16-Jan-2015

INDEX of Key Sections, Charts and Graphs

Date of submission: January 16, 2015

16-Jan-2015

Exemption Request Form

1. Name and contact details

1.1 Name and contact details of applicant

American Chamber of Commerce to the EU (AmCham EU) ID number: 5265780509-97	**European Semiconductor Industry Association (ESIA) is part of the European Electronic Component Manufacturers Association** ID Number: 22092908193-23	**Japan Electronics and Information Technology Industries Association (JEITA)** ID number: 519590015267-92	**Avago Technologies**
Communications and Information network Association of Japan (CIAJ)	**Information Technology Industry Council (ITI)** ID number: 061601915428-87	**LIGHTINGEUROPE** ID number: 29789243712-03	**Diodes Incorporated**
DIGITALEUROPE ID number: 64270747023-20	**IPC – Association Connecting Electronics Industries**	**TechAmerica Europe (TAE)** ID number: 2306836892-93	**Knowles (UK) Ltd**
European Committee of Domestic Equipment Manufacturers (CECED) ID number: 04201463642-88	**Japan Business Council in Europe (JBCE)** ID number: 68368571120-55	**ZVEI - Zentralverband Elektrotechnik- und Elektronikindustrie e. V.** ID number: 94770746469-09	**Linear Technology Corp.**
European Garden Machinery Industry Federation (EGMF) ID number: 82669082072-33	**Japan Business Machine and Information System Industries Association (JBMIA)** ID number: 246330915180-10	**European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry (COCIR)** ID number: 05366537746-69	**ON SEMICONDUCTOR**

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European Passive Components Industry Association (EPCIA) ID number: 22092908193-23	**Japan Electrical Manufacturers´ Association (JEMA)**		

1.2 Name and contact details of responsible person for this application (if different from above):

Company:	Freescale Semiconductor	Tel.:	1-512-895-2519
Name:	Griffin Teggeman	E-Mail:	Griffin.Teggeman@Freescale.com
Function:	EPP Manager	Address:	6501 William Cannon Dr. W Austin, Texas 78735 USA

2. Reason for application:

Please indicate where relevant:

☐ Request for new exemption in:

☐ Request for amendment of existing exemption in

☒ Request for extension of existing exemption in

☐ Request for deletion of existing exemption in:

☐ Provision of information referring to an existing specific exemption in:

☒ Annex III ☐ Annex IV

No. of exemption in Annex III or IV where applicable: 7a

Proposed or existing wording:

Existing wording:

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

Duration where applicable:

We apply for renewal of this exemption for categories 1 to 7, 10 and 11 of Annex I for an additional validity period of 5 years. For these categories, the validity of this exemption may be required beyond this timeframe. Although applications in this exemption renewal request may be relevant to categories 8 & 9, this renewal request does not address these categories. Further, categories 8 & 9 have separate maximum validity periods and time limits for application for renewals.

☐ Other: _______

3. Summary of the exemption request / revocation request

We are requesting a renewal for the lead in high melting temperature solder applications. Alternative technologies with similar ductility and strength as lead (Pb) and that can survive a standard reflow process (or several) with either leaded or unleaded solder are as yet unavailable for the intended uses identified below in Section 4.(A)1.

4. Technical description of the exemption request / revocation request

4(A) Description of the concerned application:

4(A)1. To which EEE is the exemption request/information relevant?

Name of applications or products:

Required critical minimum scope:

High melting point solder (85% by weight or more lead) may be necessary in many electrical and electronic equipment applications, including

- 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.

4(A)1a. List of relevant categories: (mark more than one where applicable)

☒ 1 ☒ 7
☒ 2 ☐ 8
☒ 3 ☐ 9
☒ 4 ☒ 10
☒ 5 ☒ 11
☒ 6

4(A)1b. Please specify if application is in use in other categories to which the exemption request does not refer:

Although applications in this exemption renewal request may be relevant to categories 8 & 9, this renewal request does not address these categories. Therefore, we have not completed section 4(A)1.c. Further, categories 8 & 9 have separate maximum validity periods and time limits for application for renewals.

4(A)1c. Please specify for equipment of category 8 and 9:

The requested exemption will be applied in -

☐ monitoring and control instruments in industry
☐ in-vitro diagnostics
☐ other medical devices or other monitoring and control instruments than those in industry

4(A)2. Which of the six substances is in use in the application/product?

(Indicate more than one where applicable)

☒ Pb ☐ Cd ☐ Hg ☐ Cr-VI ☐ PBB ☐ PBDE

4(A)3. Function of the substance:

Lead is one ingredient of the solder; it gives practical performance such as electrical joining / heat conduction / high melting point / ductility and reliability. The details are in Section 4(C) below.

Content of substance in homogeneous material (%weight):

85% or more by weight of homogeneous material

4(A)4. Amount of substance entering the EU market annually through application for which the exemption is requested:

Although we have tried various avenues to obtain an estimated amount of Pb entering the EU each year due to RoHS exemption 7a for HMP lead (Pb) solders, any estimates appear to be highly subjective.

Here are our best estimates of HMP lead (Pb) solders for RoHS applications in the EU compared to all 2008 estimated Pb usage volumes.

Pb Comparison/Year	2008 Estimate	2014 Estimate
JBCE / JEITA	3,600 t/year	2,667 t/year
Industry Associations*	47 t/year	49.8 t/year
Syfer Tech Ltd.**	5.2 kg/year	N/A

* Surveyed industry associations and participating members included SIA, IPC, JBCE, JEITA, ZVEI, TechAmerica-Europe, etc. Information was solicited from over 50 companies.

** This data represented a single company. No comparison available for 2014.

Please supply information and calculations to support stated figure.

We conducted research and contacted consultants and solder associations to obtain estimated total HMP lead (Pb) solder volumes, the amount used within EEE, and the amount of HMP lead (Pb) solder from EEE placed on the market in the EU. While some total Pb usage estimates were available for all EEE (e.g. Paumanok Publications, Inc., 16-May-2014 estimated 70% reduction in 10 years), we found no trusted database and no reliable calculation method to determine the annual HMP lead (Pb) solder (RoHS 7a) used in RoHS products within the EU.

The authors of this paper subsequently launched a 2014 survey of participating manufacturing associations and individual companies. Companies were reluctant to share precise details about amounts of HMP lead (Pb) solder entering the EU per year since this might reveal market positions in specialized businesses. We obtained estimated global 2013 company usage from five semiconductor companies. The estimates ranged between 70kg and 31 tonnes per year with minimum and maximum weight per unit ranging between 0.0013 mg to 226 mg. The total usage from these 5 companies was normalized according to their combined market share of the estimated €230B semiconductor market, as 1.9 metric tonnes of HMP lead (Pb) solder per €1B in global semiconductor sales. Extended across the €230B market, this calculates 437 global tonnes of HMP lead (Pb) solder. Assuming the EU represents 11.4% of global semiconductor sales, this translates to 49.8 metric tonnes in 2013.

We also undertook an alternative estimation process through JBCE and their counterparts at JEITA in Japan. Since high-melting temperature type solders are used in a large number of end products, it is actually impossible to precisely calculate the amount of substance entering the EU market annually. The JBCE estimate was derived in similar fashion as their 2008 calculations. It was based upon “Consumption Amount of Electrolytic Lead in a Global Basis Ratio by Region (Years 2009-2011)” by ILZSG (International Lead & Zinc Study Group); and the "Consumption Amount and Ratio of Lead by Application in Japan (2007-2011)" by the Ministry of Economy, Trade and Industry of Japan and the Trade Statistics of Japan and Japan Mining Industry Association "Production Amount of Lead-Containing HMP Type Solders (85% by Weight or More) Manufactured in Japan (FY 2012-2013). The JBCE / JEITA calculations were:

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

Both estimates are intended to capture the entire EEE market. The EU EEE RoHS 7a results vary widely based upon the calculation methods and based upon the quality of underlying statistics.

4(A)5. Name of material/component:

Material is Solder

4(A)6. Environmental Assessment:

LCA: ☐ Yes
☒ No

Although no LCA exists, the amount of Pb in HMP solders for EEE is estimated to be less than 0.2% of the total Pb placed on the market per year.

A research paper from AIST (National Institute of Advanced Industrial Science and Technology) concludes that substitution of Pb in solders has a very small impact concerning risk to ecosystems. We 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. The paper can be downloaded from the URL below. An English translation shall be submitted with this dossier.

http://www.aist-riss.jp/main/modules/product/RTA_cleaners_J_downloadform.html?ml_lang=en

4(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?

Table 1 (August 2013, shown below) lists typical types and melting temperatures for solders currently used in applications falling under this exemption. For your reference, it also lists restricted types and melting temperatures of solders containing 85% or less lead which are restricted under the RoHS Directive and may be covered under other exemptions. As shown in the table, the amount of lead (Pb) has direct impact on the melting temperature of the solder.

Category	Solder Type	Alloy Composition [wt %]	Melting Temperatures (Solidus Line / Liquidus Line)
Lead-containing Solder	High temperature type lead-containing solder (Falling under exemption 7a of RoHS Directive)	Sn-85Pb	226~290 °C
		Sn-90Pb	268~302 °C
		Sn-95Pb	300~314 °C
	Lead-containing solder (Use restricted under RoHS Directive and may be exempted by exemptions 7b and 15.)	Sn-37Pb (Conventionally used)	183 °C
		Sn-60Pb	183~238 °C
		Sn-70Pb	183~255 °C
		Sn-80Pb	183~280 °C

***Table 1**: Composition and Melting Temperature of Lead-Containing Solders*

Table 2 lists intended uses and related products in which high melting point (HMP) lead (Pb) solders under RoHS exemption 7a are utilized. The table also includes reasons why they are needed.

Intended HMP 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 Figure 1, Figure 2, Figure 3, Figure 4 & Figure 5]	– 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 Figure 6]	
– 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 Figure 7]	

***Table 2**: Intended Use and Examples for Related Products*
in which HMP lead (Pb) solders are utilized

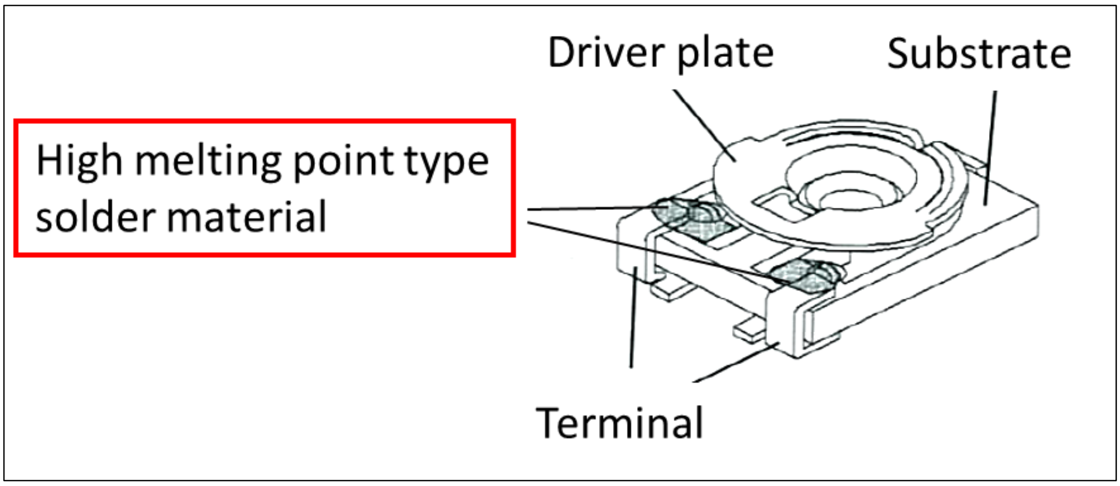


Figure 1: *Schematic view of potentiometer with HMP lead (Pb) solder visible from the outside.*

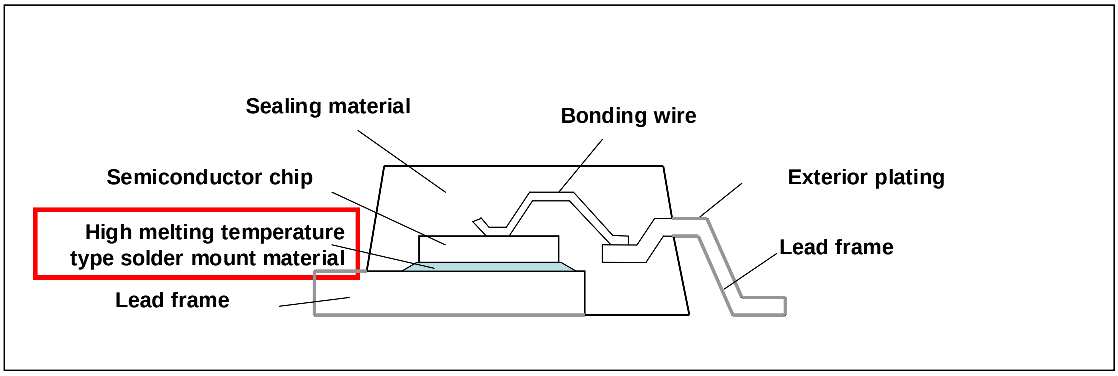


Figure 2: *Schematic cross sectional view of power semiconductor.*

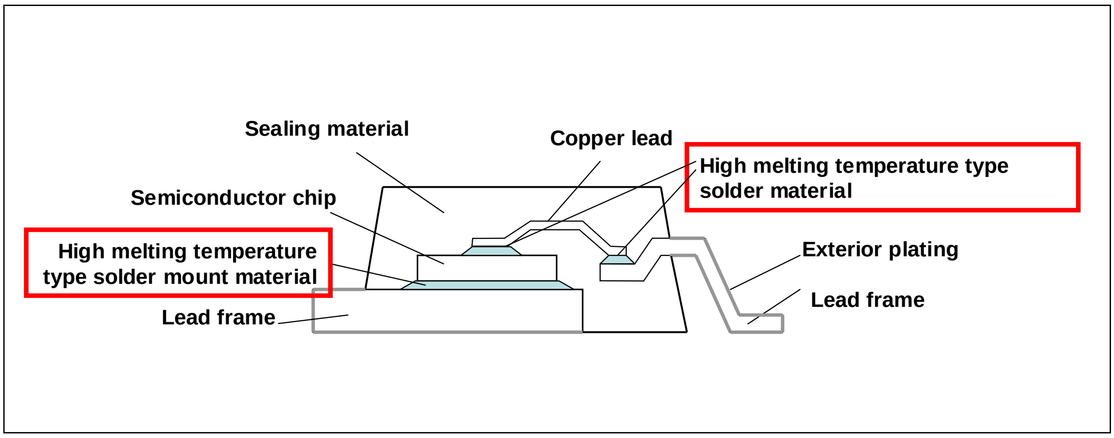
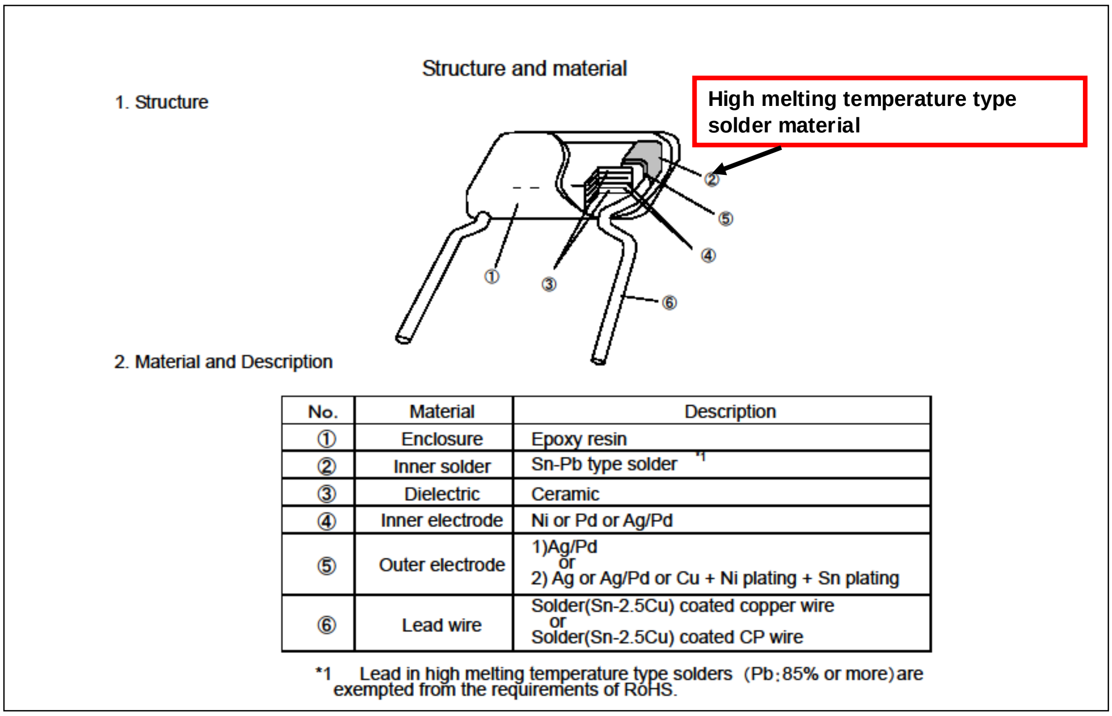


Figure 3: *Schematic cross sectional view of internal connection of semiconductor.*



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.

***Figure 4**: Schematic view of capacitor with lead wire.*

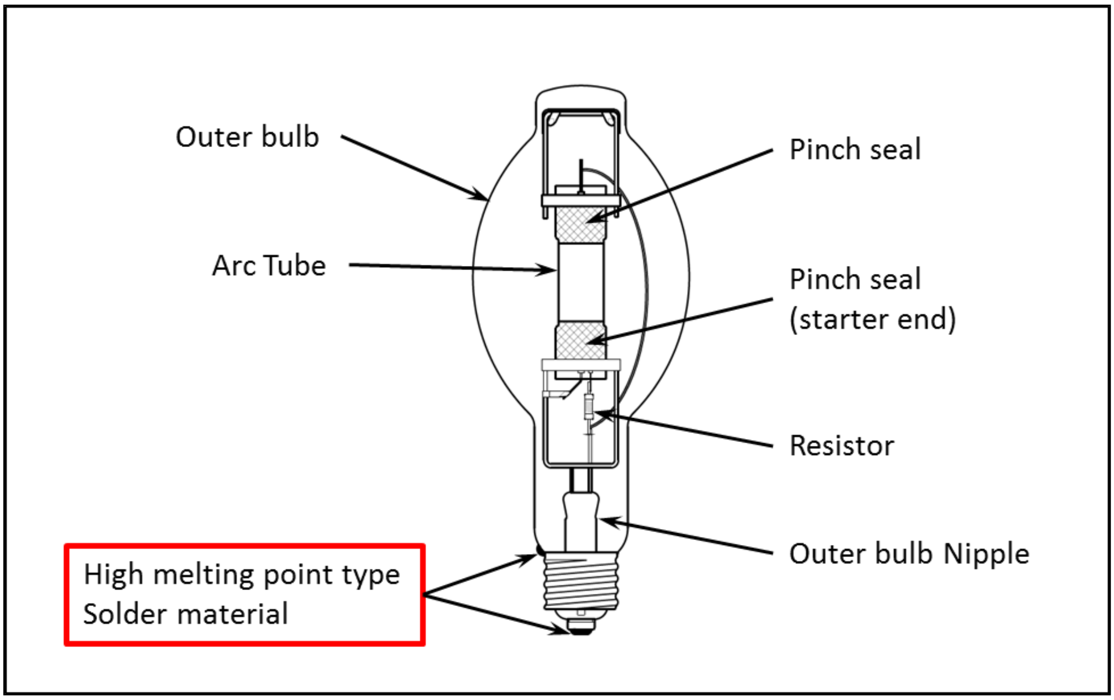


***Figure 5**: Schematic view of HID lamp.*

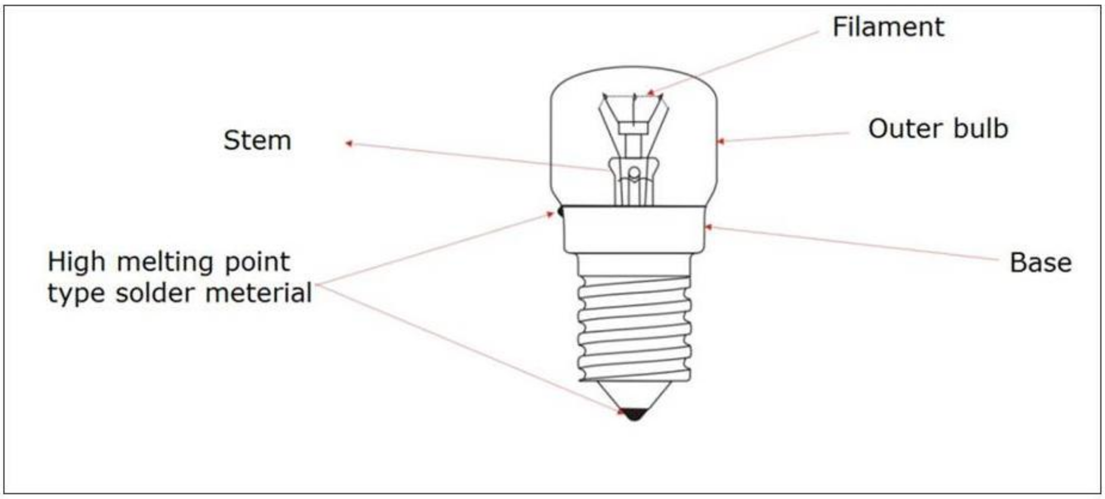


Figure 5b: Oven Lamp with High Temperature Lead Solder

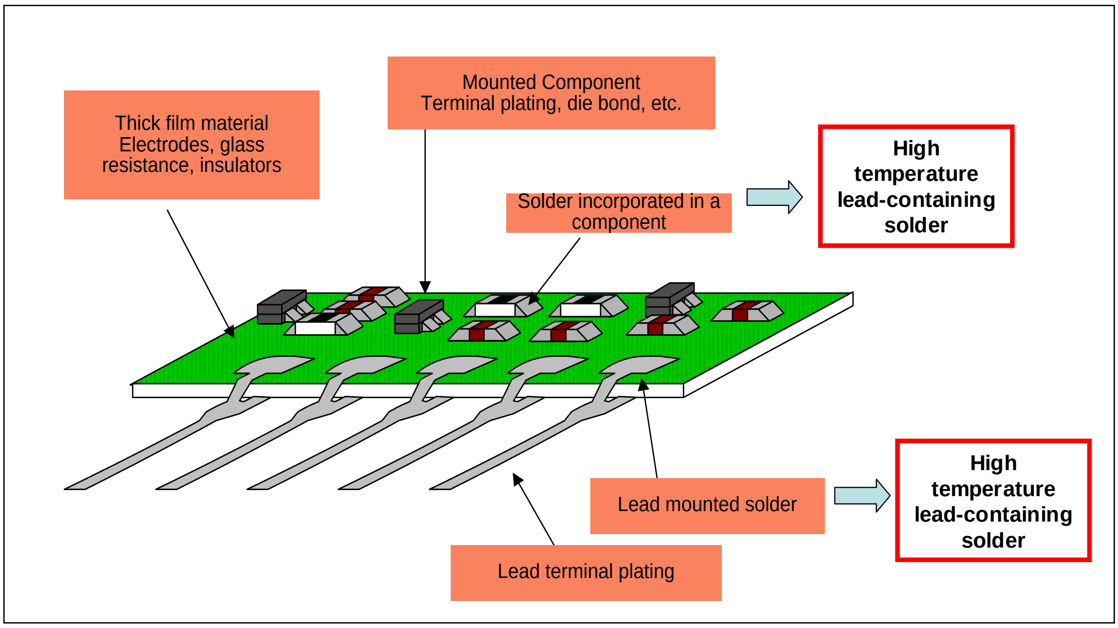


Figure 6: *Schematic view of circuit module component.*

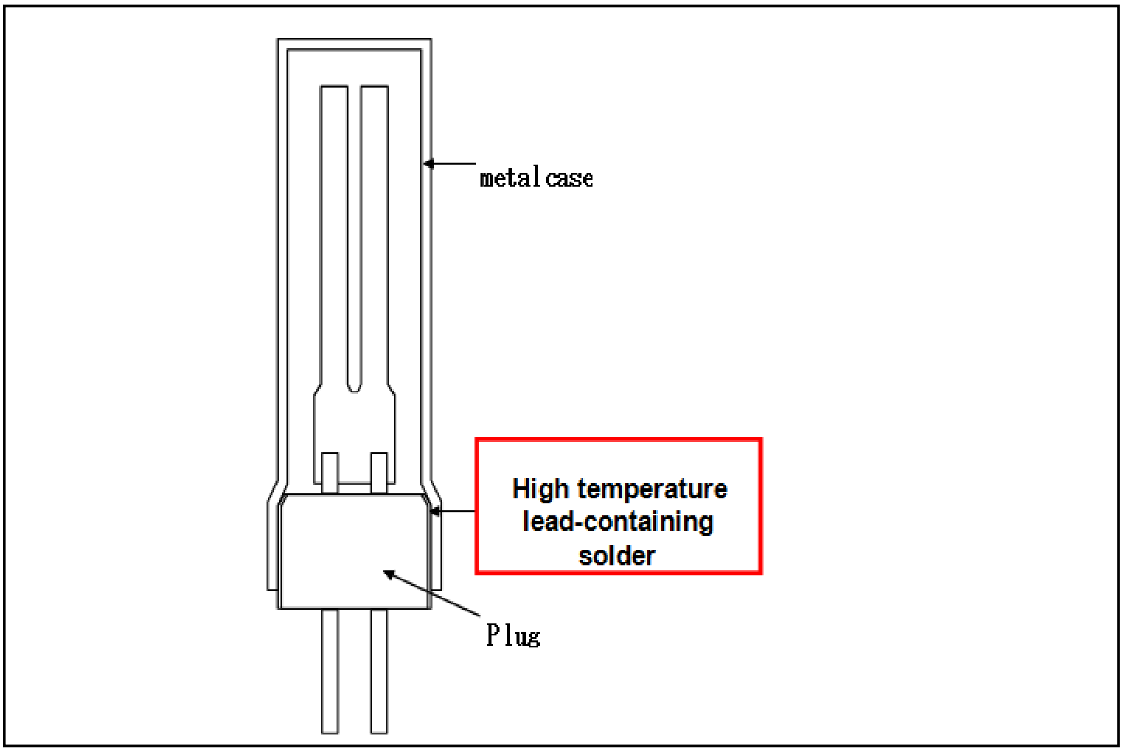


Figure 7: *Schematic view of crystal resonator.*

4(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?

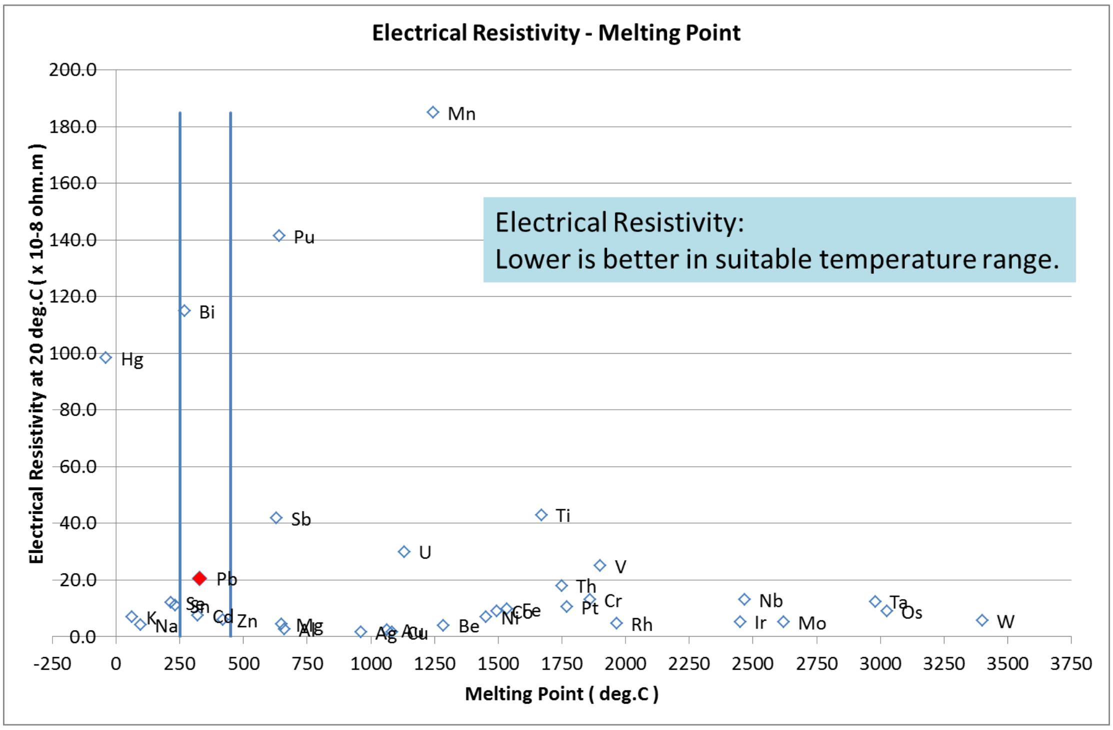
The most important property for HMP lead (Pb) solders is high melting points, which are solely managed by the lead composition. Other practical properties, such as electrical conductivity, thermal conductivity, ductility, corrosion-resistivity, appropriate oxidation nature, and wettability are also inherent in lead. Lead is the only known element which gives all these properties.

Table 3 (below & continued on next page) shows the properties necessary for HMP solders, reasons for the necessities, function of lead for each property and their data. 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.

Performance requirements	Reasons for the requirements	Function of lead	Data
High melting points	Not to be melted during secondary installations. Functionality of electrical parts not to deteriorate.	While solders for high melting point (HMP) applications require minimum melting points above 250^{o}C, solder processes have an upper limit defined as 450^{o}C. Few elements have melting points in this range. Note that 250^{o}C is a critical limit, and in reality for most applications the melting point for the HMP specific to that application is higher. Lead has the lowest hazardous property among these elements such as tellurium, cadmium or thallium.	Melting points Graph 1, Graph 2, Graph 3, Graph 4, Graph 5, Graph 6, Graph 7, Graph 8, Graph 9, Graph 10 & Figure 8
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 Graph 1 & Graph 2
Thermal conduction	To ensure the reliability of electronic components due to the heat dissipation		Thermal conductivity Graph 3 & Graph 4
Ductility	To join the materials having the different coefficients of expansion together (To ensure mechanical reliability)		Young's modulus Graph 5 & Graph 6

Corrosion-resistivity	To ensure the reliability		Ionization tendency (Very low next to hydrogen, it means difficult to oxidize) Graph 7 & Graph 8
Oxidation nature	To prevent oxidation at the secondary mounting; To ensure the reliability		Standard electrode potential Graph 9 & Graph 10

***Table 3**: Required performance to the high melting point solder and role, function of the lead and scientific data*



***Graph 1**: Electrical Resistivity – Melting Point. (Wide temperature range)*

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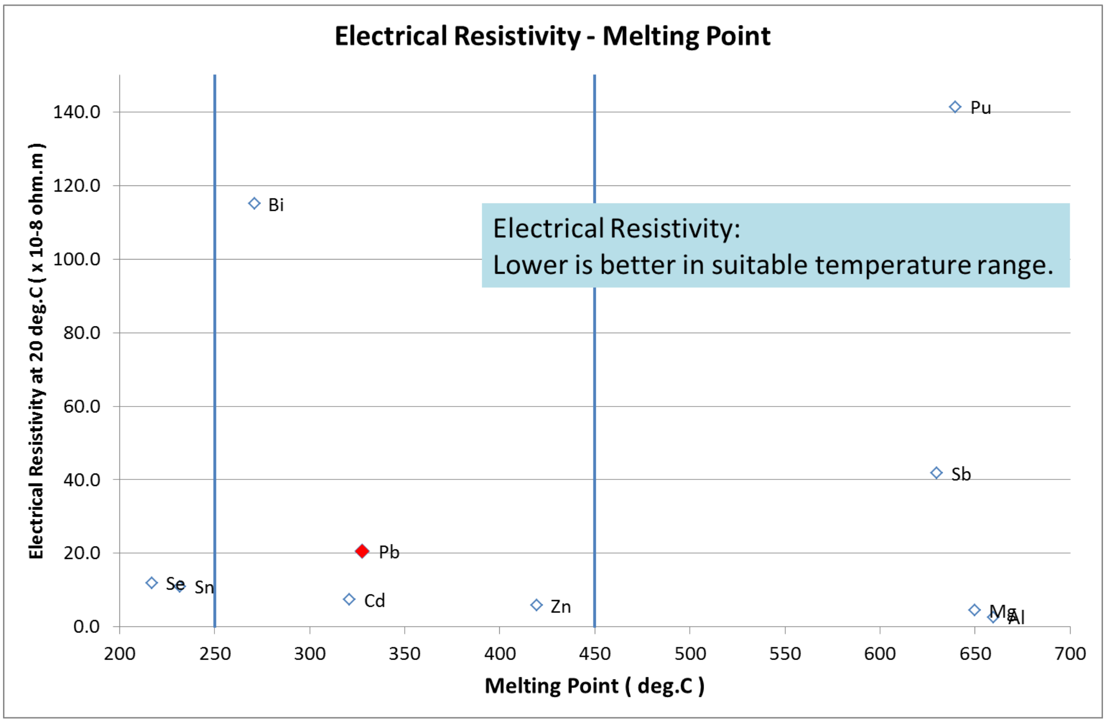
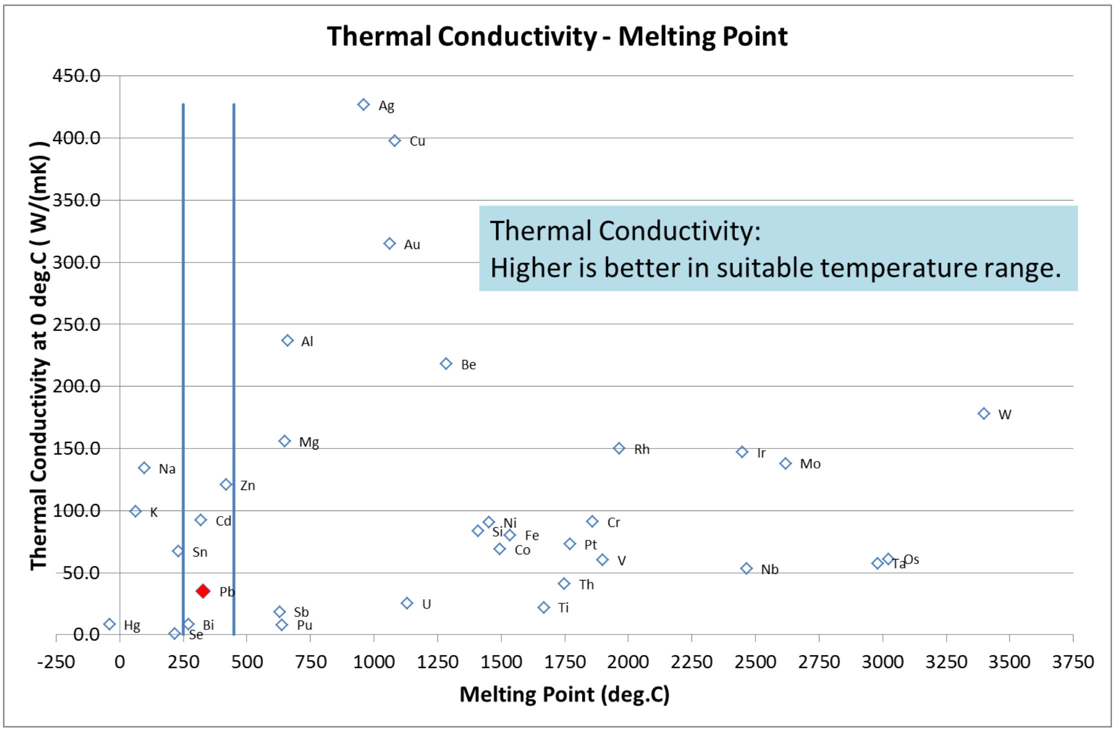
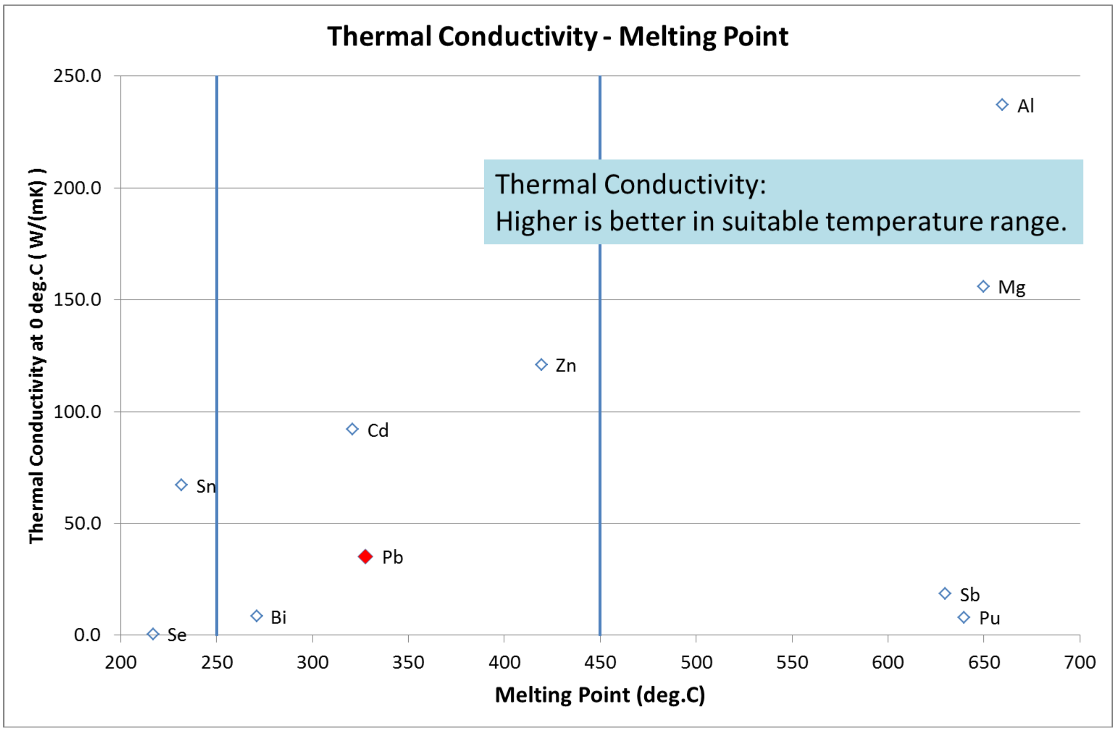


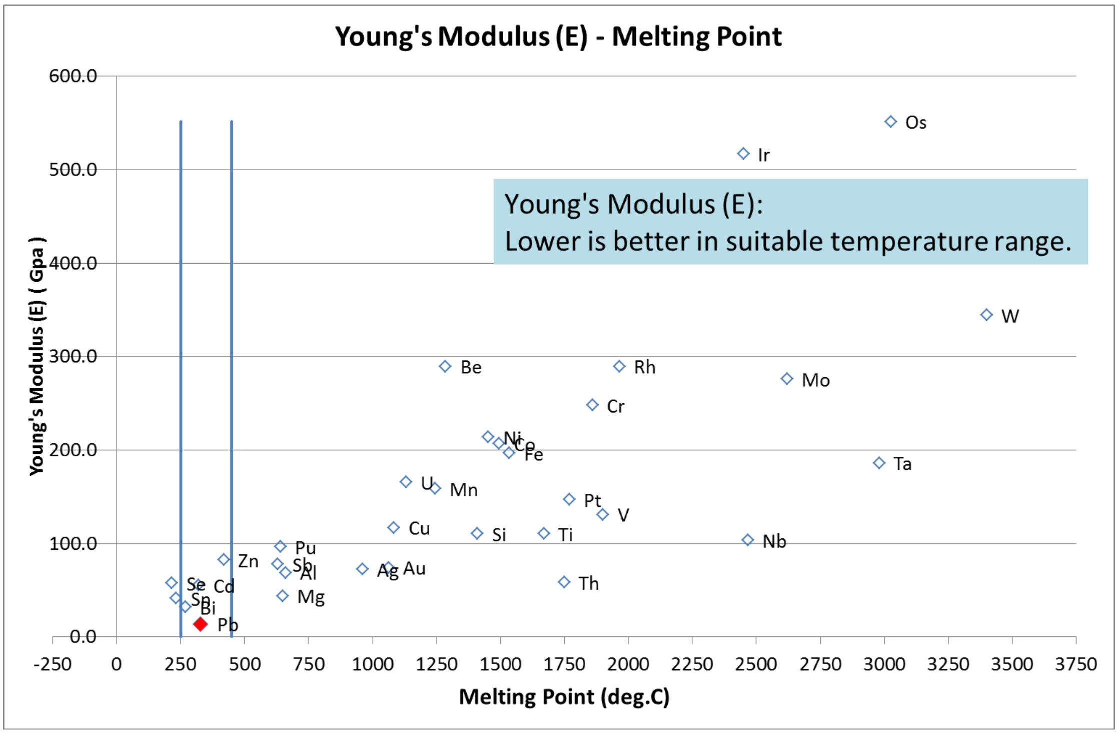
Graph 2: *Electrical Resistivity – Melting Point. (Narrow temperature range)*



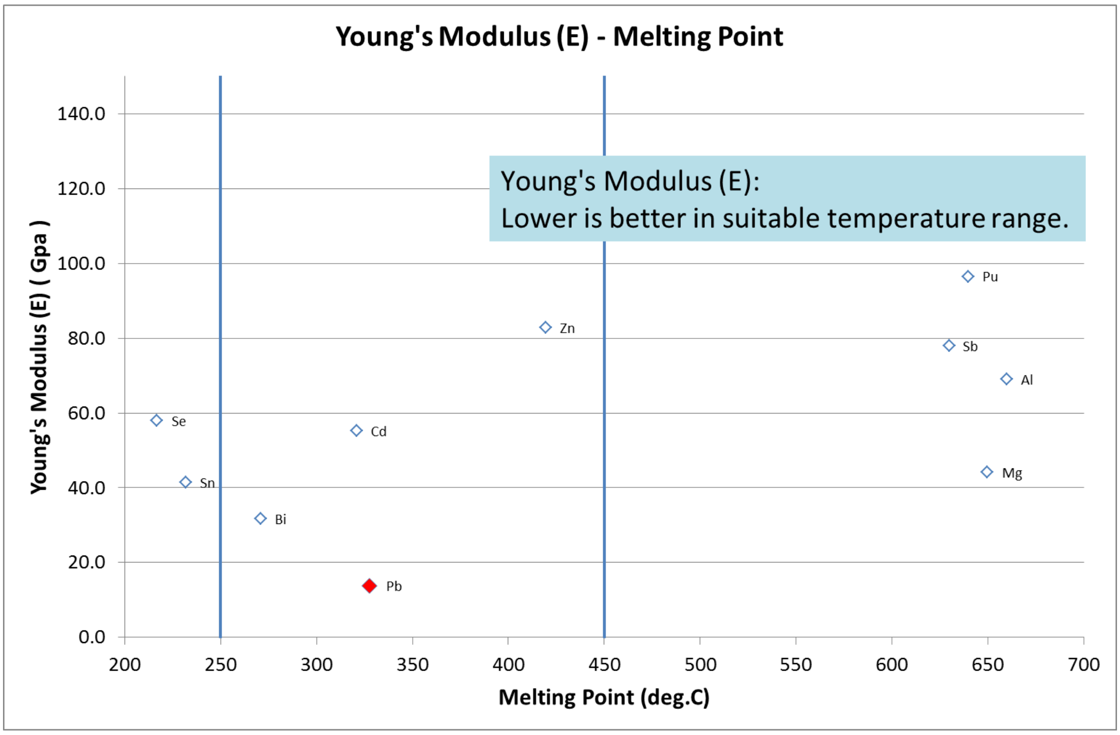
Graph 3: *Thermal Conductivity – Melting Point. (Wide temperature range)*



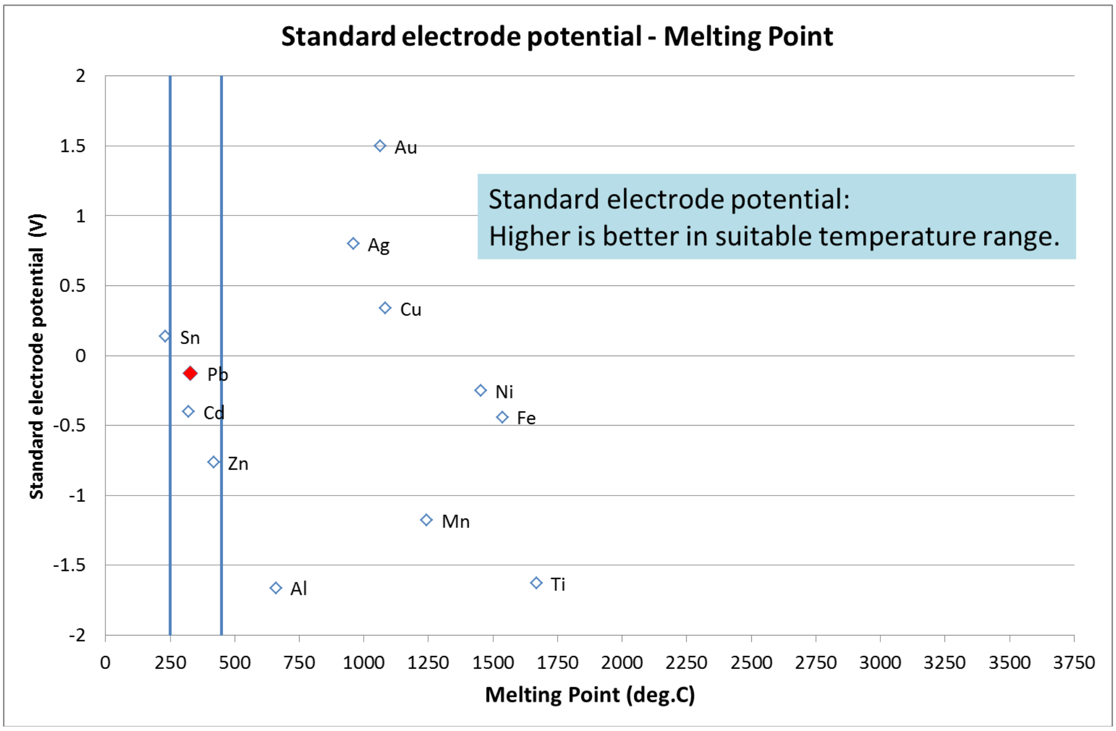
***Graph 4**: Thermal Conductivity – Melting Point. (Narrow temperature range)*



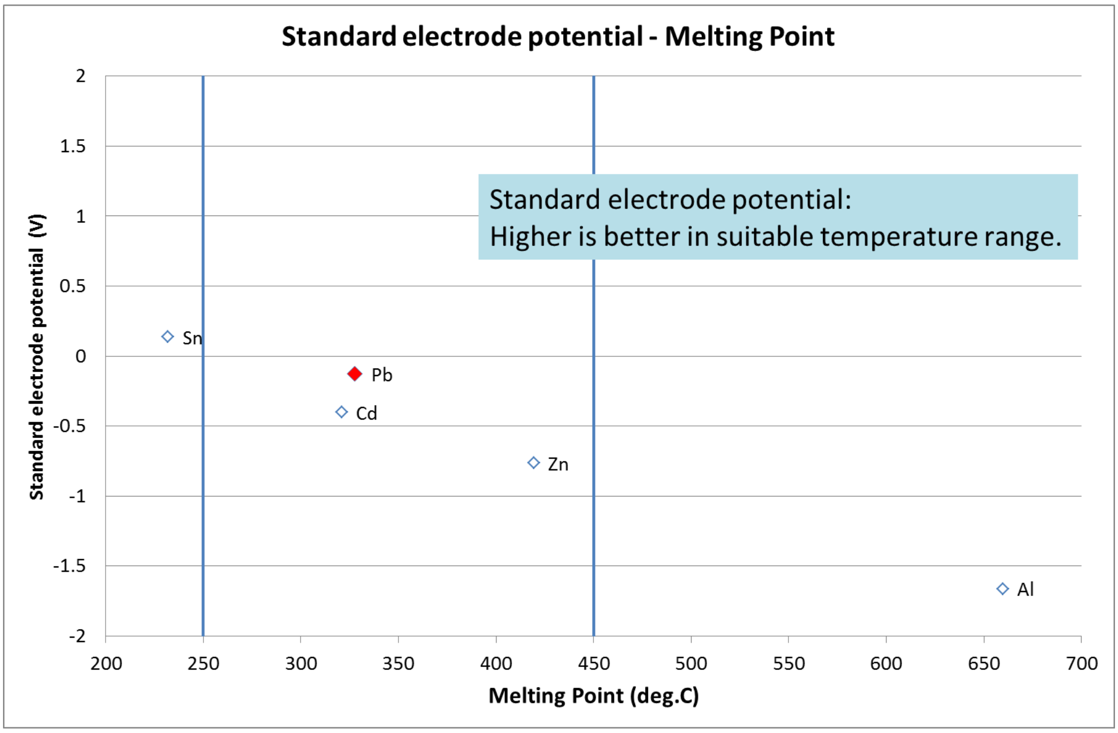
***Graph 5**: Young's Modules (E) – Melting Point. (Wide temperature range)*



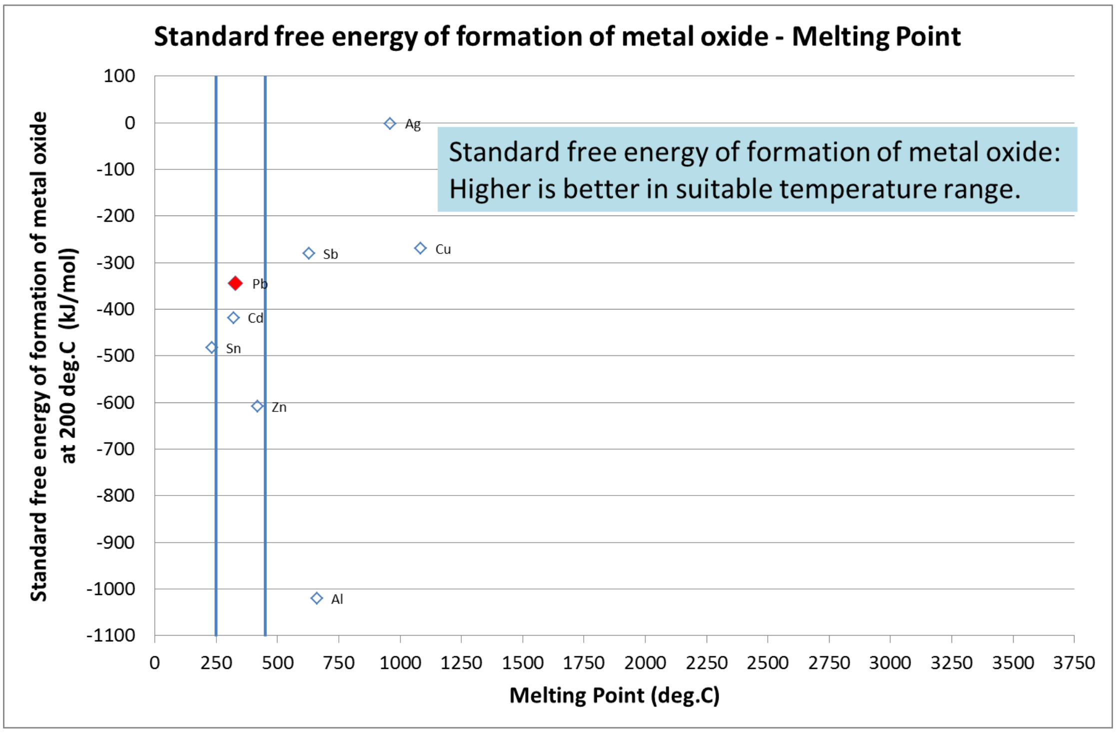
***Graph 6**: Young's Modules (E) – Melting Point. (Narrow temperature range)*



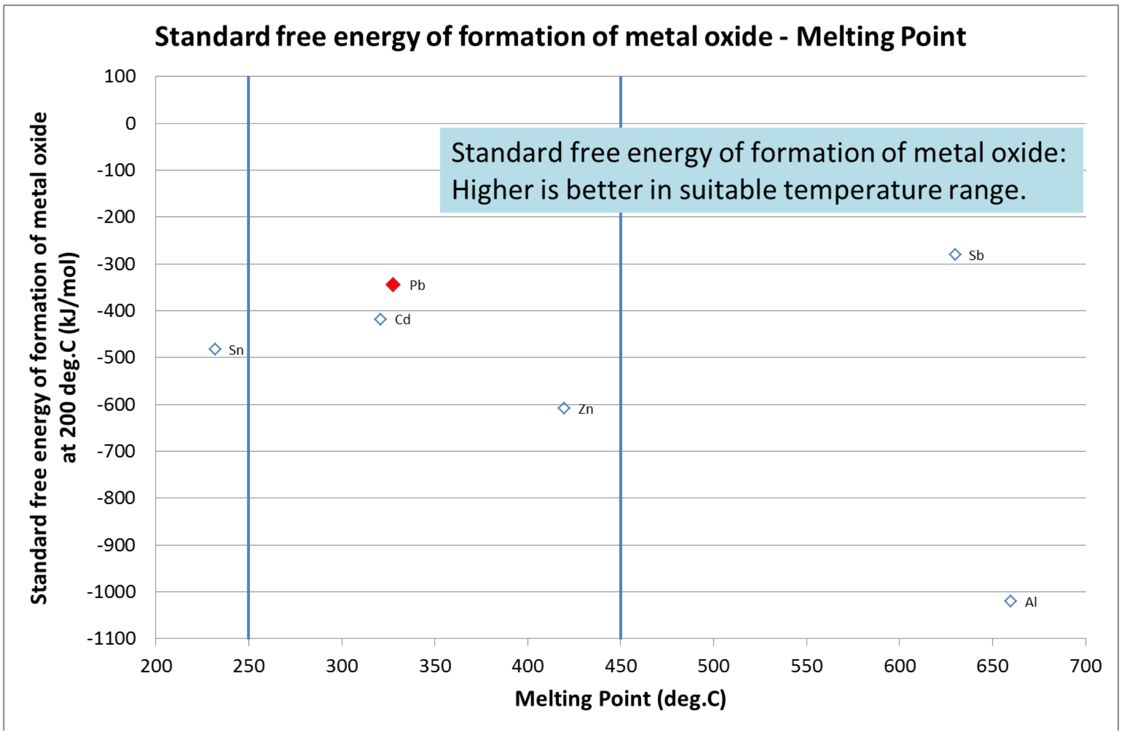
***Graph 7**: Standard electrode – Melting Point. (Wide temperature range)*



***Graph 8**: Standard electrode – Melting Point. (Narrow temperature range)*



***Graph 9**: Standard free energy of formation of metal oxide - Melting Point. (Wide temperature range)*



***Graph 10**: Standard free energy of formation of metal oxide - Melting Point. (Narrow temperature range)*

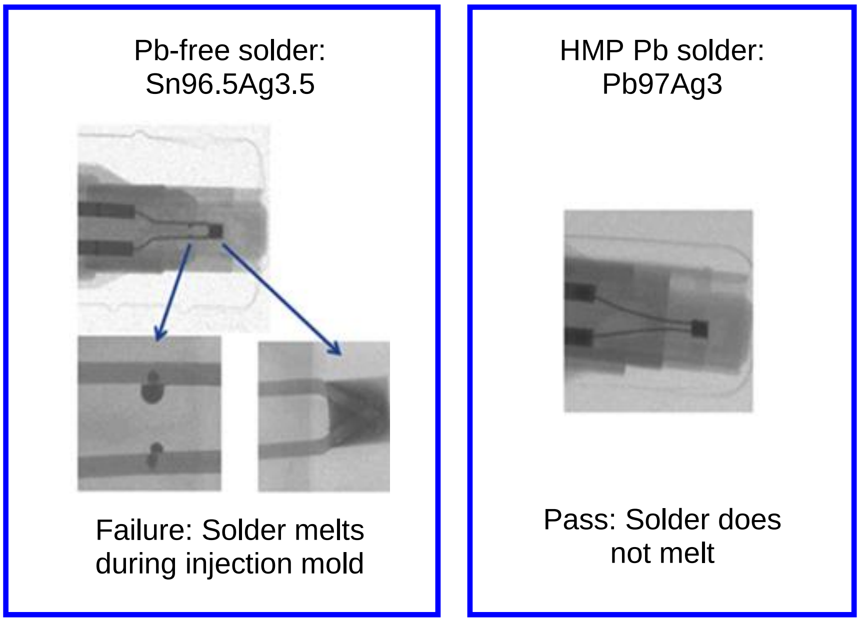


***Figure 8**: Thermistor Requirement for HMP Lead (Pb) Solder.*

Figure 8 (above) explains why a thermistor requires high melting point solder. Thermistor devices are used in high temperature / harsh applications. This requires plastic over-molding with materials having a working temperature of ~ 260^{o}C. High temperature solder is required to avoid any reflows which weaken the connecting lead (not Pb) to thermistor adhesion. The picture on the left details the solder reflow from plastic over-molding with lead free type solders. The picture on the right depicts high temperature lead base solder in the same over-molding operation.

Similar circumstances are relevant with CL (current limiting) thermistor products. Current limiting thermistors can reach temperatures up to 240^{o}C during normal operating conditions in the field. In order to stay above the plastic / melting point of the solder for this application, high lead (Pb) content solders are the only commercially available solution at this time.

5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste

5.1) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)

No closed loop system exists specifically for HMP lead (Pb) solders. HMP lead (Pb) solders are incorporated into the larger EEE and should be recycled under WEEE.

5.2) Please indicate where relevant: WEEE is required by EU legislation to be collected and recycled in the EU and may undergo most of the routes below. The presence of HMP solder does not affect which route is taken.

- ☐ Article is collected and sent without dismantling for recycling
- ☐ Article is collected and completely refurbished for reuse
- ☐ Article is collected and dismantled:
  - ☐ The following parts are refurbished for use as spare parts: ____
  - ☐ The following parts are subsequently recycled: ____
- ☐ Article cannot be recycled and is therefore:
  - ☐ Sent for energy return
  - ☐ Landfilled

5.3) Please provide information concerning the amount (weight) of RoHS sub-stance present in EEE waste accumulates per annum

As explained in Section 5-1, there is no closed loop system for capturing or identifying the final destination for the EEE containing HMP lead (Pb) solder. While some EEE containing at least one component with HMP lead (Pb) solder might be involved in each category of articles below, the volume is impossible to estimate.

- ☐ In articles which are refurbished ____
- ☐ In articles which are recycled ____
- ☐ In articles which are sent for energy return ____
- ☐ In articles which are landfilled ____

6. Analysis of possible alternative substances

6(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken

As described below in section 7(A), there is no suitable substance for substituting lead. Therefore such information and analysis are not applicable for this case.

6(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application

As described below in section 7(A), lead-containing high melting point solder is an essential element of EEE and there is no suitable lead-free substitute for it. Therefore, such information is not applicable for this case.

7. Proposed actions to develop possible substitutes

7(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.

Lead-free solders of metallic systems that have a required solidus line temperature of 250°C or higher and electrically conductive adhesive systems have important disadvantages (as shown below in Table 5) and thus cannot substitute for HMP lead (Pb) solders. In addition, as a trend of EEE components, further miniaturization of structures proceeds, and brings increase of thermal and mechanical load on components. Lead properties described in section 4(C) ensure fewer defects during manufacturing and high reliability throughout the life of the component, thereby also resulting in longer life of components and reduced waste(1). In addition, in the event that substitution production technology becomes available, a very careful scrutiny is needed to maintain the required high quality of components in the process to avoid failure in actual field so that such new technology can be adopted.

(1) Note: In this proposal we reference a document by the UK's BERR (now UK's BIS) at http://www.berr.gov.uk/files/file40576.pdf on page 18.

Table 4 (below) lists types and melting temperatures of lead-free solders that are currently (as of January 2014) in use and of which commercial viability is currently under study.

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

***Table 4**: Composition and Melting Temperatures of Main Lead-free Solders*

Figure 9 (below) shows the relationship of types and melting temperatures of lead-containing solder and lead-free solders, based on the data shown in Table 2 and Table 4 (above).

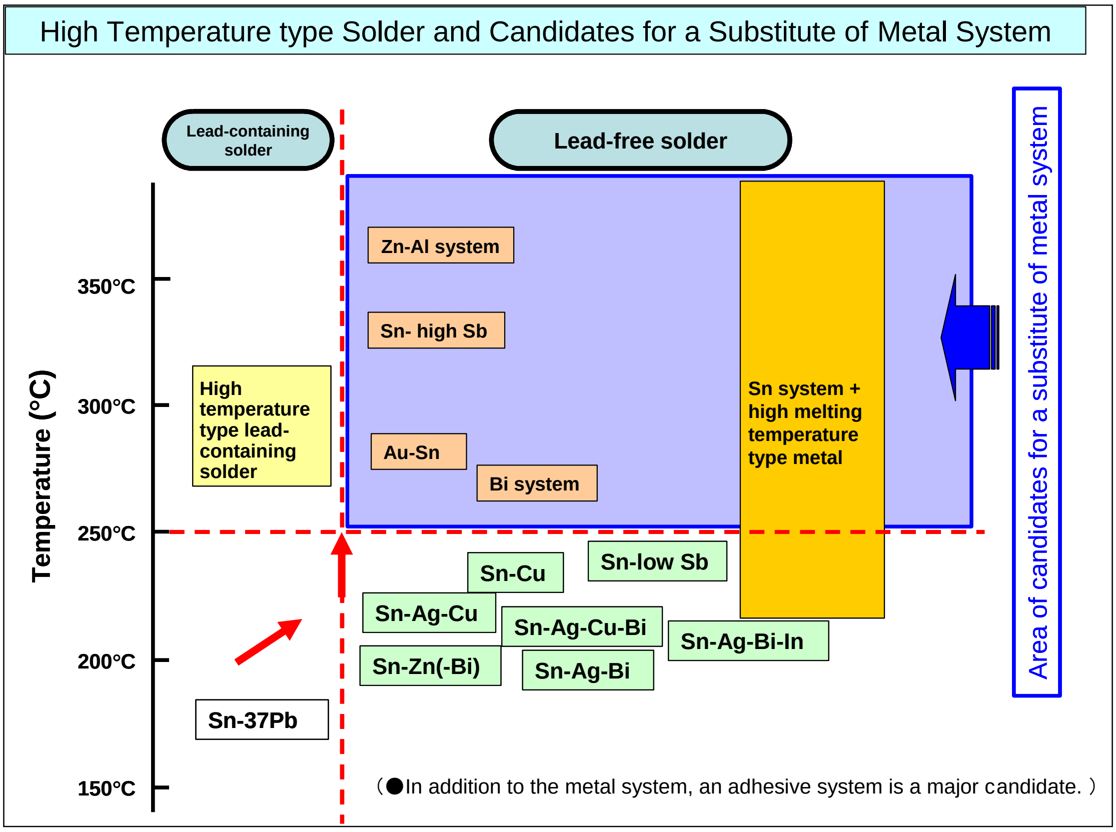


***Figure 9**: Relationship Diagram of Solders and Melting Temperature**

** This diagram borrowed from ACEA submission for ELV exemption 8e, November 2013.*

The RoHS Directive has encouraged the transition from lead solders to lead-free solders for external terminations and board attachment. 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.

The following, Table 5 shows advantages and disadvantages of lead-free solders and electrically conductive adhesives with a solidus line temperature of 250 °C or higher. Those are the candidates for the replacement of high temperature type lead-containing solders as shown previously in Figure 8.

Candidate for Substitution		Advantages	Disadvantages
	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 HMP Pb solder
	Sn-high Sb	• Solidus line is high	• Low ductility • Concern of Sb toxicity • Temperature required to solder is ~50°C 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

***Table 5**: Advantages and Disadvantages of High Temperature Lead-free Solders*

As shown in Table 5 above, both lead-free solders of metallic systems and electrically conductive adhesive systems that have solidus line temperature of 250°C or higher have important disadvantages which do not qualify them for substituting high temperature type lead-containing solders.

The above data explains that no alternative Pb-free HMP materials currently in the market meet or exceed the required functionality and reliability for the uses identified above in section 4(A). Yet the materials industry continues to develop potential future alternatives in conjunction with component manufacturers.

The Die Attach 5 (or DA5) study has been working with suppliers for several years to identify and evaluate alternatives to HMP lead (Pb) solders. They have evaluated a variety of new materials from leading global suppliers of solders, adhesives, Ag sintering and transient liquid phase sintering (TLPS) materials. The DA5 evaluations recognize continuous improvement in the evaluated materials over the past 5 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 high Pb solders. More information is provided below in Section 9(A). 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.

International Rectifier also offers reliability failure information for their evaluation of promising Ag epoxy materials from 4 different suppliers and 5 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). The partial melt solders failed industry criteria for MSL preconditioning prior to reliability testing; those solders partially melted during 260oC reflow and caused massive package delamination and solder squirt.

More information about the DA5 and I.R. industry development efforts are available in Sections 9A and 9B of this document, 'Other Relevant Information'.

7(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.

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

It should also be mentioned that the EEE industry and automotive industry have an extensive overlap in their supply chains. We would recommend that the EU maintain consistent wording between RoHS exemption 7a and ELV exemption 8e where feasible[1].

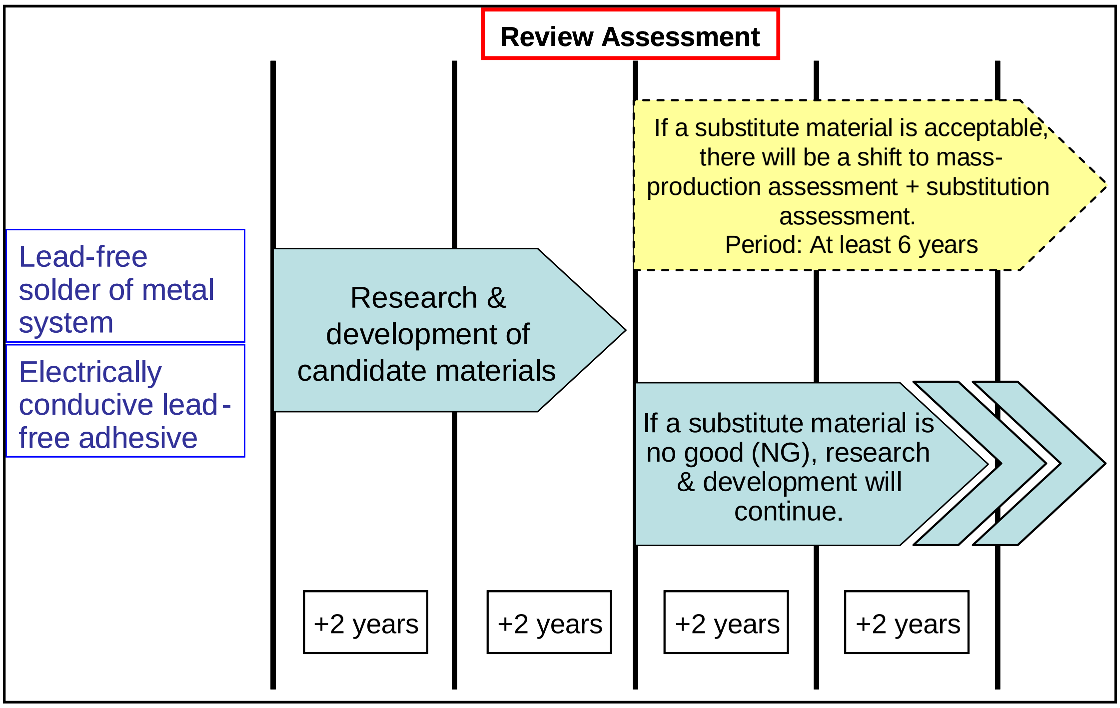


***Figure 10**: Material transition Process*

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 (Customer Presentation). 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.

[1] http://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/20141105_ELV-Exemptions_Final_20141121.pdf

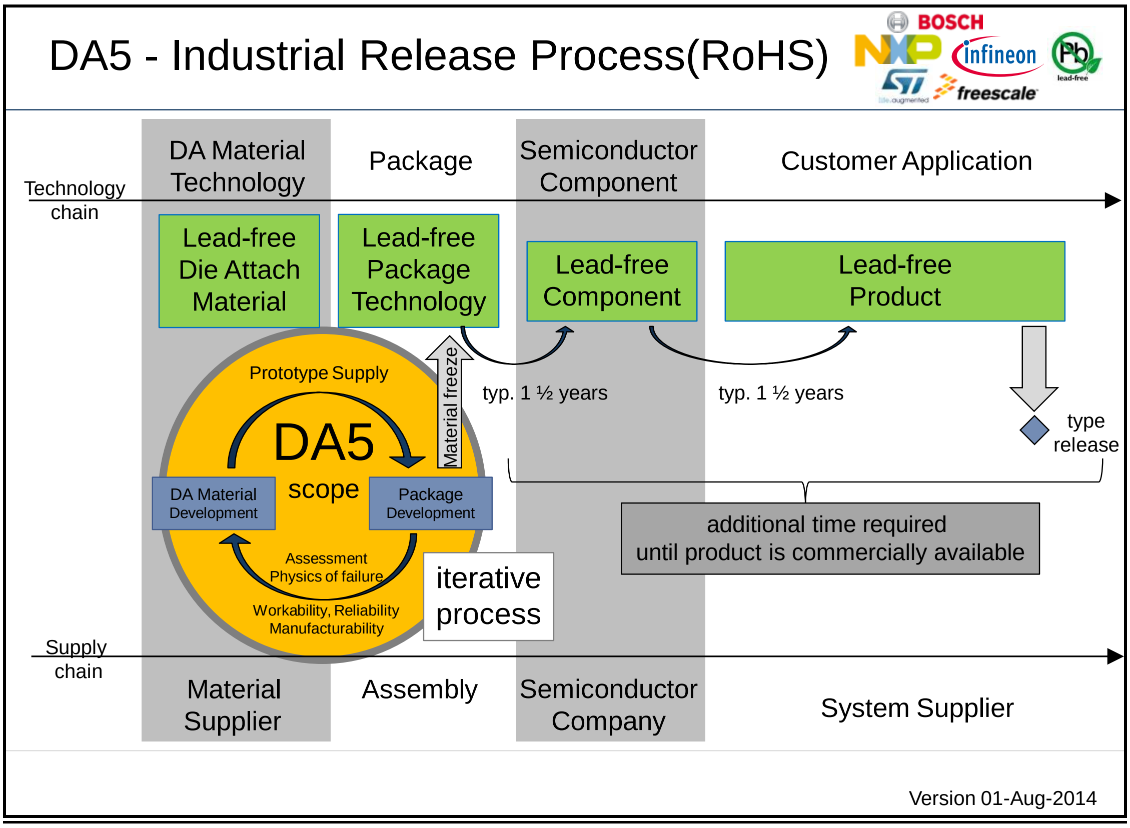


***Chart 1**: Cycle Time to Conversion (DA5)*

8. Justification according to Article 5(1)(a)

8(A) Links to REACH／REACH: (substance + substitute)

8(A)1 Do any of the following provisions apply to the application described under (A) and (C)?

- ☐ Authorisation
  - ☐ SVHC
  - ☐ Candidate list
  - ☐ Proposal inclusion Annex XIV
  - ☐ Annex XIV
- ☐ Restriction
  - ☐ Annex XVII
  - ☐ Registry of intentions
- ☒ Registration

8(A)2) Provide REACH-relevant information received through the supply chain.
Name of document

ECHA registration dossier: http://apps.echa.europa.eu/registered/data/dossiers/DISS-9c85aae9-b4e7-32ec-e044-00144f67d249/AGGR-e141b9a3-ba29-4962-80c5-be90cb034c31_DISS-9c85aae9-b4e7-32ec-e044-00144f67d249.html#section_3_5

8(B) Elimination/substitution:

8(B)1 Can the substance named under 4.(A)2 be eliminated?

☐ Yes. Consequences? _____

☒ No. Justification: see Section 7(A) & 7(B)

8(B)2 Can the substance named under 4.(A)2 be substituted?

☐ Yes.

☐ Design changes:

☐ Other materials:

☐ Other substance:

☒ No. Justification: see Section 7(A) & 7(B)

8(B)3 Give details on the reliability of substitutes (technical data + information):

There is no available and functionally equivalent alternative, so not able to provide reliability assessment data for alternatives. See reliability documentation within DA5 charts under Sections 7(A) and 7(B) for potential reliability problems.

8(B)4 Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to

1) Environmental impacts:
2) Health impacts:
3) Consumer safety impacts:

➔ Do impacts of substitution outweigh benefits thereof?
Please provide third-party verified assessment on this: _____

There is no available and functionally equivalent alternative, so not able to provide environmental assessment data for alternatives in above items 8(B)3 and 8(B)4. At least one proposed alternative contained dibutyltin dilaurate (CAS# 77-58-7) which is a REACH SVHC.

8(C) Availability of substitutes:

8(C)a) Describe supply sources for substitutes:

8(C)b) Have you encountered problems with the availability? Describe:

8(C)c) Do you consider the price of the substitute to be a problem for the availability?

☐ Yes ☐ No

8(C)d) What conditions need to be fulfilled to ensure the availability? ______

There is no functionally equivalent alternative, so not able to provide availability assessment data. Solder manufacturers continue to modify the formulations for proposed alternatives in order to improve the thermal/mechanical/electrical performance, reliability and manufacturability. Solder manufacturers are only providing samples of these materials under a strict NDA until patents are complete. No single solution has emerged from this development/evaluation process.

Once a solder material is available with supplier commitment for at least 15 years of stable production, the electronics industry must develop and install compatible manufacturing processes and equipment before qualifying and ramping production. This process will take many years to complete. Based upon the history from lead terminations, the conversion process could extend for up to 10 years.

8(D) Socio-economic impact of substitution: Not applicable

➔ What kind of economic effects do you consider related to substitution?

- ☐ Increase in direct production costs
- ☐ Increase in fixed costs
- ☐ Increase in overhead
- ☐ Possible social impacts within the EU
- ☐ Possible social impacts external to the EU
- ☐ Other: ______

➔ Provide sufficient evidence (third-party verified) to support your statement: ______

There is no available and functionally equivalent alternative, so not able to evaluate the socio-economic impact of substitution. Evaluations include direct material cost, production yield and efficiency, equipment and process changes, and current / future regulatory requirements like conflict mineral sourcing.

9. Other relevant information

Please provide additional relevant information to further establish the necessity of your request:

9(A) Efforts of the Die Attach 5 (DA5)

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.

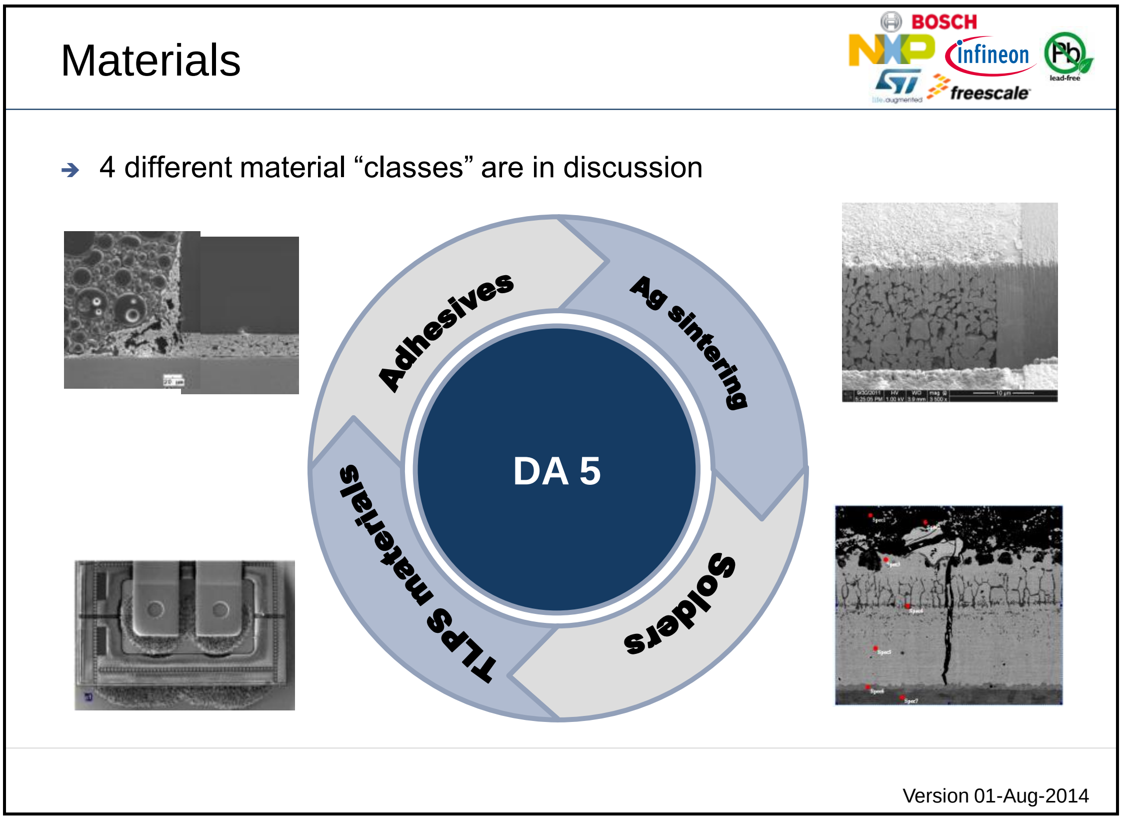
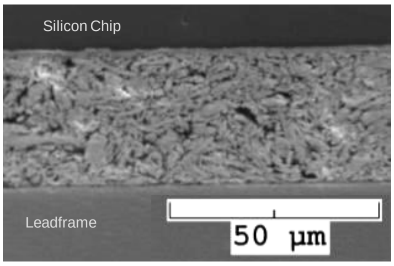


***Chart 2**: Potential alternative materials*

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).

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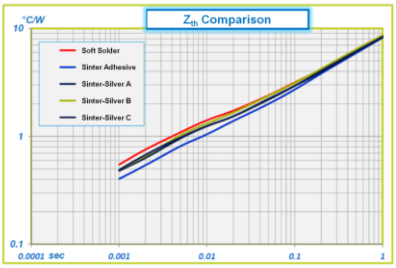
***Chart 3**: High Thermal Conductive Adhesives I*

Conductive Adhesives II

Advantages

- Good adhesion to different types of chip backside and leadframe plating.
- Good thermal and electrical performance.
- Common production methods and equipment can be used for the application of the material and placement of the chip.
- Curing in box ovens under usual conditions in air or Nitrogen atmosphere.
- Pass automotive environment stress test conditions.



Comparison of transient thermal resistance of highly silver filled adhesive vs. high-lead soft solder and sintered silver materials.

Scanning acoustic microscopy shows no delamination of die attach after 2000cycles TC -50°C / +150°C.

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***Chart 4**: High Thermal Conductive Adhesives II*

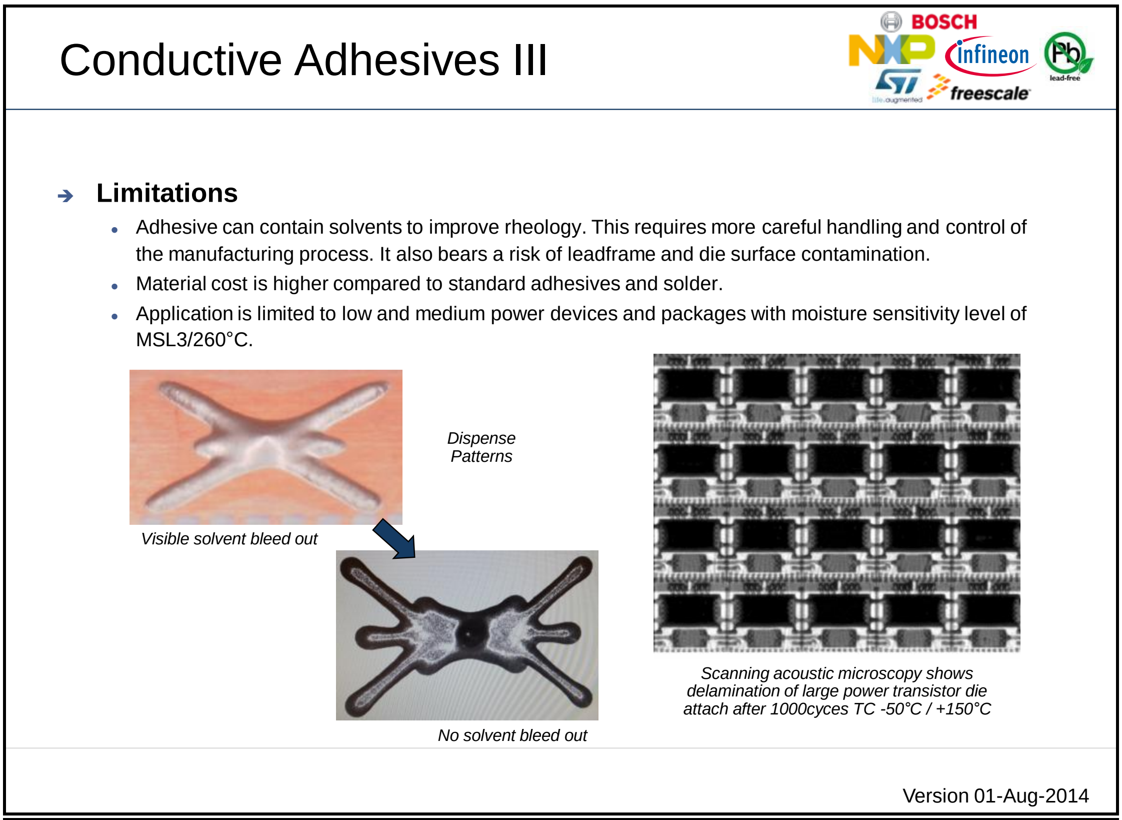

***Chart 5**: High Thermal Conductive Adhesives III*

<u>High Thermal Conductive Adhesives</u>

In general these 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 leadframes (~200µm) due to unacceptable leadframe 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.

Limits of Thermal Conductive Adhesives versus HMP lead (Pb) Solder requirements:

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 ➔ HMP lead (Pb) solder required
- Also the chip size for adhesive is limited to ~30mm^2. 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.

16-Jan-2015

Ag Sintering I – Overview

- Principle
  - Ag-sinter pastes: Ag particles (µm- and/or nm-scale) with organic coating, dispersants, & sintering promoters
  - Dispense, pick & place die, pressureless sintering in N2 or air in box oven
  - Resulting die-attach layer is a porous network of pure, sintered Ag
- Advantages
  - Fulfills many of the drop-in replacement requirements for a paste
  - Better thermal and electrical performance than Pb-solder possible
- Disadvantages
  - No self-alignment as with solder wetting
  - nm-scale Ag particles are at risk of being banned
  - New concept in molded packaging - no prior knowledge of feasibility, reliability or physics of failure
  - Production equipment changes might be needed (low-O_2 ovens?)
- Elevated risks
  - Potential limitations in die area/thickness, lead frame & die finishes
  - Potential reliability issues: cracking (rigidity), delamination or bond lift (organic contamination, thickness reduction due to continued sintering), interface degradation or electromigration of Ag (O_2 or humidity penetration, unsintered Ag particles in die-attach layer)

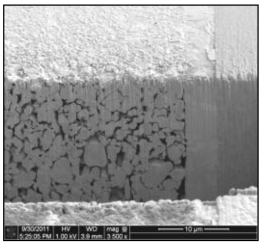

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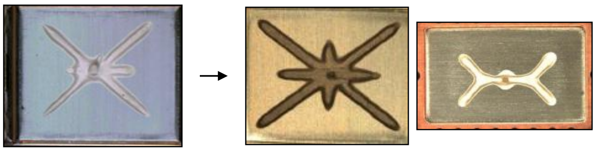
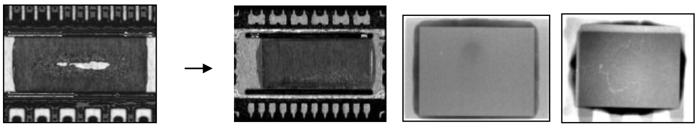
***Chart 6**: Silver Sintering I – Overview*

Ag Sintering II – Assembly

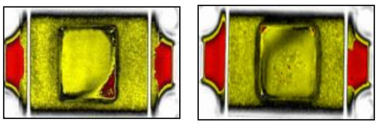
- Dispensability and staging time are improving, but issues persist



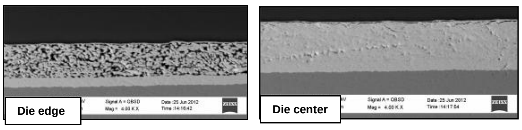
- Voiding is improving



- Process control issue: C-SAM scans are difficult to interpret



- Bond line density differences and un-sintered material should be improved



- Unsintered Ag-particles are improving

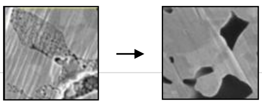


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***Chart 7**: Silver Sintering II – Assembly*

Ag Sintering III – 0-hr & Reliability Results

- Oxidation and/or delamination of interfaces is common, even at 0-hr, lowering adhesion and electrical & thermal performance. Potential solutions (not yet proven):
  - Reduce oxygen content in atmosphere during curing
  - Change paste formulation to allow for lower sintering temperature or less interaction with back-side metallization
  - Change back-side metallization
- In cases with no delamination, high DSS (20 N/mm^2) and good thermal performance can be had with Ag finishes
  - In-package electrical performance still lags Pb-solder
- No test configuration has yet to pass all required reliability tests after MSL1 preconditioning
  - Results after MSL3 preconditioning are better, with reduced cracking and delamination
  - Recent results show further improvements,
    - but still some delamination after temperature cycling and pressure pot / autoclave tests
    - but failures during biased tests (THB, HAST) are common
- Physics of failure understanding missing/ongoing: already porosity and bond line thickness changes seen
  - Die penetration test shows non-hermetic die attach (at least for ~1mm from the edges of the die)

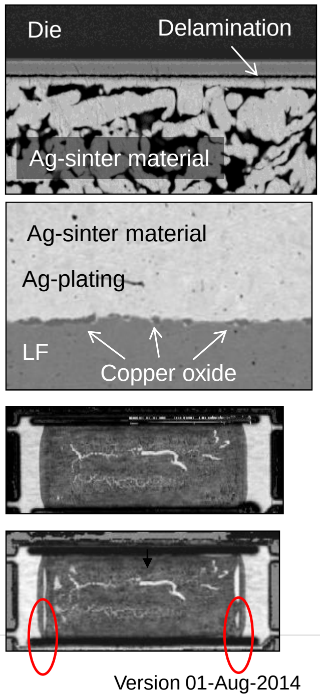

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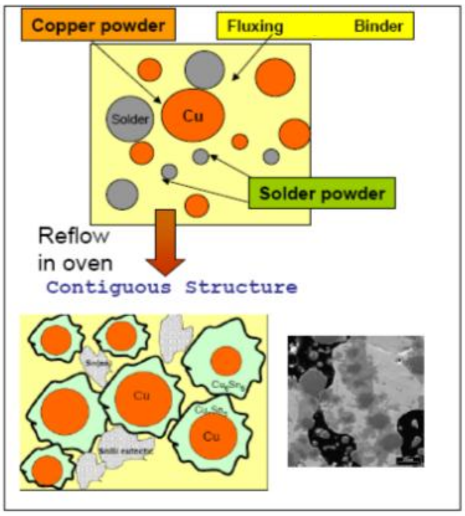
***Chart 8**: Silver Sintering III – 0-hr & Reliability Results*

TLPS materials I



Principle

- Advantages
  - Fulfills many of the drop-in replacement requirements for a paste
  - Better cost position compared to Ag sintering solutions
  - Good electrical performance on Ag-plated leadframes
- Disadvantages
  - Medium metal content in die attach
  - High space rate, filled with Epoxy
  - New concept in molded packaging - no prior knowledge of feasibility or reliability
  - Only suitable for medium dies < 24 mm^2
  - Compatibility issue with Cu leadframes
- Elevated risks
  - Potential limitations as die attach for high power devices (low electrical and thermal conductivity compared to Pb solder)
  - Potential reliability issues: spaces lead to cracks in die attach

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***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/mm^2)
- Strong brittle intermetallic phase growth with Cu

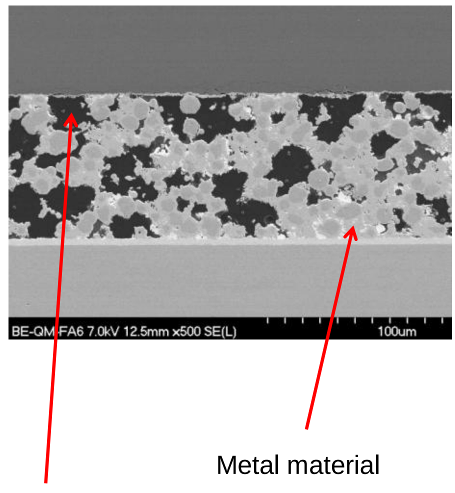

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***Chart 10**: TLPS Materials II*

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

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***Chart 11**: Alternative Solders I*

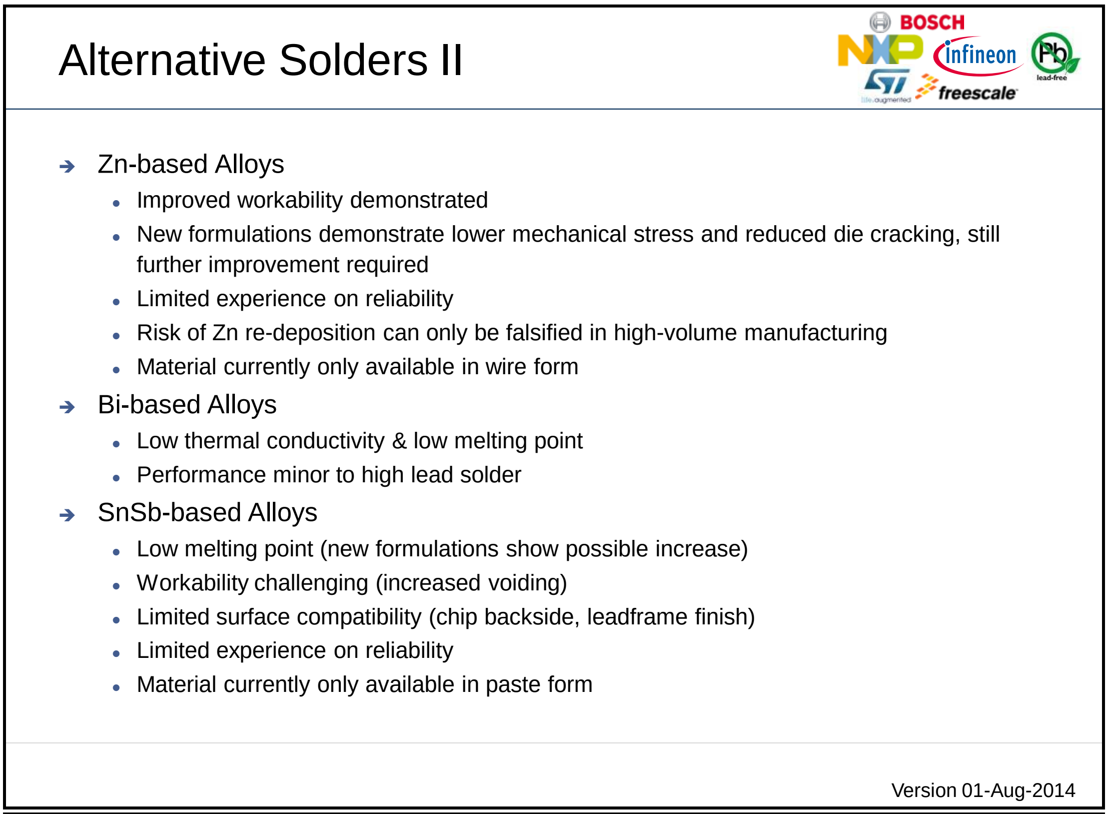


***Chart 12**: Alternative Solders II*

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.

16-Jan-2015

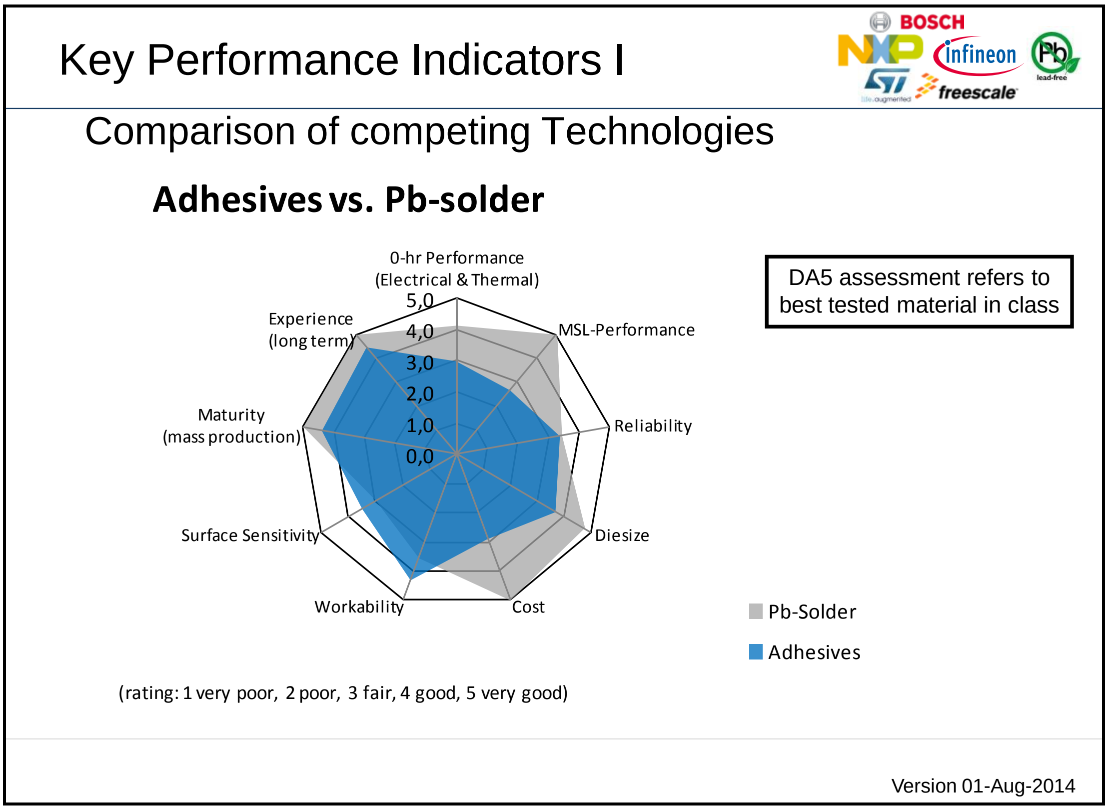


***Chart 13**: KPI-1 for Adhesives vs. Pb-solder*

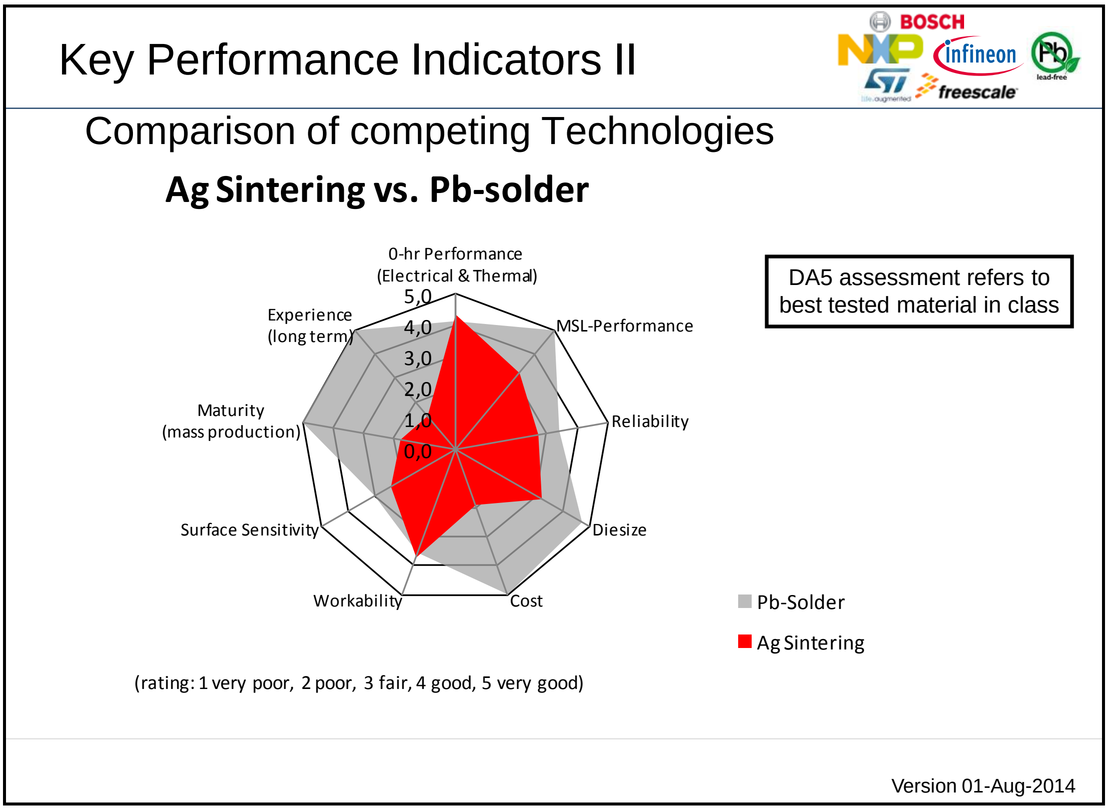


***Chart 14**: KPI-2 for Silver Sintering vs. Pb-solder*

16-Jan-2015

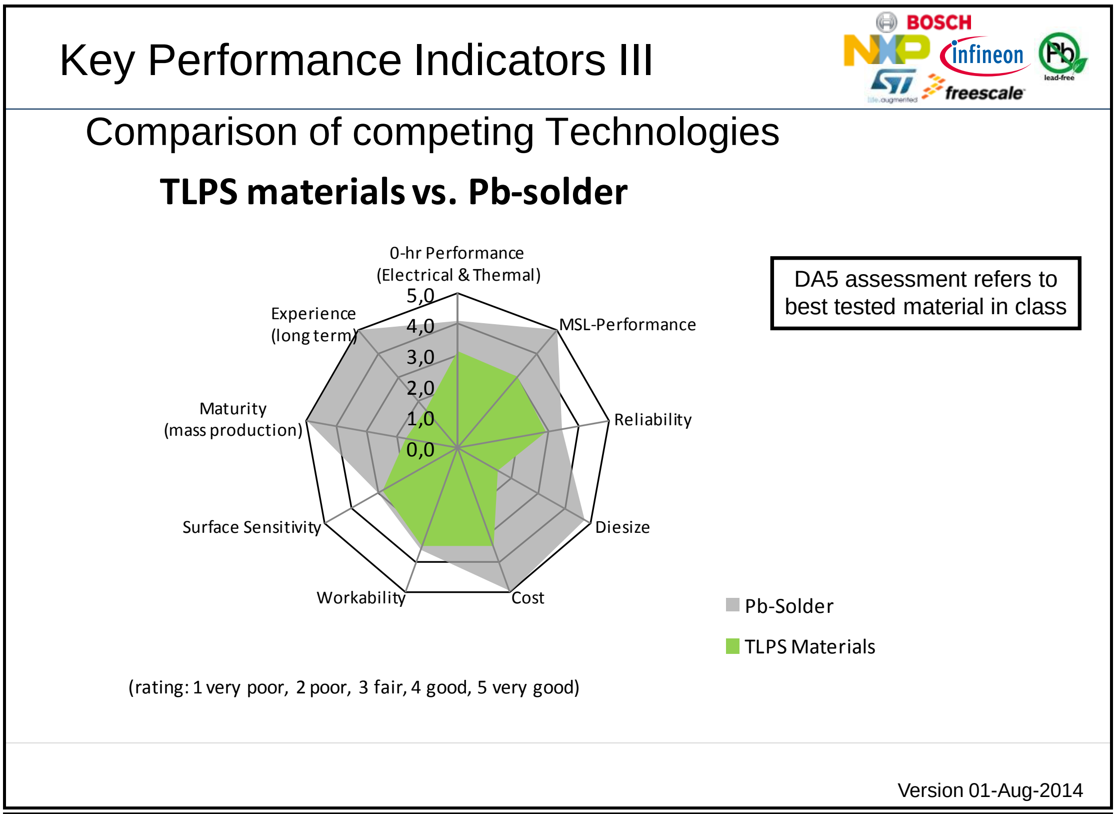


***Chart 15**: KPI-3 for Transient Liquid Phase Sintering (TLPS) vs. Pb-solder*

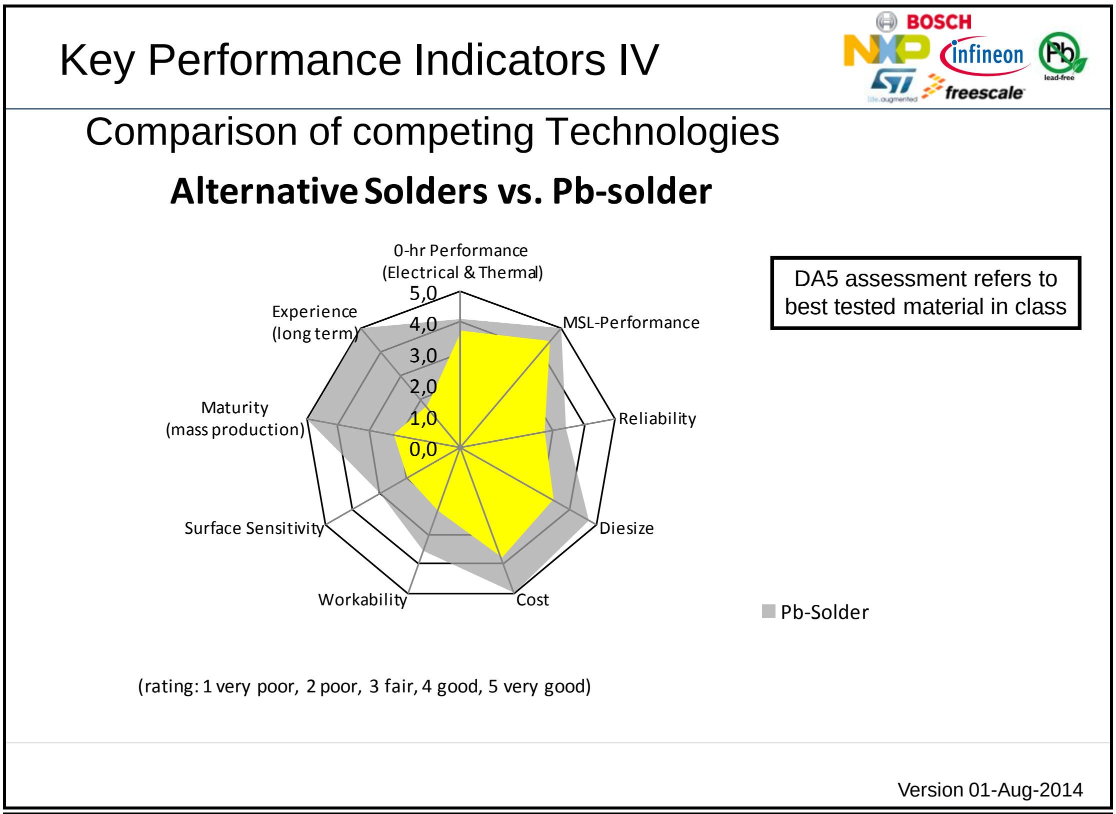


***Chart 16**: KPI-4 for Alternative Solders vs. Pb-solder*

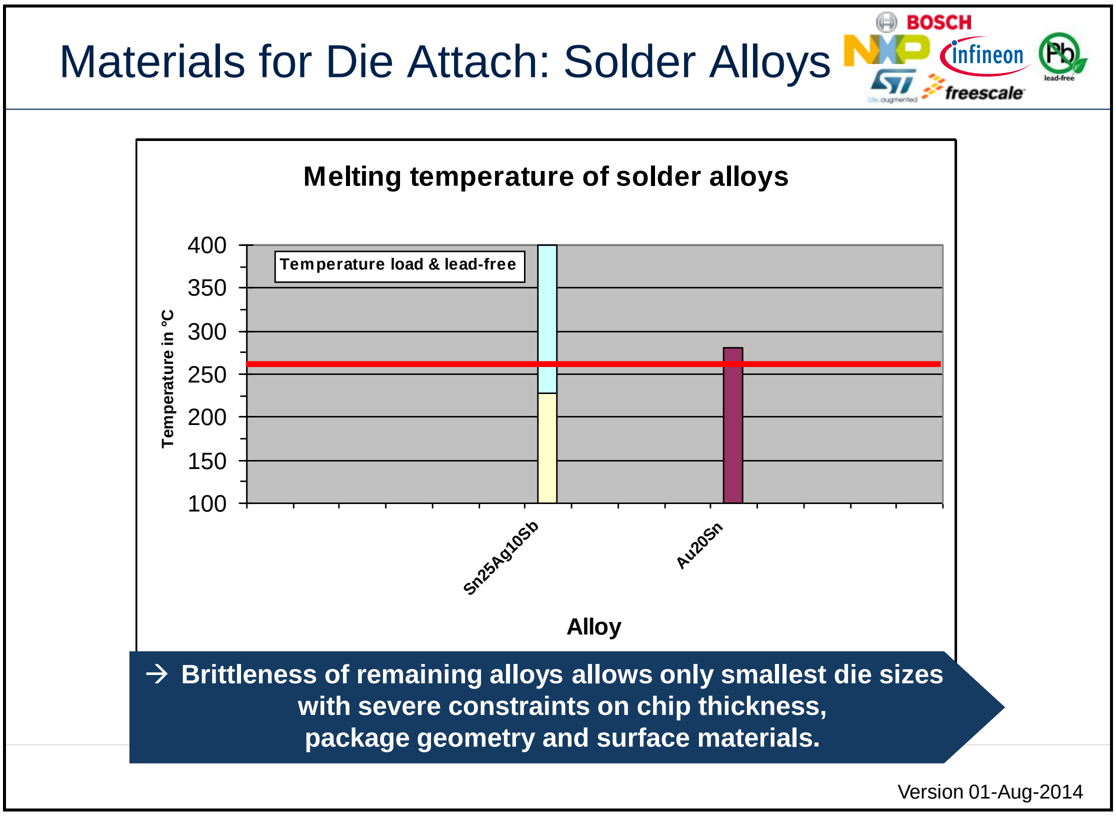


***Chart 17**: Melting Temperature of Solder Alloys*

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.

<u>DA5 Note and Conclusion about Conductive Die Attach Films (CDAF)</u>: 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
bodo.eilken@infineon.com

9(B) Efforts of International Rectifier (IR)

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 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.

16-Jan-2015

Introduction

- **International Rectifier has been evaluating replacement materials for high lead die attach solder for over five years**
- **Our internal packaging R&D teams and our Operations teams have worked in collaboration with material vendors and our assembly subcontractors to evaluate all viable options**
- **We are all working based on an RoHS directive that currently would see an exemption for high Pb die attach solders dropped in June 2016**
- **Replacement material candidates are evaluated with respect to:**
  - Performance
  - Cost
  - Reliability
  - CapEx requirements

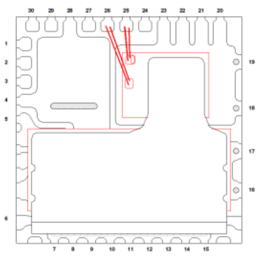
Solder	Solidus / Liquidus temp	Thermal conductivity	Electrical resistivity (uOhm.m)	Elastic Modulus
Pb5Sn	308'C/312'C	35W/m'K	0.19	9GPa

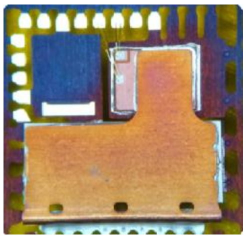
IOR International Rectifier 2

***Slide 1**: Pb Free Evaluation Introduction*

Project Test Vehicle

- **Test vehicle is IR3550MPBF**
  - 6x6 PQFN
  - Includes 2 FETs (Q1 and Q2) and 1 IC (U1)
  - Q1 mounted face up on leadframe, Q2 mounted face down
  - Cu clip connects source of Q1 to drain of Q2
  - Exclude IC from test parts as simplifies test process
- **Reliability Test**
  - MSL3
  - AC 121°C, 100%RH, 96hrs
  - TC -55°C to +150°C, 1000cyc
  - IOL 100°C ΔT_j, 12,000cyc
    - with RDSon shift data gathering





IOR International Rectifier 3

***Slide 2**: IR Project Test Vehicle*

Partial Melt Solders

- **5 new Pb free solder materials evaluated**
  - Evaluate performance of high liquidus temp solder vs. MSL @ 260ºC
  - All materials have solidus less than 260ºC
  - Electrical and thermal performance similar to Hi Pb solder

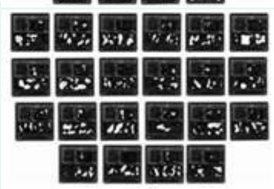
Solder	Solidus / Liquidus temp	Thermal conductivity	Electrical resistivity (uOhm.m)	Elastic Modulus
Pb5Sn	308'C/312'C	35W/m'K	0.19	9GPa
Alloy 1	227'C/300'C	65W/m'K	0.12	47GPa
Alloy 2	228'C/395'C	55W/m'K	0.15	25GPa
Alloy 3	217'C/353'C	55W/m'K	0.13	48GPa
Alloy 4	222'C/384'C	50-55W/mK	0.135	46-50Gpa
Alloy 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)

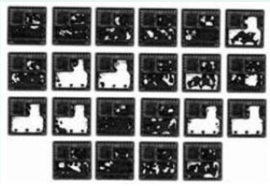
Partial Melt Solders

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		

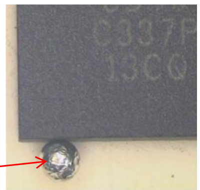
IOR International Rectifier 5

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

IOR 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.

IOR 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

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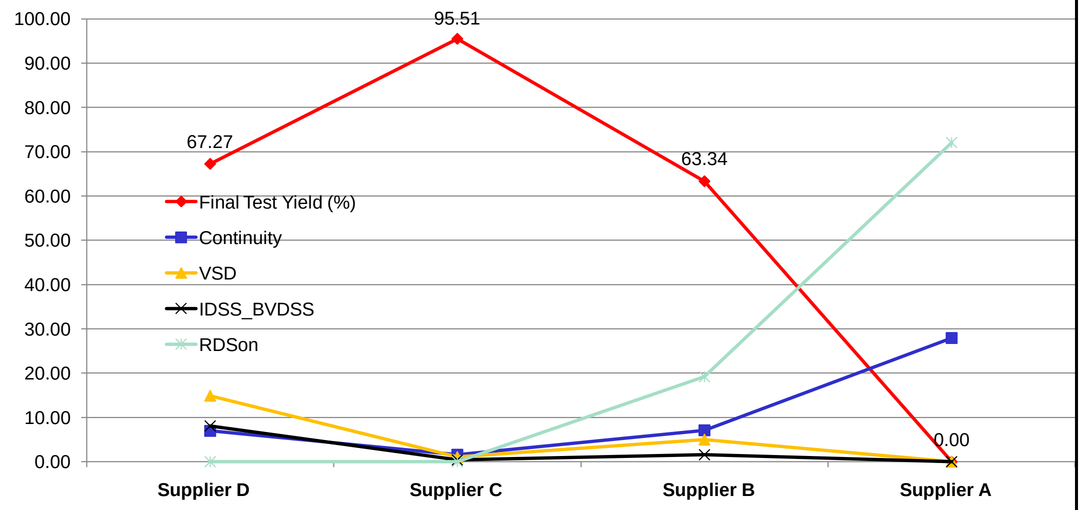

- **Severe Final test yield loss detected except Supplier C material**
  - FA confirmed
    - Continuity and IDSS_BVDSS failure as "Excessive epoxy on Q1 die"
    - RDSon failure as "D/A and Clip Delamination"

IOR International Rectifier 9

Slide 8: Ag Epoxy Materials – Final Test (1)

Ag Epoxy Materials – Final Test

IOR

Supplier D

- All of units has D/A delamination even final tested good unit
- Continuity and IDSS_BVDSS failed units are confirmed as epoxy fillet short on Q1

Supplier B

- All of units has D/A delamination even the final tested good unit
- Continuity failed units are confirmed as epoxy fillet short on Q1

IOR International Rectifier 10

***Slide 9**: Ag Epoxy Materials – Final Test (2)*

Ag Epoxy Materials– Final Test

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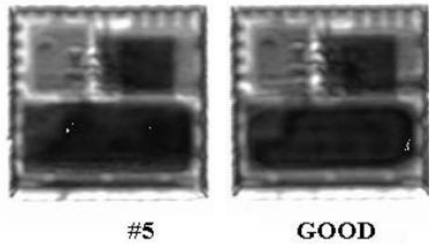
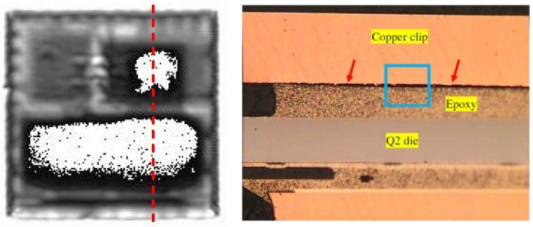
Suppler C

- FA didn't find any abnormality or delamination



Supplier A

- Severe epoxy to clip delamination



IOR International Rectifier 11

***Slide 10**: Ag Epoxy Materials – Final Test (3)*

Ag Epoxy Materials– Reliability Test

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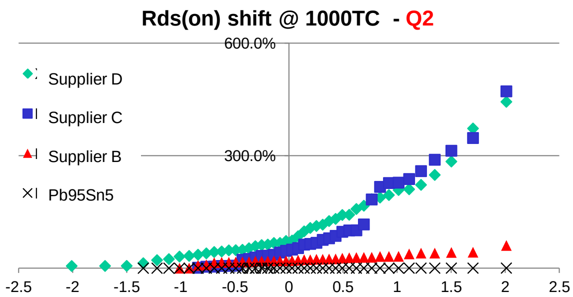
Reliability

- 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

IOR

- 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 - Conclusion*

9(C) Timing devices, which are quartz crystals and components including these, like oscillators of all kinds and real time clock modules (RTCs)

Quartz crystal resonators are available in metal cans not using any Pb, but this device can withstand only lower process and storage temperatures and thus requires 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.

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 (machine soldered joints are more reliable and consistent than manual joints).

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, so that these processes require the use of higher temperature cylinder seals based on HMP lead (Pb) solder. 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.

Reflow solder processes run on higher temperatures and SMD-mounting require 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 HMP lead (Pb) solder 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 reliable hermetic sealing between the metal cylinder and the plug over a wide temperature range during storage and operation.

Even more, many applications can’t work with a pure crystal, but need an oscillator of some type (i.e. Temperature-Compensated-Oscillators (TCXOs) for GNSS 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, HMP lead (Pb) solder 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).

Metal can crystals with HMP lead (Pb) solder cannot be completely replaced by crystals packed into ceramic packages, as the characteristics and covered frequencies are vastly different. The most remarkable differences are:

- 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 available 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 electrical energy in operation. As many of this cylinder crystals are used for so called "clock" applications, so using a 32.768kHz crystal to derive a time signal out of it, this oscillators have to be operated all the time (so even while the application is not in use), so would impact the standby and "off" current of applications as required by applicable EU regulations. Beside the pure power consumption concern, it is further important to mention that power consumption is for several reasons (legislations, environmental, operation time on i.e. 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 using today's technologies 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.

9(D) Oven Lamps

Oven lamps are commonly used in many household ovens. 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 HMP solder.

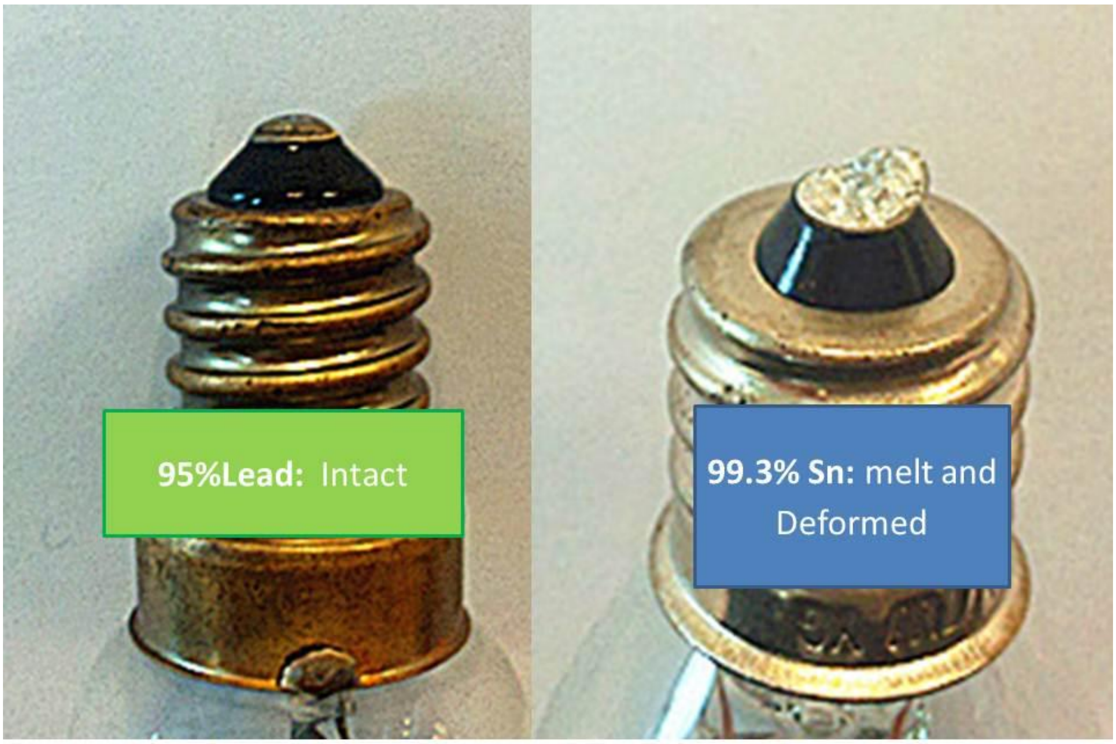


***Figure 11**: Oven Lamp Failure*

10. Information that should be regarded as proprietary

Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

Data in this document is available for public review.