







DA5 Consortium
Customer presentation



Updates to last version from 16.04.2026

- Updated content was retained for slides 2, 6-7, 9, 13, 22-26, 28-29, 33 and 36.
- Repeated visual elements were standardized across the deck.
- Dense paragraphs were shortened into presentation-ready decision points.

© 2026 DA5 Consortium

Agenda

01 **Motivation: health & environment** — current section

02 Legislation status

03 Lead in electronics

04 DA5 structure & approach

05 Partners & sustainability

06 Requirements & alternatives & results

07 Timeline & conclusion

© 2026 DA5 Consortium

Lead: Environmental and Health Endangerment

Lead is a persistent toxic substance; the health and environmental rationale for substitution is clear.

Environmental dangers

- Contamination of water, air and soil
- Persistence in ecosystems
- Accumulation across exposure pathways

Health dangers

- Neurotoxin; accumulates in soft tissues and bones
- Can damage the nervous system
- Linked to blood and brain disorders in mammals



Further information: WHO fact sheet on lead poisoning and health: https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health

© 2026 DA5 Consortium

Agenda

The storyline follows the decision logic: why lead matters, where it remains technically needed, and what DA5 is doing to replace it responsibly.

01 Motivation: health & environment

02 **Legislation status** — **current section**

03 Lead in electronics

04 DA5 structure & approach

05 Partners & sustainability

06 Requirements & alternatives & results

07 Timeline & conclusion

© 2026 DA5 Consortium

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

Lead can still be used in defined semiconductor applications, but only within regulated exemptions and declaration rules.

REACH – Reg 1907/2006

SVHC candidate list; declaration needed above 0.1% w/w in articles. Included REACH, Annex XVII (Restriction List). Restrictions are not directly applicable to semiconductor/ electronic sector use cases.

RoHS – Dir 2011/65/EU

Restricted to 0.1% w/w in homogeneous material unless the application is covered by Annex III exemptions.
Exemptions renewed as per Delegated Directive published in official journal, November 21, 2025.

ELV – Dir 2000/53/EC

Restricted to 0.1% w/w with Annex III exemptions; reviews continue even where expiry dates have passed. Regulation (EU) 2026/1738 published July 24, 2026; no splitting of wording; next review 2031.

Practical implication

For high-melting temperature solders, compliance depends on exemption status, renewal timing and material declaration obligations.

© 2026 DA5 Consortium

	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	Regulation 2026/1738/EU published on 24.07.2026	Possible to move to Annex XIV – no more use in Europe unless authorized
	Renewal dossier to be presented by 30.06.2026 → done 26.06.2026		
	In case not renewed no more use starting (from worse case) from 30.06.2029		

© 2026 DA5 Consortium

Agenda

The storyline follows the decision logic: why lead matters, where it remains technically needed, and what DA5 is doing to replace it responsibly.

01 Motivation: health & environment

02 Legislation status

03 Lead in electronics — **current section**

04 DA5 structure & approach

05 Partners & sustainability

06 Requirements & alternatives & results

07 Timeline & conclusion

© 2026 DA5 Consortium

Use of Lead in Electronics

The replacement challenge has shifted from PCB-level soldering to package-level die and clip attach.

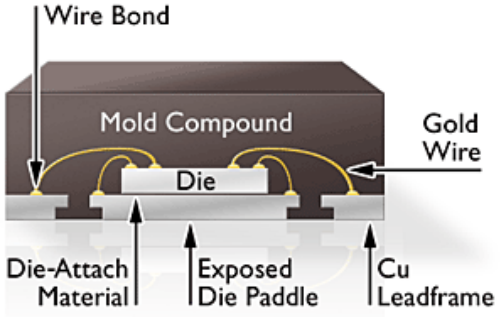
PCB-level solders

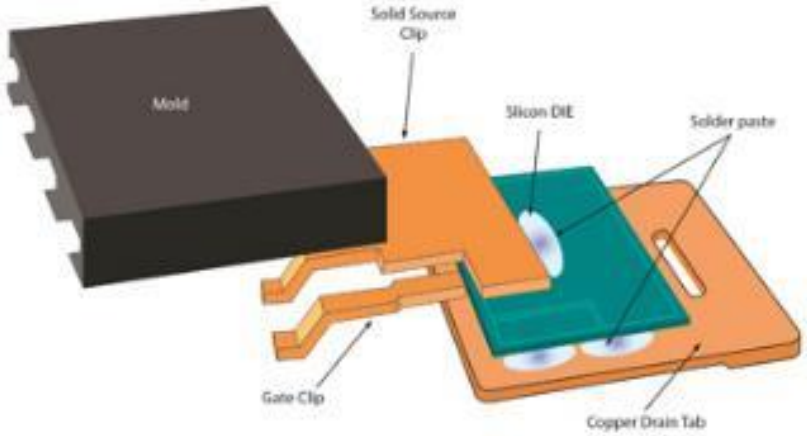
- PbSn63/ PbSn62Ag2 have been used on printed circuit boards.
- Lead-free alternatives such as SAC (SnAg3.8Cu0.7) are known and implemented.

Package-level attach

- High-lead solders remain used for die and clip attach inside components.
- As of July 2026, no general replacement fulfills all requirements.







Key requirements: no re-melting at 260°C, reliable wettability, ductility and competitive manufacturing cost.

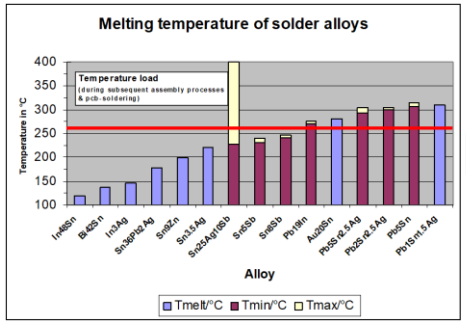
© 2026 DA5 Consortium

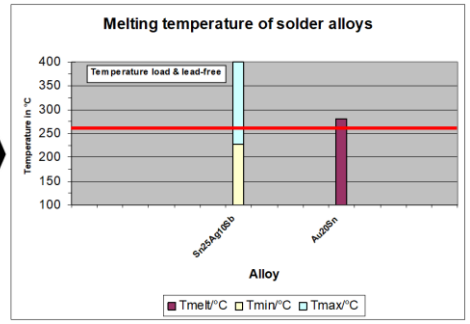
Materials for Die Attach: Solder Alloys

Brittleness of remaining alloy candidates limits reliability—especially for larger die, thin chips and constrained package geometries.

Why substitution is hard

- High-melting behavior must survive board-level reflow.
- The attach layer must buffer thermal expansion mismatch.
- Wetting, voiding and brittle intermetallic growth all affect reliability.





Reliability pressure points

Constraint	Effect on candidate alloys
Larger die area	Higher mechanical stress
Thin die	Greater crack sensitivity
Package geometry	Less process margin
Surface materials	Wetting/ adhesion risk

© 2026 DA5 Consortium

Agenda

The storyline follows the decision logic: why lead matters, where it remains technically needed, and what DA5 is doing to replace it responsibly.

01 Motivation: health & environment

02 Legislation status

03 Lead in electronics

04 DA5 structure & approach — **current section**

05 Partners & sustainability

06 Requirements & alternatives & results

07 Timeline & conclusion

© 2026 DA5 Consortium

DA5 Project at a Glance

DA5 = Die-Attach 5: a joint semiconductor consortium focused on feasible lead-free die and clip attach technologies.



04/2009

DA5 consortium formed by ST, NXP, Infineon, Bosch and Freescale

12/2015

NXP and Freescale merge into NXP

07/2017

Nexperia joins DA5 consortium

Today

Focus remains on high-melting solder alternatives for power packages

Project focus

- High-melting solder in semiconductor applications.
- Especially die attach and clip attach in power packages.
- Alignment with ELV and RoHS exemption context.

© 2026 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 CO_2 emission savings amounting to approximately 143 million tons of CO_2 equivalents during their use-phase. For the sixteenth 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 over 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.



© 2026 DA5 Consortium

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.



© 2026 DA5 Consortium

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.

© 2026 DA5 Consortium

DA5 Project Objectives

Objective: identify sustainable, robust, standardized, reliable and dependable lead-free solutions for customers.

1. Develop direction: Jointly define Pb-free die- and clip-attach technology direction with suppliers.
2. Evaluate candidates: Screen available and potential alternatives and prioritize material candidates.
3. Anticipate regulation: Ensure development considers current rules and regulatory evolution.
4. Define requirements: Use the DA5 requirement specification as the common benchmark for lead-free solutions.

© 2026 DA5 Consortium

Agenda

The storyline follows the decision logic: why lead matters, where it remains technically needed, and what DA5 is doing to replace it responsibly.

01 Motivation: health & environment

02 Legislation status

03 Lead in electronics

04 DA5 structure & approach

05 Partners & sustainability — **current section**

06 Requirements & alternatives & results

07 Timeline & conclusion

© 2026 DA5 Consortium

DA5 Setup for Pb-free Die-Attach

Supplier engagement is global, continuous and focused on work packages with the most promising candidates.

37

major material suppliers identified

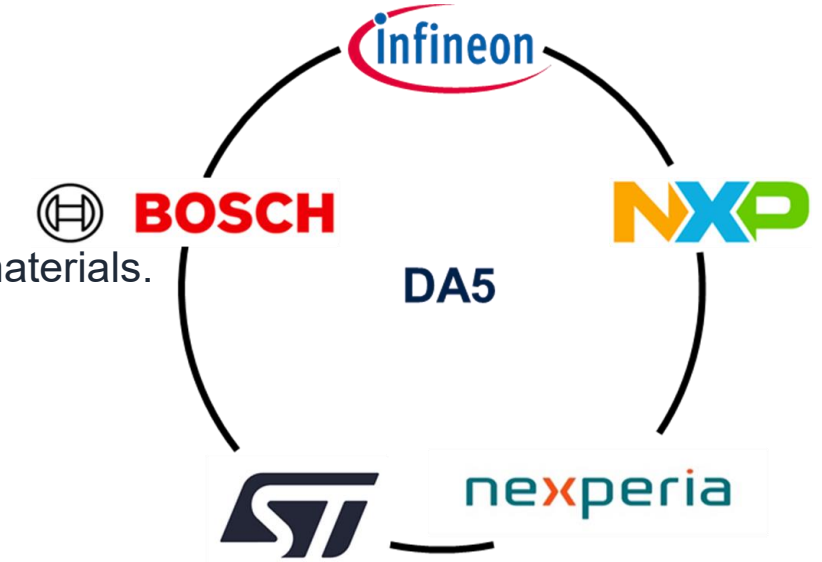
4

suppliers working continuously with DA5

3×/year

common supplier update cadence

- Major suppliers from Europe, the US and Asia have been assessed.
- Continuous contact is maintained; some suppliers stopped offering relevant materials.
- DA5 continues to search for further suppliers with suitable materials.



© 2026 DA5 Consortium

Agenda

The storyline follows the decision logic: why lead matters, where it remains technically needed, and what DA5 is doing to replace it responsibly.

01 Motivation: health & environment

02 Legislation status

03 Lead in electronics

04 DA5 structure & approach

05 Partners & sustainability

06 Requirements & alternatives & results — **current section**

07 Timeline & conclusion

© 2026 DA5 Consortium

Challenges/ Requirements

A viable material must combine high-temperature stability, process compatibility, reliability and electrical/ thermal performance.

Thermal stability

- No re-melting or delamination after 3× 260°C PCB reflow
- Comparable or better thermal conductivity

Package compatibility

- Thin die <120µm and large die up to 70mm²
- Multiple lead-frame and backside metallizations

Reliability

- AEC-Q-100/ AEC-Q-101 expectations
- Stress buffering for CTE differences

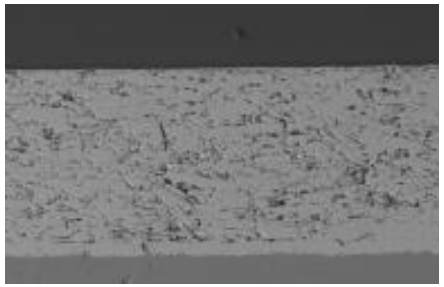
Manufacturing

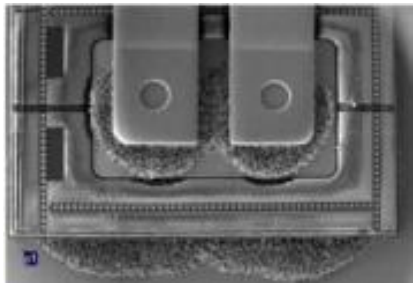
- Dispense/ printing workability
- Clip bonding and die-top coverage without shorts

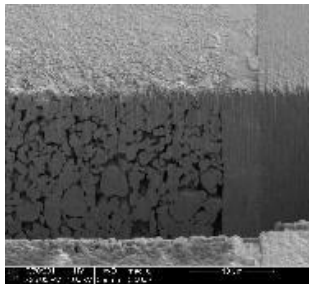
Detailed requirements are documented in “DA5 Die Clip Attach Material Requirement Specification”.

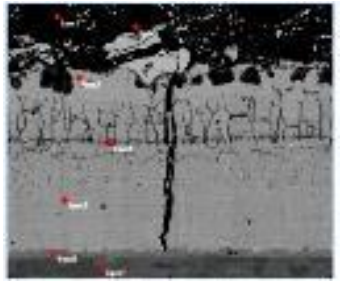
© 2026 DA5 Consortium

Alternatives Evaluation









Adhesives

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

TLPS

- High melting metal powders in organic flux (**Cu, Ag)**
- Limitation
  - Die thickness
  - 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

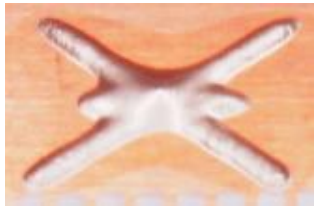
© 2026 DA5 Consortium

Conductive Adhesives

Principles

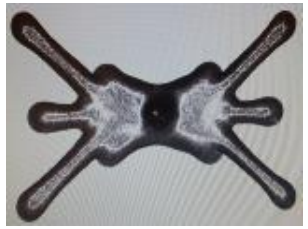
- Smaller particles (nano) → higher sintering degree, which increases electrical/ thermal conductivity.
- Organic resin reduces elastic modulus to absorb more mechanical stress → less delamination.
- Bimodal distribution of Ag particles (nano and micro) reduces risk of metal fatigue/ cracks.
- Higher 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 (<120um)
▪ 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

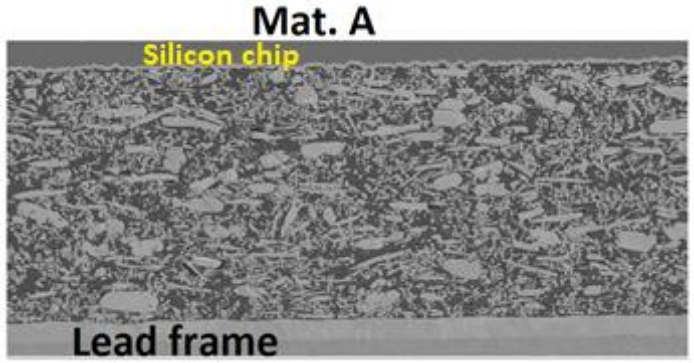


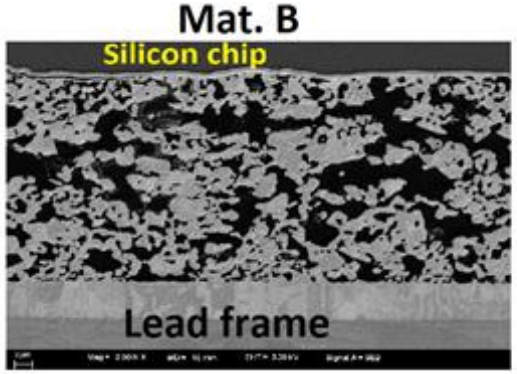
Dispense Patterns

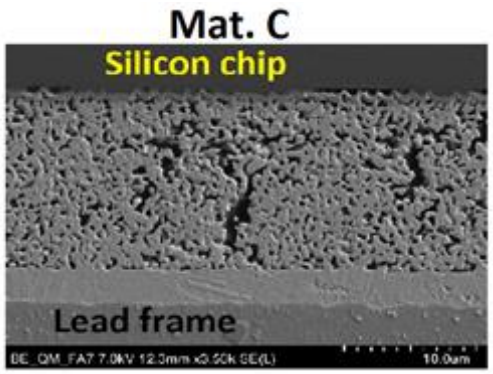
Visible solvent bleed out



No solvent bleed out







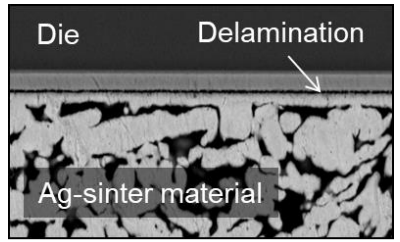
Increasing sintering levels, electrical + thermal conductivity, and elastic modulus

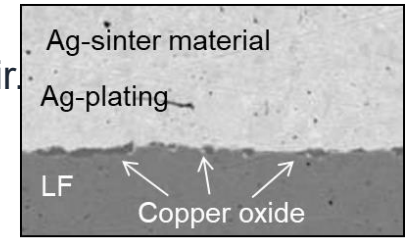
© 2026 DA5 Consortium

Metal Sintering

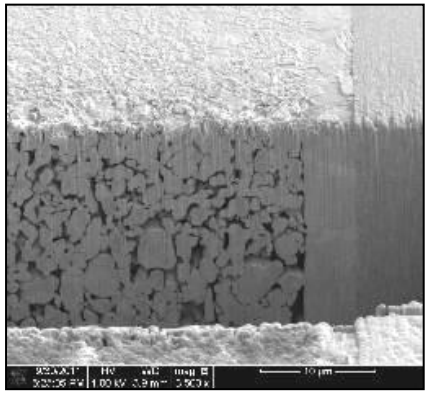
Principle

- 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

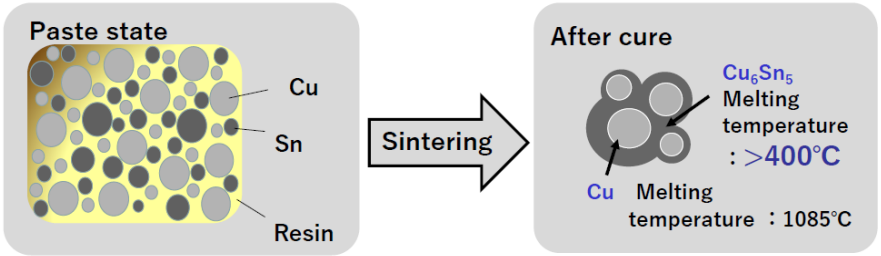
	▪ nm-scale metal particles are at risk of being banned
	▪ New concept in molded packaging - no prior knowledge of feasibility, reliability or physics of failure
	▪ Potential production equipment changes (low-O2 ovens, sintering presses)
		▪ Potential reliability issues:
		  ▪ Die crack, breaks inside bondline, delamination or die lift,
		  ▪ Organic contamination,
		  ▪ Continued sintering → thickness reduction
		  ▪ Interface degradation or electromigration

© 2026 DA5 Consortium

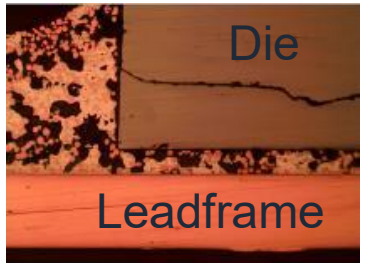
TLPS: Transient Liquid Phase Sintering

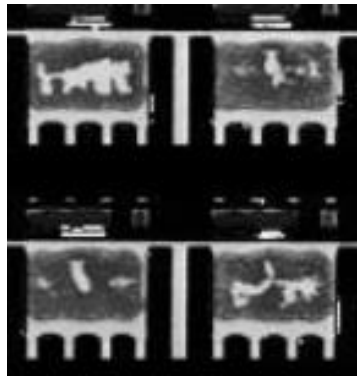
Principle

- 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 like 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



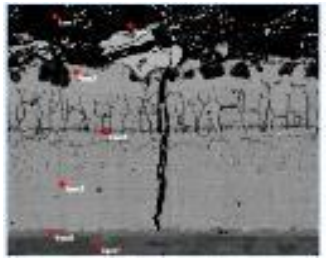


© 2026 DA5 Consortium

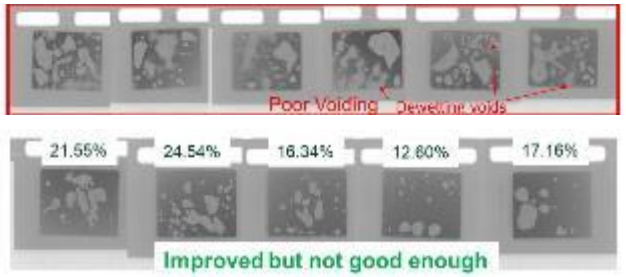
Alternative Solders

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 temperature 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

© 2026 DA5 Consortium

Key Performance Indicators

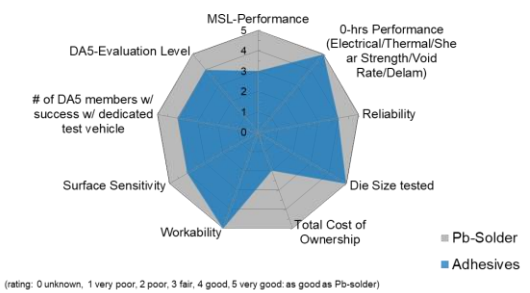
DA5 uses a revised rating system with Pb-based solder set as the reference value of 5 for each criterion.

How to read the assessment

- Assessment refers to the best material tested in each class.
- Valid for die thickness >120 µm.
- Applies to die attach; clip attach is not yet rated.

Technology comparison snapshots

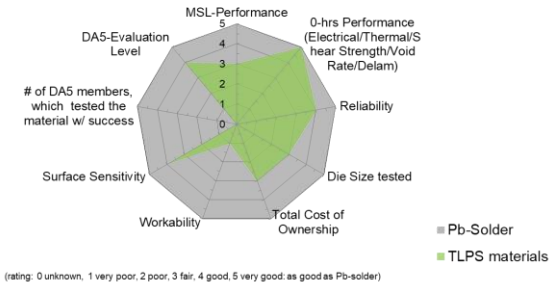
Adhesives vs. Pb-solder



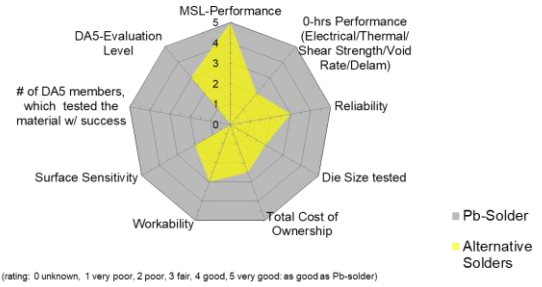
Metal Sintering vs. Pb-solder



TLPS materials vs. Pb-solder



Alternative Solders vs. Pb-solder



© 2026 DA5 Consortium

Agenda

The storyline follows the decision logic: why lead matters, where it remains technically needed, and what DA5 is doing to replace it responsibly.

01 Motivation: health & environment

02 Legislation status

03 Lead in electronics

04 DA5 structure & approach

05 Partners & sustainability

06 Requirements & alternatives & results

07 Timeline & conclusion — **current section**

© 2026 DA5 Consortium

Timeline

DA5 maintains a regular supplier cadence and continues material evaluation alignment between workshops.



Three times/ year

Common update meetings with selected material suppliers

Between workshops

Alignment between supplier and DA5 work package leader

July 2026

Last DA5-supplier workshop held face-to-face

November 2026

Next DA5-supplier workshop planned

© 2026 DA5 Consortium

Summary DA5-supplier workshop July 2026

The workshop combined supplier updates, DA5 feedback and internal alignment on how to improve supplier support.

Supplier updates

- Latest activities on Pb replacement
- Updates of already introduced materials
- New materials based on Cu/ Cu sintering

Technical discussion

- Results discussed thoroughly
- DA5 evaluation results shared and challenged

Next support actions

- Detailed feedback to material suppliers
- Internal discussion on improved supplier support inc. sample build, reliability and failure analysis

© 2026 DA5 Consortium

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,...

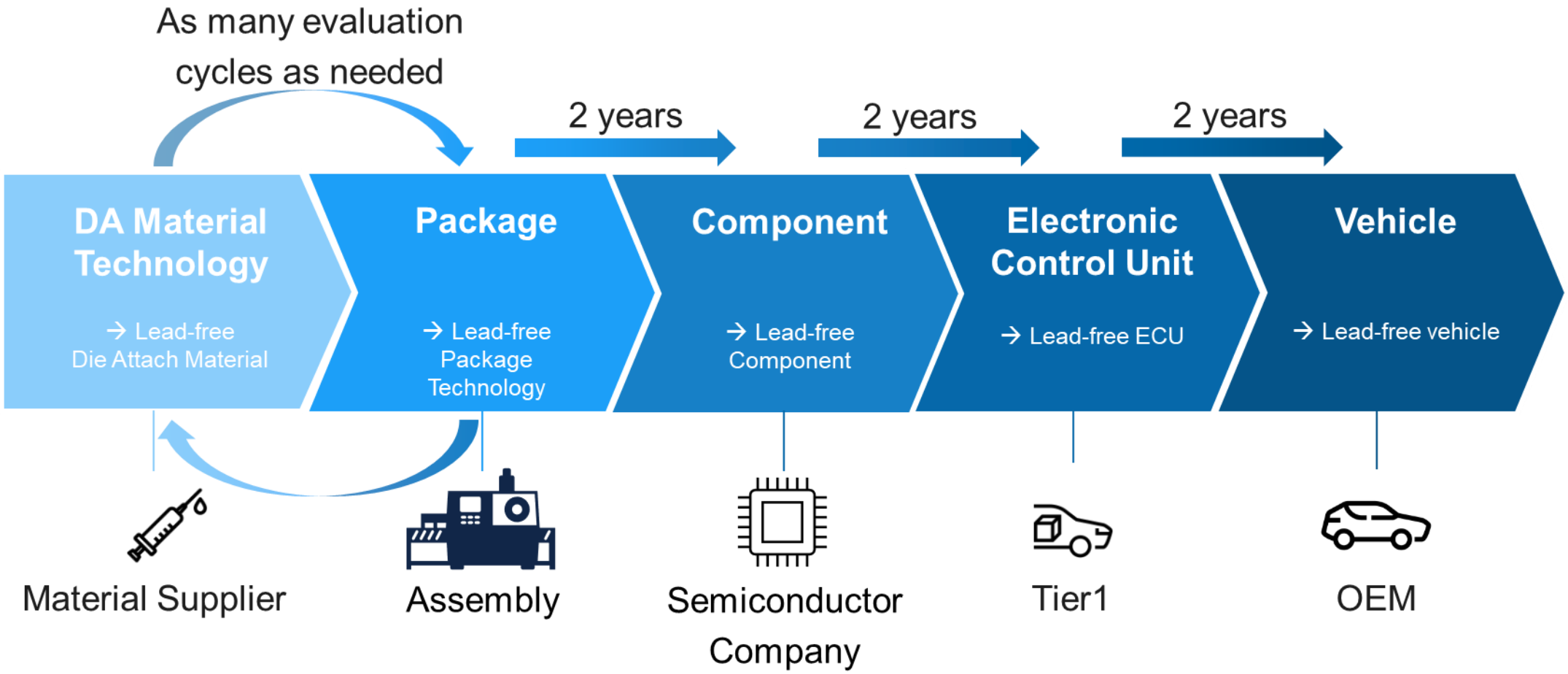
Blind spots
- Unforeseen

Full set of requirements can be provided upon request.

** According to latest proposed changes in regulatory requirements*

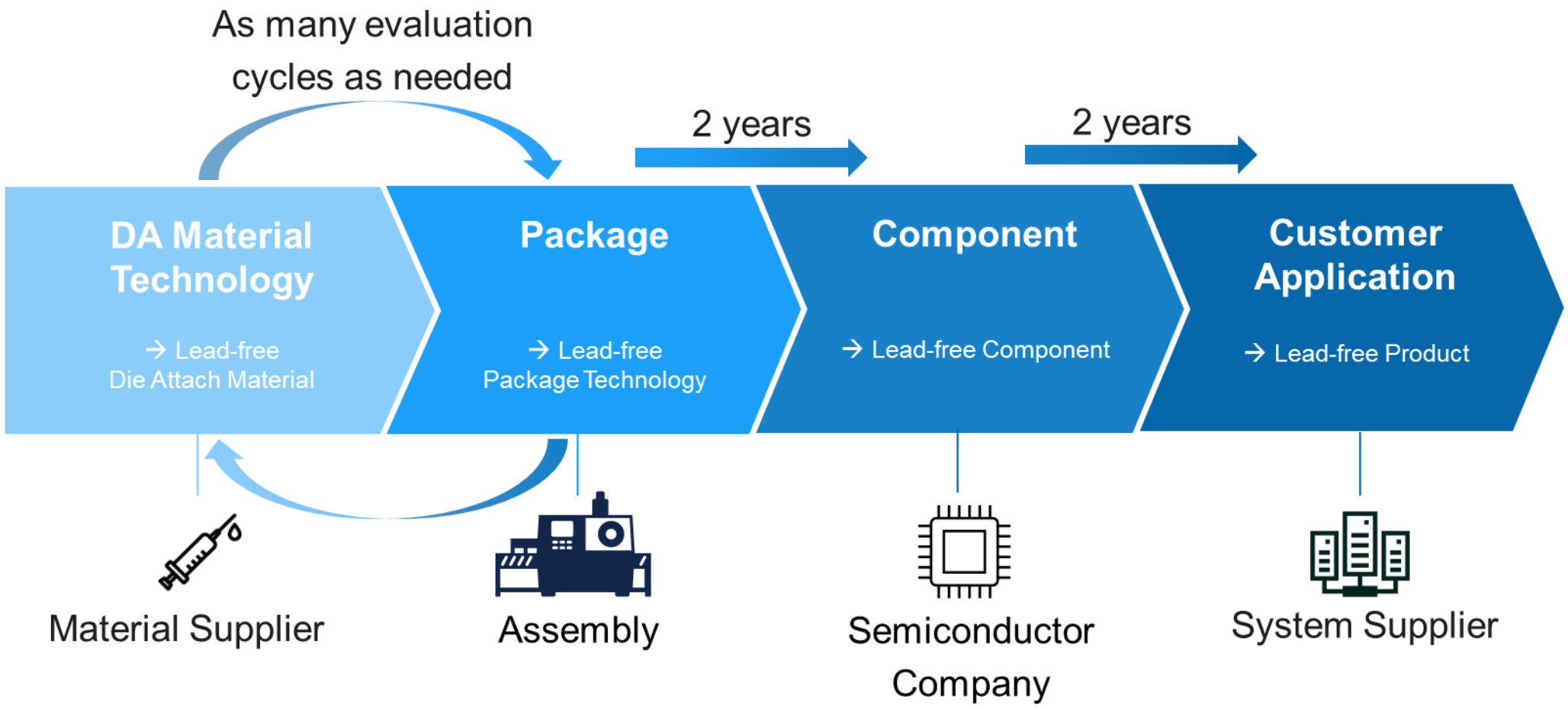
© 2026 DA5 Consortium

DA5 - Automotive Release Process (ELV)



© 2026 DA5 Consortium

DA5 - Industrial Release Process (RoHS)



© 2026 DA5 Consortium

Conclusion I

No currently available lead-free material technology is ready to replace high-melting temperature lead solders across semiconductor applications.

1. More than 15 years of development have produced promising but application-specific results.
2. DA5 evaluated more than 218 materials from more than 18 suppliers; more than 50 materials received extensive testing.
3. No candidate has yet proven suitable as a general Pb-replacement solution for power semiconductor packages.
4. Material evaluations continue with suppliers, but qualification and conversion can begin only once a reliable technology is available.

© 2026 DA5 Consortium

Conclusion II

The deployment path remains sequential: technology freeze → semiconductor qualification → customer qualification → supply-chain conversion.

- Customer qualifications and supply-chain ramp-up can only begin after package technology and component qualification.
- No universal lead-free solution is in sight; different applications will require different materials.
- DA5 expects limited application adoption to increase over the next decade as new materials mature.
- Based on current status, DA5 supports continuation of lead exemptions under RoHS, ELV and equivalent worldwide legislation.

Bottom line

Lead reduction remains the goal; exemption continuity is needed until qualified, scalable, and reliable substitutes are available.

© 2026 DA5 Consortium

List of Abbreviations

Ag	Silver	AEC	Automotive Electronics Council	CTE	Coefficient of Thermal Expansion
Au	Gold	ELV	End-of-Life Vehicle	HTS	High Temperature Storage
Bi	Bismuth	EU	European Union	IMC	Intermetallic Compound
Cu	Copper	MSL	Moisture Sensitivity Level	PCB	Printed Circuit Board
DA5	Die-Attach 5	N_2	Nitrogen	Pb	Lead
DSS	Die Shear Strength	OEM	Original Equipment Manufacturer	RoHS	Restriction of Hazardous Substances
TLPS	Transient Liquid Phase Sintering	Zn	Zinc	ppm	parts per million

Most-used terms only; the complete abbreviation list can remain in supporting material if required.

© 2026 DA5 Consortium

Contact Information

Speaker of the DA5 consortium

Riccardo Villa
STMicroelectronics srl
Email: riccardo.villa@st.com

DA5 customer presentation

https://www.infineon.com/row/public/documents/corporate/company/sustainability/da5-customer-presentation.pdf

The full “DA5 Die Clip Attach Material Requirement Specification” document is available upon request at DA5.

© 2026 DA5 Consortium