Michael Matthews, Ken Holcomb, **Jim Haley**, Rick Weaver
Dr. ES Barber and Catherine Shearer

Ormet Circuits, Inc.
10080 Willow Creek Road, San Diego, CA, 92131
Phone: 858.831.0010
Fax: 858.831.1437
Web: ormetcircuits.com

Biography:
Jim Haley brings twenty years of industry selling experience to Ormet Circuits with positions ranging from customer service to executive sales and marketing in early adoptive and fortune 100 companies.
Previous to Ormet, Jim was asked to join start up InNet Technologies in packaging a new component that joined two common industry technologies consisting of a RJ45 connector and magnetic interface module into one integrated component. Adoption of the idea was slow at first, but InNet prevailed and grew from a small lab in San Diego to five manufacturing sites in China and over forty million dollars in revenue before its acquisition.
Mr. Haley received his Bachelor of Business Degree from St. Norbert College in Wisconsin. He participates in several organizations relating to the electronics industry and is an active member in both IPC and IMAPS.

Title:
Lead Free Die Attach Technology for High Power Applications

Abstract:
The long historical use of lead based solders as the primary die attach technology used in semiconductor power IC packages and the impact of European legislation restricting the use of hazardous substances in these products is proving to be the catalyst for new advancements in materials. In addition to Lead, solders also contain a high proportion of volatile solvents and flux materials that are essential to the performance of the material in these applications. Transient liquid phase sintering materials offer a Lead-free and low VOC solution with equivalent reliability performance. This paper will explore the use Transient Liquid Phase Sintering (TLPS) materials to replace High temperature lead free solders and lead bearing solders in the packaging of Power Devices.

Introduction:
The restriction of the use of certain hazardous substances in electrical equipment (RoHS) was adopted in 2003 by the European Union and was originally set to be law by 2006. The difficulties in enacting this legislation have proven far greater the task than originally thought especially when focused on the high power IC packages for the semiconductor industries. Exemptions to the RoHS legislation have been extended as alternatives to Lead-based solders have failed to meet industry reliability requirements.

The community of electronic materials suppliers, semiconductor and IC assembly companies persist in their progress to identify environmentally friendly solutions that are as robust as Lead-based solutions.

The Electronics Industry has been implementing alternatives to PbSn solders in the effort to reduce environmental impact of assembly materials in the environment and reduce the toxins that are buried in the earth after the device reaches maturity. Many of the efforts studied looked at SnAgCu alloys, SnBi eutectic solder, Ag Nano particle sintering and Ag plated Cu-based sintering metal alloys. This paper studies the use and provides data as it relates to the installation of TLPS pastes and its applicable segments in replacing PbSn solders for power device packages.

Market:

The target market to replace solder die attach materials with TLPS materials is in high-power semiconductor applications such as Thyristors, Mosfets and IGBT's. These component devices and packages require excellent electrical performance of the die attach materials, and also have a significant thermal management aspect to their design. Other applications include motor control, HBLEDs, solar concentrator cells, and RF and microwave circuits used in radar and telecommunications equipment.
From a packaging perspective, there are a number of common requirements for all these high-power applications: they must manage high electrical currents, dissipate large amounts of heat, withstand thermal expansion-induced stresses for high reliability, and this must all be accomplished at low cost. RoHS regulations also add some new dimensions to these considerations.

Problem:

Many high power semiconductor packages primarily dissipate heat through the Die Attach material. It is typically the first material between the die and heat spreader and must provide critical thermal characteristics in order for the die to perform at peak operating levels. Several characteristics contribute to the proper performance and are well known and understood in the assembly materials today. The main contributors are the thickness of the die material, bulk thermal conductivity, thermal resistance between the interface of the die and heat spreader along with its ability to be set in a package supporting the die.

Electrical conductivity is a critical property in the performance of high power semiconductor applications. Good conductivity provides a path for electrical signals and with little resistance promotes good thermal dissipation through the package. Electrical efficiency in the packaged device is influenced by the material choice used for the die attach layer. The material choice sets the stage for the electrical resistance (RDson) performance. If the die attach material provides good electrical conductivity, the Rdson performance of the device will remain consistent, thus ensuring a predictable performance of the device.

Many physical properties of the semiconductor packaging materials contribute to the complexity of die attach material selection for use in power IC devices. PbSn solders have been effective for the assembly and reliability performance of power die in the past, and demonstrate why the transition is difficult with many power products today.

Many of the issues with finding a suitable replacement for Lead are based on the die attach materials response to the Thermal Coefficient of Expansion (TCE) of the disparate packaging materials in the device. Most semiconductor die is made from brittle, crystalline materials with a low TCE, and with copper based lead frame with a much higher TCE. The thermally induced stress between these two materials can cause cracks and delaminations in the die attach material resulting in the electrical failure of the device. Below is a list of key factors when considering suitable replacements for PbSn solders:

Die Size
Modulus
Die attach temperature
Curing temperature
TCE between substrate and Die
Pad Flatness

Beyond technical complexity of assembly and reliability performance enters the next critical property in selecting the proper die attach material; cost. Material costs include assembly along with die attach material price. Manufacturing throughput and yield is well characterized as they relate to PbSn solders but new material sets are being explored and the assembly means can be quite different and offer poor results if the application process is not followed succinctly. Many alternatives to Pb-based solders use a high proportion of precious metals such as silver or gold in their compositions. As a result, these materials may eventually meet the technical requirements for a low VOC, Lead-free die attach solution, but fail to become an economically viable option for high volume replacement of Pb-solders.

There is a wide offering for materials in use by an array of applications. The applications range from popular PbSn solders to higher performing metallurgies such as Gold-based solders. Silver filled conductive adhesives are often used as die attach in small packages requiring low amounts of heat dissipation. They have been used in and are used in HVM environments in less heat sensitive die packages. Their disadvantage typically falls to two areas consisting of cost and poor interfacial electrical resistance after reliability testing. Between the substrate and die, high modulus the large differential in TCE typically causes stress that leads to the die cracking or an increase in electrical resistance. As the package becomes stressed the adhesively bonded interface to the die or lead frame surface degrades and the resulting shift in electrical performance leads to inadequate results for the long-term performance of the package.

TLPS Solutions:

TLPS MATERIAL

Transient liquid-phase sintered (TLPS) material is a composite metal-based material that undergoes some dynamic structural changes during low-temperature heat treatment. It has been used for a number of years as a via-fill paste but is now being utilized as a die attach material for power semiconductors. The die attach layer comprises three distinct metallic phases: pure copper, CuSn intermetallic compound phase, and Bi metal. There is also a small volume of an organic phase present, but the weight loss of TLPS materials during sintering is much lower than that of solder-based materials. The copper-colored phase is Cu, the dark grey is CuSn, and the light grey phase is the Bi. The dark isolated spots are the organic filler.

There are a number of key points which can be seen in the microstructure of First is the high volume of copper-containing phases. This is a key point because these phases carry both electrical current and heat conduction. A second key point is the metal-metal interfacial structure between the copper particles on either side of the die attach layer and the metal components (Cu, CuSn, and Bi phases) in the die attach layer. This metallic bonding between the die attach material and surrounding metal is the key distinguishing characteristic of the Ormet technology, and also results in low interfacial thermal resistance.

During processing, the low-melting SnBi alloy melts, enabling the Sn to create a fused inter-metallic network between the copper particles, the metallization on the back of the IC and the lead frame. The resulting continuous metal network is highly conductive and exhibits electrical and thermal stability above 265°C.

Because of the presence of a continuous metallic phase, the thermal conductivity of the TLPS material ranges between 25 and 60 W/m-K, comparable to Pb-based solder. From a mechanical standpoint, the material is less ductile than solder due to the presence of CuSn inter-metallic compound (IMC) phases, but is more ductile than many Ag-filled epoxy formulations.

Summary:

TLPS materials are an attractive alternative to PbSn for IC power device packaging. They provide a low VOC composition, lead free die attach solution that meets the RoHS guidelines. TLPS materials also demonstrate the desired electrical and thermal reliability properties demanded by these devices. Industry changes to green compositions and cleaner assembly materials normally draw great cost increases due to change of operation. TLPS materials are managing the technical properties for conductivity and thermal drain at lower costs than the precious metal-containing materials being offered today as Pb-free die attach options for IC power device packages.

Lead Free Die Attach Technology for High Power Applications

Rick Weaver
Michael Matthews, James Haley Catherine Shearer
and Dr. ES Barber
Ormet Circuits, Inc.
10080 Willow Creek Road, San Diego, CA, 92131
p: 858.831.0010, f:858.831.1437, ormetcircuits.com

Contents

- The Problem and Goal: Lead-free electronics
- Transient Liquid Phase Sintering
- Material Properties
- Functional Performance
- Summary

The Problem: Lead

- Lead: **Environmental and health danger**
- Health dangers:
  - – Neurotoxin: accumulates in soft tissues & bones
  - – Damage to organs & nervous system
    - Children at greatest risk
  - – Causes brain disorders
- Environmental dangers
  - Affects fish and animals

Lead is Useful in Manufacturing Electronics

- Use of Lead containing solders in PCB assembly
  - Eutectic PbSn63 solder has been used for soldering components onto a printed circuit board (PCB)
  - Pb-free solutions for PCB Assembly
    - Lead-free solders broadly implemented: SAC Alloys
- Use of Lead containing Solders as die attach materials
  - PbSn5 commonly used for die attach applications
    - Excellent electrical and thermal conductivity
    - High reliability
    - Low cost
    - Compatible with Pb-free PCB reflow processes used in PCB Assembly

No drop in solution to replace Pb-based solder for die attach

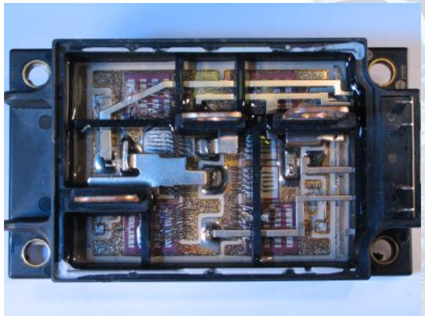
Legislation Status

- European (ELV) Directive mandates conversion to environmentally friendly materials
  - Exemptions in place for applications where no Pb-free solution is known
  - Exemption review planned in 2014;
  - Exemption will be cancelled immediately if a solution is available
- European RoHS Directive (2002/95/EG)
  - Restricts the use of hazardous substances in electrical and electronic equipment
    - Exemption valid until 2016

Pb-free die attach requires a new technology to meet industry goals.

Target Applications

- Power Modules
- MosFETs
- IGBTs



Performance requirements vary by application, and may require different die attach solutions.

Candidate Lead Free Die Attach Materials

- Pb-free solders
- Silver sintering
- Conductive Adhesives
- Transient Liquid Phase Sintering

Technology Limitations

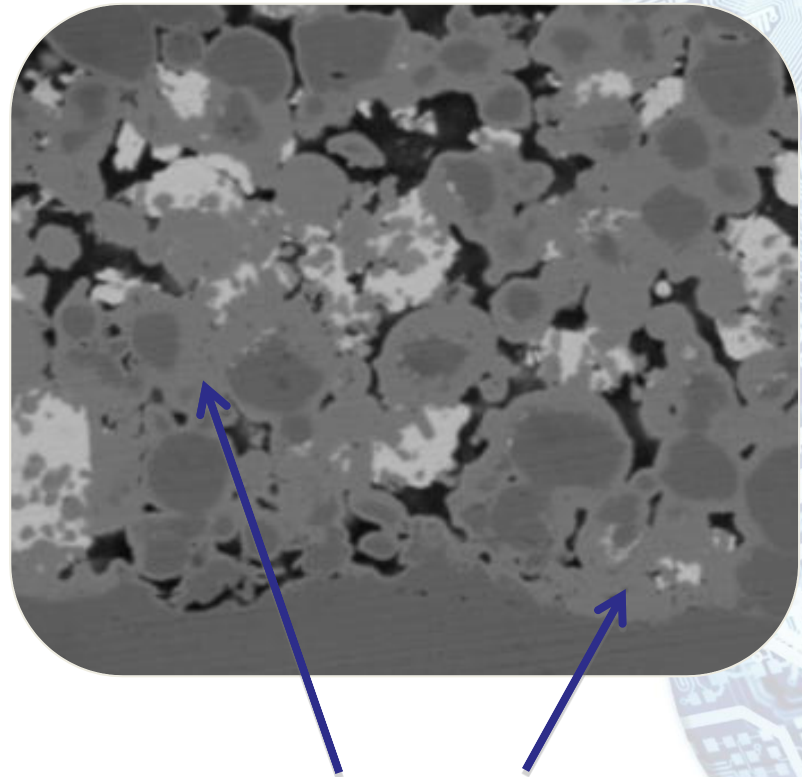
- Lead-free solders
  - + Low cost
  - – SAC alloys remelt during PCB assembly
  - – Gold-tin solders are mechanically rigid, and expensive
  - – BiAg solders have shown cracking and wetting issues
- Silver sintering
  - + High thermal conductivity
  - – Only bonds to silver or gold surfaces
  - – Expensive
- Conductive adhesives
  - – Unstable electrical performance after reliability testing

Explaining Transient Liquid Phase Sintering (TLPS)

Liquid Paste Before Cure

Copper and alloy particles
in a liquid organic formulation

Sintered Network After Cure

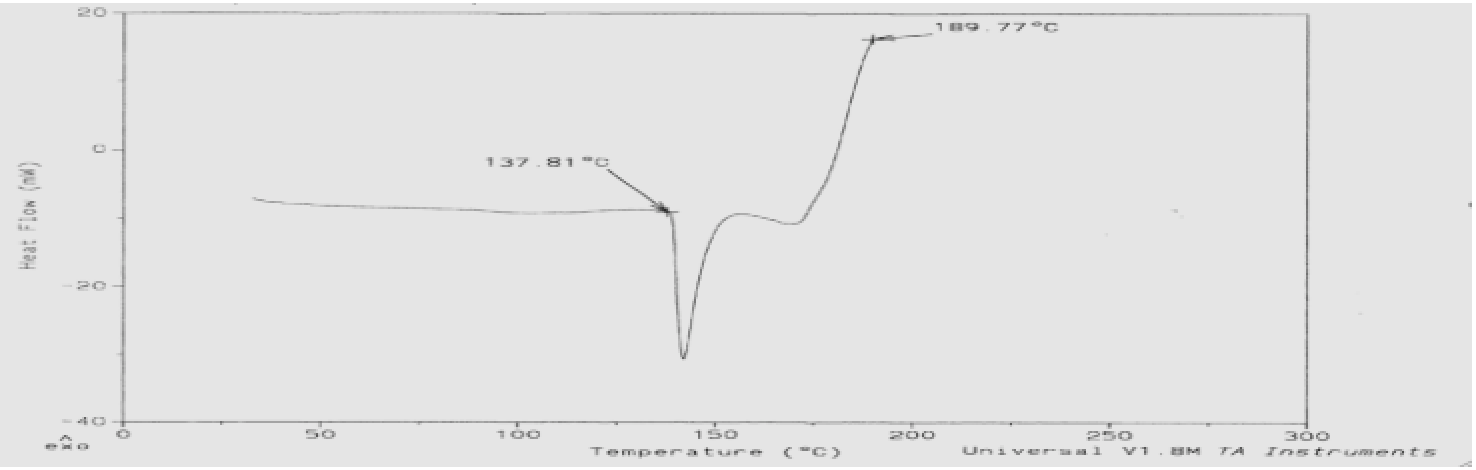


Sintered metal network

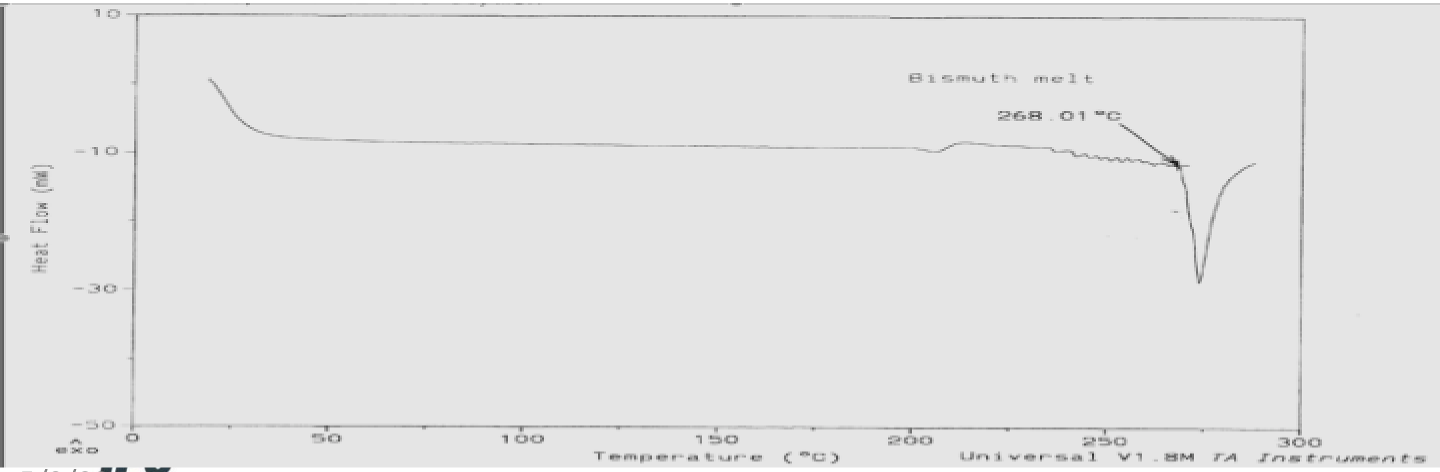
Proprietary Organics, Metal Powders and Alloys using
Transient Liquid Phase Sintering Process (TLPS)

TLPS Materials
Do Not Remelt After Cure

DSC Analysis of Ormet 700 Lead Free Composition



Cure Process showing sintering



Second thermal cycle, no re-melt below 265ºc.

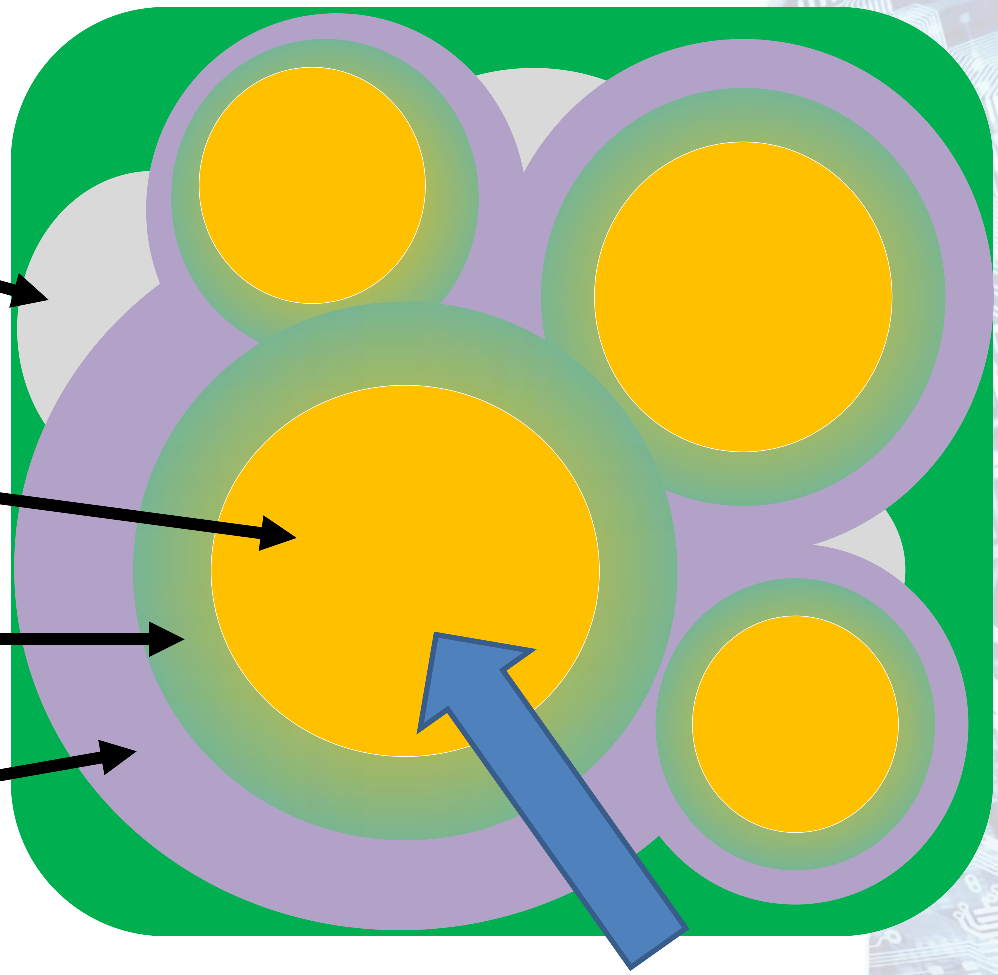
TLPS Material Are Thermally Stable Above Pb-free Solder Reflow Temperatures

Bismuth
Melt 267° C
10-16% of total matrix

Copper
Melt 1085° C

Cu_3Sn intermetallic
Melt 640° C

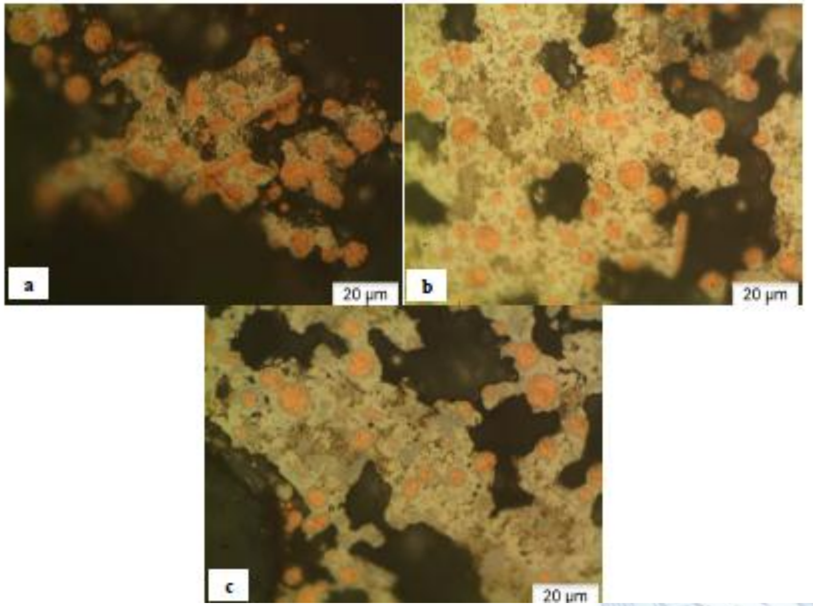
Cu_6Sn_5 intermetallic
Melt 415° C



Direction of tin migration

The TLPS Network Forms at Low Temperatures

- Exposure to higher temperatures
  - Does not change or damage the network structure
  - Redistributes the phases in the microstructure of the network to an equilibrium state
  - Electrical and thermal conductivity will change somewhat with phase redistribution
  - Once phase equilibrium is reached, the conductivity remains constant

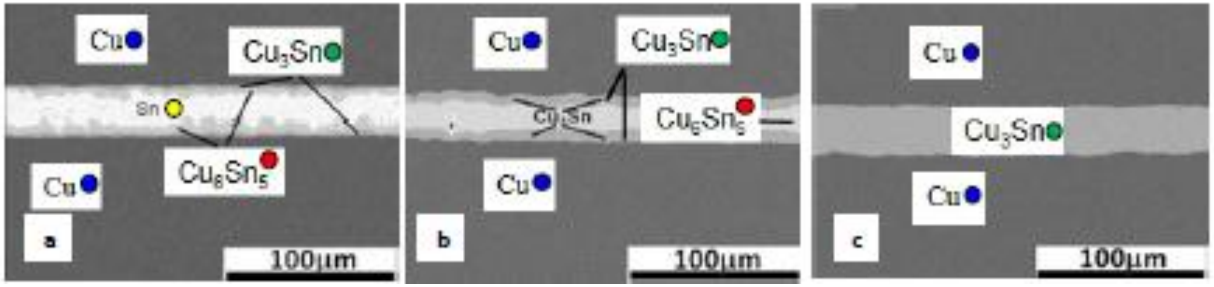


TLPS paste microstructure after exposure to 180, 205 and 215°C respectively

"Low Temperature Lead-Free Assembly via Transient Liquid Phase Sintering," Joseph Flanagan, Evan Anderson, Heehun Bae, Kirstyn Sudhoff, Carol Handwerker, Purdue University; Richard Parker, Delphi Electronics and Safety

Attributes of TLPS Adhesives

- "…can be processsed below the device's operating temperature to form solid phases without remelting when heated to the operating temperature."
- "Due to the metallic elements involved, TLPS systems can have high thermal and electrical conductivity."
- "…conceptually suitable for any application in which conventional solder is already used,"
- "…one particularly attractive option…is to use TLPS as an alternative thermal interface material."



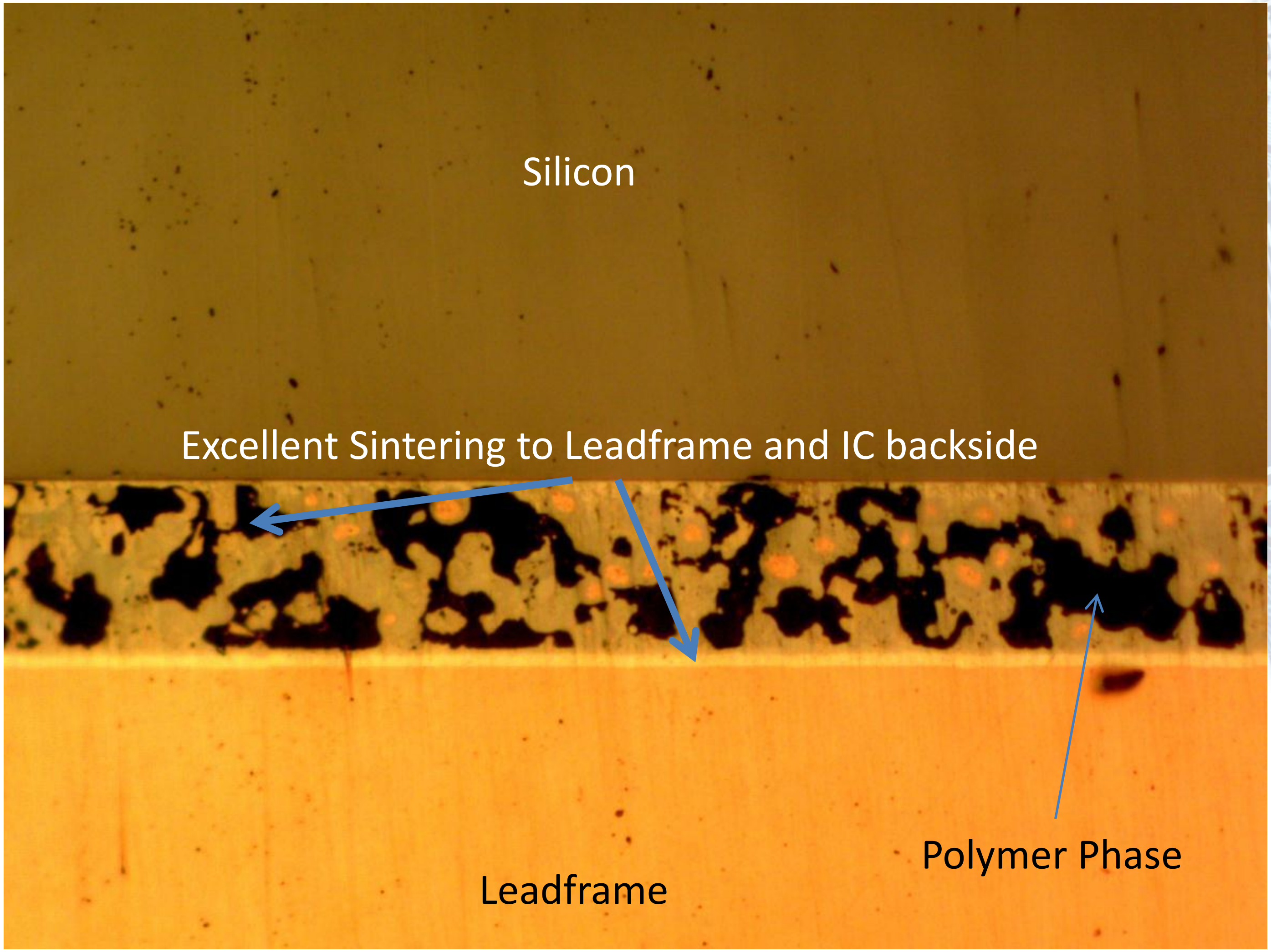
An example of TLPS using tin and copper foils annealed at 340°C (so that the tin foil is liqufied)

"Low Temperature Lead-Free Assembly via Transient Liquid Phase Sintering," Joseph Flanagan, Evan Anderson, Heehun Bae, Kirstyn Sudhoff, Carol Handwerker, Purdue University; Richard Parker, Delphi Electronics and Safety

TLPS Provides
Enabling Materials Technology

- Low temperature metallic joining
  - Processing temperatures between 175-205C
- Compatible with Pb-free solder reflow profiles
  - Thermally stable up to 280C
- Superior shear strength versus conductive adhesives at elevated temperatures
  - Metallic joining 25%+ higher strength versus adhesives
- Pb-free & Halogen-free composition
  - Copper and Tin/Bismuth alloys
- Excellent Electrical and Thermal Conductivity
  - <100 uohm-cm volume resistivity
  - 15-30 W/mK Thermal Conductivity

Sintering to the Die and Leadframe is Key to Achieving RDson Performance



Typical Product Properties

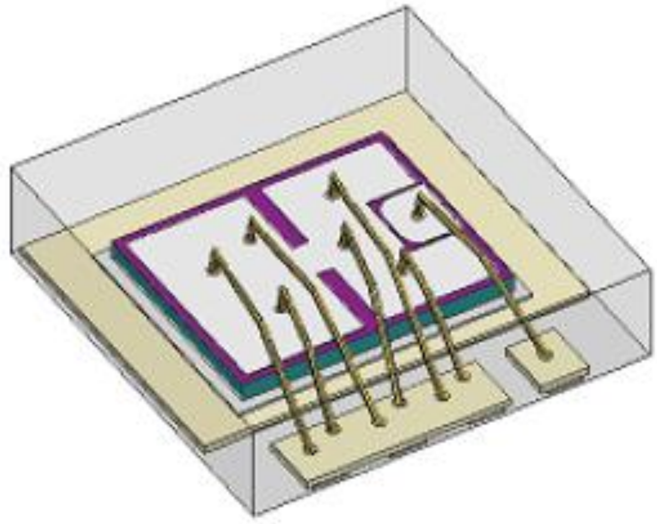
Cone & Plate type Brookfield viscometer
Spindle # : CP 51 @25C

		Product A	Product B	Product C
Viscosity, (cP)	0.5rpm	75,000	56,000	94,000
	5.0rpm	38,000	25,000	52,000
Thix. index	0.5/5.0	2.0	2.2	1.8
Electrical Conductivity	µohm-cm	<100	<100	<100
Thermal Conductivity	W/mK	14	22	30
Cure Profile		45 minute ramp to 205C + 90 minutes at 205C	45 minute ramp to 205C + 90 minutes at 205C	60 minute ramp to 240C + 30 minutes @ 240C

Good rheological properties for dispensing and printing applications

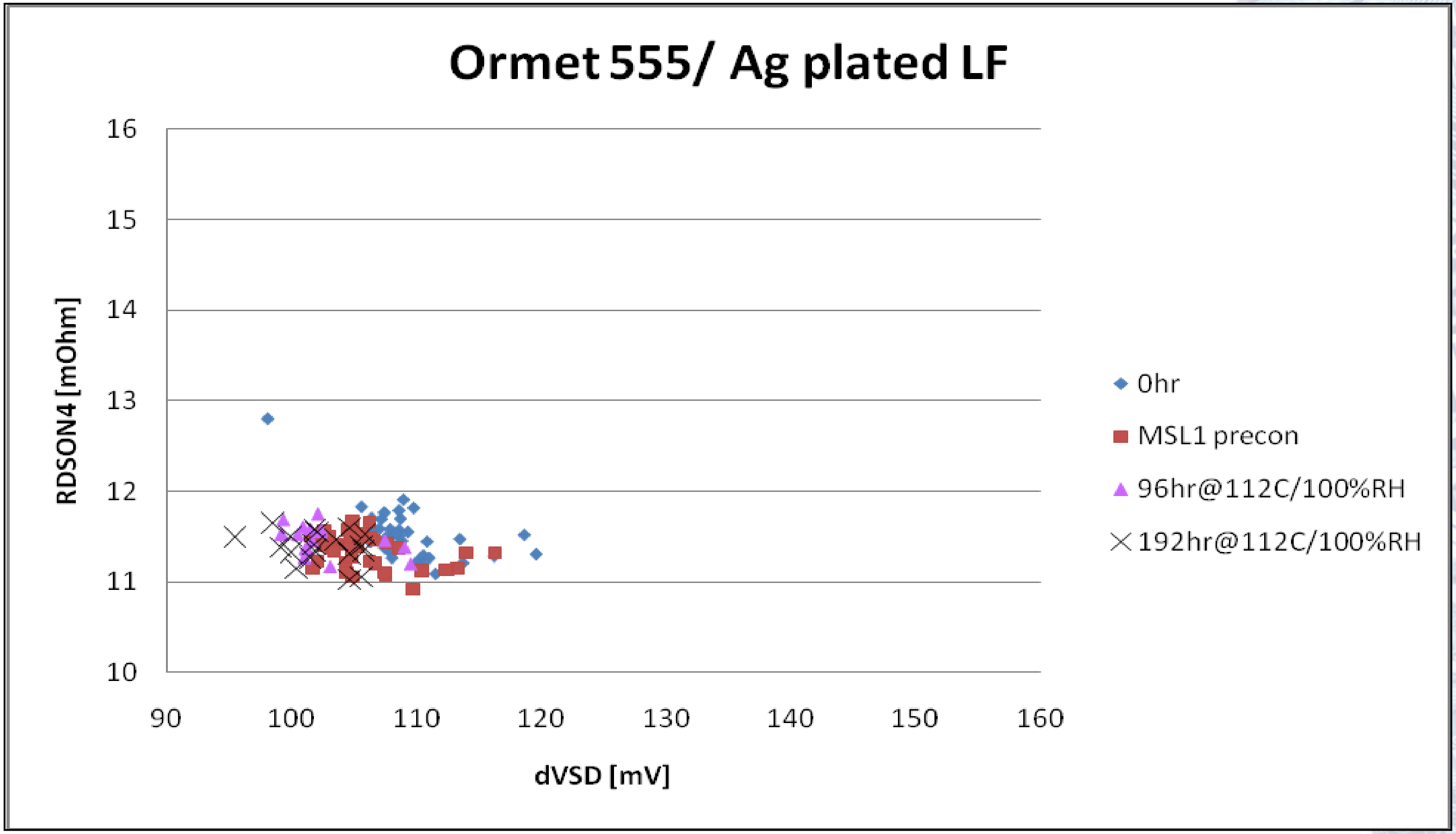
TLPS Die Attach Performance

- Test carrier: medium power MOSFET product
  - Package: 3.3x3.3mm QFN
  - Lead frame: Ag-plated copper
  - Die: 2.2x1.7x0.15mm
  - Backside plated with TiNiAg
- Measured are:
  - dVSD – a measure for the thermal resistance of the die attach material
  - RDSON – the electrical resistance of the package, including die attach material



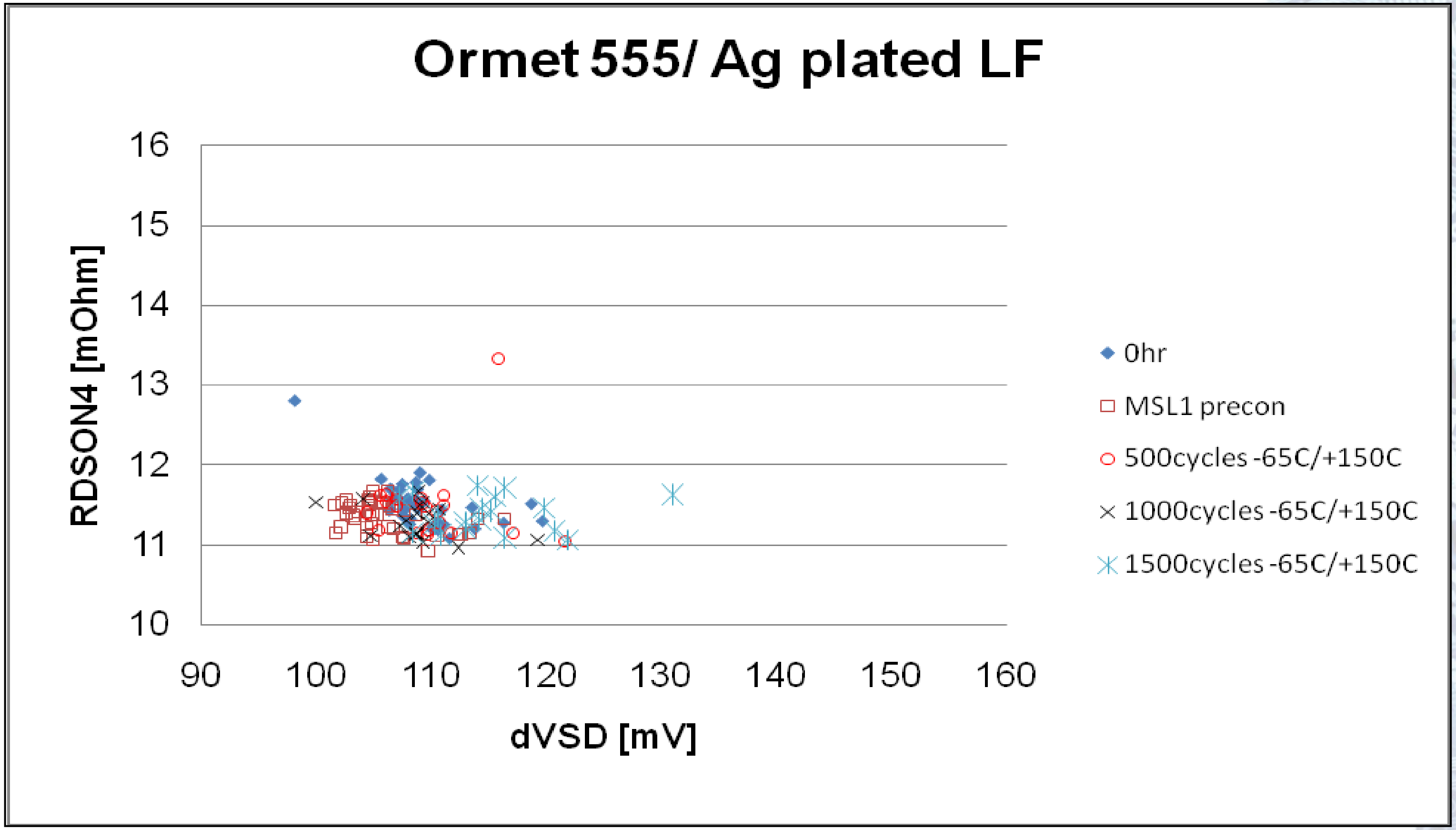
Functional Data, Moisture Resistance

MSL1 preconditioning: no effect on die attach resistance
PPOT (192hrs): no effect on die attach resistance



Functional Data, Temperature Cycling

MSL1 preconditioning: no effect on die attach resistance
TMCL (1500 cycles) :1 sample starts to degrade
Comparison: Pb-solder degradation starts after 1000 cycles



Summary

- Transient Liquid Phase Sintering materials have many of the advantages of solders and conductive adhesives
  - Low processing temperature
  - High thermal and electrical conductivity
- TLP-based die attach materials are able to replace High-Pb solder for die attach applications.
- Transient Liquid Phase Sintering materials enable customers to meet next generation device requirements
  - Low cost PCBs for mobile applications
  - Pb-free assembly materials for Semiconductor Packaging
  - High density flash memory packaging for mobile devices