DA5 Consortium
Customer presentation

Updates to last version from 25.08.2025

- Slides number 2, 6-7, 9, 12-14, 17, 19-23, 26-32 updated
- For all slides the design of the DA5 Customer Presentation was changed

Agenda

- **Motivation: Environmental and health endangerment by lead**
- Status on legislation
- Situation: Lead & the use in Electronics
- DA5 Structure and Project:
  - Cooperations and partners
  - Sustainability Efforts
  - Requirements, Applications and Approaches for possible solutions
  - Results
- Timeline and Conclusion

Lead: Environmental and Health Endangerment

- Environmental dangers:
  - Poisoning of water, air and soil
- Health dangers:
  - Neurotoxin
    - Accumulates in soft tissues & bones
  - Damage to nervous system
  - Causes brain disorder
  - Causes blood disorder in mammals
  - Further information can be found at:
  - https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health

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Lead (Pb) CAS 7439-92-0 in Europe

- REACH – Reg 1907/2006
  - Included in SVHC Candidate List
    - Need to be declared in case content is > 0.1 % w/w
  - Included REACH, Annex XVII (Restriction List)
    - Restriction not applicable to semiconductor/electronic sector
- RoHS – Dir 2011/65/EU
  - Restricted to use to 0.1 % w/w in homogenous material
    - Unless use is covered by Exemptions reported in Annex III
    - Exemptions renewed as per Delegated Directive published in official journal, 21st of November 2025
- ELV – Dir 2000/53/EC
  - Restricted to use to 0.1 % w/w in homogenous material
    - Unless use is covered by Exemptions reported in Annex III
    - Exemptions are valid and regularly reviewed, despite expire dates passed – Decision on last review: Expected in 2025

Lead Can Be Used

	RoHS – Restriction of Hazardous Substances Directive	ELV – End of Life of Vehicle Directive	REACH – Regulation on Registration Evaluation and Authorization of Chemical
Reference	2011/65/EU	2000/53/EC	1907/2006/EC
Status	Restricted Substance In Annex II	Restricted Substance In Annex I	Included in SVHC
Concentration	1000 ppm in homogenous materials		0.1 % w/w in article
	Threshold limit for content		Threshold limit for reporting
Use possible	Under Annex III/IV Exemptions	Under Annex II Exemptions	Compliant with Annex XVII
Use in soft solder	Exemption 7(a)-I As per Directive 2025/182/EU	Exemption 8(e)	Allowed – must be declared in products as per concentration threshold
	Expiration date 31.12.2027	Possible Review Expected in 2027	Possible to move to Annex XIV – no more use in Europe unless authorized
	Renewal dossier to be presented by 30.06.2026		
	In case not renewed no more use starting (from worse case) from 30.06.2029		

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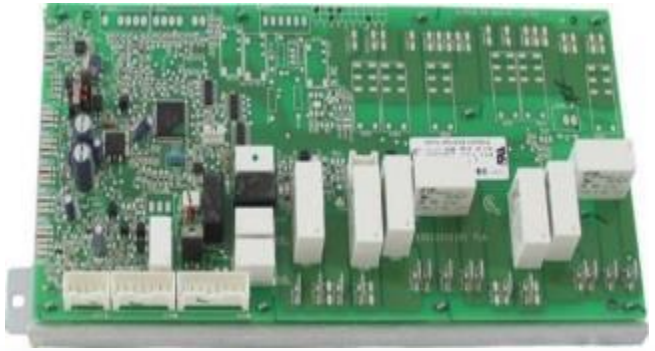
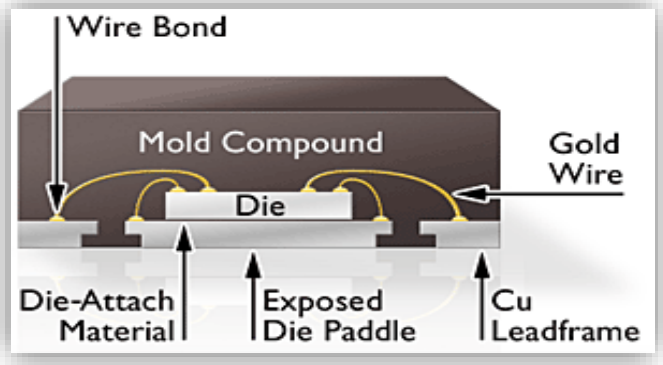
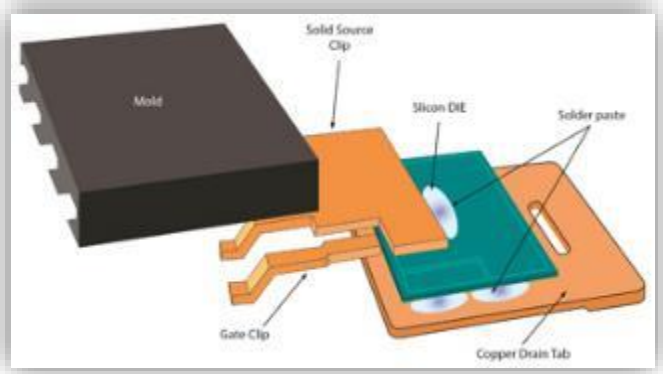
Use of Lead in Electronics



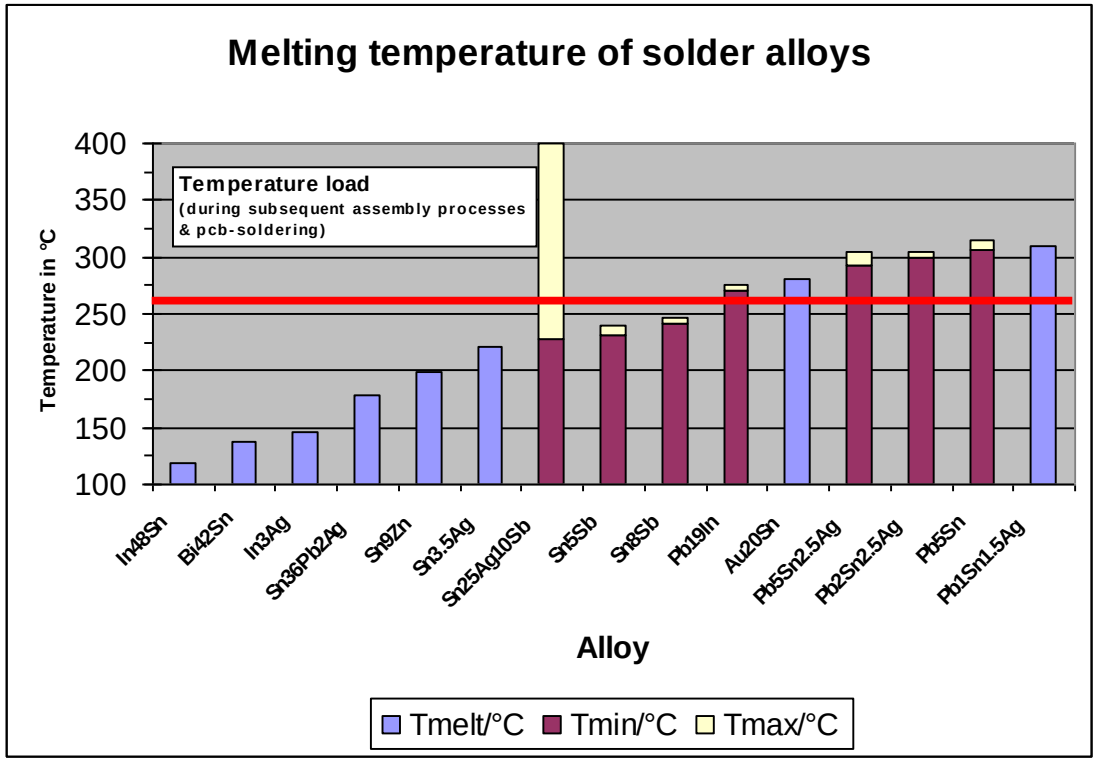
- Use of Lead containing Solders on PCB-level
  - PbSn63 or PbSn62Ag2
    are & have been used for soldering components onto a printed circuit board (PCB)
  - Lead-free alternative solders known & implemented
    - E.g. SnAg3.8Cu0.7 (SAC)

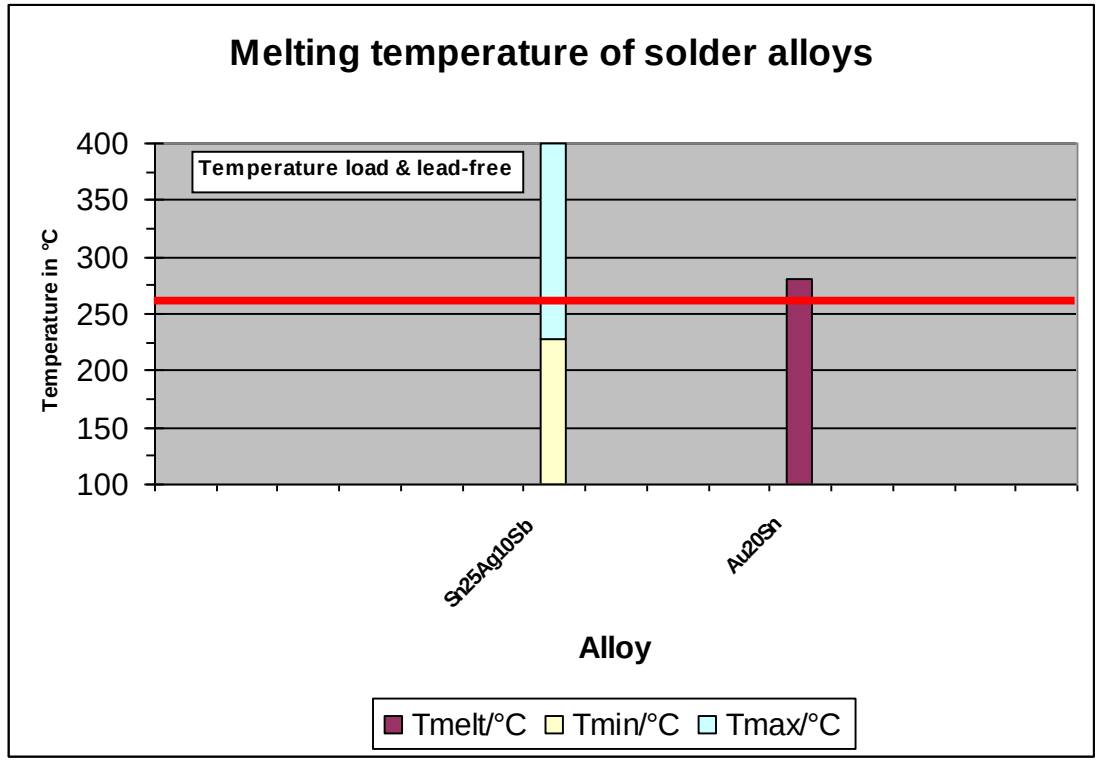
- Use of high Lead containing Solders on package-level
  - PbSn5 and PbSn2Ag2.5 are used for both die and clip attach inside components
  - As of November 2025, there is no capable replacement for lead-solder available that fulfills the requirements
    - No re-melting during PCB reflow process (260°C)
    - Excellent wettability
    - Reliable due to ductility
    - Commercially competitive





Materials for Die Attach: Solder Alloys





- 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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DA5 Project at a Glance

- 04/2009: Decision to form DA5 consortium: STMicroelectronics, NXP Semiconductors, Infineon Technologies, Robert Bosch, and Freescale Semiconductors
- DA5 = Die-Attach 5
- ELV Annex2, exemption 8(e) and RoHS 7(a) 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:

Sustainability Efforts I

Infineon:

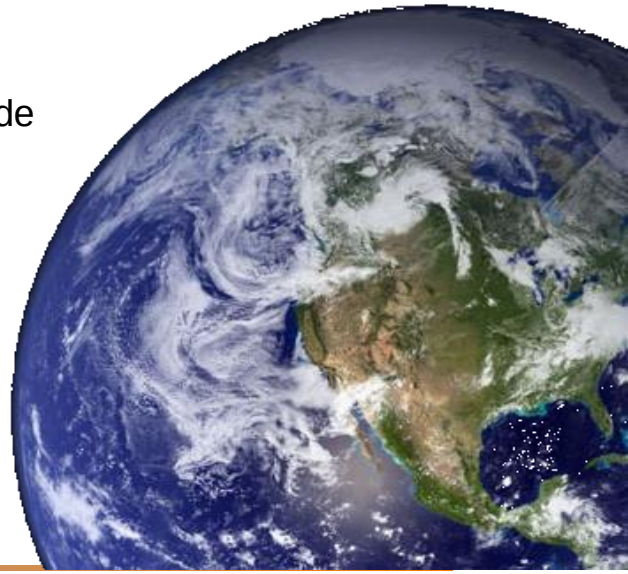
We understand sustainability as the symbiosis between economy, ecology and social engagement. At Infineon, we responsibly manage the handling of hazardous materials to safeguard human health and environmental protection. As part of Infineon Group Policy for Environmental Protection, Energy Management, 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, photovoltaics, wind energy enable CO2 emission savings amounting to approximately 130 million tons of CO2 equivalents during their use-phase. For the fourteenth time in a row, Infineon has been listed in the “Dow Jones Sustainability™ Index”.

Bosch:

We firmly believe that our operations must be ecological, economical, and socially sustainable. This attitude shapes the entire Bosch Group and is reflected in our actions.

ST:

In ST, we create sustainable technology for a sustainable world, in a sustainable way. Sustainability has been embedded in our business model and culture for nearly three decades; and we aim to be carbon neutral each year from 2027, covering scope 1 and scope 2 emissions, plus product transportation, business travel, and employee commuting emissions from scope 3. We design and build products, solutions, and ecosystems that address our customers’ challenges and opportunities, and the need to support a more sustainable world. With our Sustainable Technology program, we take a holistic approach to make our operations and our products more sustainable through a comprehensive lifecycle approach.



Sustainability Efforts II

NXP:

Sustainability is deeply integrated into our long-term business strategy and is a core part of our operational culture.

We strive to innovate technologies that contribute to a better, safer, more secure and more sustainable world, while continuously improving how we use resources and manage our environmental impact. Our approach emphasizes ethical conduct, respect for human rights and the creation of a safe, inclusive, and collaborative workplace. We engage transparently with stakeholders, foster trust through responsible governance and proactively assess risks to build resilience. By aligning sustainability with innovation and leveraging the strength of our global team, we aim to drive meaningful progress across our value chain and contribute to global sustainability initiatives.

Nexperia:

We are committed to provide a safe working environment, promote good health, minimize the environmental impact of our activities, and protect the environment, including the prevention of pollution with our way of working and the products we develop.

We are on track to achieve carbon neutrality for our Scope 1 and 2 emissions by 2035, based on yearly reduction targets. We foster innovations and creative solutions that add value for our customers, communities, and our planet. We define Sustainability as part of our business strategy.

At Nexperia, we have a strong focus on sustainability and social responsibility issues which signify much more than just legal compliance with the relevant laws. Sustainability is part of everyday work of all employees worldwide, from the Executive Management Team to each single employee, from product development until disposal.

DA5 Approach
Press Release (Q2/2010) at start of DA5 project

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.

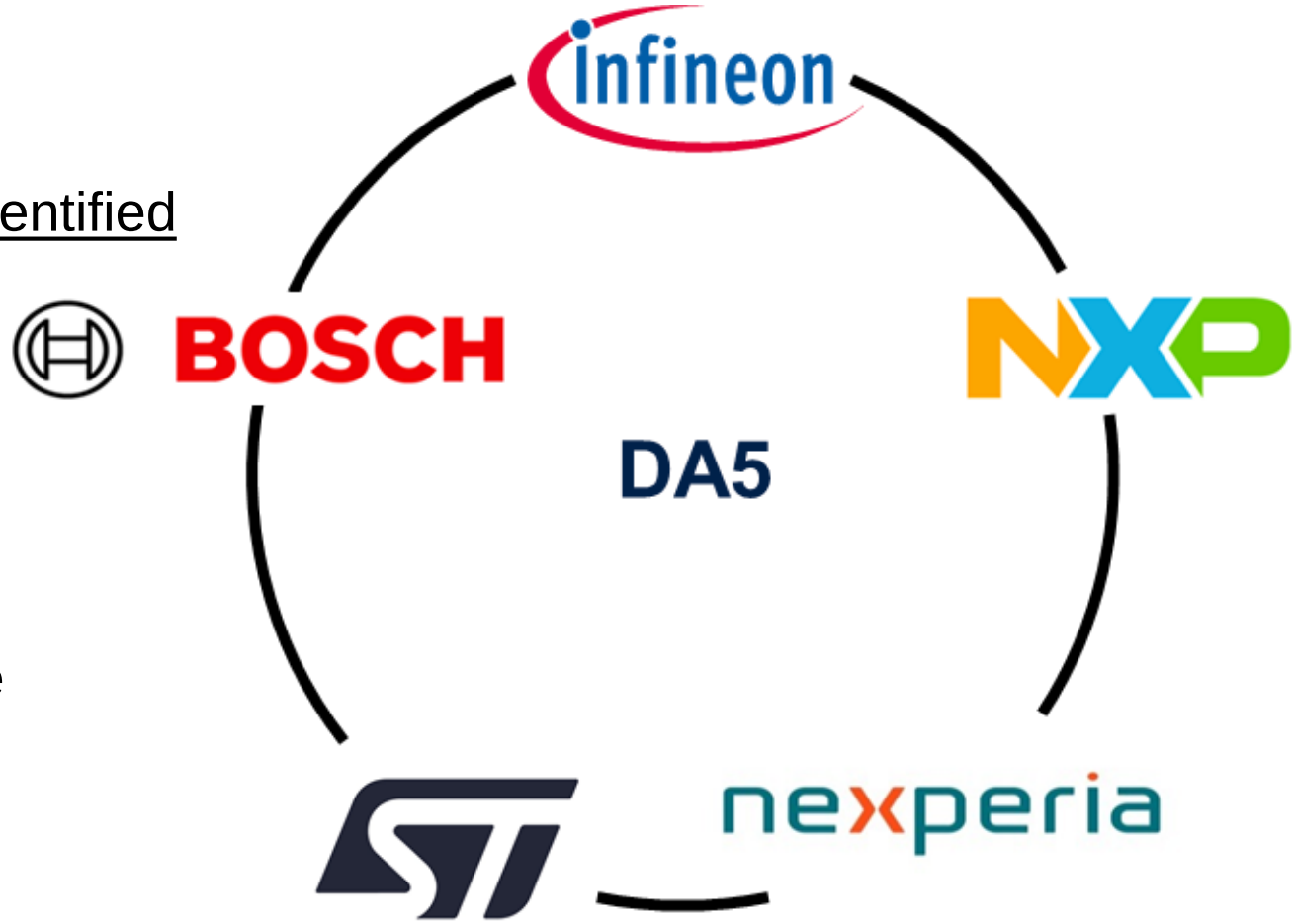
Currently, there is no proven alternative for these high-lead die attach solders. Therefore, the DA5 consortium companies are soliciting input from die attach material suppliers to jointly evaluate and develop possible alternatives. This approach is expected to speed up implementation and customer acceptance of the environmentally friendly materials.

DA5 Project Objectives

- Joint development by **semiconductor and material suppliers** to address and **mutually define** the direction of Pb-free solder die- and clip-attach technology
- DA5 is working with material suppliers to find feasible alternative solutions for lead-free die- and clip-attach
  - Evaluate available and potential alternatives
  - Prioritize the evaluation of potential material candidates
- DA5 supports suppliers in ensuring new materials development considering compliance with current regulation and anticipating regulation evolution
- DA5 developed a list of applicable regulations that is proposed to suppliers and requests regular updates at regulation changes
- General requirements like reliability and processing of die- and clip-attach materials are collected in the **“DA5 Die Clip Attach Material Requirement Specification”** document, 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, robust, standardized, reliable and dependable solutions for our customers**

DA5 Setup for Pb-free Die-Attach

- Major material suppliers from Europe, US and Asia were assessed
- 37 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
- 4 material suppliers are working continuously with DA5
  - To develop specific solutions within the DA5 project work packages



Challenges/ Requirements

- Potential die- and/ or clip-attach materials have to withstand the 260°C temperature during second level soldering on PCBs (no re-melting or delamination after 3 times reflow)
- Potential die- and/ or clip-attach materials have to support
  - Thin die usage (thickness < 120µm, fillet height control)
  - Large die usage (die size up to 70mm2, low void level)
  - Reliability requirements (e.g. AEC-Q-100/ AEC-Q-101)
  - Several lead frame/ chip backside metallization (e.g. Cu, Ag, Ni)
  - Comparable or better thermal and electrical conductivity as lead based solder
  - Stress buffer for CTE differences between die and lead frame
  - Usability for different clip-sizes with several metallizations
- Excellent workability characteristics (dispense and printing)
- Compatible with clip bonding
  - Top of die material coverage (manage source and gate size differences)
  - Prevent shorting of source and gate (no flow or bleed of material)
  - Withstand forces during processing, e.g. in molding and trim & form
- A detailed requirement list can be found in the document:

  “DA5 Die Clip Attach Material Requirement Specification”

Alternatives Evaluation

Adhesives

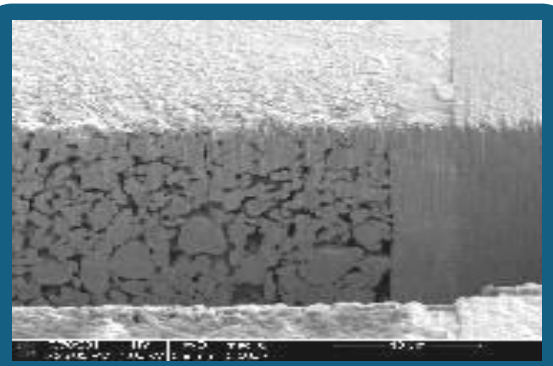
- Metal filler in organic resin **(Ag)**
- Volatile solvent
- Limitation
  - Die size/ die thickness
  - Electrical/ thermal conductivity
- Failure
  - Moisture sensitivity

TLPS (*) Materials

- High melting metal powders in organic flux (**Cu, Ag)**
- Limitation
  - Die thicknes
  - Stiffness and CTE (**)
- Failure
  - Cu oxidation
  - Strong brittle intermetallic growth

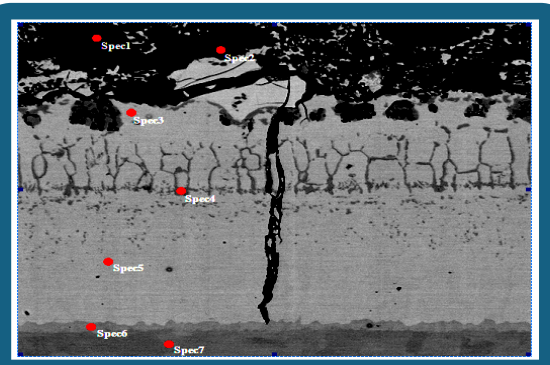
(*) Transient Liquid Phase Sintering

(**) Coefficient of Thermal Expansion



Metal Sintering

- Ag/ Cu µm- and/ or nm-scale particles
  - Organic coating
  - Sintering promoters
- Limitation
  - Die size/ thickness
  - Dispensability
  - Metallization
- Failure
  - Cu oxidation
  - Voids



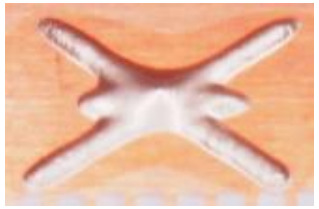
Solders

- Metal alloys
  - **Zn**
  - **Bi**
  - **SnSb**
  - **SAC SnSb**
- Failure
  - Voids
  - Brittle intermetallic growth

Conductive Adhesives

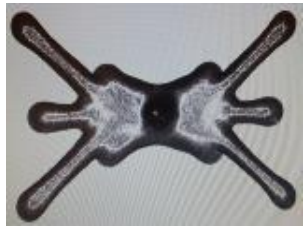
- **Principles**
  - Smaller particles (nano) -> higher sintering degree, which increases electrical/thermal conductivity
  - Organic resin reduces elastic modulus to absorb more mechanical stress -> less delamination
  - Bimodal distribution of Ag particles (nano and micro) reduces risk of metal fatigue / cracks.
  - Higher organic resin improves adhesion to bare Cu or to dies without back side metal.

Advantages	Limitations
• Compatible with Ag, Cu, Au PPF platings	• Epoxy bleed-out from components added for viscosity control
• Low elastic modulus, reduced delamination risk	• Risk of die top contamination (shortages) on thin dies (<120 um)
• Lower curing temperature, decreased mechanical stress	• Limited MSL1 reliability due to moisture absorption by resin
• Reduced risk of metal fatigue	• Lower adhesion strength to die and leadframe than for solders
• Can use existing die bond equipment (drop-in solution)	• Tailoring of process window needed for specific die size/ package

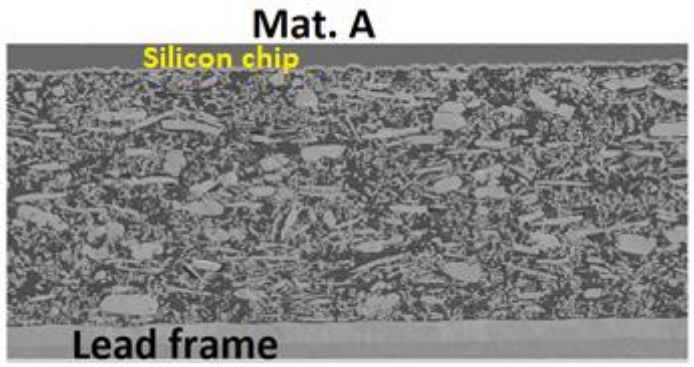


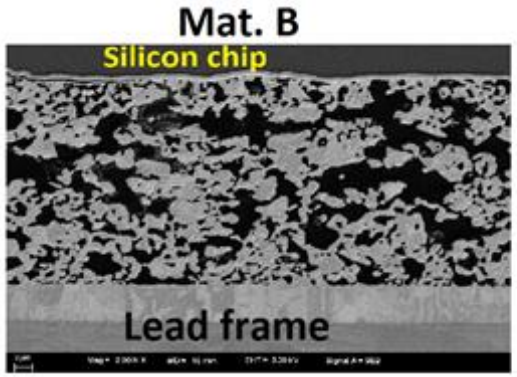
Dispense Patterns

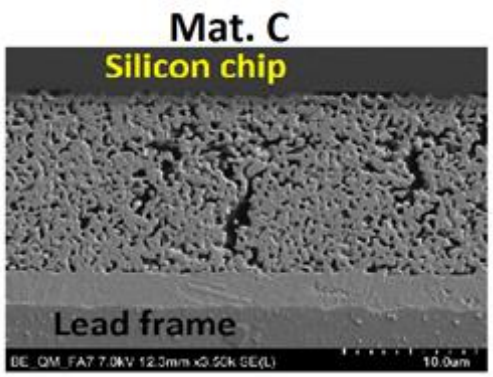
Visible solvent bleed out



No solvent bleed out

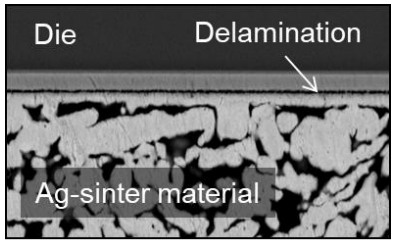


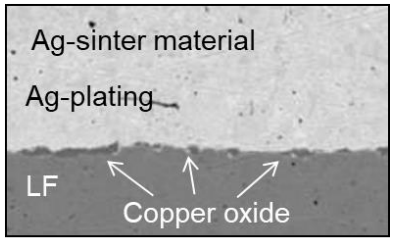




Increasing sintering levels, electrical + thermal conductivity, and elastic modulus

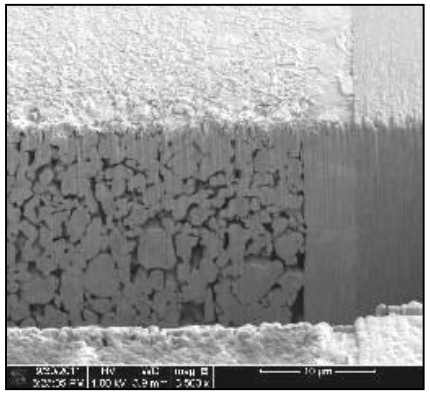
Metal Sintering





- **Principle**
  - Material: Ag- or Cu-sintering pastes: Ag or Cu particles (µm- and/or nm-scale) with organic coating, dispersants, and sintering promoters
  - Process: Dispense/ screen print → pick & place die → pressure-less/ -assisted sintering under N_2 or air
  - Resulting die-attach layer is a porous network of pure, sintered Ag or Cu

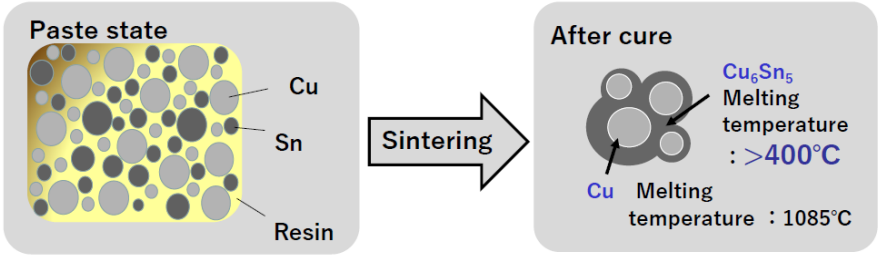
Advantage	Limitations	Main Risks
• Significantly better thermal & electrical performance compared to Pb-solder possible	• No self-alignment as with solder wetting	• Limitations found in die area/ thickness, lead frame & die finishes

	• nm-scale metal particles are at risk of being banned	• Potential reliability issues:
		  • Die crack, breaks inside bondline, delamination or die lift,
		  • Organic contamination,
		  • Continued sintering → thickness reduction
		  • Interface degradation or electromigration

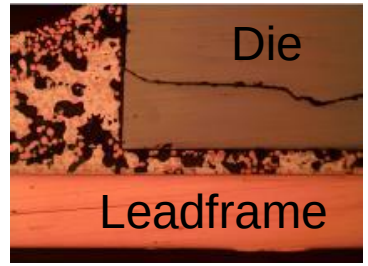
	• New concept in molded packaging - no prior knowledge of feasibility, reliability or physics of failure	
	• Potential production equipment changes (low-O2 ovens, sintering presses)	

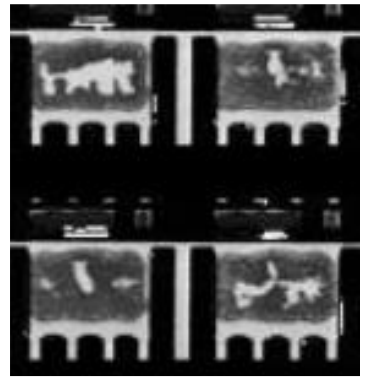
TLPS: Transient Liquid Phase Sintering

- **Principle**
  - TLPS Paste is in general a mixture of a high melting metal powder (e. g. Cu or Ag) and a Pb-free solder powder (e. g. Sn based) in an organic flux
  - After curing a matrix of e.g. pure Cu, CuSn alloy (melting temp. > 400°C) and resin is formed



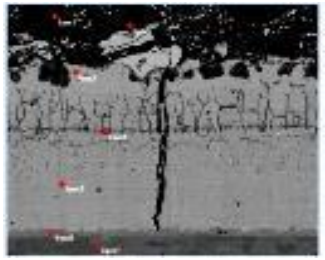
Advantages	Limitations	Main Risks
• Compatible with existing assembly methods like dispensing and printing	• Relatively new concept in molded packaging; incompatible with thin die	• Risk of shorts between gate and source caused by overflow and bridging
• Better cost position compared to (hybrid) Ag sintering solutions	• Limited knowledge of feasibility or reliability (CTE induced stress)	• High risk of Cu oxidation during sintering under nitrogen atmosphere containing over 300ppm of oxygen
• Sintering is possible in a reflow oven or batch oven	• Thermal, electrical performance similar to Pb solder, differences between various versions	• Reliability risk: die crack due to high modulus, CTE, potential Kirkendall voids; TLPS material not reliable at current stage – some suppliers stopped their development



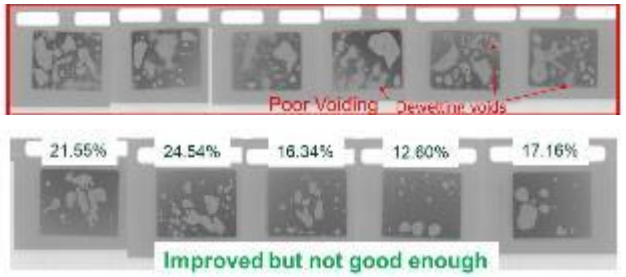


Alternative Solders

- **Principle**
  - Alternative solders (Zn-, Bi-, SnSb-based, SAC-SnSb alloys) form intermetallic phases during reflow, creating a metallurgical bond between die backside metallization and leadframe.
  - These alloys rely on solid-state diffusion and phase transformation at elevated temperatures to achieve mechanical integrity.
  - Intermetallic layers (e.g., SnSb IMCs or Zn-rich phases) provide high melting points and thermal stability, enabling operation beyond standard SAC limits.
  - Controlled alloy composition ensures wetting and adhesion while minimizing excessive brittle IMC growth



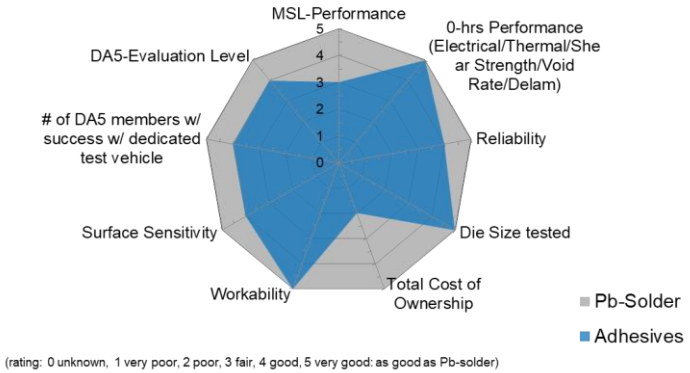
Brittle Zn intermetallics



Advantages	Limitations	Main Risks
• Good thermal conductivity and electrical performance for power devices	• Narrow process window: precise temperature control to avoid incomplete bonding, excessive IMC formation	• Die cracking due to high stiffness and thermal mismatch during cool-down
• Better cost position versus Au-based or sintered Ag solutions	• Compatibility issues with certain die metallizations and leadframe finishes	• Formation of brittle intermetallic phases, reducing mechanical robustness
		• Thermal/ electrical fails due to voiding
		• Long-term aging effects due to IMC growth

Key Performance Indicators

Adhesives vs. Pb-solder

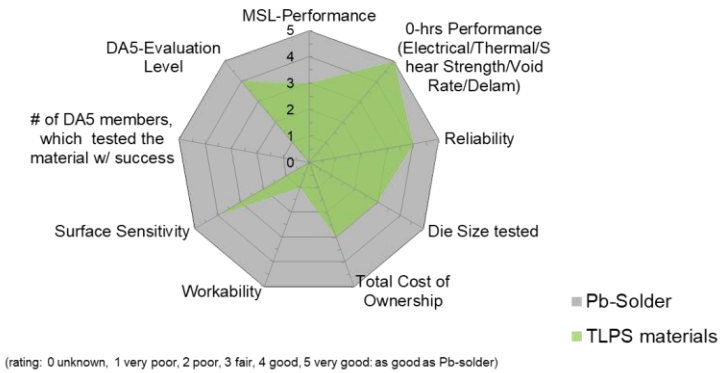


(rating: 0 unknown, 1 very poor, 2 poor, 3 fair, 4 good, 5 very good: as good as Pb-solder)

- Comparison of competing Technologies

- 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 the best material tested in its class
- DA5 assessment only valid for die thickness > 120µm
- DA5 assessment only valid for die-attach, not for clip-attach (not rated till now)

TLPS materials vs. Pb-solder



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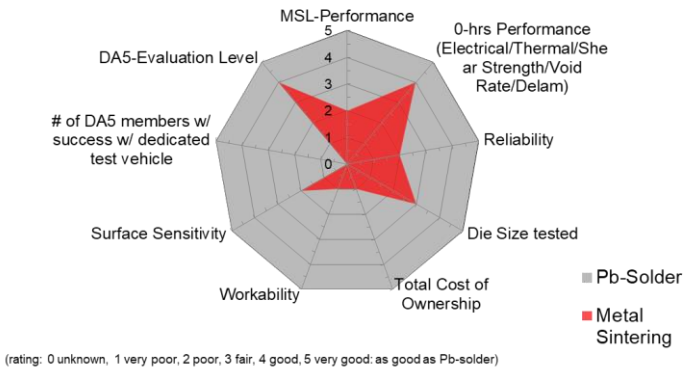
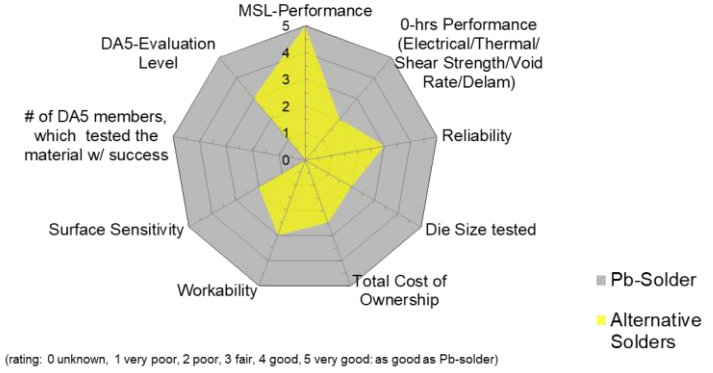
Metal Sintering vs. Pb-solder



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

Alternative Solders vs. Pb-solder



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

Agenda

- Motivation: Environmental and health endangerment by lead
- Status on legislation
- Situation: Lead & the use in Electronics
- DA5 Structure and Project:
  - Cooperations and partners
  - Sustainability Efforts
  - Requirements, Applications and Approaches for possible solutions
  - Results
- **Timeline and Conclusion**

Timeline

- DA5 meets the selected material suppliers three times a year for a common update of the latest material evaluation results
- In between alignment meetings between the material supplier and the DA5 work package leader (one DA5 company per selected material supplier) take place
- Last DA5-supplier workshop took place as face-to-face meeting in November 2025
- Next DA5-supplier workshop planned in March 2026

Summary DA5-supplier workshop July 2025

- Several suppliers presented their latest activities on Pb replacement for die attach materials
  - The results have been discussed thoroughly during the meeting
  - DA5 provided detailed feedback related to the presented materials
- DA5 companies presented their evaluation results and discussed with the involved material supplier
- Further new updates of the already introduced materials were presented
- DA5 internal discussion about how to improve the support for the material supplier continued

Boundary Conditions

Package Type / Geometry
- Die size & thickness
- Clip and/or wire bond package

Physical Properties
- El./th. conductivity, yield strength, ...

Processability
- Voids, porosity, fillet, tilt, UPH, clip attach...

Voltage*/ Current*
- Blocking voltage beyond 10V
- Transient/impulse current ≥ 0.1A

Chemical Interactions
- Ionic content
- Legal restrictions, e.g. ELV & RoHS

Metallizations Die/Clip/LF
- Cu, Ni, Ag, Pd/Au, Ni/Au, Ni/Ag, µPPF, PPF, Ni/NiNiP

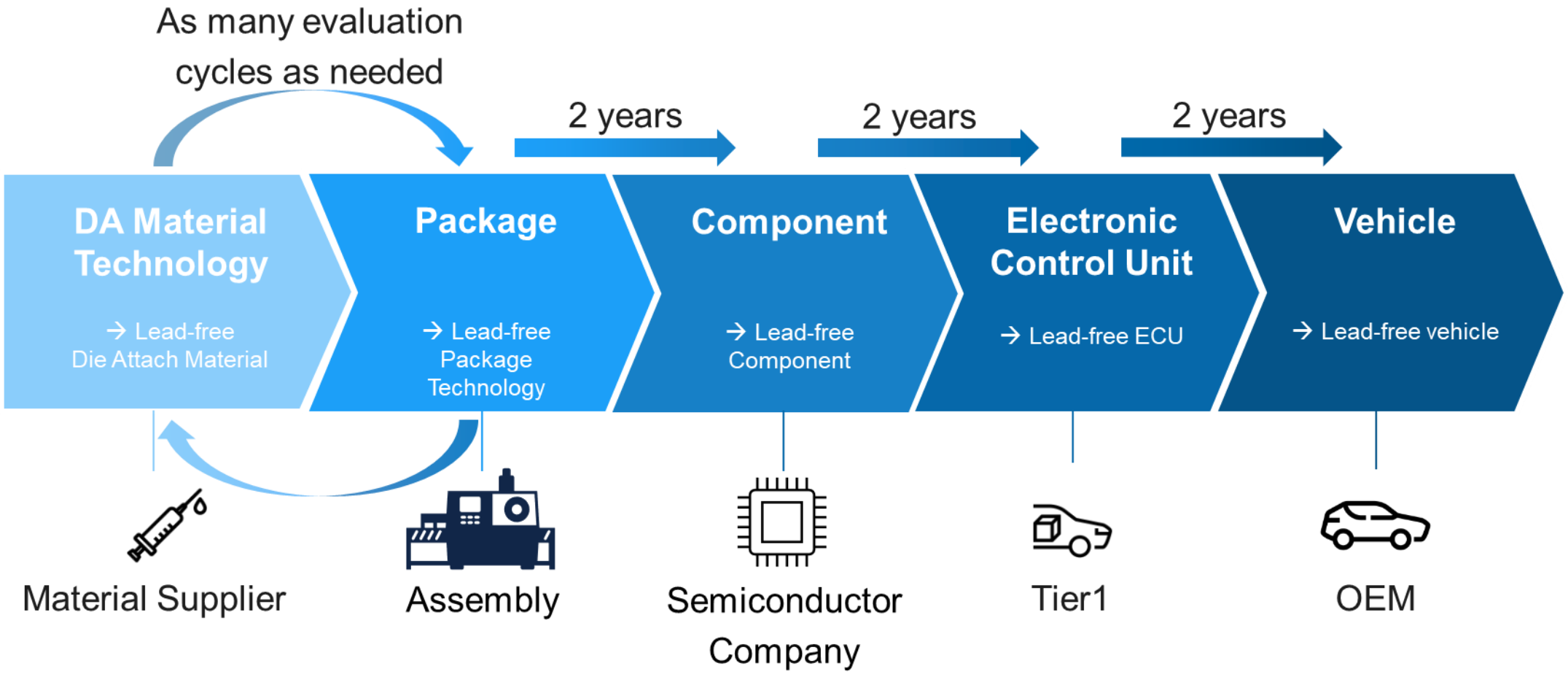
Reliability/MSL
- MSL 3 to 1
- HTS, TC, TCT, THB,...

Blind spots
- Unforeseen

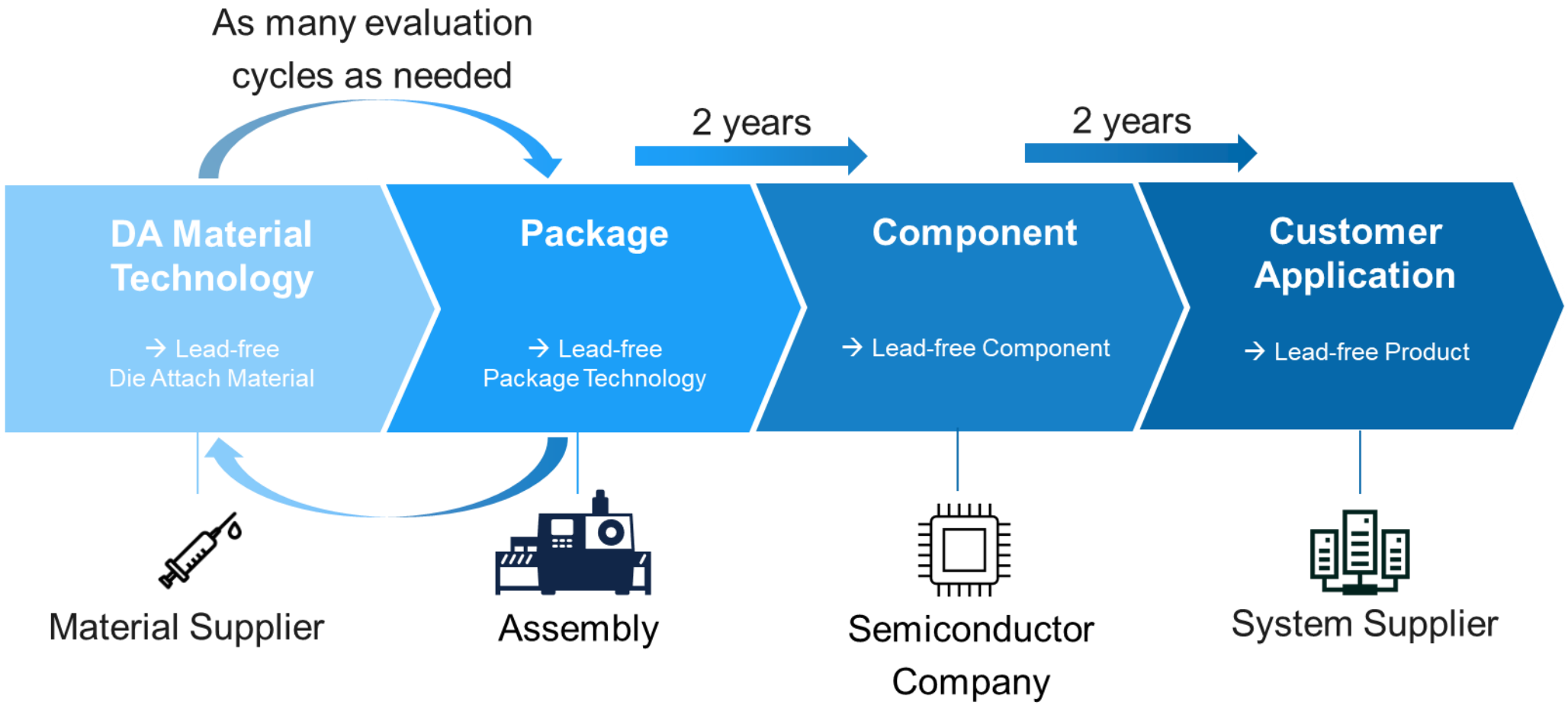
Full set of requirements can be provided upon request.

** According to latest proposed changes in regulatory requirements*

DA5 - Automotive Release Process (ELV)



DA5 - Industrial Release Process (RoHS)



Conclusion I

- Today's lead-free material technologies for semiconductor applications (die attach, clip attach) are not ready to substitute **L**eaded **H**igh **M**elting **T**emperature **S**olders
- **Substantial development efforts have been running since more than 15 years. More than 210 materials from more than 18 suppliers were evaluated. More than 50 of those materials were selected for extensive testing by DA5 member companies. Although some promising results were identified in specific applications, none of the materials proved suitable 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

Conclusion II

- **Customer qualifications (TIER1 and OEM) and supply chain conversion/ ramp up can only begin after package technology and semiconductor component qualification**
- No fit for all lead-free solution is in sight! Different applications will need different solutions
- The DA5 consortium expects that in the next decade more and more devices using newly available lead-free materials will enter the market for limited applications
- Moreover, availability of lead-free materials for the entire semiconductor components portfolio cannot be anticipated
- Based on current status, DA5 supports the continuation of the lead exemptions under RoHS and ELV EU Directives (and equivalent WW legislations)
- **Once a solution is identified and the material frozen, per slides 29/ 30, lead free materials widespread deployment on generic application will be possible**

List of Abbreviations

Ag	Silver	DSS	Die Shear Strength	MSL	Moisture Sensitivity Level	RoHS	Restriction of Hazardous Substances
Au	Gold	ELV	End-of-Life Vehicle	N_2	Nitrogen	Sb	Antimony
Bi	Bismuth	EU	European Union	Ni	Nickel	Sn	Tin
C-SAM	Scanning Acoustic Microscopy	EU COMM	European Union Commission	O_2	Oxygen	TC	Thermal Cycles
CO_2	Carbon Dioxide	HTS	High Temperature Storage	OEM	Original Equipment Manufacturer	TLPS	Transient Liquid Phase Sintering
CTE	Coefficient of Thermal Expansion	IMC	Intermetallic Compound	Pb	Lead	Zn	Zinc
Cu	Copper	In	Indium	PCB	Printed Circuit Board		
DA5	Die-Attach 5	LHMTS	lead in high melting temperature type solders	ppm	parts per million		

Contact Information

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DA5 customer presentation:

http://www.infineon.com/da5customerpresentation

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