ARIECA

Modern Materials for a Connected Society

Highly Accelerated Stress Testing (HAST) of Liquid Metal based Thermal Interface Materials

For Presentation at

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2025-3-4

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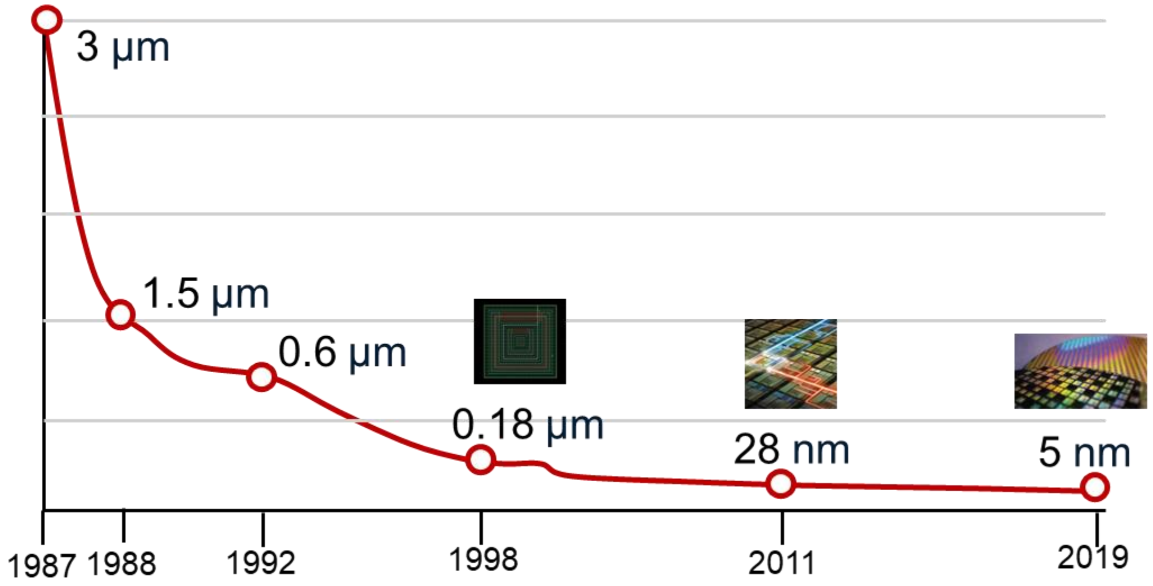
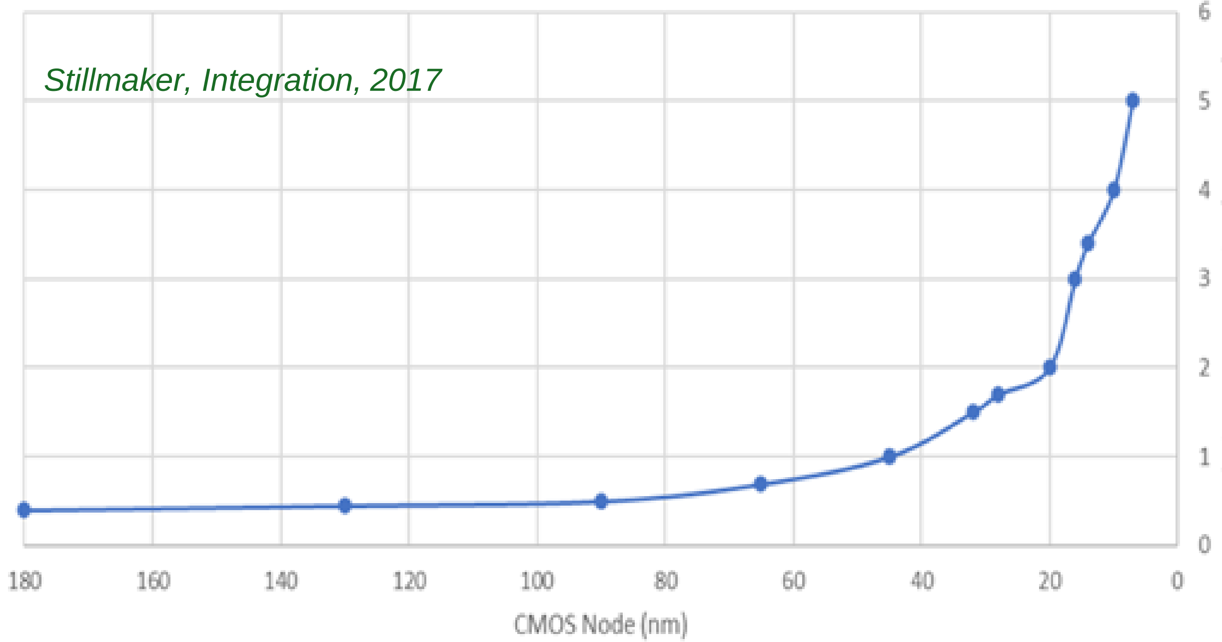
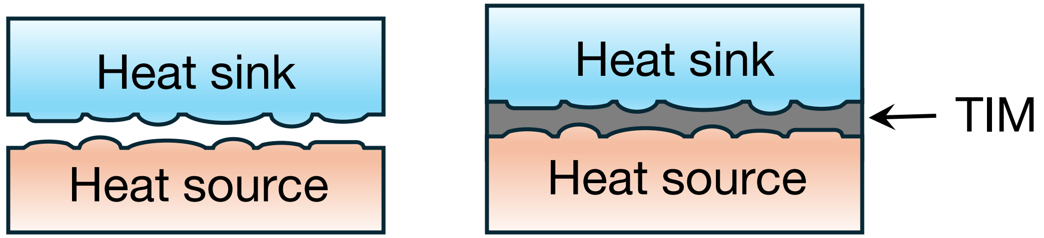
Thermal challenges constrain technology



Miniaturization of transistor over the year



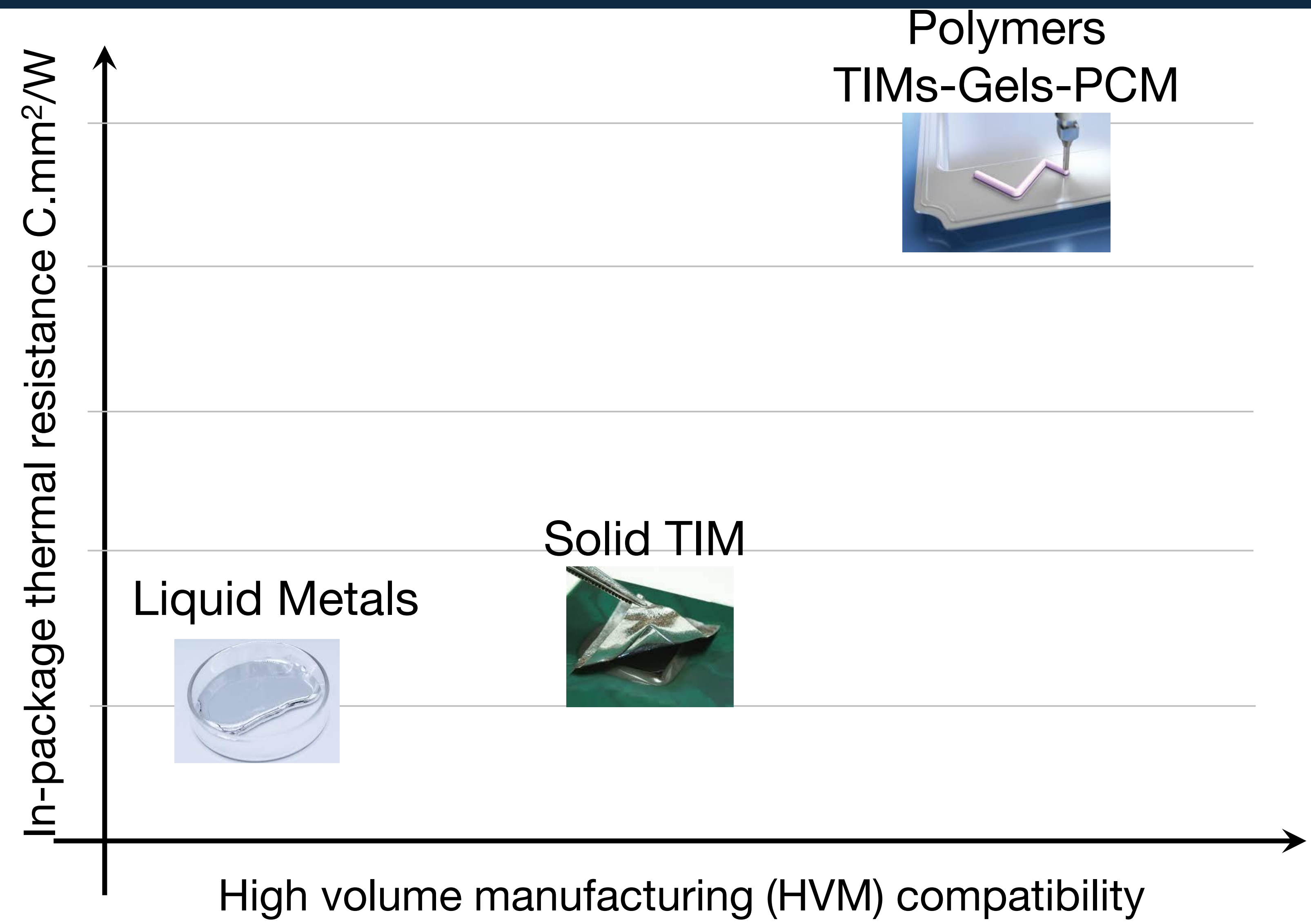
Miniaturization of transistor demand high power density



Progress requires new TIMs that maintain low thermal resistance to improve device lifetime.

Is Smaller Always Better for Transistor Size? - TechSparks 10554

Existing solutions - Thermal Interface Materials (TIMs)



<u>Present challenges</u>

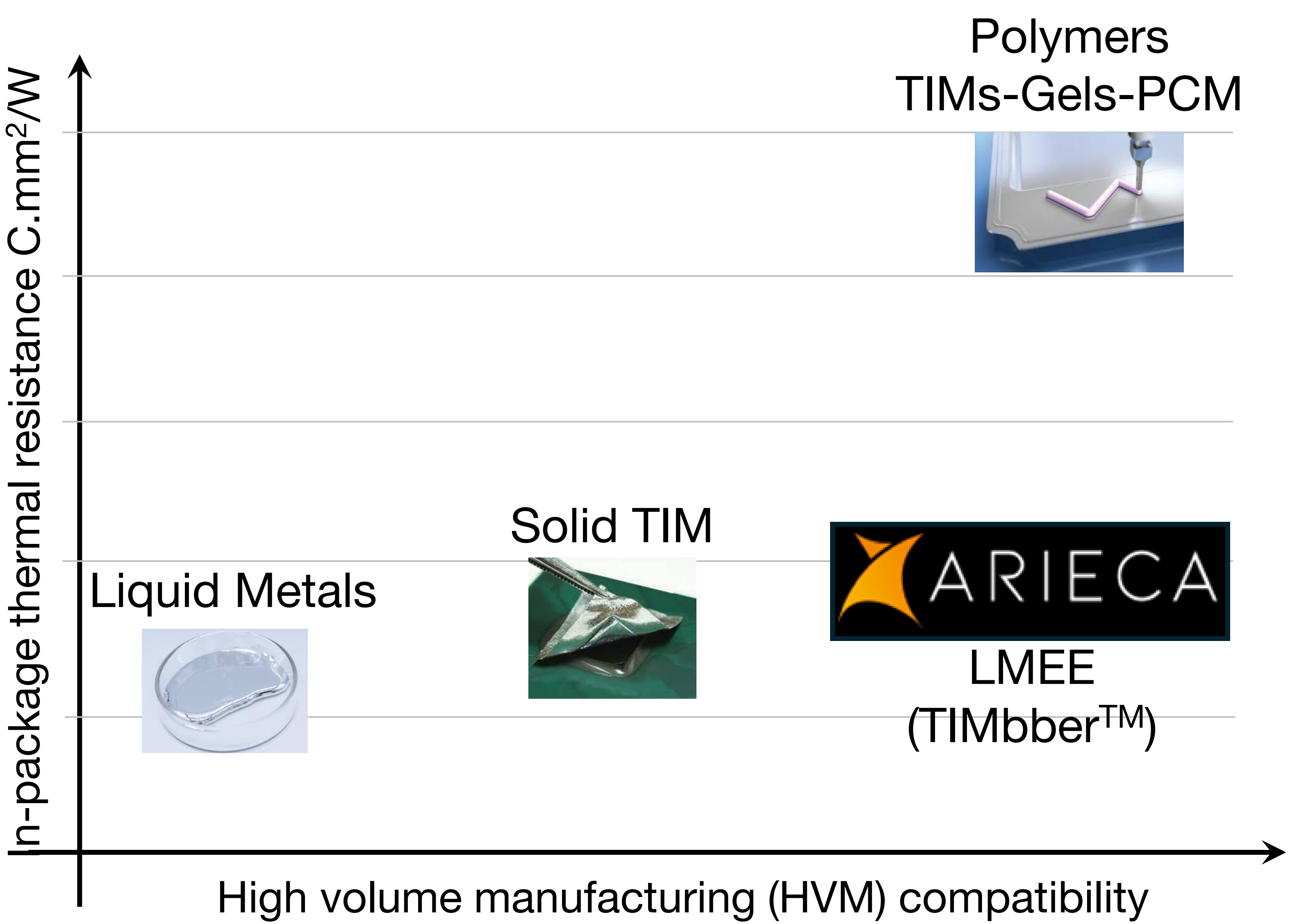
Solid TIM
- Requires metallization
- Reliability
- Expensive

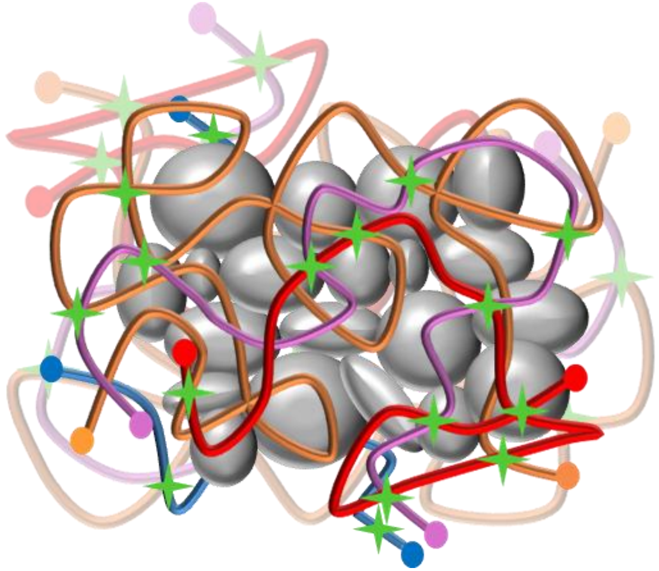
Polymer TIMs-Gels-PCM
- High in-package thermal resistance
- Phase separation

Liquid metals
- Difficulty in application
- LM leakage
- Reliability

Chiechi et al., Angew. Chemie - Int. Ed. 2008
Boley et. al. Adv. Funct. Mater. 2014

Liquid Metal Embedded Elastomer (LMEE)

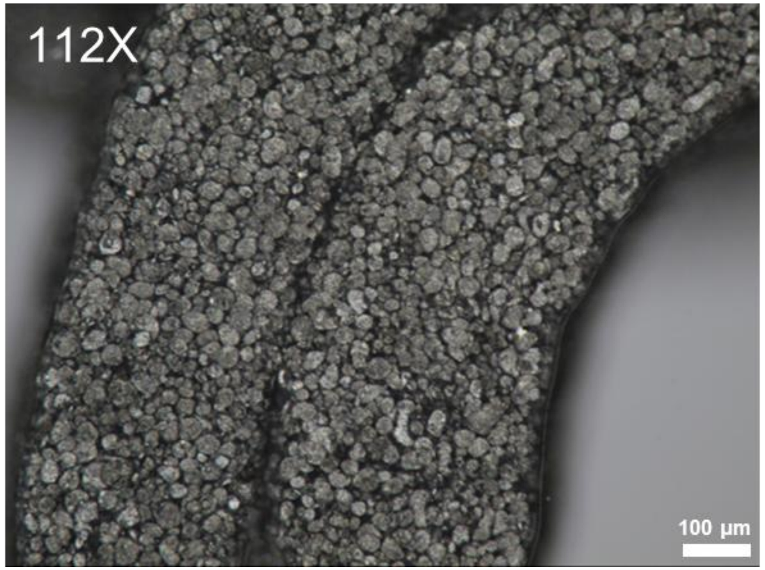




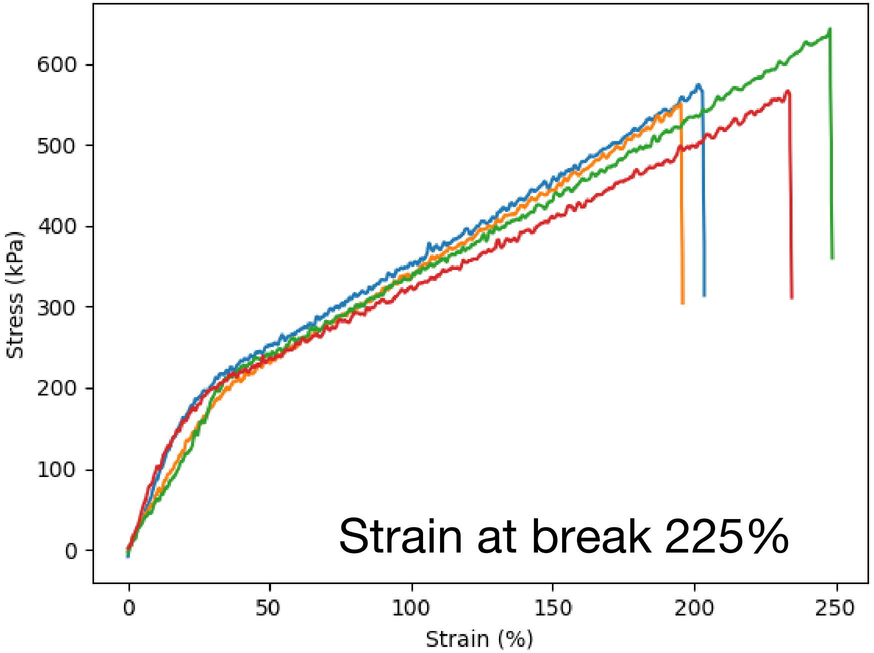
- In LMEE, LM is encapsulated in polymer matrix to improve the reliability of LM.
- The elastomeric property of the polymer is maintained in LMEE.
- Elastomeric properties prevent delamination during warpage.

Bartlett et. al. PNAS. 2017

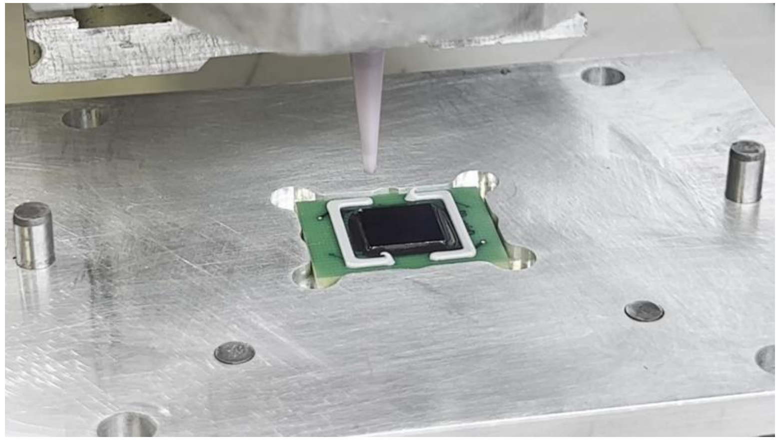
LMEE : A customizable TIM



Adaptable droplet size



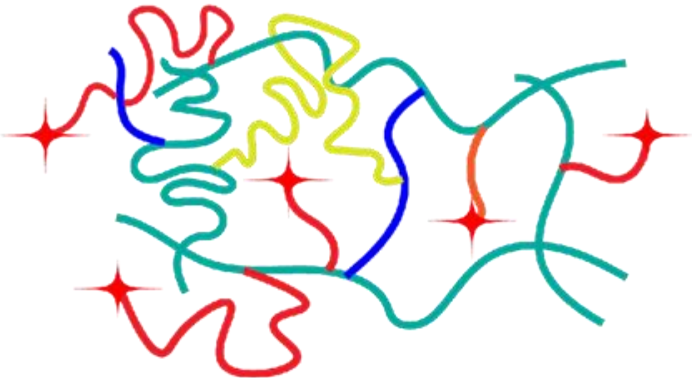
Optimized elastomeric properties



Easy application
No LM Leakage

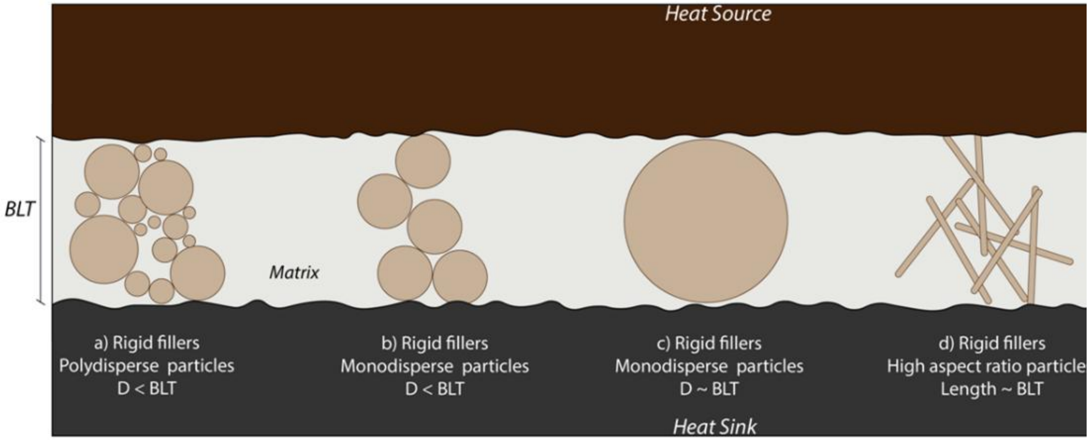
Development of Liquid Metal Embedded Elastomer (LMEE)

Optimized Polymer Formulation

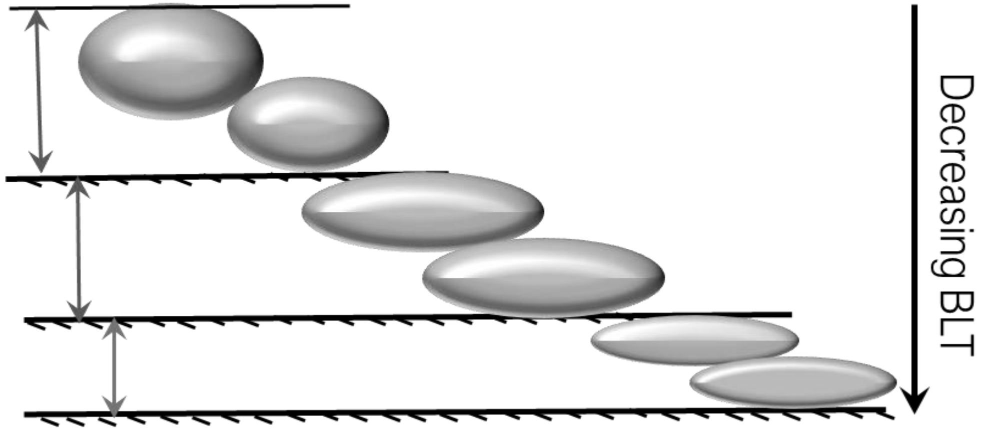


- Provides structure to support liquid metal droplets
- Enables adhesion and high elongation
- Allow crosslinking to form high reliability elastic solid

Exceptional thermal properties of LMEE



Thermal resistance is limited by contact resistance of fillers



Deformable LM droplets decrease contact resistance

$$R_{th} = \frac{BLT}{\kappa} + R_{contact}$$

- <u>Other polymer TIMs</u> microstructures (a-d) have high contact resistance between particles, as well as between particles and interfaces. Particle Size < BLT.
- <u>Arieca's Liquid Metal TIM</u> provides extremely low thermal resistances by compressing liquid metal particles at low BLT. Particle Size > BLT.
- Minimizing contact resistance with decreasing BLT decreases thermal resistance.

HAST Reliability of TIM for commercial use

- HAST (Highly accelerated stress test)

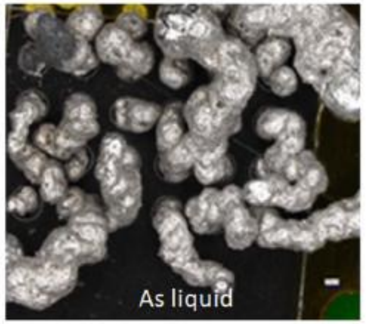
This test examines the TIM to uphold its thermal properties under extreme high temperature, humidity for prolonged time.

1. **130 °C, 85% Rh, 96 h.**
2. 110 °C, 85% Rh, 192 h.
3. 85 °C, 85% Rh, 1000 h.

- So far, LM does **not** qualify for any HAST condition limiting its commercial usage.
- Common Failure Mode : Formation of nonconductive GaO(OH) due to moisture induced oxidation of Ga.

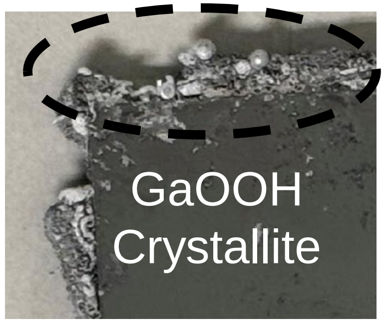
$$Ga_2O + H_2O \rightarrow Ga_2O_3 + H_2$$
$$Ga_2O_3 + H_2O \rightarrow 2GaO(OH)$$
$$2Ga + H_2O \rightarrow Ga_2O_3 + H_2$$

Weak oxide shell on Gallium bursts from pressure being exerted by H_2 gas release



85 °C, 85% Rh, 500 h

Meyyappan et. al. (2024) Adv. Eng. Mater. 2024



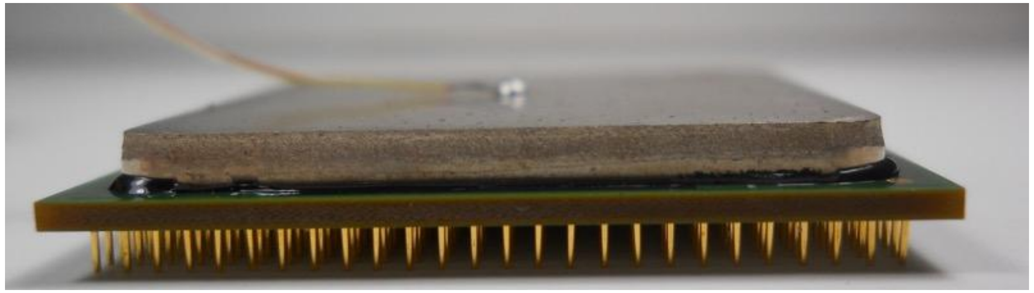
130 °C, 85% Rh, 96 h

T0 Thermal Results – TTV

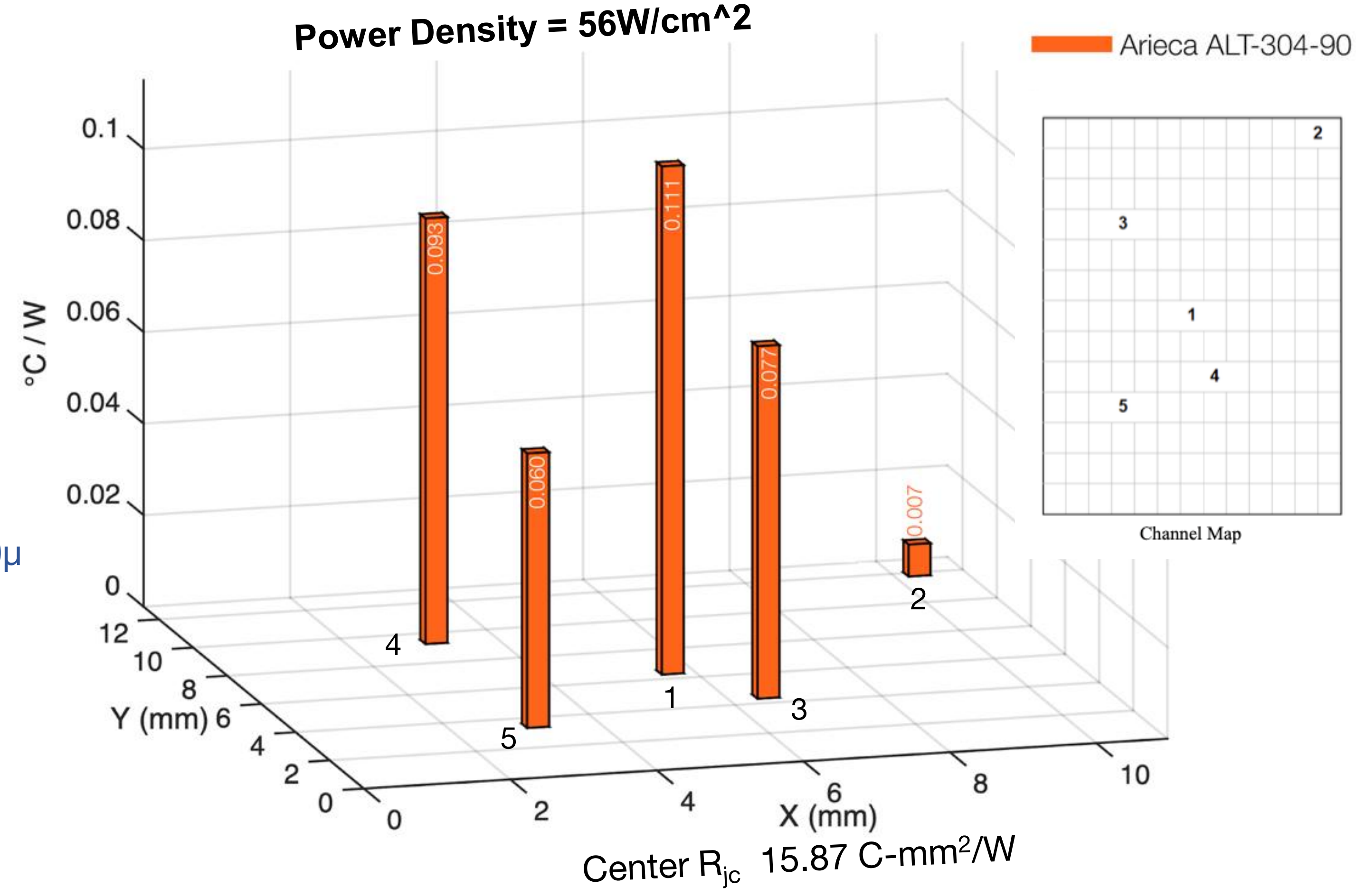
ENERDYNE SOLUTIONS

Presented in IMAPS DPC 2022

18TH INTERNATIONAL CONFERENCE & EXHIBITION ON DEVICE PACKAGING
FOUNTAIN HILLS, AZ • WWW.DEVICEPACKAGING.ORG • MARCH 7-10, 2022



Die dimensions: 11mm x 13mm



Thermal Resistance junction to case (C*mm²/W)

15.87

Thickness

2100μ +/- 50μ

Thermal Resistance		Thickness
3.72	Lid	1500μ
6.86	TIM	
5.29	Si Die	610μ

Long Term Reliability

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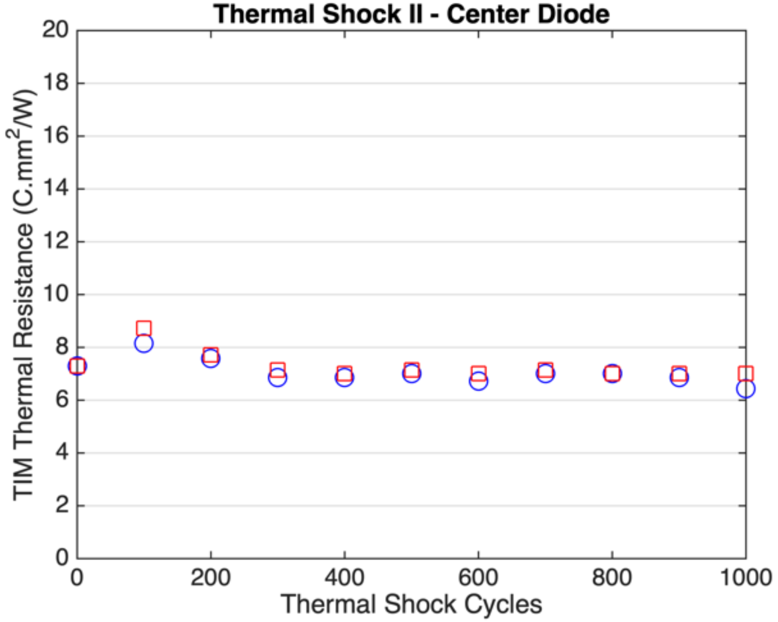
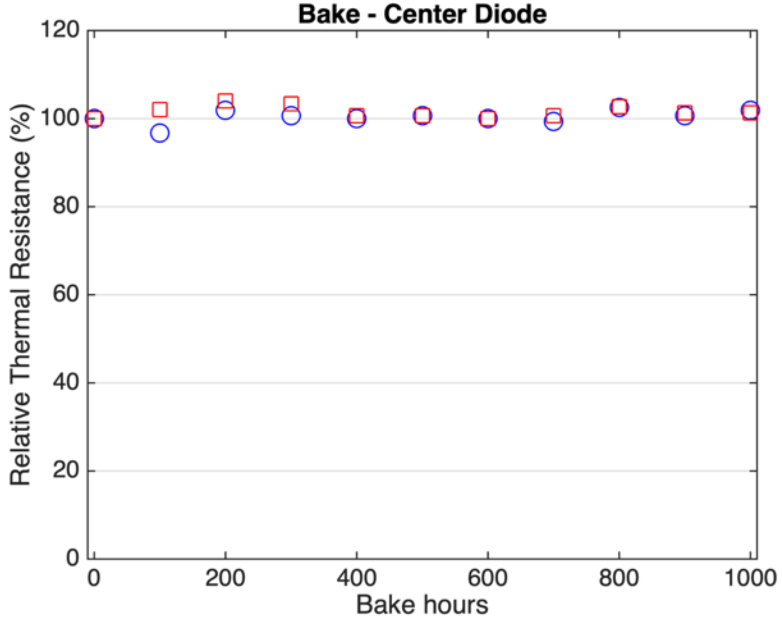
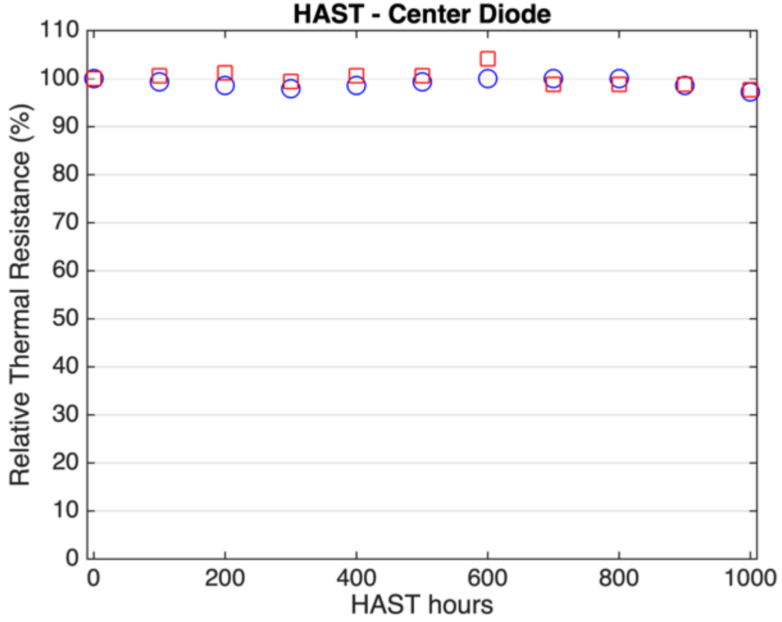






Thermal shock
per MIL-STD-883B:
Test area shall at -55°C (-10°C, +0°C) and +125°C (+10°C , -0°C) for a minimum of 10 minutes

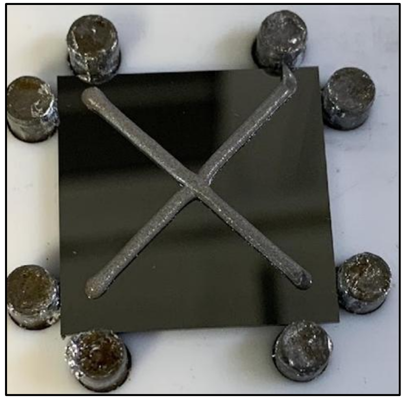
High Temperature Storage
per JEDEC 22-A103 Condition A:
+125°C (-0°C, +10°C).

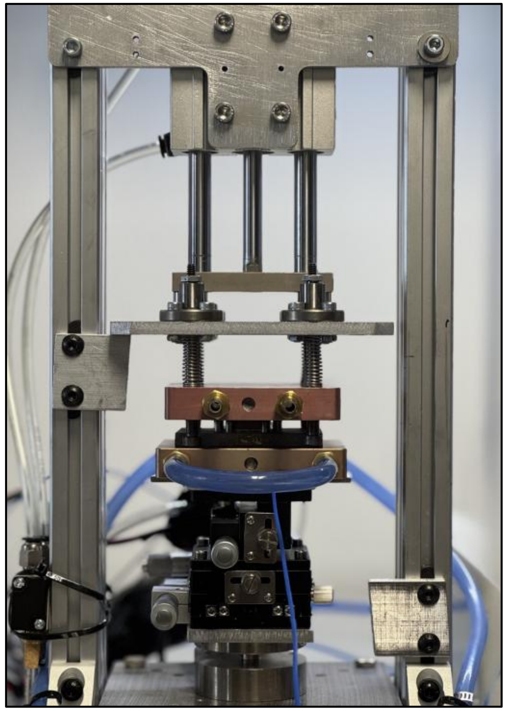
HAST (85/85)
per JEDEC 22-A101:
85 ±2°C, 85 ±5%RH

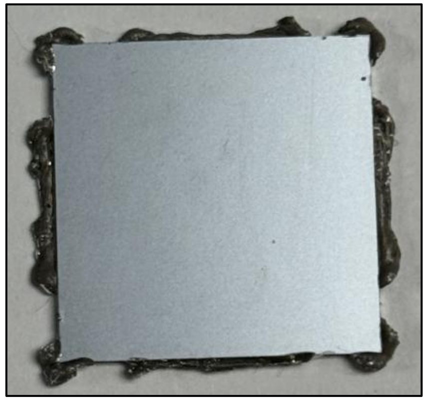
Methods to analyze HAST performance of LMEE

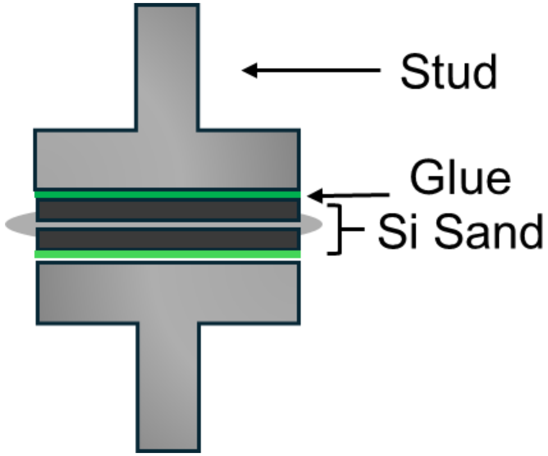
- 130 °C, 85% Rh, 96 h HAST condition is targeted.
- Evaluate the adhesion strength of LMEE (Stud-pull test).
- Evaluate the thermal properties of LMEE.
  - Si-Sandwich
  - TTV
- Evaluate the delamination of LMEE using dye & pry test.

Steps for sample preparation of stud-pull test









Dispensed LMEE on Si wafer (10x10 mm^2) (25X25 mm^2)

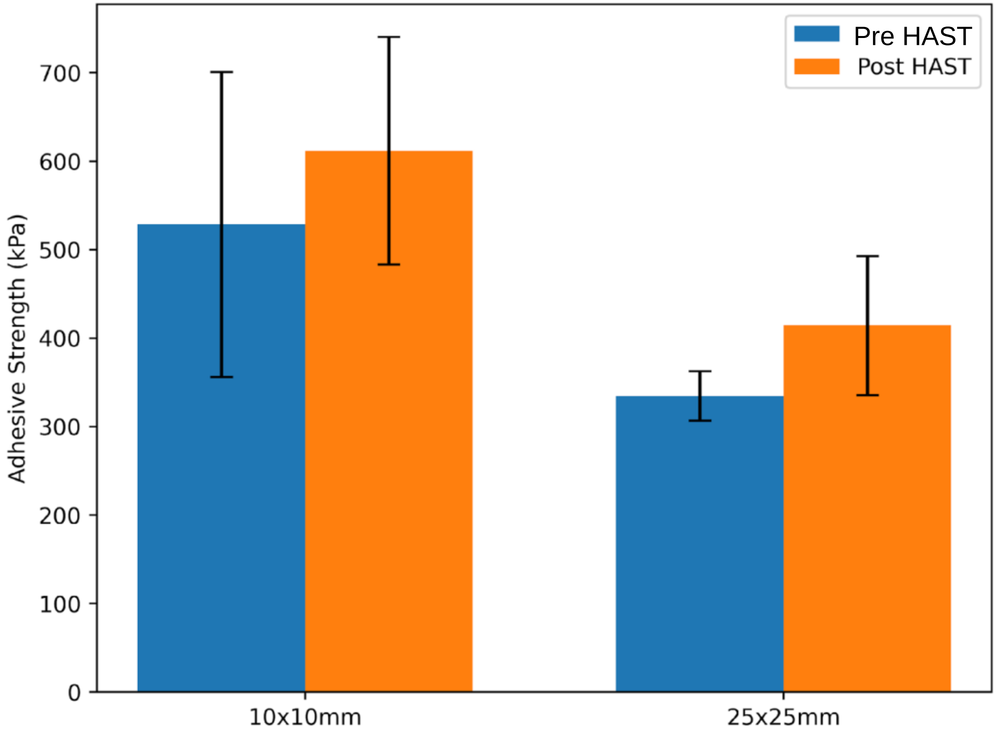
Snap cure Conditions:
Pressure: 30-40 PSI (180-275 kPa)
Time: 12 minutes
Heater Temperature: 150 °C
Targeted BLT : 20-30 μm

Baking condition:
150 °C, 1 h

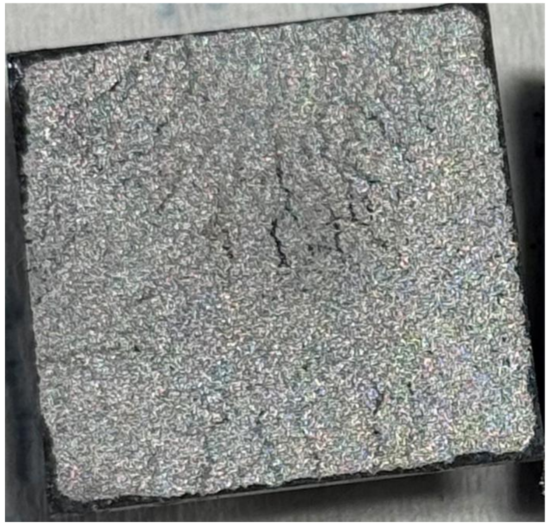
Sample preparation: Studs were glued on both side of the Si wafer with cyano acrylate adhesive.

Effect of HAST : mechanical properties

Stud pull condition:
Control speed: 10 mm/min



- Adhesive strength averaged over 5 samples.
  - Error bar = standard deviation

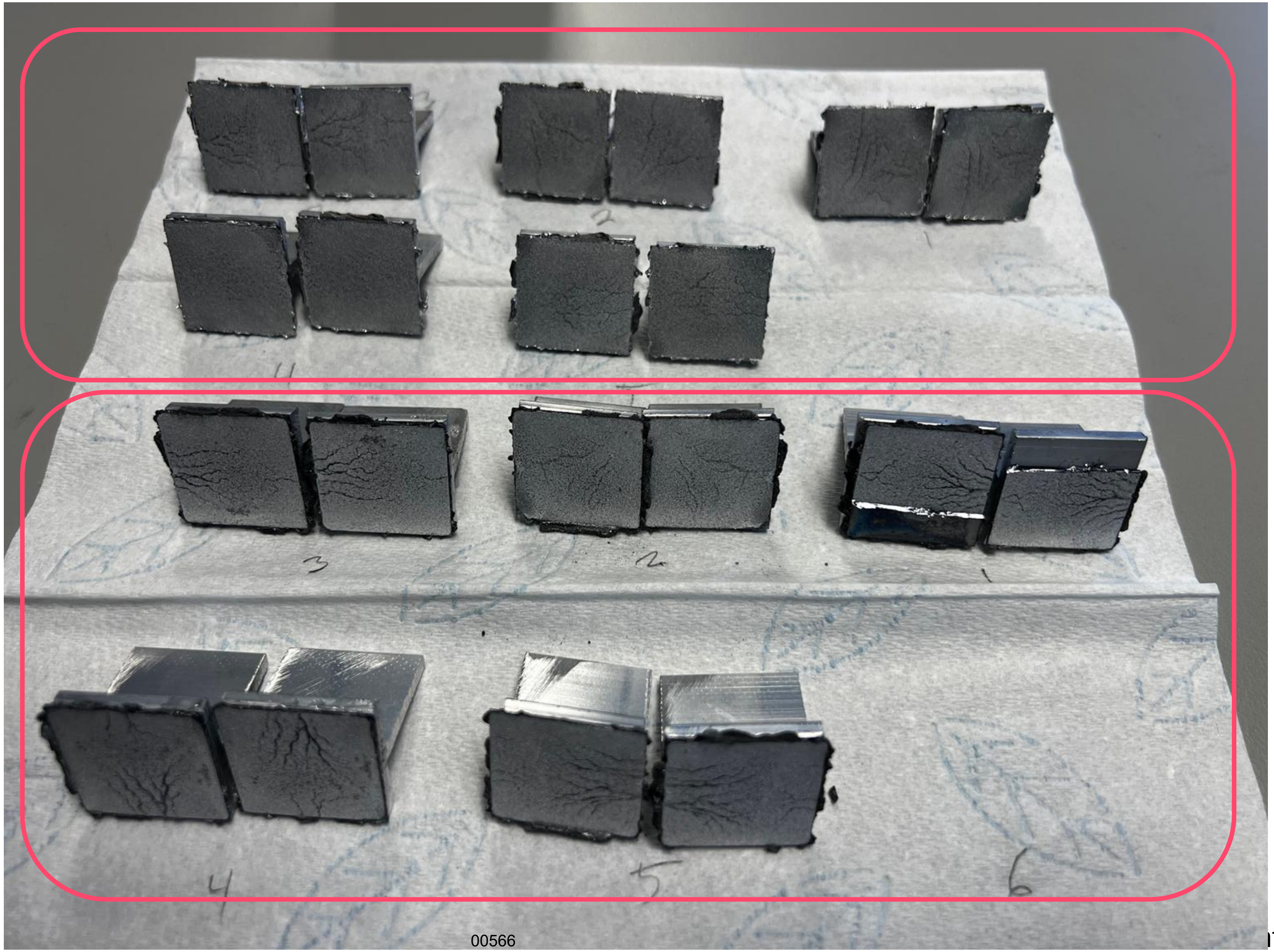


No sign of LM oxidation after HAST

Similar adhesive strength of Pre-HAST and Post-HAST sample shows intact mechanical properties

Pulled Si Sandwich Stacks

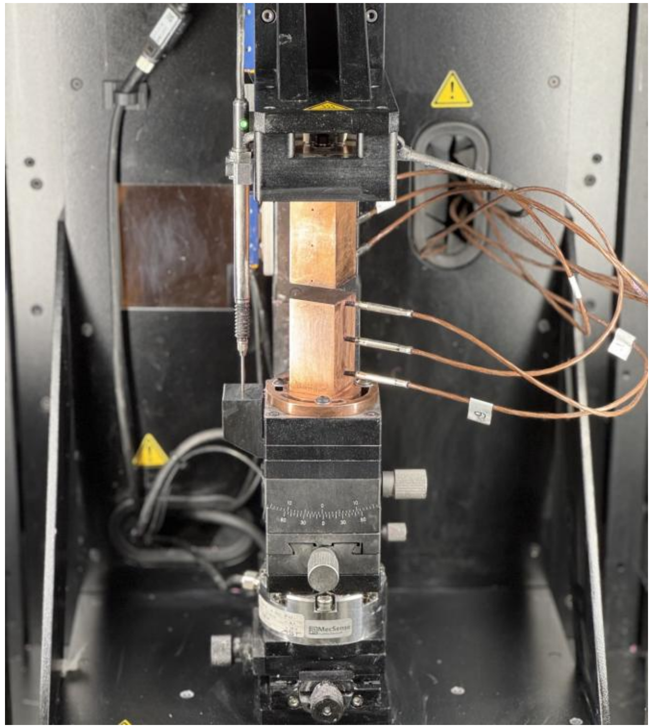
- Si-sandwiches failed cohesively at T_0 and after HAST
- Shiny LM was observed at the interface after HAST

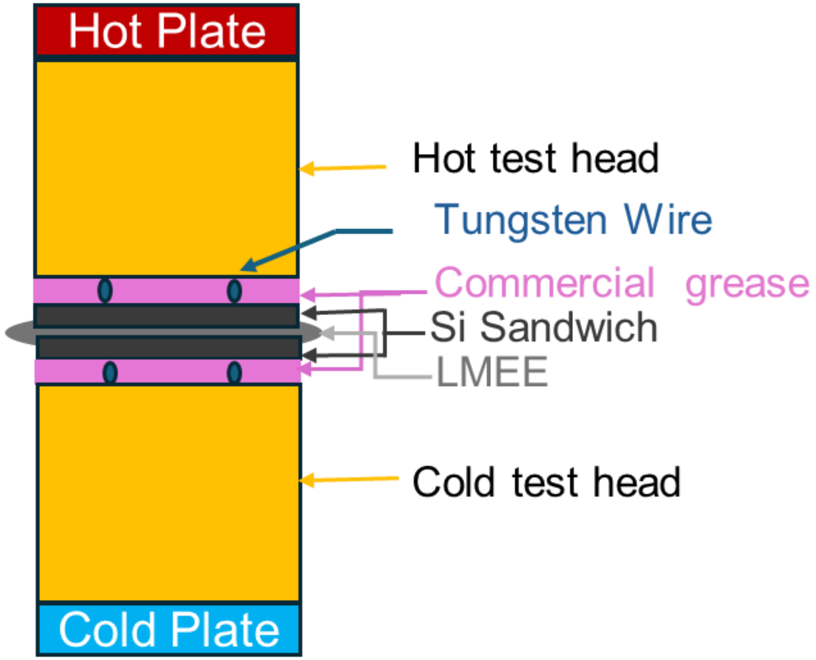


T_0

Post HAST

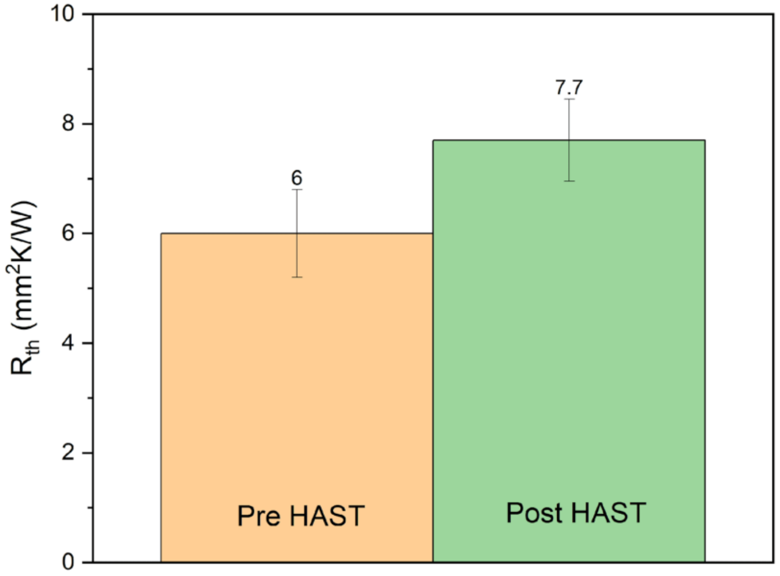
Effect of HAST : thermal resistance





TIMA procedure

- Modified ASTM D5470 procedure
- Under 20 psi pressure
- Sample temperature: 25 °C
- Cold plate temperature: 15 °C



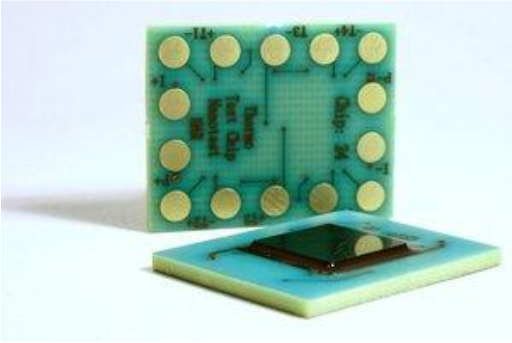
To estimate TIM R_{th}, 39 mm^{2}K/W was subtracted (R_{th} of 2 Si Wafer + 2 layers of thermal paste at 40 um

- Negligible change in R_{th}.
- Thermal property is retained after HAST.

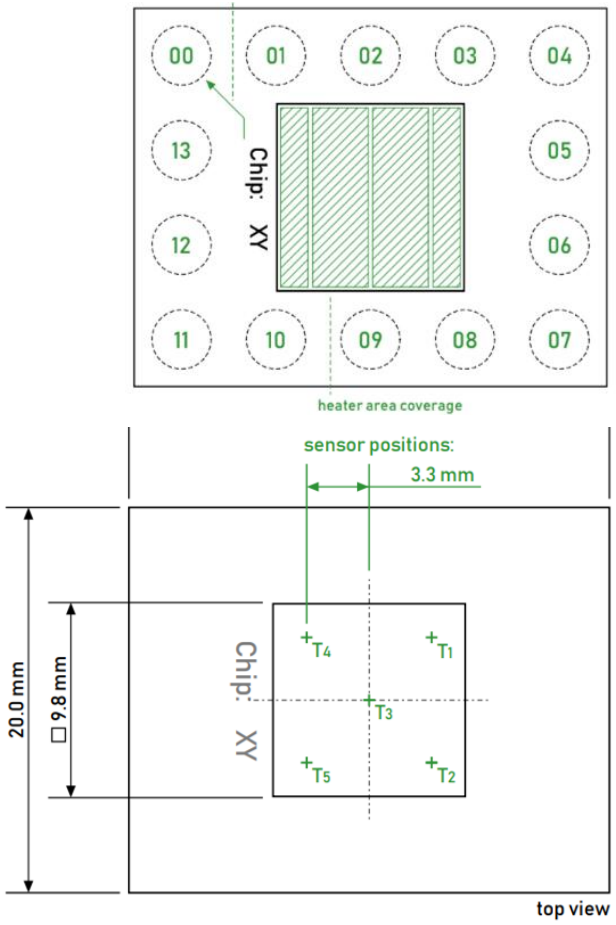
TTV testing : mini-OSAT complete product testing

Dispense Optimization | Snap-Cure Compatibility & Lid Sealant Interaction → BLT Measurement | In-Package Thermal Performance → HAST, TST, HTS, Reflow | Post Rel. Thermals, CSAM, Delid

NANOTEST



- General purpose Thermal Test Vehicle (TTV)
- 10x10mm Die
- 5 Temperature Sensors



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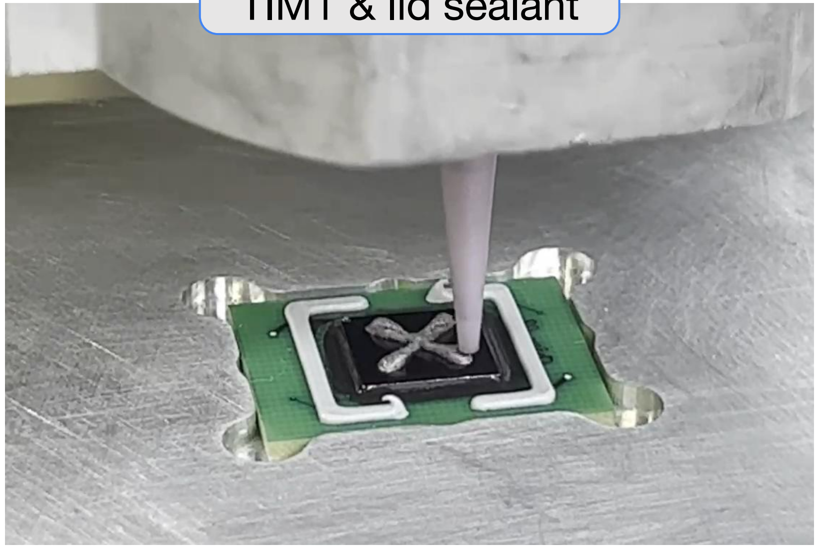
TTV assembly

Assembly

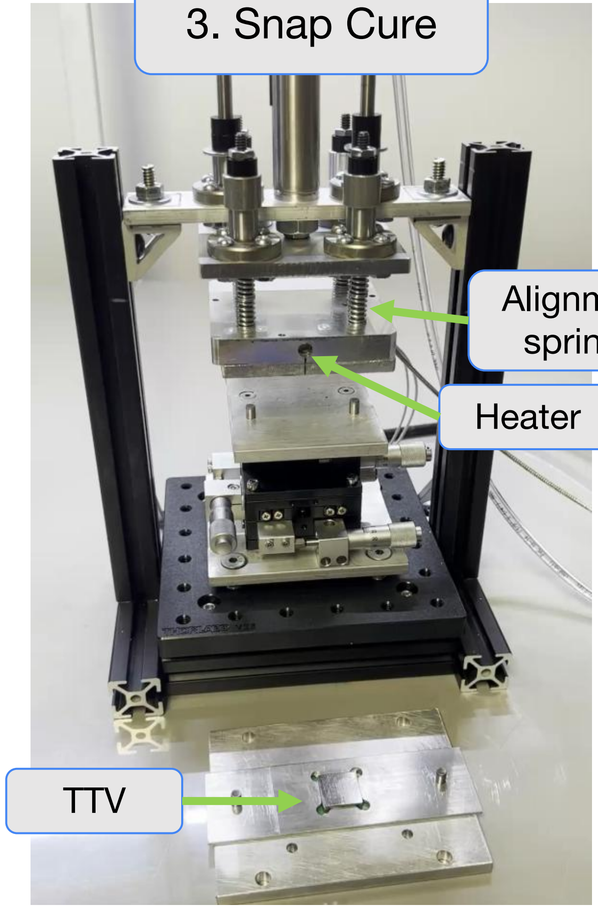
- Dispense Optimization
- Snap-Cure Compatibility & Lid Sealant Interaction

1. CNC Dispense TIM1 & lid sealant

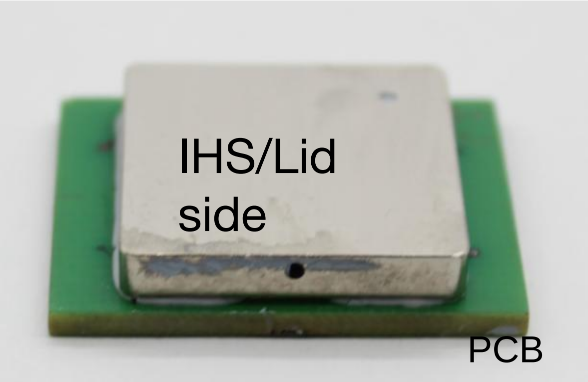


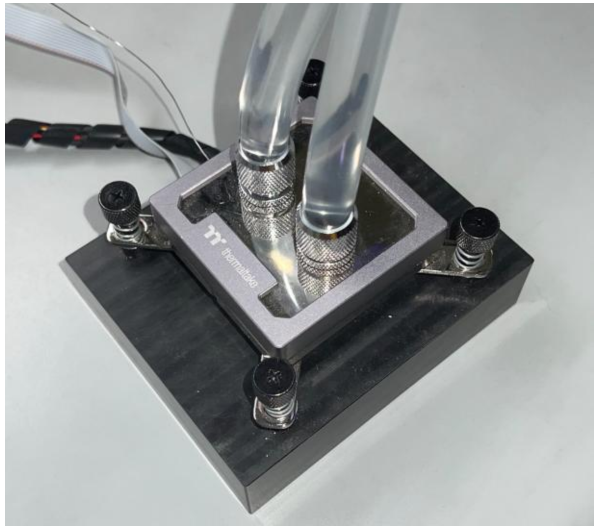
2. Pick and Place Lid

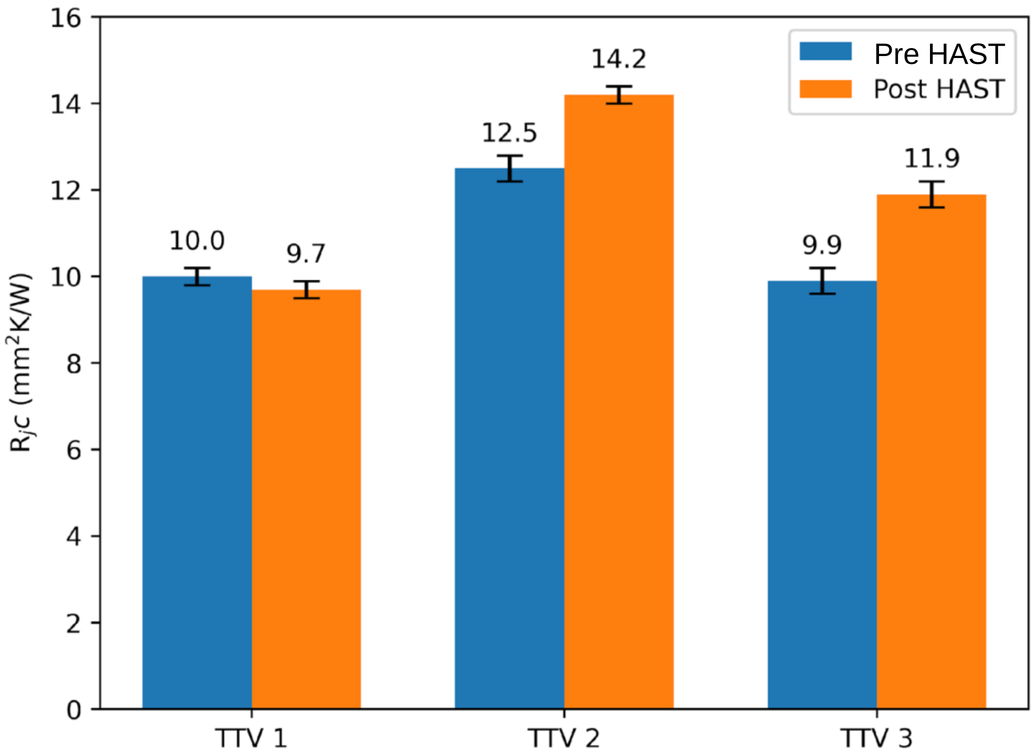
3. Snap Cure



Pre and post HAST in-package thermal performance







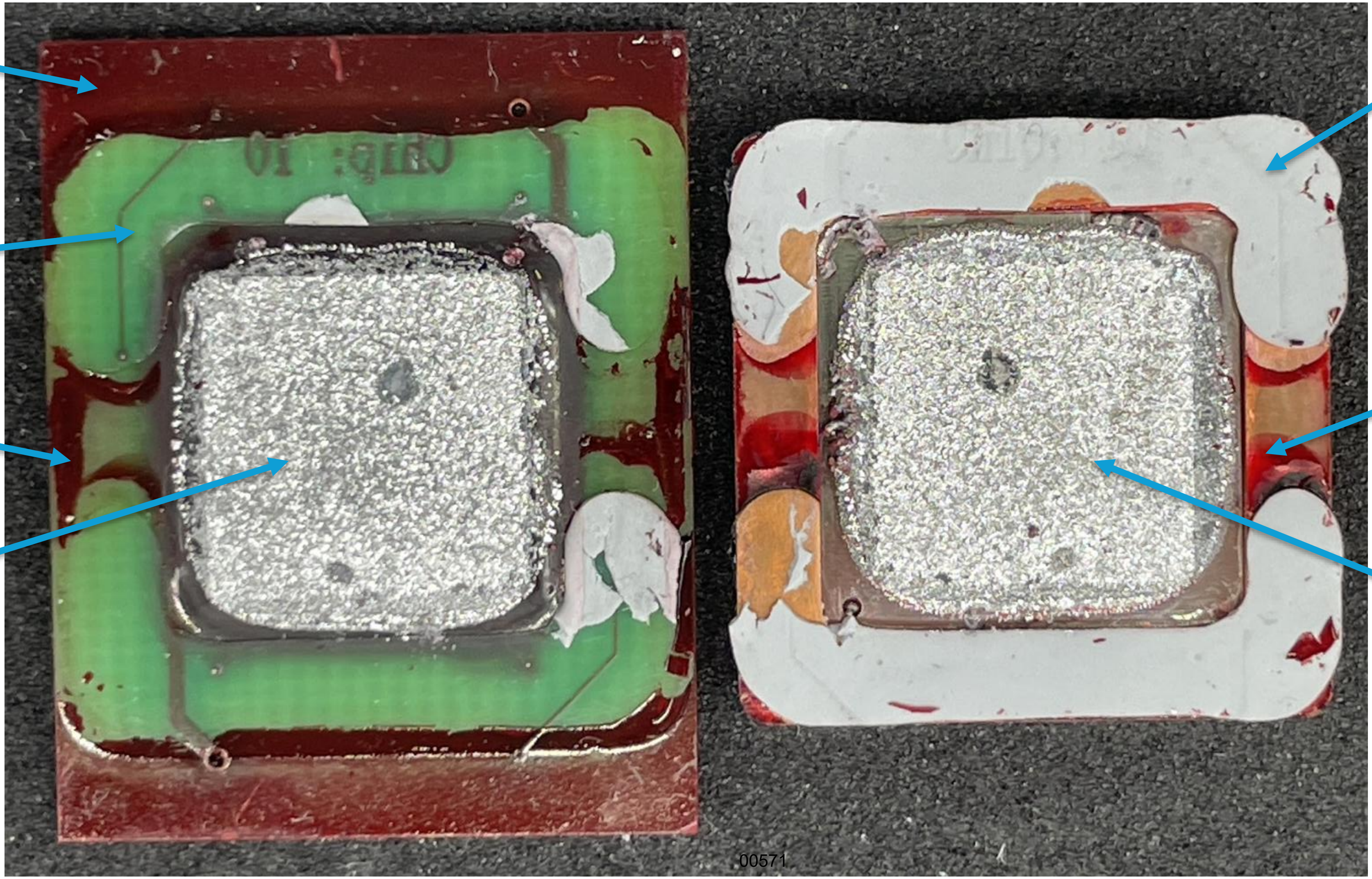
- $R = \left(T_{avg} - T_c\right) * \frac{A}{P}$.
- R_{jc} = Average of R over 10 W, 20 W, 30 W.

Delidded TTV after HAST

Minimal change in R_{jc} of LMEE Post-HAST confirmed that thermal property is preserved after HAST.

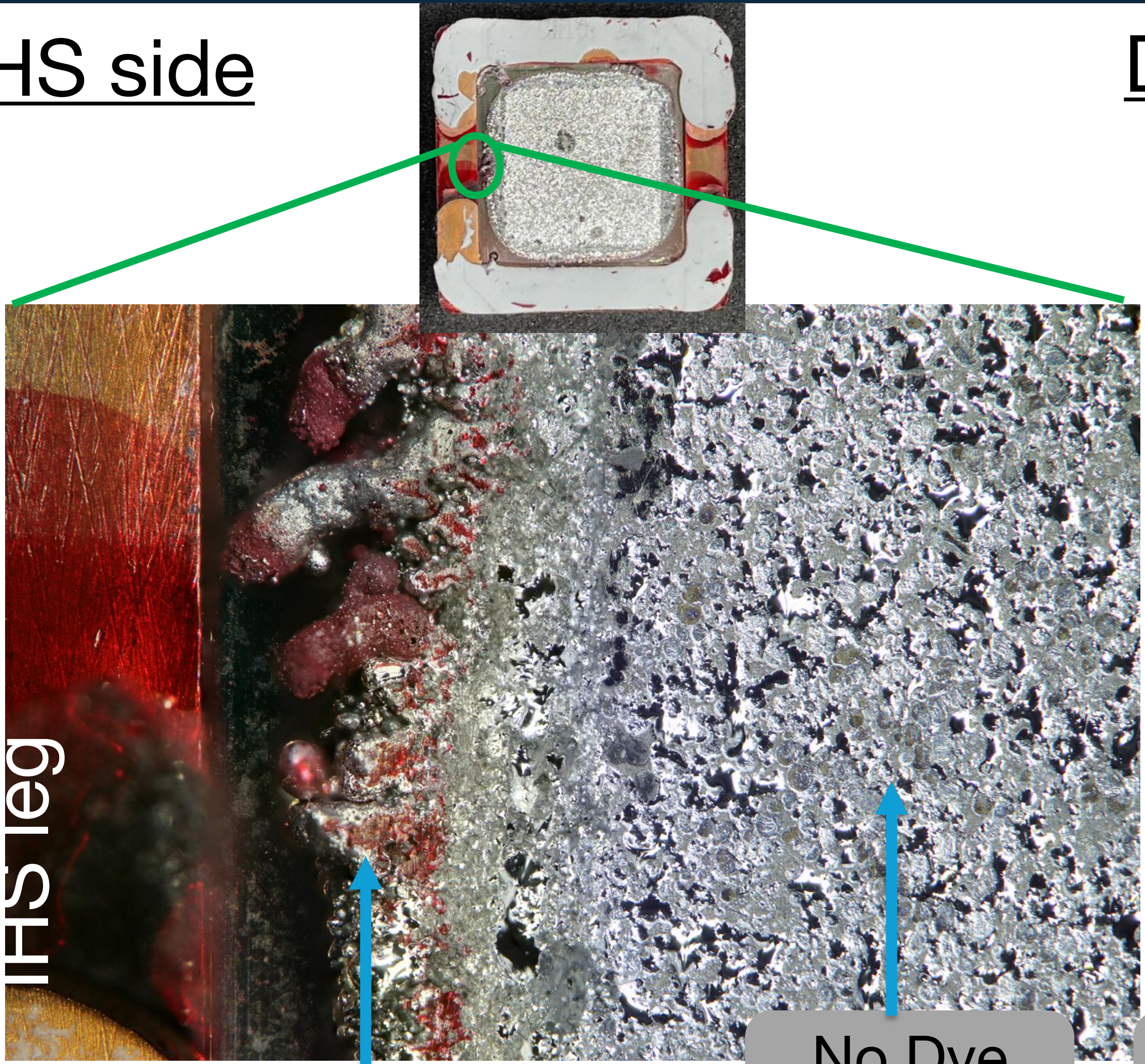
Failure analysis – dye and pry

- Dye & Pry Test following IPC-TM-650 standard after uHAST 96hr



Failure Analysis – dye and pry – zoomed-in microscopy

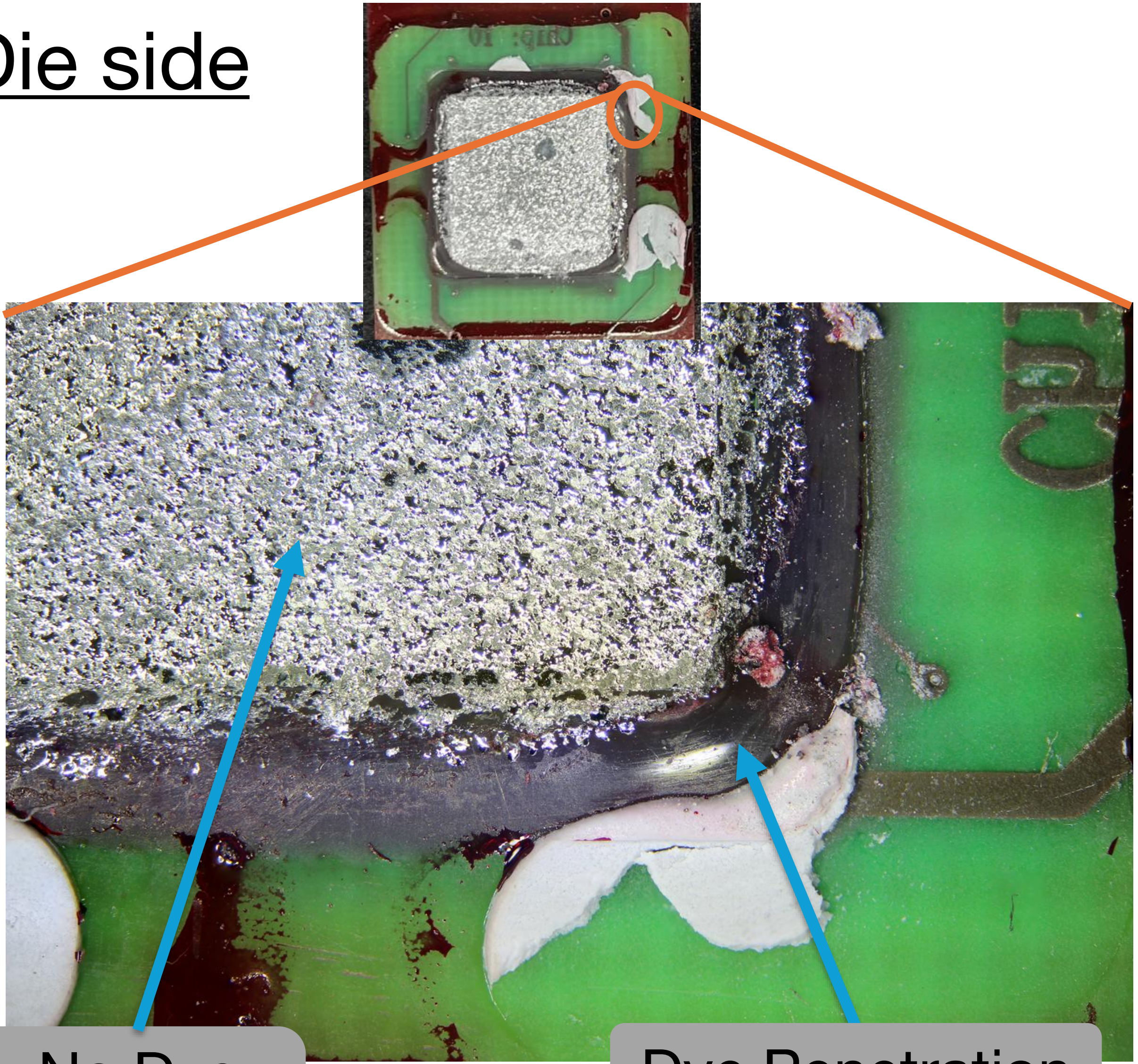
IHS side



Dye Penetration

No Dye Penetration

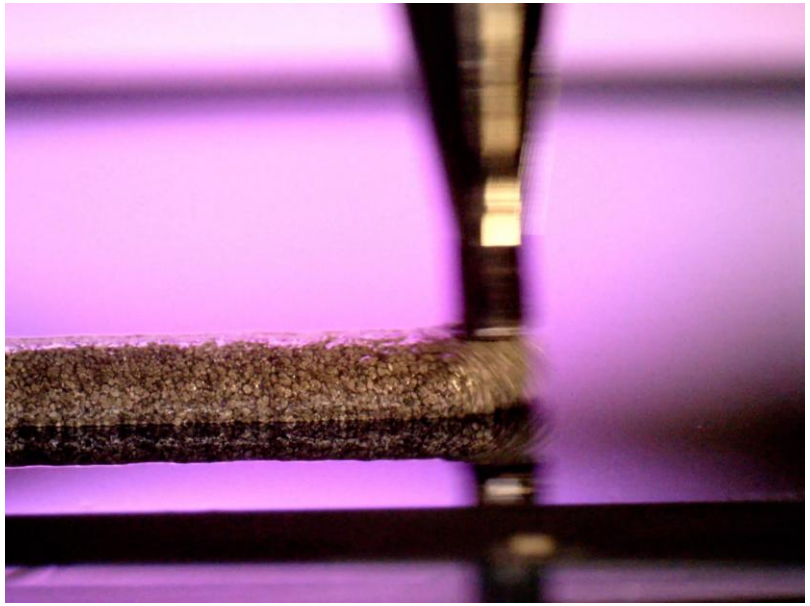
Die side



No Dye Penetration

Dye Penetration

LMEE : Comprehensive solution for TIM



1. Easy application
2. Low thermal resistance
3. No LM leakage
4. No delamination
5. Qualify 130 °C, 85% Rh, 96 h HAST.

Acknowledgement

Dr. Keyton Feller

Loren Russell

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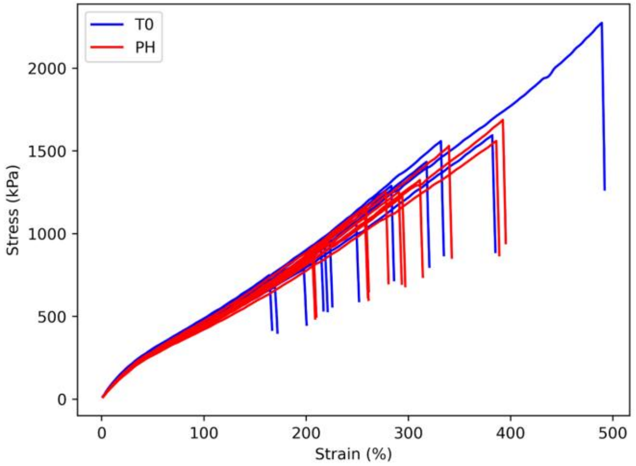
Back Up Slides

HAST effect on polymer matrix and dye-pry test

Tensile test of Polymer matrix

Pre-HAST and Post-HAST



Tensile test indicated no change in polymer matrix

$$Ga_2O + H_2O \rightarrow Ga_2O_3 + H_2$$
$$Ga_2O_3 + H_2O \rightarrow 2GaO(OH)$$
$$2Ga + H_2O \rightarrow Ga_2O_3 + H_2$$

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