempts failed. Major problems that occurred when using glass types without lead were:

- Bubbles and voids in the glass which can lead to sparks, i.e. shorts along the chip junction;
- Cracks in the glass;
- Poor electrical characteristics due to high leakage currents.

Figure 34-2 shows a HVD with lead-free glass that was cut for optical analysis of the glass, and a cross section of that diode. GE et al.[1916] explain that the silicon chip can be seen in the centre, which is embedded in the Pb-free glass. The yellow circles indicate bubbles as one of the problems with Pb-free glasses. If such bubbles are located at the pn-junction, sparking can occur with high voltages.

[1913] Ibid.
[1914] General Electric et al. 2016a “Answers to questionnaire 2, document "Exe_37_Questionnaire-2_GE-et-al_2016-02-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 11 February 2016” unpublished manuscript,
[1915] Op. cit. General Electric et al. 2015a 2015a
[1916] Op. cit. (General Electric et al. 2016a)

Figure 34-2: Cross-cut HVD (left) and analysis of the glass (right, bubbles marked with yellow circles)



Source: GE et al.[1917]

GE et al.[1918] think the root cause of the mechanism leading to bubbles in the glass is most probably a chemical redox reaction between ingredients of the Pb-free glass and chemicals from the chip. The most critical bubbles are those at the interface of the glass and the chip.

GE et al.[1919] admit that with some of the evaluated glasses in combination with optimized process parameters (sintering temperature profile, sintering atmosphere and pressure, viscosity of the glass slurry, etc.), it was possible to significantly reduce the occurrence of bubbles but claim that electrical characteristics like high leakage, "round" current-voltage curves, and sometimes reduced breakdown voltages are still poor.

GE et al.[1920] [1921] report about such experiments conducted at Vishay with lead-free glasses. HVD with typical 1,600 V breakdown voltage and less than 1 µA leakage current measured at reverse bias of 1,350 V were manufactured with the Pb free glasses under evaluation, electrically tested and compared to the reference control group using Pb-glass. The evaluated Pb-free glasses are labelled as "A" and "B" in Table 34-1.

[1917] Ibid.

[1918] General Electric et al. 2016b "Answer to third questionnaire, document "Exe_37_Questionnaire-3_GE-et-al_2016-03-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016: Answers to third questionnaire" unpublished manuscript,

[1919] General Electric et al. 2016a

[1920] Op. cit. (General Electric et al. 2016a)

[1921] Op. cit. (General Electric et al. 2016b)

Table 34-1: Chemical composition of the tested Pb-free ZnB glasses

		Pb-free "A": ZnB	*Pb-free "B": ZnB*
PbO	**wt%**	0	0
B2O3	**wt%**	10-50	12,1
Al2O3	**wt%**	0	5,4
SiO2	**wt%**	1-10	23,4
ZnO	**wt%**	>50	58,1
Sb2O3	**wt%**	0,1-1	
CeO2	**wt%**	0,1-1	
Bi2O3	**wt%**	1-10	
MnO			0,91
Na2O	**ppm**	48	
Li2O	**ppm**		<0,005
Fe	**ppm**	33	

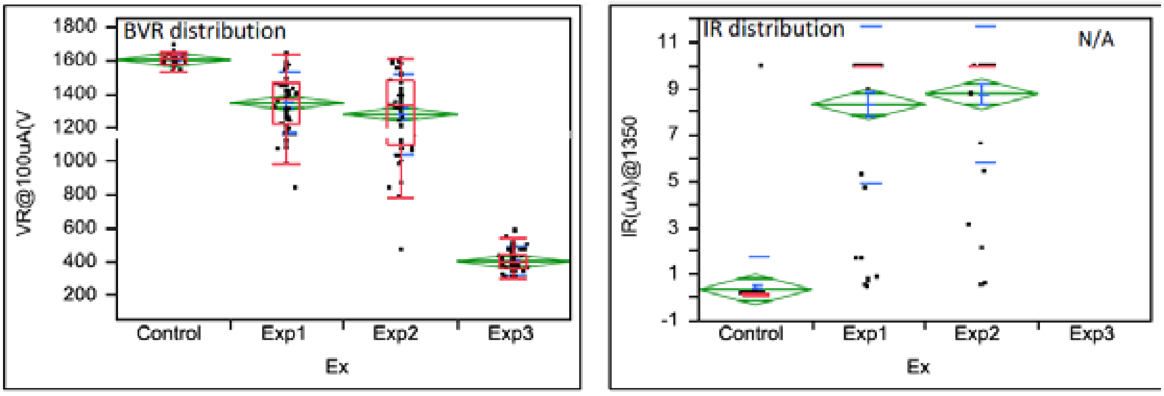
Source: GE et al.[1922]

GE et al. [1923] explain that the sintering profile is an important parameter in optimising and influencing mechanical and electrical characteristics. Glass "A" was therefore processed with two different sintering profiles in order to show the related process influence (EXP1 and EXP2 in the below figures and table).

Figure 34-3 shows the measured breakdown voltage (VBR). The control group (zinc-borate (ZnB) glass with 1-10 weight percent Pb) has a narrow VBR distribution around 1,600 V. Use of the Pb-free glasses A and B reduced the mean value of the breakdown voltage to about 1,300V (EXP1, EXP2) for glass "A" and to less than 400 V for glass "B" (EXP3). All groups have an extremely broad VBR distribution. The measured leakage current (IR) of the control group is less than 0.5 mA. Use of Pb-free glasses (EXP1-3) increased the leakage by a factor more than 20 to about 8-9 mA with broad IR distribution.

[1922] Ibid.
[1923] Ibid.

Figure 34-3: Distribution of breakdown voltage (BVR) and leakage current (IR)



Source: GE et al.[1924]

Table 34-2 lists the electrical yields at final testing regarding internally defined test limits for VBR and IR. Those yields are a direct consequence of the VBR and IR data shown in Figure 34-3. For the control group with Pb-glass, 9,368 out of 11,263 tested diodes passed the given VBR and IR limits, which results in 83,2% electrical yield. Equivalent evaluation for EXP1-3 is summarized in Table 34-2. Due to the very broad distributions of VBR and IR some devices from EXP1 and EXP2 even passed the limits. The yield for EXP3 was 0% because of the stronger degradation of VBR down to 400 V.

Table 34-2: Experimental electrical test results of lead-free glasses

Type	PN	Supplier	EXP NO	TMTT Yield(100% electric testing)		
				Input(ea)	Output(ea)	Yield(%)
Pb-Glass	Pb-glass	SUPPL. 1	Control	11,263	9,368	83.2%
Pb-Free Glass	Pb-free A	SUPPL. 1	EXP1	11,493	1,108	9.6%
	Pb-free A	SUPPL. 1	EXP2	11,399	2,130	18.7%
	Pb-free B	SUPPL. 2	EXP3	11,276	-	0.0%

Source: GE et al.[1925]

GE et al.[1926] highlight that the above evaluation only provides information on IR and VBR. These tests were, however, chosen in order to select first select the lead-free glass devices with the best electrical properties, which were then subjected to high reliability testing according to standard AEC-Q101. One important test which is crucial to proper chip and passivation quality is the High Temperature Reverse Bias (HTRB) test. In this

[1924] Ibid.
[1925] Ibid.
[1926] Ibid.

test, 77 diodes are biased at 100% rated reverse voltage at elevated (maximum data sheet specs) ambient temperature. The electrical device characteristics before and after testing are compared. Table 34-3 shows the results.

Table 34-3: Result of high reliability testing results of the lead-free samples

Hi-Rel No. :							
Test Item & Condition	Lot No.	EXP1¶			EXP2¶		
	Duration	Sample Size	Parametric failure (P)	Catastrophic failure (C)	Sample Size	Parametric failure (P)	Catastrophic failure (C)
H.T.R.B--(Tj=175°C)	168 Hrs	77	9	0	77	6	1
	500 Hrs	77	11	1	77	10	1
	1000 Hrs	77	11	3	77	12	2

Source: GE et al.[1927]

Table 34-4 presents the results of the control lot manufactured with lead-containing glass, which shows no failures.

Table 34-4: High reliability testing results of the lead control

Test Item & Conditions	Lot No.	Control Lot		
	Duration	Sample Size	Parametric failure (P)	Catastrophic failure (C)
H.T.R.B (Tj=175°C)	168 Hrs	77	0	0
	500 Hrs	77	0	0
	1000 Hrs	77	0	0

Source: GE et al.[1928]

GE et al.[1929] summarize that the use of Pb-free glasses results in degradation of the electrical characteristics (premature breakdown, increased leakage current, “round” current-voltage curves). Even the selected devices with the best electrical properties dramatically fail the high reliability test.

GE et al.[1930] explain that for good electrical characteristics of a chip embedded in glass, a number of properties need to be ensured:

[1927] Ibid.
[1928] General Electric et al. 2016c “E-mail communication, document "E-Mail-Communication_GE-et-al_2016-03-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, until 16 March 2016” unpublished manuscript,
[1929] Op. cit. (General Electric et al. 2016b)
[1930] Ibid.

- Proper charge balance in the glass to reduce the electrical field at the interface silicon-glass;
- Low mechanical strain, i.e. good match of thermal expansion between silicon and glass. The glass transition temperature TG of Pb-free glass types is significantly higher compared to Pb-glasses which generates higher mechanical strain during cooling after the sintering process;
- Good wettability of the silicon by the glass to avoid delamination etc.

According to GE et al.,[1931] so far none of the evaluated glass types ensured the combination of all those features, which results on device level in electrical characteristics ranging from shorts (worst case) to high leakage currents, "round" current-voltage curves, reduced breakdown voltage and also parametric drifts and thermal runaway of selected "acceptable" devices during HTRB testing.

GE et al.[1932] conclude that the tested lead-free glass materials are not yet mature for use in zinc-borate glass HVD.

34.2.2 Elimination of Lead

Besides substitution, elimination (i.e. the use of alternative technologies) is a principal way to avoid the use of lead, e.g. via a redesign of electronic circuits so that these HVD are no longer required.

GE et al.[1933] [1934] claim that HVD are used in high voltage power supplies, inverters, converters and freewheeling diode applications where their use is indispensable. GE et al.[1935] roughly group the uses of HVD as follows:

- Automotive applications (classical use: ignition);
- Lighting (classical use: electronic ballast);
- Industrial (classical use: Switch mode power supply - SMPS, inverters, freewheeling, etc.);
- Medical (often used in circuits for X-ray and CT (computer tomography). Use in high voltage power supply (i.e. where > 100 000V needs to be generated).

GE et al.[1936] give examples for applications in the scope of the RoHS Directive and of this review as follows.

34.2.2.1 HVD in Lighting Application (Electronic Ballasts)

A classical use of HVD in lighting applications is in electronic ballast of neon glow lamps. HVD are used in several positions of the ballast circuit:

1931 Ibid.
1932 Op. cit. (General Electric et al. 2016a)
1933 Op. cit. (General Electric et al. 2015b)
1934 Op. cit. (General Electric et al. 2016b)
1935 Ibid.
1936 Ibid.

- Bridge input rectification circuit;
- Power factor correction circuit;
- Others.

GE et al.[1937] claim that according to their knowledge and according to customers' inputs, HVD are inevitable devices for such circuits.

34.2.2.2 HVD in Industrial Electronics

According to GE et al.[1938], HVD are used in Switch Mode Power Supplies (SMPS). Their basic functions are:

- First step: the conversion of incoming alternate current (AC) to direct current (DC);
- Second step: the transformation to various DC voltage levels (including HV) dependent on final application.

GE et al.[1939] state that HVD among others must block main voltage spikes. GE et al. say that to their best knowledge and also according to customers' inputs HVD cannot be omitted in such circuits.

34.2.3 Avoidance of the Lead Contamination of the Plating Layer

34.2.3.1 Alternative Manufacturing Process

GE et al.[1940] [1941] explain that the leads of the HVD are plated in an electroplating process at typically 25 °C to 50 °C. Major process steps are:

- Pre-cleaning to remove oxides from the copper leads to be plated. The main component used of this pre-cleaning is H_2SO_4 (sulphuric acid);
- Electroplating in a galvanic bath with metasulfonic acid (MSA) and a tin chemical solution (SN chemical) as main components;
- Post cleaning with the main component (Na_3PO_4) (sodium phosphate).

GE et al.[1942] say that the lead contaminates the galvanic bath because the bath chemistry slightly etches the glass so that traces of lead dissolve and deposit onto the plating layer.

Reversing the order of processing, i.e. applying the tin plating prior to the glass bead, could in principle avoid the lead contamination of the plating layer. GE et al.[1943] explain that the glass bead is sintered at temperatures in the range of 700 °C. Tin has a melting

[1937] Ibid.
[1938] Ibid.
[1939] Ibid.
[1940] Op. cit. (General Electric et al. 2016a)
[1941] Op. cit. (General Electric et al. 2016b)
[1942] Ibid.
[1943] Op. cit. (General Electric et al. 2016a)

point of around 231 °C so that the tin plating would not survive this high temperature process and hence needs to be applied after the glass bead.

34.2.3.2 Inhibition of Lead Contamination

The presence of lead in the plating layer could be avoided by inhibiting the lead in the bath to penetrate into the plating layer, e.g. by protective layers, or additives to the plating bath. GE et al.[1944] say that additives to the plating bath will not help because PbO is dissolved in the galvanic bath. Additives to the bath would not prevent dissolution. However, protecting the glass during immersion in the galvanic bath to prevent the contact of the glass with the acids in the bath might be a potential way to solve the lead contamination issue. GE et al.[1945] embedded the glass body into a protective compound, which then will remain on the final product so that the product will change and that way prevented dissolving of PbO in the galvanic acid. GE et al.[1946] will further pursue related activities, but have to investigate the consequences of the product modification and to understand whether so far unidentified barriers will be encountered.

34.3 Roadmap for Substitution or Elimination of RoHS-Restricted Substance

According to GE et al.,[1947] there is no suitable substance for substituting lead. They claim that significant efforts are undertaken to eliminate lead in the glass body of the diode, but that so far no technical mature solution is available. Once lead can be eliminated in the glass body, it will also solve the contamination of the tinning. There are no prospects concerning the technical scope of Exemption 37 for a comprehensive substitution in the foreseeable future. Therefore such information and analysis required for a roadmap are not applicable in this case.

34.4 Critical Review

34.4.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 of this report lists various entries in the REACH Regulation annexes that restrict the use of lead in various articles and uses.

The exemption allows the use of lead.

Annex XIV contains several entries for lead compounds, whose use requires authorization:

- 10. Lead chromate
- 11. Lead sulfochromate

[1944] Op. cit. (General Electric et al. 2016b)
[1945] Ibid.
[1946] Ibid.
[1947] Op. cit. (General Electric et al. 2015a 2015a)

- 12. Lead chromate molybdate sulphate red

In the applications in the scope of the reviewed exemption, lead is used in electronic components that become parts of articles. None of the above listed substances is relevant for this case, neither as directly added substances nor as substances that can reasonably be assumed to be generated in the course of the manufacturing process.

Annex XVII bans the use of the following lead compounds:

- 16. Lead carbonates in paints
- 17. Lead sulphate in paints

Neither the substances nor the application are, however, relevant for the exemption in the scope of this review.

Appendix A.1.0 of this report lists Entry 28 and Entry 30 in Annex XVII of the REACH Regulation, stipulating that lead and its compounds shall not be placed on the market, or used, as substances, constituents of other substances, or in mixtures for supply to the general public. A prerequisite to granting the requested exemption would therefore be to establish whether the intended use of lead in this exemption request might weaken the environmental and health protection afforded by the REACH regulation.

In the consultants' understanding, the restrictions for substances under Entry 28 and Entry 30 of Annex XVII do not apply. The use of lead in this RoHS exemption in the consultants' point of view is not a supply of lead and its compounds as a substance, mixture or constituent of other mixtures to the general public. Lead is part of an article and as such, Entry 30 of Annex XVII of the REACH Regulation would not apply.

Entry 63 of Annex XVII stipulates that lead and its compounds

- "shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0.05 % by weight." This restriction does not apply to internal components of watch timepieces inaccessible to consumers;
- "shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0.05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children." This restriction, however, does not apply to articles within the scope of Directive 2011/65/EU (RoHS 2).

The restrictions of lead and its compounds listed under entry 63 thus do not apply to the applications in the scope of this RoHS exemption.

No other entries, relevant for the use of lead in the requested exemption could be identified in Annex XIV and Annex XVII (status February 2016). Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

34.4.2 Substitution and Elimination of Lead

The stakeholders' justification and other information provided may have created the impression that Exemption 7c-I would allow the presence of lead in the plating layer, which is addressed in the scope of Exemption 37. On request, GE et al.[1948] confirm that this is not the case. Exemption 7c-I covers the use of lead in the glass of the HVD only. Exemption 37, however, only allows the occurrence of lead in the tin wire plating as a result of lead diffusion into the metal (tin) plating from the lead-containing glass during the plating process. While Exemption 7c-I covers the use of lead in the glass, Exemption 37 covers the lead in the tin plating of the HVD. Exemption 37 can therefore not be integrated into exemption 7c-I.

The occurrence of lead in the platings of zinc-borate glass HVD is the consequence of the use of lead-containing glass in the glass bead of such HVD as covered by Exemption 7c-I. There are three principle ways to overcome the problem:

- To use lead-free glass; or
- Eliminate the lead problem by applying alternative technologies that can replace HVD; or
- Change the process, in particular by applying the plating before the glass bead; or
- Inhibiting the diffusion of lead out of the lead glass bead of the HVD.

GE et al.[1949] [1950] claimed to have made considerable efforts to solve the problem, but the information GE et al. had provided in the exemption request and in the clarification questionnaire was highly insufficient to justify the renewal of the requested exemption. Only upon repeated requests[1951] [1952] [1953] [1954] did GE et al. present step by step more detailed and more specific information.

Based on the information available, the use of HVD must be considered to be indispensable so that the elimination of the lead problem by alternative technologies replacing HVD is technically impracticable at the current state of technology.

GE et al. present tests of lead-free materials for the HVD glass beads, the latest from 2015, to prove that lead-free glass materials are not yet mature for use in zinc-borate glass HVD. These tests are plausible and show some efforts by GE et al. to find lead-free alternatives to the lead glass that is used in HVD. Based on these tests, it can be concluded that currently lead-free glasses are not appropriate to prevent the lead contamination of the HVD plating layer.

[1948] Op. cit. (General Electric et al. 2015b 2015)
[1949] Op. cit. (General Electric et al. 2015a 2015a)
[1950] Op. cit. (General Electric et al. 2015b 2015)
[1951] Op. cit. (General Electric et al. 2015b)
[1952] Op. cit. (General Electric et al. 2016a)
[1953] Op. cit. (General Electric et al. 2016b)
[1954] Op. cit. (General Electric et al. 2016c)

The same applies to changing the process order, i.e. applying the lead glass bead prior to the plating process so that lead from the glass bead cannot contaminate the plating layer. The lower melting tin layer would not survive the high process temperature for the sintering of the glass bead onto the HVD so that a reverse process order is not a solution to the lead contamination problem.

The inhibition of lead diffusion out of the lead glass seems to be a promising approach. A protective layer around the glass bead could prevent its contact with the acids in the plating bath so that lead can no longer contaminate the bath and thus the plating layer. GE et al. had only mentioned this aspect very late within the review process for this exemption in response to the last submitted questionnaire[1955] after the reviewers had previously specifically asked for the viability of alternative approaches to solve the lead contamination problem. GE et al.[1956] then claimed they had conducted tests already and intend to further pursue this possibility, but also have to investigate the consequences of such a protective layer on the electrical and mechanical properties of the component. GE et al. did not indicate any time frame or present further details on this approach. Given the limited timeframe of the evaluation and the fact that GE et al. were given several possibilities already to present detailed information substantiating their exemption request, the consultants did not ask for further details.

The applicants' exemption request and the answers to the clarification questionnaire were made available through the public online consultation (i.e. to industry, governments, NGOs and other stakeholders). A questionnaire had been prepared for the public stakeholder consultation with specific questions to stakeholders. No further information supporting or discrediting the technical application in question was received.

34.4.3 Conclusions

Based on the information available, the reviewers conclude that the avoidance of lead in the plating layers of zinc borate HVD is currently scientifically and technically impracticable. The approach to apply a protective layer to the glass bead during the plating process to prevent the lead contamination of the plating layer should, however, be further investigated.

The available information allows concluding that avoiding the contamination of the plating layer of HVD currently is technically impracticable. RoHS Art. 5(1)(a) would allow the renewal of the exemption. As the applicants did not provide details about the status and timing of research to avoid the lead contaminations, it cannot be excluded that substitution or elimination of lead becomes scientifically and technically practicable within less than five years so that Art. 5(1)(a) would not allow granting the exemption for the maximum validity period. The consultants therefore recommend to renew the

---

[1955] Op. cit. (General Electric et al. 2016b)
[1956] Ibid.

exemption for three years only, until 21 July 2019, which would allow to restrict the scope of the exemption and still leave sufficient time for industry to apply for the continuation of the exemption should it still be required by then.

34.5 Recommendation

Based on the presented information, the reviewers conclude that currently avoiding the lead in the plating layer of zinc-borate glass high voltage diodes is scientifically and technically impracticable. Art. 5(1)(a) in this situation would justify the continuation of the exemption in its current scope and wording. Protective coatings of the glass bead to prevent lead from the glass bead contaminating the plating layer are, however, discussed as a possible approach. It is therefore recommended to renew exemption 37, but to set an expiry date on 21 July 2019 as the applicants' information does not allow excluding that the substitution or elimination of lead shall become scientifically and technically practicable in less than five years.

<table>
<tr><th>Exemption 37</th><th>Expires on</th></tr>
<tr><td rowspan="4">Lead in the plating layer of high voltage diodes on the basis of a zinc borate glass body</td><td>21 July 2019 for categories 1-7 and 10</td></tr>
<tr><td>21 July 2021 for
· medical equipment in category 8
· monitoring and control instruments in category 9</td></tr>
<tr><td>21 July 2023 for in vitro diagnostic medical devices in category 8</td></tr>
<tr><td>21 July 2024 for industrial monitoring and control instruments in category 9</td></tr>
</table>

34.6 References Exemption 37

General Electric et al. 2015a Request for continuation of exemption 37, document "37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf" 2015b. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/general_elcetric/37_RoHS_V_Application_Form_-_Exemption_37_lead_in_high_voltage_diodes_final.pdf.

General Electric et al. 2015b Answers to first questionnaire (clarification questionnaire). http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/Exe_37_GE_et_al_Questionnaire-1_2015-09-15_reply.pdf.

General Electric et al. 2016a Answers to questionnaire 2, document "Exe_37_Questionnaire-2_GE-et-al_2016-02-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 11 February 2016.

General Electric et al. 2016b Answer to third questionnaire, document "Exe_37_Questionnaire-3_GE-et-al_2016-03-11_reply.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, on 12 March 2016.

General Electric et al. 2016c E-mail communication, document "E-Mail-Communication_GE-et-al_2016-03-16.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from James Vetro, General Electric, until 16 March 2016.

Gensch, Carl-Otto, Stéphanie Zangl, and Otmar Deubzer Adaptation to scientific and technical progress under Directive 2002/95/EC 2007. http://ec.europa.eu/environment/waste/weee/pdf/rohs.pdf.

IXYS Semiconductor GmbH 2014 Request for continuation of exemption 37, document "37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf" 2014. http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_37/IXYS/37_IXYS_RoHS_V_Application_Form_pass_glasses.pdf.

IXYS Semiconductor GmbH 2016b Agreement to shift exemption request to exemption 7c-I, document "IXYS_Shift-to-exe.-7c-I.pdf", received via e-mail by Dr. Otmar Deubzer, Fraunhofer IZM, from Markus Bickel, IXYS Semiconductor GmbH, on 5 February 2016.

APPENDICES

A.1.0 Appendix 1: Relevant REACH Regulation Entries

Relevant annexes and processes related to the REACH Regulation have been cross-checked to clarify:

- In what cases granting an exemption could "weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006" (Article 5(1)(a), pg.1)
- Where processes related to the REACH regulation should be followed to understand where such cases may become relevant in the future;

The last consolidated version has been consulted in this respect, published on 2 February 2016. Compiled information in this respect has been included, with short clarifications where relevant, in the following tables: Table A. 1 lists those substances appearing in Annex XIV, subject to Authorisation, which are relevant to the RoHS substances dealt with in the requests evaluated in this project. As can be seen, at present, exemptions have not been granted for the use of these substances.

Table A. 1: Relevant Entries from Annex XIV: The List of Substances Subject to Authorization

Designation of the substance, of the group of substances, or of the mixture	Transitional arrangements		Exempted (categories of) uses
	Latest application date (1)	Sunset date (2)	
4. Bis(2-ethylhexyl) phthalate (DEHP) **EC No: 204-211-0** **CAS No: 117-81-7**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
5. Benzyl butyl phthalate (BBP) **EC No: 201-622-7** **CAS No: 85-68-7**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
6. Dibutyl phthalate (DBP) **EC No: 201-557-4** **CAS No: 84-74-2**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
7. Diisobutyl phthalate (DIBP) **EC No: 201-553-2** **CAS No: 84-69-5**	21 August 2013	21 February 2015	
10. Lead chromate **EC No: 231-846-0**	21 Nov 2013	21 May 2015	-

Designation of the substance, of the group of substances, or of the mixture	Transitional arrangements		Exempted (categories of) uses
	Latest application date (1)	Sunset date (2)	
CAS No: 7758-97-6			
11. Lead sulfochromate yellow (C.I. Pigment Yellow 34) EC No: 215-693-7 CAS No: 1344-37-2	21 Nov 2013	21 May 2015	-
12. Lead chromate molybdate sulphate red (C.I. Pigment Red 104) EC No: 235-759-9 CAS No: 12656-85-8	21 Nov 2013	21 May 2015	-
16. Chromium trioxide EC No: 215-607-8 CAS No: 1333-82-0	21 Mar 2016	21 Sep 2017	-
17. Acids generated from chromium trioxide and their oligomers Group containing: Chromic acid EC No: 231-801-5 CAS No: 7738-94-5 Dichromic acid EC No: 236-881-5 CAS No: 13530-68-2 Oligomers of chromic acid and dichromic acid EC No: not yet assigned CAS No: not yet assigned	21 Mar 2016	21 Sep 2017	-
18. Sodium dichromate EC No: 234-190-3 CAS No: 7789-12-0 10588-01-9	21 Mar 2016	21 Sep 2017	-
19. Potassium dichromate EC No: 231-906-6 CAS No: 7778-50-9	21 Mar 2016	21 Sep 2017	-
20. Ammonium dichromate EC No: 232-143-1 CAS No: 7789-09-5	21 Mar 2016	21 Sep 2017	-
21. Potassium chromate EC No: 232-140-5 CAS No: 7789-00-6	21 Mar 2016	21 Sep 2017	
22. Sodium chromate EC No: 231-889-5 CAS No: 7775-11-3	21 Mar 2016	21 Sep 2017	
28. Dichromium tris(-chromate) EC No: 246-356-2 CAS No: 24613-89-6	22. July 2017	22 January 2019	
29. Strontium chromate EC No: 232-142-6 CAS No: 7789-06-2	22 July 2017	22 January 2019	
30. Potassium hydroxyoctaoxodizincatedichromate EC No: 234-329-8 CAS No: 11103-86-9	22 July 2017	22 January 2019	
31. Pentazinc chromate octahydroxide EC No: 256-418-0 CAS No: 49663-84-5	22 July 2017	22 January 2019	

For the substances currently restricted according to RoHS Annex II: cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyls and polybrominated diphenyl ethers and their compounds, we have found that some relevant entries are listed in Annex XVII of the REACH Regulation. The conditions of restriction are presented in Table A. 2 below. Additionally, some amendments have been decided upon, and are still to be included in the concise version. These may be seen in Table A. 3.

Table A. 2: Conditions of Restriction in REACH Annex XVII for RoHS Substances and Compounds

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
8. Polybromobiphenyls; Polybrominatedbiphenyls (PBB) **CAS No 59536-65-1**	1. Shall not be used in textile articles, such as garments, undergarments and linen, intended to come into contact with the skin. 2. Articles not complying with paragraph 1 shall not be placed on the market.
16. Lead carbonates: **(a) Neutral anhydrous carbonate ($PbCO_3$)** **CAS No 598-63-0** **EC No 209-943-4** **(b) Trilead-bis(carbonate)-dihydroxide $2PbCO_3$-$Pb(OH)_2$** **CAS No 1319-46-6** **EC No 215-290-6**	Shall not be placed on the market, or used, as substances or in mixtures, where the substance or mixture is intended for use as paint. However, Member States may, in accordance with the provisions of International Labour Organization (ILO) Convention 13, permit the use on their territory of the substance or mixture for the restoration and maintenance of works of art and historic buildings and their interiors, as well as the placing on the market for such use. Where a Member State makes use of this derogation, it shall inform the Commission thereof.
17. Lead sulphates: **(a) $PbSO_4$** **CAS No 7446-14-2** **EC No 231-198-9** **(b) $Pb_x SO_4$** **CAS No 15739-80-7** **EC No 239-831-0**	Shall not be placed on the market, or used, as substances or in mixtures, where the substance or mixture is intended for use as paint. However, Member States may, in accordance with the provisions of International Labour Organization (ILO) Convention 13, permit the use on their territory of the substance or mixture for the restoration and maintenance of works of art and historic buildings and their interiors, as well as the placing on the market for such use. Where a Member State makes use of this derogation, it shall inform the Commission thereof.
18. Mercury compounds	Shall not be placed on the market, or used, as substances or in mixtures where the substance or mixture is intended for use: (a) to prevent the fouling by micro-organisms, plants or animals of: — the hulls of boats, — cages, floats, nets and any other appliances or equipment used for fish or shellfish farming, — any totally or partly submerged appliances or equipment; (b) in the preservation of wood; (c) in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture; (d) in the treatment of industrial waters, irrespective of their use.
18a. Mercury **CAS No 7439-97-6** **EC No 231-106-7**	1. Shall not be placed on the market: (a) in fever thermometers; (b) in other measuring devices intended for sale to the general public (such as manometers, barometers, sphygmomanometers, thermometers other than fever thermometers). 2. The restriction in paragraph 1 shall not apply to measuring devices that were in use in the Community before 3 April 2009. However Member States may restrict or prohibit the placing on the market of such measuring devices.

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	3. The restriction in paragraph 1(b) shall not apply to: (a) measuring devices more than 50 years old on 3 October 2007; (b) barometers (except barometers within point (a)) until 3 October 2009. 5. The following mercury-containing measuring devices intended for industrial and professional uses shall not be placed on the market after 10 April 2014: (a) barometers; (b) hygrometers; (c) manometers; (d) sphygmomanometers; (e) strain gauges to be used with plethysmographs; (f) tensiometers; (g) thermometers and other non-electrical thermometric applications. The restriction shall also apply to measuring devices under points (a) to (g) which are placed on the market empty if intended to be filled with mercury. 6. The restriction in paragraph 5 shall not apply to: (a) sphygmomanometers to be used: (i) in epidemiological studies which are ongoing on 10 October 2012; (ii) as reference standards in clinical validation studies of mercury-free sphygmomanometers; (b) thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers until 10 October 2017; (c) mercury triple point cells which are used for the calibration of platinum resistance thermometers. 7. The following mercury-using measuring devices intended for professional and industrial uses shall not be placed on the market after 10 April 2014: (a) mercury pycnometers; (b) mercury metering devices for determination of the softening point. 8. The restrictions in paragraphs 5 and 7 shall not apply to: (a) measuring devices more than 50 years old on 3 October 2007; (b) measuring devices which are to be displayed in public exhibitions for cultural and historical purposes.
23. Cadmium and its compounds **CAS No 7440-43-9** **EC No 231-152-8**	For the purpose of this entry, the codes and chapters indicated in square brackets are the codes and chapters of the tariff and statistical nomenclature of Common Customs Tariff as established by Council Regulation (EEC) No 2658/87 (1). 1. Shall not be used in mixtures and articles produced from the following synthetic organic polymers (hereafter referred to as plastic material): — polymers or copolymers of vinyl chloride (PVC) [3904 10] [3904 21] — polyurethane (PUR) [3909 50] — low-density polyethylene (LDPE), with the exception of low-density polyethylene used for the production of coloured masterbatch [3901 10] — cellulose acetate (CA) [3912 11] — cellulose acetate butyrate (CAB) [3912 11] — epoxy resins [3907 30] — melamine-formaldehyde (MF) resins [3909 20] — urea-formaldehyde (UF) resins [3909 10] — unsaturated polyesters (UP) [3907 91] — polyethylene terephthalate (PET) [3907 60] — polybutylene terephthalate (PBT) — transparent/general-purpose polystyrene [3903 11] — acrylonitrile methylmethacrylate (AMMA)

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	— cross-linked polyethylene (VPE) — high-impact polystyrene — polypropylene (PP) [3902 10] Mixtures and articles produced from plastic material as listed above shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight of the plastic material. By way of derogation, the second subparagraph shall not apply to articles placed on the market before 10 December 2011. The first and second subparagraphs apply without prejudice to Council Directive 94/62/EC (13) and acts adopted on its basis. By 19 November 2012, in accordance with Article 69, the Commission shall ask the European Chemicals Agency to prepare a dossier conforming to the requirements of Annex XV in order to assess whether the use of cadmium and its compounds in plastic material, other than that listed in subparagraph 1, should be restricted. 2. Shall not be used in paints [3208] [3209]. For paints with a zinc content exceeding 10 % by weight of the paint, the concentration of cadmium (expressed as Cd metal) shall not be equal to or greater than 0,1 % by weight. Painted articles shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,1 % by weight of the paint on the painted article. 3. By way of derogation, paragraphs 1 and 2 shall not apply to articles coloured with mixtures containing cadmium for safety reasons. 4. By way of derogation, paragraph 1, second subparagraph shall not apply to: — mixtures produced from PVC waste, hereinafter referred to as 'recovered PVC', — mixtures and articles containing recovered PVC if their concentration of cadmium (expressed as Cd metal) does not exceed 0,1 % by weight of the plastic material in the following rigid PVC applications: — (a) profiles and rigid sheets for building applications; (b) doors, windows, shutters, walls, blinds, fences, and roof gutters; (c) decks and terraces; (d) cable ducts; (e) pipes for non-drinking water if the recovered PVC is used in the middle layer of a multilayer pipe and is entirely covered with a layer of newly produced PVC in compliance with paragraph 1 above. Suppliers shall ensure, before the placing on the market of mixtures and articles containing recovered PVC for the first time, that these are visibly, legibly and indelibly marked as follows: '*Contains recovered PVC*' or with the following pictogram:  In accordance with Article 69 of this Regulation, the derogation granted in paragraph 4 will be reviewed, in particular with a view to reducing the limit

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	value for cadmium and to reassess the derogation for the applications listed in points (a) to (e), by 31 December 2017. 5. For the purpose of this entry, ‘cadmium plating’ means any deposit or coating of metallic cadmium on a metallic surface. Shall not be used for cadmium plating metallic articles or components of the articles used in the following sectors/applications: (a) equipment and machinery for: — food production [8210] [8417 20] [8419 81] [8421 11] [8421 22] [8422] [8435] [8437] [8438] [8476 11] — agriculture [8419 31] [8424 81] [8432] [8433] [8434] [8436] — cooling and freezing [8418] — printing and book-binding [8440] [8442] [8443] (b) equipment and machinery for the production of: — household goods [7321] [8421 12] [8450] [8509] [8516] — furniture [8465] [8466] [9401] [9402] [9403] [9404] — sanitary ware [7324] — central heating and air conditioning plant [7322] [8403] [8404] [8415] In any case, whatever their use or intended final purpose, the placing on the market of cadmium-plated articles or components of such articles used in the sectors/applications listed in points (a) and (b) above and of articles manufactured in the sectors listed in point (b) above is prohibited. 6. The provisions referred to in paragraph 5 shall also be applicable to cadmium-plated articles or components of such articles when used in the sectors/applications listed in points (a) and (b) below and to articles manufactured in the sectors listed in (b) below: (a) equipment and machinery for the production of: — paper and board [8419 32] [8439] [8441] textiles and clothing [8444] [8445] [8447] [8448] [8449] [8451] [8452] (b) equipment and machinery for the production of: — industrial handling equipment and machinery [8425] [8426] [8427] [8428] [8429] [8430] [8431] — road and agricultural vehicles [chapter 87] — rolling stock [chapter 86] — vessels [chapter 89] 7. However, the restrictions in paragraphs 5 and 6 shall not apply to: — articles and components of the articles used in the aeronautical, aerospace, mining, offshore and nuclear sectors whose applications require high safety standards and in safety devices in road and agricultural vehicles, rolling stock and vessels, — electrical contacts in any sector of use, where that is necessary to ensure the reliability required of the apparatus on which they are installed. 8. Shall not be used in brazing fillers in concentration equal to or greater than 0,01 % by weight. Brazing fillers shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight. For the purpose of this paragraph brazing shall mean a joining technique using alloys and undertaken at temperatures above 450 °C. 9. By way of derogation, paragraph 8 shall not apply to brazing fillers used in defence and aerospace applications and to brazing fillers used for safety reasons. 10. Shall not be used or placed on the market if the concentration is equal to or

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	greater than 0,01 % by weight of the metal in: (i) metal beads and other metal components for jewellery making; (ii) metal parts of jewellery and imitation jewellery articles and hair accessories, including: — bracelets, necklaces and rings, — piercing jewellery, — wrist-watches and wrist-wear, — brooches and cufflinks. 11. By way of derogation, paragraph 10 shall not apply to articles placed on the market before 10 December 2011 and jewellery more than 50 years old on 10 December 2011.
28. **Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as carcinogen category 1A or 1B (Table 3.1) or carcinogen category 1 or 2 (Table 3.2) and listed as follows:** **— Carcinogen category 1A (Table 3.1)/carcinogen category 1 (Table 3.2) listed in Appendix 1** **— Carcinogen category 1B (Table 3.1)/carcinogen category 2 (Table 3.2) listed in Appendix 2:** **Chromium (VI) trioxide** **Zinc chromates including zinc potassium chromate** **Nickel chromate** **Nickel dichromate** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Chromyl dichloride; chromic oxychloride** **Potassium chromate** **Calcium chromate** **Strontium chromate** **Chromium (VI) compounds, with the exception of barium chromate and of compounds specified elsewhere in Annex VI to Regulation (EC) No 1272/2008** **Chromium III chromate; chromic chromate** **Sodium chromate** **Cadmium oxide** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate**	Without prejudice to the other parts of this Annex the following shall apply to entries 28 to 30: 1. Shall not be placed on the market, or used, — as substances, — as constituents of other substances, or, — in mixtures, for supply to the general public when the individual concentration in the substance or mixture is equal to or greater than: — either the relevant specific concentration limit specified in Part 3 of Annex VI to Regulation (EC) No 1272/2008, or, — the relevant generic concentration limit specified in Part 3 of Annex I of Regulation (EC) No 1272/2008. Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labelling of substances and mixtures, suppliers shall ensure before the placing on the market that the packaging of such substances and mixtures is marked visibly, legibly and indelibly as follows: 2. By way of derogation, paragraph 1 shall not apply to: (a) medicinal or veterinary products as defined by Directive 2001/82/EC and Directive 2001/83/EC; (b) cosmetic products as defined by Directive 76/768/EEC; (c) the following fuels and oil products: — motor fuels which are covered by Directive 98/70/EC, — mineral oil products intended for use as fuel in mobile or fixed combustion plants, — fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Regulation (EC) No 1272/2008; (e) the substances listed in Appendix 11, column 1, for the applications or uses listed in Appendix 11, column 2. Where a date is specified in column 2 of Appendix 11, the derogation shall apply until the said date.

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
Cadmium sulphide Cadmium (pyrophoric) Chromium (VI) trioxide Lead Chromate Lead hydrogen arsenate Silicic acid, lead nickel salt Lead sulfochromate yellow; C.I. Pigment Yellow 34; Lead chromate molybdate sulfate red; C.I. Pigment Red 104;	
29. Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as germ cell mutagen category 1A or 1B (Table 3.1) or mutagen category 1 or 2 (Table 3.2) and listed as follows: — Mutagen category 1A (Table 3.1)/mutagen category 1 (Table 3.2) listed in Appendix 3 — Mutagen category 1B (Table 3.1)/mutagen category 2 (Table 3.2) listed in Appendix 4 Cadmium chloride Cadmium fluoride Cadmium Sulphate Chromium (VI) trioxide Potassium dichromate Ammonium dichromate Sodium dichromate Chromyl dichloride; chromic oxychloride Potassium chromate Sodium chromate	
30. Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as toxic to reproduction category 1A or 1B (Table 3.1) or toxic to reproduction category 1 or 2 (Table 3.2) and listed as follows: — Reproductive toxicant category 1A adverse effects on sexual function and fertility or on development (Table 3.1) or reproductive toxicant category 1 with R60 (May impair fertility) or R61 (May cause harm to the unborn child) (Table 3.2) listed in Appendix 5	

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
— Reproductive toxicant category 1B adverse effects on sexual function and fertility or on development (Table 3.1) or reproductive toxicant category 2 with R60 (May impair fertility) or R61 (May cause harm to the unborn child) (Table 3.2) listed in Appendix 6: **Bis(2-ethylhexyl) phthalate; di-(2-ethylhexyl) phthalate; DEHP** **Benzyl butyl phthalate; BBP** **Dibutyl phthalate; DBP** **Diisobutyl phthalate** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Sodium chromate** **Nickel dichromate** **Lead compounds with the exception of those specified elsewhere in this Annex** **Lead hydrogen arsenate** **Lead acetate** **Lead alkyls** **Lead azide** **Lead Chromate** **Lead di(acetate)** **Lead hydrogen arsenate** **Lead 2,4,6-trinitroresorcinoxide, lead styphnate** **Lead(II) methane- sulphonate** **Trilead bis- (orthophosphate)** **Lead hexa-fluorosilicate** **Mercury** **Silicic acid, lead nickel salt**	
47. Chromium VI compounds	1. Cement and cement-containing mixtures shall not be placed on the market, or used, if they contain, when hydrated, more than 2 mg/kg (0,0002 %) soluble chromium VI of the total dry weight of the cement. 2. If reducing agents are used, then without prejudice to the application of other Community provisions on the classification, packaging and labelling of substances and mixtures, suppliers shall ensure before the placing on the market that the packaging of cement or cement-containing mixtures is visibly, legibly and indelibly marked with information on the packing date, as well as on the storage conditions and the storage period appropriate to maintaining the activity of the reducing agent and to keeping the content of soluble chromium VI below the limit indicated in paragraph 1. 3. By way of derogation, paragraphs 1 and 2 shall not apply to the placing on the market for, and use in, controlled closed and totally automated processes in which cement and cement-containing mixtures are handled solely by machines

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	and in which there is no possibility of contact with the skin. 4. The standard adopted by the European Committee for Standardization (CEN) for testing the water-soluble chromium (VI) content of cement and cement-containing mixtures shall be used as the test method for demonstrating conformity with paragraph 1. 5. Leather articles coming into contact with the skin shall not be placed on the market where they contain chromium VI in concentrations equal to or greater than 3 mg/kg (0,0003 % by weight) of the total dry weight of the leather. 6. Articles containing leather parts coming into contact with the skin shall not be placed on the market where any of those leather parts contains chromium VI in concentrations equal to or greater than 3 mg/kg (0,0003 % by weight) of the total dry weight of that leather part. 7. Paragraphs 5 and 6 shall not apply to the placing on the market of second-hand articles which were in end-use in the Union before 1 May 2015.
51. The following phthalates (or other CAS and EC numbers covering the substance): **(a) Bis (2-ethylhexyl) phthalate (DEHP)** **CAS No 117-81-7** **EC No 204-211-0** **(b) Dibutyl phthalate (DBP)** **CAS No 84-74-2** **EC No 201-557-4** **(c) Benzyl butyl phthalate (BBP)** **CAS No 85-68-7** **EC No 201-622-7**	1. Shall not be used as substances or in mixtures, in concentrations greater than 0,1 % by weight of the plasticised material, in toys and childcare articles. 2. Toys and childcare articles containing these phthalates in a concentration greater than 0,1 % by weight of the plasticised material shall not be placed on the market. 4. For the purpose of this entry 'childcare article' shall mean any product intended to facilitate sleep, relaxation, hygiene, the feeding of children or sucking on the part of children.
63. Lead and its compounds **CAS No 7439-92-1 EC No 231-100-4**	1. Shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0,05 % by weight. 2. For the purposes of paragraph 1: (i) 'jewellery articles' shall include jewellery and imitation jewellery articles and hair accessories, including: (a) bracelets, necklaces and rings; (b) piercing jewellery; (c) wrist watches and wrist-wear; (d) brooches and cufflinks; (ii) 'any individual part' shall include the materials from which the jewellery is made, as well as the individual components of the jewellery articles. 3. Paragraph 1 shall also apply to individual parts when placed on the market or used for jewellery-making. 4. By way of derogation, paragraph 1 shall not apply to: (a) crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Council Directive 69/493/EEC (*); (b) internal components of watch timepieces inaccessible to consumers; (c) non-synthetic or reconstructed precious and semiprecious stones (CN code 7103, as established by Regulation (EEC) No 2658/87), unless they have been treated with lead or its compounds or mixtures containing these substances; (d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of minerals melted at a temperature of at least 500 °C. 5. By way of derogation, paragraph 1 shall not apply to jewellery articles placed

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
	on the market for the first time before 9 October 2013 and jewellery articles articles produced before 10 December 1961. 6. By 9 October 2017, the Commission shall re-evaluate paragraphs 1 to 5 of this entry in the light of new scientific information, including the availability of alternatives and the migration of lead from the articles referred to in paragraph 1 and, if appropriate, modify this entry accordingly. 7. Shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0,05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children. That limit shall not apply where it can be demonstrated that the rate of lead release from such an article or any such accessible part of an article, whether coated or uncoated, does not exceed 0,05 µg/cm 2 per hour (equivalent to 0,05 µg/g/h), and, for coated articles, that the coating is sufficient to ensure that this release rate is not exceeded for a period of at least two years of normal or reasonably foreseeable conditions of use of the article. For the purposes of this paragraph, it is considered that an article or accessible part of an article may be placed in the mouth by children if it is smaller than 5 cm in one dimension or has a detachable or protruding part of that size. 8. By way of derogation, paragraph 7 shall not apply to: (a) jewellery articles covered by paragraph 1; (b) crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Directive 69/493/ EEC; (c) non-synthetic or reconstructed precious and semi-precious stones (CN code 7103 as established by Regulation (EEC) No 2658/ 87) unless they have been treated with lead or its compounds or mixtures containing these substances; (d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of mineral melted at a temperature of at least 500 ° C; (e) keys and locks, including padlocks; (f) musical instruments; (g) articles and parts of articles comprising brass alloys, if the concentration of lead (expressed as metal) in the brass alloy does not exceed 0,5 % by weight; (h) the tips of writing instruments (i) religious articles; (j) portable zinc-carbon batteries and button cell batteries; (k) articles within the scope of: (i) Directive 94/62/EC; (ii) Regulation (EC) No 1935/2004; (iii) Directive 2009/48/EC of the European Parliament and of the Council (**); (iv) Directive 2011/65/EU of the European Parliament and of the Council (***) 9. By 1 July 2019, the Commission shall re-evaluate paragraphs 7 and 8(e), (f), (i) and (j) of this entry in the light of new scientific information, including the availability of alternatives and the migration of lead from the articles referred to in paragraph 7, including the requirement on coating integrity, and, if appropriate, modify this entry accordingly. 10. By way of derogation paragraph 7 shall not apply to articles placed on the market for the first time before 1 June 2016. (*) OJ L 326, 29.12.1969, p. 36. (**) Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys (OJ L 170, 30.6.2009, p. 1). (***) Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (OJ L 174, 1.7.2011, p. 88).

Table A. 3: Summary of Relevant Amendments to Annexes Not Updated in the Last Concise Version of the REACH Regulation

Designation of the substance, of the group of substances, or of the mixture	Conditions of restriction	Amended Annex	Amendment date
Addition of Entry 62 concerning: **(a) Phenylmercury acetate** **EC No: 200-532-5** **CAS No: 62-38-4** **(b) Phenylmercury propionate** **EC No: 203-094-3** **CAS No: 103-27-5** **(c) Phenylmercury 2-ethylhexanoate** **EC No: 236-326-7** **CAS No: 13302-00-6** **(d) Phenylmercury octanoate** **EC No: -** **CAS No: 13864-38-5** **(e) Phenylmercury neodecanoate** **EC No: 247-783-7** **CAS No: 26545-49-3**	1. Shall not be manufactured, placed on the market or used as substances or in mixtures after 10 October 2017 if the concentration of mercury in the mixtures is equal to or greater than 0,01% by weight. 2. Articles or any parts thereof containing one or more of these substances shall not be placed on the market after 10 October 2017 if the concentration of mercury in the articles or any part thereof is equal to or greater than 0,01% by weight.'	Annex XVII, entry 62	20 Sep 2012

As of 28 September 2015, the REACH Regulation Candidate list includes those substances relevant for RoHS listed in Table A. 4 (i.e., proceedings concerning the addition of these substances to the Authorisation list (Annex XIV) have begun and shall be followed by the evaluation team to determine possible discrepancies with future requests of exemption from RoHS (new exemptions, renewals and revocations))[1957]:

Table A. 4: Summary of Relevant Substances Currently on the REACH Candidate List

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
Cadmium fluoride	232-222-0	7790-79-6	17 December 2014	Carcinogenic (Article 57 a); Mutagenic (Article 57 b); Toxic for reproduction (Article 57 c); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium sulphate	233-331-6	10124-36-4 31119-53-6	17 December 2014	Carcinogenic (Article 57 a); Mutagenic (Article 57 b); Toxic for reproduction (Article 57 c); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium chloride	233-296-7	10108-64-2	16 June 2014	Carcinogenic (Article 57a);

[1957] Updated according to http://echa.europa.eu/web/guest/candidate-list-table

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
Cadmium sulphide	215-147-8	1306-23-6	16 Dec 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Lead di(acetate)	206-104-4	301-04-2	16 Dec 2013	Toxic for reproduction (Article 57 c);
Cadmium	231-152-8	7440-43-9	20 Jun 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium oxide	215-146-2	1306-19-0	20 Jun 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Pyrochlore, antimony lead yellow	232-382-1	8012-00-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead bis(tetrafluoroborate)	237-486-0	13814-96-5	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead dinitrate	233-245-9	10099-74-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Silicic acid, lead salt	234-363-3	11120-22-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead titanium zirconium oxide	235-727-4	12626-81-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead monoxide (lead oxide)	215-267-0	1317-36-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped ***[with lead (Pb) content above the applicable generic concentration limit for 'toxicity for reproduction' Repr. 1A (CLP) or category 1 (DSD); the substance is a member of the group entry of lead compounds, with index number 082-001-00-6 in Regulation (EC) No 1272/2008]***	272-271-5	68784-75-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Trilead bis(carbonate)dihydroxide	215-290-6	1319-46-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead oxide sulfate	234-853-7	12036-76-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead titanium trioxide	235-038-9	12060-00-3	19 Dec 2012	Toxic for reproduction (Article 57 c)
Acetic acid, lead salt, basic	257-175-3	51404-69-4	19 Dec 2012	Toxic for reproduction (Article 57 c)
[Phthalato(2-)]dioxotrilead	273-688-5	69011-06-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Tetralead trioxide sulphate	235-380-9	12202-17-4	19 Dec 2012	Toxic for reproduction (Article 57 c)
Dioxobis(stearato)trilead	235-702-8	12578-12-0	19 Dec 2012	Toxic for reproduction (Article 57 c)
Tetraethyllead	201-075-4	78-00-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Pentalead tetraoxide sulphate	235-067-7	12065-90-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Trilead dioxide phosphonate	235-252-2	12141-20-7	19 Dec 2012	Toxic for reproduction (Article 57 c)
Orange lead (lead tetroxide)	215-235-6	1314-41-6	19 Dec 2012	Toxic for reproduction (Article 57

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
				c)
Sulfurous acid, lead salt, dibasic	263-467-1	62229-08-7	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead cyanamidate	244-073-9	20837-86-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead(II) bis(methanesulfonate)	401-750-5	17570-76-2	18 Jun 2012	Toxic for reproduction (Article 57 c)
Lead diazide, Lead azide	236-542-1	13424-46-9	19 Dec 2011	Toxic for reproduction (article 57 c),
Lead dipicrate	229-335-2	6477-64-1	19 Dec 2011	Toxic for reproduction (article 57 c)
Dichromium tris(chromate)	246-356-2	24613-89-6	19 Dec 2011	Carcinogenic (article 57 a)
Pentazinc chromate octahydroxide	256-418-0	49663-84-5	19 Dec 2011	Carcinogenic (article 57 a)
Potassium hydroxyoctaoxodizincatedichromate	234-329-8	11103-86-9	19 Dec 2011	Carcinogenic (article 57 a)
Lead styphnate	239-290-0	15245-44-0	19 Dec 2011	Toxic for reproduction (article 57 c)
Trilead diarsenate	222-979-5	3687-31-8	19 Dec 2011	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Strontium chromate	232-142-6	7789-06-2	20 Jun 2011	Carcinogenic (article 57a)
Acids generated from chromium trioxide and their oligomers. Names of the acids and their oligomers: Chromic acid, Dichromic acid, Oligomers of chromic acid and dichromic acid.	231-801-5, 236-881-5	7738-94-5, 13530-68-2	15 Dec 2010	Carcinogenic (article 57a)
Chromium trioxide	215-607-8	1333-82-0	15 Dec 2010	Carcinogenic and mutagenic (articles 57 a and 57 b)
Potassium dichromate	231-906-6	7778-50-9	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproduction (articles 57 a, 57 b and 57 c)
Ammonium dichromate	232-143-1	7789-09-5	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproducetion (articles 57 a, 57 b and 57 c)
Sodium chromate	231-889-5	7775-11-3	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproduction (articles 57 a, 57 b and 57 c)
Potassium chromate	232-140-5	7789-00-6	18 Jun 2010	Carcinogenic and mutagenic (articles 57 a and 57 b).
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	215-693-7	1344-37-2	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c))
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	235-759-9	12656-85-8	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Lead chromate	231-846-0	7758-97-6	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Lead hydrogen arsenate	232-064-2	7784-40-9	28 Oct 2008	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Sodium dichromate	234-190-3	7789-12-0, 10588-01-9	28 Oct 2008	Carcinogenic, mutagenic and toxic for reproduction (articles 57a, 57b and 57c)

Additionally, Member States can register intentions to propose restrictions or to classify substances as SVHC. The first step is to announce such an intention. Once the respective dossier is submitted, it is reviewed and it is decided if the restriction or authorisation process should be further pursued or if the intention should be withdrawn.

As at the time of writing (Fall 2015), it cannot yet be foreseen how these procedures will conclude. It is thus not yet possible to determine if the protection afforded by REACH Regulation would in these cases consequently be weakened by approving the exemption requests dealt with in this report. For this reason, the implications of these decisions have not been considered in the review of the exemption requests dealt with in this report. However for the sake of future reviews, the latest authorisation or restriction process results shall be followed and carefully considered where relevant.[1958]

As for registries of intentions to identify substances as SVHC, as of 28 September 2015, Sweden has submitted intentions regarding the classification of cadmium fluoride and cadmium sulphate as CMR, intending to submit dossiers in August 2014.None of the current registries of intentions to propose restrictions apply to RoHs regulated substances.[1959]

As for prior registrations of intention, dossiers have been submitted for the substances listed in Table A. 5.

Table A. 5: Summary of Substances for which a Dossier has been submitted, following the initial registration of intention

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
Restriction	Cadmium and its compounds	17 Jan 2014	Sweden	Artist paints
	Cadmium and its compounds	17 Oct 2013	ECHA	Amendment of the current restriction (entry 23) on use of paints with TARIC codes [3208] & [3209] containing cadmium and cadmium compounds to include placing on the market of such paints and a concentration limit.
	Lead and lead compounds	18 Jan 2013	Sweden	Placing on the market of consumer articles containing Lead and its compounds
	Chromium VI	20 Jan 2012	Denmark	Placing on the market of leather articles containing

[1958] European Chemicals Agency (ECHA), Registry of intentions to propose restrictions: http://echa.europa.eu/registry-of-current-restriction-proposal-intentions/-/substance/1402/search/+/term (28.09.2015)

[1959] ECHA website, accessed 28.09.2015: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/registry-of-intentions

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
				Chromium VI
	Phenylmercuric octanoate; Phenylmercury propionate; Phenylmercury 2-ethylhexanoate; Phenylmercury acetate; Phenylmercury	15 Jun 2010	Norway	Mercury compounds
	Mercury in measuring devices	15 Jun 2010	ECHA	Mercury compounds
	Lead and its compounds in jewellery	15 Apr 2010	France	Substances containing lead
	Cadmium chloride	03 Feb 2014	Sweden	CMR; other;
	Cadmium sulphide	05 Aug 2013	Sweden	CMR; other;
	Lead di(acetate)	05 Aug 2013	Netherlands	CMR
	Cadmium	04 Feb 2013	Sweden	CMR; other; Substances containing Cd
	Cadmium oxide	04 Feb 2013	Sweden	CMR; other; Substances Containing Cd
SVHC Classification	Trilead dioxide Phosphonate; Lead Monoxide (Lead Oxide); Trilead bis(carbonate)di-hydroxide; Lead Dinitrate; Lead Oxide Sulphate; Acetic acid, lead salt, basic; Dioxobis(stearato)trilead; Lead bis(tetrafluoroborate); Tetraethyllead; Pentalead tetraoxide sulphate; Lead cyanamidate; Lead titanium trioxide; Silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped; Silicic acid, lead salt; Sulfurous acid, lead salt, dibasic; Tetralead trioxide sulphate; [Phthalato(2-)]dioxotrilead; Orange lead (lead tetroxide); Fatty acids, C16-18, lead salts; Lead titanium zirconium oxide	30 Aug 2012	ECHA	CMR; substances Containing Lead
	Lead(II) bis(methanesulfonate)	30 Jan 2012	Netherlands	CMR; Amides
	Lead styphnate; Lead diazide; Lead azide; Lead dipicrate	01 Aug 2011	ECHA	CMR; Substances containing lead
	Trilead diarsenate			CMR; Arsenic compounds
	Strontium Chromate	24 Jan 2011	France	CMR; Substances containing chromate
	Acids generated from chromium trioxide and their oligomers: Chromic acid; Dichromic acid; Oligomers of chromic acid and dichromic acid	27 Aug 2010	Germany	CMR; Substances containing chromate
	Chromium Trioxide	02 Aug 2010	Germany	CMR; Substances containing chromate
	Sodium chromate; Potassium chromate; Potassium Dichromate	10 Feb 2010	France	CMR; Substances containing chromate

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
	Lead chromate molybdate sulfate red (C.I. Pigment Red 104); Lead sulfochromate yellow (C.I. Pigment Yellow 34)	03 Aug 2009	France	CMR; substances Containing Lead
	Lead Chromate	03 Aug 2009	France	CMR; Substances containing chromate
	Lead hydrogen arsenate	27 Jun 2008	Norway	CMR; Arsenic compounds
	Sodium dichromate	26 Jun 2008	France	CMR; Substances containing chromate

Concerning the above mentioned processes, as at present, it cannot be foreseen if, or when, new restrictions or identification as SVHC might be implemented as a result of this proposal; its implications have not been considered in the review of the exemption requests dealt with in this report. In future reviews, however, on-going research into restriction and identification as SVHC processes and the results of on-going proceedings shall be followed and carefully considered where relevant.

A.5.0 Appendix 5: Exemption 7(a)

A.5.1 DA5 Research for Alternatives to LHMPS Die Attach

All information provided in this chapter is taken from the exemption request of Freescale/NXP et al.[1960] The numbering of the figures starts with "Chart2" like in the original document.

"Looking specifically at high-lead solder for attaching die to semiconductor packages, in 2Q 2010, Bosch (Division Automotive Electronics), Freescale Semiconductor, Infineon Technologies, NXP Semiconductors and STMicroelectronics formed a consortium to jointly investigate and standardize the acceptance of alternatives for high-lead solder during manufacturing. The five company consortium is known as the DA5 (Die Attach 5), and is actively supporting the demands of the European Union towards reduced lead in electronics.

Evaluations of different materials have been performed within the DA5 consortium together with several material suppliers specific to the die-attach application. This includes four main classes of materials:

- High Thermal Conductive Adhesives,
- Silver-sintering materials,
- TLPS (Transient Liquid Phase Sintering) materials, and
- Alternative solders.

At present, no material has been identified that fulfils the required properties of a replacement material. The slide images below provide a summary of results for the different material classes.

[1960] Op. cit. Freescale Semiconductors/NXP et al. 2015a

Materials

→ 4 different material "classes" are in discussion

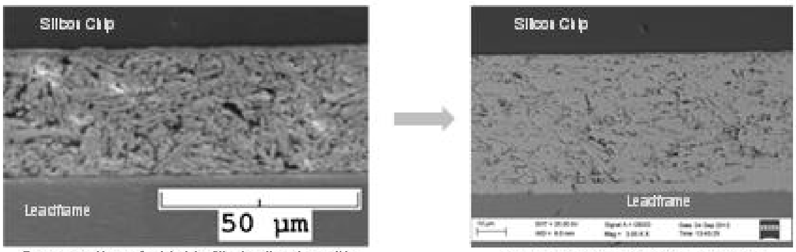
Version 01-Aug-2014

Chart 2: Potential alternative materials

Conductive Adhesives I

→ **Principle**

- High electrical and thermal conductivity of adhesives is achieved with an increased silver content and very dense packing of filler particles.
- The development of very high conductivity adhesives is heading towards a further reduction of filler particle size, thus stimulating a sintering process between the single silver particles during the resin cure process.
- These hybrid materials combine the advantages of an silver filled adhesive (thermal-mechanical stability, low sensitivity to surfaces) with the high conductivity of an sintered silver material.



Cross-section of a highly filled adhesive with dense packing of silver particles in the bond line.

Cross-section of an adhesive with sintered silver particles (dark spots are remaining resin content).

Version 01-Aug-2014

Chart 3: High Thermal Conductive Adhesives I

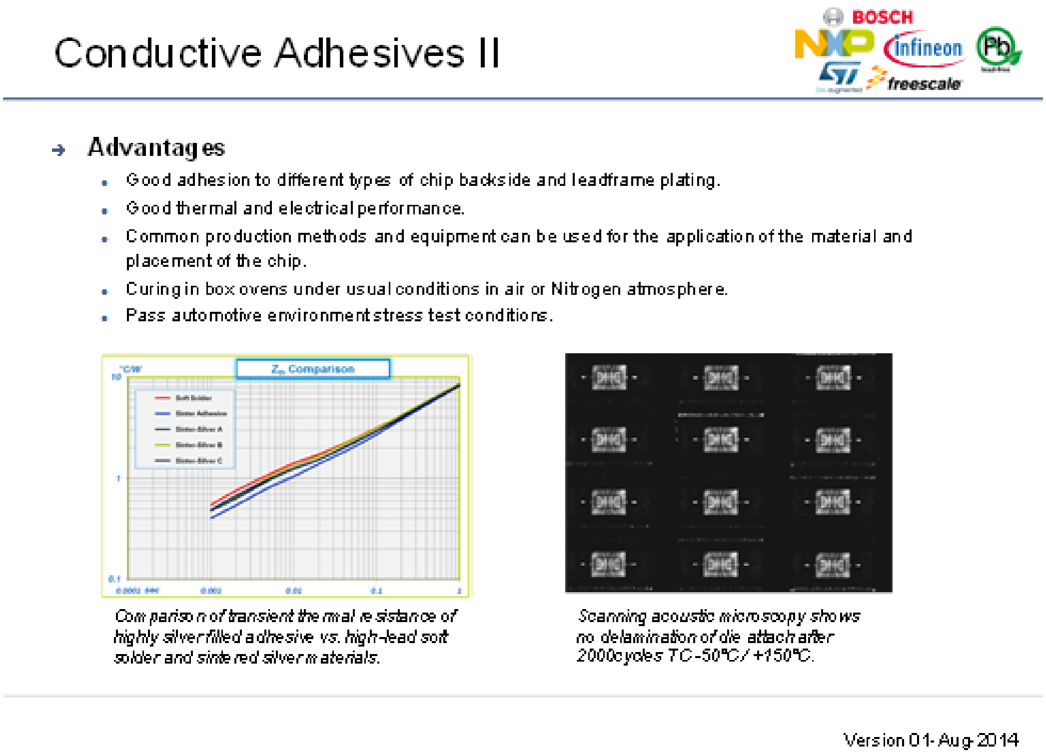


Chart 4: High Thermal Conductive Adhesives II

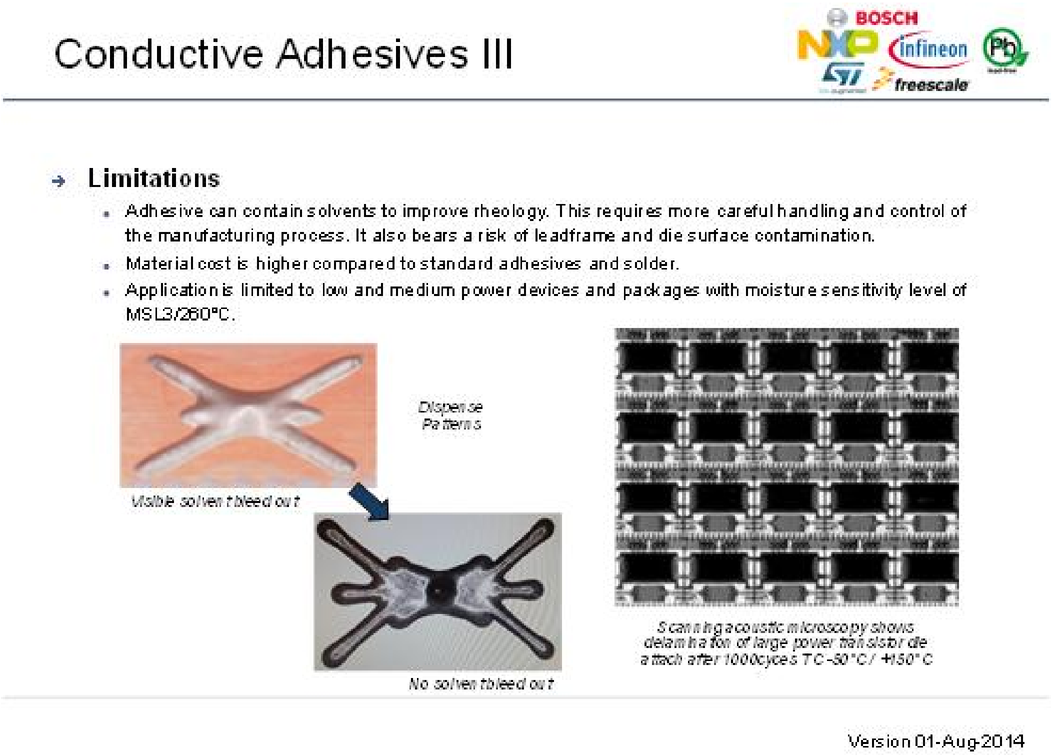


Chart 5: High Thermal Conductive Adhesives III

In general, high thermal conductive adhesives have some favourable properties that may be acceptable for many applications within industry. Adhesives can be a solution for packages which don't need to be exposed to the higher soldering temperature (~400°C soldering temperature versus ~150°C glue curing temperature). E.g. Ball Grid Array (BGA) packages with organic substrates use adhesives for die attach. Adhesives are the typical solution for very thin lead frames (~200µm) due to unacceptable lead frame bending after a high temperature soldering process. In general adhesives have a bigger process window as compared to solder and can be used also for non-metalized chip backsides.

Nevertheless adhesives have severe limitations, especially in terms of performance, that justify the continued use of HMP lead (Pb) solders.

An overview in terms of key performance indicators of high performance adhesives in comparison with HMP lead (Pb) solder shows a significant gap that is still present with solutions available today. Especially for power devices there are major restrictions for the usage of adhesives. The bulk electrical and thermal conductivity of an adhesive is much smaller (<1*10^6 S/m and max. 25W/mK) as compared to a HMP lead (Pb) solder (~5*10^6 S/m and ~50W/mK). This keeps products that are covered with HMP lead (Pb) solder today from converting to conductive adhesives.

- Existing adhesives can only be used for chip thickness >120µm due to glue creepage on the side walls of the chips. Due to performance reasons, new chip technologies tend to go for 60µm or even thinner thickness è HMP lead (Pb) solder required
- Also the chip size for adhesive is limited to ~30 mm². This is due to the shrinkage of the glue during curing and thermo-mechanical instability. Mechanical strength is lower compared to HMP lead (Pb) solder (reliability issue).
- Another issue is the worse humidity behaviour of glue during reliability. Moisture uptake of adhesives can lead to moisture-induced failure during reflow soldering (MSL).
- Adhesives can't be used for products with a high junction temperature (>175°C). At such high temperatures the organic components of the glue tend to degrade.
- Conductive adhesives are based on an Ag/organic matrix. Ag tends to migrate under voltage and humidity. Higher power density increases the risk of electro migration.

As of mid 2014, the DA5 are not aware of any solution (glue or other materials) that can replace HMP lead (Pb) solder at the moment. The limitations of adhesives are detailed above. HMP solders and adhesives belong to completely different material classes and perform very differently.

The electronics industry naturally works toward eliminating HMP high-lead (Pb) solder because alternatives (e.g. conductive adhesive) are typically easier to manufacture; the HMP lead (Pb) solders are only used when no other options are available that enable the required product reliability and functionality.

The necessary uses for the exemption are outlined within Table 2, above. These applications require HMP lead (Pb) solder to reduce stress, to maintain reliability when subsequent temperatures after initial application exceed 250^{o}C to 260^{o}C, to achieve special electrical or thermal characteristics during operation due to electrical or heat conductivity, or to achieve reliability in temperature and power cycles.

Pb free adhesive alternatives that are available on the market today are not feasible for the types of products and applications where HMP solders are used.

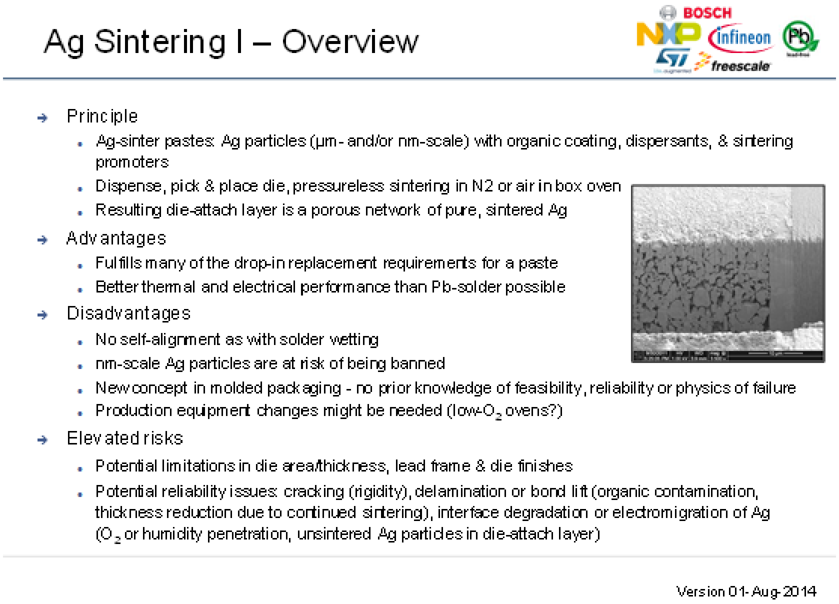


Chart 6: Silver Sintering I – Overview

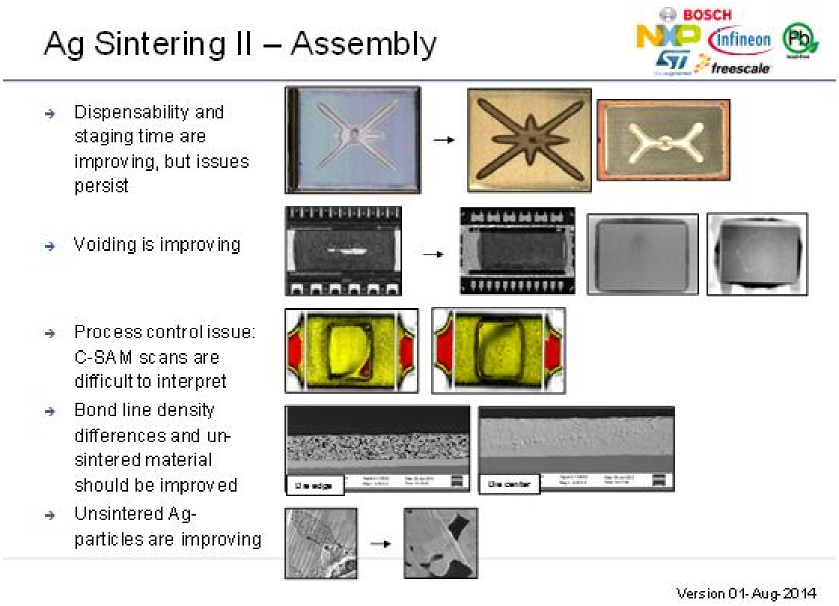


Chart 7: Silver Sintering II – Assembly

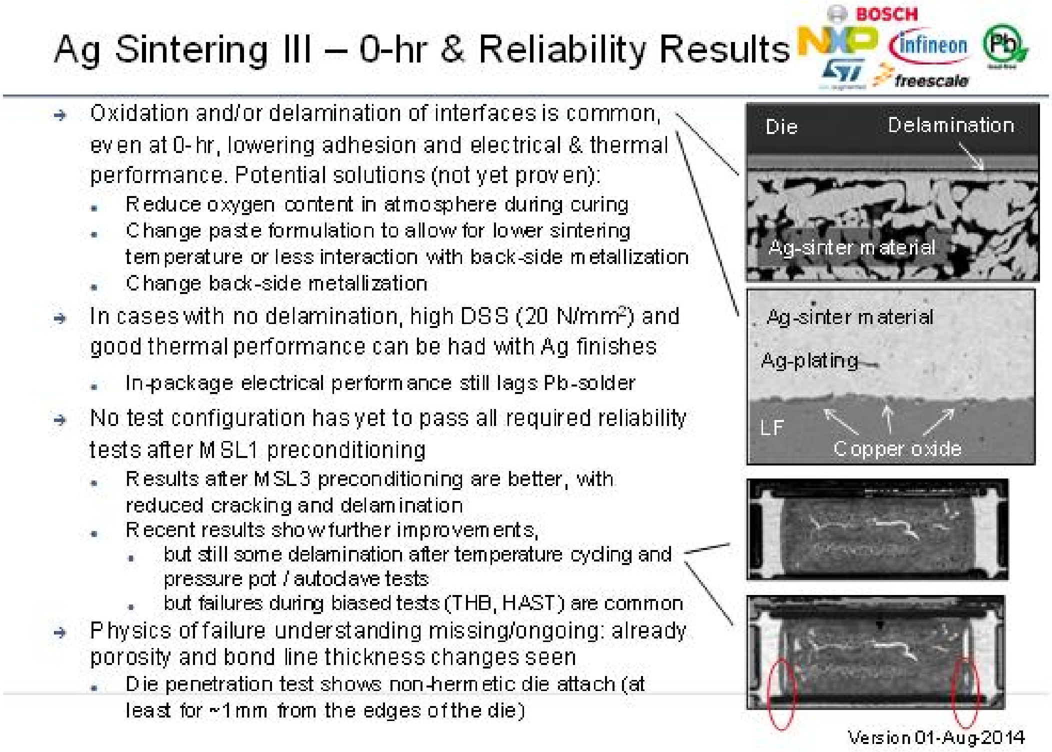


Chart 8: Silver Sintering III – 0-hr & Reliability Results

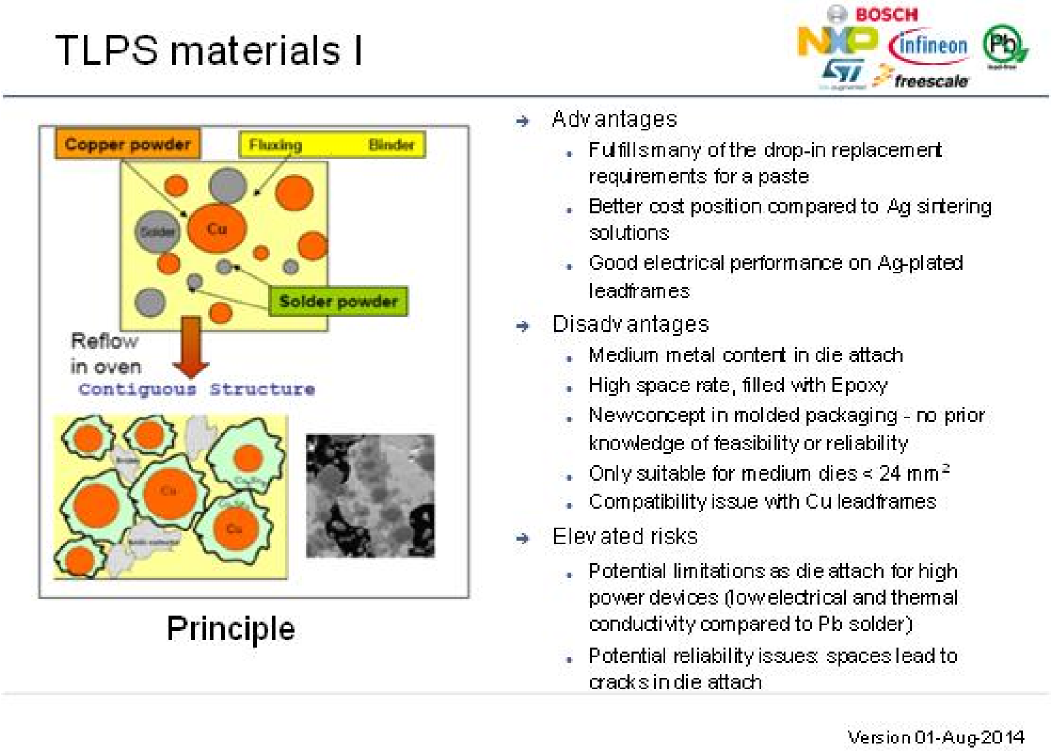
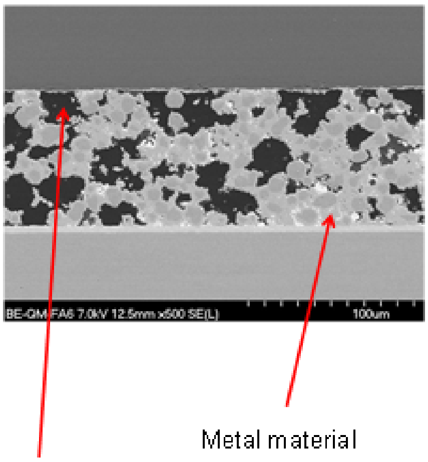


Chart 9: TLPS Materials I

TLPS material II

- The hybrid material showed a very high space rate. The spaces are filled with epoxy material
- The reflow process is very critical and has to be further optimized, the reflow profile seems to be product specific
- Reliability results are contradictory. Results are package/leadframe material dependant. A low space rate is mandatory to survive reliability
- Shear values at 260°C are low, barely above the minimum needed value (5N/mm²)
- Strong brittle intermetallic phase growth with Cu



Version 01-Aug 2014

Chart 10: TLPS Materials II

Alternative Solders I

Properties to be considered

- Robust manufacturing process
  - Repeatable solder application
  - Stable wetting angle
  - Surface compatibility (chip backside, lf finish)
- Reliability
  - Voiding / cracking / disruption after stress
  - Growth of brittle intermetallics at high temperature
  - Disruption during temperature cycling

Version 01-Aug 2014

Chart 11: Alternative Solders I

Alternative Solders II

- Zn-based Alloys
  - Improved workability demonstrated
  - New formulations demonstrate lower mechanical stress and reduced die cracking, still further improvement required
  - Limited experience on reliability
  - Risk of Zn re-deposition can only be falsified in high-volume manufacturing
  - Material currently only available in wire form
- Bi-based Alloys
  - Low thermal conductivity & low melting point
  - Performance minor to high lead solder
- SnSb-based Alloys
  - Low melting point (new formulations show possible increase)
  - Workability challenging (increased voiding)
  - Limited surface compatibility (chip backside, leadframe finish)
  - Limited experience on reliability
  - Material currently only available in paste form

Version 01-Aug-2014

Chart 12: Alternative Solders II

DA5 Conclusion on Alternative Solders: Although we find no mass market alternatives to HMP lead (Pb) solder, there are a few candidate materials in initial production as part of the long term manufacturability development efforts.

The DA5 customer presentation listed two potential alternative candidate materials based solely upon melting temperature evaluations in Chart 17 (below): Sn25Ag10Sb and Au20Sn. Considering only the brittleness and melting temperature, these alternative solders might be technically feasible – but only for very small die size when constraining die thickness, package geometry and surface materials.

KPI for Alternatives to HMP lead (Pb) Solders: As seen in the preceding charts, the DA5 evaluated the likely alternatives to HMP lead (Pb) solder against the required capabilities. The DA5 documented the suppliers and technical details for various alternatives within each alternative material category. The material suppliers prevent disclosure of this information due to their NDA with each DA5 company. The comparative strengths and weaknesses of the best tested material in each class are show in the following Key Performance Indicator charts.

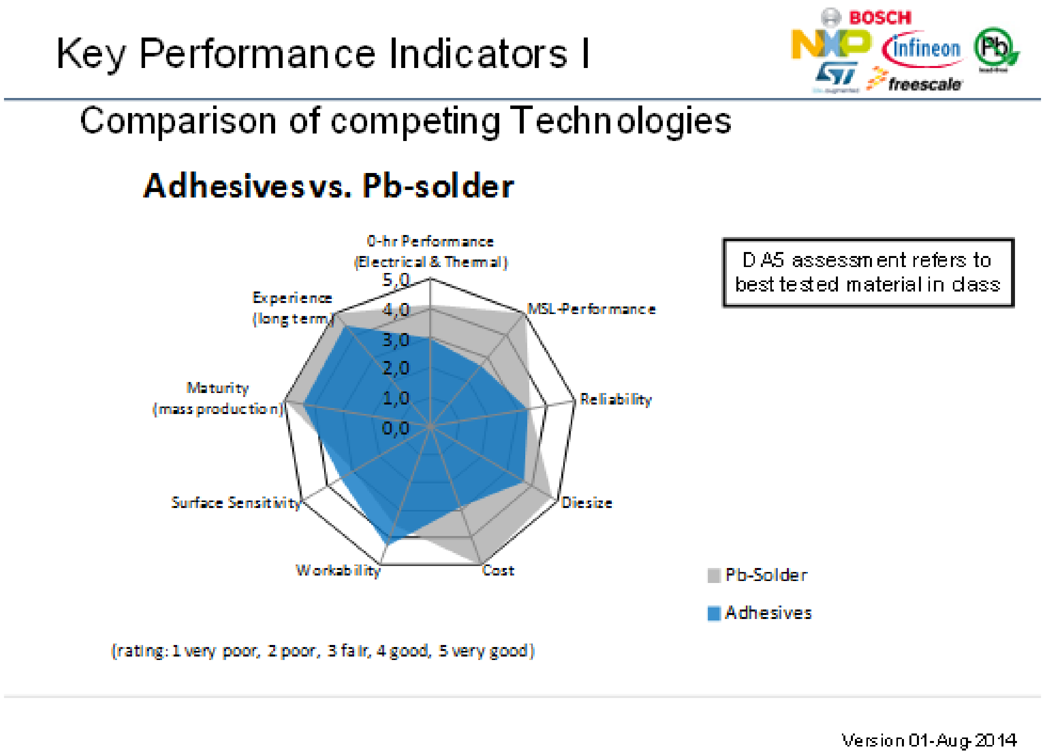


Chart 13: KPI-1 for Adhesives vs. Pb-solder

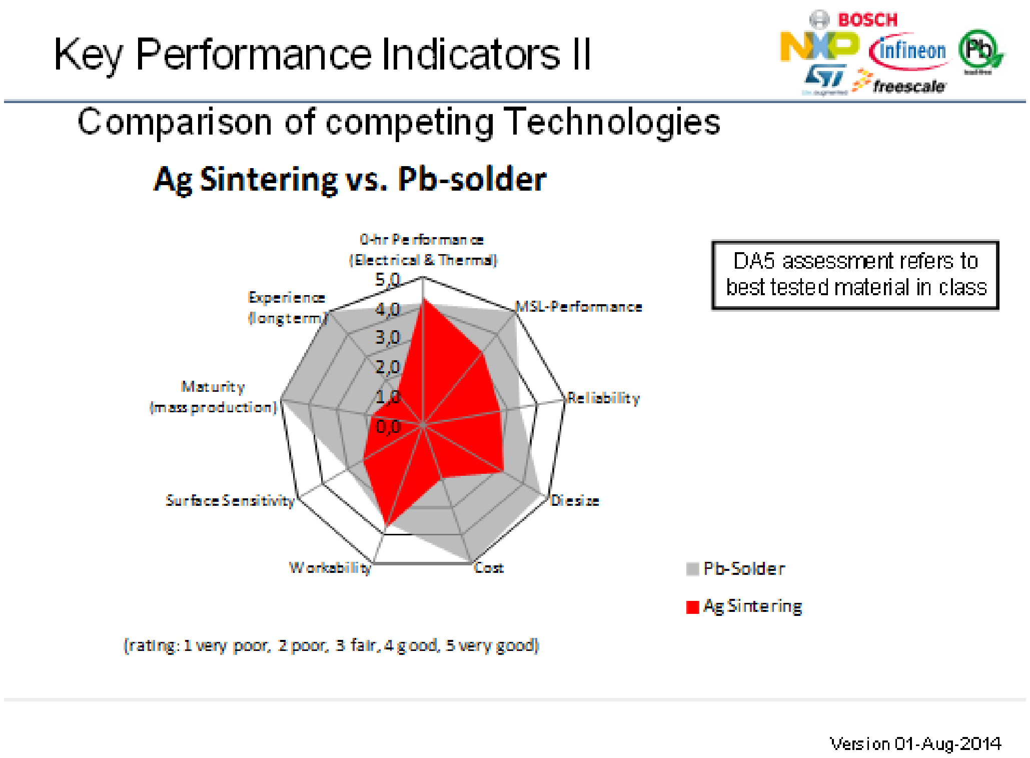


Chart 14: KPI-2 for Silver Sintering vs. Pb-solder

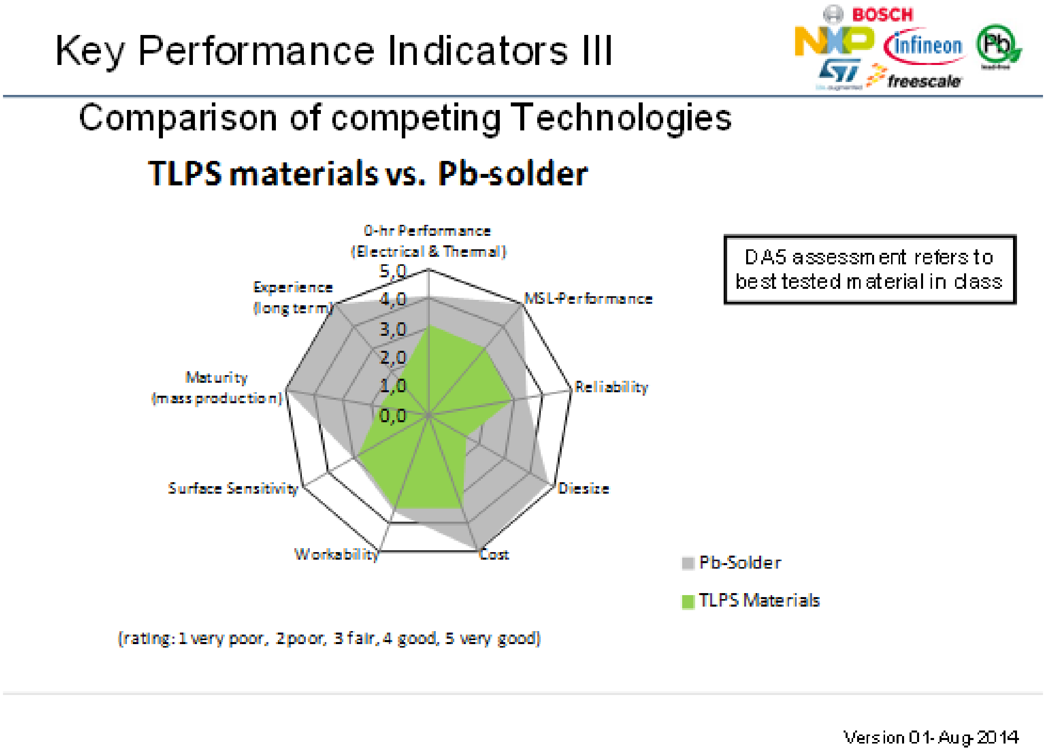


Chart 15: KPI-3 for Transient Liquid Phase Sintering (TLPS) vs. Pb-solder

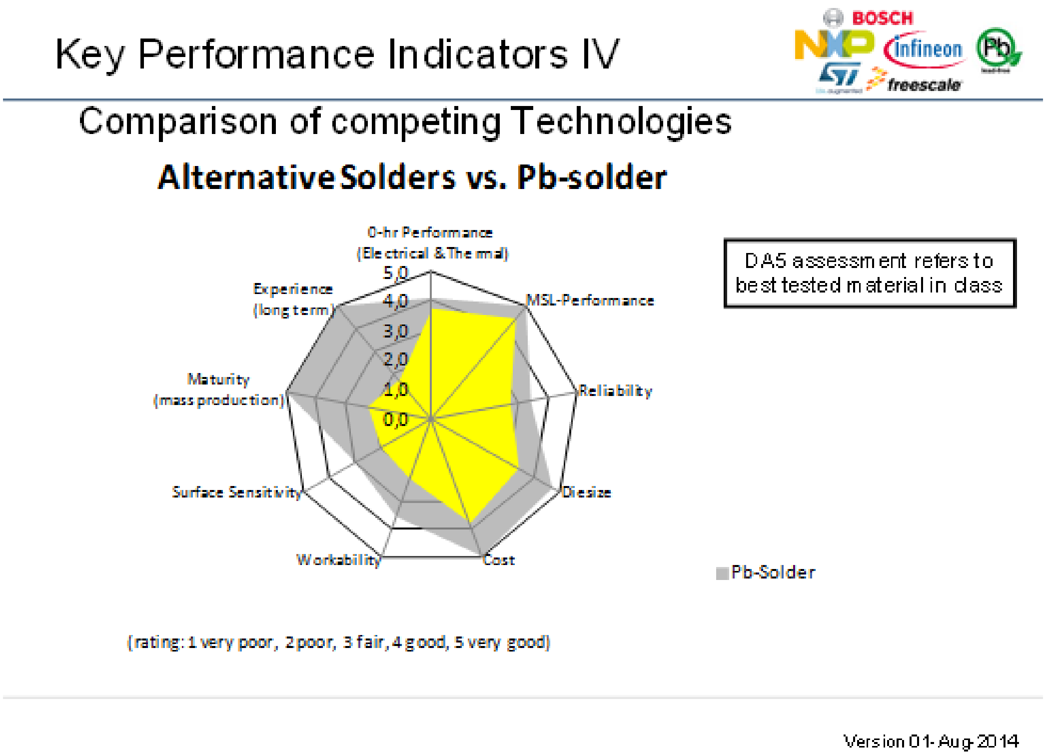


Chart 16: KPI-4 for Alternative Solders vs. Pb-solder

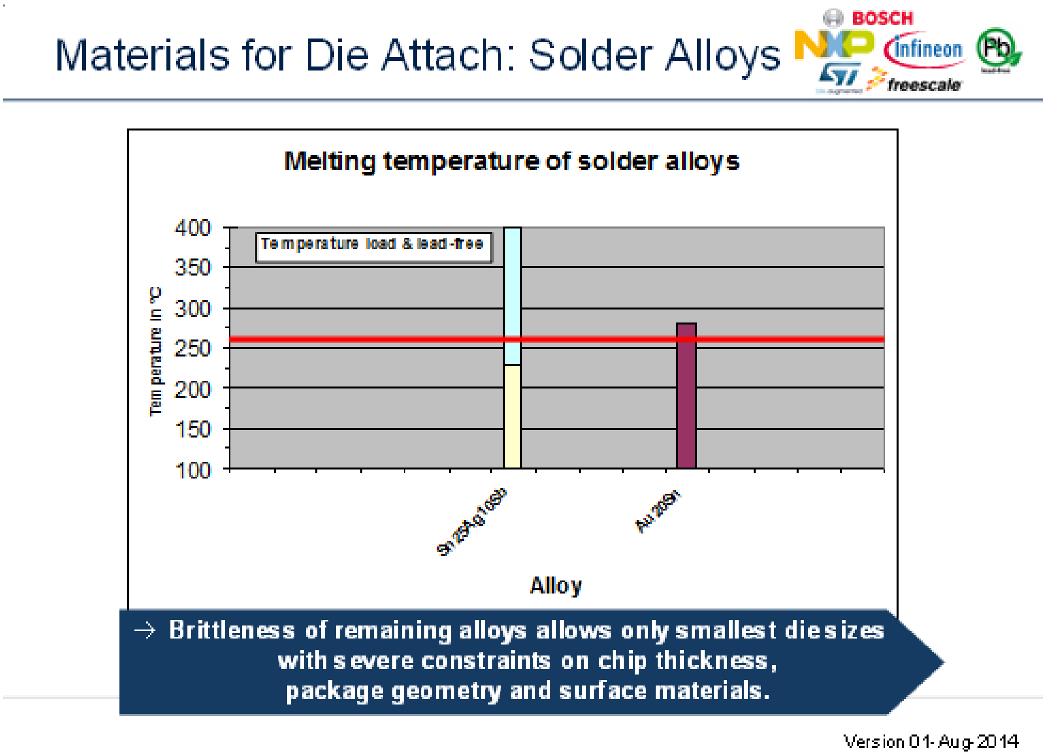


Chart 17: Melting Temperature of Solder Alloys

As noted in Chart 17, DA5 experience has shown that die size and melting temperatures are not the only requirements for alternative Pb-free solders. Additional design restrictions on chip thickness, package geometry and surfaces have to be carefully optimized to make such materials work at all. Optimization is difficult due to unfavorable mechanical properties of the die attach materials, like brittleness. Conversion would only be possible for new semiconductor products:

(1) that are specifically designed for these materials,

(2) where manufacturing processes and equipment have been designed and developed to support the change, and

(3) where the application can accept the material related limitations (e.g. design, functionality, reliability and/or manufacturability).

The resulting new semiconductor design will not be compatible with all customer applications.

In summary, the DA5 evaluation of alternatives to HMP lead (Pb) solder die attach materials determined that no current alternative solder materials can maintain product system performance and pass all qualification tests.

DA5 Note and Conclusion about Conductive Die Attach Films (CDAF): This alternative has not been mentioned in the DA5 evaluations above as an alternative for HMP lead (Pb) solder in die attach, although it is used as a die attach material in some products. Conductive Die Attach Films (CDAF, conductive glue prepared as a tape) are used to replace conductive glue but not to replace HMP lead (Pb) solder.

These conductive tapes are mainly used where clearance between die dimensions and die pad is very small and glue cannot be used due to bleeding which causes some glue constituents to start to migrate on the leadframe. Today, conductive tape is a potential improvement for products that use standard conductive glues. It cannot replace HMP lead (Pb) solder.

The thermal and electrical performance of available tapes is not comparable with HMP lead (Pb) solder. High power devices, particularly the so called "vertical current" devices where significant current flow is driven through the die attach material, would not work with conductive tape. The tape is too resistive and the maximum current that can pass through the tape is much lower than the current capability of HMP lead (Pb) solder.

So for the products which use HMP lead (Pb) solder today, a further exemption is still required. The DA5 evaluations have determined that no feasible alternative is available in the market."

DA5 References:

Latest DA5 Customer Presentation:

http://www.infineon.com/dgdl/DA5_customer_presentation_200813.pdf?folderId=db3a30433162923a013176306140071a&fileId=db3a30433fa9412f013fbd2aed4779a2

DA5 Material Requirement Specification can be provided on request:

Speaker of the DA5 consortium:

Bodo Eilken

Infineon Technologies AG

A.5.2 Efforts of International Rectifier (IR) for LHMPS Substitution

All information in this chapter was taken from Freescale/NXP et al.[1961]

International Rectifier Corporation (IR®) is a world leader in power management technology. Leading manufacturers of computers, energy efficient appliances, lighting, automobiles, satellites, aircraft and defense systems rely on IR's power management

[1961] Ibid.

benchmarks to power their next-generation products. Products range from discrete MOSFETs and IGBTs and high-performance analog, digital and mixed-signal ICs to integrated power systems, IR's innovative technologies.

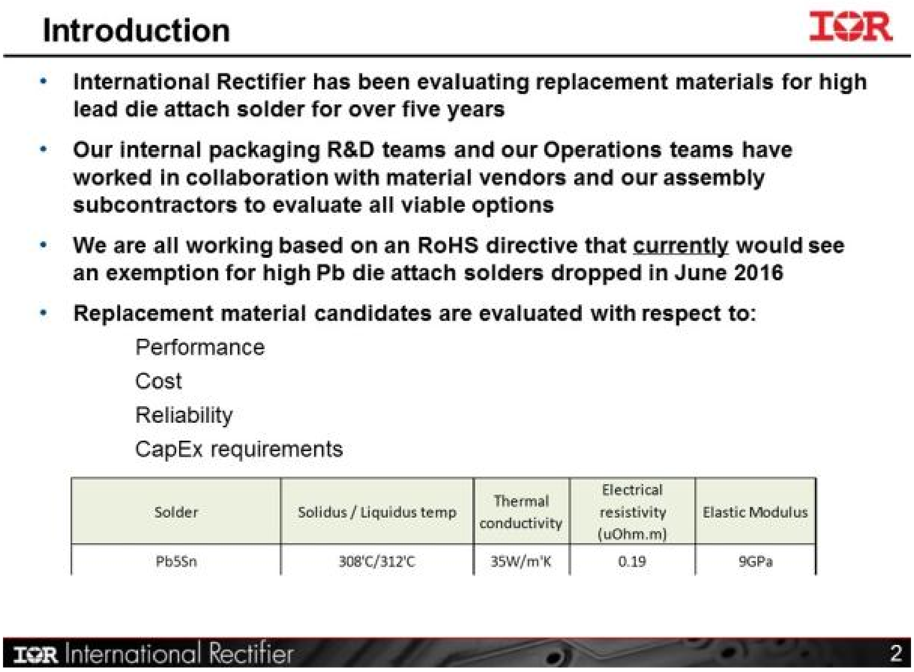
IR has evaluated numerous suppliers and alternative Pb free high melting point materials to replace HMP lead (Pb) solder. This documentation recently became available to the industry organizations submitting this exemption extension proposal and provides more evidence of difficulties in identifying and qualifying alternative materials to replace HMP lead (Pb) solder. This includes the following Pb-free solders:

SnSb solders: The solidus temperature of SnSb is 235^{o}C and the liquidus is 240^{o}C which is still too low to stop the solder from completely melting during a customer's 260^{o}C reflow process. We did look at solder variants that include SnSb such as J-alloy (SnAg25Sb10) that still have a solidus BELOW 260^{o}C but a liquidus ABOVE 260^{o}C which meant that they would be pastey or partially melted during a customer reflow. This was not successful as the resultant board attach process window was not large enough to allow customers to reliably board mount the components without seeing degradation of the die attach joint internal to the package. IR frequently saw 'solder squirt' with the die attach solder being forced out of the package during board attach.

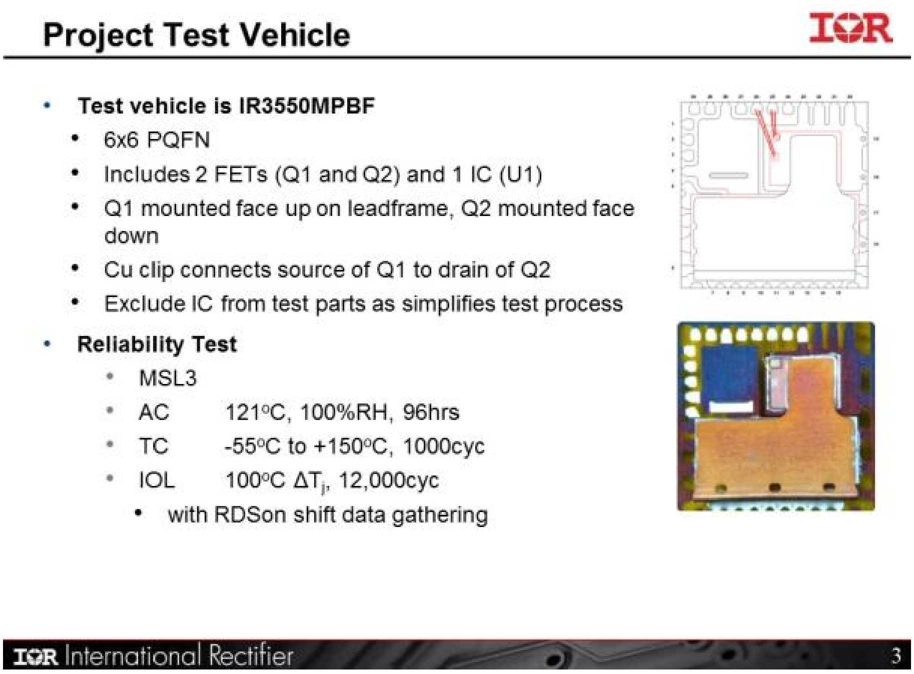
BiAg solder: Processability and application is limited as it does not form good intermetallics with Cu or Ni. Additionally any intermetallics formed are brittle and weak resulting in reliability fails. The electrical and thermal performance of the BiAg solder is worse than that of the existing solder options containing Pb. The electrical resistivity is 4.5X worse and the thermal performance is 4X worse. On very low rds(on) MOSFETs this can greatly reduce the current rating of a given part resulting in customers having to go for much larger solutions. There are BiAg solders currently being evaluated in the industry which include additives to improve wetting; however, these additives need to remain separate from the BiAg alloy prior to melting, which means that it is only available in a solder paste form. It would not be possible to use on packages that require solder wire or preforms for die attach. The combination of poor electrical and thermal performance and the solder-paste 'only' option means that these newer BiAg versions could be used on is limited and very niche products. The materials are still under investigation at this time.

AuSn solder: This has been around for quite some time in the industry but with limited use. The alloy is over 4X harder than Pb solders which results in a lot more stress being transferred to the die. The hardness causes die cracking problems on larger die sizes and has meant that the application of this material for die attach has been limited to die sizes smaller than many power semiconductors.

At present, no identified Pb-free materials pass reliability tests, especially moisture sensitivity preconditioning. See the detailed analysis slides below.



Slide 1: Pb Free Evaluation Introduction



Slide 2: IR Project Test Vehicle

Partial Melt Solders

IOR

- **5 new Pb free solder materials evaluated**
  - Evaluate performance of high liquidus temp solder vs. MSL @ 260°C
  - All materials have solidus less than 260°C
  - Electrical and thermal performance similar to Hi Pb solder

Solder	Solidus / Liquidus temp	Thermal conductivity	Electrical resistivity (uOhm.m)	Elastic Modulus
Pb5Sn	308'C/312'C	35W/m'K	0.19	9GPa
Alloy 1	227'C/300'C	65W/m'K	0.12	47GPa
Alloy 2	228'C/395'C	55W/m'K	0.15	25GPa
Alloy 3	217'C/353'C	55W/m'K	0.13	48GPa
Alloy 4	222'C/384'C	50-55W/mK	0.135	46-50Gpa
Alloy 5	220'C/356'C	50-55W/mK	0.135	46-50Gpa

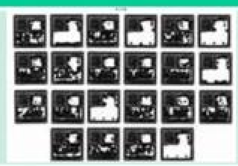
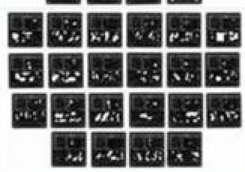
- Samples assembled using all material options
  - Process optimisation required due to increased solder voids and insufficient solder coverage
  - Test yields all good with Rds(on) in line with existing product
- Samples submitted to reliability testing including MSL3 preconditioning

IOR International Rectifier 4

Slide 3: Partial Melt Solders (1)

Partial Melt Solders

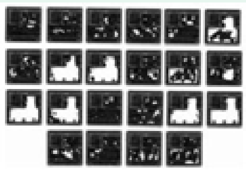
IOR

Solder solidus/liquidus	C-SAM after assembly	C-SAM after MSL3
Alloy 5 220°C/356°C		
Alloy 1 227°C/300°C		
Alloy 2 228°C/395°C		

IOR International Rectifier 5

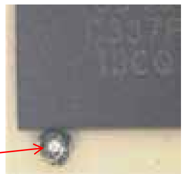
Slide 4: Partial Melt Solders (2)

Partial Melt Solders

Solder solidus/liquidus	C-SAM after assembly	C-SAM after MSL3
Alloy 4 222°C/384°C		
Alloy 3 217°C/353°C		

- In all cases significant die attach paddle and clip delamination observed after MSL3 preconditioning
- Visual inspection of parts show solder squirt from the edge of the package

Die and clip attach solder has squirted out of the side of the package after 3x 260 ° C reflows



International Rectifier 6

Slide 5: Partial Melt Solders (3)

Partial melt solders- Conclusions

- **All materials are unsuitable due to failure in MSL preconditioning prior to reliability testing**
  - **Solders partially melt during 260°C reflow causing massive package delamination and solder squirt**
- Materials could be used to replace Pb based solders with little change in process or equipment set used today.
- Final test electrical performance looks acceptable with Rds(on) comparable with Pb based solder.

International Rectifier 7

Slide 6: Partial Melt Solders – Conclusions

Ag Epoxy Materials

IOR

- **4 Ag Epoxy Materials evaluated**
  - Electrical and thermal performance comparable with Pb based solders – bulk properties to be confirmed in application

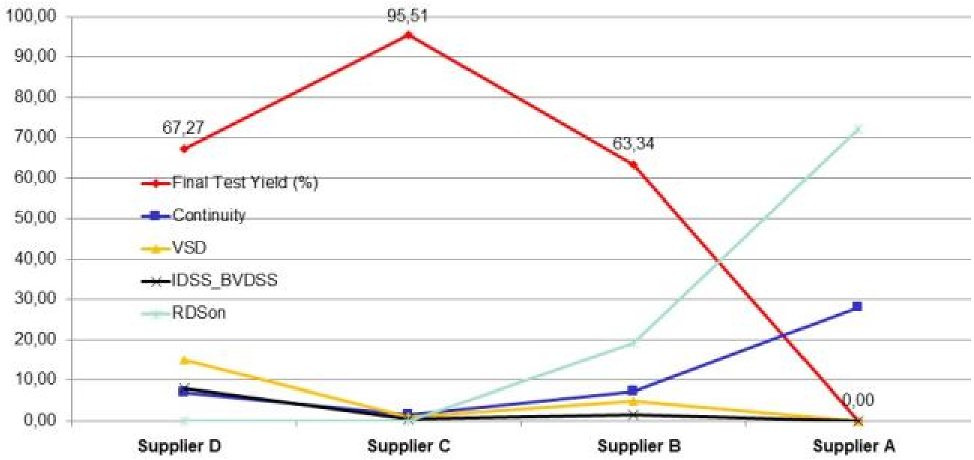
Epoxy	Cure Temp/Time	Thermal conductivity	Electrical Resistivity	Elastic Modulus	Tg	CTE1	CTE2
Supplier A	200°C/30min ramping + 200°C/60min cure	24W/m°K	50μOhm-cm	4.3GPA(25°C) / 1.4GPa(250°C)	44°C	60ppm	150ppm
Supplier B	150°C/30min ramping + 150°C/30min cure + 250°C/40min ramping + 250°C/90min cure	50W/m°K	30μOhm-cm	6.8GPa(25°C) / 5.4GPa(260°C)	63°C	25ppm	45ppm
Supplier C	180°C/50min ramping + 180°C/30min cure + 215°C/15min ramping + 215°C/60min cure	10W/m°K	100μOhm-cm	7.7GPa(25°C) / 0.45GPa(250°C)	-	35	-
Supplier D	230°C/40min raming + 230°C/90min cure	125W/m°K	5μOhm-cm	14.7GPa(25°C) / 8.9GPa(260°C)	100°C	20	50

IOR International Rectifier 8

Slide 7: Ag Epoxy Materials

Ag Epoxy Materials – Final Test

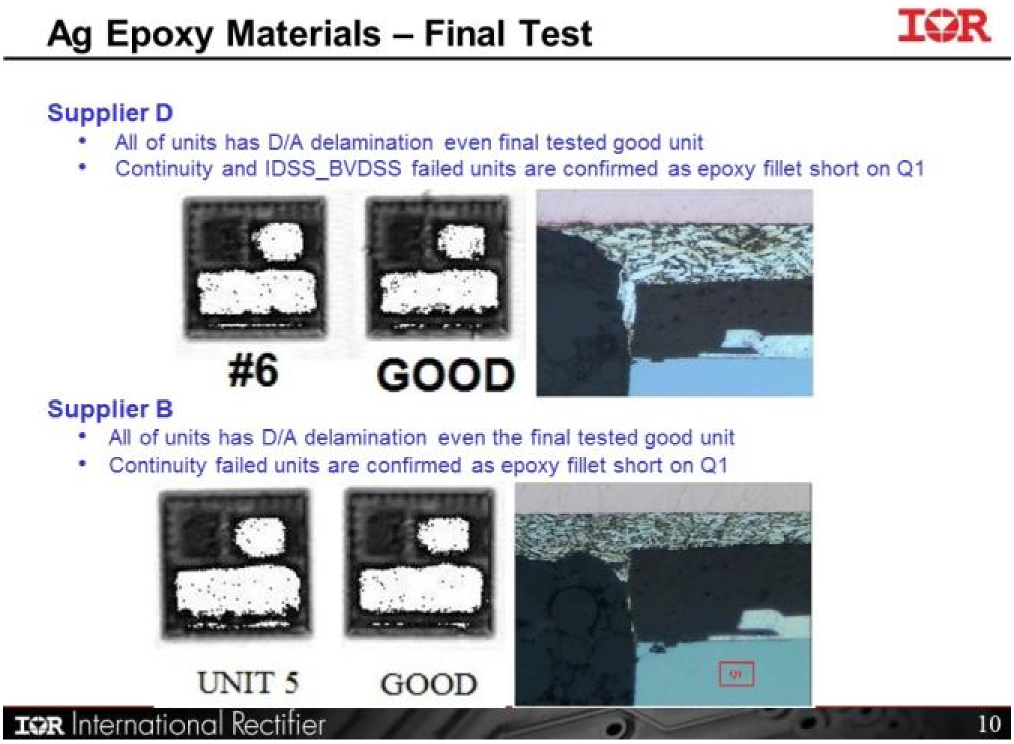
IOR



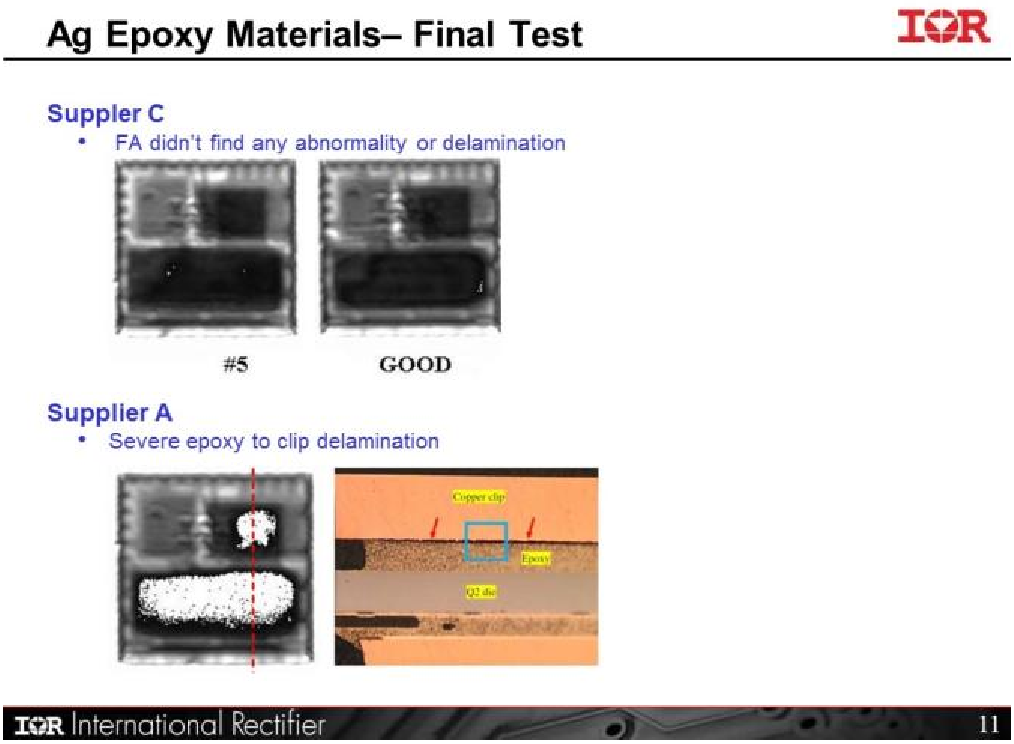
- **Severe Final test yield loss detected except Supplier C material**
  - FA confirmed
    - Continuity and IDSS_BVDSS failure as "Excessive epoxy on Q1 die"
    - RDSon failure as "D/A and Clip Delamination"

IOR International Rectifier 9

Slide 8: Ag Epoxy Materials – Final Test (1)



Slide 9: Ag Epoxy Materials – Final Test (2)



Slide 10: Ag Epoxy Materials – Final Test (3)

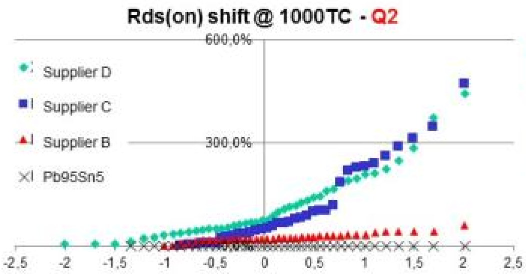
Ag Epoxy Materials– Reliability Test

Reliability

- Supplier D : Pass MSL3, failed TC250 and AC96hr by RDSon
- Supplier C : Pass MSL3, failed TC250 and AC96hr by RDSon
- Supplier B : Pass MSL3, TC1000, AC96hr
- Supplier A : Pass MSL3, no other test submitted as time zero severe delamination

RDSon Shift post TC1k cyc

- Supplier B material passed RDSon limit but Rdson shift = 23% avg, 61% max
- POR 95/5 high lead solder max Rds(on) shift 0.3%



Rds(on) Shift	Supl B	Supl C	Supl D	Pb95Sn5
Max	61%	472%	444%	0.3%
Avg	23%	95%	112%	0.1%

IOR International Rectifier 12

Slide 11: Ag Epoxy Materials – Reliability Test

Ag Epoxy Materials - Conclusions

- Materials are difficult to process for Cu clip products where material needs to be contained to contacts without overspill
  - Assembly yield adversely affected material overspill
- Final test electrical performance looks acceptable with Rds(on) comparable with Pb based solder
- **Reliability severely affected by package delamination causing unacceptable shifts in Rds(on)**

IOR International Rectifier 13

Slide 12: IR Ag Epoxy Materials - Conclusions

A.5.3 Timing devices, which are quartz crystals and components including these, like oscillators of all kinds and real time clock modules (RTCs)

According to Freescale et al.[1962], quartz crystal resonators are available in metal cans not using any Pb, but these devices can withstand only lower process and storage temperatures. They require manual soldering due to the lower heat resistance caused by the use of Pb-free low melting solder for the cylinder sealing. However, it has been shown in the past 10 years that this lead-free sealing still bears the risk of tin whisker growth. Tin whisker growth can potentially short parts and has been found in "lead-free" sealed crystals of all manufacturers.

Freescale et al.[1963] explain that manual assembly soldering processes are used in some dedicated industries like in the watch industry. Nearly all other industries however cannot use this manual process due to process compatibility, meaning the compatibility with mounting processes for other components on the complex modules, and reliability reasons as machine soldered joints are more reliable and consistent than manual joints.

According to Freescale et al.[1964], the wider temperature range of SMD assembly/reflow soldering however requires the use of higher solder temperatures which would cause the sealing of low melting solders to leak. These processes require the use of higher temperature cylinder seals based on LHMPS. While manual soldering was quite common many years ago, it is not compatible with modern PCB production machines and would require a manual and thus labor intensive and expensive mounting process not compatible with the process and quality requirements for all other components on conventional PCBs.

Freescale et al.[1965] say that reflow solder processes run on higher temperatures and SMD-mounting requires the cylinder crystals commonly to be mounted on a lead frame by means of a first soldering process before this combination is molded into a plastic and undergoing a final reflow process for mounting onto customers printed circuit board. Due to the fact that the cylinder sealing is exposed to multiple soldering processes including reflow soldering with higher temperatures than manual soldering, the components are thermally more stressed during assembly and thus it is necessary to increase the melting point of the cylinder capsulation (hermetic sealing of the metal cylinder with a plug) in this cases compared to the one where the cylinder is directly hand-soldered onto the PCB. For these cases the use of LHMPS is needed, as no other material has been found so far which combines the high melting point and the mechanical characteristics (i.e. softness and ductility) required to assure prolonged

[1962] Ibid.
[1963] Ibid.
[1964] Ibid.
[1965] Ibid.

reliable hermetic sealing between the metal cylinder and the plug over a wide temperature range during storage and operation.

Even more, Freescale et al.[1966] state, many applications can't work with a pure crystal, but need an oscillator of some type, i.e. Temperature-Compensated-Oscillators (TCXOs) for GNSS (Global Navigation Satellite System) applications or real time clock modules). In these cases, the hermetically sealed crystal resonator has to be mounted together onto a kind of module with an IC. So the same basic structure and arguments about the multiple soldering processes as mentioned above are valid in this case, as the cylinder crystal (where used) has to be mounted onto a PCB, lead-frame or similar together with the semiconductor before molding.

In other words, Freescale et al.[1967] put forward, LHMPS as sealing material is not only required for cylinder crystals to enable SMD soldering, but as well in widely spread components like RTC modules and others, where an IC and hermetically sealed quartz crystal have to be combined together inside one package/module to achieve desired specifications (e.g. accuracy).

Freescale et al.[1968] claim that metal can crystals with LHMPS cannot be completely replaced by crystals packed into ceramic packages, as the characteristics and covered frequencies are vastly different. The most remarkable differences are (Freescale et al.[1969]):

- Due to the different dimensions (fitting into the packages), the smaller crystals have a significantly different "pullability". This is the capability to change the frequency when external circuit parameters, namely the load capacitance of the oscillation circuit, are changed. This is a feature used to correct the initial tolerance and frequency drift over temperature as well as aging of the crystal and is required to meet standards for wireless and wired communication as well as GNSS applications. The high pullability of larger cylinder crystals is especially important in wide temperature applications like in automotive use, as the frequency temperature tolerance is far larger due to the wider temperature range which has to be covered which consequently needs a wider pulling range (so range in which the frequency can be changed).
- Due to the physical sizes of applicable ceramic packages, the crystals inside ceramic packaged quartzes are smaller compared to the ones inside metal cylinders. The smaller size of the quartz crystal however increases its internal loss (so called "ESR"; electrical serial resistance), thus requires oscillator circuits which can drive significantly more current and thus require more

1966 Ibid.
1967 Ibid.
1968 Ibid.
1969 Ibid.

electrical energy in operation. As many of this cylinder crystals are used for so called “clock” applications, so using a 32.768 kHz crystal to derive a time signal out of it, these oscillators have to be operated all the time, even while the application is not in use, which would impact the standby and “off” current of applications as required by applicable EU regulations. Power consumption is for several reasons (legislations, enviro nmental, operation time on batteries) very important for nearly all applications. For this reason, nearly all Semiconductor Manufacturers are putting technologies in place to reduce the power consumption of their ICs. As a result, the available energy for the oscillator is going down as well so that many of the latest ICs require extremely low ESR crystals which can use today’s technologies and can only be achieved with crystals packed into a metal cylinder due to size reasons as mentioned above.

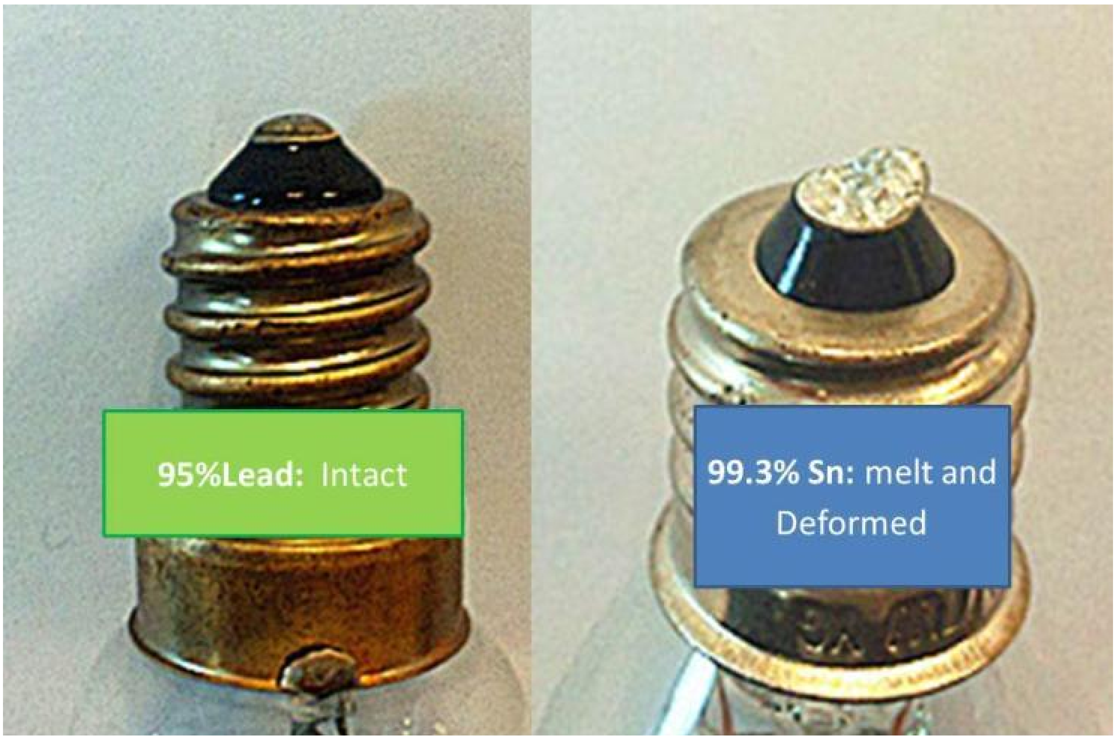
- Since the outer dimensions of the quartz crystal define its resonance frequency, the smaller ceramic packages do not allow to generate rather low frequencies like 4MHz, 6MHz or 8MHz, which however are often used to clock CPUs. Increasing this frequency would require different CPU chips and increase the power consumption in use unnecessarily.

A.5.4 Oven Lamps

Oven lamps are commonly used in many household ovens. Freescale et al.[1970] say that the temperature of the lamp during the baking process can reach 300 ^{C}. Alternative lead-free solders will ’melt‘ under these conditions. When the solder melts, the lamp fails and the consumer expects to replace the lamp. Lack of compatible replacement bulbs could result in premature oven replacement. The current technology (Incandescent, CFL, LED lamps) has no reliable alternative replacement light source available without LHMPS.

[1970] Ibid.

Figure 34-4: Oven lamp failure



Source: Freescale et al.[1971]

[1971] Ibid.