Addressing solder hierarchy issues in power module packaging with TLPS pastes

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Agenda

- Trends impacting power packaging
- Limitations of solder solutions
- Alternative paste materials for mechanical, electrical and thermal interconnect
- TLPS solutions
  - Historical uses
  - Different implementations in packaging
- The advantages of paste-form TLPS
- Implementation of TLPS pastes
- Results of TLPS assemblies

Heterogeneous integration

Disruption is overtaking the entire packaging industry

- SoC -> Chiplet
- Discrete semi packaging -> System in package (SiP, WLP, PLP, 2.5, 3.0, PoP, EMIB, TSV)
- Core function discretes -> Module (RF, power, MEMS, optoelectronic, LIDAR)
- Separate analog and digital -> Integrated with EMI shielding
- Surface assembly of PCB -> Embedded passives and actives
- PCB fabrication -> Stacked subconstructions, mixed function layers of different dielectric materials, mixed mode interconnect

Power packaging is also impacted by the heterogenous trend

Drivers behind the migration to integration
Module advantages

Discretes

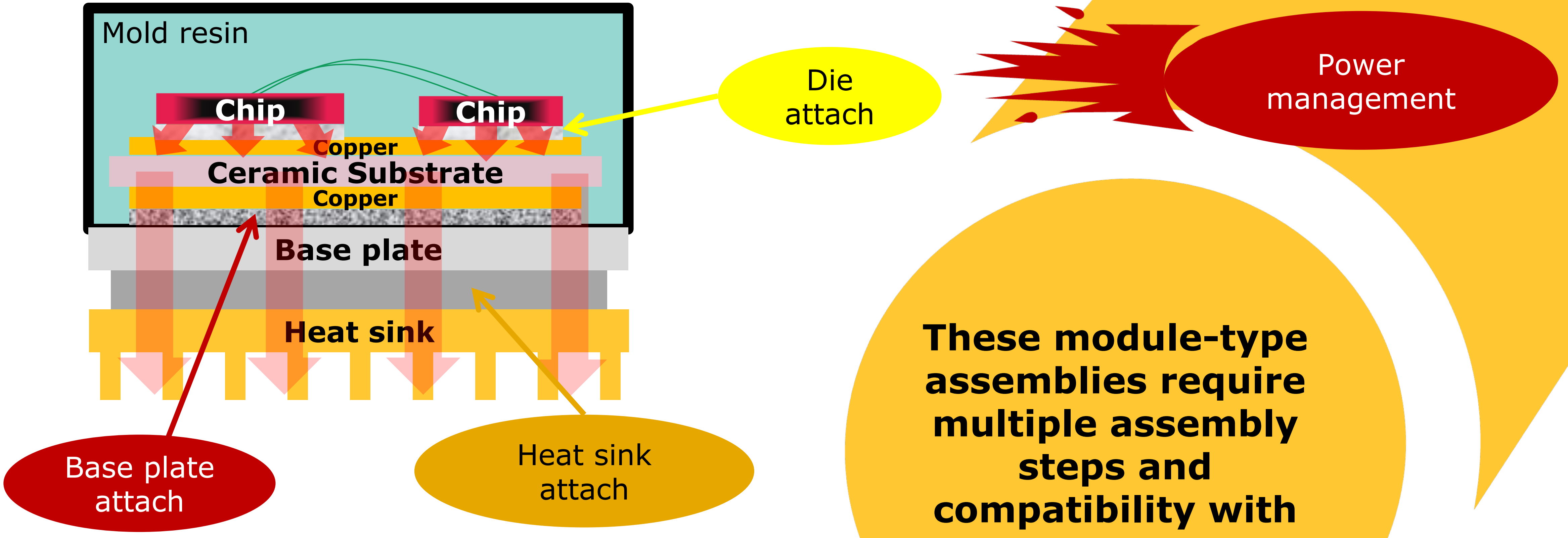
- Source components
- Application specific design
- Design risk – optimization cycle
- Large footprint
- No 3D capability
- Lossy

modules

- Known good design
- Plug and play across generations
- Reduced parasitics
- Reduced power consumption
- More rugged (overmolded vs. SMT)
- Simplified BOM for PCB designer
- Faster time to market
- Improve functionality while maintaining footprint

…but how to manage solder assembly hierarchies?

WBG semiconductors drive performance requirements
Harsh environment and high power cycle



These module-type assemblies require multiple assembly steps and compatibility with harsh operating conditions

Solder limitations in power packaging

!

Solder hierarchy

- Mostly outside current lead-exemption
- Limited melt temperature differential between candidates
- Sb is under scrutiny
- SnBi and SnIn have operating temp limitations

High operating temperature

- Lead exemption status has an uncertain future
- Trend is toward temperatures that will exceed leaded solder capabilities
- The Au alternatives are capable, but $$$

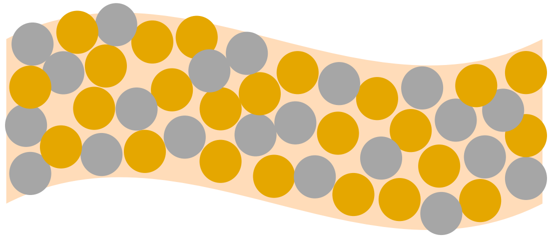
Diffusion issues

- Solder joints have undesirable continued phase growth with continued thermal exposure
- Reliability concern in cycling

Properties	Au	80Au20Sn	88Au12Ge	96.8Au3.2Si
Solidus (°C)	1064	280	356	363
Liquidus (°C)	1064	280	356	363
Thermal Conductivity (W/mK)	318	57	44	27
Tensile Strength (PSI)	20,000	40,000	26,835	36,975
Shear Strength (PSI)	20,000	40,000	26,825	31,900
Thermal Expansion Coefficient @20°C (PPM/°C)	14	16	13	12

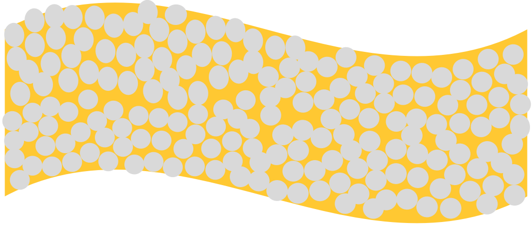
Technology platforms competing with solder

TLPS paste



Sn-based + Cu | Legacy Ormet

Hybrid sinter/adhesive

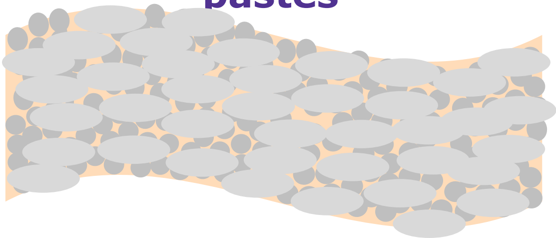


Ag

Nano sintering paste

Ag or Cu

Nano-micron hybrid pastes



Ag or Cu

Pro: Thermoset metal, versatile, high operating temperature

Con: Brittle end-products, no self-align during assembly, moderate thermal perf, no rework

Use: Die attach, component assembly/attach, PCB interconnect

Pro: High thermal performance, ease of use, no remelt

Con: Thermal durability due to adhesive, limited surface compatibility, no rework

Use: Die attach – primarily for thermal performance

Pro: Very high thermal performance, no remelt

Con: Limited surface compatibility and CAPEX for processing, no rework

Use: Die attach for high power module

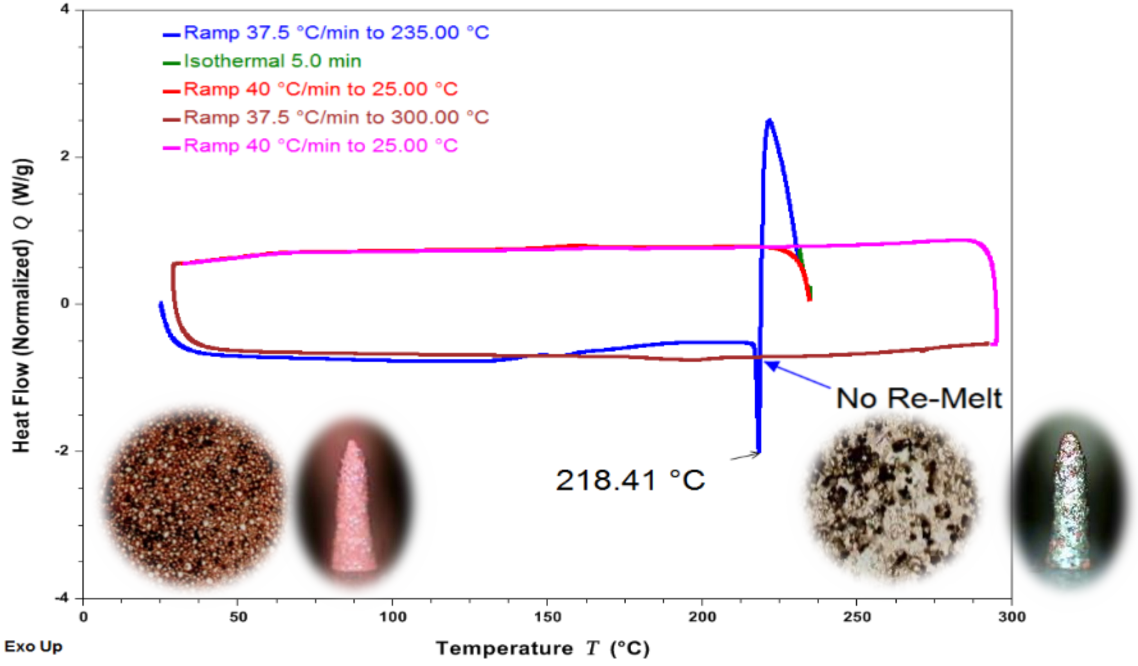
Pro: High performance and potential compatibility with component assembly, no remelt

Con: Process complexity and limited surface compatibility, no rework

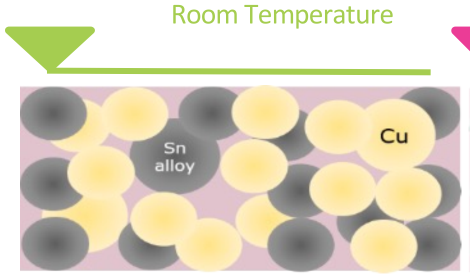
Use: Power module

Only TLPS offers the versatility of solder

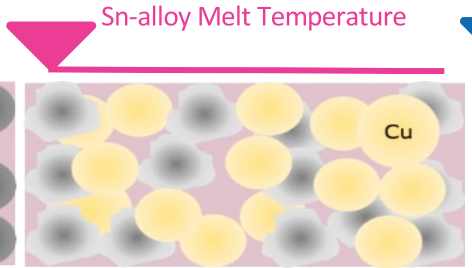
What is TLPS?
Transient Liquid Phase Sintering



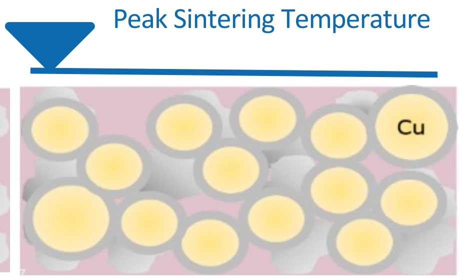
- **Processes like solder**
- **Electrical, thermal and mechanical characteristics like solder**
- **Does *not* remelt like solder – multiple assembly steps can be accomplished with the same paste formulation**



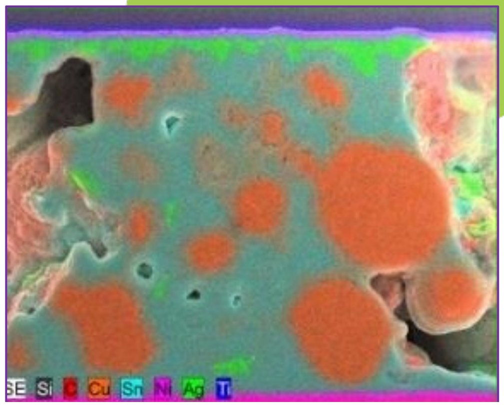
Cu and Sn-alloy particles are suspended in a flux vehicle



Alloy particles melt and wet the copper particles and metallized surfaces



Sn and Cu interdiffusion to form new alloys with melting temperatures **>400°C**



SEM of sintered TLPS paste

Historical uses of TLPS
Dental amalgams

History

- Amalgam -- First used by Chinese. There is a mention of silver mercury paste by Sukung (659AD) in the Chinese medic

↓

- 1578-Ishitichen used 100 parts if Hg, 45 parts of Ag and 100 parts of Sn

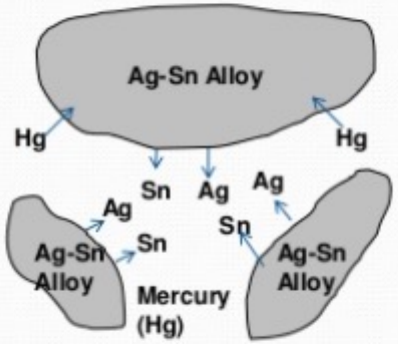
↓

- Liu Wen-Thai (1508) and Li Shih-Chen (1578) discussed its formulation; 100 parts of mercury to 45 parts of silver and 900 parts of tin, trituration of these ingredients produced a paste said to be as solid as silver.

AMALGAMATION REACTION/ SETTING REACTION

Low copper conventional amalgam alloy

- Dissolution and precipitation
- Hg dissolves Ag and Sn from alloy
- Intermetallic compounds formed



$$\underset{\gamma}{Ag_3Sn} + Hg \Rightarrow \underset{\gamma}{Ag_3Sn} + \underset{\gamma_1}{Ag_2Hg_3} + \underset{\gamma_2}{Sn_8Hg}$$

TLPS for electrical interconnect applications
Early work in Japan as a solder replacement

United States Patent [19]

Hasegawa et al.

[11] **Patent Number: 4,740,252**

[45] **Date of Patent: Apr. 26, 1988**

[54] **SOLDER PASTE FOR ELECTRONIC PARTS**

[75] Inventors: **Eietsu Hasegawa**, Satte; **Rikiya Kato**, Souka, both of Japan

[73] Assignee: **Senju Metal Industry Co., Ltd.**, Tokyo, Japan

[21] Appl. No.: **9,979**

[22] Filed: **Feb. 2, 1987**

[30] **Foreign Application Priority Data**

Jan. 31, 1986 [JP] Japan 61-18187

[51] **Int. Cl.**[4] **B23K 35/34**; B22F 1/00

[52] **U.S. Cl.** **148/24**; 75/255

[58] **Field of Search** 75/255; 148/24

[56] **References Cited**

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4,478,638 10/1984 Smith 75/255

4,483,905 11/1984 Engstrom 75/255

Primary Examiner—Peter D. Rosenberg

Attorney, Agent, or Firm—Sughrue, Mion, Zinn, Macpeak, and Seas

[57] **ABSTRACT**

A solder paste comprises a solder paste portion containing powdered solder and metallic spheres which are made of a material having a higher melting point than the solder paste portion and whose surface can be wet by molten solder. The metallic spheres have a diameter of 0.07–0.3 mm. The metallic spheres can comprise a single metal or two metals, one of which forms the center of the sphere and the second of which is plated on the surface of the first.

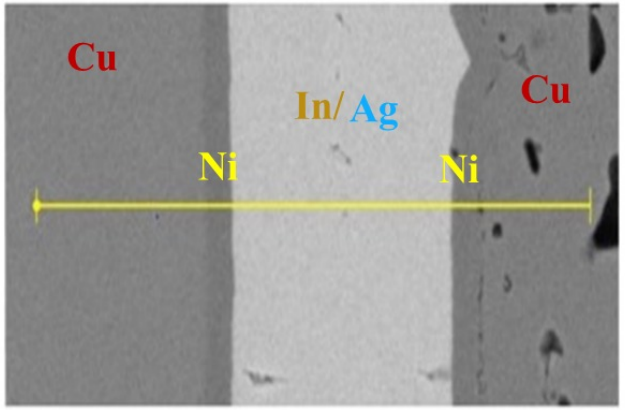
7 Claims, 2 Drawing Sheets

"New" technology has a long gestation

Both technology and market must be ripe

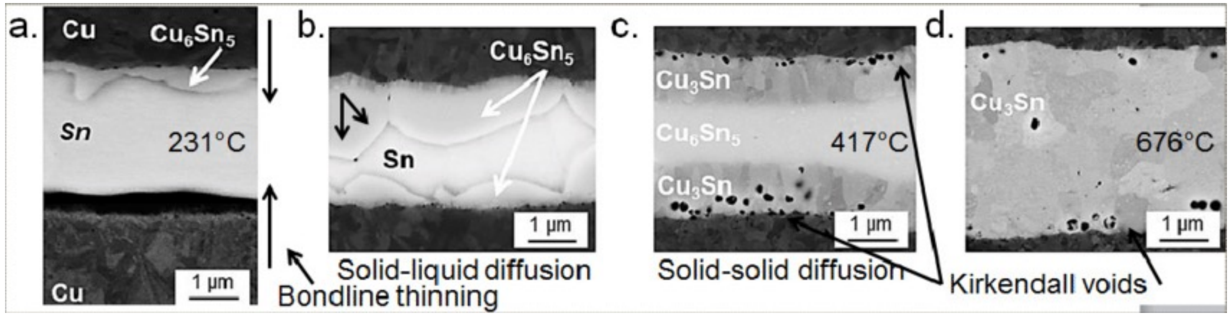
TLPS in electronics applications
Implementation architecture varies

Paste + plating

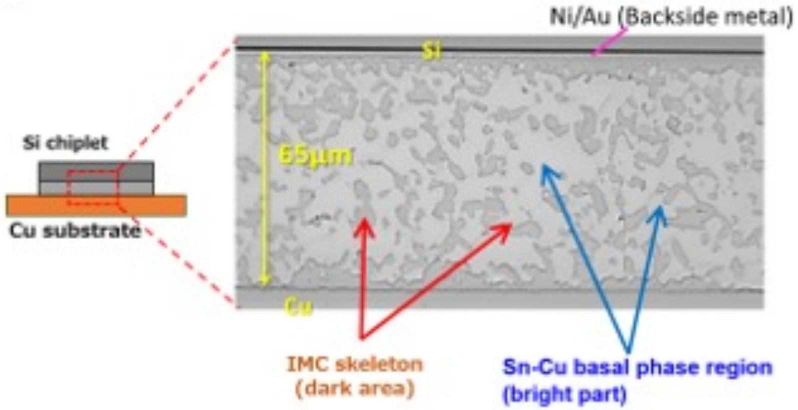


Source: Kemet

SLID - plated layers

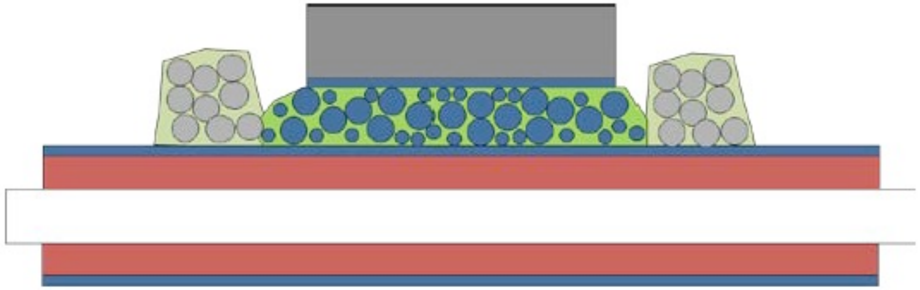


SnCu preform seeded with Cu-Sn-Ni IMC crystals



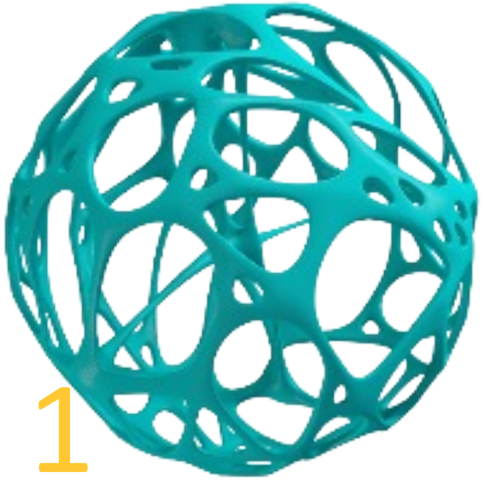
Source: M Napra

TLPS Paste + solder paste



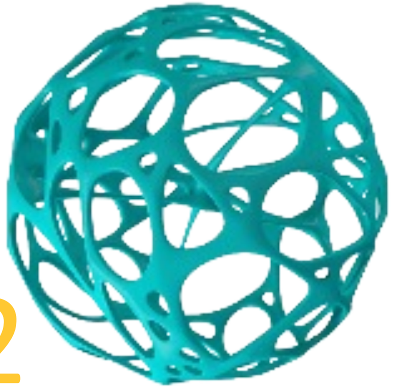
Source: U. Maryland

TLPS implementation in integrated architectures
Why paste vs. alternative formats?



1

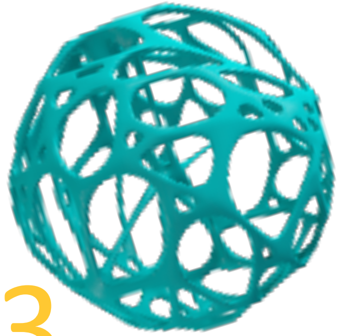
Use existing infrastructure for deposition, placement and processing



2

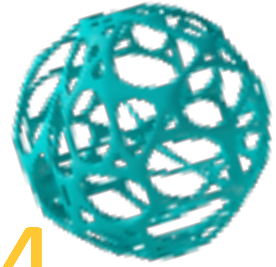
Does not require coplanarity

Supports 3D integration



3

No complex plating operations



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Compatibility across multiple surface finishes in a single assembly

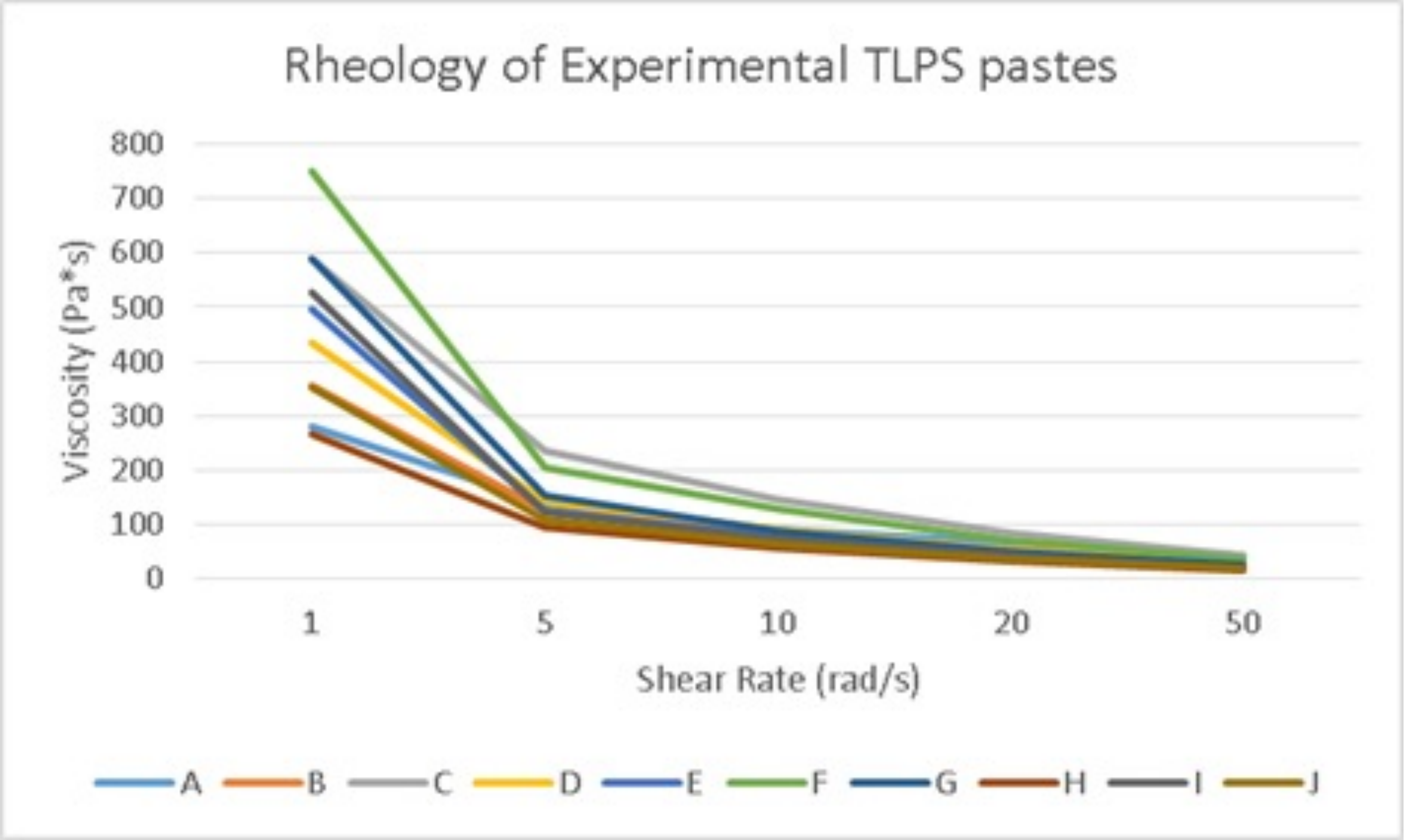
Why is assembly with TLPS paste particularly attractive?

- **Standard SAC solder paste processing**
  - Lead-free reflow with inert environment
  - Dispense or stencil print
  - Compatible with all solderable finishes
- **After reflow, will not remelt below 400°C**
  - Step soldering (all lead-free)
  - High operating temperature (>250°C, lead-free)
- **Maintains deposition footprint on copper without soldermask**
- **Does not liquify and consolidate**
  - Reduced opportunity for shorting
  - No tombstoning
- **Comparable electrical, thermal and mechanical properties to solder**
- **Compatible with other interconnect technologies**

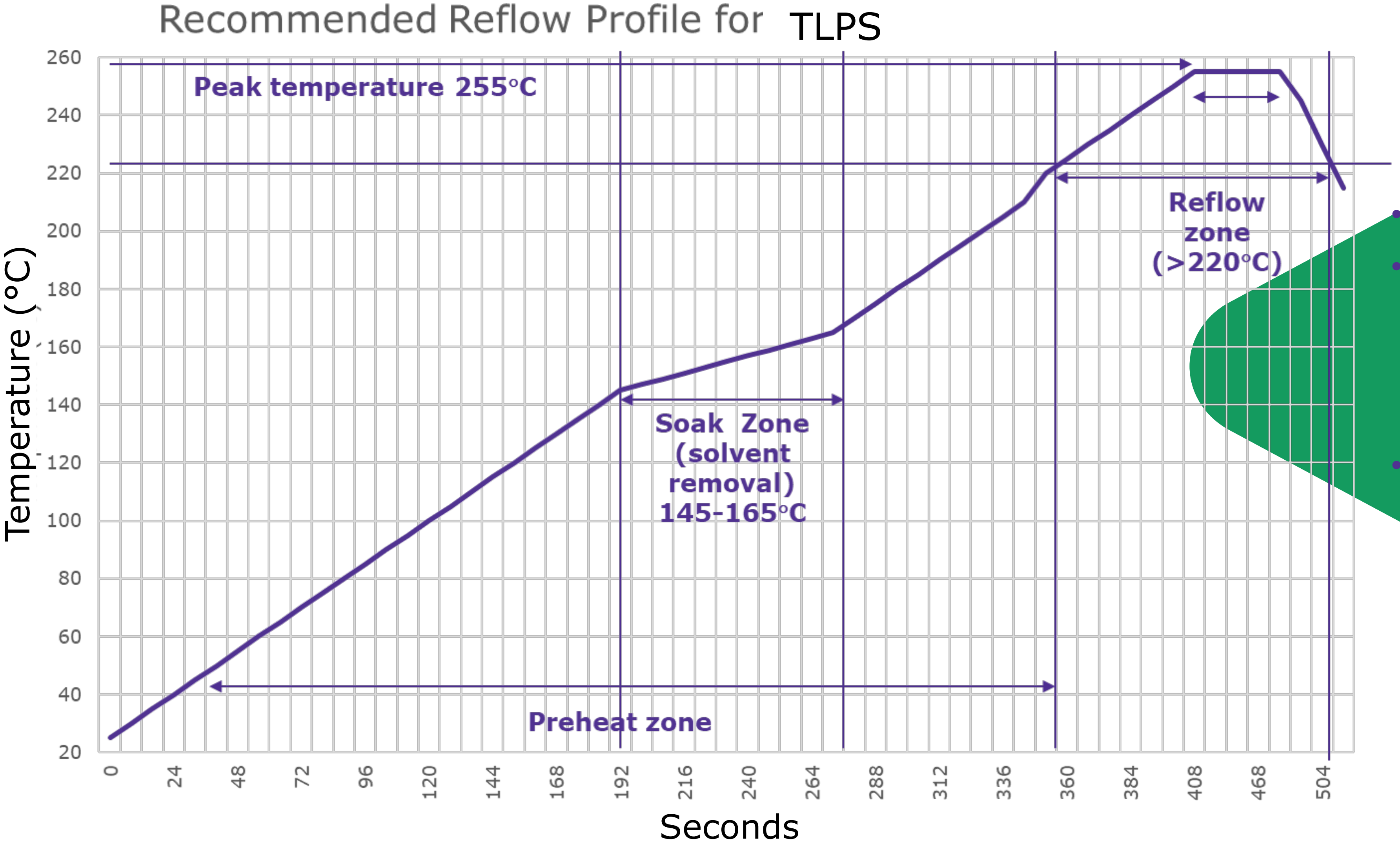
"Our charter is to be disruptive…The art is to make a change without changing all the equipment, without demanding a whole new line. Some of your biggest deltas can still happen by being smart about how you make the disruption"

- Johanna Swan, Intel Fellow

Putting TLPS paste to use
Deposition versatility like solder



Putting TLPS paste to use
Reflow is similar to solder

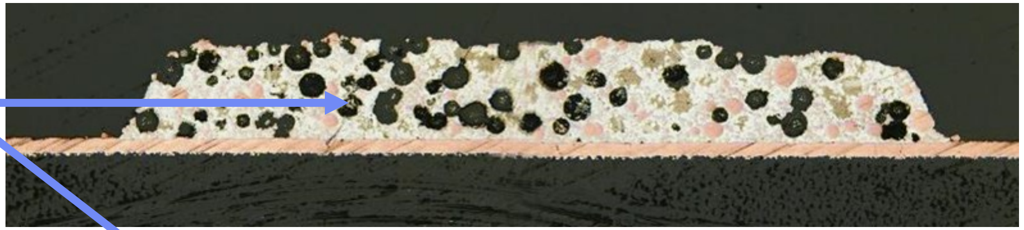


- Modified SAC 305 profile
- Slower ramp:
  - Metals 'snap cure'
  - Critical to eliminate volatiles before alloy melt
- Longer dwell at peak
  - TLPS joints get stronger with more thermal work

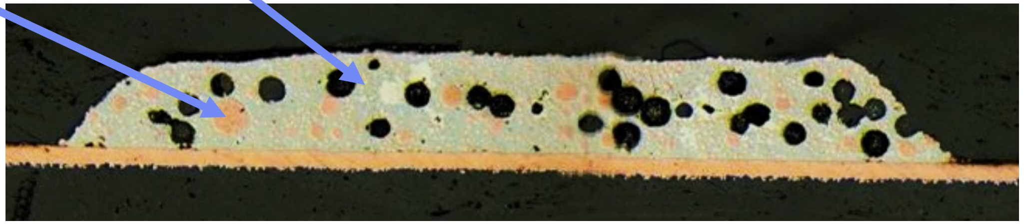
Putting TLPS paste to use
TLPS metallurgy prevents uncontrolled IMC growth

Intermetallic phases

Residual copper cores

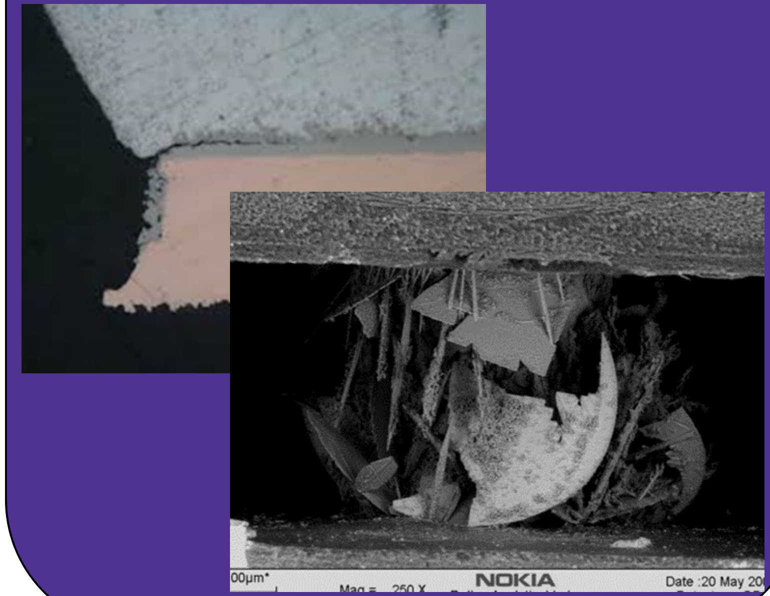


Initial reflow



2000 hours @ 170°C

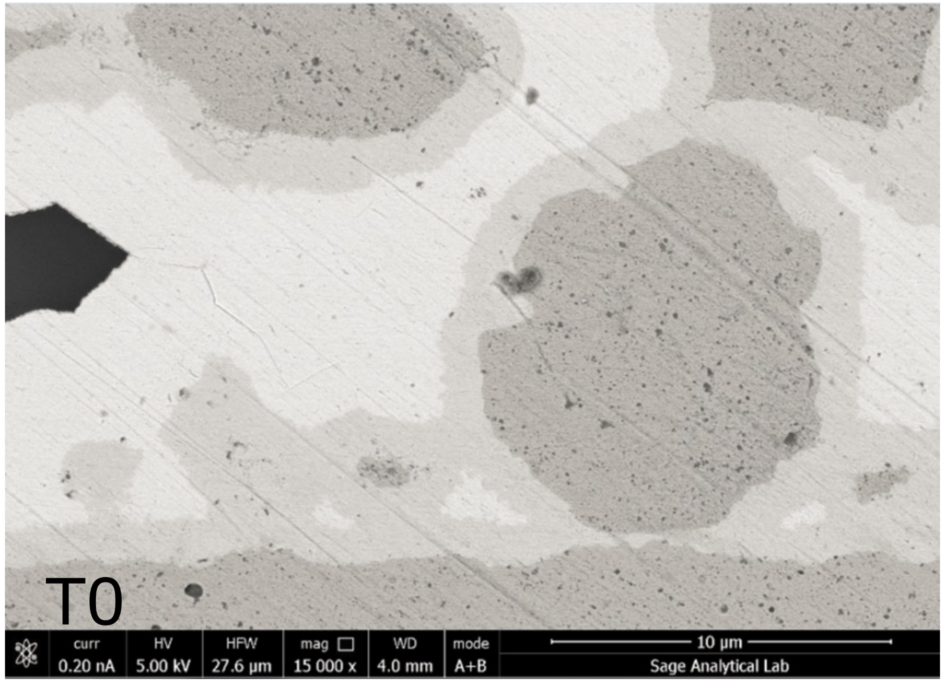
Solder

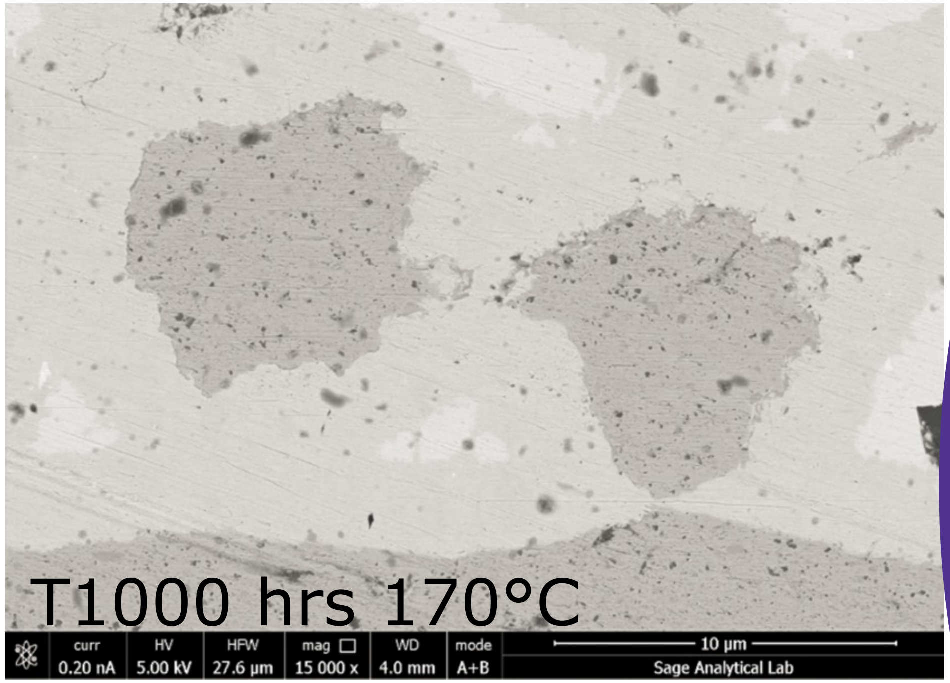


- **IMC formation is critical to a stable metallurgical joint**
- **TLPS prevents uncontrolled IMC growth at the interface**

Putting TLPS paste to use

IMC conversion occurs at the interface and through the bulk



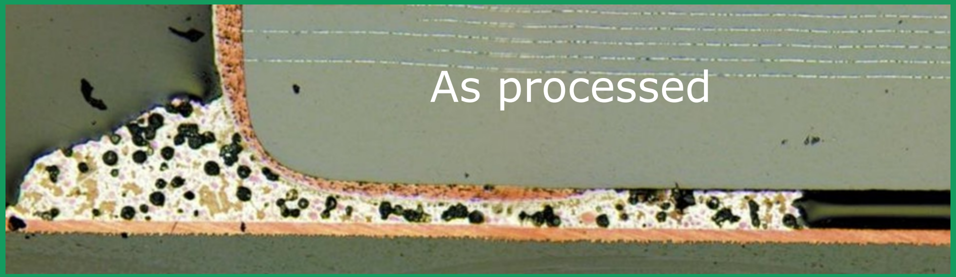


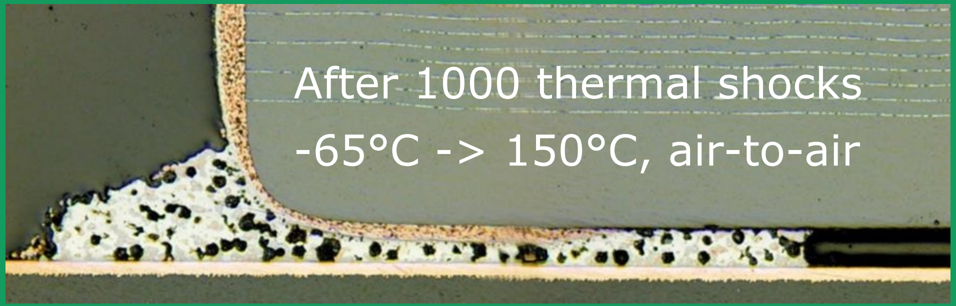
Thermal work does not degrade joint performance

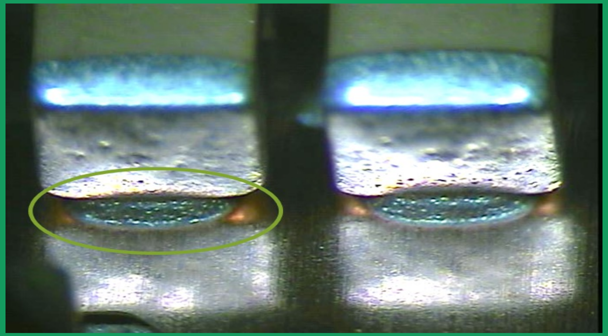
	Post Oven Cure	100hrs @170°C	250hrs @170°C	500hrs @170°C	1000hrs @170°C
AVG. IMC (um)	1.475	2.043	2.119	2.733	3.384
Strength (kg/mm^2)	1.2	1.303	1.328	1.429	1.434

Putting TLPS paste to use
Joint morphology: matte grey, with distributed pores and no fillet

- TLPS joints have a dull grey, textured surface
- No fillet will be formed
  - + No tombstoning
  - + Reduced risk for shorting
  - - No self-alignment
  - - AOI criteria adjustment needed
- Interior pores are a normal feature
  - Do not consolidate with thermal work
  - Superior fatigue resistance to SAC solder
  - Extremely stable microstructure





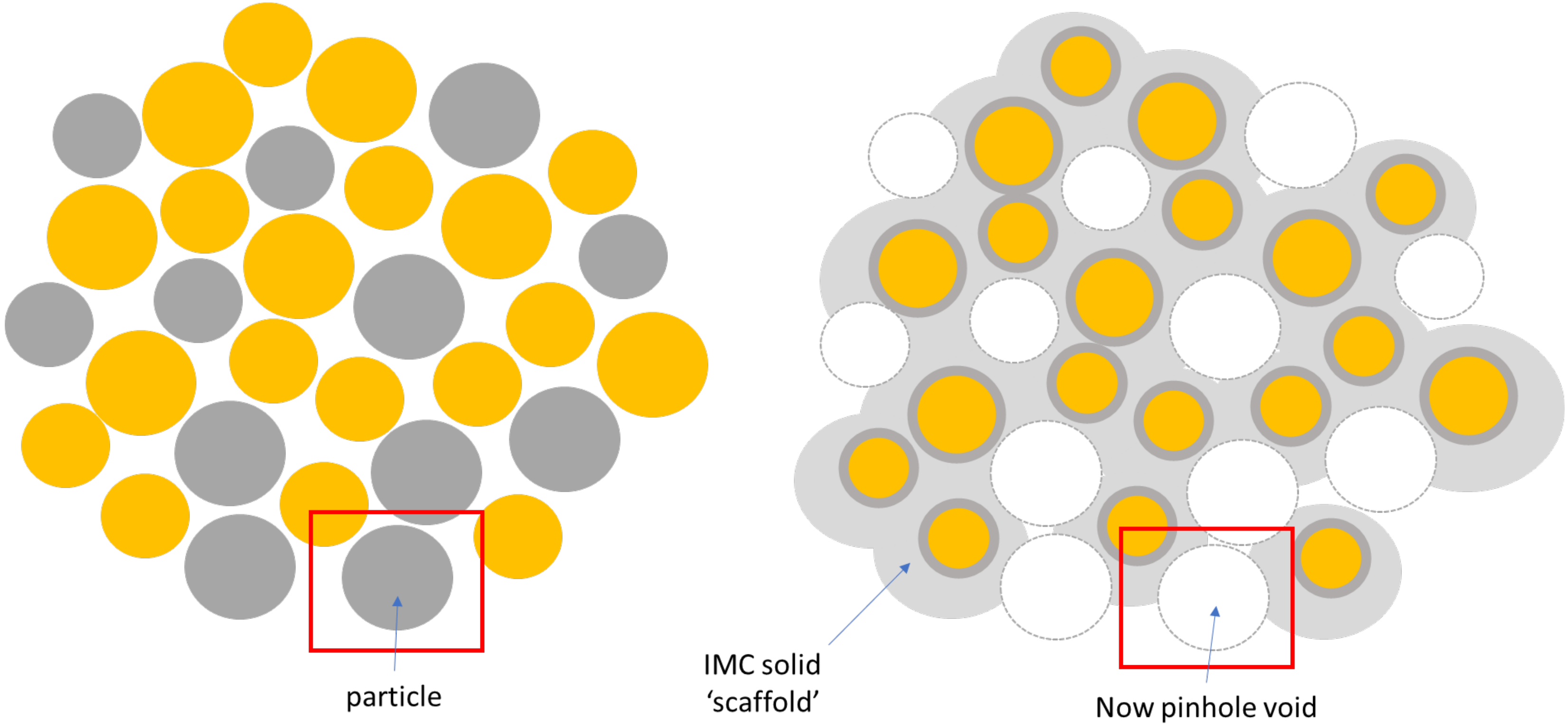


Putting TLPS paste to use
Pores are a normal feature and do not reduce reliability

Function of metal solidification kinetics

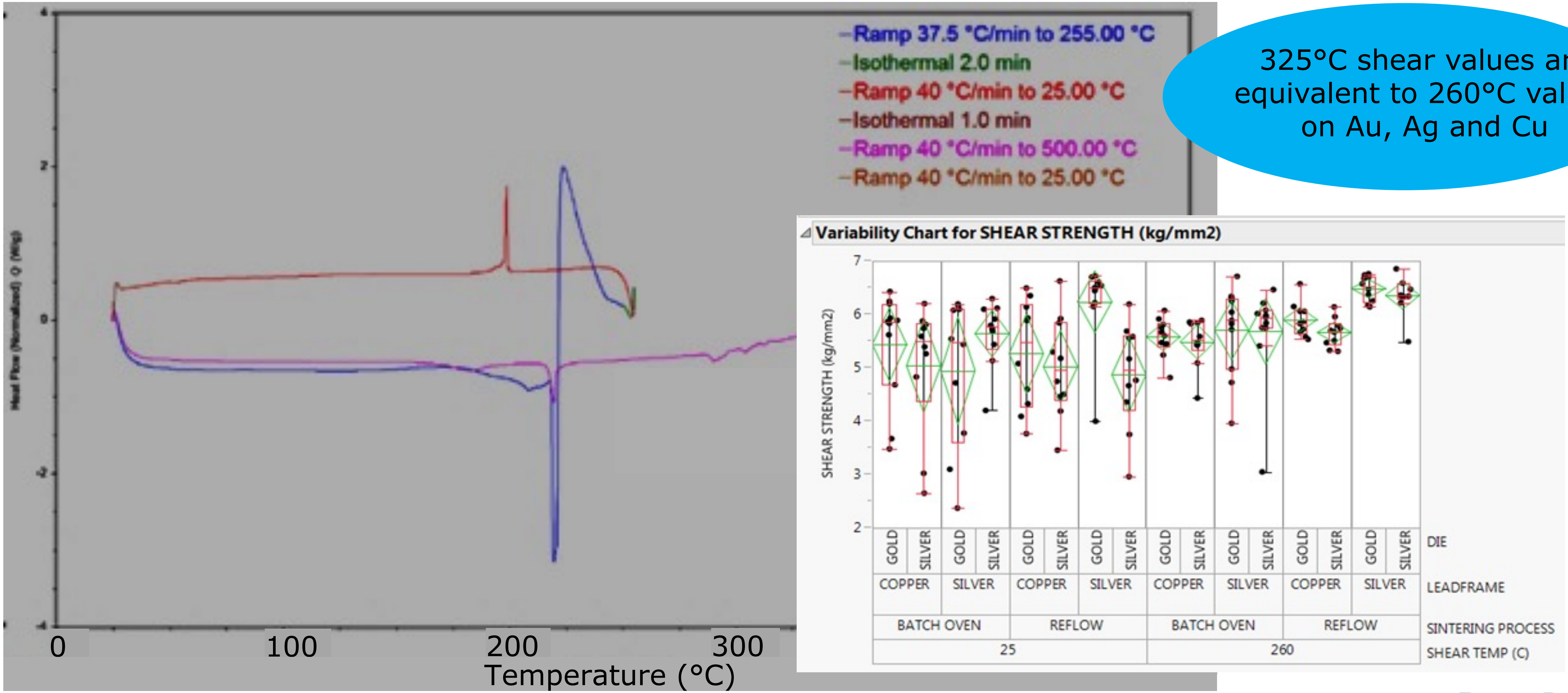
Pinholes are well distributed and <20um

Do not consolidate with thermal work



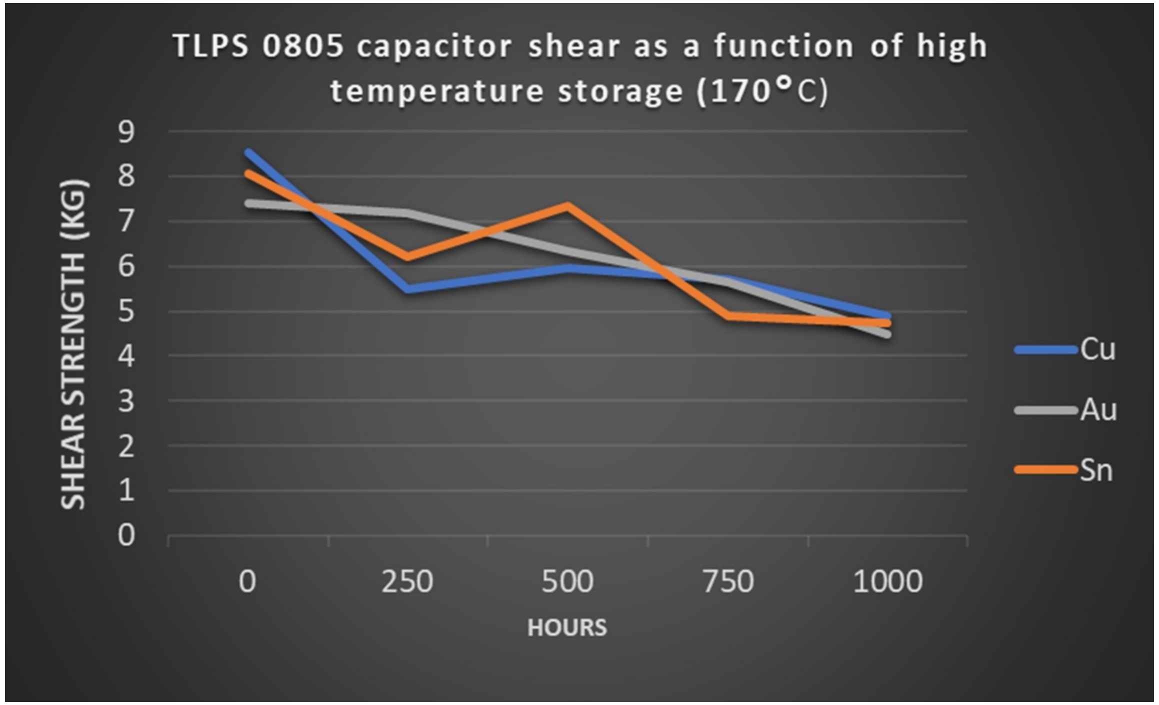
Putting TLPS paste to use

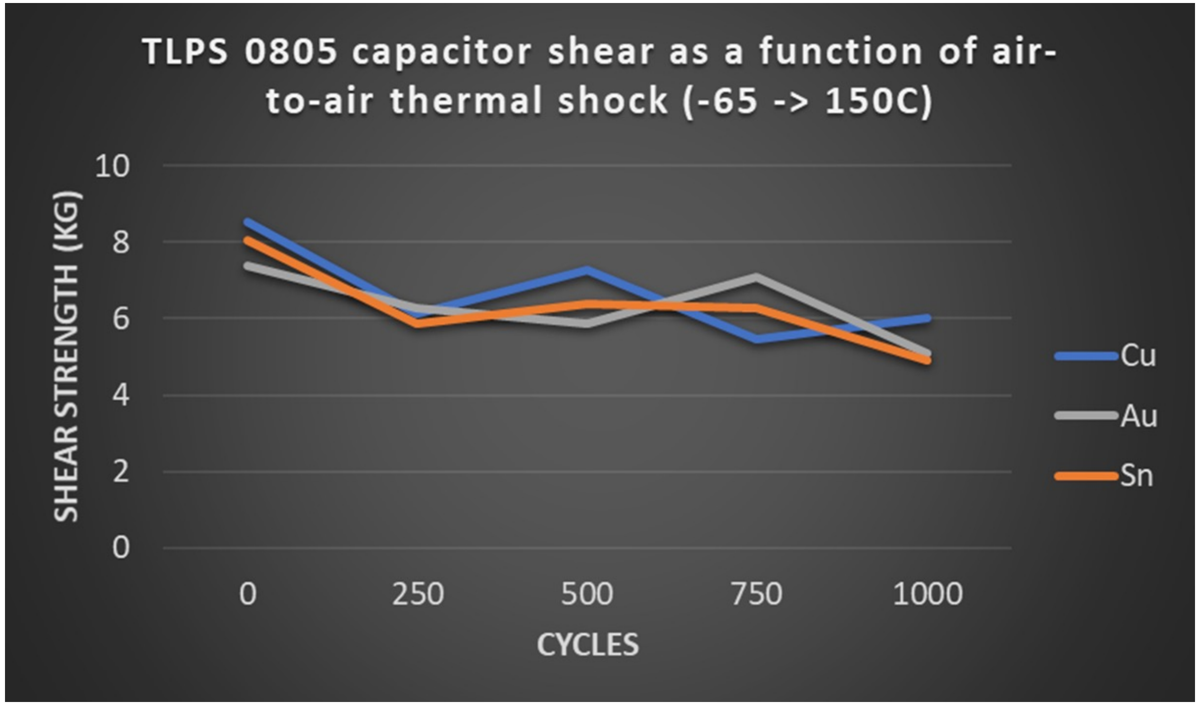
Surface finish versatility and high temperature stability in die attach



325°C shear values are equivalent to 260°C values on Au, Ag and Cu

Putting TLPS paste to use
Broad surface finish and geometry compatibility in SMT





TLPS will not liquify and ‘grab’ components, but sintered joints are stable across a variety of surface finishes and geometries

Summary

The power packaging industry is facing many of the same challenges and disruption as the packaging industry as a whole

- Modularity and integration
- Multiple assembly cycles and non-planar geometries

Solder and alternatives have limitations

- Remelt, pressure requirements, surface finish compatibility
- TLPS presents a versatile alternative

TLPS is not a single format or system – it is a platform

- There are many metallic systems that can exploit the TLPS mechanism

TLPS is a disruptive technology – but it's not new

- Enables new architectures for electrical interconnect and thermal transfer
- The challenge is to leverage the solder-like versatility while managing the differences

TLPS is a well-suited for assembly in power packaging applications