This document provides the DA5 responses to the "Stakeholder Consultation on Renewal of Exemptions 8(e), 8(f), 8(g), 8(j) and 10(d) of Annex II to Directive 2000/53/EC (ELV)". The Consultation was announced on 09-September-2013 and concludes on 04-November-2013.

In 2Q 2010, Bosch (Division Automotive Electronics), Freescale Semiconductor, Infineon Technologies, NXP Semiconductors and STMicroelectronics formed a consortium to jointly investigate and standardize the acceptance of alternatives for high-lead solder for attaching die to semiconductor packages during manufacturing. The five company consortium is known as the DA5 (Die Attach 5).

The DA5 consortium aims to lead the industry into the next phase of the lead-free semiconductor evolution. In this way the DA5 companies are also actively supporting the demands of the European Union towards reduced lead in electronics.

Consultation Questionnaire Exemption No. 8(e)

Annex II of the ELV Directive was reviewed in 2009/2010. It was assessed that at that time high melting point (HMP) solders were used in the following applications:

1. Internal electrical interconnections in components
2. Die attach
3. Plastic overmoulding
4. Ceramic BGAs
5. High power applications
6. Hermetic sealings

1. Please indicate whether there are any other applications where HMP lead-solders are used.

   DA5 Response: This DA 5 response only addresses selected applications for HMP lead solder. We do not exclude other possible uses. So long as clip and component attach (single, multiple, active and passive) are included, the DA 5 applications are covered by HMP within the following applications as identified in this consultation

   1. Internal electrical interconnections in components
   2. Die attach
   3. Plastic overmoulding
   4. Ceramic BGAs
   5. High power applications
   6. Hermetic sealings

2. In 2009, the investigation and development of a few possible alternatives to the use of HMP solders was already underway, but it was not possible to identify applicable alternatives at the time. Please describe:

   a) in which applications the use of lead-containing HMP solders has become avoidable.

DA5 Response: No lead-free solutions have yet been identified for any HMP solder die-attach applications that currently use lead.

b) the tests or other works that have been performed to this extent, and explain the results with respect to the applicability of lead-free solutions for one or more of the above applications of lead HMP solders.

DA5 Response: Evaluations of different materials have been performed within the DA5 consortium together with several material suppliers for the die-attach application. This includes four main classes of materials: alternative solders, conductive adhesives, silver-sintering materials, and TLPS (Transient Liquid Phase Sintering) materials. At present, no material has been identified that fulfills the required properties of a replacement material. A summary of the results for the different material classes is attached. Further detailed evaluation and reliability results can be provided on request.

Materials

➔ 4 different material “classes” are in discussion

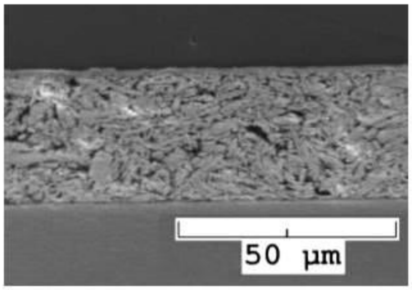
High Thermal Conductive Adhesives I

➔ Principle
- Very high conductivity of adhesives is achieved with an increased silver content and very dense packing of filler particles.
- Key factors are optimized silver particle size distribution with smaller particles and/or partial/full sintering of the silver particles during the resin cure process.

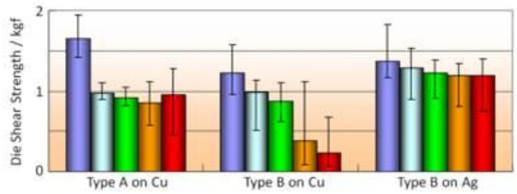
➔ Advantages
- Common production methods and equipment can be used for the application of the material and placement of the chip.
- Adhesives pass automotive environment stress test conditions.

➔ Limitations
- The high filler loadings make the rheology of the materials more critical and tighter process control is required.
- Some materials contain a solvent , where contamination of bond and leadframe surfaces is possible.
- Different leadframe plating and die backside require a dedicated adhesive type.
- Material cost is higher compared to standard adhesives and solder.
- Application is restricted to low and medium power devices and packages with maximum moisture sensitivity level of MSL3/260°C.

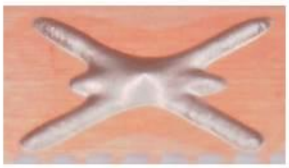
High Thermal Conductive Adhesives II



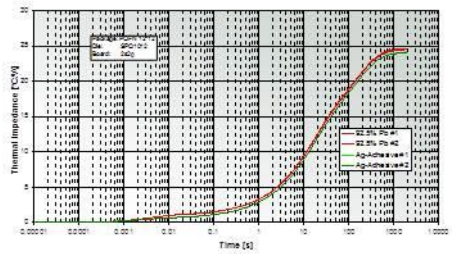
Dense packing of silver particles in the x-section of a adhesive bond line



Hot die shear test at 260°C shows influence of leadframe plating on bond strength



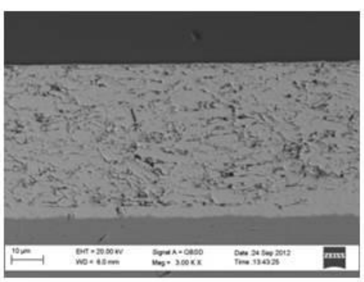
Dispense pattern with solvent bleed on the leadframe surface



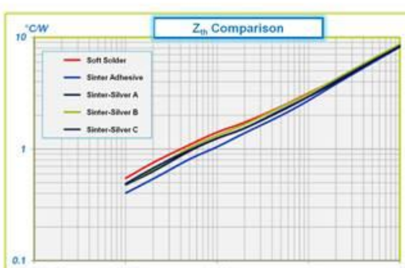
Thermal performance of the device is comparable to solder die attach

High Thermal Conductive Adhesives III

- The development of very high conductivity adhesives is heading towards a further reduction of filler particle size, thus stimulating a sintering process between the single silver particles during the resin cure process.
- The technology shall combine the advantages of an adhesive (thermal-mechanical stability, adhesion to various surfaces) with the high conductivity of an sintered silver material.
- The boundaries between the respective fields of this kind of adhesives and silver sintering pastes overlap.



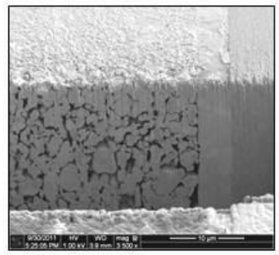
Cross-Section of Bondline with sintered silver particles



Comparison of Thermal Resistance
Sintered Adhesive vs. Soft-Solder, Sinter-Ag

Ag sintering I – Overview

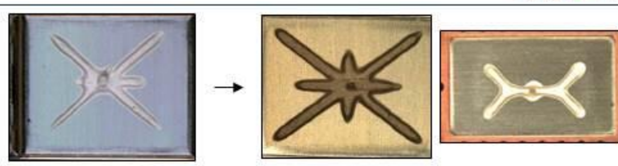
- **Principle**
  - Ag-sinter pastes: Ag particles (µm- and/or nm-scale) with organic coating, solvents, & sintering promoters
  - Dispense, pick & place die, pressureless sintering in N2 or air in box oven
  - Resulting die attach layer is a porous network of pure sintered Ag



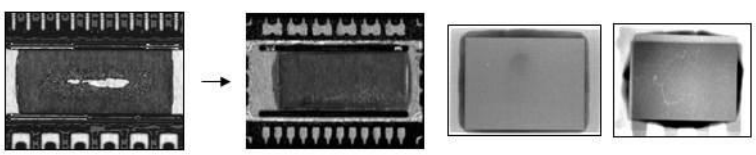
- **Advantages**
  - Fulfills many of the drop-in replacement requirements for a paste
  - Better thermal and electrical performance than Pb-solder possible
- **Disadvantages**
  - No self-alignment as with solder wetting
  - nm-scale Ag particles are at risk of being banned
  - New concept in molded packaging - no prior knowledge of feasibility, reliability or physics of failure
  - Production equipment changes might be needed (low-O_2 ovens?)
- **Elevated risks**
  - Potential limitations in die area/thickness, lead frame & die finishes
  - Potential reliability issues: cracking (rigidity), delamination or bond lift (organic contamination, thickness reduction due to continued sintering), interface degradation or electromigration of Ag (non-hermetic structure allows O_2 or humidity penetration?)

Ag sintering II – Assembly

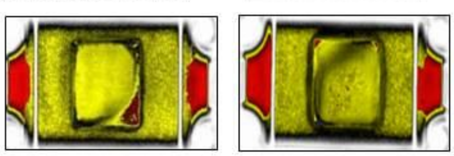
- Dispensability and staging time are improving:



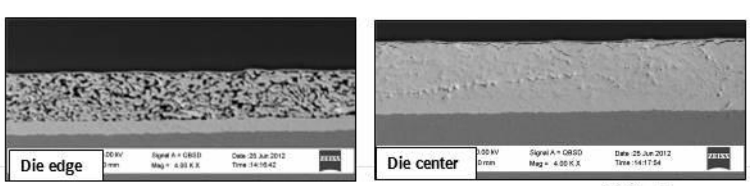
- Voiding is improving:



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

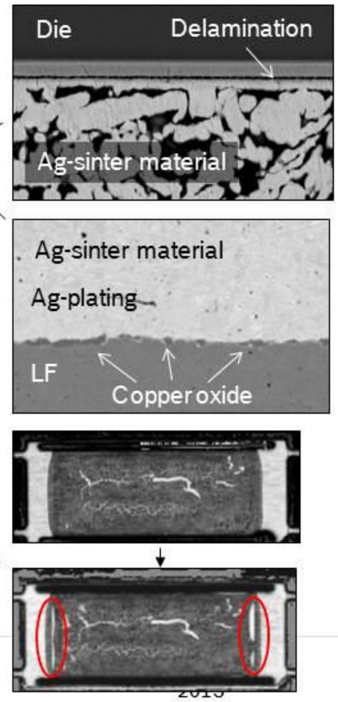


- Bond line density differences and un-sintered material should be improved:

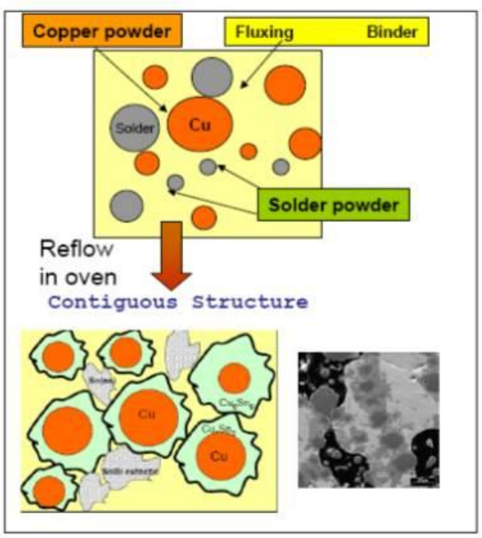


Ag sintering III – 0-hr & Reliability Results

- In cases with no delamination, high DSS (20 N/mm^2) and good thermal and electrical performance can be had with Ag finishes
- 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
  - Change die back-side metallization
- No test configuration has yet to pass all required reliability tests after MSL1 preconditioning
  - Results after MSL3 preconditioning are better, with reduced cracking and delamination
  - Recent results show further improvements, but still some delamination after temperature cycling and pressure pot / autoclave tests
- Reliability tests showing end-of-life behavior (physics of failure) still to be done



TLPS materials I

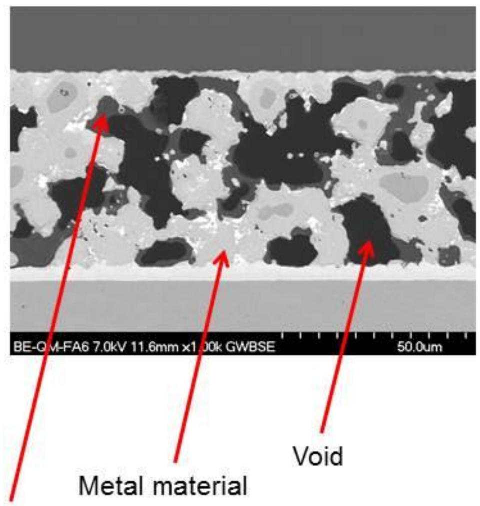


Principle

- Advantages
  - Fulfills many of the drop-in replacement requirements for a paste
  - Better cost position compared to Ag sintering solutions
- Disadvantages
  - Low metal content in die attach
  - High void rate, partly filled with Epoxy
  - New concept in molded packaging - no prior knowledge of feasibility or reliability
  - Only suitable for small dies < 13mm^2
- Elevated risks
  - Potential limitations as die attach for high power devices (low electrical and thermal conductivity compared to Pb solder)
  - Potential reliability issues: voids lead to cracks in die attach

TLPS material II

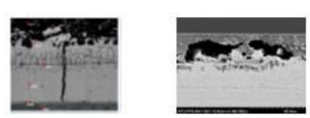
- The hybrid material showed a very high void rate. The voids are partly filled with epoxy material
- The reflow process is very critical and has to be further optimized, the reflow profile seems to be product specific
- Reliability results are contradictory. Results are package dependant. A low void rate is mandatory to survive reliability
- Shear values at 260°C are very low, below the minimum needed value (5N/mm^2)



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



Alternative Solders II

Current test results & rating

- Zn-based Alloys
  - + improved workability demonstrated
  - 0 new formulations demonstrate lower mechanical stress and reduced die cracking, still further improvement required
  - 0 no comprehensive reliability data available
  - \- availability of both, wire and paste needed
  - \- risk of Zn re-deposition can only be falsified in high-volume manufacturing

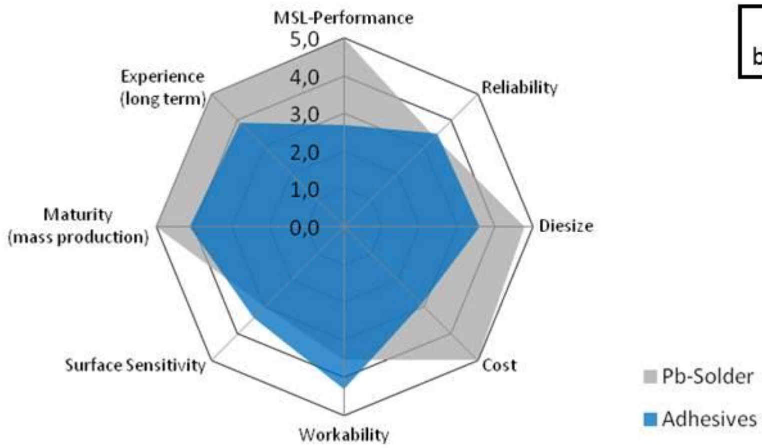
- Bi-based Alloys
  - low thermal conductivity & low melting point
  - performance minor to high lead solder

Key Performance Indicators I

Comparison of competing Technologies

Adhesives vs. Pb-solder

DA5 assessment refers to best tested material in class



(rating: 1 very poor, 2 poor, 3 fair, 4 good, 5 very good)

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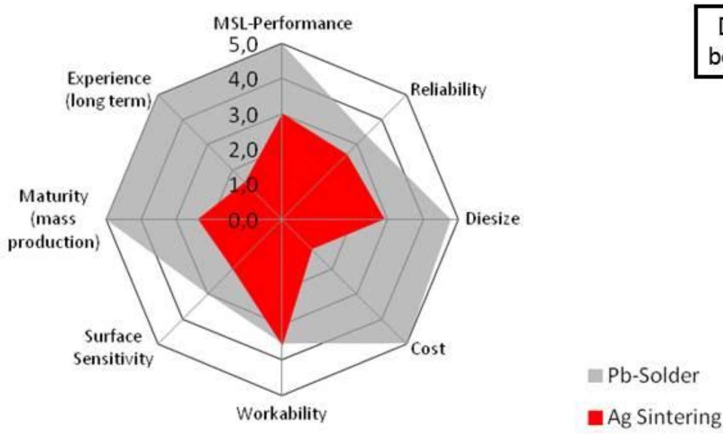
10 October, 2013

Key Performance Indicators II

Comparison of competing Technologies

Ag Sintering vs. Pb-solder

DA5 assessment refers to best tested material in class



(rating: 1 very poor, 2 poor, 3 fair, 4 good, 5 very good)

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10 October, 2013

Key Performance Indicators III

Comparison of competing Technologies

TLPS materials vs. Pb-solder

DA5 assessment refers to best tested material in class

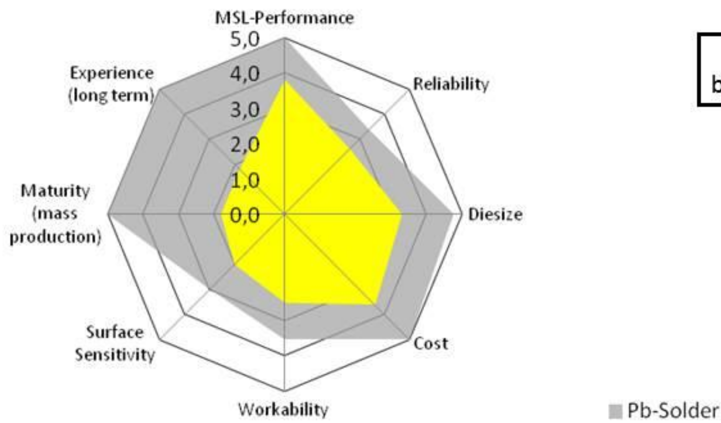
(rating: 1 very poor, 2 poor, 3 fair, 4 good, 5 very good)

35 10 October, 2013

Key Performance Indicators IV

Comparison of competing Technologies

Alternative Solders vs. Pb-solder



DA5 assessment refers to best tested material in class

(rating: 1 very poor, 2 poor, 3 fair, 4 good, 5 very good)

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3. For hermetic sealings, Swatch had applied for an exemption under the RoHS Directive for the use of lead used in hermetic sealings in quartz crystal resonators. The exemption request was assessed and recommended not to be granted, as lead-free solutions were available. The consultants therefore assume that at least in this application, the use of lead is avoidable. Please explain:

a) whether and how far you agree with this conclusion. If you do not agree, please provide evidence that lead-free solutions offered, for example in Annex III in the report of Öko-Institut (2006), are not viable for hermetic sealings used in automotive applications.

   DA5 Response: DA5 companies are not using lead solder in hermetic sealings with HMP solder (please note that the processes used in typical packaging & assembly processes are not comparable with the swatch application). We do however use hermetic sealings as covered by exemption 10(a).

b) in which other hermetic sealings are lead HMP solders used, and whether and how far the above lead-free solution is transferable to these applications.

   DA5 Response: DA5 companies are not using lead in hermetic sealings.

c) whether there are any other solutions for hermetic sealings making the use of lead avoidable, if not yet explained under question 2.

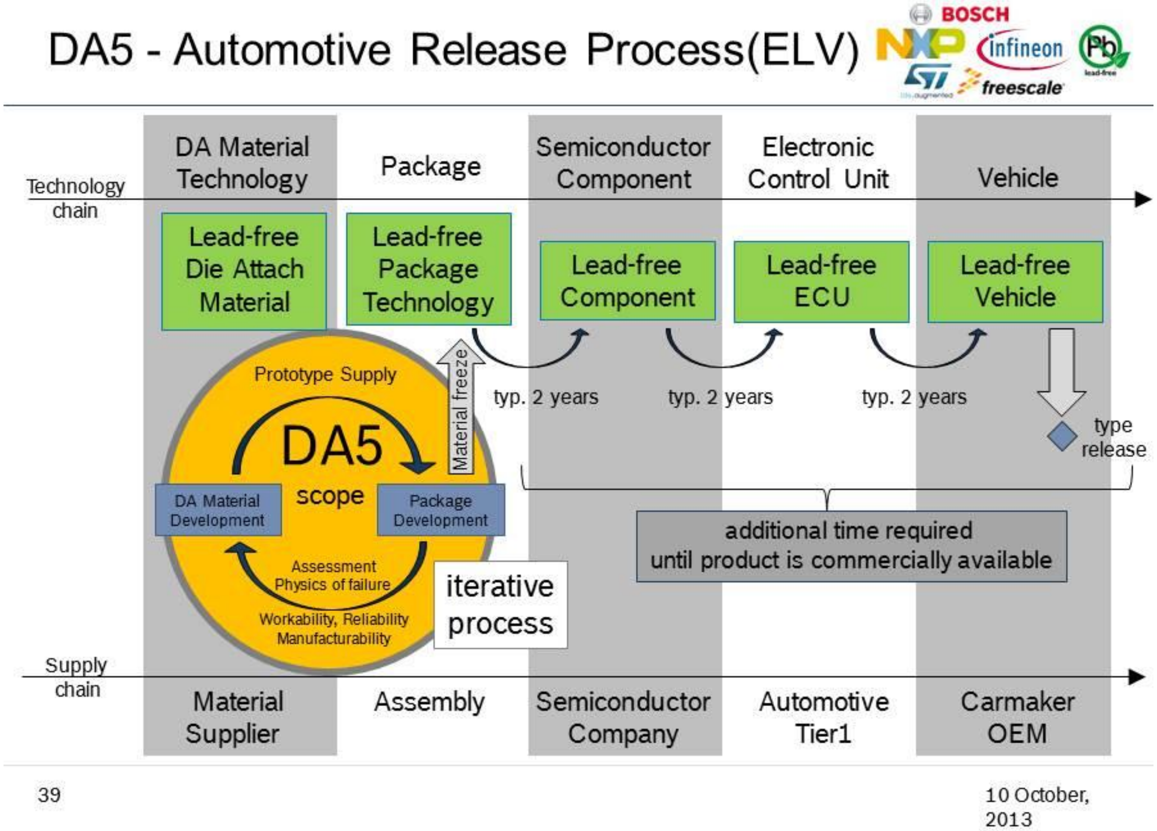
   DA5 Response: DA5 companies are not using lead in hermetic sealings.

4. Please indicate how much lead would be used under those applications in which the use of leaded HMP solders is unavoidable. Please substantiate the amount of lead with a calculation for vehicles put on the European market, and worldwide.

   DA5 Response: Please see calculation (based on ACEA calculation from 2009 updated with ACEA volumes from 2012). This calculation includes lead from all applications covered by 8(e) and is not limited to die-attach. End result: Assuming 13.4 million vehicles registered per year (EU27 + EFTA), the total amount of lead is 13.4 million x 0.47 g = 6.3 t of HMP solder per year. With a lead content of at least 85%, the amount of lead in these solders is at least 5.4 t per year in the EU27 + EFTA.

5. Please provide a roadmap towards ELV-compliance for those applications where the use of lead HMP solders is still unavoidable. Please break down the roadmap into steps to be performed and present and explain the related timelines.

   DA5 Response: The DA5 consortium is working with selected material suppliers on the selection of an appropriate replacement for lead solder (DA5 scope). The properties of the needed die-attach material is specified by the DA5 (material requirement specification) and provided to the material suppliers. Selected material suppliers offer their materials, which are evaluated by one of the DA5 companies together with the supplier. The detailed results are discussed with the material suppliers 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 6 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.



References:

DA5 Customer Presentation (status August 2013):
http://www.infineon.com/dgdl/DA5_customer_presentation_200813.pdf?folderId=db3a30433162923a013176306140071a&fileId=db3a30433fa9412f013fbd2aed4779a2

Material Requirement Specification can be provided on request.