Die Attach 5 Project
Updates to last version from 24.07.2019

Following slides were updated:

slide 4, 15, 16, 25, 35, 41, 44
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
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, cleaner, and more economical, and to develop eco-friendly products in general. Ecology is thus a driver of innovation: in 2018, more than half of research and development expenditure at Bosch went into products that help improve energy efficiency, environmental protection, and resource conservation.

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 CO₂ emission savings amounting to approximately 56 million tons of CO₂ equivalents during their use-phase. For the tenth time in a row, Infineon has been listed in the “Dow Jones Sustainability™ Index”.
**NXP:**
At NXP we make every effort to ensure that our products and working practices are responsible and sustainable. Our ambition is to go beyond compliance and to establish a global benchmark for sustainability in our industry. We foster ethical principles and respect for the environment, people, and in the communities in which we work. Sustainability is a part of the way we conduct our business, the way we manage our company, and the way we interact with society at large.

**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.

**STM:**
As part of ST Sustainable Technology Program, embedded in its 5th EHS Decalogue 2014-2020, ST is committed to design products continuously decreasing energy consumption and enabling more energy efficient applications that create value for all stakeholders, with a focus on healthcare, safety/security, society and environment, strive towards a «product greening strategy» through Ecopack® program deployment and 100% recyclable packing materials free of hazardous substances, as well as continuously applying the eco-design process for new products.
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>
<thead>
<tr>
<th>Exemption</th>
<th>Expiry / Review Date</th>
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<tbody>
<tr>
<td>Lead in soldering on PCB, the components and their finishes</td>
<td>E/2015</td>
</tr>
<tr>
<td>Lead in solder for other application, not on PCB or glass</td>
<td>E2010</td>
</tr>
<tr>
<td>Lead in finishes of Al-Capacitors</td>
<td>E/2012</td>
</tr>
<tr>
<td>Lead in soldering on glass for mass-flow sensors</td>
<td>E/2014</td>
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<tr>
<td>Lead in high temperature melting solders</td>
<td>Review 2019</td>
</tr>
<tr>
<td>Lead in compliant pin connector systems</td>
<td>Review 2019</td>
</tr>
<tr>
<td>Lead in solder between die and carrier in flip chip packages</td>
<td>Review 2019</td>
</tr>
<tr>
<td>Lead in solder of IC assemblies with &gt;1cm² die and &gt;1A/mm²</td>
<td>Review 2014</td>
</tr>
<tr>
<td>Carry over parts without expiry date</td>
<td>not recommended.</td>
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</tbody>
</table>

Expiry Dates referring to vehicle type approval
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**
Melting temperature of solder alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Temperature in °C</th>
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<tbody>
<tr>
<td>In48Sn</td>
<td>100</td>
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<tr>
<td>Bi42Sn</td>
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</tr>
<tr>
<td>In3Ag</td>
<td>200</td>
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<td>Sn36Pb2Ag</td>
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<td>Pb5Sn2.5Ag</td>
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<td>Pb5Sn</td>
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<tr>
<td>Pb1Sn1.5Ag</td>
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</tbody>
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Temperature load (during subsequent assembly processes & pcb-soldering)
Melting temperature of solder alloys

Temperature load (during subsequent assembly processes & pcb-soldering)

Alloy

- Sn25Ag10Sb
- Pb19In
- Au20Sn
- Pb5Sn2.5Ag
- Pb2Sn2.5Ag
- Pb5Sn
- Pb1Sn1.5Ag

Temperature in °C

- Tmelt/°C
- Tmin/°C
- Tmax/°C
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 Adaptation

- 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.

- **Exemption may be cancelled if an alternative is available and proven.**

- The exemption 8(e) is due for review in 2024 in order to adapt it to the state of scientific and technological development.

- The entry in the Official Journal is expected in spring 2020

- RoHS exemptions allow temporary use of restricted substances. See Annex III in 2011/65/EU (RoHS-2) for exemptions.

- RoHS II recast went into force 1st of July 2011.

- Industry associations consortium (34 associations involved) sent an extension dossier regarding exemption 7a to the EU COMM on 16th of January ’15.

- The revision process was finished; regarding 7a the EU COMM and the EU Parliament decided to extend the exemption 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 Umbrella Industry Project, more than 60 Industry Associations worldwide are involved, will send an extension dossier to the EU COMM in time.
Agenda

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➤ Status on legislation

➤ DA5 Structure and Project:
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  • Results

➤ Timeline and Conclusion
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.
DA5 Project Objectives

- 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**
DA5 Setup for Pb-free Power Die Attach

- Major material suppliers from Europe, US and Asia were assessed
- 16 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
Materials

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.

Dispense Patterns

Visible solvent bleed out

No solvent bleed out

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

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

detected
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)
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
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)
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
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.
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 If 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
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)
Key Performance Indicators II

Comparison of competing Technologies

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TLPS materials vs. Pb-solder

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### DA5 Timeline (Overview/Milestones) I

#### Technology review & Supplier feedback

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<tr>
<th>Event</th>
<th>Date</th>
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<tbody>
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<td>1st F2F Sibiu</td>
<td>Q1 2009</td>
</tr>
<tr>
<td>2nd F2F Reutlingen</td>
<td>Q2 2009</td>
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<td>3rd F2F Agrate</td>
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#### General project activities

- **Start of cooperation**
- **NDA signature**
- **Press release**
- **Report Dr. Deubzer**
- **Project plan review**
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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 F2F
- Reutlingen  Munich  Nijmegen  Hamburg

**General project activities**
- 11.-14.11.19
- last meeting
- 09.-12.03.20
- next meeting
- Supplier meeting  with potential material freeze

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1 December, 2019
Substitute Material(s) for High-Lead Solders

DA5 - Automotive Release Process (ELV)

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

Package
- Lead-free Component
- Lead-free ECU
- Lead-free Vehicle

Technology chain

Semiconductor Component

Electronic Control Unit

Vehicle

Assembly
- Semiconductor Company

Automotive Tier1

Carmaker OEM

Supply chain

Prototype Supply

DA5 scope
- Material freeze
- Package Development

DA Material Development

Assessment
- Physics of failure
- Workability, Reliability, Manufacturability

Manufacturing

Prototype development

Typ. 2 years

Typ. 2 years

Typ. 2 years

Additional time required until product is commercially available
DDA5 - Industrial Release Process (RoHS)

Supply chain:
- Material Supplier
- Assembly
- Semiconductor Company
- System Supplier

Technology chain:
- DA Material Technology
- Package Technology
- Semiconductor Component Technology
- Customer Application

Prototype Supply

Material freeze

DA5 scope

DA Material Development
- Assessment: Physics of failure
- Workability, Reliability, Manufacturability

Package Development

Typically 1½ years

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

Lead-free Product

Typically 1½ years

Iterative process

Additional time required until product is commercially available

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

Substantial development efforts have been running for more than 10 years. Over 100 materials 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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Email: bodo.eilken@infineon.com

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.