**This public feedback** is submitted on behalf of SCHOTT AG.

Concerning the parts on the general questions we refer to the answer of the Umbrella Project ("UP")´s Exemption #7c-I technical Working Group ("WG") (hereafter referred to as "UP Exemption #7c-I WG Participants").

Answers to the questions and additional comments have been inserted into the document in dark blue color in pages 13 to 20.

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# Clarification Questionnaire Exemption No. 7(c)-I

## *Exemption for „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“*

### Abbreviations and Definitions

| | |
|---|---|
| ALD | Atomic layer deposition |
| Bourns | Bourns Incorporated |
| COCIR | The European Coordination Committee of the Radiological, Electromedical and Healthcare IT Industry |
| CTE | Coefficient of thermal expansion |
| EEE | Electrical and Electronic Equipment |
| EHS | Environmental Health and Safety |
| LMP | Low-melting point |
| MCP | Micro-channel plates |
| Pb | Lead |
| Photonis | Photonis Scientific, Inc. |
| PTC | Positive Temperature Coefficient |
| PZT | Lead zirconium titanate |
| OPF | Optical Fiber Packaging Ltd |
| RoHS | Directive 2011/65/EU on the Restriction of Hazardous Substances in Electrical and Electronic Equipment |

### Background

The Oeko-Institut has been appointed by the European Commission, within a framework contract[1], for the evaluation of applications for exemption from Directive 2011/65/EU (RoHS), to be listed in Annexes III and IV of the Directive.

[1] The contract is implemented through Framework Contract No. ENV.B.3/FRA/2019/0017, led by Ramboll Deutschland GmbH.

Your organisations (Schott AG, Bourns Inc., COCIR, Optical Fiber Packaging Ltd, Photonis Scientific, Inc. and the RoHS Umbrella Project represented by Murata Electronics Europe B.V. and VISHAY BC components BEYSCHLAG GmbH) have submitted requests for the renewal of the above-mentioned exemption. These have been subject to an initial evaluation. A summary of the main argumentation for justifying the request is provided below as a first basis to be used in the stakeholder consultation planned as part of this assessment.

Please review the summary of the argumentation provided to ensure that your line of argumentation has been understood correctly and provide answers to the questions that follow that address aspects requiring additional information and/or clarification.

# 1. Summary of argumentation of applicant on the justification of the exemption

## 1.1. Background

A number of applicants apply for exemption 7(c)-I of Annex III of the RoHS Directive:

| | |
|---|---|
| *"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"* | Applies to categories 1-7 and 10 (except applications covered under point 34) and expires on 21 July 2021.<br><br>For categories 8 and 9 other than in vitro diagnostic medical devices and industrial monitoring and control instruments expires on 21 July 2021. |

All applicants request the renewal of the exemption with its current wording and for the maximum duration possible (5 to 7 years depending on the EEE category). The applicants raise different areas of application for which they argue that the exemption is still needed as alternatives are currently not available that could substitute or eliminate the need for lead in such applications.

Applications of lead-based glass, used to connect between two elements made of glass, metal or ceramic materials are addressed in the applications of Schott AG (Schott 2020), Optical Fiber Packaging (OFP 2020) and the Umbrella Project (2020). These applications are also termed by some applicants as **lead-glass sealing materials, lead-glass solders or low-melting point (LMP) glass solders** and are used to connect elements on the one side, but usually also to ensure a hermetic connection which protects from ingress of external elements such as humidity, acidity, etc. Schott (2020) explains that lead-glass solders are needed to manufacture high-quality hermetic housing components for optoelectronic applications, for passivation and encapsulation of semiconductor components and to hermetically connect power electronics. OFP (2020), which requests the exemption only for category 3 (IT and telecommunications equipment) use the LMP glass to manufacture miniature hermetic seals to optical fibres contained within small metallic tubes. The small seal subassembly is then used to allow optical fibres to hermetically penetrate into an 'optical module'.

Bourns (2020) refers to use of lead-containing glass in thick film inks/glazes used in electronic components. Thick film is a resistive and conductive film greater than 0.0001" thick resulting from firing a paste or ink that has been deposited on a ceramic substrate. This is also called a **glass frit** and is used in several applications as barrier layers for stopping the migration of silver or as a sealing material for ensuring hermetic packages. The Umbrella Project (2020) refers to **chip resistors,** which are widely used in all types of EEE for current control, current detection, voltage division, amplification ratio determination, termination, dumping, pull-up and discharge applications in E&E

devices. The resistor elements of these chip resistors consist of mixed sintered bodies of conductive particles which contain lead. In distinction from lead-glass solders, here lead-containing glass is understood to be used for **encapsulating** semiconductor components, which is also mentioned by SCHOTT (2020).

COCIR (2020) request the exemption for Category 8 medical devices for the use of lead zirconium titanate (**PZT) as a piezoelectric material**. The request mainly deals with the use of PZT in polycrystalline ultrasound transducers but also mention other electronic components that contain lead in glass or ceramics that are applied in medical devices. The Umbrella Project (2020) also mentions PZT components used in transducers used in ultrasonic sensor applications for distance measurement to objects, crack detection in concrete and metal, detection of foreign bodies inside food as well as every type of life-saving medical diagnosis.

Photonis Scientifict, Inc. (Photonis 2020) requests the exemption only for medical devices of Cat. 8 monitoring and control instruments of Cat. 9. The Photonis request focuses on lead-oxide based glasses termed "**electronic glasses**" necessary to provide the electrical characteristics necessary for electron multiplication to occur. Such materials are needed both for the forming and the proper operation Microchannel Plates (MCPs), Single Channel Electron Multipliers (CEMs) and Resistive Glass Products (RGPs).

According to the Umbrella Project (2020) the exemption is also needed for PTC (**Positive Temperature Coefficient**) thermistors which make use of semiconductor ceramics having the property that their electrical resistance increases as temperature rises. These are used for temperature/current control and protection of circuits from abnormal heating and overcurrent. In PTC thermistors, materials become semi-conductive by the addition of rare earth elements, etc. to barium titanate, however in order to ensure the thermal characteristics and resistive value stability it is necessary to add lead.

### 1.1.1. The history of the exemption

When Directive 2002/96/EC (RoHS 1 2003) was published in 2003, two exemptions covered applications in scope of Ex. 7(c)-I. Exemption 5 allowed the use of lead in glass and exemption 7d covered the use of lead in ceramics of electronic components. An additional exemption for "Lead in cermet-based trimmer potentiometer elements" was added to the Directive as exemption 34 following a request made in 2006, after the applicant argues that the homogeneous material in this case, the thick-film layer containing the lead, in itself is neither a glass nor a ceramic material. Nonetheless, in 2007/2008, Exemption 11 of Annex II in Directive 2000/53/EC (ELV Directive), which is equivalent to exemption 7c-I of RoHS Annex III, was reviewed and it was decided that it also covered lead in cermet-based trimmer potentiometer elements. Following the review of exemption 7d in 2007/2008, the ELV wording was adopted as the current Ex. 7(c)-I to eliminate uncertainties.

Ex. 7(c)-I was last reviewed in 2015/2016 (Gensch et al. 2016). It was concluded that "*the substitution of lead in ceramics is scientifically and technically still impractical in the majority of applications"* though practical to a certain degree in some cases, but it could not be clarified whether this would justify and enable narrowing the scope of the exemption. For lead in glass or in a matrix of glass or ceramic compounds, it was concluded that it was still scientifically and technically impracticable to substitute lead. During the assessment, an effort was made to specify the exemption into these two sub-groups of applications, however the discussions with stakeholders did not allow concluding this process. The following exemption specification was recommended as a starting point for the current assessment. exemption 7(c)-I. Exemptions 7(c)-II, 7(c)-III and 7(c)-IV were integrated into this wording proposal[2]:

*Lead in*

i) *piezoelectric ceramics in electrical and electronic components, i.e.*
   - *ferroelectric ceramics*
   - *pyroelectric ceramics*
   - *other piezoelectric ceramics*

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*

vii) *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*

The summary of the discussion on this proposal is reproduced in Annex I.

### 1.1.2. Possible overlaps of the applications mentioned as being covered by exemption 7(c)-I with other exemptions

A few of the applications mentioned by the applicants are also mentioned in the formulation of other exemptions. Should a renewal of the exemption be recommended, it shall be necessary to ensure

[2] In other words, the formulation includes applications covered by other exemptions listed under Annex III, as part of an effort to ensure that possible overlaps in the various items are avoided.

that overlaps do not exist with such exemptions (formulations are reproduced from the consolidated version of RoHS 2):

Lead in glass frit is also covered by:

- Ex. 25 of Annex III for "Lead oxide in surface conduction electron emitter displays (SED) used in structural elements, notably in the seal frit and frit ring which has expired for categories 1-7 and 10.
- Ex. 4 of Annex IV for "Lead oxide in surface conduction electron emitter displays (SED) used in structural elements, notably in the seal frit and frit ring";
- Ex. 32 of Annex III for "Lead oxide in seal frit used for making window assemblies for Argon and Krypton laser tubes";

Micro channel plate is also covered by:

- Ex. 3 of Annex IV for "Lead in electromagnetic radiation amplification devices: micro-channel plate and capillary plate"[3];
- Ex. 39 of Annex IV for: "Lead in micro-channel plates (MCPs) used in equipment where at least one of the following properties is present: […]" (see further detail in legal text)[3].

Piezoelectric materials are also covered by:

- Ex. 14 of annex IV for: "Lead in single crystal piezoelectric materials for ultrasonic transducers"

### 1.1.3. Volume of lead to be placed on the EU market through the exemption

Schott (2020) estimates that the lead consists of up to 75% of the glass solder for connecting glass windows and lenses or between 5% and 50% when encapsulating semiconductor components. Schott estimates the lead consumption for industrial applications placed on the European market in 2018 to be between 550t ~ 750t but explains this to be a rough estimation for reference purposes only. The Umbrella Project (2020) refers to the same reference estimation, but state that up to 93 wt% lead is used for the various applications. The estimation is based on a survey performed by ZVEI in which 14 member companies provided data on lead use in industrial applications.

Bourns (2020) states that the homogeneous material in relation to glass frit is the glass included in the thick film ink or encapsulation (homogeneous material), which is then fired on a substrate. The lead content will vary and can range from 1-75% of the glass. The total ink/encapsulation including the glass is generally <1% of the finished part. It is not possible for Bourns to determine the total amount of lead in glass for all products entering the EU market, seeing as once parts are sold (directly or through distribution). Bourns produces parts that are used in the assembly of other goods and does not have information on how all parts are used nor where parts that claim exemption 7c-I are applied and finally placed on the market.

For medical ultrasound piezoelectric dielectrics, COCIR (2020) estimates that 64 wt% of the PZT is lead. 4.2 kg of lead is estimated by an ultrasound probe manufacturer to enter the EU market annually through the lead in medical ultrasound transducers based on numbers of equipment sold in the EU, average mass of lead per probe and the market share of the manufacturer.

[3] Exemption currently under assessment, see: https://rohs.biois.eu/requests.html

OFP (2020) estimates that 0.1% of lead is contained in the LMP glass used to manufacture miniature hermetic seals for optical fibres and that 50 kg of lead enter the EU market through this application.

Photonis (2020) states that the glass used to make MCPs, CEMs and RGPs are lead silicate glasses containing between 47.5 to 58% by weight (26.5 to 31.5% by mol) of lead oxide (PbO) (in another place 44%-54% Pb is specified). An estimation of amounts is provided on pg. 8 of the application for the three uses. In total, Photonis estimates that 133 kg of Pb are placed on the global market through these applications (in another place 145 kg is mentioned) annually, with a rough estimation of the European share being 25% or ~36kg.

Looking at the various values reported by the various applicants, it is not clear if 750 tons per annum represents the top range for all possible applications or only for certain applications (i.e. for industrial applications of Ex. 7(c)-I, whereas some of the applicants mention also uses in non-industrial applications (i.e., private consumer applications).

## 1.2. Technical description

In general, a differentiation can be made between applications where lead is part of a glass material or part of a ceramic material. In this respect, lead used in a glass atop a ceramic material would be included in the first group:

- **Lead in glass materials and components:**
  - **Low-melting point (LMP) glass solders** – SCHOTT (2020) explains that lead is essential for realisation of low working temperatures. In optoelectronic components, solder glasses are needed as otherwise excessive process temperatures would lead to the destruction of the component (glass window or lens, semiconductor and other applications that are manufactured using glass solder). This is also mentioned for the following component encapsulation applications. The Umbrella Project (2020) specifies that lead-containing glasses have melting temperatures of about 300 to 340°C. Important properties mentioned include excellent wettability with both metals and ceramics which is important for bonding different materials, weather and corrosion resistance due to the chemical stability of lead, less susceptibility to dielectric breakdown under high electric loads and high mechanical strength due to the small thermal expansion coefficients of lead and its crack resistance. OFP (2020) further explains that the presence of lead supports several important functions in such applications:
    - Significantly reducing the melting point of the glass (from 1000°C to 270°C), which is important to maintain the optical fibre coating (typically acrylate) during production.
    - Significantly reduces the viscosity of glass mix (by about 100 times), allowing melted glass to flow into very tight spaces required for reliable fibre optics glass seal. Furthermore, for achieving a vacuum-tight seal, the seal must not contain bubbles. Low viscosity of PbO based glass mix allows bubbles to escape before solidifying the glass.
    - Allows varying and precisely matching the coefficient of thermal expansion (CTE) of the glass to match those of metal and fibre optics glass (or other materials). When the CTEs do not match, this can induce breakage upon cooling or result in a non-hermetic seal.
    - Allows wetting of the metal surface (or other materials) to create a proper physical bond and vacuum tight sealing.
  - **Glass frit, chip resistors and lead-containing glass used for encapsulating of semiconductor components** – Bourns (2020) explains that lead oxide is used to lower melting temperature and viscosity for processing below 550°C and to raise dielectric strength. The lead

oxide content of the glass can be adjusted to control the CTE which is favourable for high sintering temperature operations.

  - **Electronic glasses** used for producing MCPs, CEMs and RGPs - Lead oxide, as a glass constituent, is responsible for providing crucially necessary current flow within signal multiplying detection devices to accomplish electron multiplication, or in other words for providing the electrical properties to the glass. This is provided through positive lead ions which agglomerate on the glass during the production process and later act as electron donors leading to the conduction property. The presence of Pb in the glass melt also decreases the viscosity of the glass at high temperatures, making it suitable for the complex forming operations required to make these products. (Photonis 2020)

- **Lead in ceramic materials and components:**
  - **Piezoelectric materials** – COCIR (2020) mentions five properties as important piezoelectric parameters:
    - Coupling factor – this is the efficiency of the material's ability to convert mechanical energy from vibrations into an output electrical charge and vice-versa. It is explained as the most critical property as it is impossible to compensate for inferior coupling factors by design change.
    - Piezoelectric constant - this defines the properties of the material and thus also its performance.
    - Dielectric constant – this affects the impedance of a transducer element. Low values can be somewhat compensated by changing the electrical control circuit design and using multilayer piezoelectric materials. The best single crystal materials have relatively higher values.
    - Insertion and other losses - insertion loss is proportional to the material's sensitivity and is thus important for image quality. A loss in performance can be dealt with by increasing power, but this can cause heating which will in turn decrease performance. Losses cannot be zero but should not be greater than 10%.
    - Depoling and Curie temperatures - above the Curie temperature, PZT materials lose their ferroelectric properties due to the depoling process, which makes them unusable for ultrasound transducer applications. This can be accompanied by a corresponding strain and result in cracking or change of the PZT properties. Piezoelectric materials with low phase transition temperatures show unstable performance during operation and can depole during shipping or storage in areas with a hot environment, affecting the performance of ultrasound transducer. Curie temperature should be sufficiently high so that solder bonding, use and storage do not degrade performance.
    - Velocity - Low ultrasound velocity requires a thinner transducer, but thinner materials have higher capacitance, which is good for smaller piezoelectric elements, however making fabrication more difficult.
  - **Positive Temperature Coefficient thermistors** – Lead is added to ensure the thermal characteristics and resistive value stability of the ceramic material, thus also related to the electric resistance of the material remaining stable under changing temperatures (Umbrella Project 2020).

## 1.3. Applicant's justification for the requested exemption

### *1.3.1.* **Availability of alternatives** *(Substitution or Elimination, roadmap to substitution, reliability of substitutes)*

Looking at the candidates for substitution, the applicant's argumentation is mainly based on why the lead substitutes investigated so far are not considered sufficient in their intended field of application.

**Low-melting point (LMP) glass solders** – The Umbrella Project (2020) mentioned that the melting temperatures of lead-free glasses are about 120-160°C higher than those of lead-based glasses. This means a higher bonding temperature which causes larger stress due to the larger difference in the extent of thermal expansion that will be generated and can result in cracks and difficulties to maintain the sealing/bonding and electrical insulation. This will increase the risk for malfunctions over time. The increase in the glass bonding temperature also has a negative effect on the wettability of the glass on the metal surface resulting in bonding strength degradation and leading to solder bonding failures. OFP (2020) also argues along these lines, explaining that over the last 20+ years multiple attempts to create alternative low melting point glass mixes, such as β-eucryptite, zirconium vanadate (ZrV2C>7), and zirconium tungstate (ZrW208) or BaO(SrO,CaO)-B2O3-Bi2O3 systems, for example, have been made. However, these materials resulted in non-homogeneous or crystalized seals or did not wet to metals, thus not creating reliable seals or actually even vacuum tight seals.

Schott (2020) mentions two approaches for substitution, though not explaining how they differ. The one refers to the use of BeO or $UO_2$ and is said to not be functional from an environmental health and safety (EHS) perspective though without detailing why. The other is not specified, though requirements and limitation of various glass alternatives are provided in table on page 6 of application. For the second approach it is explained that intermediate soldering and high CTE sealing have been found suitable in some cases, due to the general nature of the glasses. Specific compositions are not mentioned in this respect, but it is explained that those with higher melting temperatures generally exhibit a low CTE. Existing PbO-free glasses can be used almost exclusively in specially processed components (extremely fast soldering by induction or laser) and/ or in special, encapsulated environments, but usually do not fulfil all requirements, thus PBO glass solders usually still need to be used.

**Glass frit, chip resistors and lead-containing glass used for encapsulating and passivation** of semiconductor components - The Umbrella Project (2020) states that based on research, lead-free resistor element materials have low moisture resistance during load heating and low mechanical strength during overload heating, leading to inferior reliability. Resistance value variations, exceeding those of the present lead-containing resistors, will occur over time or in sudden outbreaks, depending on the resistance value range for the EEE and is problematic for uses where power is applied at high-temperatures or in a high-humidity environment or where pulse overloads are applied such as in switching power supplies widely used in EEE. In light emitting diodes, this can lead to shortening of service life or to a decrease in illumination intensity. In current detection applications this can lead to heat damage to the motor or complete failure. Solving such issues would require hermetic sealing of the EEE, which however is often not practical due to size, resulting overheating of circuits and the increase in the consumption of energy and resources during the life cycle. Bourns states that it has been experimenting with various non-lead glass formulations. While success for low to mid-level resistance values have been implemented on some individual models, other potential alternatives are still in the design/test stage. Schott explains that for passivation, the glass systems meet a higher tolerance of process temperature (glass systems which have lower CTEs at higher melting temperatures). The ZnO-B2O3 systems are promising candidates but need optimization with regard to their chemical resistance. For diode passivation, the current PbO-free development glasses still show undesirable interactions with the semiconductor, which reduce the electric strength below an acceptable level. A Pb-free glass for bonding NiFe alloys and other materials that meets the requirements for chemical resistance in long-term use at an equivalent level to that of leaded glass is yet to be found.

**Electronic glasses** – Photonis (2020) details limitations of alternatives in relation to the three application types. For micro channel plate (MCP) in particular the high length to diameter ratios and the small channel size (2.5 to 25 microns) required cannot be achieved with non-glass material. A few alternatives for substituting the type of glass, explaining their limitations, are presented. These include the use of soda-lime glass, borosilicate glass, crystalline or amorphous silicon and ceramics. Only borosilicate glass allows producing applicable alternatives for MCP. Despite the hollow-draw process used for production leading to hexagonal channel shapes and significant channel deformation at the boundaries of the multifibres, these glasses are still suitable for large area MCPs, however these are explained to cover only a small share of all MCPs. Most of MCPs are 25mm diameter small channel MCPs used for image intensifier tubes.

On the technological level, atomic layer deposition (ALD) is mentioned as a prospective candidate for MCP. In this process a series of independent, self-terminating gas reactions of alternating precursor gases are used to build up a film with a desired chemistry one atomic layer at a time. The composition of the film is determined by the chemical components of the precursor gases, and these precursors must be carefully selected to produce films with the desired final chemistry. For lead glass MCPs, the manufacturing steps for producing the resistive and emissive layers are inter-dependent processes, so that properties of resistive and emissive layers can be selected be adjusted independently. Though promising developments are mentioned, these are still being researched. Progress has been made in the last ten years. The projected future of ALD development leads Photonis to estimate that it will take at least 5 more years for this process to become sufficiently reliable for commercial manufacturing of MCPs as particle detectors. Applications for night vision equipment are estimated to require a longer time to develop. (Photonis 2020)

Photonis (2020) has also used ALD to create functional CEMs as part of its research and development programs. These detectors demonstrate that ALD can be used to make CEMs, but the full range of characteristics for this type of CEM have not yet been studied.

Additional technological alternatives (discrete dynode multiplier, photodiodes, photomultiplier tube and Electron-bombarded CCD) are compared in relation to application areas of MCPs and CEMs in table 1 of section 6.1.3 of the application. Unique properties of MCPs are shown on pg. 15, explaining that alternate detectors do not possess all of these properties, but could eventually allow for eliminating the need for lead-glass MCPs. (Photonis 2020)

ALD is also considered for resistive film for resistive glass capillary inlet tubes (RGP). The ALD coating of resistive glass capillaries inlet tubes has produced tubes with poor resistance uniformity along the length of the inlet tube. The films produced by ALD deposition on capillary inlet tubes were not stable over the broad temperature range (350°C-450°C) and eventually failed and became non-conducting after a few hours at temperatures >200°C. There are three main alternatives to resistive glass capillary inlet tubes; non-conducting glass tubes, metal tubes, and orifices. Non-conducting glass tubes transport ions in a similar fashion to resistive glass tubes, but the fact that they do not conduct electricity limits their performance in two key areas. The first is that the build-up of charge on the inside of the tube leads to decreased ions transmission compared to resistive glass capillary inlet tubes. The second is the speed at which the inlet can be electrically switched between positive and negative ion modes. Metal tubes and orifices do not have the switching time limitations of the glass tubes, but cannot support a voltage drop, which means the two sides must be at the same potential. This can complicate the post capillary ion-neutral atom separation process. (Photonis 2020)

To summarise, though Photonis (2020) shows that many candidates are under consideration, none are currently mature enough to allow for substitution in most of the application range of MCPs, CEMs and RGPs.

**Piezoelectric materials** – On the substance substitution level, COCIR (2020) states that extensive research has been carried out into lead-free piezoelectric materials, but so giving very inferior performance. Table 1 of the application compares properties of possible PZT alternatives and Figure 1 of the application compares the dielectric constant of lead-free and lead based materials. Reference to a review by Taghaddos is also made, which looks at additional materials and devices. The bottom line is that these are inferior to PZT in performance, whereas there is a risk that the use of lead-free transducers might entail medical misdiagnosis and is thus not practical for medical applications.

An alternative technology mentioned by COCIR (2020) is capacitive Micromachined Ultrasonic Transducers (cMUT), which do not contain lead. cMUTs have the potential to be a lead-free alternative for ultrasound imaging with potentially wider bandwidths and smaller feature size. However, cMUT technology has yet to overcome significant technical limitations necessary to be a clinically viable alternative, including output pressure, reliability and linearity. Information from studies is provided to allow a comparison between the technologies in relation to insertion loss and reliability results. Recognizing these limitations, researchers have focused their investigations on applications that play to the strengths of cMUTs, namely their ability to produce small feature sizes and wide bandwidths. These applications include catheters, endoscopic probes, high frequency linear arrays and probes with wide clinical coverage. Transducers for these applications cannot be fabricated easily using PZT or single crystal technology and therefor accept the reduced acoustic output performance associated with cMUTs. This technology is still in development, but it is considered highly unlikely by COCIR that sufficient performance will be obtained in the next 5-10 years.

The Umbrella Project (2020) refer to the MRS Bulletin[4] and explains that though it would be scientifically and technically possible to use lead-free piezoelectric material, the actual physical properties such as dielectric properties and elasticity as well as their temperature dependence will be significantly different to those of lead-containing material. There are two prominent lead-free piezo materials: Potassium Sodium Niobate (KNN) and Bismuth Sodium Titanate (BNT) / Sodium Bismuth Titanate (NBT). Compared to PZT, lead-free piezoelectric ceramics like (K,Na)NbO3 (KNN) ceramics have several disadvantages:

- Low piezoelectric performance (piezoelectric constant), so in order to achieve equivalent electrical performance it is necessary to increase the element size several times (i.e. component will not fit in current designs of printed wiring boards, a particular disadvantage for medical devices that need to be inserted into the body);
- Low depolarization temperature, so operating temperatures must be lowered in order to achieve the required electrical functions. (e.g. cooling of EEE will be necessary);

[4] Cited as: MRS Bulletin, 43 (8). pp. 581-587, A. J. Bell and O. Deubzer

- Inferior fatigue properties and mechanical strength result in the reduction of the service life of EEE within a range from several tens to several hundreds of times (e.g. a few months service time instead of 10 years approximately).
- A more complex sintering process with lower yields is necessary. Moreover, niobium is a critical raw materials and presents a supply risk.
- **Positive Temperature Coefficient (PTC) thermistors** - The Umbrella Project asserts that industry has conducted research and development activities to find materials that are candidates for lead-free PTC thermistors, such as alkali metals, alkali earth metals and bismuth as additive elements in substitution of lead. Under actual operation conditions, part of the alkali metals will precipitate in the crystal grain boundary and cause the electrical resistance to change, hindering the long-term stability of electrical functions and reliability. Service life is also reduced to one tenth of the original lifespan. (Umbrella Project 2020)

### *1.3.2.* **Environmental and health arguments** *(also LCA aspects)*

The Umbrella Project (2020) assures that the use of lead-containing glass and ceramics helps saving energy and resources along the entire product lifecycle. This encompasses the production and use phase of EEE, where lead-containing ceramics show high efficiency even when reduced in size and thickness. The use of lead also achieved long service life and high reliability, which results in higher resource efficiency. Results of a Life Cycle Assessment of lead-free piezo-electrics (by Ibn-Mohammed et al.) are quoted to illustrate some of the environmental impacts of PZT and its alternatives, referring to strengths and weaknesses of the alternatives compared.

Photonis (2020) raises limitations of the ALD technology, which is a candidate substitute for **Electronic glasses.** These are not reproduced here as the technology is understood to be under development.

### 1.3.3. Socioeconomic impacts

COCIR (2020) explains that, if the exemption was withdrawn, some uses of ultrasound transducers could be substituted by MRI. However, this would impose additional costs to medical facilities and is not considered a practical solution (MRI typically cost €2 million each compared to less that €20,000 for ultrasound, MRI also requires more space and have much higher running costs). This could affect the level of available services for some EU patients possibly also with impacts on diagnosis and treatment.

OFP (2020) warns that its core business would be badly affected if the exemption is not renewed with over 100 jobs at stake. More than 90% of OFP’s products use the current low melting point glass.

## 2. Clarification Questions

**Questions for all applicants**

1. The amounts of lead estimated, even when only given as a reference are quite high. It could be inferred that misuse of the exemption is difficult to exclude.

   SCHOTT Answer to 1:

   SCHOTT, in its role as glass and glass-component manufacturer, is at a much more upstream value-added stage for electrical and electronic products than most of the other applicants. Based on this and on the measures customary in high-tech industries to protect innovation and market information, SCHOTT does not have sufficient reliable information available to answer this question in a forward-looking manner.

   Based on its participation in a group of experts from industry representatives who met to answer these questions and who, due to their position in the value chain, have a much more precise and detailed overview of the market, SCHOTT does not issue a separate statement at this point and supports the corresponding expert opinion: Umbrella Project ("UP") 's Exemption # 7c-I technical Working Group ("WG") (hereafter referred to as "UP Exemption # 7c-I WG Participants")

   a. Please consider an approach for specifying the exemption in relation to specific application areas (please use the proposal form the last assessment detailed under section 1.1.1 as a starting point for discussion). Please state the advantages and disadvantages of this approach and where relevant propose alternative formulations for suitably covering the various application areas.

   b. As an alternative, please consider whether the exemption formulation can be specified in relation to the properties required from the lead-based applications in the various sub-application types specified (see also question 2). Please provide possible formulation for the application areas your organisation has requested the exemption for and include specification of threshold levels of the required performance.

2. Looking at the information provided from various applicants, the following table specifies properties or functions that the addition of lead to the glass or ceramic material supports in the various application areas. Please check that the properties detailed for application areas you have mentioned in your application are specified for that area and either confirm or specify additional properties of relevance. Keep in mind that only properties connected to the addition of lead should be specified (i.e. not general properties of the glass or ceramic material/application). If additional application areas are relevant, please add to table and specify the relevant properties and function that the addition of lead enables.

   SCHOTT Answer to 2

   Here, too, SCHOTT shares the opinion of the expert committee (UP Exemption # 7c-I WG Participants).

| | Low melting point glass solders | Glass frit, chip resistors, encapsulation | Electronic glasses (MCPs, CEMs and RGPs) | Piezoelectric materials | Positive temperature coefficient thermistors |
|---|---|---|---|---|---|
| **Reducing melting temperature of glass** | X | X | | | |
| **Improving wettability of glass to metals and ceramics (ensuring strong and hermetic bond and preventing ingress of moisture, chemicals)** | X | X | | | |
| **Reducing the viscosity of the glass** | X | X | X | | |
| **Adjusting the CTE of the glass to that of the materials being bonded** | X | | | | |
| **Chemical and corrosion resistance of the bond** | X | X | | | |
| **Less susceptibility to dielectric breakdown under high electric loads/raise dielectric strength/ High dielectric constant** | X | X | | X | |
| **High mechanical strength / high crack resistance;** | X | | | X | |
| **Provision of current flow within the glass** | | | X | | |
| **High curie temperature and depolerisation temperature /stability of material properties under changing temperature conditions** | | | | X | X |
| **High piezoelectric property constants (charge and voltage)** | | | | X | |
| **High coupling factor** | | | | X | |

3. Please clarify if the use of lead is necessary for all RoHS Annex I EEE categories in the following application areas:

   SCHOTT Answer to 3:

   Since SCHOTT is hardly active in these application fields, we refuse answer. Reference to UP Exemption # 7c-I WG Participants.

   a. Electronic glasses (MCPs, CEMs and RGPs) – provided information suggests that electronic glasses are only applied in Cat. 8 and Cat. 9 EEE.

   b. Lead zirconate titanate (PZT) piezoelectric materials – provided information suggests that these materials are only applied in Cat. 8 medical devices.

**Questions for Schott**

4. Schott refers to two approaches to substitution. Please provide more detail for the two substitute approaches, i.e. so that the difference between the approaches are clear and not only the limitations.
5. For the first approach, please detail against which EHS requirements this approach has been disregarded (aside from substance's hazardous properties specified in application).

Due to the complex relationship between the topics of questions 4 and 5, we do not deal with these two questions separately but provide the desired information in the form of a continuous text.

In the scope of RoHS, SCHOTT glass types are mainly used in two fields of application. This is on the one hand passivation (mechanical and electrical encapsulation of semiconductor components) and on the other hand soldering applications (electrically insulating, hermetic joints of varying materials).

In **the field of passivation** the following properties are technologically required:

- Thermal expansion (CTE) less than 5, preferably less than 4 ppm/K for adaptation to silicon-based semiconductor components with CTE at around 3 ppm/K, in order to avoid stress-related component failure
- Highly electrically insulating => free of alkali ions, resp. contents less than 100 ppm
- Melt-down temperatures up to a maximum of 700°C, as higher process temperatures cause irreparable damage to the semiconductor components

In this sense, the lead-containing glass types used so far show the following range of properties in the material mixture with their fillers. For comparison, a lead- and alkali-free standard glass family with a matching CTE is compared:

| Glass family | CTE | Melt-down temp. | Remarks |
|---|---|---|---|
| Lead-Silica-Borates<br>Zinc-Lead-Borates | < 4 ppm/K | < 700°C | Due to sufficient crystallization stability the addition of CTE-reducing fillers is possible. |
| Earthalkaline-Alumo-Silicates | <5 ppm/K | >1.300 °C | Intrinsically matching CTE but inacceptable high melt-down temperature. |

In addition to low melting temperatures, the various lead borate families also originally have higher CTE values as pure glass. However, because of their good crystallization stability due to the lead as a network former in the glass, they accept a high, CTE-reducing filler content.

In **the field of soldering applications**, on the other hand, the following technological properties are required:

- Thermal expansion (CTE) between 5 and 20 ppm/K to adapt to various joining partners from the areas of glass, ceramics and metal in order to avoid stress-related component failure
- Moderate electrical insulation => low levels of alkali ions acceptable
- Melting temperatures below 500°C, as optical components (e.g. windows or lenses) are often melted together. The process temperature must remain below the glass transition temperature (Tg) of the joining partner in order to ensure dimensional stability.
- Sufficient chemical resistance to environmental influences

In this sense, the lead-containing glass types used so far show the following range of properties in the overall combination with their fillers. For comparison, a lead-free, moderately alkaline standard glass family with a suitable CTE is compared:

| Glass family | CTE | Melt-down temp. | Remarks |
|---|---|---|---|
| Lead-Borates | 5 - 15 ppm/K | < 500°C | Due to sufficient crystallization stability the addition of CTE-reducing fillers is possible. |
| Lead-Alkaline-Phosphates | 13 - 20 ppm/K | < 500°C | No fillers needed due to intrinsically matching CTE |
| Zinc-phosphates | 13 – 16* ppm/K<br>*no filler | 450 - 600 °C | Crystallization tendency is inacceptable high that not even a minimum process window would be left |

In addition to low melting temperatures, this lead borate family also originally had higher CTE values. Because of its good crystallization stability due to the lead in the glass as a network former, it also accepts a high, CTE-reducing filler content. The lead-alkali phosphates do not require any filler, since their viscoelastic properties have been specially adapted to uses for the increased expansion values.

Since the 1990s, SCHOTT has been systematically and continuously identifying lead-free glass families and examining them with regard to their property profiles and thus their potential fields of application.

Unfortunately, none of the characterized glass families has so far shown a sufficiently adapted property profile that a complete substitution can be regarded as successful even in only one field of application. Even the overall consideration of partial solutions via the coupling of different new families cannot yet completely cover all applications.

However, **some good partial successes in soldering applications** have been recorded recently.

In the area of **passivation**, **no progress has been made that far**. So far none of the developed glasses can meet the required properties of the subsequent processors in all relevant characteristics.

In principle, the search for and development of glass families with lower risk potential is continuously pursued at SCHOTT (keyword REACh / "Substitution requirement").

This special development process does not lead directly to an independent article, but to components or semi-finished products for further processing by customers in business areas closer to the market. Therefore the complete development cannot be responsibly driven singularly by the glass manufacturer. Individual, extremely application and process-specific properties can only be specified, evaluated and finally approved by the group of downstream users. This results in an intrinsically iterative, often very prolonged and thus costly and capacitive complex development process.

Therefore, a quick, complete substitution of all lead-containing glass families in the scope of RoHS is unfortunately not to be expected.

The monitoring of relevant scientific literature to find further potential development approaches, as well as their evaluations, however, have a continuous character.

The glass systems or families listed below (list exemplary and not exhaustive!) were also evaluated with regard to their substitution potential. For various reasons, however, **they were disqualified as not being effective**.

They can be roughly divided into those that have not proven to be technically effective and those that can only be classified as candidates for a so-called "bad substitution", since their chemical hazard potential exceeds that of the starting substances to be replaced (lead glasses).

Glasses and frit materials in REACh are scientifically correct defined as substances themselves and not as mixtures of their batch substances. Therefore, the hazard potential of those UVCB substances is not simply to be derived from a mixture approach of the batch substances (as they are tightly bound into the glasses' network structure). But in case of low chemical resistance, the oxides of the cationic glass matrix might leach out under specific, not appropriate chemical circumstances (bioavailability, e.g. acc. to Fraunhofer-Bio-Accessibility Test). That is why a first, very rough estimation of the hazard potential of low chemical resistance glass and frit types could be compiled by a mixture approach of those leaching substances / substances' amounts. For comparing those hazards of potential substitutes, the oxides' C&L profiles and entries of Annex VI / CLP taken from EChA's substance databases were taken into account (see Appendix of this answer).

a) Vanadate based glasses

Potential: extremely low melt-down temperatures (Tg < 300°C, melt down < 400°C), moderate CTE (~10 ppm/K), low crystallization tendency

Exclusion criteria: high electric conductivity => not suitable for passivation
very poor chemical resistance => not suitable for both applications
C&L-Inventory profile worse than lead glasses => "bad substitution"

b) Zinc-phosphate based glasses

Potential: very low melt-down temperatures (Tg < 350°C, melt down < 450°C)
C&L- profil better than that of lead glasses: slightly irritant (~diluted H3PO4) & environmental hazard (ZnO) => "good substitution"

Exclusion criteria: CTE (> 13 ppm/K (without filler)) => high required portion of filler to lower CTE to target (CTE < 10 ppm/K).
Very heavy crystallization tendency does not accept any filler at all => no process window for hermetic glazing => not suitable for both applications.
Low chemical resistance => not suitable for both applications

c) Beryllium oxide or uranium oxide stabilized glasses

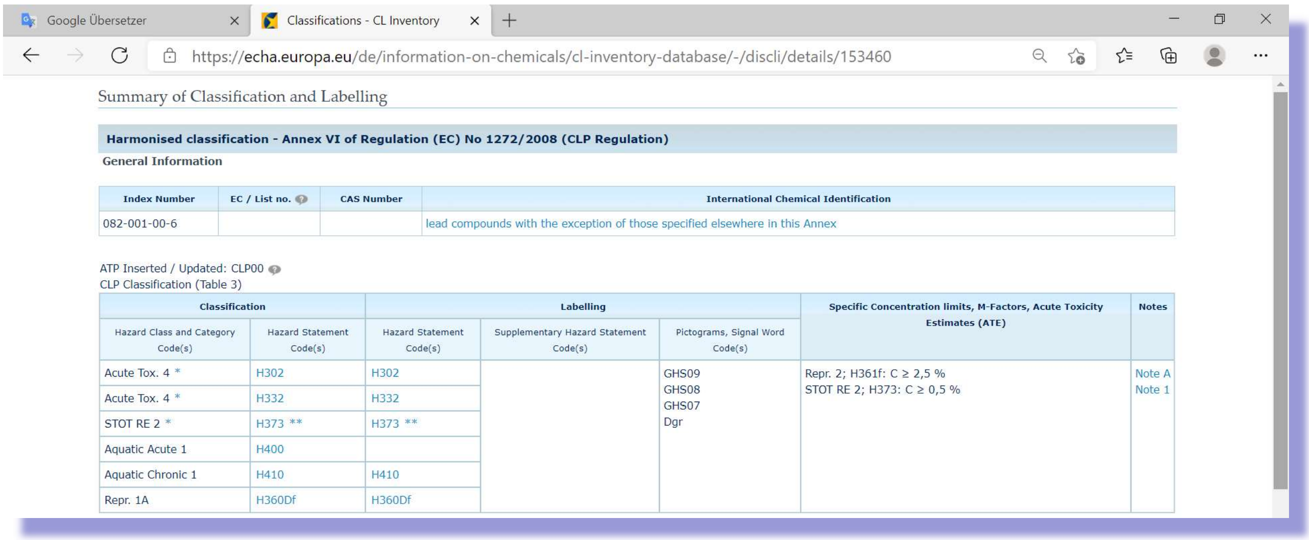
In these glasses, e.g. based on one of the already described lead-free families, the addition of a certain amount of one of the extremely powerful network formers could nearly eliminate the crystallization tendency. Thus high amounts of fillers are accepted. So the melt-down temperature could be lowered at moderate / adapted CTE values. The chemical resistance gets better. So from technical point of view this approach (formerly referred to as "first approach") could be seen as very effective substitute.

But the comparative C&L evaluation shows that this would be a so called "bad substitution": while eliminating the hazards lead provide, the risk of the additional network formers have to be evaluated: BeO as well as UO2 show a comparable pronounced health risk profile as PbO. An additional negative aspect is the higher bioavailability of the hazards: BeO is more effective in migrating out of the glass' matrix and UO2 shows an additional radiation hazard even if tightly bound to the matrix. So both substances are not acceptable as substitutes for lead oxide.

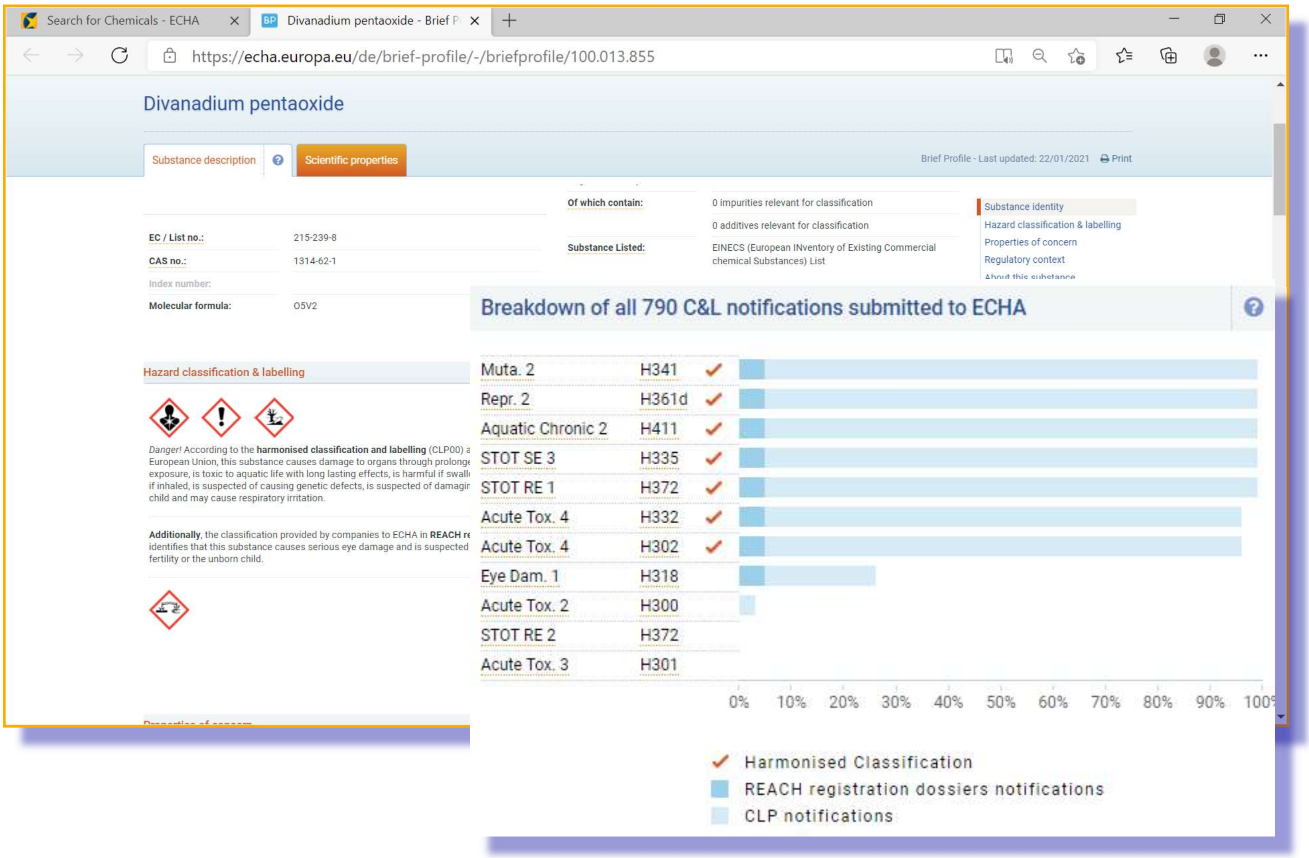
d) Several further glass families either do not show sufficiently low melt-down temperatures or no CTE values in the required range: Boros-Silicates, (Earth-)Alkaline-Silicates, (Fluoro-)Barium-Phosphates, Oxyfluorides, Tellurides, Rare-Earth-Borates, and others.

# Appendix: Excerpts of EChA databases of questionable, potential **glass batch compounds**

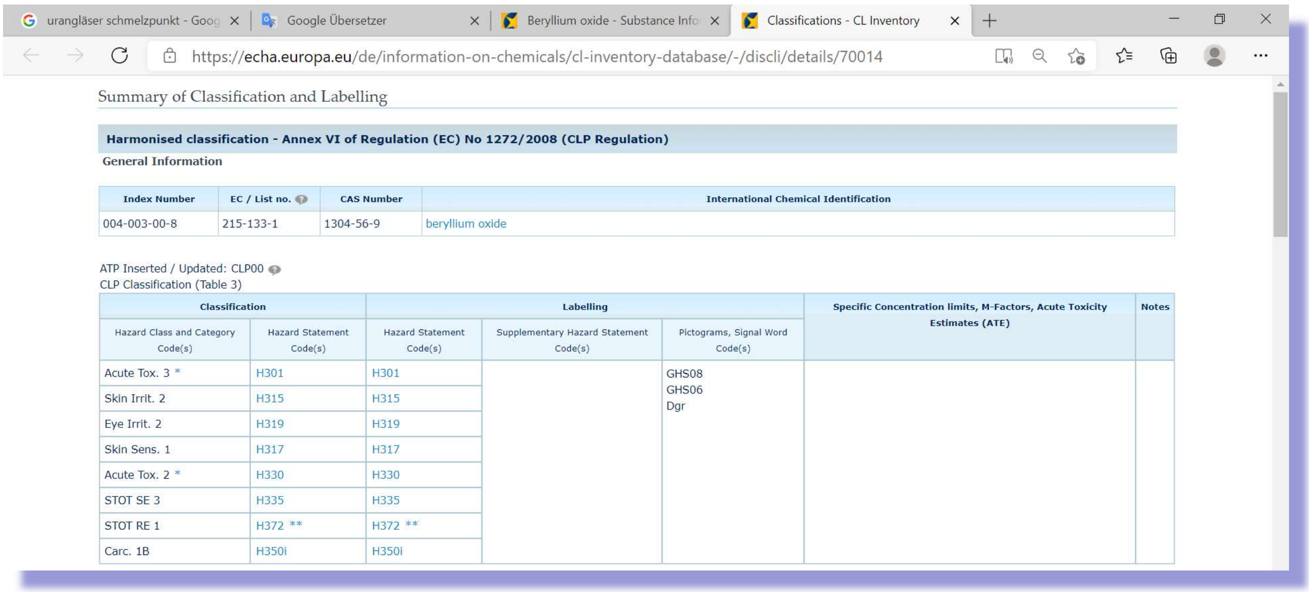
## Lead Oxide (PbO) as member of the group "lead compounds":




## Vanadate (V2O5):



## Beryllium Oxide (BeO):



Summary of Classification and Labelling

Harmonised classification - Annex VI of Regulation (EC) No 1272/2008 (CLP Regulation)

General Information

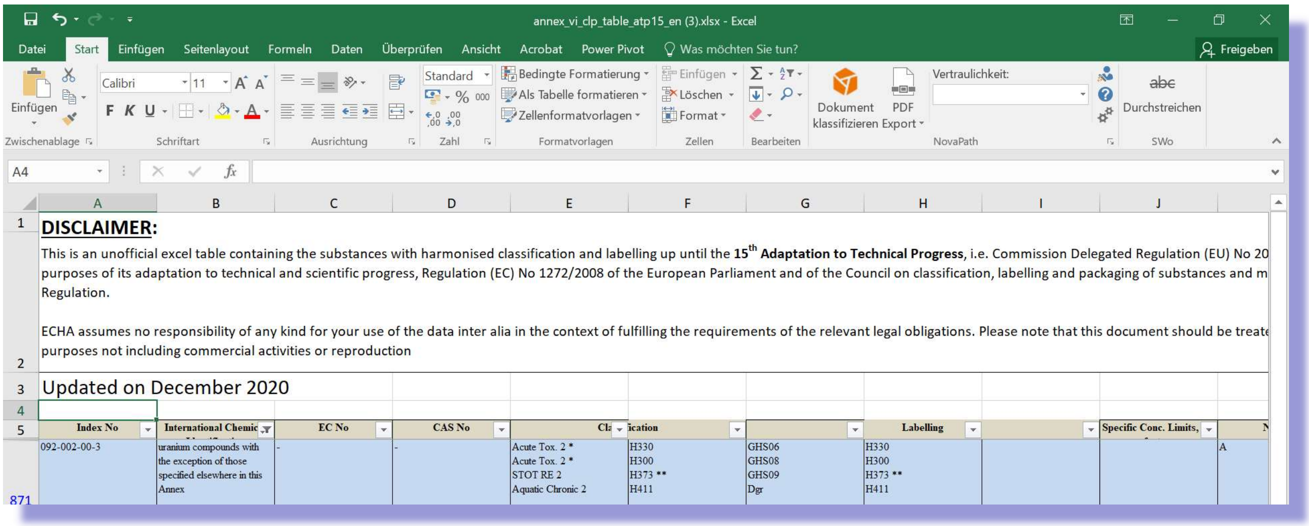
| Index Number | EC / List no. | CAS Number | International Chemical Identification |
|---|---|---|---|
| 004-003-00-8 | 215-133-1 | 1304-56-9 | beryllium oxide |

ATP Inserted / Updated: CLP00

CLP Classification (Table 3)

| Classification | | Labelling | | | Specific Concentration limits, M-Factors, Acute Toxicity Estimates (ATE) | Notes |
|---|---|---|---|---|---|---|
| Hazard Class and Category Code(s) | Hazard Statement Code(s) | Hazard Statement Code(s) | Supplementary Hazard Statement Code(s) | Pictograms, Signal Word Code(s) | | |
| Acute Tox. 3 * | H301 | H301 | | GHS08<br>GHS06<br>Dgr | | |
| Skin Irrit. 2 | H315 | H315 | | | | |
| Eye Irrit. 2 | H319 | H319 | | | | |
| Skin Sens. 1 | H317 | H317 | | | | |
| Acute Tox. 2 * | H330 | H330 | | | | |
| STOT SE 3 | H335 | H335 | | | | |
| STOT RE 1 | H372 ** | H372 ** | | | | |
| Carc. 1B | H350i | H350i | | | | |

## Uranium Oxide (UO2) as member of the group "uranium compounds":



DISCLAIMER:

This is an unofficial excel table containing the substances with harmonised classification and labelling up until the 15th Adaptation to Technical Progress, i.e. Commission Delegated Regulation (EU) No 20 purposes of its adaptation to technical and scientific progress, Regulation (EC) No 1272/2008 of the European Parliament and of the Council on classification, labelling and packaging of substances and m Regulation.

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Updated on December 2020

| Index No | International Chemic | EC No | CAS No | Cla | ication | | Labelling | | Specific Conc. Limits, | N |
|---|---|---|---|---|---|---|---|---|---|---|
| 092-002-00-3 | uranium compounds with the exception of those specified elsewhere in this Annex | - | - | Acute Tox. 2 *<br>Acute Tox. 2 *<br>STOT RE 2<br>Aquatic Chronic 2 | H330<br>H300<br>H373 **<br>H411 | GHS06<br>GHS08<br>GHS09<br>Dgr | H330<br>H300<br>H373 **<br>H411 | | | A |

**Questions for Photonis:**

6. Please explain why the use of lead-oxide based glasses in MCPs, CEMs and RGPs would not be covered under Ex. 3 or 39 of Annex IV or how applications covered by Ex. 7(c)-I differ from applications covered by these other exemptions.
7. Table 1 in section 6.1.3 of your application shows alternative technologies that can be used for MCP and CEM application areas. Each of the application areas is covered by at least one additional technology. Please explain in more detail why this would not allow eliminating the need for the exemption for lead for MCP and CEM?

**Questions for OFP:**

8. OFP estimates that 0.1% of lead is contained in the glass of the lead-glass solders it uses. The RoHS threshold specified in Annex II for the content of lead is 0,1 % by weight in homogeneous materials. It is thus assumed that either more than 0.1% lead is needed in this application or that the exemption is needed as the level of lead cannot be precisely determined. Please clarify the amount of lead needed in the homogenous material. In this respect, based on the explanation of the need to adapt the glass CTE to that of the metal or material being attached to, please clarify whether the amount of lead varies between application depending on the required CTE and explain if below or above a certain CTE, the amount of lead can be limited so that it is below the RoHS Annex II threshold.

**Questions for COCIR**

9. In your application you refer to Ex. 14 of Annex IV for "Lead in single crystal piezoelectric materials for ultrasonic transducers"[5] and mention the possibility of merging this exemption with Ex. 7(c)-I. The application refers also to the necessity of lead in PZT materials in polycrystalline ultrasound transducers. Seeing as the assessment of Ex. 7(c)-I shall focus on clarifying an exhaustive list of sub-applications for which the exemption is needed, please explain whether Ex. 14 could be expanded to cover also the use PZT in polycrystalline ultrasound transducers, excluding this application from Ex. 7(c)-I.
10. Please clarify if and in what cases single crystal piezoelectric materials can replace polycrystal materials for ultrasonic transducers or vice versa. In this respect, please discuss not only the comparable performance but also the comparable content of Pb and whether one strategy could at least lead to a decrease in the amount of Pb placed on the market in certain cases.
11. In your application it is stated that the dielectric constant affects the impedance of a transducer element. Does this mean that the dielectric constant is a factor that determines the electrical capacitance and thus the impedance of a transducer element?

**Questions for Bourns:**

[5] Exemption currently under assessment, see: https://rohs.biois.eu/requests.html

12. In your application, the share of lead in the homogenous material of glass frit is specified as a range, however Bourns explains that it cannot provide an estimation as to the amount of Pb placed on the EU market in light of lack of data on actual use and place of marketing. Please provide an estimation as to the amount of Pb that Bourns uses annually in its production for components benefiting from this exemption. If this information cannot be specified precisely please provide a rough estimation or range to allow understanding the order of magnitude.

13. Your organisation refers to the use of lead-containing glass in thick film inks/glazes used in electronic components. "*Thick film is a resistive and conductive film greater than 0.0001" thick resulting…*". It is assumed that the inch unit is referred to in this reference. Please confirm and clarify on the basis of what conversion factor this dimension to be converted to millimetre units.

14. What are the "low to mid-level resistance values" for which developed substitutes could be implemented?

    a. Please provide a threshold resistance above which substitutes are not practical. If limitations exist also for low to mid-level resistances, please explain which.

    b. Please specify the development stage of such solutions (i.e. for low to mid-level resistance) where this is still in design or testing stage. What is the estimated time to market?

15. At least for some components, it is specified that lead in glaze is used for passivation of thick film resistors for some legacy products that are targeted for phase out in the next 5 years. Does this refer to new EEE being placed on the market or only spare parts for servicing EEE already in stock? For example, in the case of CRTs referred to in the report referenced from March 2008, the latter is assumed to be the case. Please explain if such legacy uses can be distinguished from others in terms of the properties needed in the application.

16. Please explain why the use of lead containing glass-frit would not be covered under Ex. 25 of Annex III or Ex. 4 or Ex. 32 of Annex IV or how applications covered by Ex. 7(c)-I differ from applications covered by these other exemptions.

**In case parts of your contribution are confidential, please provide your contribution in two versions (public /confidential). Please also note, however, that requested exemptions cannot be granted based on confidential information!**

**Finally, please do not forget to provide your contact details (Name, Organisation, e-mail and phone number) so that Oeko-Institut can contact you in case there are questions concerning your contribution.**

## Annex I – discussion on exemption specification proposal made in the course of the 2015/2016 assessment

Reproduced as is from (Gensch et al. 2016), aside from section numbers:

### 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.

#### 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*

*viii) piezoelectric ceramics in electrical and electronic components, i.e.*

- *ferroelectric ceramics*
- *pyroelectric ceramics*
- *other piezoelectric ceramics*

*ix) 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 $T_C$ ≥ 120 °C and resistivity of less than 1,000 Ωcm*
- *with $T_C$ ≥ 120 °C and resistivity of 1,000 Ωcm and more*

*x) 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*

*xi) 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*

*xii) PZT-based dielectric ceramic materials for capacitors which are part of integrated circuits or discrete semiconductors*

*xiii) other ceramics*

Murata/JEITA et al.[6] [7] 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.[8] [9]

Murata/JEITA et al.[10] 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

[6] 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,

[7] 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,

[8] 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

[9] 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

[10] Op. cit. (Murata et al./Jeita et al. 2016b)

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 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.

**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.[11] 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. [12] [13] 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.[14] 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. [15]

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.

[11] 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,

[12] Ibid.

[13] 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,

[14] Ibid.

[15] *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)

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