INDEX of Key Sections, Charts and Graphs

Date of submission:

Exemption Request Form

1. Name and contact details

1.1 Name and contact details of applicant

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On behalf of the Company/Business organizations/Business associations listed below participants in the **RoHS Umbrella Industry Project ("the Umbrella Project"):**

Here the logos of the supporting associations will appear

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 the categories marked in Section 4 further below for the respective maximum validity periods foreseen in the RoHS2 Directive, as amended. For these categories, the validity of this exemption may be required beyond those timeframes.
With regard to Category 11, we request that this application is not processed earlier than the applicable latest date foreseen in RoHS2, as amended (i.e. 18 months before the respective maximum validity periods foreseen in RoHS2).

☐ Other: _______

3. Summary of the exemption request / revocation request

We are requesting a renewal for the lead in high temperature melting point (HMP) solder applications. Alternative technologies with similar ductility and strength as lead (Pb) alloys and that can survive a standard reflow process (or several) on PCB 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:

High-melting point solders (85% by weight or more lead) are used in a wide range of electronic components as well as to manufacture equipment. This exemption is required in many types of electrical and electronic equipment applications (in all RoHS categories), including in the following applications, but not limited to

- combining elements integral to an electrical or electronic component such as:
  - a functional element (e.g. die, lamp socket, …) with a functional element; or,
  - a functional element with wire/terminal/heat sink/substrate, etc.;
- mounting electronic components onto sub-assembled modules or sub-circuit boards;
- sealing materials between a ceramic package or plug and a metal case;
- connecting magnet wire coil to flexible conductor.

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:

With regard to Category 11, we request that this application is not processed earlier than the applicable latest date foreseen in RoHS2, as amended (i.e. 18 months before the respective maximum validity periods foreseen in RoHS2).

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 alloys used to electrically or physically join two elements. Lead provides practical performance characteristics such as strong heat conduction, high melting point, high ductility, and high 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 the electronic industry has 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.
The EU is maintaining statistics of the EEE yearly put in the EU market:

http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee

Latest data are relevant up to year 2016 and up to 10 million tons of EEE.

We have evaluated the quantity of lead (Pb) solder (RoHS 7a) in those EEE and we came to the conclusion that depending on the type of equipment the use of lead may vary significantly, therefore an estimation cannot be easily achieved.

Please supply information and calculations to support stated figure.

We conducted interviews with the member companies and we came to the conclusion that the estimated usage (obtained from a few member companies of this working group) ranged between few kg and 31 tons per year with minimum and maximum weights per unit ranging between 0.0005 mg to 226 mg. (Please note that due to the need for modern semiconductors to be smaller in size, the minimum lead quantity reduced from 0.0013 mg to 0.0005 mg per device).

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.

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?

Lead is used as the majority component in HMP solder alloys to make electrical connections. Based on the type of application, the amount of lead being >85% is necessary to achieve the required melting temperature and other material properties.

Table 1 (August 2019, 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 Table 1, the amount of lead (Pb) has direct impact on the melting temperature of the solder.

Category	Solder Type	Alloy Composition [wt %] (Main Components Only)	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 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 HMP lead (Pb) solders under RoHS exemption 7a are utilized and their critical functionality.

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, leaded inductors, power semiconductors, discrete semiconductors, microcomputers, ICs, LSIs, chip EMI, chip beads, chip inductors, chip transformers, power transformers, lamps, resistance temperature devices (RTD), electromechanical relays for automotive (just as reference) and industrial use, etc. – [See Figure 1, Figure 2, Figure 3, Figure 4, Figure 5 & Figure 8]	– 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 (this is the typical solder reflow temperature used for PCBs and wave soldering) – It is needed to achieve electrical characteristics and thermal characteristics during operation, due to high electric conductivity, high heat conductivity/ thermal dissipation, etc. – It is needed to gain high reliability for temperature cycles and power cycles due to stress relaxation from higher ductility material, 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]	
– For connecting magnet wire coil to flexible conductor	– High power transducers (both low and high frequency) used for Professional Sound application [See Figure 9]	– Sustain the heat dissipation, the high temperatures of the magnet wire and the proximity to the magnet wire coil

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

Additional uses for the lighting industry:

Oven lamps are commonly used in various household ovens. The temperature of the lamp can reach >250°C during the baking process and it may reach 300°C during the oven cleaning cycle, the so-called pyrolysis. The electrical contact between lamp and lamp socket is provided by mechanical contact of the solder in the lamp base with a spring in the lamp socket. Any oxidation between these parts will cause an increased electrical resistance that may result in electrical arcs which poses a safety risk.

Various combinations of solder and spring materials have been proven in use for a long time in existing oven technologies, all of which rely on the use of HMP solder. An oven end user expects to be able to replace an oven lamp when it has reached its end of life, as inter alia claimed by EU circular economy provisions regarding reparability to ensure long oven lifetimes. Commonly available Pb free solders ($Sn_xAg_yCu_z$) usually exhibit melting points up to 230°C, and thus will melt under maximum temperature regimes in ovens. After cooling down to ambient temperature, the again hardened solder will have established a permanent mechanical fixation of the lamp base with the spring in the lamp socket. A subsequent removal of the lamp (at its end of life) will most likely cause damage of the spring resulting inter alia in an exchange of the whole lamp socket, if possible. Thus, a lack of adequate light bulbs for replacement could result in the replacement of the whole oven before its proper end of life. In addition, currently available lamp technologies (Incandescent, CFL, LED lamps) are unable to provide any reliable or safe alternatives for light sources using HMP lead (Pb) solders.

Additionally for category 9:
A wide range of strain-gauged devices (extensometers) are used by customers in materials testing research applications to develop new high-temperature materials/alloys for use in multiple market segments (Power generation etc.). The devices use fine gauge wire which is soldered to the strain-gauges, the whole of which is exposed to a temperature range of ±200°C. Until a suitable lead-free solder is available which can tolerate this range of temperature, it is required to continue to use lead-based high melting point solder.

The following images show some diverse examples of types of devices and locations of HMP throughout various industries.

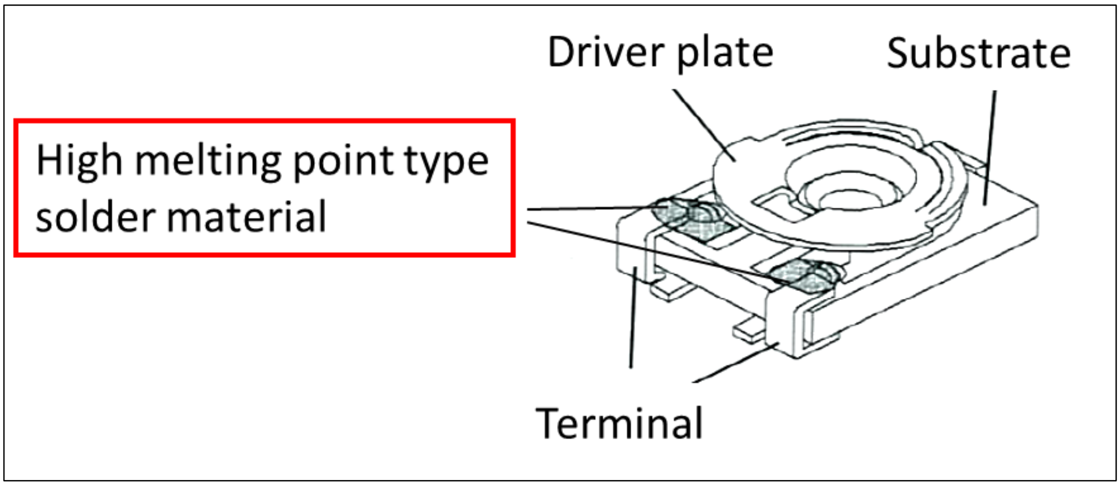


Figure 1: *Schematic view of potentiometer with HMP lead (Pb) solder visible from the outside*

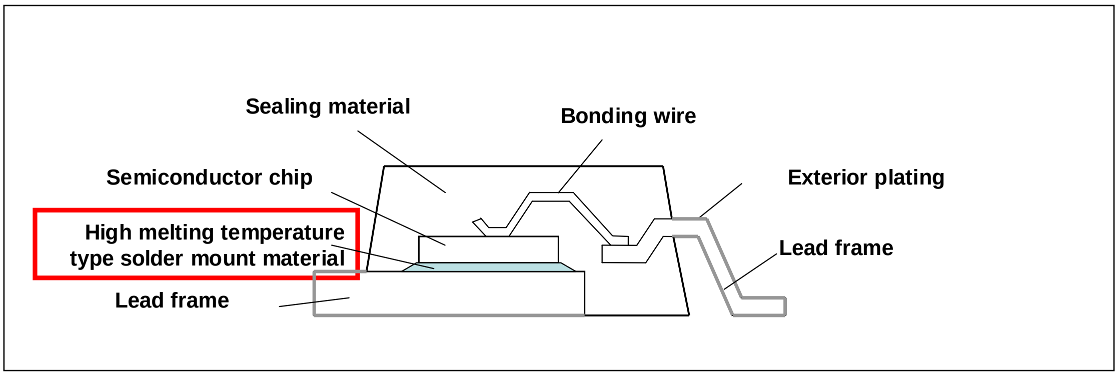


Figure 2: *Schematic cross sectional view of power semiconductor*

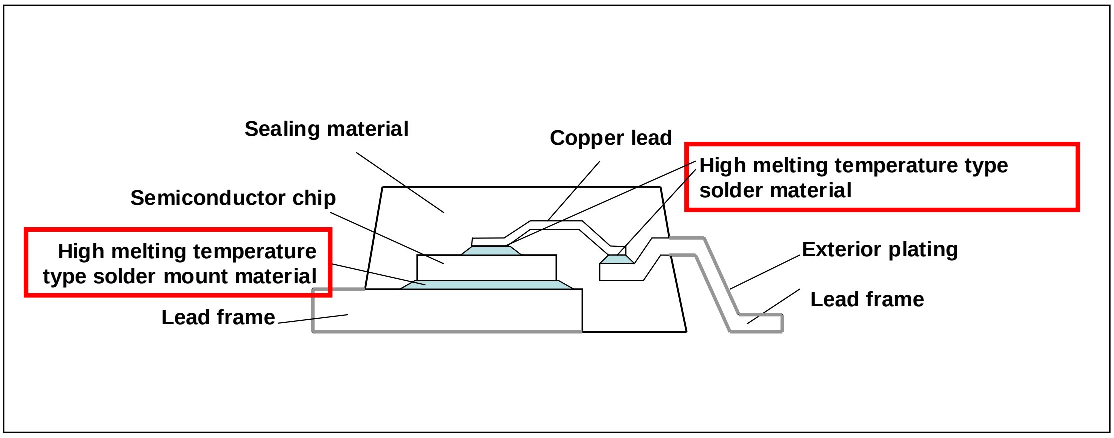
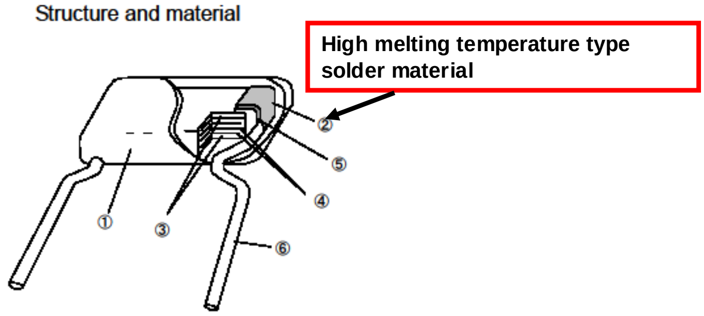


Figure 3: *Schematic cross sectional view of internal connection of semiconductor*

Structure and material

1. Structure



2. Material and Description

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

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

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

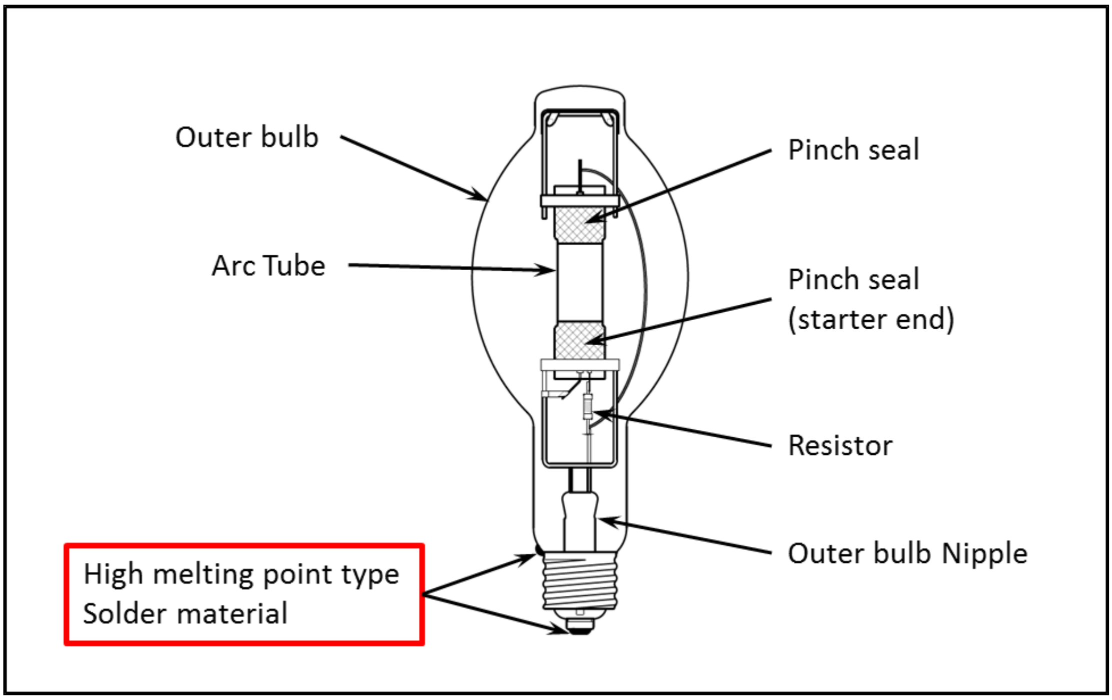


Figure 5*: Schematic view of HID lamp*

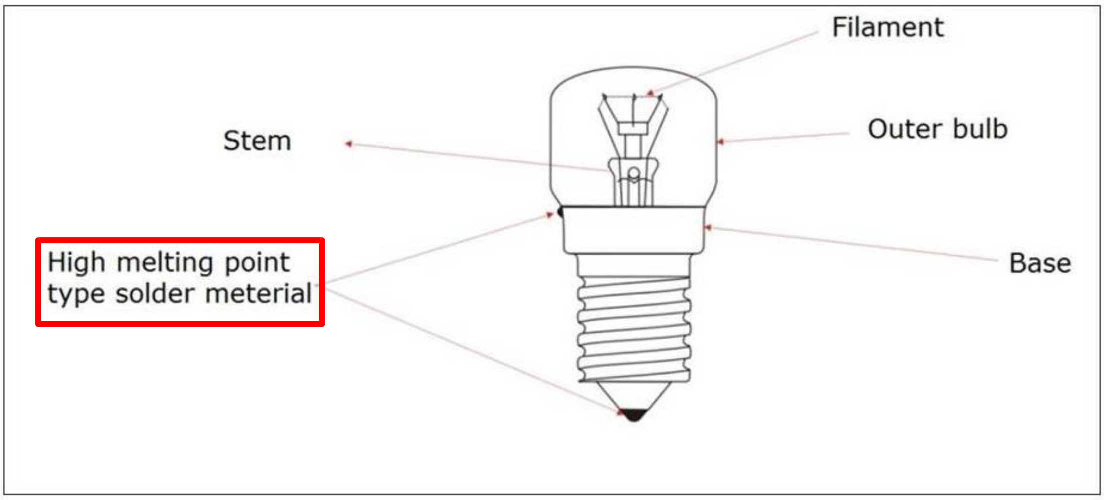


***Figure 5b**: Schematic view of oven Lamp with High Temperature Lead Solder*

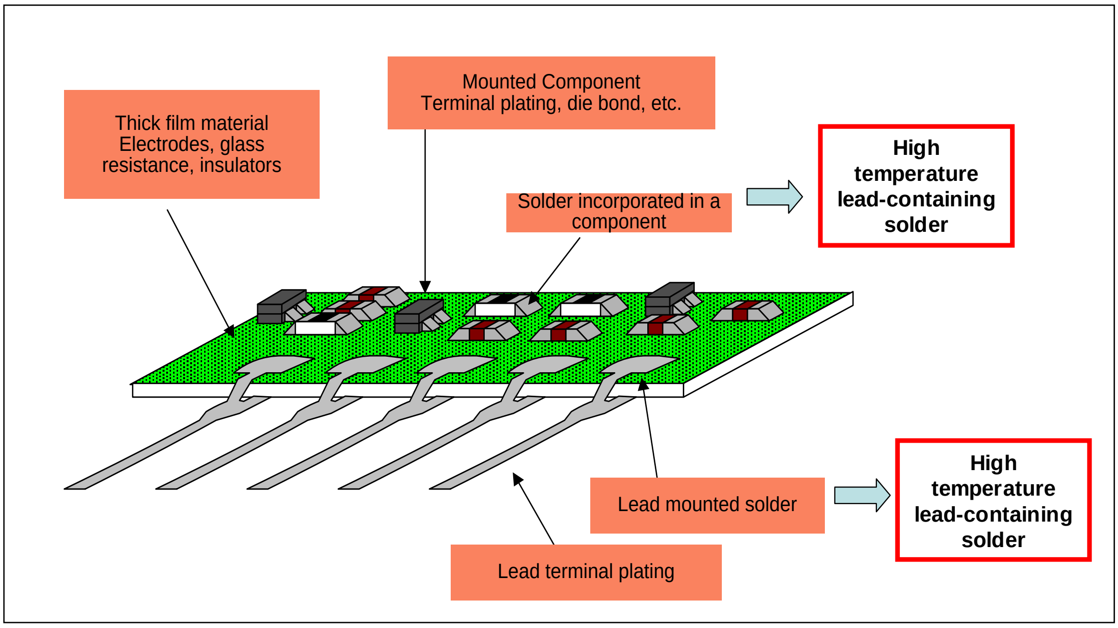


***Figure 6:** Schematic view of circuit module component*

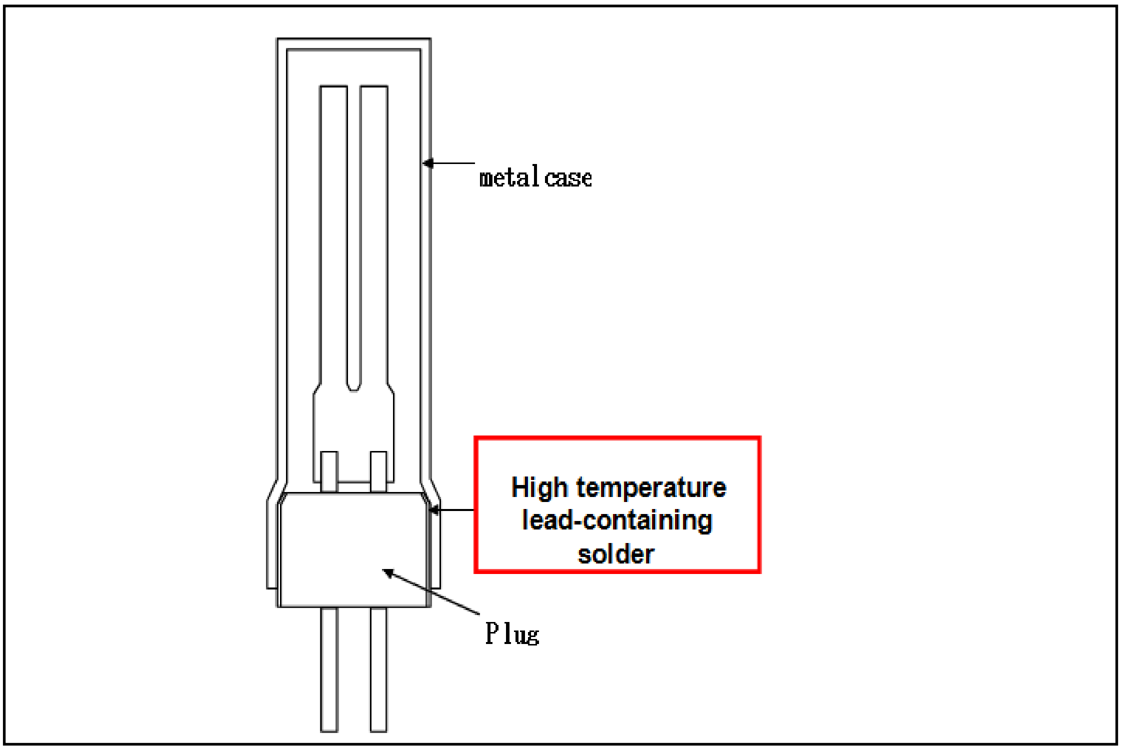


Figure 7: *Schematic view of crystal resonator*

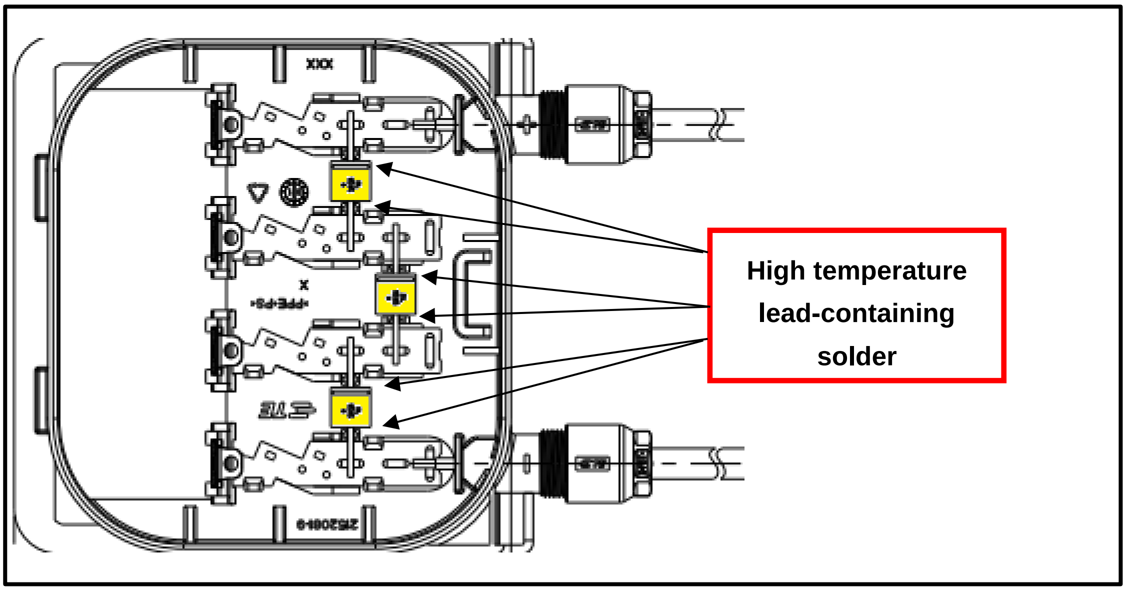


Figure 8: *Bypass diodes (3) used in photovoltaic array connection module*

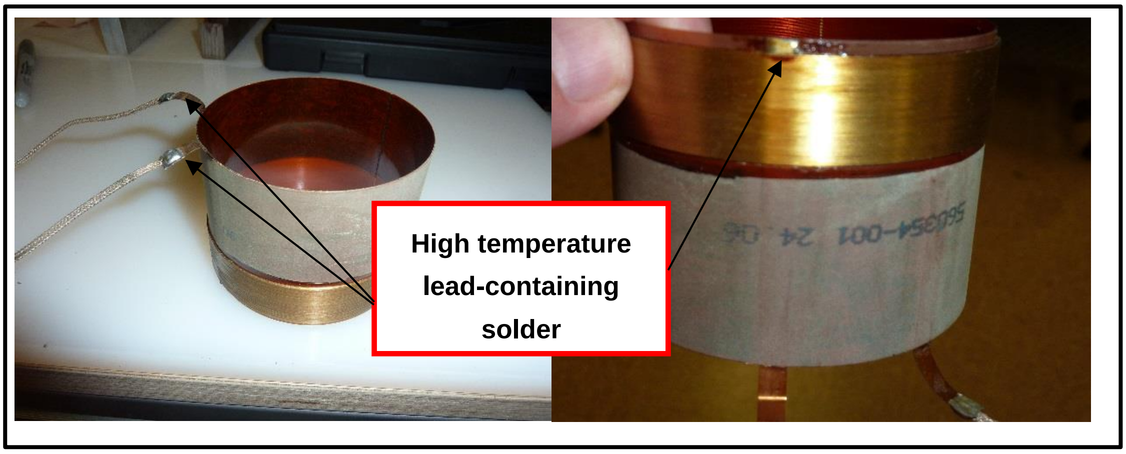


Figure 9: *Picture of voice coils High power transducers*

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

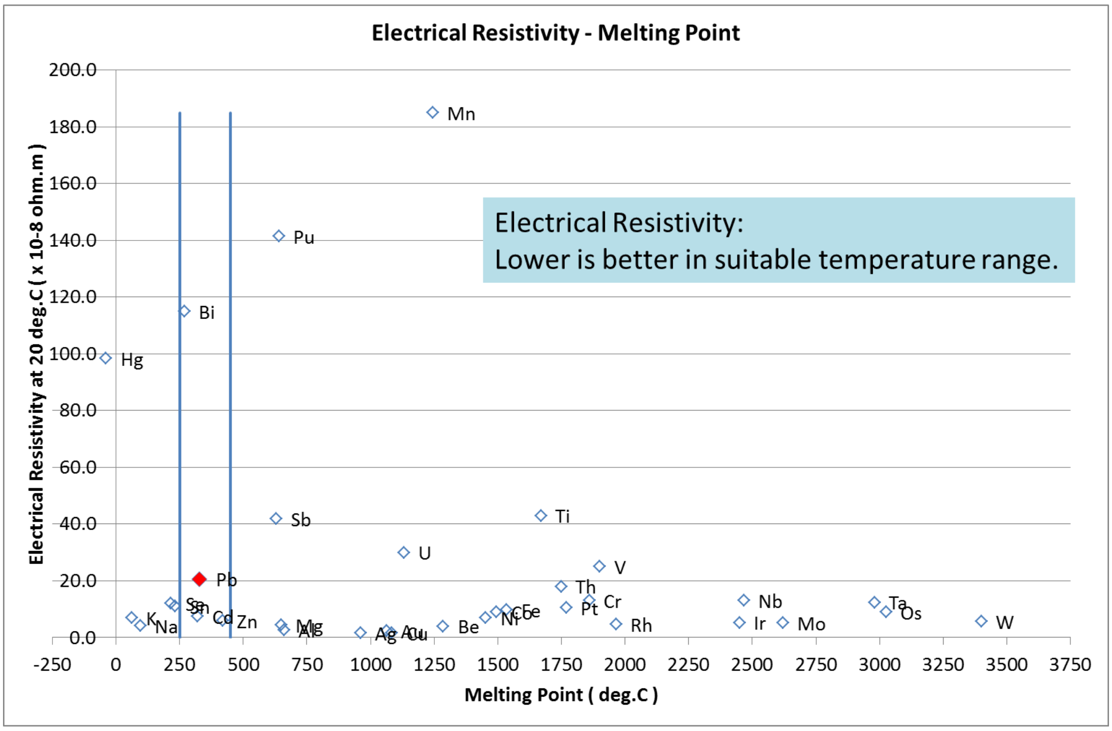
The most important property for HMP lead (Pb) solders is a melting point that is higher than standard eutectic solders, which is solely managed by the lead composition. Other practical properties, such as electrical conductivity, thermal conductivity, ductility, corrosion-resistivity, appropriate oxidation nature, and wettability are also inherent in lead-based solders. 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 combination of 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 for the unique combination of essential properties of HMP solders with lead, not any single property.
Due to the nature of manufacturing processes and the limitations of other materials that are used in these processes, the temperature range would have a specific working temperature range.

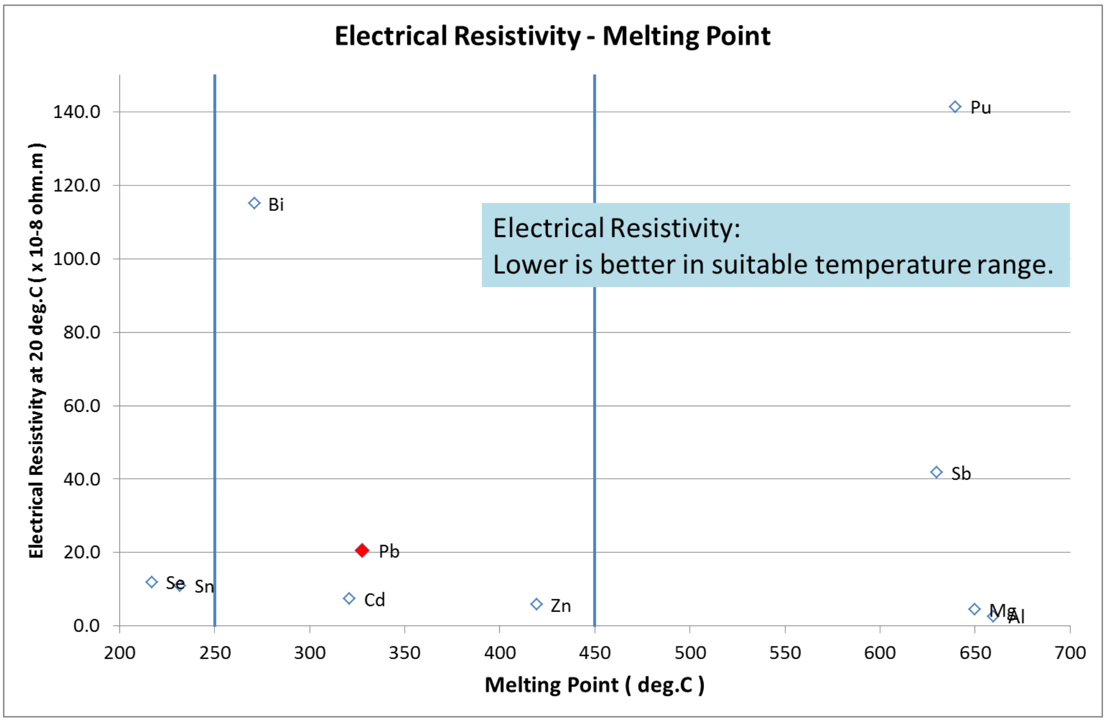
Performance requirements	Reasons for the requirements	Function of lead	Data
High melting points	Not to be melted during secondary installations Functionality of electrical parts not to deteriorate	While solders for HMP applications require minimum melting points above 250ºC, solder processes have an upper limit defined as 450ºC (to avoid damage to other materials). Few elements have melting points in this range. Note that 250ºC is a critical limit, and in reality for most applications the melting point for the HMP specific to that application is higher	Melting points Graph 1, Graph 2, Graph 3, Graph 4, Graph 5, Graph 6, Graph 7, Graph 8, Graph 9, Graph 10 & Figure 10
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 thermal 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

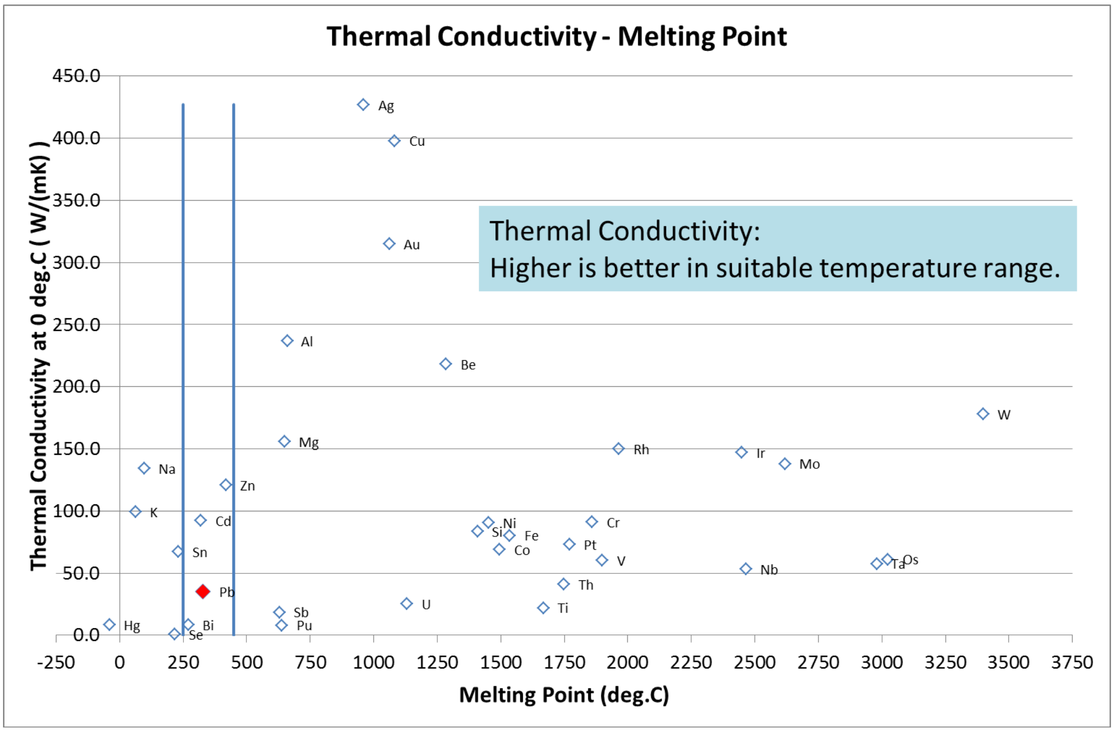
***Table 3**: Required performance of the high melting point solder and role, function of the lead*



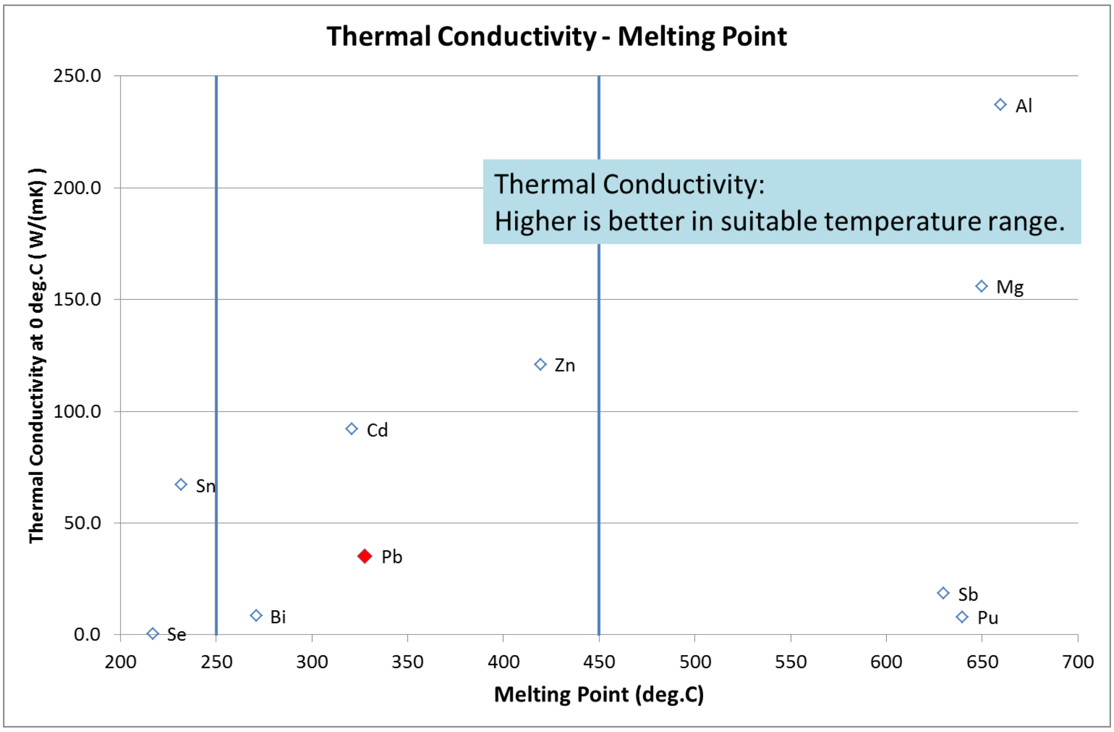
***Graph 1**: Electrical Resistivity – Melting Point. (Wide temperature range)*



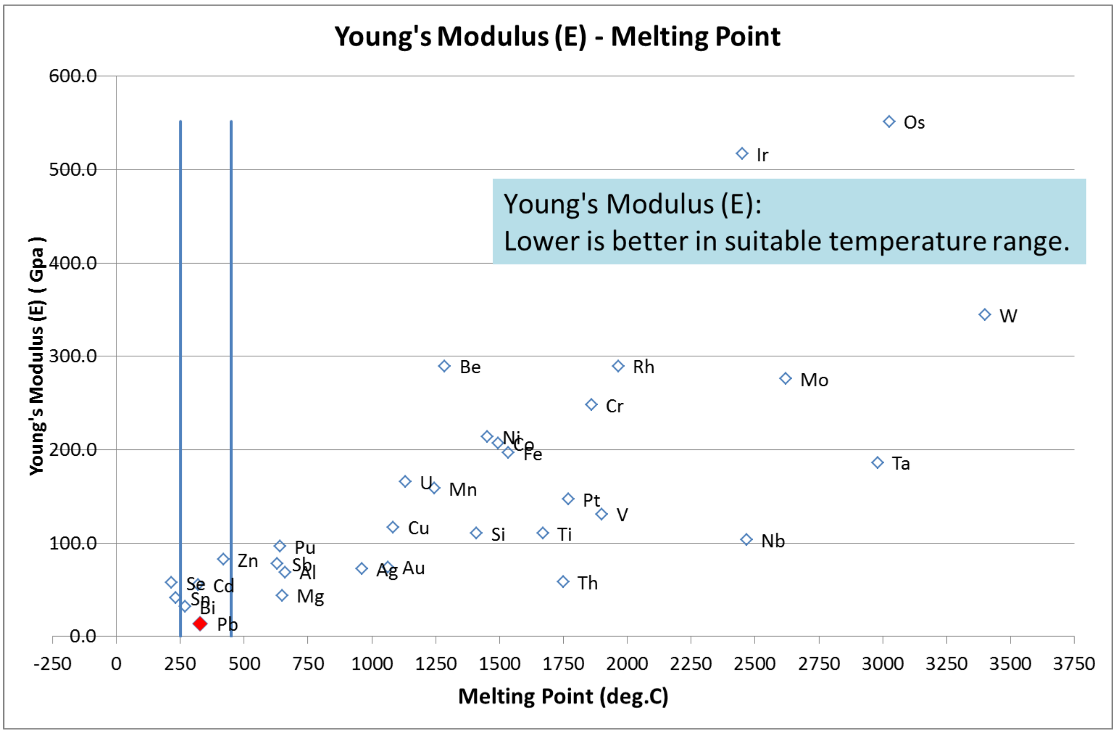
***Graph 2**: Electrical Resistivity – Melting Point. (Narrow temperature range)*



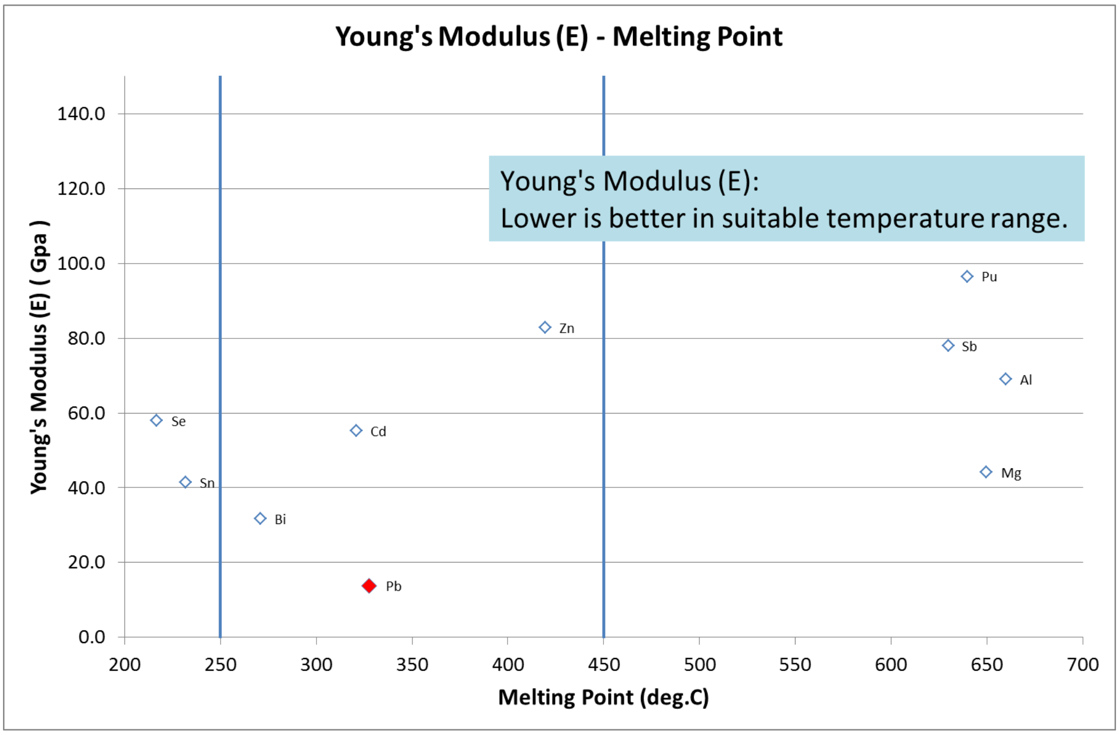
***Graph 3**: Thermal Conductivity – Melting Point. (Wide temperature range)*



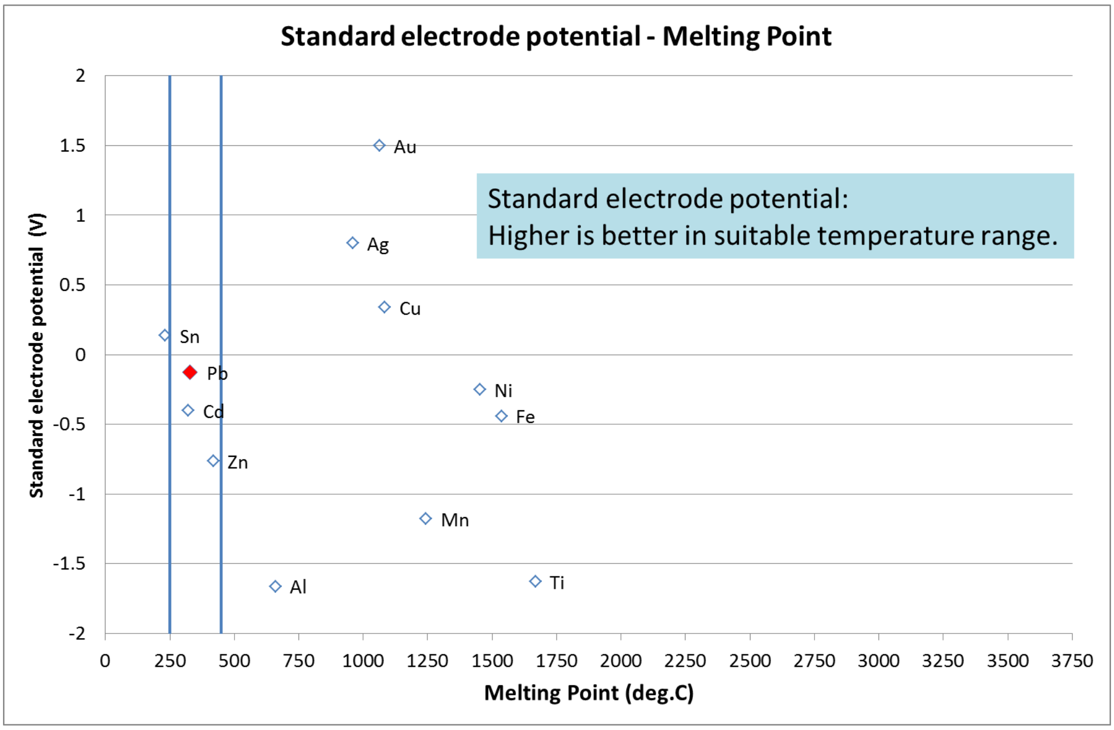
***Graph 4**: Thermal Conductivity – Melting Point. (Narrow temperature range)*



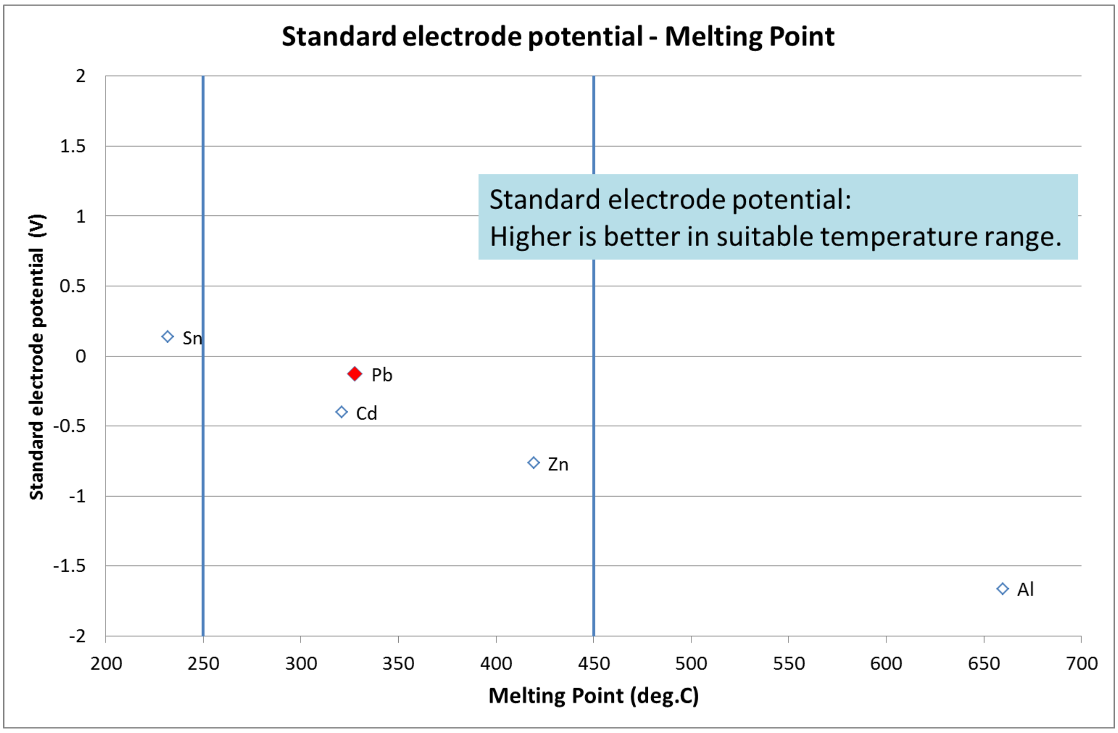
***Graph 5**: Young's Modules (E) (an indication of ductility) – Melting Point. (Wide temperature range)*



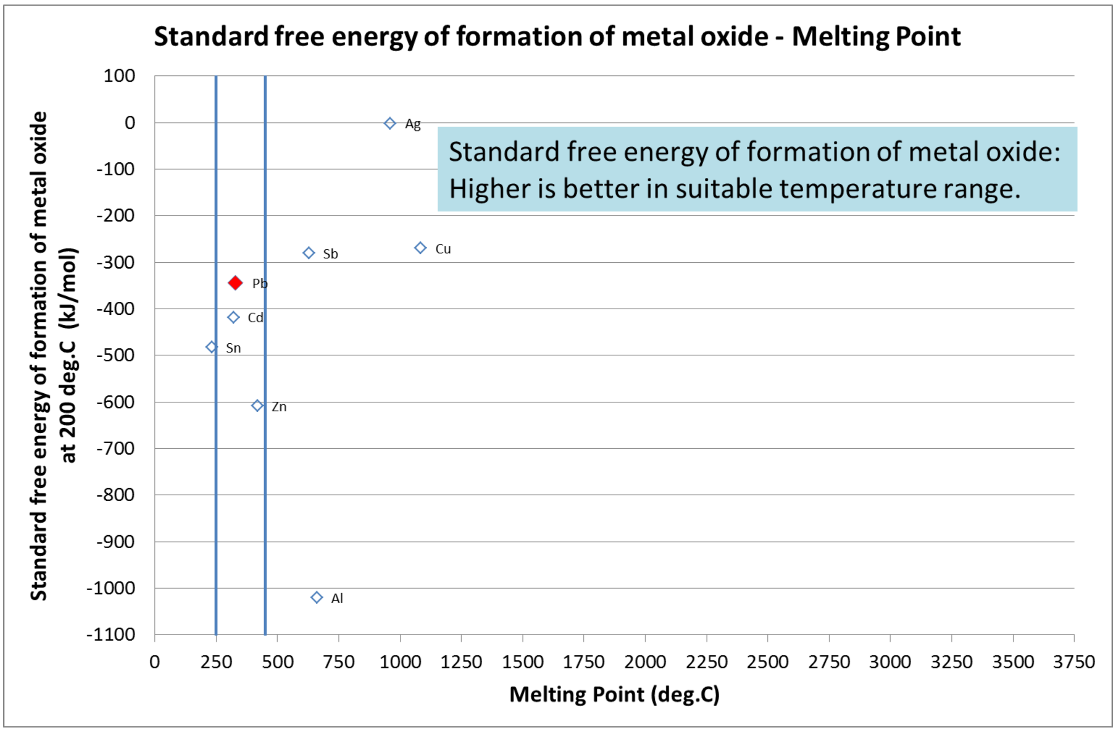
Graph 6: *Young's Modules (E) (an indication of ductility) – Melting Point. (Narrow temperature range)*



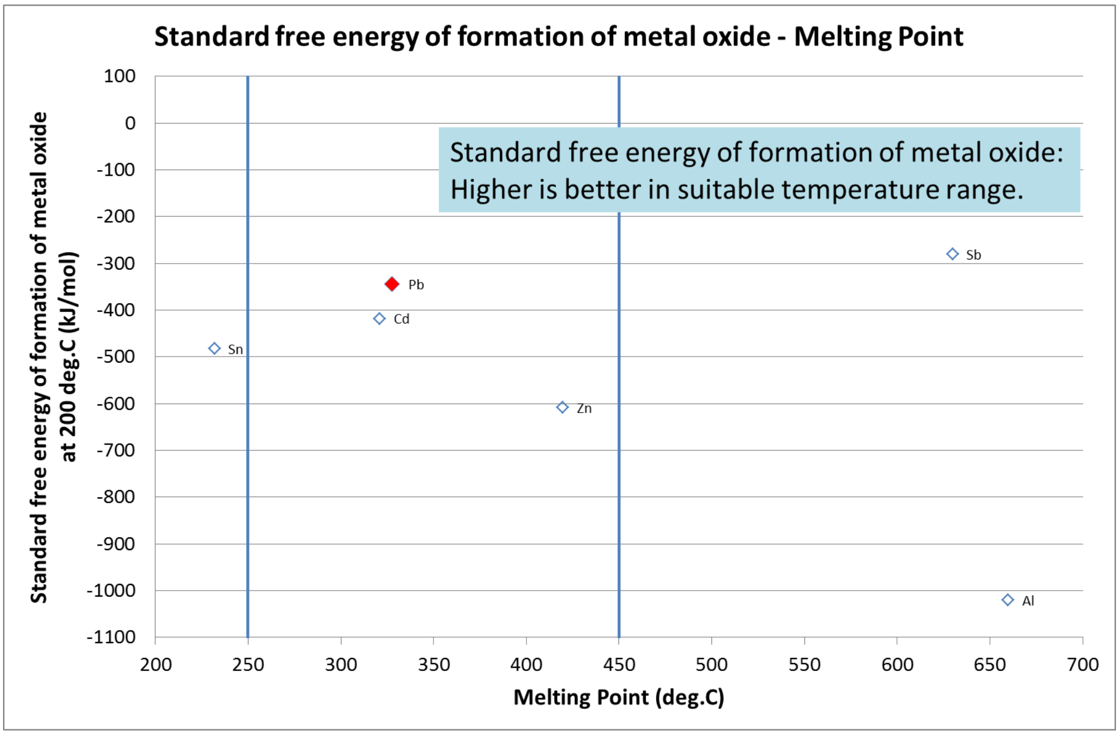
Graph 7: *Standard electrode potential (an indication of corrosion resistance) – Melting Point. (Wide temperature range)*



Graph 8: Standard electrode potential (an indication of corrosion resistance) – Melting Point. (Narrow temperature range)



Graph 9: Standard free energy of formation of metal oxide (resistance to thermal oxidation) - Melting Point. (Wide temperature range)



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

Thermistor bonding

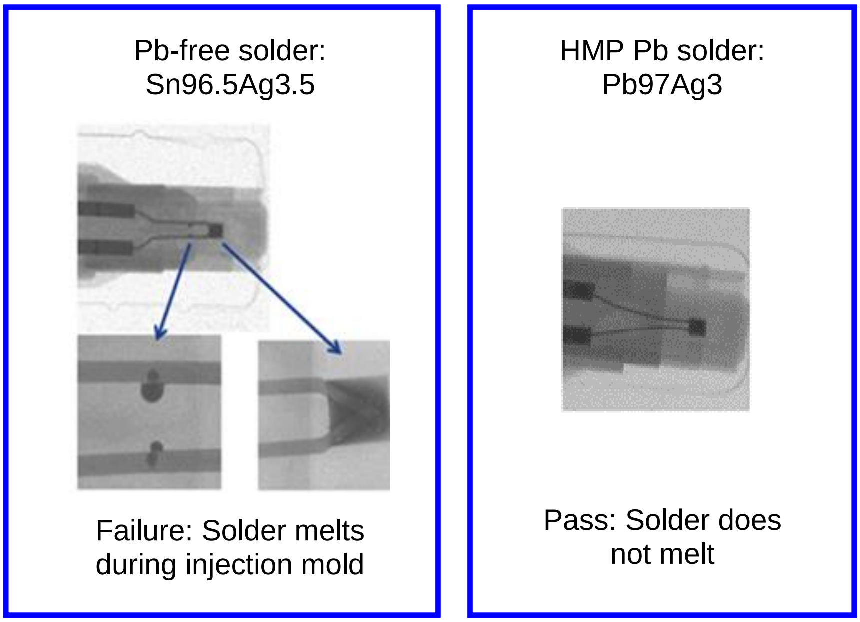


***Figure 10**: Thermistor Requirement for HMP Lead (Pb) Solder*

Figure 10 (above) explains why a thermistor requires high melting point solder. Thermistor devices are used in high temperature/harsh applications. This temperature requires plastic over-molding with materials having a working temperature of ~ 260°C. High temperature solder is required to avoid any reflows (melting of solder) which would weaken the connecting terminal to thermistor adhesion. The picture on the left details the solder reflow from plastic over-molding with lead-free type solders showing that the solder has melted and de-wetted from the terminals. This will cause an open circuit. The picture on the right depicts high temperature lead base solder in the same over-molding operation. The solder dimensions are unchanged so that the solder bond is unaffected.

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

Transducer coil soldering

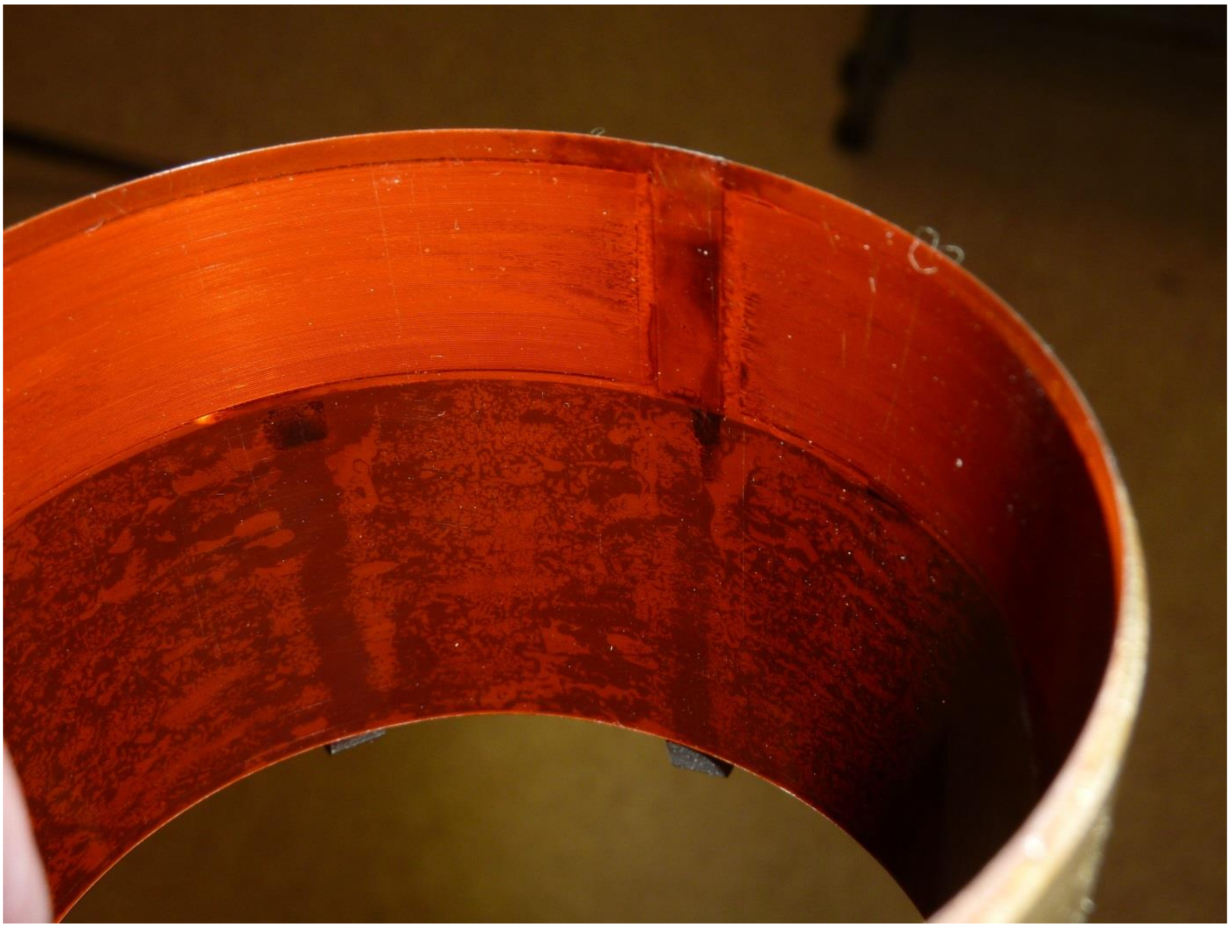


***Figure 11**: Shows the coils of high power transducers*

High power transducers (both low- and high frequency) used for professional sound applications in loudspeakers are used with power amplifiers capable of producing outputs greater than 200V and 30A (>6kW). This amount of energy creates a significant amount of heat dissipated in the loudspeakers voice coil. Therefore the resulting temperature in the transducer's voice coil will rapidly exceed the melting point of the highest temperature Pb free solder with in as little as 100 seconds, resulting in catastrophic failures when the solder melts and de-bonds. In addition the solder used must be compatible with copper and aluminum wire, i.e. to form stable bonds without dissolving the wires completely.

Why we cannot use connection techniques other than solder:
In high-power loudspeaker designs it is necessary to transition between a high flexibility, high cross sectional area conductor down to the very fine gauge wire used to make the coil of wire that provides the electromotive force to drive the transducer. These solder joints must be made in close proximity to the magnet wire coil of turns for a variety of reasons:
If the coil wire terminates at the top of the coil, nearest to the diaphragm, the solder joint may need to be very close to the coil stack. A primary reason for the proximity is structural integrity. The fine gauge magnet wire is often not able to withstand the high amounts of vibrational energy in the coil structure. This magnet wire can be Aluminum, Copper-clad Aluminum, or Copper. All of these magnet wires experience bending fatigue. If the solder joint is too far from the coil of magnet wire this lead out section of wire may mechanically fail due to highly repetitious bending modes. These fractures can create an electrical arc across the break in the wire that can ignite nearby materials.
Below the coil of wire there is simply not enough space to move the solder joint away. Adding more length would increase the depth of the permanent magnet circuit and even if that was feasible/possible we then would face even worse mechanical issues than at the other end of the coil. Since the support structure under the wire is only supported on one end, the motion would be much greater.
This proximity in conjunction with the high temperatures of the magnet wire in the coil makes HMP lead (Pb) solder a necessity.

Ribbon cable connections to capacitors in medical devices (category 8)

A medical device manufacturer connects capacitors to ribbon cables using a HMP solder which are then reflow soldered to a printed circuit board (PCB) using lead-free solder. The higher melting point of the HMP solder is essential to prevent the bonds to the capacitors failing during reflow of the PCB, which is typically at 240 - 260°C. The medical device manufacturer is evaluating alternative lead-free solders, but as yet has not found a reliable alternative. If standard lead-free solders are used to connect to capacitors, these melt and debond when the cables are soldered to the PCB.

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 as most component and equipment supplier do not take back their own products at the end of life. HMP lead (Pb) solders are incorporated into the larger EEE and should be recycled according to the requirements of the WEEE Directive and EU waste legislation.

According to the International and Lead Zinc Study Group, in 2015, around 10,000 tons of lead were used in the EU for 'miscellaneous' uses which includes leaded alloys and solders, presumably including those going into the electronics sector. This amount represents approx. 1% of the total EU usage of lead per year. Lead recovery is a mature process, in part due to high volumes of lead acid storage batteries. Approximately 85% of lead used in the EU is used to make lead batteries, and the collection rate at end-of-life is approaching 100% in North America and the EU. [Lisa Allen, International Lead Association, Sept. 5, 2019].

In addition to formal methods of WEEE collection, the value of precious metals in many electronic products has resulted in a kind of "urban mining" which economically drives recovery from the consumer toward established recycling schemes. "Urban Mining of E-Waste is Becoming More Cost-Effective Than Virgin Mining," according to the title of a 2018 paper. [Xianlai ZengJohn, A. Mathews and Jinhui Li, Environ. Sci. Technol.2018, 52, 8, 4835-4841.]

Across the EU, several metal operations handle waste from EEE and separate lead, or lead with similar metals, into fractions that are then used again by industry. One such example is shown in the following figure, where it will be noted that Lead is one of the outputs of the recovery process, which is then fed back to the stream of commerce.

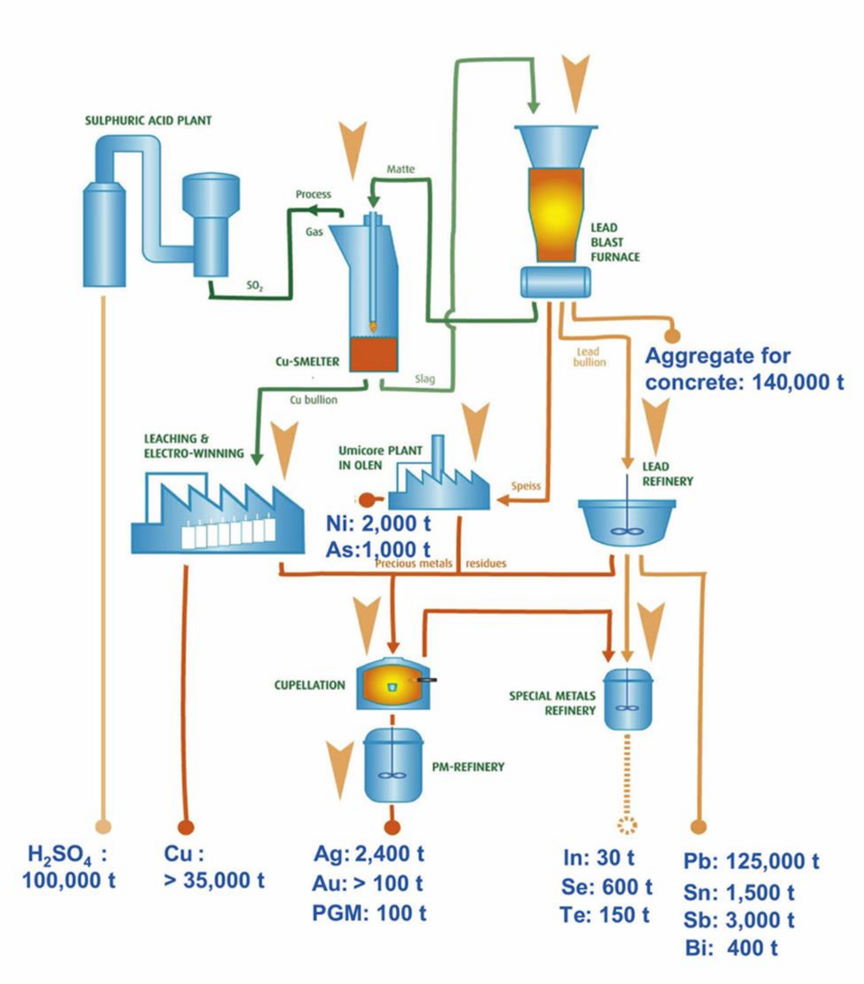


***Figure 12**: Principal flowsheet of Umicore smelter and refinery*

Figure reference: Umicore
https://www.researchgate.net/figure/Principal-flowsheet-of-Umicores-smelter-and-refinery-at-Hoboken-Belgium_fig1_293549795

WEEE is one of several feedstock for metal recovery, and recovery of metals including lead in electronics is well established.
"Lead and other metals can be recovered from secondary raw materials and waste, such as leaching residues from zinc smelters, dross from lead refineries, mattes, slags, sludges and flue-dust. Additional feed can consist of complex primary raw materials (e.g. copper/lead concentrates) and end-of-life materials (e.g. electronic scrap). This leads to a complex flowsheet where not only lead, but also other metals such as copper, nickel, tin, antimony, precious metals, selenium, tellurium and indium can be recovered."
[Section 5.1.3.5, p. 512, in the Best Available Techniques reference document, https://eippcb.jrc.ec.europa.eu/reference/BREF/NFM/JRC107041_NFM_Bref_2017.pdf].

In conclusion, while dedicated closed loop recovery for HMP lead (Pb) solders specifically is not practical, recovery and recycling of lead is well established for the larger flow of WEEE where these solders are used.

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 specifically 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

HMP solders are used for a wide variety of applications as described in Section 4. There are “apparent” substitutes for many of these, but when the physical and chemical properties of substitutes are compared with HMP solder bonds, it can clearly be shown why they are unsuitable. For example:

- Standard lead-free solders – These have lower melting point than HMP lead (Pb) solders, but crucially these solders are also used for reflow soldering of PCBs. As a result when used for sealing components and for making bonds inside components or in modules, they would melt during reflow and this will cause bond failure. Several examples that show this effect are given in this renewal request
- Welding and brazing are alternative bonding methods but require much higher temperatures. Brazing alloys typically melt at >400°C and welds are formed at >1000°C. The polymers used in electronic components and the silicon chip will be destroyed at these temperatures
- Crimp connections are often used in electrical equipment but suffer from many disadvantages. They obviously cannot be used for sealing, but their size also precludes their use inside small electronic components. However their main limitation is reliability as repeated temperature cycles and vibration cause very small movements between crimp and terminal that cause the exposure of the underlying base metals that re-oxidise after their natural air-formed oxide is disrupted. As the amount of oxide increases, this can increase contact resistance to a value where the equipment no longer functions. In power circuits, the increased resistance will cause heating that can lead to fires
- Conducting adhesives – see explanation in Section 7A and Section 9A below

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 260°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. The properties of lead 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. In addition, in the event that substitution production technology becomes available, a very careful scrutiny is needed to maintain the required high quality and reliability of components in the process to avoid failures when electrical equipment is used. So that such new technology can be adopted; this process will take many years, as explained in Section 7(B).

Table 4 (below) lists types and melting temperatures of lead-free solders that are currently (as of January 2019 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
	Sn65.0Ag25.0Sb10.0	Sn-Ag-Sb “J-alloy”	228 / 395°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
	Bi system	BiAgX®	263 / 320°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*

Since the last exemption RoHS 7a renewal request was submitted in January 2015, no new lead-free HMP solder alloys have been discovered. This is hardly surprising as extensive research was carried out when RoHS was adopted in 2002 and all possible combinations and permutations of chemical elements available in the periodic table have been evaluated. However industry continues to research novel substitute technologies as is described below in Section 7.

Figure 13 (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).

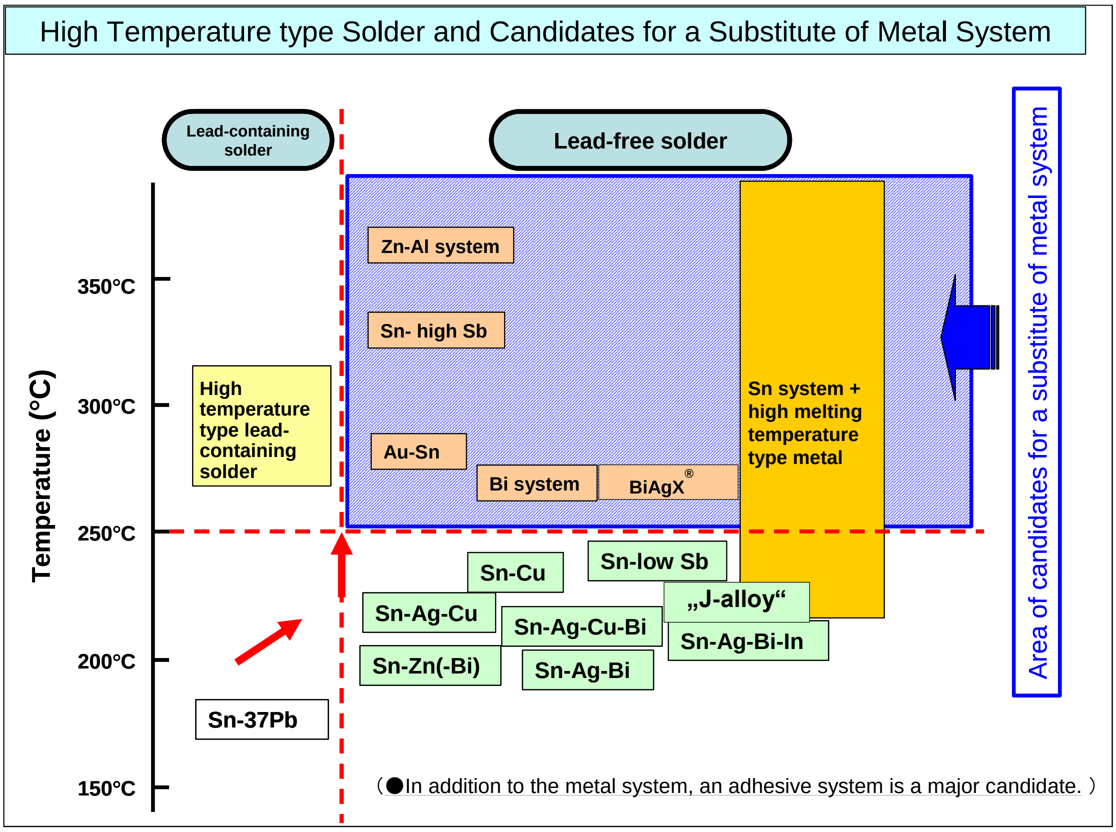


***Figure 13**: Relationship Diagram of Solders and Melting Temperature**

** This diagram borrowed from ACEA submission for ELV exemption 8e, November 2018*

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 lead-containing solder joints are typically 230°C to 250°C. The increased processing temperature for lead-free solder joints expanded the requirement for HMP lead (Pb) solder for adding multiple devices to a board (PCB). 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. These are the candidates for the replacement of high temperature type lead-containing solders as shown previously in Figure 13.

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 (very brittle) • Low strength • High electrical resistivity
	BiAgX®	• Easy drop in replacement for Pb-containing solder paste • Relatively low cost	• Brittle solder joints (solder cracks) • poor wetting, solder voids (can cause bond failure and other reliability issues) • thermal impedance increases (so unsuitable where heat conduction is required) • Melting temperature is 263°C
	Au-Sn	• Solidus line is high • Joint operating temperature is comparable with conventional high temperature type solders. • Strength is high	• Low ductility (too hard, so when used between parts with different CTE, this causes high strain leading to bond failure) • Lower melting point compared to HMP lead (Pb) solder
	Sn-high Sb	• Solidus line is high	• Low ductility • Concern of Sb toxicity (on REACH CoRAP list) • Temperature required to solder is ~50°C higher than Pb-based HMP solder and is too hot for some processes (as this will damage most polymers and possibly the silicon chip)
	Zn-Al system	• Solidus line is high	• Brittle and low ductility • Susceptible to corrosion and early failure • Temperature required to solder is significantly higher than Pb-based HMP 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 of brittle inter-metallic 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 • Insufficient reliability when qualifying for higher (Tjmax=175°C or above) junction temperature • Concern of some components' toxicity (classified as CMR)
Ag sintering systems	• No concern of remelting due to thermal hardening and/or pressure assisted sintering • High electrical and thermal performance	• Additional stress during processing (pressure assisted sintering) on the chip • Susceptible to humidity (porosity of Ag sponge) • High stress on chip due to stiff die-attach material • Concern of some components' toxicity (classified as CMR)

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

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

The above data explains that alternative Pb-free HMP materials currently in the market do not 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, a consortia to develop a Pb-free die-attach solution, consisting of STMicroelectronics, NXP Semiconductors, Infineon Technologies, Bosch (Division Automotive Electronics), and nexperia) consortia has been working with suppliers for several years to identify and evaluate alternatives to HMP lead (Pb) solders. An introduction to the DA5 and summed up results can be downloaded from following link:

https://www.infineon.com/dgdl/DA5_customer_presentation_1612016.pdf?fileId=5546d4616102d26701610905cfde0005

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 10 years, but even the best of these materials do not meet the DA5 requirements for quality, reliability and manufacturability. This research has shown that the substitute bonding technologies 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 yet for mass production.

Vishay provided summary results of their evaluation of promising lead free materials for internal die-attach. Solder pastes and solder wires based on the BiAg, AuSn and SnAgCu systems were evaluated, also silver sinter pastes, sinter epoxy and silver epoxy from several suppliers. In conclusion, none of the evaluated materials have proved capable of replacing HMP lead (Pb) solder in terms of manufacturability, quality and reliability.

More information about the DA5 and Vishay 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 is continuously researching alternatives, however currently no lead-free alternative technology can be predicted accurately for the short term.

If a possible substitute is identified for evaluation, widespread conversion from use of HMP lead (Pb) solders in related applications, it 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 14 below shows a typical timescale from identification of a suitable substitute to commercial use in electrical equipment. Some sectors however require longer timescales. For example, with medical devices (category 8) if a design change is required or if reliability might be affected, reliability testing of the equipment is required, clinical trials may be needed and medical

[1] https://elv.exemptions.oeko.info/fileadmin/user_upload/Final_Report/ELV_PACK_3_draft_20191001_Published_20191014.pdf

devices cannot be sold until they are approved by Notified bodies. Gaining global approval for new designs can take up to two years and so the timescale from identification of a substitute to commercial use can add up to another 4-6 years to the timescale shown in Figure 14. Some safety critical category 9 products also need longer timescales.

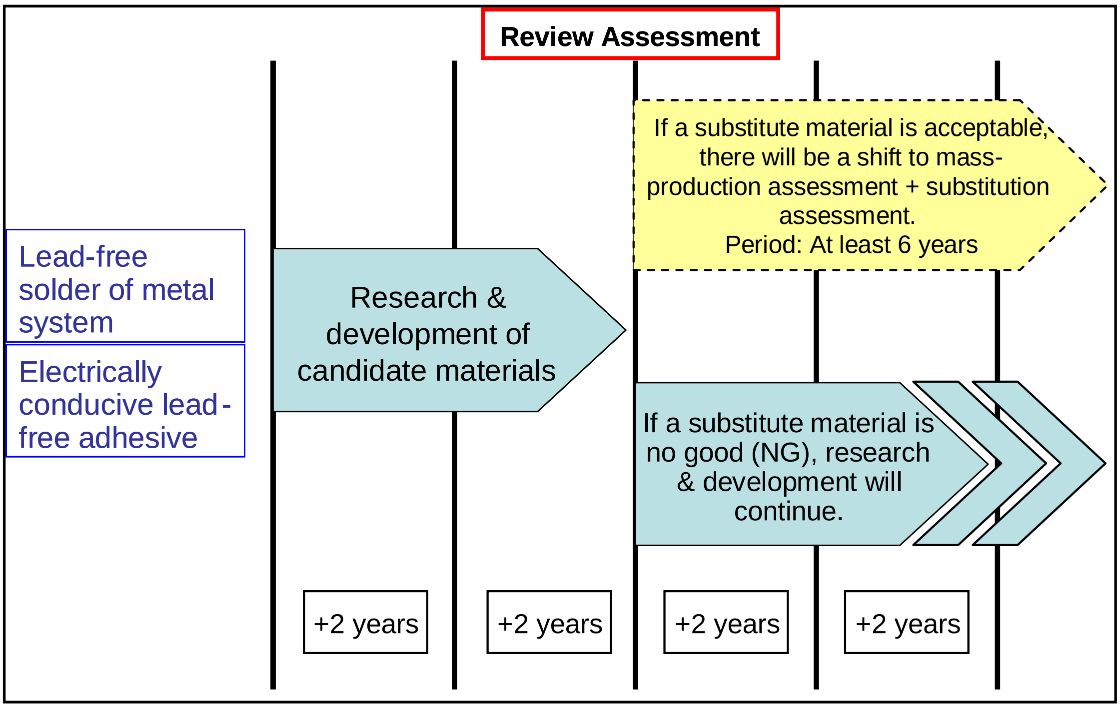


***Figure 14**: Material transition Process*

Looking at HMP lead (Pb) solder for attaching die within 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 are 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.

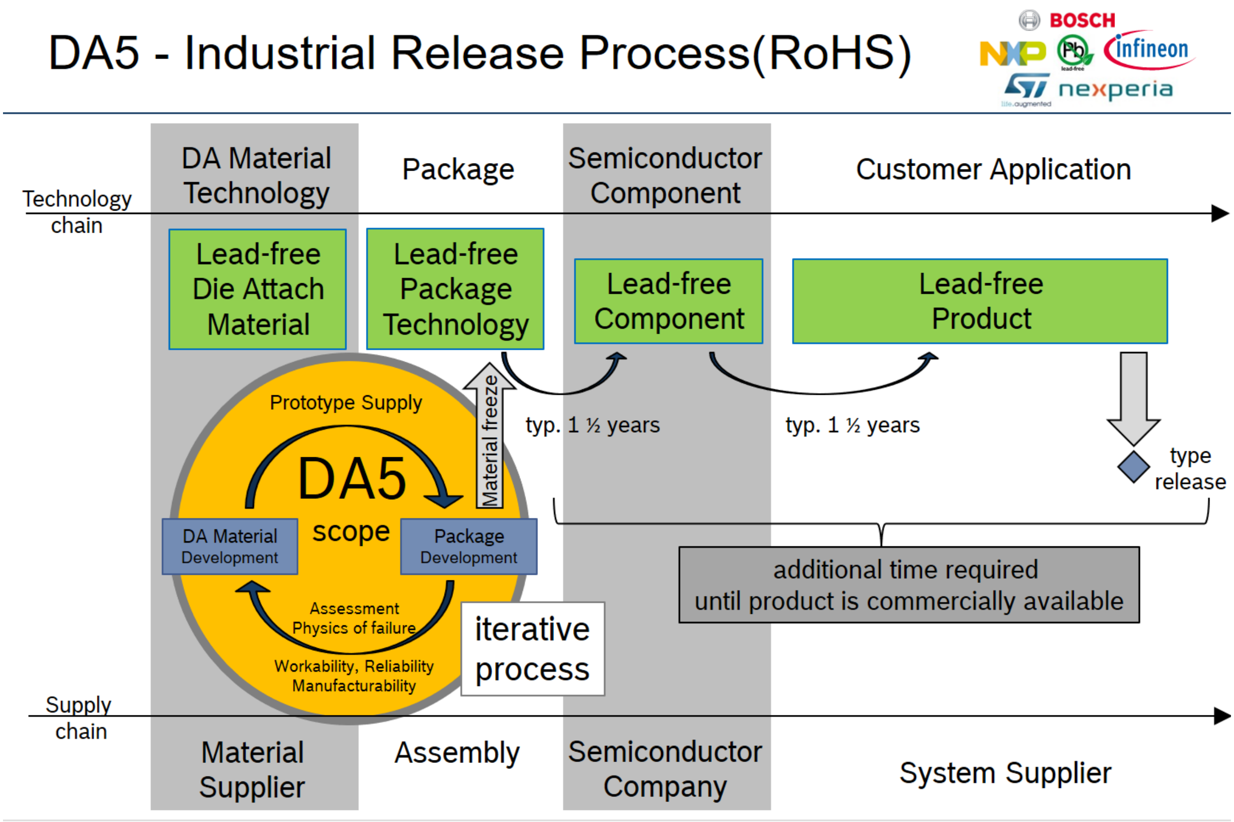


***Chart 1**: Cycle Time to Conversion (DA5)*

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

Based on the current status of REACH Regulation Annexes XIV and XVII, the requested exemption renewal would not weaken the environmental and health protection afforded by the REACH Regulation. The requested exemption is therefore justified as other criteria of Art.5 (1)(a) apply.

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) and 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) and 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, while other materials under current evaluation deal with the Ag CLP hazard classification change proposal, the Sb Scrutiny under Corap and the presence of other CMR classified substances.

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 as hazard classification change and conflict mineral sourcing.
If exemption RoHS exemption 7a is not renewed, a very large proportion of the electrical equipment currently used in the EU could not be sold in the EU, which would have a disastrous impact on the EU's economy.

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 (merged with NXP in 2015), 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 companies' consortium is known as the DA5 (Die Attach 5), and is actively supporting the demands of the European Union towards reduced lead in electronics over the last 10 years. In 2017 nexperia joined the DA5.

Evaluations of different materials (in the meantime more than 100 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 (DA5 already evaluated together with the material supplier more than 100 different materials). The slide images below provide a summary of results, updated to July 2019, for the different material classes (the whole document can be downloaded from the link: https://www.infineon.com/dgdl/DA5_customer_presentation_1612016.pdf?fileId=5546d4616102d26701610905cfde0005).

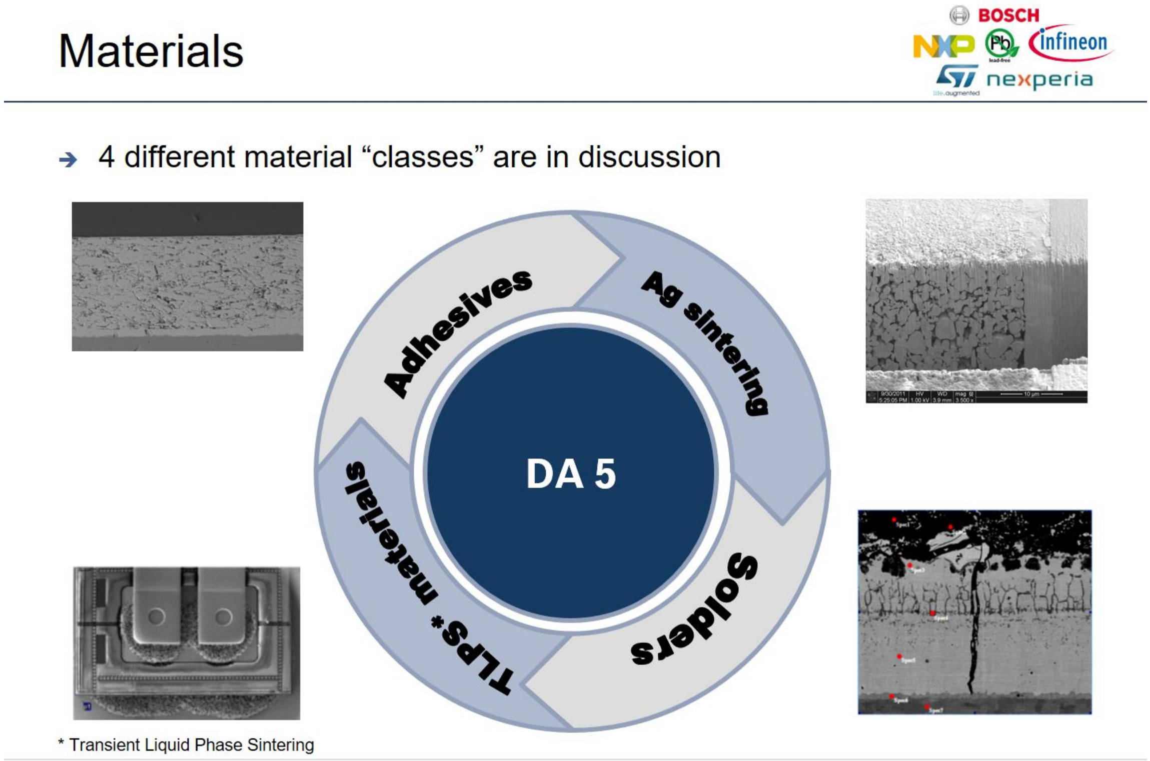


Chart 2: Potential alternative materials

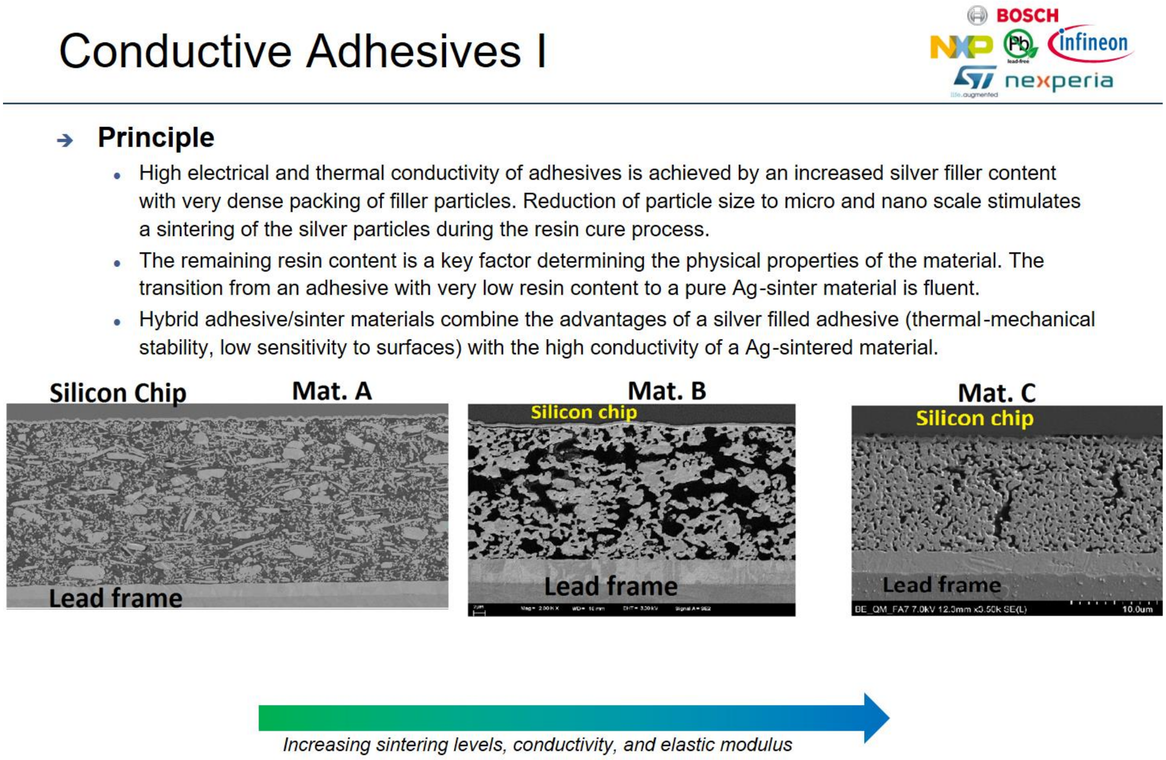
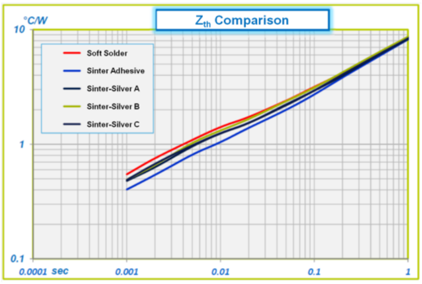


Chart 3: High Thermal Conductive Adhesives I

Conductive Adhesives II

Advantages

- Organic resin improves adhesion to different types of chip backside metals and leadframe platings.
- Same or better mechanical, thermal, and electrical properties compared to solder, similar to sintered silver.
- Commonly used die bond equipment can be used for dispensing, chip placement, and curing of the material (Drop-In Solution).
- Can pass automotive environment stress test conditions (AEC-Q100, AEC-Q101) depending on package type and die size.



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

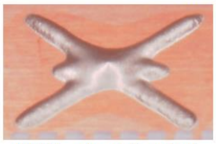
Scanning acoustic microscopy shows no delamination of die attach after 2000cycles TC -50°C / +150°C.

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

Conductive Adhesives III

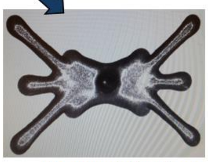
Limitations

- Materials contain solvents to improve rheology for dispensing. This requires careful handling and control of the manufacturing process. It also bears a risk of leadframe and die surface contamination.
- Material cost is higher compared to standard adhesives and solder alloy.
- Process window (bond line thickness, curing conditions) has to be determined for every die size.
- Maximum die size (~50 mm²) strongly depends on package design and bill of materials. Backside metal is required.
- Materials with sintered structure have high elastic modulus causing mechanical stresses and higher delamination risk.
- Limitation seen for high power devices and moisture sensitivity level greater than MSL3/260°C.
- Material usage only possible for die thickness >120 µm for the moment.

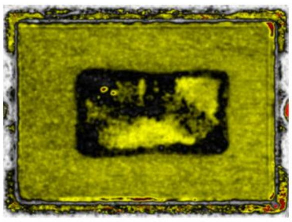


Visible solvent bleed out

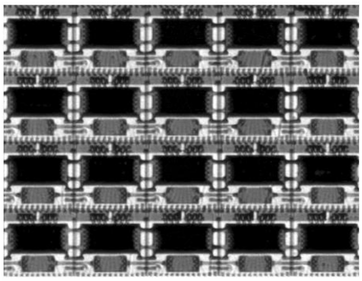
Dispense Patterns



No solvent bleed out



Scanning acoustic microscopy of an as-cured good part: apparent inhomogeneity detected



Scanning acoustic microscopy shows delamination of large power transistor die attach after 1000 th. cycles -50°C / +150°C

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

High Thermal Conductive Adhesives

In general these adhesives have some favorable 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 ~30mm². 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 behavior of glue during reliability testing. Moisture uptake of adhesives can lead to moisture-induced failure during reflow soldering (this affects the moisture sensitivity level - 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, which causes short-circuit failures.

As of mid 2019, the DA5 are not aware of any solution (glue or other materials) that can replace HMP lead (Pb) solder, for the time being. The limitations of adhesives are detailed above. HMP solders and adhesives belong to completely different material classes and perform very differently. Some adhesives constituents are classified as CMR.

The electronics industry naturally works toward eliminating HMP lead (Pb) solder because alternatives (e.g. conductive adhesive) are typically easier to use in integrated circuit packages as the die-attach material; 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°C to 260°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 lead (Pb) solders are used.

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
  - 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
  - Limitations found 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, un-sintered Ag particles in die-attach layer)

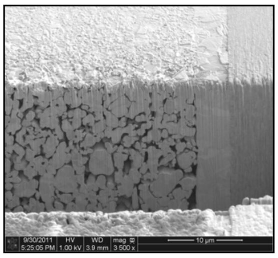


***Chart 6**: Silver Sintering I – Overview*

Ag Sintering II – Assembly

- Dispensability and staging time are improving, long run workability data not available
- Voiding is improving
- Process control issue: C-SAM scans are difficult to interpret
- Bond line density differences should be improved
- Reduction of un-sintered Ag particles is improving

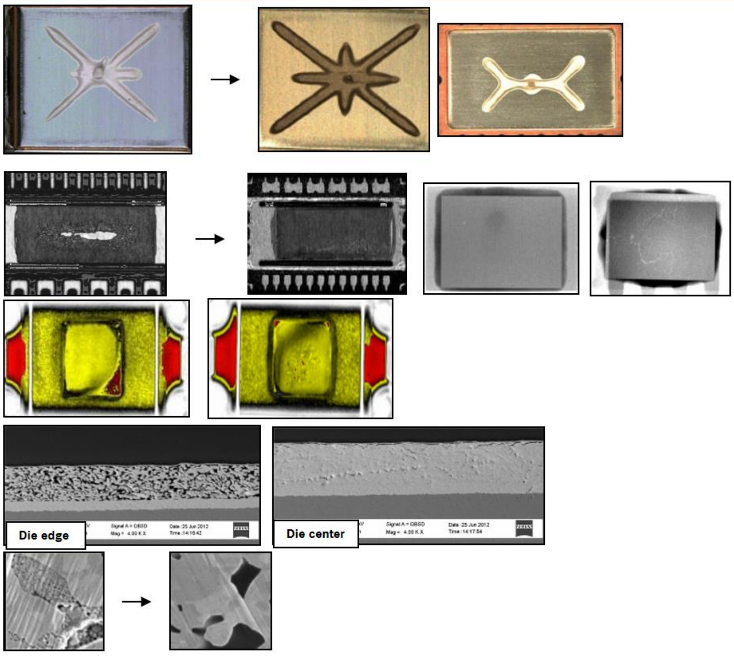


***Chart 7**: Silver Sintering II – Assembly*

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 obtained with Ag finishes
  - In-package electrical performance still lags Pb-solder
- No test configuration has passed yet 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
    - 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)

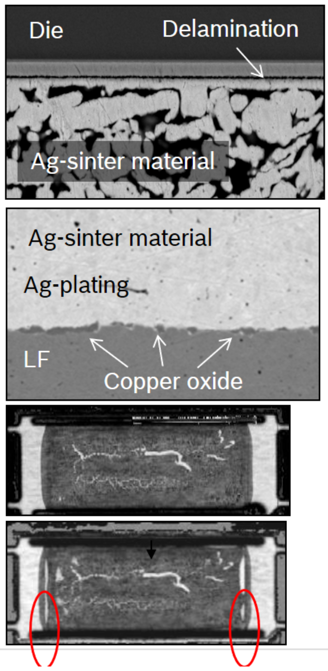
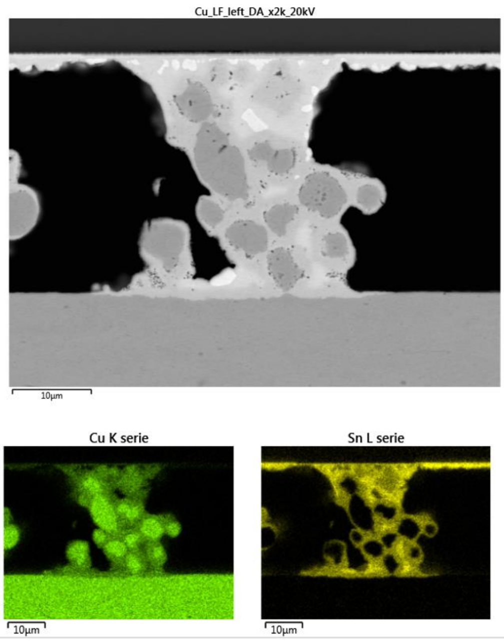


Chart 8: *Silver Sintering III – 0-hr & Reliability Results*

TLPS materials I



- 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
  - Medium space rate, filled with Epoxy
  - New concept in molded packaging - no prior knowledge of feasibility or reliability
  - Potential incompatibility for dies above 50 mm^2 due to high modulus and delamination risk
- Elevated risks
  - High risk of Cu oxidation if oxygen concentration exceeds 300 ppm during sintering under nitrogen
  - Potential reliability issues: Kirkendall voids form during IMC growth at 175°C during HTSL

Chart 9: *TLPS Materials I*

TLPS materials II

- The hybrid material showed a 1:1 metal-to-resin ratio. The spaces between metal structures are filled with epoxy resin material.
- The reflow process is very critical and has to be further optimized, the reflow profile seems to be product-specific
- Low maturity, more reliability data are needed.
  Results are package / leadframe material dependent. A low metal / epoxy ratio is needed to survive reliability, at the expense of reduced thermal performance
- Shear values at 260°C are low
- Strong brittle intermetallic phase growth with Cu
- Potential usage for SIP and clip packages
- Thin die (thickness <100µm) usage to be proven

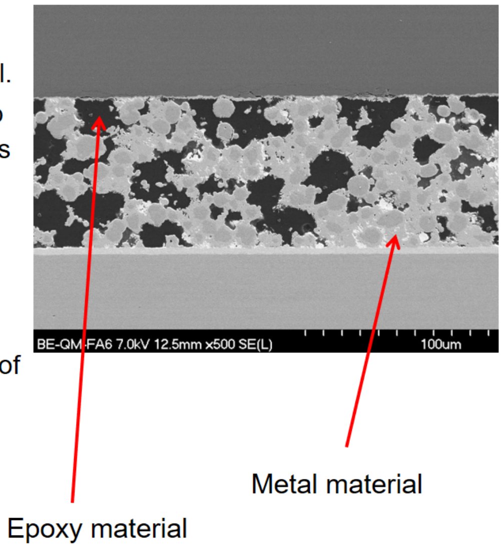


***Chart 10**: TLPS Materials II*

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

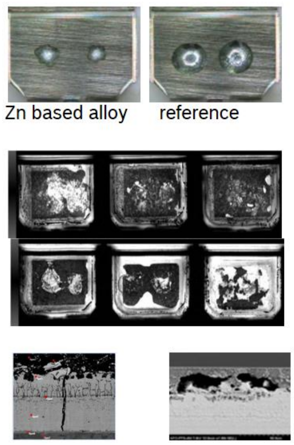


***Chart 11**: Alternative Solders I*

Alternative Solders II

- Zn-based Alloys
  - Material currently only available in wire form
  - Low wettability makes the use of special equipment necessary (capability for mass production open)
  - Process temperature very high (above 410 °C) => high risk for incompatibility with chip technologies
  - Growth of brittle intermetallics at high temperature limits reliability
  - New formulations demonstrate lower mechanical stress and reduced die cracking.
  - Improved reliability expected for die<$10mm^2$ in combination with a new experimental lf surface
  - Risk of Zn re-deposition can only be assessed in high-volume manufacturing
- Bi-based Alloys
  - Low thermal conductivity & low melting point
  - Performance minor to high lead solder → no replacement option
- SnSb-based Alloys
  - New formulations with improved melting point available
  - Workability to be improved (voiding, die cracking)
  - Limited surface compatibility (chip backside, leadframe finish)
  - Secondary reflow and reliability not yet demonstrated
  - Materials are offered in paste and as pre-form

***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.

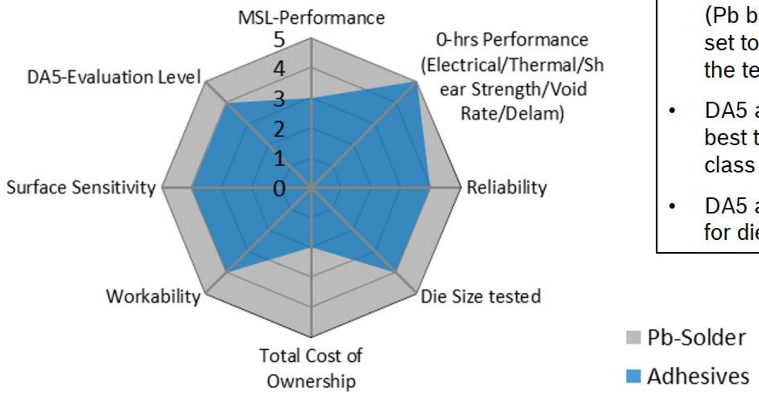
The DA5 customer presentation listed two potential alternative candidate materials based solely upon melting temperature evaluations in Chart 17 (below): Sn25Ag10Sb and Au20Sn. Considering only the brittleness and melting temperature, these alternative solders might be technically feasible in some applications – refer to the Vishay evaluation results (Slide 1-4).

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 (KPI) charts.

Key Performance Indicators I

Comparison of competing Technologies

Adhesives vs. Pb-solder



- DA5 now uses a new rating system with revised criteria (Pb based solder reference set to 5 for all criteria) for the technology comparison
- DA5 assessment refers to best tested material in class
- DA5 assessment only valid for die thickness > 120 µm

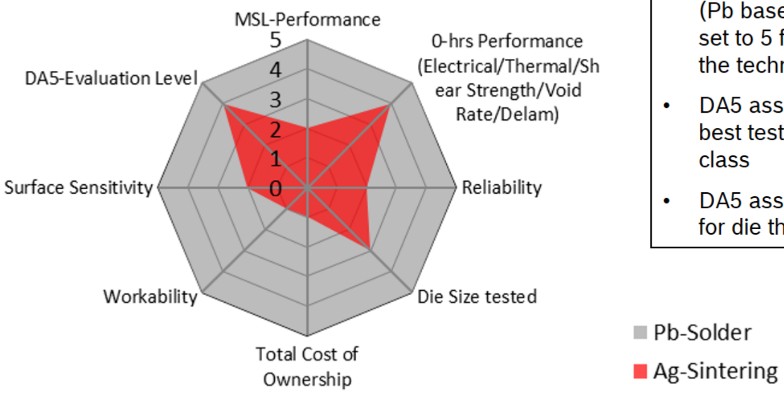
(rating: 0 unknown, 1 very poor, 2 poor, 3 fair, 4 good, 5 very good: as good as Pb-solder)

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

Key Performance Indicators II

Comparison of competing Technologies

Ag Sintering vs. Pb-solder



- DA5 now uses a new rating system with revised criteria (Pb based solder reference set to 5 for all criteria) for the technology comparison
- DA5 assessment refers to best tested material in class
- DA5 assessment only valid for die thickness > 120 µm

(rating: 0 unknown, 1 very poor, 2 poor, 3 fair, 4 good, 5 very good: as good as Pb-solder)

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

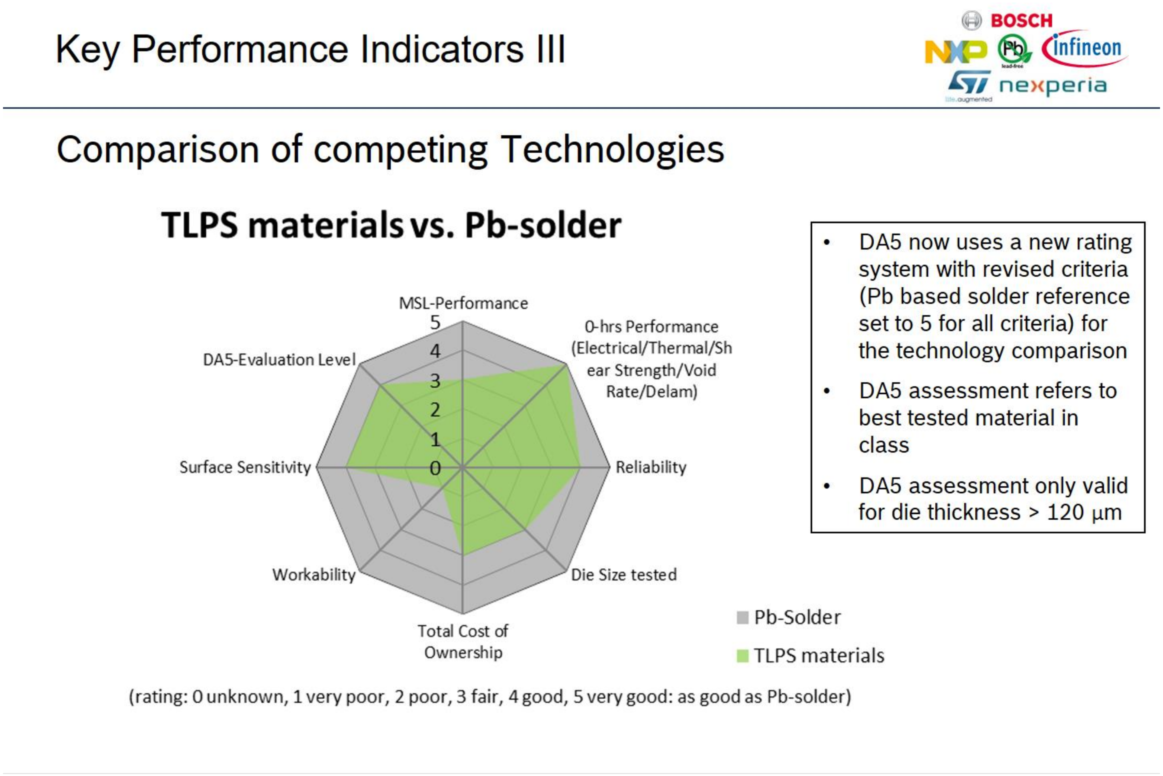


***Chart 15**: KPI-3 for Transient Liquid Phase Sintering (TLPS) vs. Pb-solder*

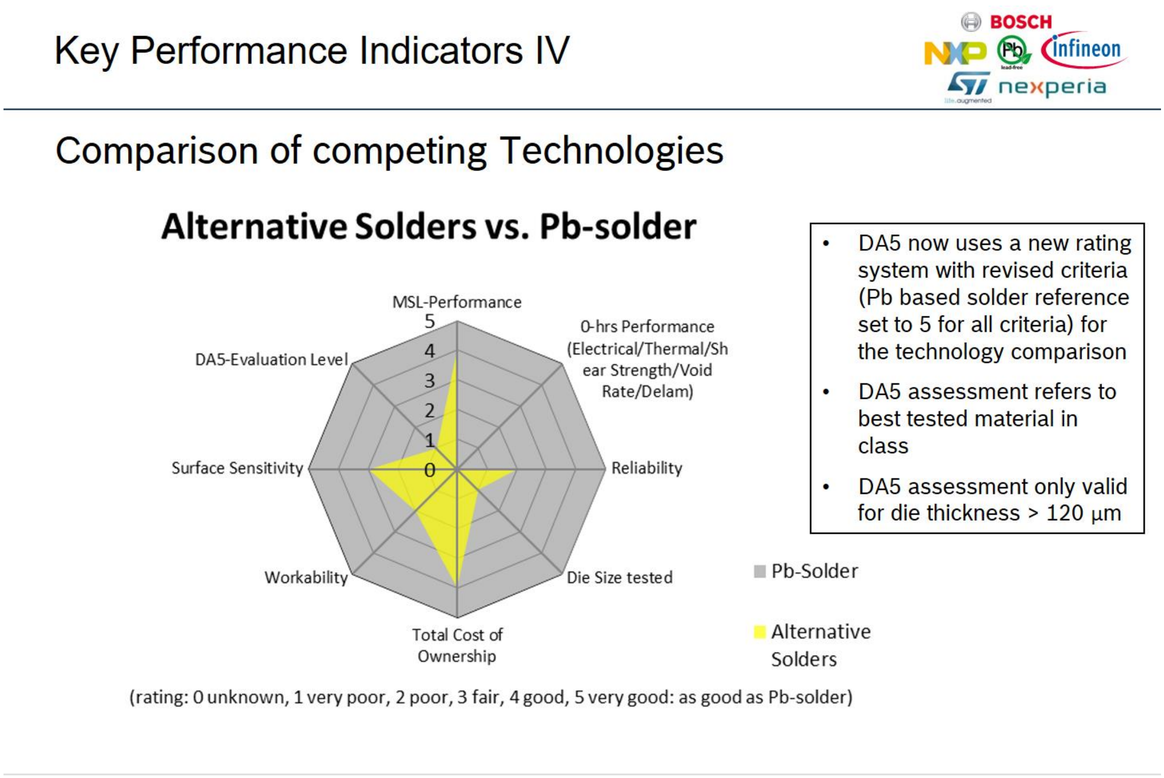


***Chart 16**: KPI-4 for Alternative Solders vs. Pb-solder*

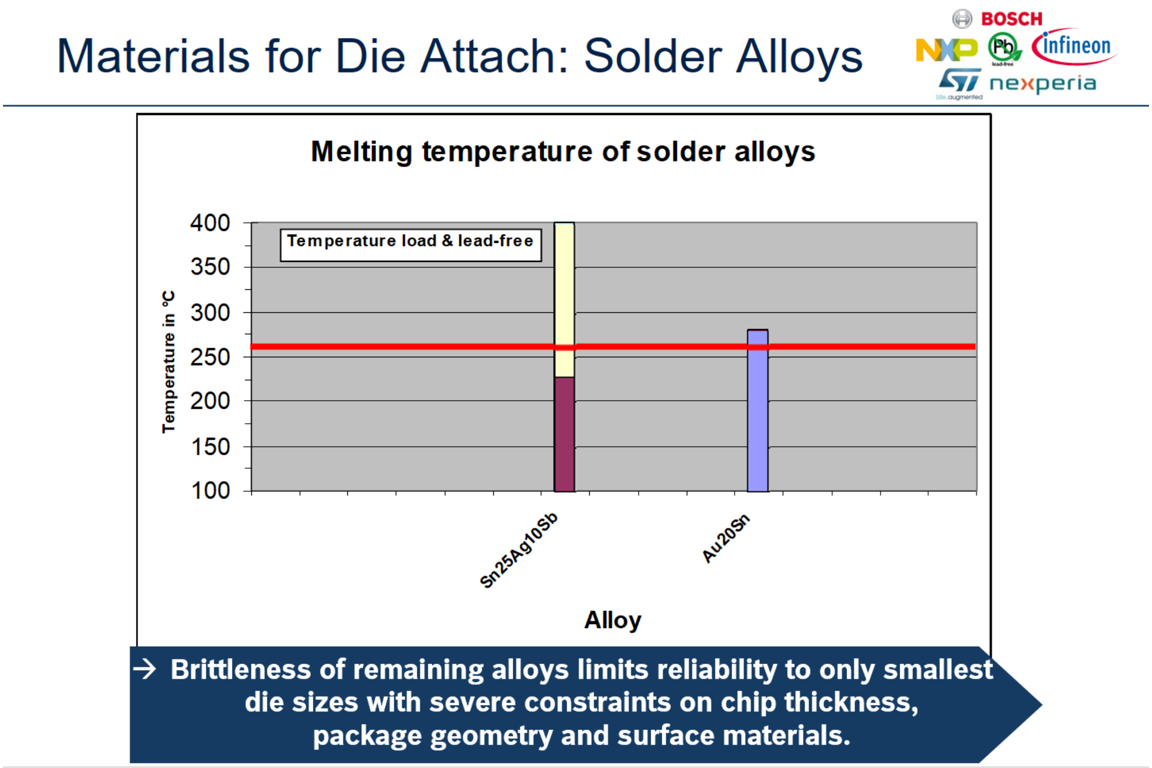


***Chart 17**: Melting Temperature of Solder Alloys*

As noted in Chart 17, DA5 experience has shown that die size and melting temperatures are not the only requirements for alternative Pb-free solders. Additional design restrictions on chip thickness, package geometry and surfaces have to be carefully optimized to make such materials work at all. The variety of requirements justify the phrasing of the RoHS exemption 7a wording. Optimization is difficult due to unfavorable mechanical properties of the die-attach materials, like brittleness. Conversion would only be possible for new semiconductor products:

(1) that are specifically designed for these materials,

(2) where manufacturing processes and equipment have been designed and developed to support the change, and

(3) where the application can accept the material related limitations (e.g. design, functionality, reliability and/or manufacturability).

The resulting new semiconductor design will not be compatible with all customer applications.

In summary, the DA5 evaluation of alternatives to HMP lead (Pb) solder die-attach materials determined that no current alternative solder materials can maintain product system performance and pass all qualification tests.

DA5 Note and Conclusion about Conductive Die-Attach Films (CDAF): This alternative has not been mentioned in the DA5 evaluations above as an alternative for HMP lead (Pb) solder in die-attach, although it is used as a die-attach material in some products. Conductive Die-Attach Films (CDAF, conductive glue prepared as a tape) are used to replace conductive glue but not to replace HMP lead (Pb) solder.

These conductive tapes are mainly used where clearance between die dimensions and die pad is very small and glue cannot be used due to bleeding, which causes some glue constituents to start to migrate on the leadframe. Today, conductive tape is a potential improvement for products that use standard conductive glues. It cannot replace HMP lead (Pb) solder as it suffers from most of the same limitations as conducting adhesives.

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 electrically 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 continuation of the exemption is still required. The DA5 evaluations have determined that no feasible alternative is available in the market.

DA5 References:
Latest DA5 Customer Presentation:
https://www.infineon.com/dgdl/DA5_customer_presentation_1612016.pdf?fileId=5546d4616102d26701610905cfde0005

DA5 Material Requirement Specification can be provided on request:
Speaker of the DA5 consortium: Bodo Eilken
Infineon Technologies AG

9(B) Efforts of Vishay

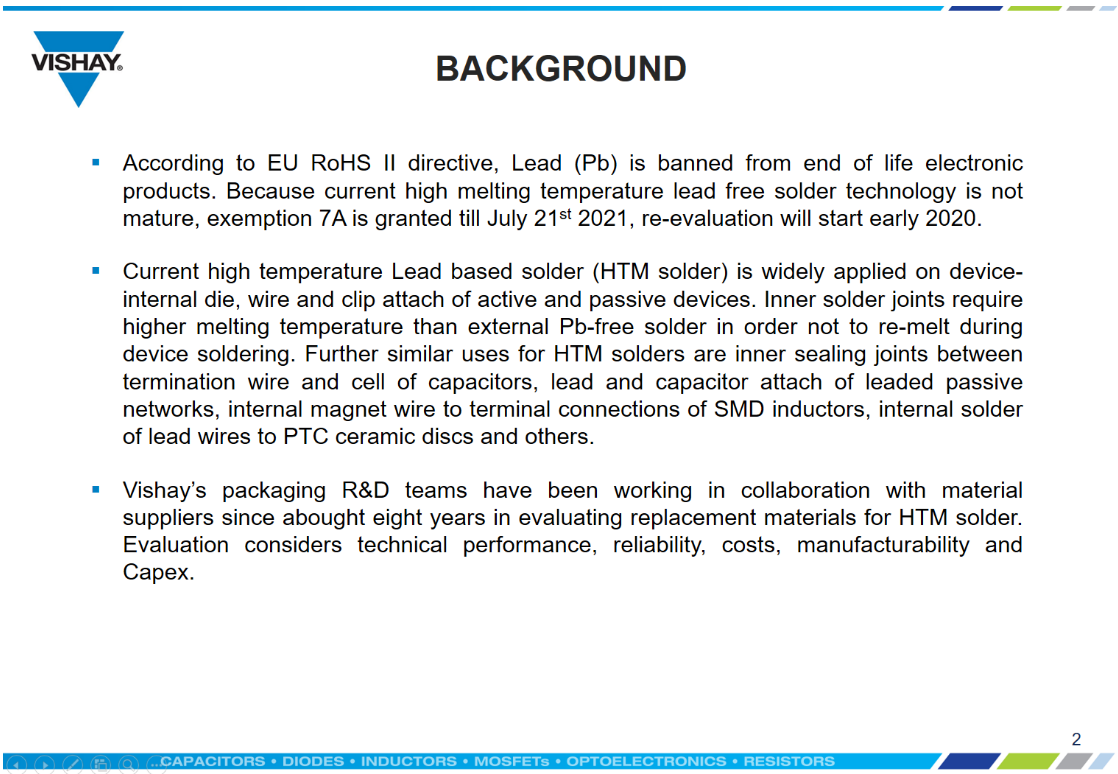
Vishay is one of the world’s largest manufacturer of discrete semiconductors and passive electronic components. Vishay has evaluated numerous suppliers and alternative Pb free high melting point materials to replace HMP lead (Pb) solder. This documentation recently became available to the industry organizations 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:
J-alloy (SnAg25Sb10) was also evaluated and even in production for internal die-attach of several Vishay diodes and thyristors for a couple of years. Similar experience as described above were made: because of brittleness of the solder material, frequent assembly/reliability issues (die cracks) occurred. Use of J-alloy finally had to be stopped.

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[2] 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

[2] rds(on) MOSFETs need to have very low electrical resistance when „on“ as MOSFETS are used as a switch. BiAg increases resistance so degrades performance (rds(on) = drain source on resistance)

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 only with limited and very niche products. The materials are still under investigation at this time.



Slide 1: Background Vishay Evaluation

VISHAY.

Lead free materials which were evaluated to replace lead HTM internal solder include:

No	Solder material	Material type
1	BiAgX®	Solder paste
2	ESL 3601 NF	Solder paste
3	Sn65Ag25Sb10 (J-alloy)	Solder wire
4	mAgic ASP 295-79D2	Silver sinter paste
5	XH9890-6	Silver sinter epoxy
6	EN-4620K	Silver epoxy

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Slide 2: List of Materials Evaluated

VISHAY.

EVALUATION RESULT SUMMARY (1)

Material Type	Solder paste			
Series	Pb-Sn Alloy (Reference)	Bi-Ag Alloy	ESL 3601 NF	J-alloy
Product	PbAg2.5Sn5	BiAgX®	Au80Sn20	Sn65Ag25Sb10
Lead contain/free	Lead contain	Lead free	Lead free	Lead free
Vishay application	In use	Evaluation	Evaluation	Was in use / stopped
Component (after)	Pb-Sn-Ag Alloy	Bi-Ag Alloy	Au-Sn Alloy	Sn-Ag-Sb Alloy
Dispensing applicable or not	Printing/dispensing	Dispensing	Dispensing	Solder wire
Working condition	Reflow Peak temp. 360-400℃	Reflow Peak temp. 320-380℃	Reflow Peak temp. 320℃	Heat station Peak temp. 300-350℃
Metal layer	Bare Cu is possible	Bare Cu is possible	Au/Au-Alloy (Bare Cu tested)	Bare Cu is possible
Advantage	-	• Soldering reflow profile is comparable • Relatively low cost • Pass reliability test	• Acceptable electrical and thermal conductivity	• No need of flux cleaning • Comparable costs • Die attach process can be optimized to achieve very low void-rate
Disadvantage	-	• Low solder liquid point and solder re-melting concern • Low electrical conductivity • Low ductility and solder crack concern • Poor wettability and high solder void rate • Low thermal conductivity	• Lower eutectic temperature (280℃) • Low ductility • Transfers most of the thermo-mechanical strain to the die -> risk of die cracks especially with increasing die size • Risk of cracked solder joints • High costs (>400x compared to Pb-solder paste)	• Very brittle, transfers lots of stress to the die • Was in use for die attach in the TO-247 package with various diode and thyristor chips. Finally needed to be changed back to Pb-containing solder because of ongoing / not resolvable die crack issues

Conclusion: Bi-AgX® and J-alloy so far assessed as not capable to replace current based solder. No final conclusion yet for Au80Sn20, but extremely high costs, also major technical concerns because of brittleness of the material.

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Slide 3: Evaluation Result Summary (1)

VISHAY.

EVALUATION RESULT SUMMARY (2)

Material Type	Sinter paste		Conductive adhesive
Series	Silver sinter paste	Silver sinter epoxy	Silver epoxy
Product	ASP295-79P2	XH9890-6	EN-4620K
Lead contain/free	Lead free	Lead free	Lead free
Vishay application	Evaluation	Evaluation	Evaluation
Component (after)	Silver (sintered)	Silver (sintered) & epoxy	Silver particle & epoxy
Dispensing applicable or not	Dispensing	Dispensing	Dispensing
Working condition	Curing Peak temp. 230℃	Curing Peak temp.200℃	Curing Peak temp.180℃
Metal layer	Ag/Au layer is must	Ag/Au layer is must	Ag/Au layer is suggested
Advantage	• Thermal and electrical conductivity better than Pb-solder • Low void rate • No re-melting concern	• Thermal and electrical conductivity comparable to Pb-solder • Low void rate • No re-melting concern • Pass reliability test	• Electrical conductivity comparable to Pb-solder • Low void rate • No re-melting concern
Disadvantage	• Additional Ag/Au plating is required • Low dispensability • Pressure sintering is suggested • Poor sintering on clip attach • Failed reliability testing • High cost	• Additional Ag/Au plating is required • Pressure sintering is suggested • Poor sintering on clip attach • Poor actual thermal performance • High cost	• Additional Ag/Au plating is suggested • Poor joint capability on clip attach • High cost

Conclusion: Above Lead free materials were evaluated as not capable to replace current Lead based solder paste.

5

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Slide 4: Evaluation Result Summary (2)

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 these devices 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 point 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 cause short-circuits and has been found in the “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 (surface mount devices) 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. Note that adhesive seals are also unsuitable as all polymers are porous to moisture and gaseous substances, which would damage the sensitive crystal. This is also the reason why adhesives cannot be used for sealing all other types of hermetically sealed components.

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 eco-design 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 lead (Pb) solder.

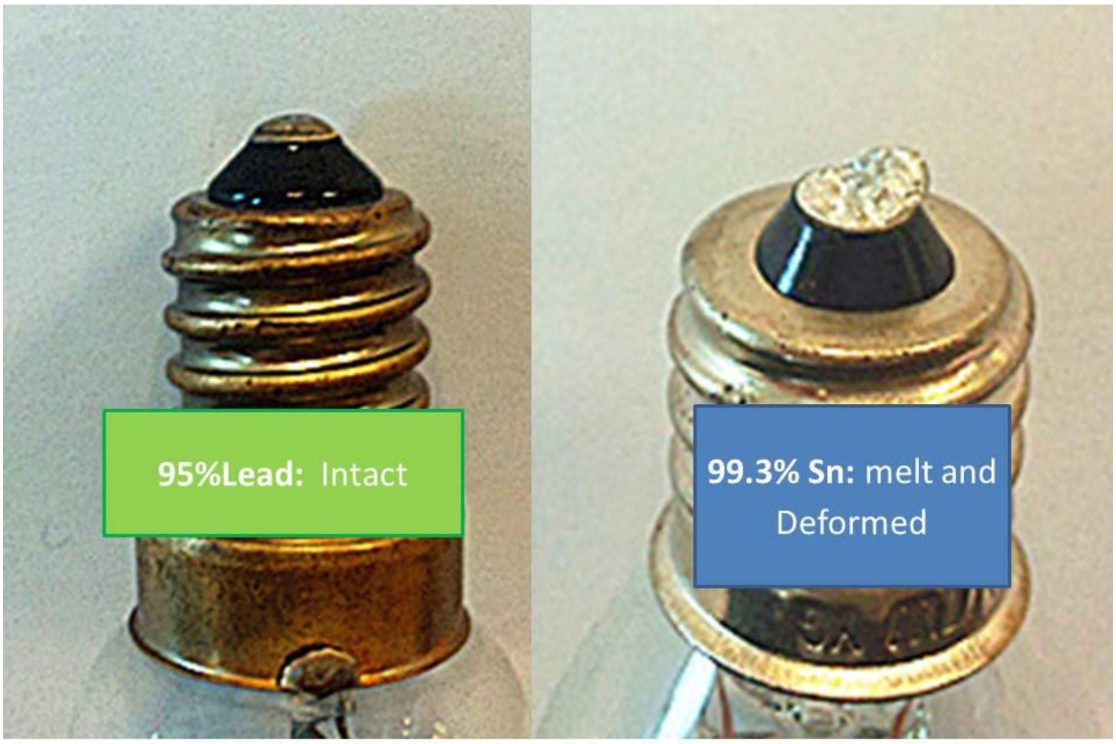

***Figure 15**: Oven Lamp Failure*

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: