IPC Electronics Midwest 2010

Die Attach Solder Materials and Application Technology

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Biography:

Brian J. Toleno, Ph.D. is the Director of Technical Service and Application Engineering for Henkel in Irvine, California. Brian obtained a Ph.D. in analytical chemistry from Penn State University, and his B.S. in chemistry from Ursinus College. Brian is an active member of SMTA, and is active within the IPC serving as the under fill handbook committee (J-STD-030) chairperson and vice-chair of the Solder Paste Standards Committee (J-STD-005). Brian has written courses on under fill materials, Pb-free soldering, and failure analysis. He has also authored many publications for trade journals and peer reviewed publications on various aspects of materials in electronics, and two chapters for electronic engineering handbooks on adhesives and materials.

Executive Summary

Advancing technology frequently requires an accompanying advancement in materials technology. Recently, these advances are also driven by changes in environmental legislation as well. Specifically, the RoHS legislation has mandated a move away from lower-temperature Sn/Pb solders to higher reflow temperature SAC alloys on the PCB assembly. This change in reflow temperature drives changes to materials used inside packages as well. In addition to material composition changes, component geometry, spacing, and design drive new process capability. In this paper we will discuss the testing and evaluation of a new die attach solder paste material, the design considerations for both process and alloys. We will discuss the requirements for these materials used in high power packages and the material properties needed to deliver on these requirements.

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Die Attach Solder and Solder Alternatives
IPC Midwest 2010

Mark Currie, Dan Maslyk, and Brian J. Toleno

September 2010

Passive/Discrete Market

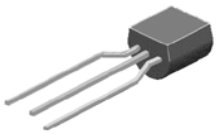
- **Power Discrete devices dominates solder D/A market**
  - High power/large discretes use solder
  - Low power/small discretes use adhesive

Packages	Interconnect solution	Packages
SO23, SOT223….	Epoxy	Small
TO 92, TO 126	Epoxy and Soft Solder	Discretes
TO 220, TO 218, TO 247, TO 264, TO 251	Soft Solder (high Pb)	Power Discretes

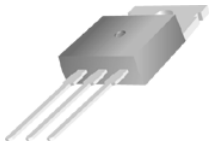
- **Dominated by solder – high Pb solder**
  - High Pb-solder currently exempted by RoHS (2013)
  - D/A interconnect solution driven by thermal and electrical considerations

Package outline – Power Packages

TO Package

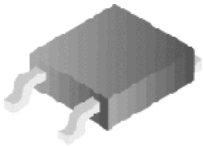


TO 92

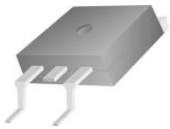


TO 220

TO 247

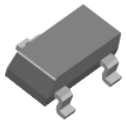


TO 252

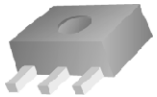


TO 263

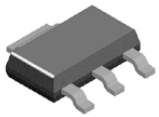
SOT Package



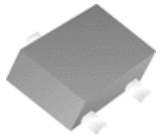
SOT 23



SOT 89



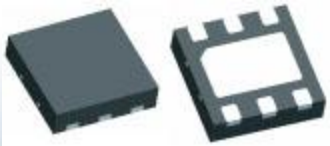
SOT 223



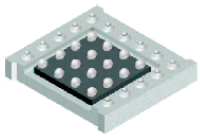
SOT 523

SOD 323

Others



MLP



WLCSP

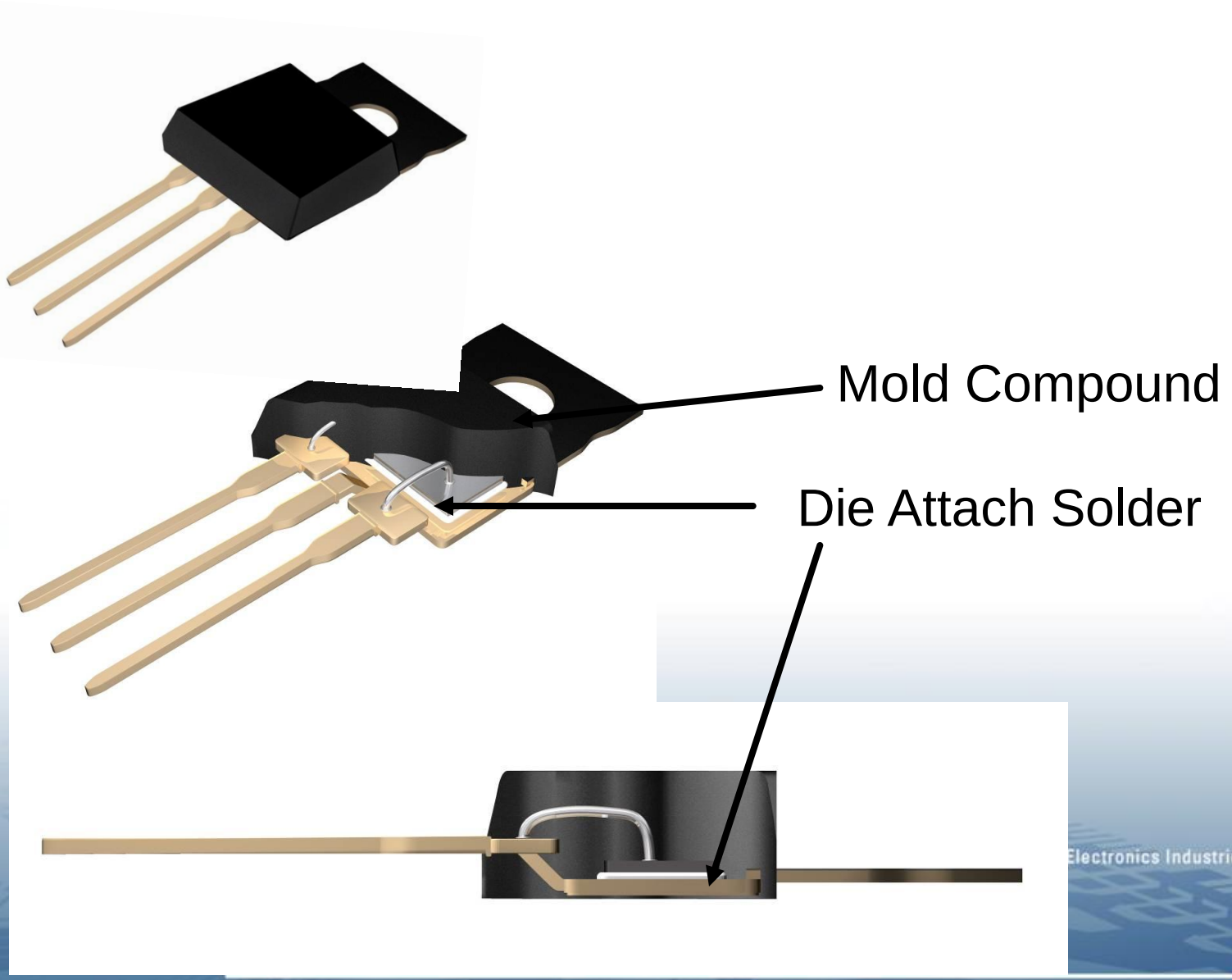
BGA

End market – wave soldering, automotive – reliability challenged

Solder vs Adhesive

- Solder is used for the following reasons:
  - It has the highest thermal & electrical performance in the industry
  - Lowest cost solution
  - Well suited for small die applications on leadframe
- Solder is not used in every solution due to:
  - Limitations in die size
  - CTE mismatch
  - Large die

T0-220



RoHS Status

- The future wording exemption 7a is proposed as:

  “Lead in high melting temperature type solders (i.e. lead-based alloys containing 85% by weight or more lead) until 30 June 2013, and lead in such soldes fo rthe repair and reuse of equipment put on the market before 1 July 2013.”

- The new wording is proposed as follows:

  “Lead in solders to complete a viable electrical connection between semiconductor die and carrier within integrated circuit flip chip packages until 31 July 2014, and for the repair, or to the reuse, of electrical and electronic equipment put on the market before 1 August 2014.”

Solder Alternatives

- Silver filled adhesives are widely used in die attach applications in many other devices
- Epoxy and adhesive matrix is “naturally” non-conductive, filler used to achieve conductivity
- Can these materials reach the same level of thermal performance in high power packages?

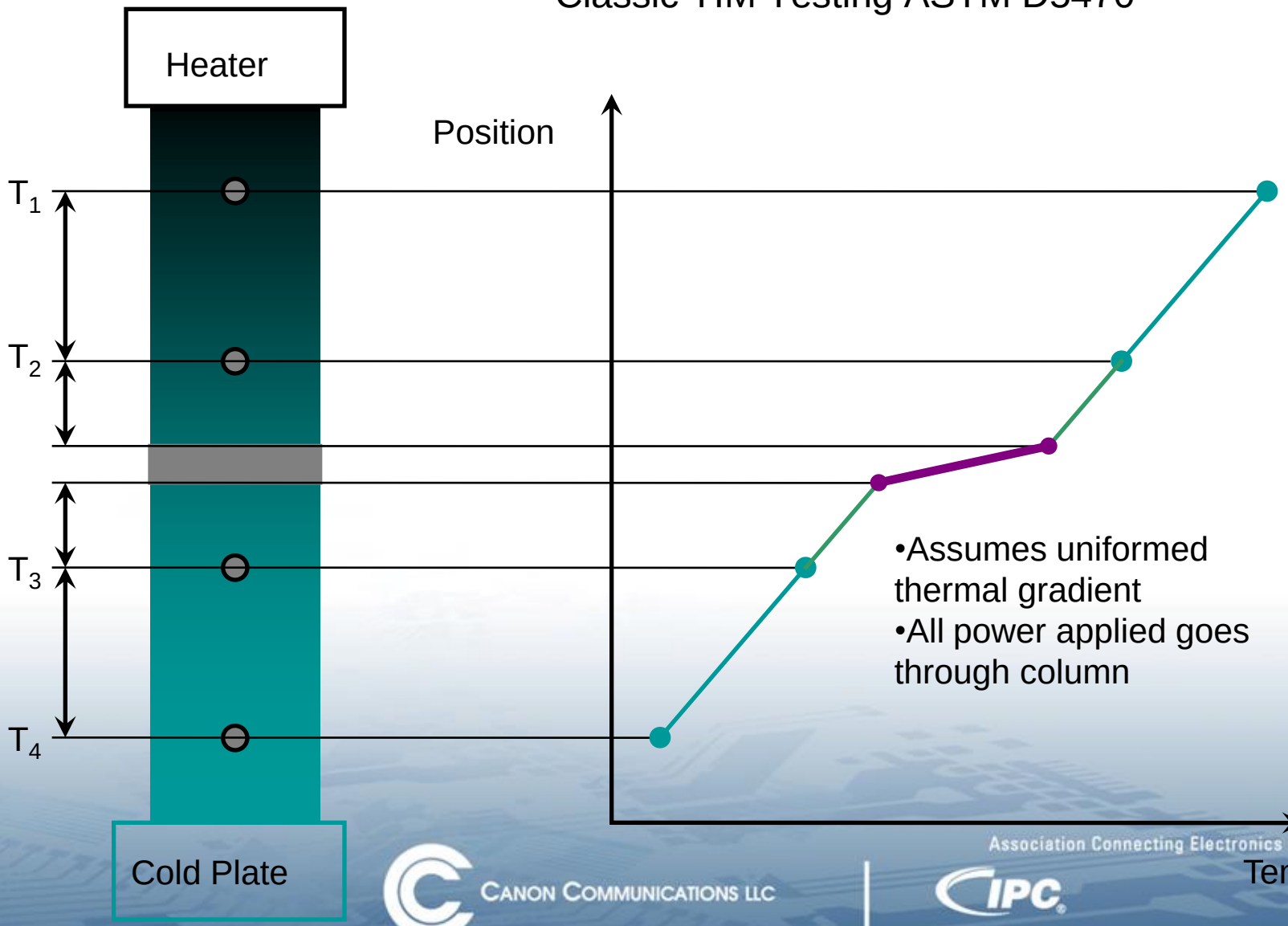
Thermal Resistance

$$\text{Thermal Resistance} = \frac{T_1 - T_2}{\text{Power}} = \text{K/W}$$

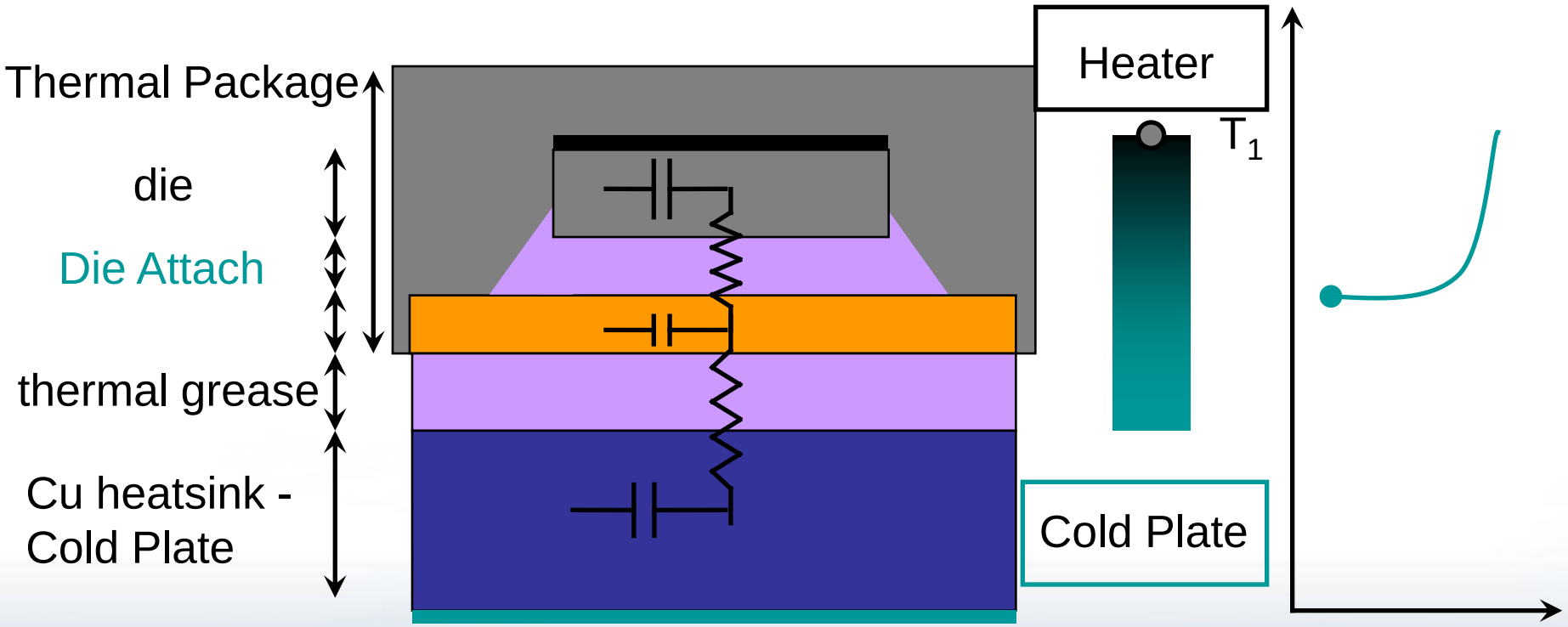
- Thermal Resistance is application specific
- Thermal Conductivity is a bulk property

Steady State Test Method

Classic TIM Testing ASTM D5470

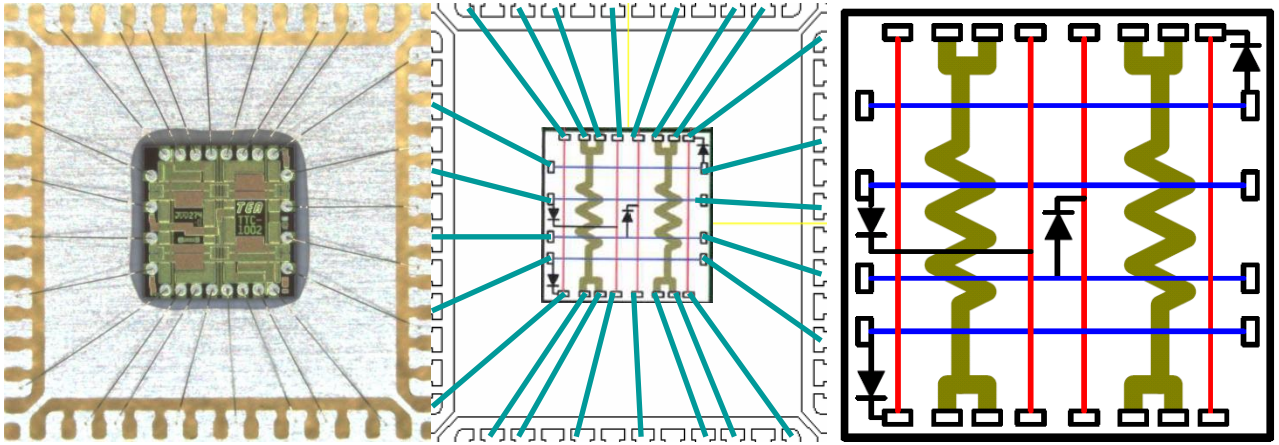


Transient Thermal Package Testing



- All power applied goes through column
- Starting point in equilibrium

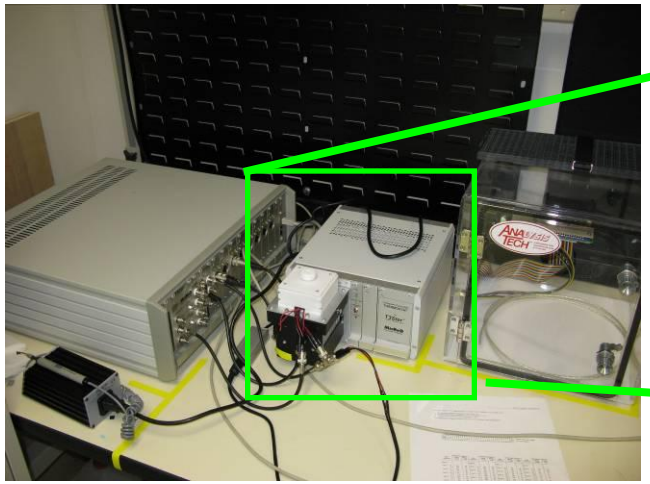
Test Die

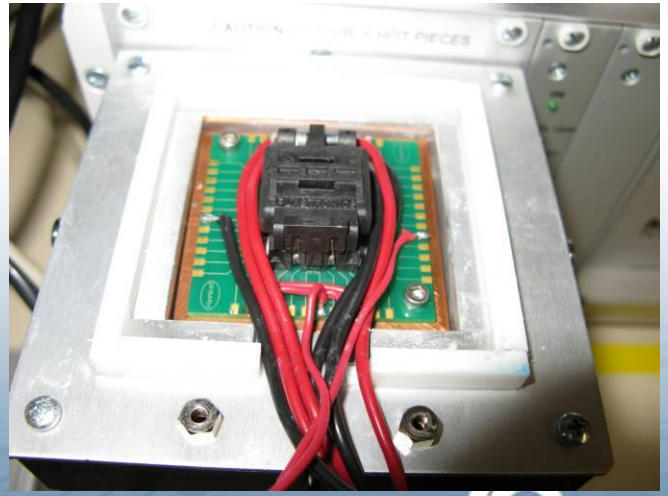


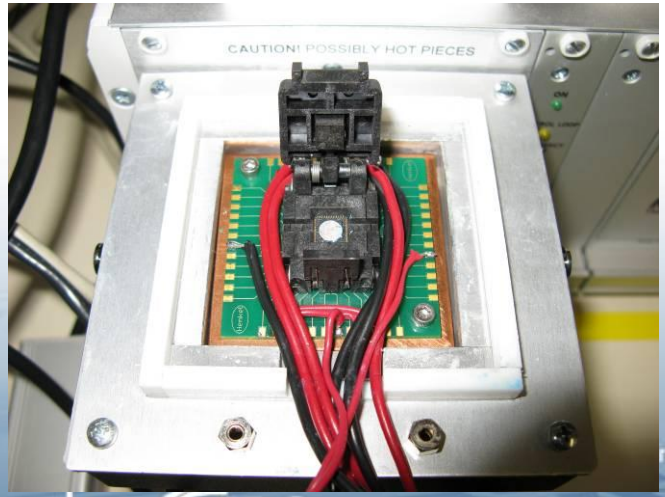
- **Separate heating source from temperature sensor**
- **4 temperature sensors**
- **Backside Metalization : Bare Si, TiNiAg, Sourcing Au**

Electrical – Heating	TTC-1002
Die Size	2.54mm
# of Resistors	2
Resistance Value	7.6 Ω ±10 % (each resistor)
Resistance Variation	±5 % (for die from a specific wafer)
Max Resistor Power	6 W (6V @ 1A) each
Connection	Force & Sense wire bond or bump pads
Resistor Coverage	>85% of die area within wire bond pads

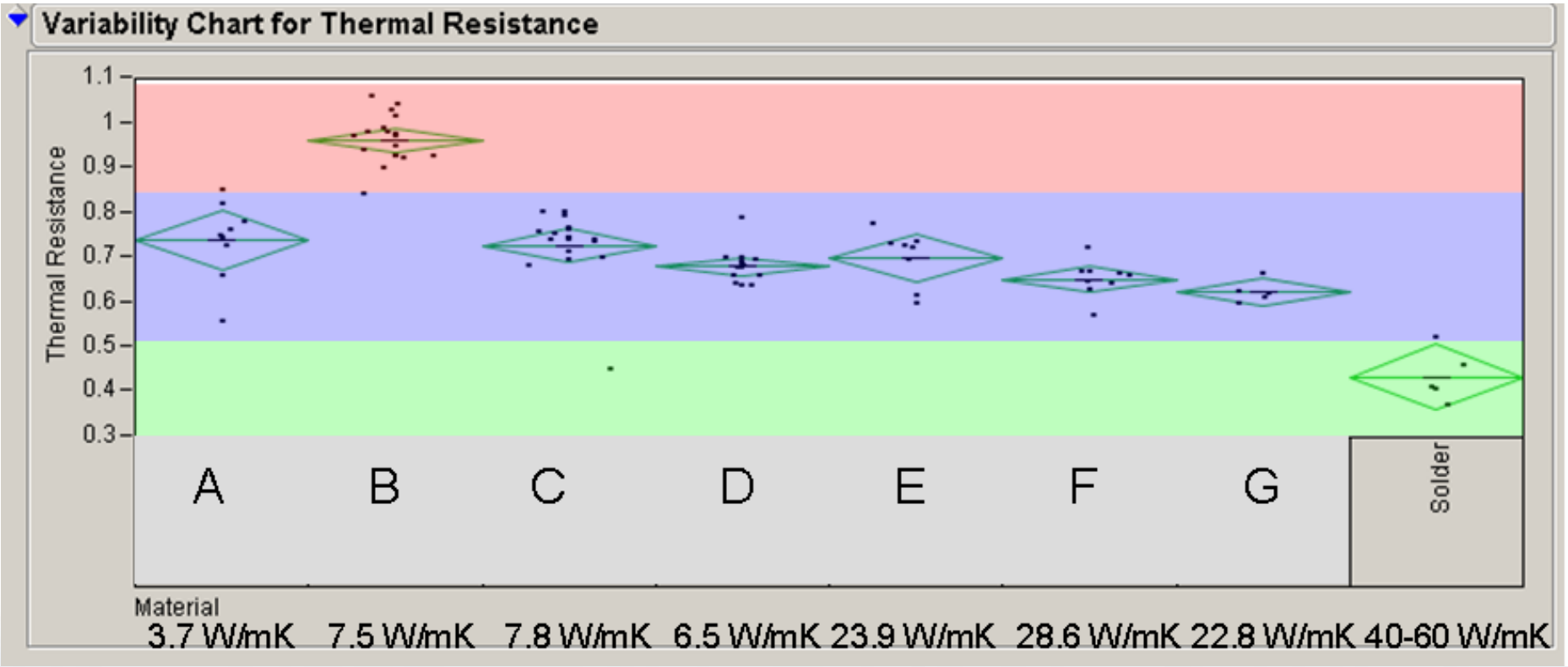
Henkel Test Setup







Thermal Performance of conductive adhesives



Note that bulk conductivity (along the bottom) doesn't always correlate with low thermal impedance (y-axis)

Adhesives versus Solder

- Conductive adhesives eliminate the need for Pb, cleaning steps, and also reduce the chance for voiding
- Conducive adhesives continue to make improvements in conductivity
- Still not yet approaching the conductivity of solder materials
- Conductive die attach materials suitable for most applications, in areas where a very high level of electrical and thermal conductivity is needed solder is still used

Die Attach Solder

- Where die attach solder is used….
  - Fast repeatable application methods are required
  - Low voiding is required
  - Reflow above SAC temperatures is required
    - Ability to be compatible with multiple high-temp alloys is desirable

Discrete Assembly Process

Materials/Inputs
Leadframe and solder paste
(Discrete; Asymtek, Alphasem..)

Die Placement
Equipment: Datacon apm+, ESEC 2007 and ESEC 2008

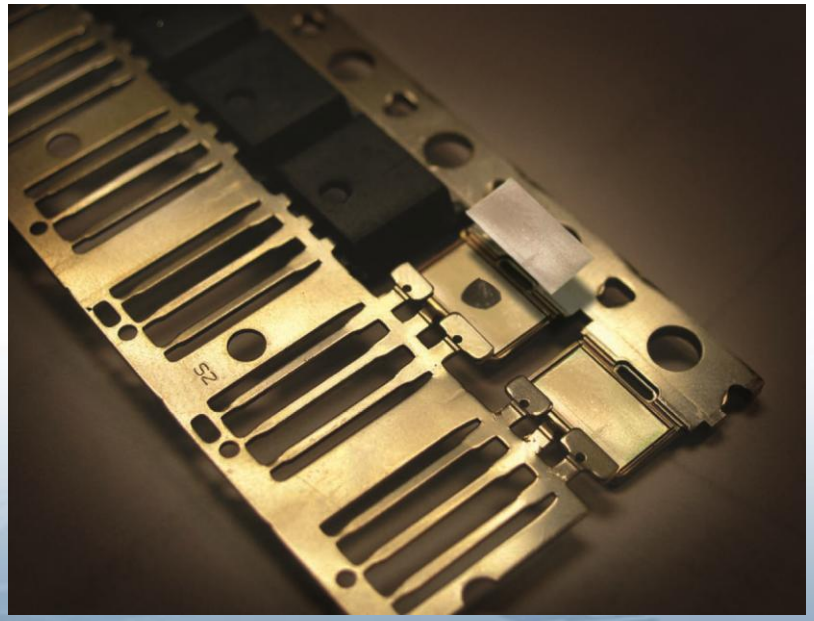
Reflow
Under forming gas or N_2 Environment

Flux Cleaning
(1) ultrasonic solvent bath at 55° C for 5 min and (2) ultrasonic DI water bath at 55° C for 1 min

Plasma
March Plasma
Time: 120 sec
Power: 125 W
Gas: Ar

Wire Bonding
Equipment: ESEC 3100
wire bonding @ 200C

Molding
Equipment: Lauffer
Cure: 120 sec @ 175C



Discrete Assembly Process-Dispense

Dispense

- **Compatible with high-Pb and non-Pb solder alloys**
- **Enhanced dispense capability – excellent pause time**
- **Excellent Dot-Dot dispense consistency**

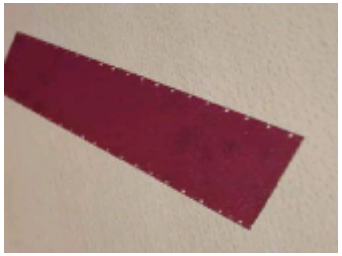
Reflow

- Excellent wetting
- Reflow process window determined – first for market
- Self Filleting

Post Reflow

- Cleaning of flux post reflow with several solvents
- Low void incidence
- Passes all reliability flux programmes
- Classified as ROLO by J-std 004-A
- Twelve-month frozen storage stability

Dispensing in Alphasem 8033

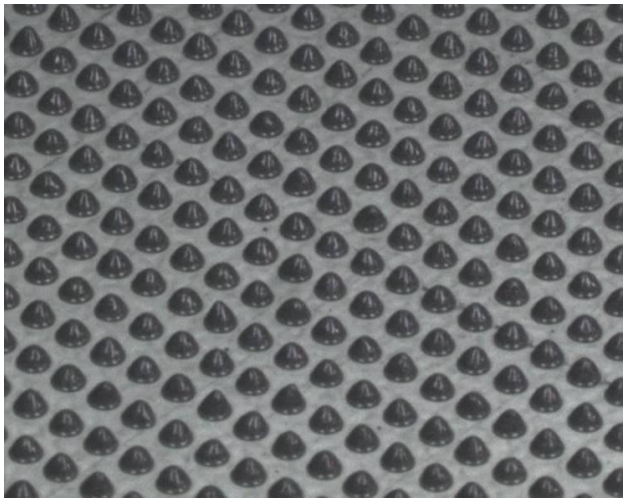


Unstamped copper lead-frame 1.5mm x 1.5mm Au finish die placed

- Excellent repeatability throughout
- 6000 dots – no issue using gauge 22 needle (0.4mm ID) with type 3 powder
- Also validated on Asymtek equipment

Dispensing

Dispensing Consistency



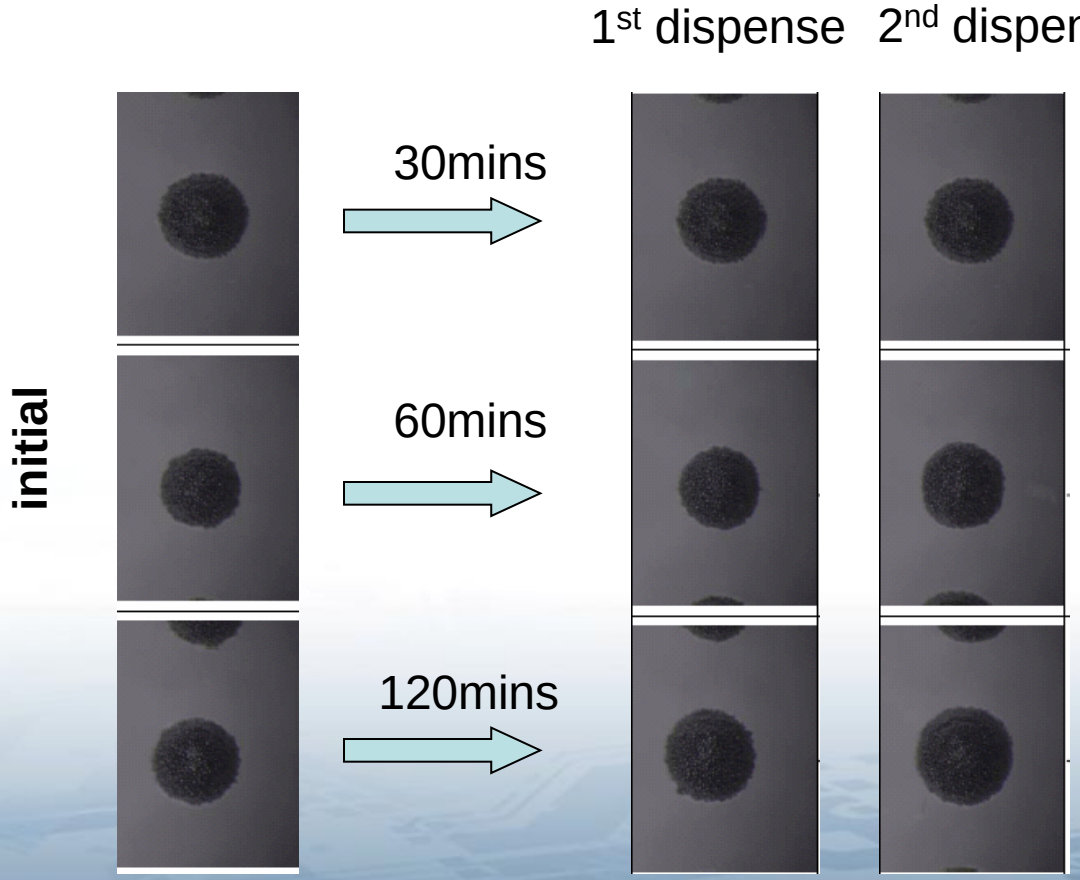
Solder Particle Size (microns)	Needle Inner Diameter (mm)	Gauge	Dot Size (mm^3)
45-75 (AGS – type 3)	0.41	22	1.8×10^{-2}
25-45 (AGS – type 3)	0.33	23	9.4×10^{-3}
10-25 (AGS – type 4)	0.25	25	4.1×10^{-3}

To assess gauge dispensability, the solder paste is:

- Tested for homogeneity in the syringe – key to have no void entrapment that would cause dot volume variability
- Repeated first dot to 6000 dot dispensing – no issue using customer gauge needle
- Validate capability on various industry standard dispensing equipment
  - 40,000 dots with gauge 22 and 23 (type 3 powder)
  - 40,000 dots for gauge 25 (type 4 powder)
- Market moving towards type 4 requests

Dispensing – Pause time effect

- For dispensing applications, it is important to ascertain dot to dot consistency, and dot to dot consistency post pause



Discrete Assembly Process-Reflow

Dispense

- Compatible with high-Pb and non-Pb solder alloys
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Reflow

- **Excellent wetting**
- **Reflow process window determined – first for market**
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Post Reflow

- Cleaning of flux post reflow with several solvents
- Low void incidence
- Passes all reliability flux programmes
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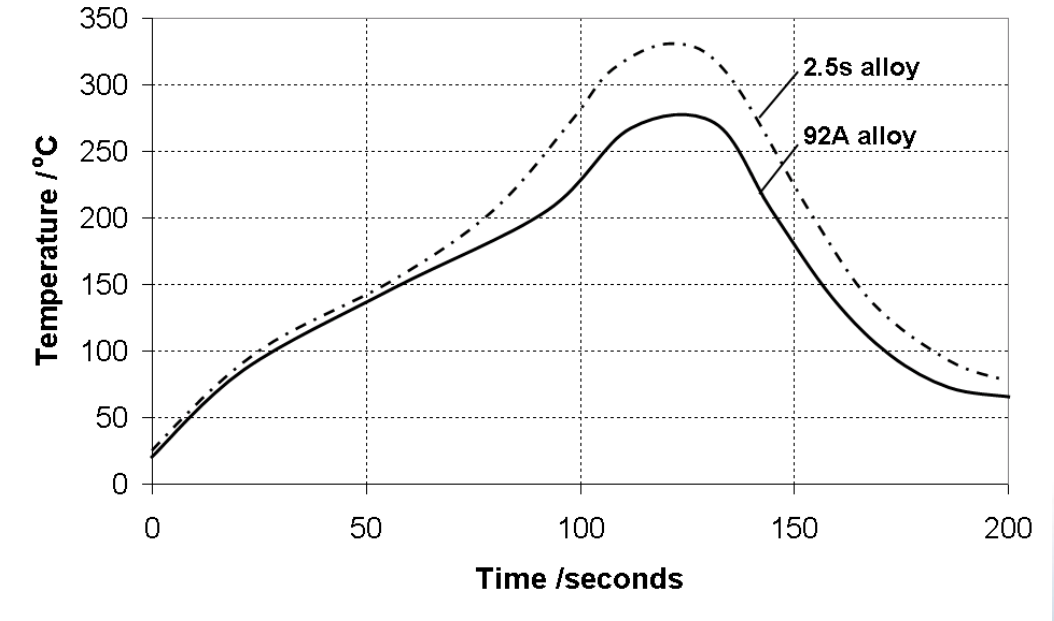
Reflow Profile Examples

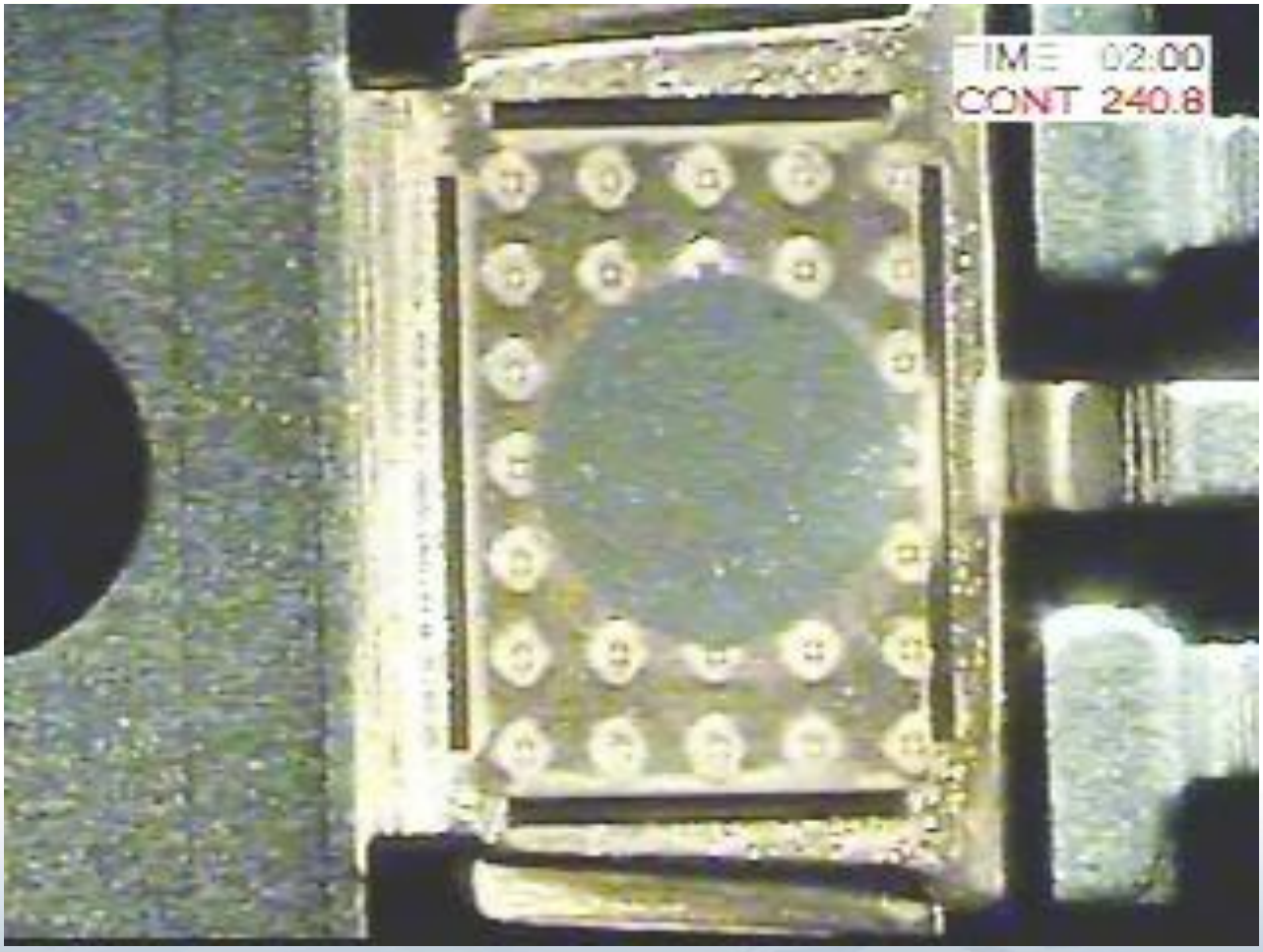
- Note the different reflow peak temperature difference between high Pb (2.5S alloy) and Pb-free alloy (92A)



- Die attach solder pastes are designed for reflow in inert atmospheres, typically forming gas (N_2/H_2) or nitrogen.
- Optimal reflow is achieved using a ramp rate of 2-3˚Cs^{-1} to a peak temperature 10-30˚C above the melting point of the alloy in use with a dwell above the alloy melting point of 20-40 seconds

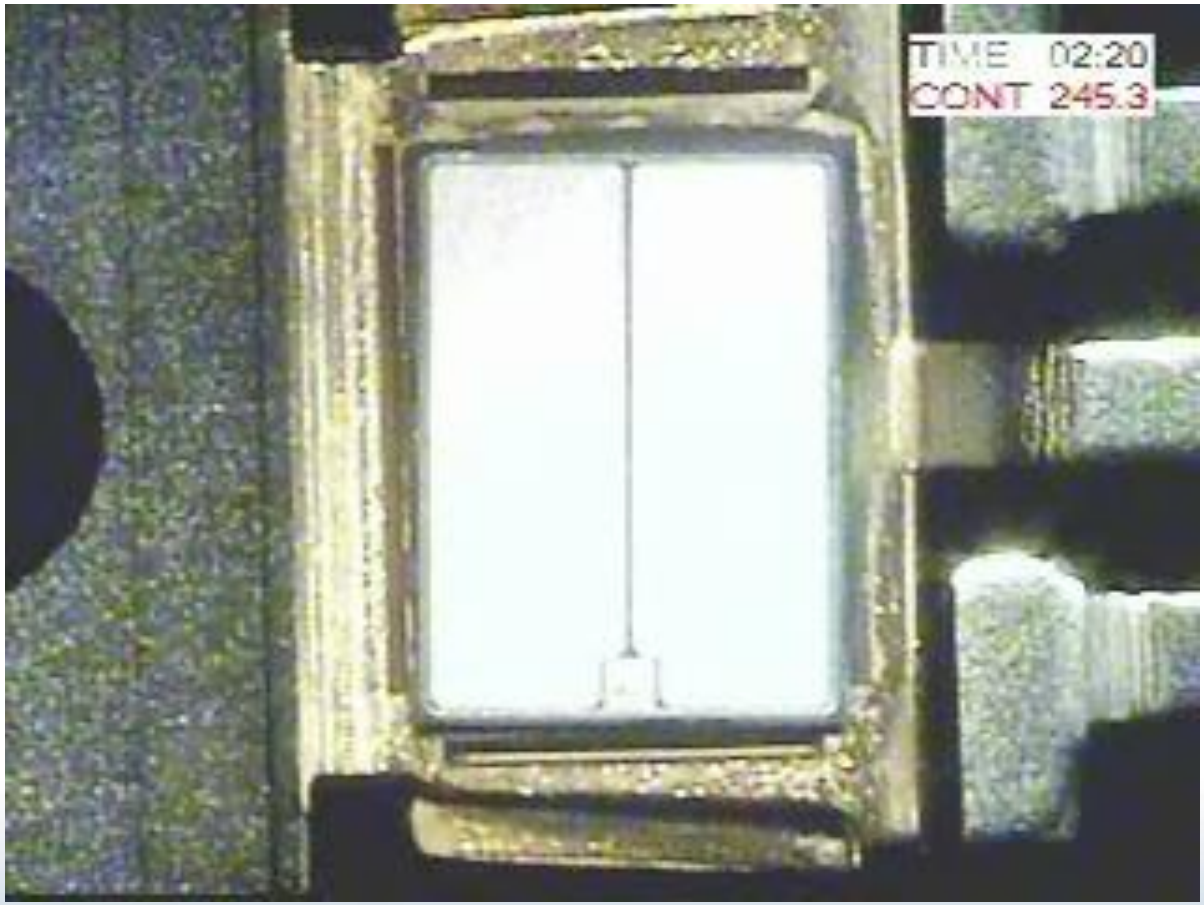
Changing Alloy – flux can withstand large temperature variants

Reflow Without Die



- Reflow without Die. Shows flux spreading out over pad - cleaning the surface. This not only cleans the surface but also aids capillary flow of the solder. Without the die you can clearly see the solder does not slump - it won't allow die to float. The solder solidifies without any lateral movement.

Reflow With Die



- Initially flux flows underneath the die in all directions - cleaning the die pad and assisting capillary flow of the solder. As the flux reaches the edge of the die it can be seen to evaporate - the flux leading the solder in this way helps to avoid any internal voiding. As the solder melts and flows to the edges of the die you can clearly see both self-allignment and self-filleting without die float.

Discrete Assembly Process- Post Reflow

Dispense

- Compatible with high-Pb and non-Pb solder alloys
- Enhanced dispense capability – excellent pause time
- Excellent Dot-Dot dispense consistency

Reflow

- Excellent wetting
- Reflow process window determined – first for market
- Self Filleting

Post Reflow

- **Cleaning of flux post reflow with several solvents**
- **Low void incidence**
- **Passes all reliability flux programmes**
- **Classified as ROLO by J-std 004-A**
- **Twelve-month frozen storage stability**

Residue Removal Examples

- To achieve the reliability MSL test specifications, the residues surrounding the mounted die from the solder paste have to be removed prior to wire bonding, and/or molding
- On top of the cleaning agent chemistries, variables in process setup for removal include:
  - included temperature;
  - ultrasonic's;
  - spray under immersion;
  - and spray in air

Example results….

- Assessment on three solvents in house
- Cleanability work ultrasonic bath:
  - @55° C for 5mins
  - and 1min DI
- Carried out on several profiles

Avoid fluxes that discolor die metallization – flux not stable

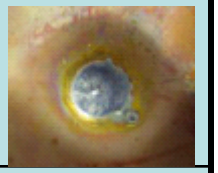
Cleaning Agent A

Cleaning Agent B

Cleaning Agent C

Benchmark

J-std 004-A: Reliability

Test	Result
Cu Corrosion	Pass – no discolouration on copper 
Cu mirror	Pass – no breakthrough 
Halides	Pass – no discolouration (halide-free) 
Fluoride	Pass – no colour change observed 
Solids content	50.9%
Electromigration	Pass
SIR	Pass

The flux must pass all tests as documented by the international protocol requirement standard Jtd-004a to show flux reliability at highest level

Flux reliability: J-Std 004-A

Average insulation resistance

Time	Control/Ω	Soldered/Ω	Soldered and Cleaned /Ω
24hrs	2.0×10^{11}	8.6×10^{10}	3.4×10^{11}
96hrs	2.4×10^{11}	5.8×10^{10}	3.2×10^{11}
168hrs	3.7×10^{11}	9.7×10^{10}	4.3×10^{11}

Appearance of boards after test

Control

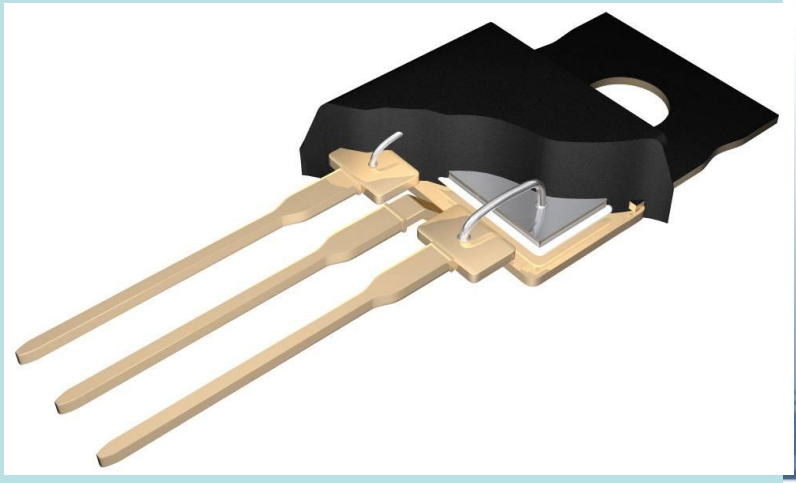
Soldered residues – not removed

Soldered and cleaned

With the data presented - J-STD 004 designation: ROL0 is achieved

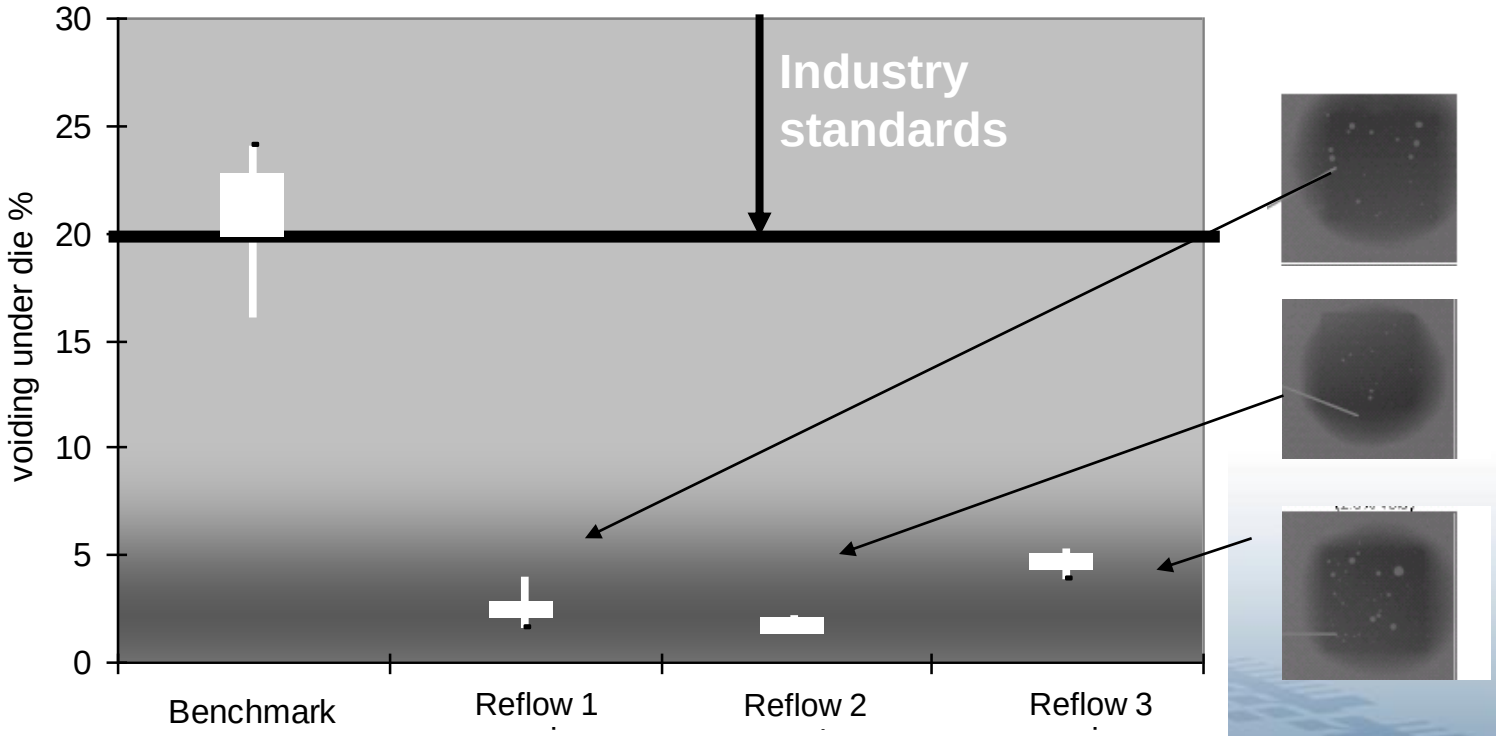
Die Attach Reliability Requirement

- Industry accepted standards
  - < 20%: Cumulative, small scattered voids
  - < 10%: Single void
- Potential problem of voids:
  - Decreased electrical & thermal conductivity
  - Imminent mechanical failure
- Limited published work on void levels for die-attach applications
- Causes of voiding:
  - Poor wetting
  - Outgassing
  - Insufficient solder volume
  - Large pad area
  - Excessive intermetallic compounds



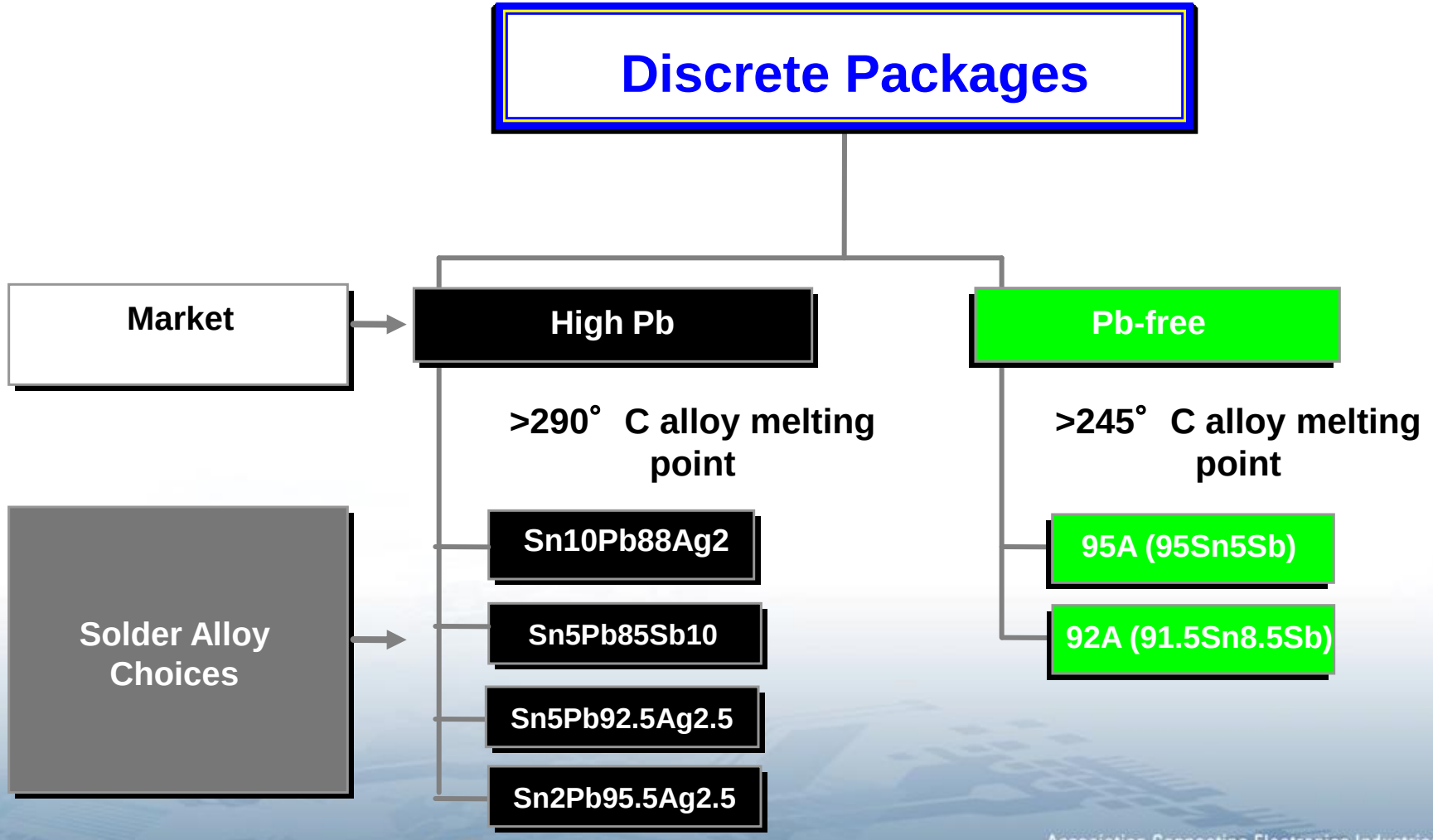
Post Reflow – Void Levels

- As with assembly product lines, chemistry and profile will affect void levels under die
- Void levels measured – meeting the requirements of industry



Less than 5%

Solder Alloy Options



Additional alloys are available

Production Comparison with Industry Standard - example

	Control	New DA Solder	Comments
Visual Inspection	21 misplaced die (Insufficient paste)	2 misplaced die (pick and place related)	
	84 missing clip (Insufficient paste)	0 missing clip	
Voiding under die	9%	<0.4%	Industry typical <20%
Residue removal	Pass	Pass	
Pause time effect	30 mins – pass 60 mins fail	30 mins – pass 60 mins – pass 120 mins – pass	
Dispense	Pass	Pass	
Storage	Pass – 24hours	Pass – 72 hours	@RT (25C)

Die Attach Solder

Product Attribute	Process Benefit
Dispensability	Low viscosity product increases throughput by 3 fold lowering investment costs Older products have poor pause time, abandon time, and high pressure requirements Vacuum mixed to eliminate voids in syringe
Flux robustness	Only dispensable product suitable for high-Pb and Pb-free in die attach market with 12month storage demonstrated
Residue removal	Improves speed & ease of post reflow inspection. Speed of removal improvement over older materials
Low voiding	Demonstrated in production. Thermal management is improved
Halide free flux classification: ROL0	High reliability of finished assembly without cleaning Older products tarnish dies impacting reliability

Conclusions

- A die attach solder material has been shown to provide the following:
  - Repeatable, consistent dispensability
  - ROL0 Performance without cleaning
  - Good Cleanability
  - Good performance with multiple alloys
  - Low voiding

- Conductive adhesives are still being explored as alternative materials
  - For high power packages conductive adhesives do not yet provide the thermal performance needed
  - Improvements are being made
  - More accurate test methods needed and are being developed

Electronics IPC Midwest

Thank You

Questions?

Henkel

Canon Communications LLC

Association Connecting Electronics Industries

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