Die Attach 5 Project
Updates to last version from 06.12.2020

- Following slides were updated:

  slide 15, 16, 41, 44, 46
Agenda

- **Motivation:** Environmental and health endangerment by lead

- **Situation:** Lead & the use in Electronics

- **Status on legislation**

- **DA5 Structure and Project:**
  - Cooperations and partners
  - Requirements, Applications and Approaches for possible solutions
  - Results

- **Timeline and Conclusion**
**Infineon:**
We understand sustainability as the symbiosis between economy, ecology and social engagement. At Infineon, we responsibly manage the handling of hazardous materials to safeguard human health and environmental protection. As part of Infineon Group Policy for Environmental Protection, Energy Management, Safety and Health, we are moving towards supply chain responsibility, focusing on the purchase of new environmentally friendly materials in the manufacture of its products. Products manufactured by Infineon in the fields of automotive electronics, industrial drives, servers, lighting, photovoltaics, wind energy, mobile phone chargers and induction cookers, enable CO\(_2\) emission savings amounting to approximately 56 million tons of CO\(_2\) equivalents during their use-phase. For the eleventh time in a row, Infineon has been listed in the “Dow Jones Sustainability™ Index”.

**STM:**
The Sustainable Technology program in ST was launched in 2011 in response to an industry trend to valorize the environmental and societal benefits of new products, in line with ST’s life.augmented vision. The program aims to strengthen ST’s leadership in sustainability by having product stewardship embedded in ST’s business strategy. It includes designing, tracking and communicating effectively on products that make a positive contribution to a more sustainable world, and demonstrates how these products contribute to our reputation and financial success. The program, which provides a common framework comprising all the elements that connect products and sustainability, has three main pillars:

- **Product Compliance**: covers legislation and customer requirements regarding REACH, RoHS, and conflict minerals
- **Responsible Products**: identifies innovative products that provide clear environmental and social benefits
- **Eco-design**: when designing products, systematically takes into account their environmental impact across the entire life cycle.
**Bosch:**
For the Bosch Group, sustainability means securing the company’s long-term success while at the same time protecting the natural resources on which present and future generations depend. The strategic imperative “Invented for life” thus expresses the aim to make mobility even safer, more efficient, and more economical, and to develop eco-friendly products in general.

**NXP:**
For NXP, Secure Connections for a Smarter World involves working practices that are responsible and sustainable. We provide a safe working environment, promote good health, and strive to minimize the environmental impact of our activities. We also work hard to do more than just comply with existing standards, we actively strive to establish a global benchmark for sustainability in our industry. NXP fosters ethical principles and respect for the environment, employees, and the communities in which we work. Quality is our number one driver, and, as a business, our goal is economic success. However, we also go to great lengths to ensure that sustainability is ingrained in our business conduct at all levels.

**Nexperia:**
We are committed to provide a safe working environment, promote good health, minimize the environmental impact of our activities and protect the environment with our way of working and the products we develop. We foster innovations and creative solutions that add value for our customers, communities and our planet. We define Sustainability as part of our "Efficiency wins" strategy through the inclusion of environmental, health & safety, social and governance issues in our business strategy. Sustainability is part of everyday work of all employees worldwide, from the Executive Management Team to each single employee, from product development until disposal.
Examples for Environmental Protection

- Powertrain
- Innovative electro-tools with Li-Ion technology
- Photovoltaic
- Saving energy in basestations
- Wind energy (gears)
- Solar thermal
- Energy efficient appliances
- Power plant
- Household/Office
- Smart grid
- More efficient SSL lighting
Lead: Environmental and Health Endangerment

- Environmental dangers

- Health dangers:
  - Poisonous substance
  - Neurotoxin
    - Accumulates in soft tissues & bones
  - Damage to nervous system
  - Causes brain disorder
  - Causes blood disorder in mammals
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## Use of Lead in Electronics

<table>
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<tr>
<td>Lead in soldering on PCB, the components and their finishes</td>
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<td>Lead in soldering on glass for mass-flow sensors</td>
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<td>Lead in high temperature melting solders</td>
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<td>Lead in solder between die and carrier in flip chip packages</td>
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<td>Lead in solder of IC assemblies with &gt;1cm² die and &gt;1A/mm²</td>
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### Expiry Dates referring to vehicle type approval

- Carry over parts without expiry date: not recommended.
Use of Lead in Electronics

- Use of Lead containing Solders in PCB
  - **PbSn63 or PbSn62Ag2**
    are & have been used for soldering components onto a printed circuit board (PCB)
  - Leadfree alternative solders known & implemented
    - E.g. SnAg3.8Cu0.7 (SAC)

- Use of high Lead containing Solders as chipsolders in packages
  - **PbSn5 or PbSn2Ag2.5**
    are used for die attach applications
    - No re-melting during PCB reflow process
    - Excellent wettability
    - Reliable due to ductility
  - Commercially competitive

- Today no alternative drop-in solution available
### Materials for Die Attach: Solder Alloys

#### Melting temperature of solder alloys

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<th>Tmelt/°C</th>
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<td>Pb1Sn1.5Ag</td>
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**Temperature load**

(during subsequent assembly processes & pcb-soldering)
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Temperature load (during subsequent assembly processes & PCB-soldering)
Brittleness of remaining alloys limits reliability to only smallest die sizes with severe constraints on chip thickness, package geometry and surface materials.
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- Annex II (2010/115/EU, exemptions 8(e-j) ELV 9th revision

- In the last review of this exemption in 2018/19 under the ELV Directive in 2019 the consultants concluded that the use of lead in high melting temperature type solders (LHMTS) in Exemption 8(e) is still unavoidable in devices in the scope of the ELV Directive. The continuation of the exemption was therefore granted in line with the requirements of ELV Art. 4(2)(b)(ii). It was no expiration date for the exemption defined.

- EU COMM decided to extend exemption 8 (e) until 2024. Automotive Industry Associations and DA5 supported the successful review process. Next ELV review is planned in 2023.

- The entry in the Official Journal was done in spring 2020.

- **Exemption may be cancelled if an alternative is available and proven.**
European RoHS Directive (2011/65/EU) restricts the use of certain hazardous substances in electrical and electronic equipment.

- RoHS exemptions allow temporary use of restricted substances. See Annex III in 2011/65/EU (RoHS-2) for exemptions.
- RoHS II Directive entered into force 21\textsuperscript{st} of July 2011.
- Industry associations consortium (34 associations involved) sent an extension dossier regarding exemption 7a to the EU COMM on 16\textsuperscript{th} of January ’15.
- The revision process was finished; regarding 7a the EU COMM and the EU Parliament decided to extend the exemption 7a to July 2021 using the same wording.
- Exemption 7a (lead in high temperature melting solders) valid until mid 2021 will automatically extend until EU COMM decides on running exemption extension process starting Jan. 2020 latest.
- The RoHS Umbrella Industry Project, more than 67 Industry Associations worldwide are involved, sent an extension dossier to the EU COMM in time, January 2020.
- The EU COMM informed that the consultants will not start their assessment before end December 2020.
- Stakeholder consultation on Pack 22 (which includes e.g. the exemption 7(a)) went from 23\textsuperscript{rd} of December 2020 to 03\textsuperscript{rd} of March 2021.
- Details can be found: https://ec.europa.eu/environment/topics/waste-and-recycling/rohs-directive/implementation-rohs-directive_en
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DA5 Project at a Glance


- DA5 = Die-Attach 5

- ELV Annex2, exemption 8e and RoHS 7a cover the use of lead in high melting temperatures type solders in various applications.

- DA5 focus on the use of high melting solder in semiconductor applications, especially for die attach in power packages.

- 12/2015: NXP and Freescale merge into NXP

- 07/2017: nexperia joined the DA5 consortium

- 07/2017: Members of DA5 consortium
DA5 Approach

Press Release (Q2/2010)

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

Implementation and availability
For environmental reasons, the semiconductor industry is making every effort to eliminate high-lead solder, where feasible. However, there is no single identified lead-free solution for all applications and there is no expectation of a substitute for a high-lead solder die attach before 2014. Any solution will require substitute material development and evaluation, internal semiconductor process and product qualification, and semiconductor production conversion to guarantee product reliability.

By jointly developing and qualifying an alternative, the DA5 consortium aims to reduce the qualification time needed by its customers and provide lead-free and environmentally friendly solutions as quickly as possible.

The consortium approach
A previous joint effort known as the E4 (IFX, STM, NXP, Freescale) successfully implemented more environmentally friendly materials for semiconductor packages. Lead-free high melting temperature die attach was not in the scope of the E4 effort since this solder material was exempted from the 2006 EU RoHS Directive.

The announced DA5 consortium aims to reinitiate the earlier E4 cooperation and use the proven formula for success 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.

Lead in semiconductor products
Semiconductor products use high-lead containing solder for a die attach material in power devices, in diodes and transistors, for clip bonding of discrete devices and for surface mount and insertion components. Many of these devices have an essential safety purpose in automotive applications. The unique properties, such as the high melting point and thermal conductivity of these high-lead alloys, are necessary for the level of reliability required for these products.

Currently, there is no proven alternative for these high-lead die attach solders. Therefore, the DA5 consortium companies are soliciting input from die attach material suppliers to jointly evaluate and develop possible alternatives. This approach is expected to speed up implementation and customer acceptance of the environmentally friendly materials.
Joint development by semiconductor suppliers to address and **mutually define** the direction of Pb-free solder d/a-technology

DA5 is working together with suppliers to find feasible alternative solutions for lead-free die-attach

- Evaluate available and potential alternatives
- Prioritize drop-in solutions

General requirements to Die Attach materials are collected in the “**DA5 Die-Attach Material Requirements**” document which is available upon request at DA5.

Lead-free solutions have to fulfill those in the same way as leaded solutions do already

**Target:**
Identification of **sustainable, enduring, standardized, reliable and dependable solutions for our customers**
Major material suppliers from Europe, US and Asia were assessed
17 major material suppliers have been identified
- Continuous contact is established. (some stopped to offer relevant materials)
- DA5 is continuously looking for further suppliers offering suitable materials
6 material suppliers are working with DA5
- To develop specific solutions within the DA5 project workpackages
Targeted Applications

- Power Modules
- Smart Power ASICs
- Power MOS-FETs & IGBTs in SMD packages
- Power MOS-FETs & IGBTs in Through-Hole packages (THT)

Different applications have different specifications and may require different lead-free solutions.
Examples of reliability requirements *

- AEC-Q100/-Q101 Grade 0

- Typical $T_{\text{junction}}$ 175°C; max. up to 200°C

- Thermal/electrical properties
  - Same or better than existing solutions with lead solder

- Reflow 260°C (SMD)
  - Moisture sensitivity level MSL3 or better (SMD)

- Wire bonding temp. up to 260°C

- Physics of failure understood

- The full specification document “DA5 Die-Attach Material Requirement Specification” is available upon request at DA5 (contact last page).

*= Requirements may be slightly different for different applications
4 different material “classes” are in discussion.

* Transient Liquid Phase Sintering
Conductive Adhesives I

**Principle**

- High electrical and thermal conductivity of adhesives is achieved by an increased silver filler content with very dense packing of filler particles. Reduction of particle size to micro and nano scale stimulates a sintering of the silver particles during the resin cure process.
- The remaining resin content is a key factor determining the physical properties of the material. The transition from an adhesive with very low resin content to a pure Ag-sinter material is fluent.
- Hybrid adhesive/sinter materials combine the advantages of a silver filled adhesive (thermal-mechanical stability, low sensitivity to surfaces) with the high conductivity of a Ag-sintered material.

*Increasing sintering levels, conductivity, and elastic modulus*
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 2000 cycles TC -50°C / +150°C.
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.
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-O₂ 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 (O₂ or humidity penetration, un-sintered Ag particles in die-attach layer)
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
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/mm²) 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)
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 mm² 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 HTS
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 <120µm) usage to be proven.
Alternative Solders I

Properties to be considered

➤ Robust manufacturing process
  • Repeatable solder application
  • Stable wetting angle
  • Surface compatibility (chip backside, If finish)

➤ Reliability
  • Voiding / cracking / disruption after stress
  • Growth of brittle intermetallics at high temperature
  • Disruption during temperature cycling
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<10mm² in combination with a new experimental IIC 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 \(\rightarrow\) 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
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)
Comparison of competing Technologies

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Key Performance Indicators III

Comparison of competing Technologies

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Key Performance Indicators IV

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 ➔ Timeline and Conclusion
DA5 Timeline (Overview/Milestones) I

Technology review & Supplier feedback

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General project activities

- start of cooperation
- NDA signature
- Press release
- Project plan review
- Reports Dr. Deubzer
- Project plan review
- Report Dr. Deubzer
- FtF Munich Dr. Deubzer
- project plan review
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Technology review & Supplier feedback

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General project review activities

- project plan review
- project plan review
- Supplier meetings
- with potential material freeze
DA5 Timeline (Overview/Milestones) II

**Technology review & Supplier feedback**
- 29th F2F
- 30th F2F
- 31st F2F
- 32nd meeting
- 33rd meeting
- 34th meeting
- 35th meeting
- Reutlingen
- Munich
- Nijmegen
- MS Teams
- MS Teams
- MS Teams

**General project activities**
- Supplier meetings
- with potential material freeze
- 16.-18.03.21 last meeting
- 05.-08.07.21 next meeting

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DA5 - Automotive Release Process (ELV)

Technology chain

- DA Material Technology
  - Lead-free Die Attach Material
  - Lead-free Package Technology

Package

- Semiconductor Component
  - Lead-free Component

Electronic Control Unit

- Lead-free ECU

Vehicle

- Lead-free Vehicle

Supply chain

- Material Supplier
- Assembly
- Semiconductor Company
- Automotive Tier1
- Carmaker OEM

Prototype Supply

DA5 scope

Material freeze

DA Material Development

Package Development

Assessment
- Physics of failure
- Workability, Reliability, Manufacturability

iterative process

typ. 2 years

additional time required until product is commercially available

30 March, 2021
DA5 - Industrial Release Process (RoHS)

Technology chain:
- DA Material Technology
  - Lead-free Die Attach Material
  - Lead-free Package Technology
- Package
- Semiconductor Component
  - Lead-free Component
- Customer Application
  - Lead-free Product

Supply chain:
- Material Supplier
  - Prototype Supply
  - Material freeze
- Assembly
  - DA Material Development
  - Package Development
  - Assessment
    - Physics of failure
    - Workability, Reliability Manufacturability
  - DA5 scope
- Semiconductor Company
  - Material freeze
- System Supplier

Iterative process:
- typ. 1 ½ years
- additional time required until product is commercially available
- type release
Conclusion I

- Today’s lead-free material technologies for semiconductor applications (die attach) are not ready to substitute Leaded High Melting Temperature Solders as drop-in solution.

- Substantial development efforts have been running for more than 11 years. 145 materials from more than 13 suppliers were evaluated. Close to 50 of those materials were selected for extensive testing by DA5 member companies. Although some promising results were seen in specific applications, none of the materials proved valuable as a general Pb-replacement solution. While the DA5 consortium has not yet found a reliable lead-free package technology for power semiconductor components, the research is promising for long-term solutions.

- Material evaluations continue in close cooperation with material suppliers, but semiconductor component qualifications, material supplier conversions and equipment conversions can only begin after a reliable lead-free package technology for replacement is available.
Customer qualifications (TIER1 and OEM) and supply chain conversion/ramp can only begin after package technology and semiconductor component qualification.

No single drop-in lead-free solution is in sight! Different applications will need different solutions. It’s likely that some application fields will not be covered by lead-free solutions and therefore need continued exemption.

Based on current status, DA5 cannot predict a date for customer sampling. As shown in the previous two slides, the release process will take a substantial amount of time.
Contact Information

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DA5 customer presentation:
http://www.infineon.com/da5customerpresentation

The full specification document “DA5 Die-Attach Material Requirement Specification” is available upon request at DA5, see contact above.