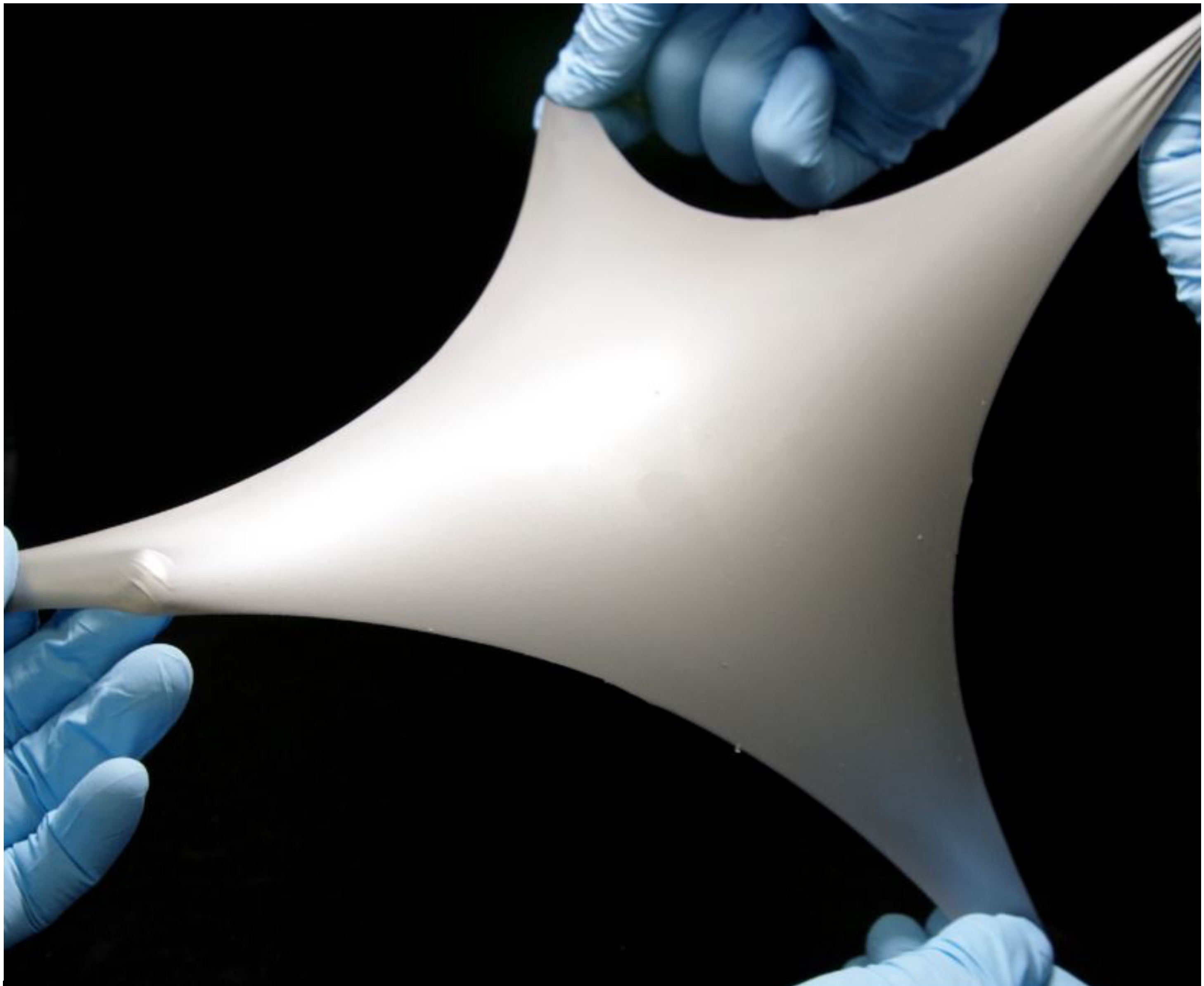

TIMbber™ ALT Series
Thermal Interface Materials
Preliminary Information
Spring 2021

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TIMbber™ ALT Series

ARIECA has created a new class of polymer composite materials based on Liquid Metal Embedded Elastomers (LMEE). Dispensed in emulsion form and cured in place, the TIMbber™ ALT (Apex Level Thermal) series is specifically designed for demanding electronic and microprocessors and graphic processor applications which require low thermal resistance, flexibility, and excellent adhesion to silicon and nickel.

Salient Characteristics:

- Single-digit thermal resistance < 6 mm^2-K/W
- Low interfacial thermal resistance < 1mm^2-K/W
- Low application pressure required < 15 psi
- Dispensing viscosity between 100- 500 cPs
- High elongation > 250% strain at break
- Low voiding characteristics < 0.2 % voiding[1]
- Excellent adhesion strength properties, Si > 150N/m, Ni > 35N/m
- Supercooling properties maintain liquid state > -55°C

Target Applications:

- Servers CPU
- Client CPU
- Graphic Processing Units (GPU)
- Game Consoles
- Routers/Switches
- System on Chip (SoC) ASICs

[1] Based on recommended curing profile

Liquid Metal Embedded Elastomer (LMEE) Filler System

TIMbber™ is based on the proprietary Liquid-Metal Embedded Elastomer (LMEE) technology developed by the team at ARIECA. It sets a new performance level for polymer-based thermal interface material (PTIM). Through a unique composition of liquid metal droplets suspended in a soft elastomer encapsulant, the full potential of liquid metal is made available to high-volume manufacturing TIM applications.

The extreme deformability of liquid metals droplets in the LMEE results in very low thermal contact resistance to silicon and nickel, extremely high elongation exceeding 200% of original bond line thickness (BLT), and excellent voiding performance below 0.2% under curing conditions. Through optimization of the base polymer, excellent adhesion to both silicon and nickel are achieved.

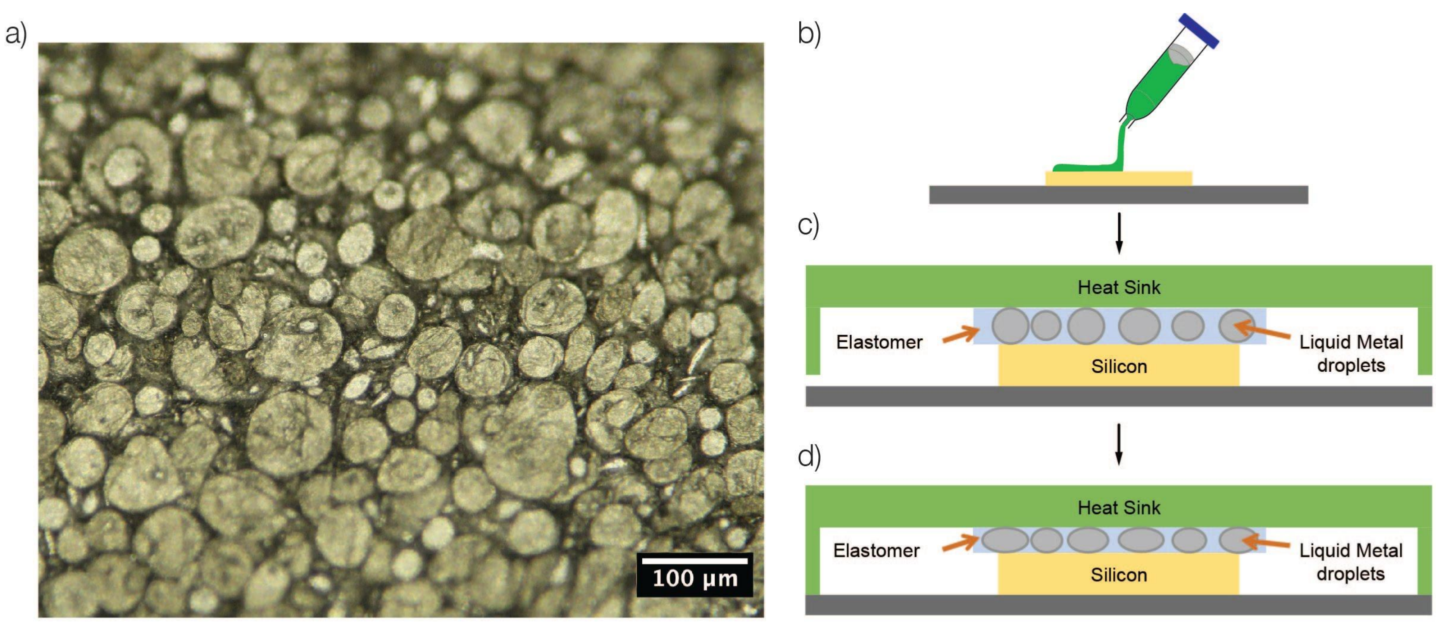


Figure 1. LMEE microstructure and application schematic

Single-Digit Thermal Resistance (mm^2-K/W)

TIMbber™ is designed to achieve single-digit thermal resistance (mm^2-K/W) with low applied pressure during the assembly process. The thermal resistance as a function of holding pressure is shown in figure 2. TIMbber™ is able to achieve < 10 mm^2-K/W with 5 psi of holding pressure. Results show that thermal resistance reduces to 5.9 mm^2-K/W when a holding pressure of 9psi is applied. Most high-volume manufacturing (HVM) processes require application pressures below 15 psi. Thus, TIMbber™ conforms well to HVM requirements.

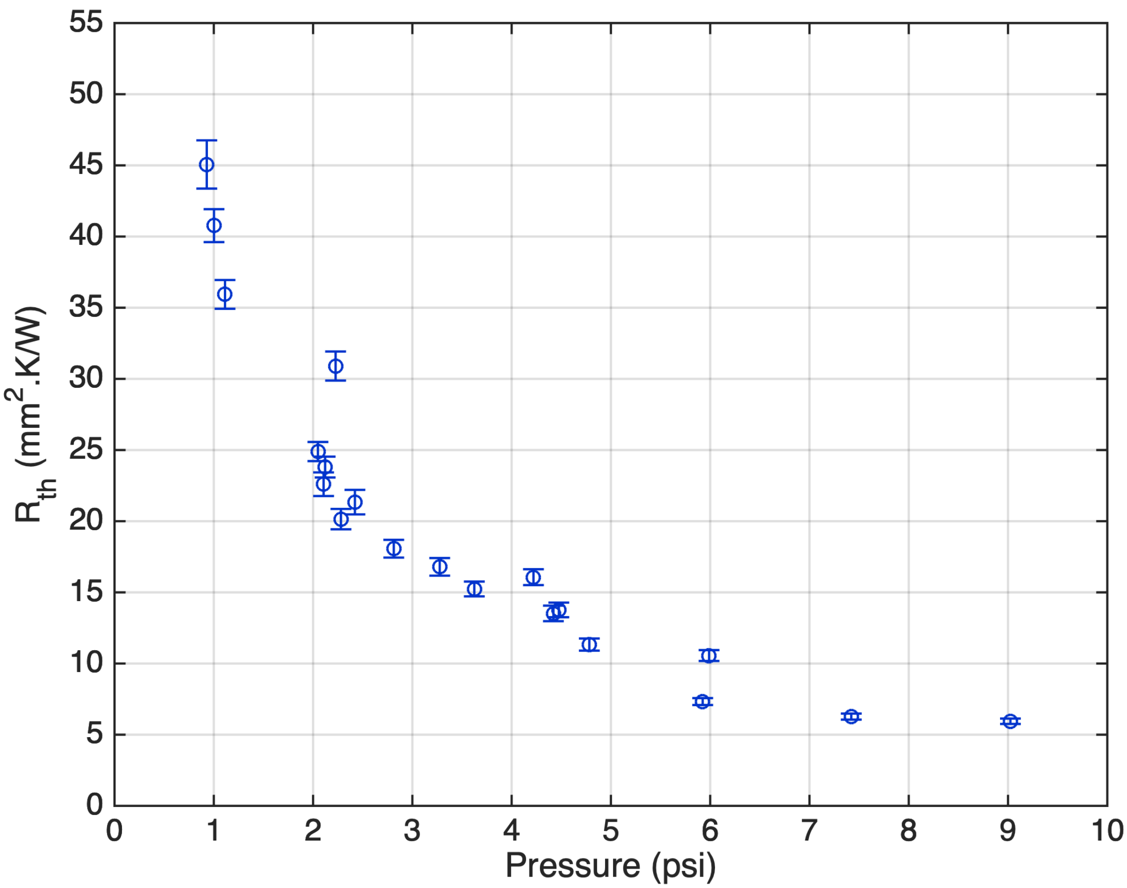


Figure 2: Thermal resistance as a function of applied pressure (ALT Series), following ASTM D5470 test procedure

ASTM D5470 analysis is shown below in figure 3. In this set up, the bond line thickness (BLT) is gradually reduced from 200µm to 20µm. The data shows that even with a modest bulk thermal conductivity (4.0 W/m-K), a low thermal resistance can be achieved due to the TIMbber^{TM}'s unique microstructure, which allows the ability of achieving a low BLT and a low interface resistance.

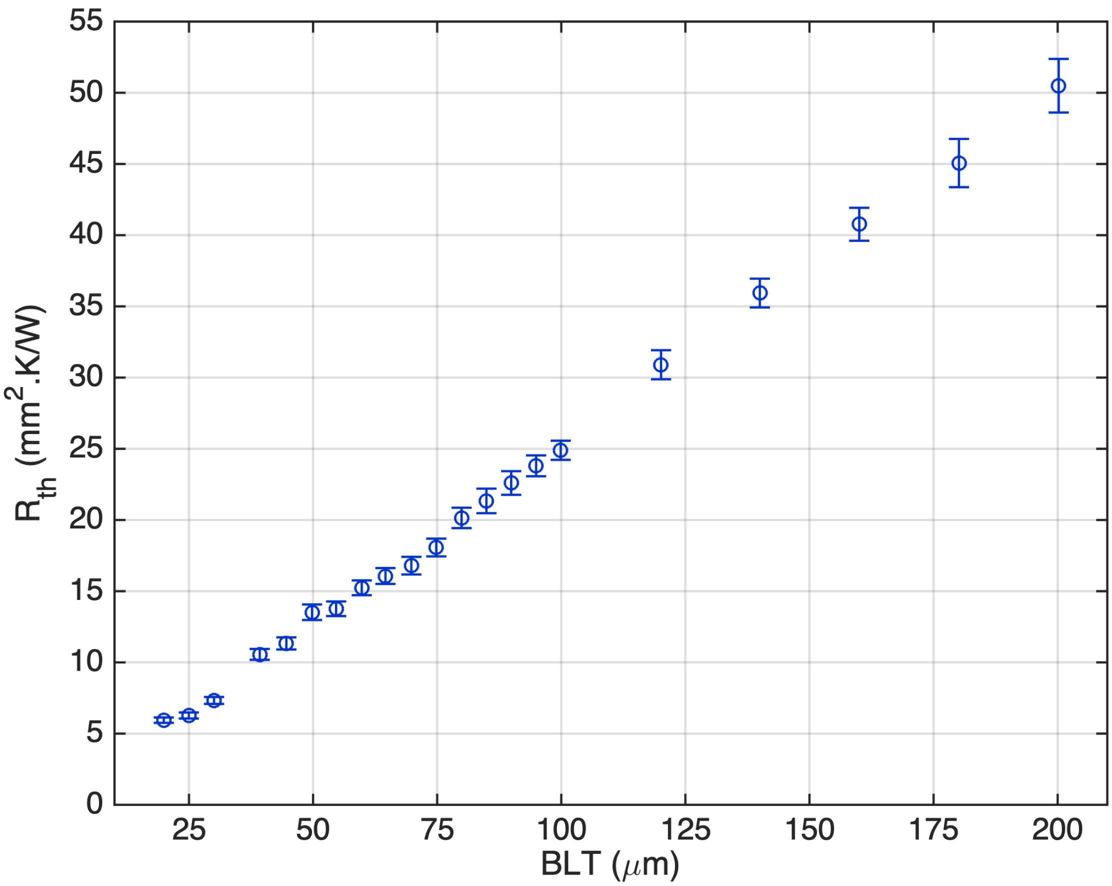


Figure 3: Thermal resistance as a function of bond line thickness (BLT), following ASTM D5470 test procedure

ASTM D5470 TTV Testing

Thermal resistance was also tested with a silicon thermal test vehicle (TTV). The TTV is shown in Figure 4 below. It consists of 5 thermal diodes that are calibrated prior to each measurement. These diodes allow us to monitor the uniformity of thermal resistance, as well as capture the interface resistance from TIM to Silicon, and TIM to the Nickel-plated Copper heat sink. The heat sink is attached to a ASTM D5470 test head, which allows us to vary to bond line thickness for each measurement.
The 5 test points measured are:

Test Point	Location
T1	Lower Right
T2	Upper Right
T3	Center
T4	Lower Left
T5	Upper Left

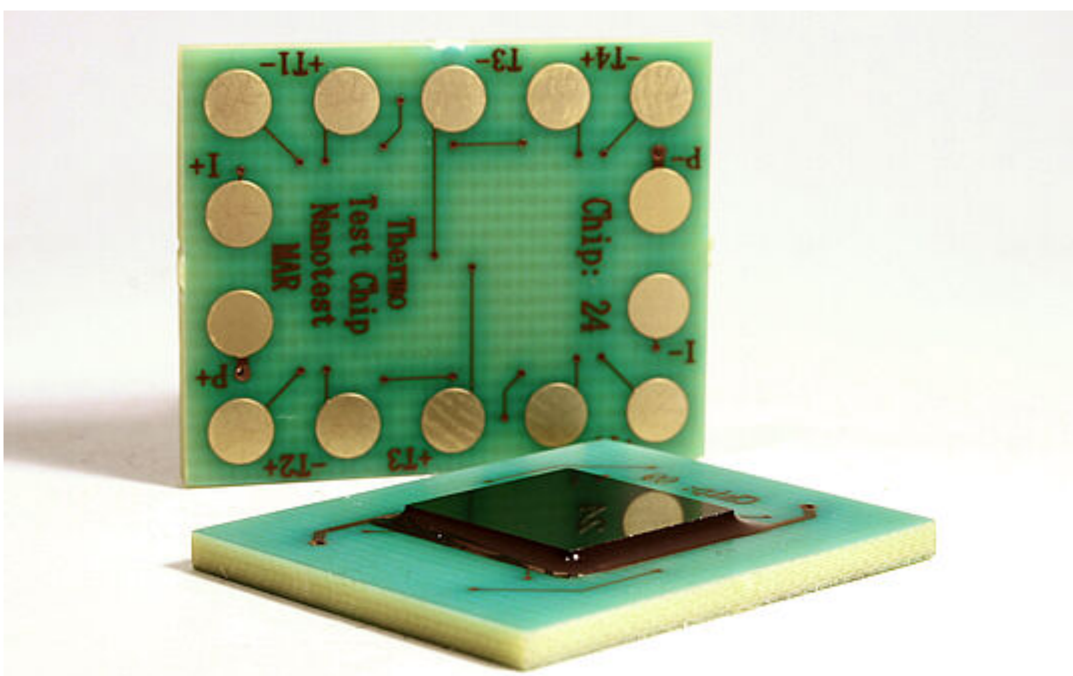
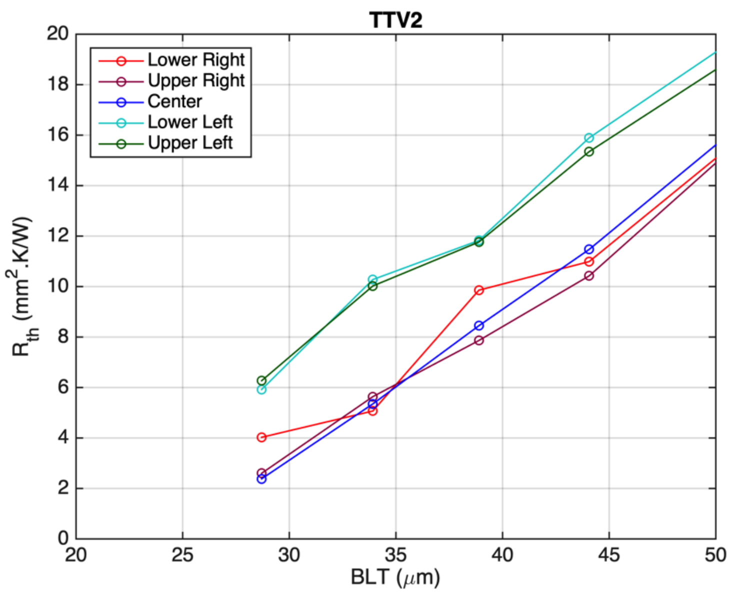
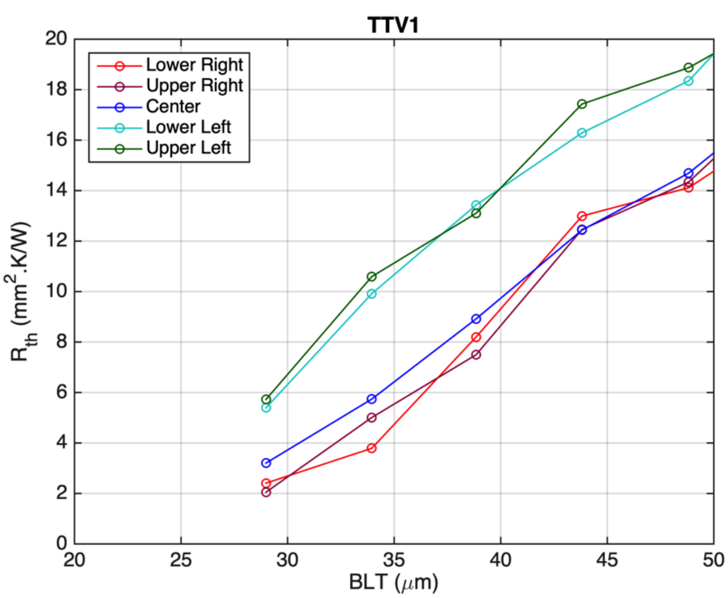


Figure 4: TTV from NanoTest GmbH

Three Independent TTV measurements were made with TIMbber™ used as the TIM material. The results are shown if figure 5 below:

In each of the 3 tests, a bond line thickness of less than 30 µm was realized, with the resulting thermal resistance below 6 mm^2-K/W. It is noticed that there is a significant gradient between the left and right sides of the TTV. Tests are ongoing to determine the cause of this systematic offset. The current hypothesis is that the thermal test head interface is not perfectly parallel with the TTV, leading to a non-uniform distribution of TIM material.





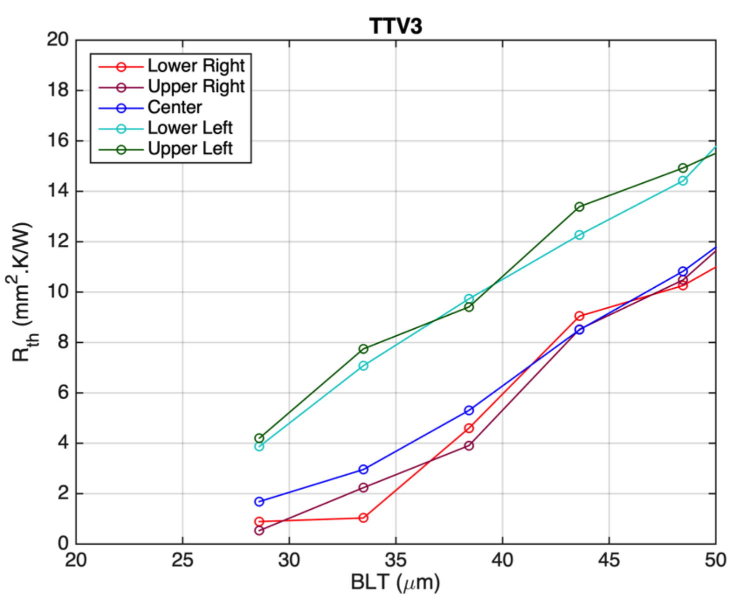
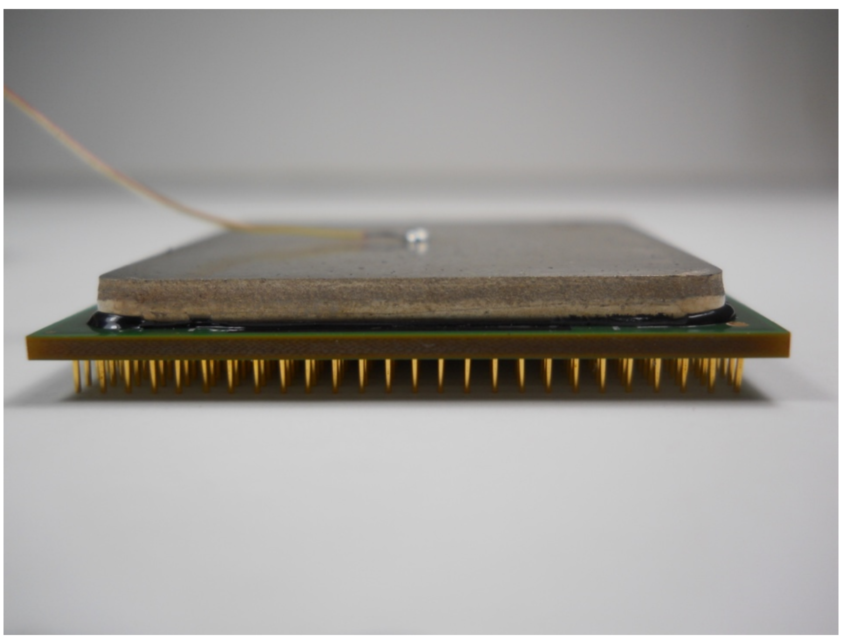


Figure 5: Results of 3 TTV Experiments

Thermal Resistance TTV Testing

The ultimate test of a TIM is its ability to produce a low thermal resistance in a semiconductor package that interfaces to an imperfect Lid or integrated heat spreader (IHS). The test setup shown in Figure 6 is used to evaluate the thermal resistance performance. Unlike the ASTM D5470 method, which measures heat transfer in a controlled environment, TTV tests are highly dependent on specific parameters of the TTV. Therefore, the thermal resistance testing was performed on the same TTV with samples of both Arieca's ALT-304-90, and ShinEtsu's X23-7921-5, allowing for the ALT-304-90 to be compared on a like-for-like basis with an industry standard TIM.



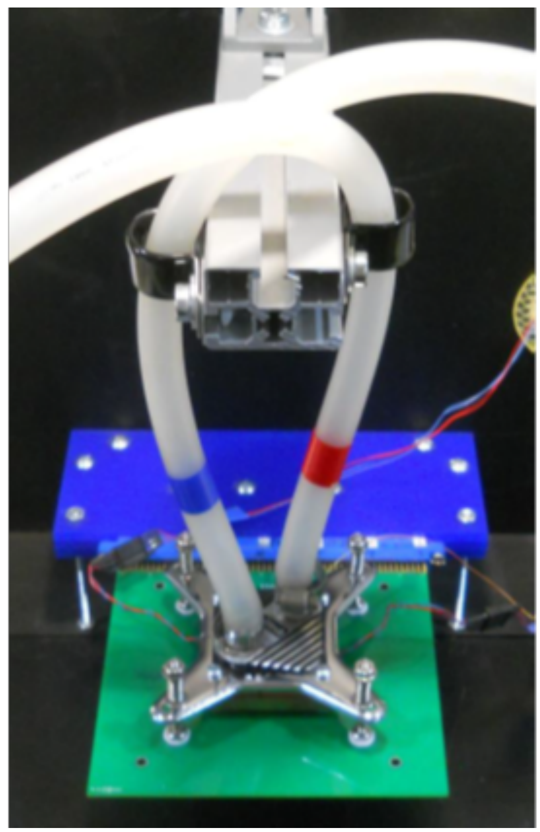


Figure 6: TTV and Thermal Evaluation Setup

Test Setup: The temperatures on the die are measured at 5 different locations using 4-wire resistive method, and the temperature of the IHS is measured following the JESD51 standard (36ga type-k). Dowsil 3-6265 is used as the lid sealant and is cured at 125 °C for 1 hr. TIMbber (as a liquid dispense adhesive TIM) is cured at 70°C for 1 hour and ramping to 125°C for another hour. Power of ~80W is applied to achieve TIM1 joint temperature of between 40-50°C. A comparative map of thermal resistance (θ_{jc}) at different location on the die is shown in Figure 7. The test results show that ALT30490 in average has a slightly lower thermal resistance than ShinEtsu's X23-7921-5.

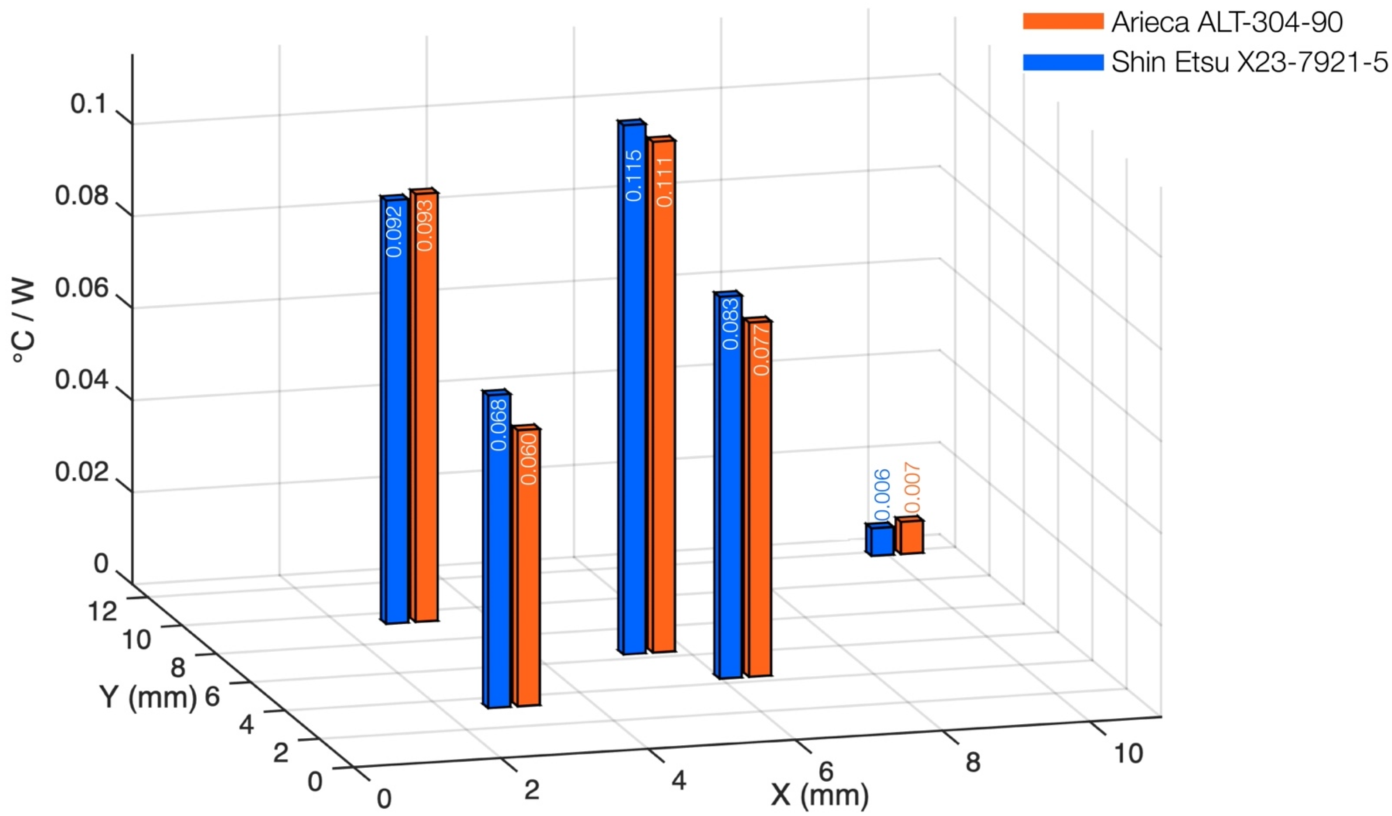


Figure 7: Comparative θ_{jc} Values at 5 different locations on the Si die

Elongation

Elongation test were performed on dog bone test samples, and were fabricated from the base polymer (ALT-30P) and TIMbber™ with different filler loading and microstructure (ALT-303-60, ALT-303-90, ALT-304-60, ALT-304-90, ALT-305-90), with thickness of 450-500μm and width of 5mm. A mechanical loading apparatus (Mark-10) with force and displacement resolutions of 0.02N and 20μm, respectively, was used to stretch each sample and record the force exerted on each sample as a function of deformation. The results, shown in Figure 8, demonstrate that elongation exceeds 200% in all cases.

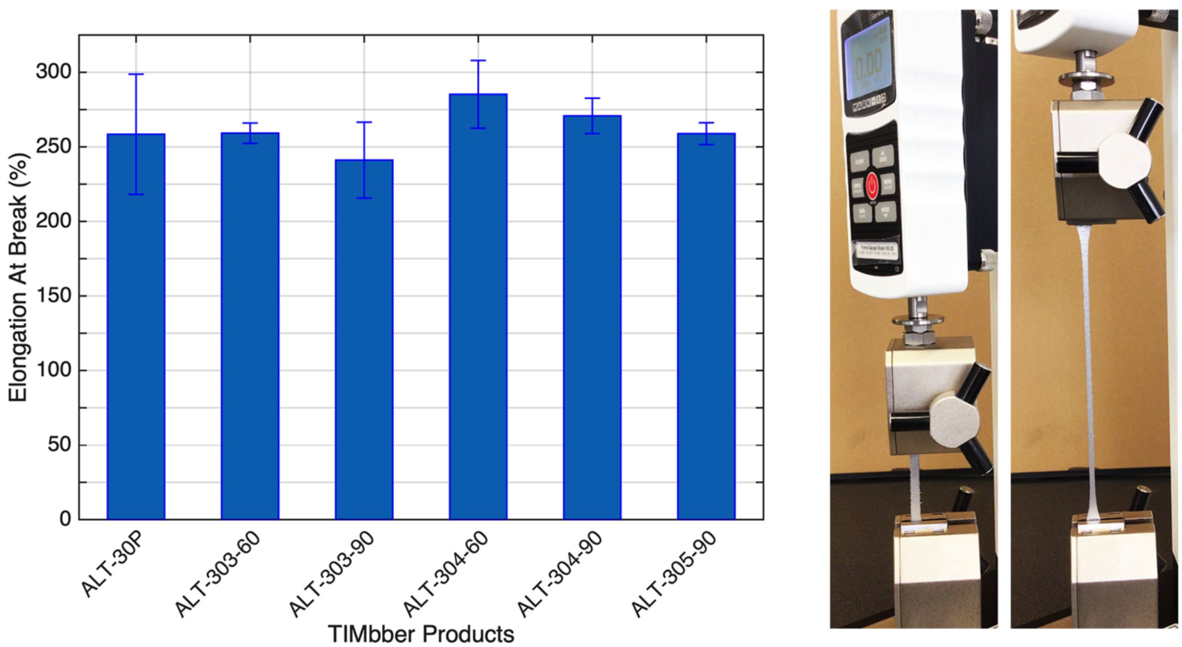


Figure 8: Strain at break of unfilled base adhesive polymer (ALT-30P) compared to TIMbber™ product with the same base polymer while changing filler loading and the microstructure

Results based on at least 3 samples of the base polymer, and the TIMbber version of those polymers, show (Figure 9) that elongation is retained, while the stress at 200% strain decreases by approximately 30%, creating softer interface to improve the reliability.

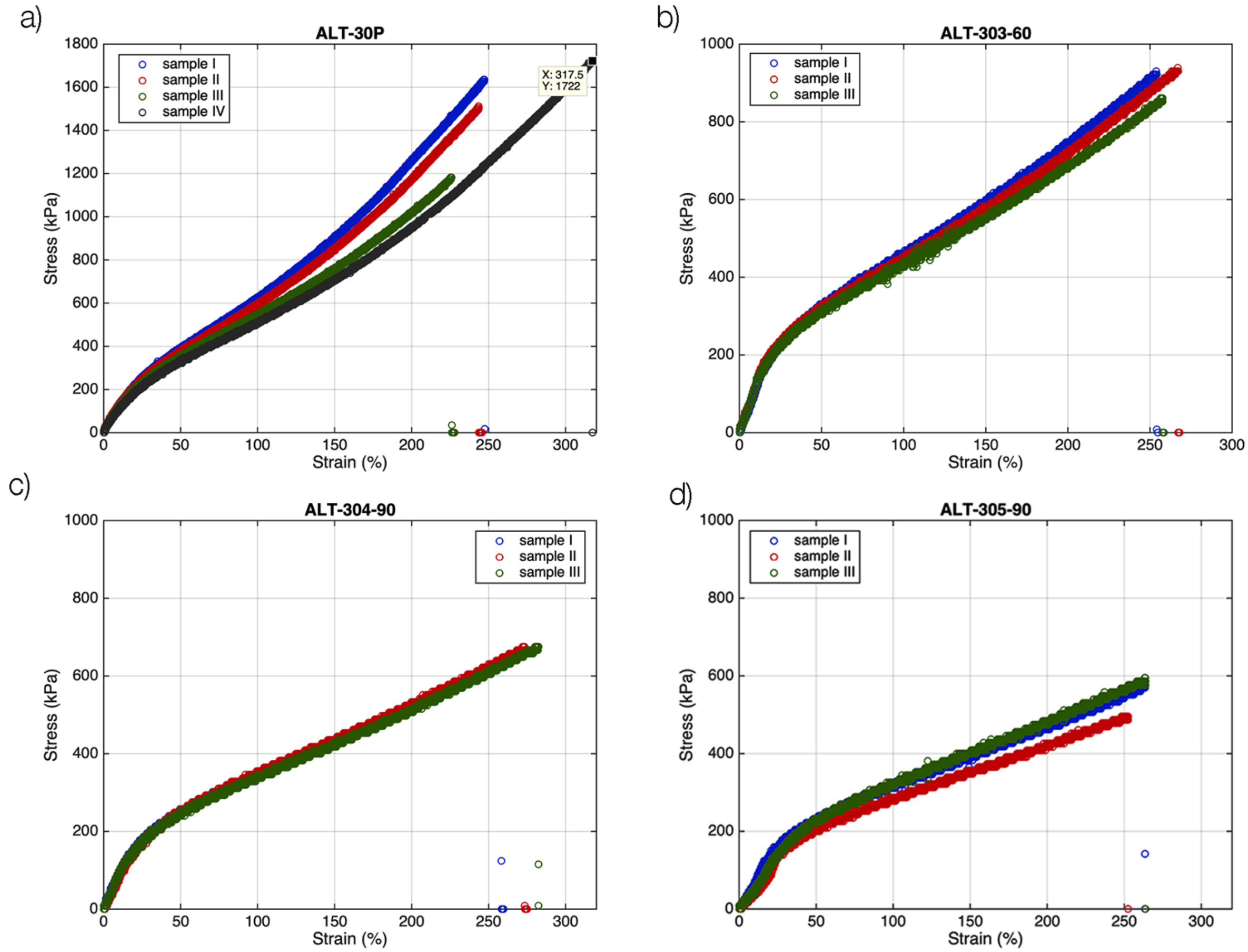


Figure 9: Stress vs Strain plots of a) ALT-30P (base polymer), b) ALT-303-60, c) ALT-304-90 , and d) ALT-305-90 (highest filler loading)

Adhesion

Adhesion is tested with the 180° peel method, with the mechanical tester (Mark-10) providing and measuring the pulling force with a 50 mm/min pulling rate.

The adhesion strength is measured by dividing the steady peak force by the width of the adhesive film. Adhesion is tested against both a Nickel plate and a silicon wafer. The results in Figure 10 show that TIMbber™ demonstrates enhanced adhesion to both surfaces.

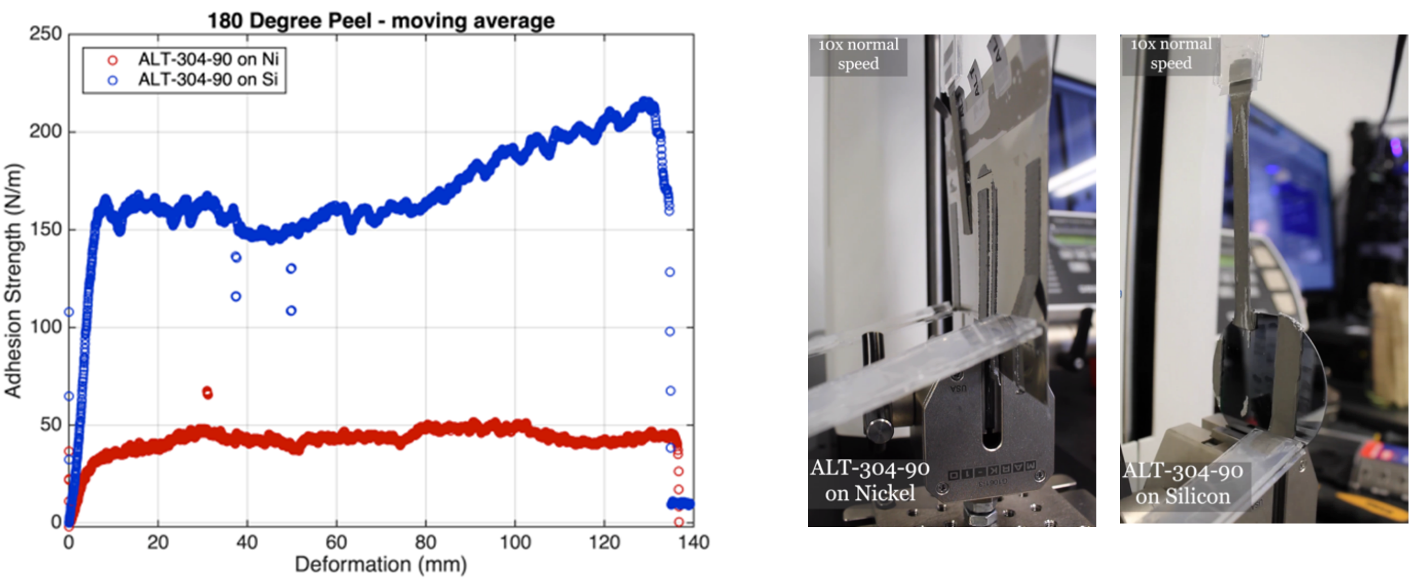
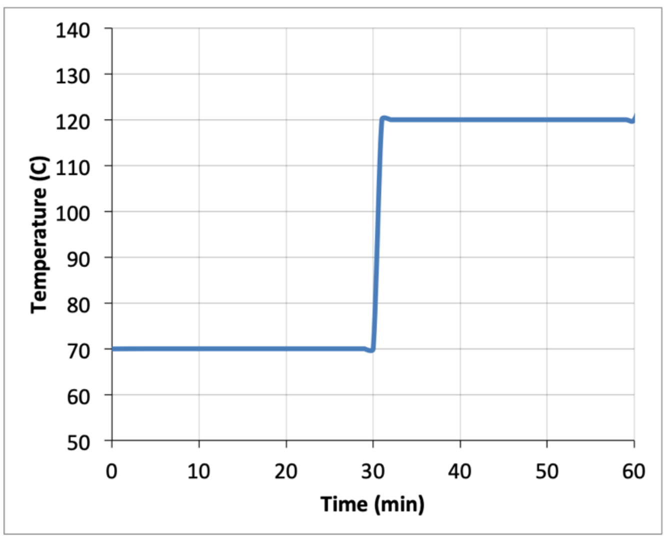


Figure 10: 180 Degree Peel Adhesion Test Set up and Results

Voiding

A high-level of TIM coverage is required to achieve low thermal resistance in commercial applications. TIMbber™ is deposited in emulsion form and must be cured. The curing conditions influence the voiding characteristics. High voiding leads to low coverage, leading to elevated thermal resistance.
The curing profile show in Figure 11-left is applied to deposited TIMbber™, and the resulting voiding performance is evaluated by performing image analysis on the amount of voids created during the curing process.



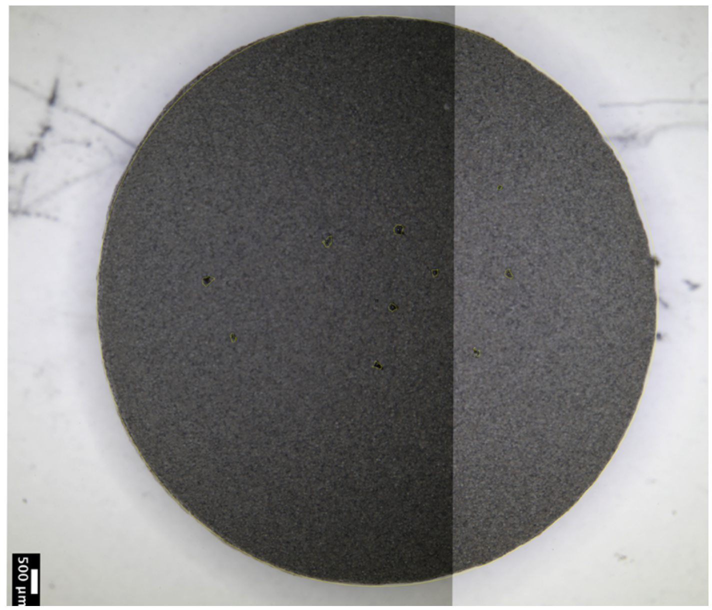


Figure 11: Voiding experiment, left) applied curing profile, right) image analysis of the coverage of TIMbber™

The resulting image analysis is shown in Figure 11-right where the voids area is divided by the total area to calculate the voiding ratio. The results show the high level of TIM coverage after curing. The coverage ratio for the sample in figure 7 is 99.83%, indicating that voiding is below the 0.2% target.

Differential Scanning Calorimetry (DSC)

The emulsion was analyzed by a DSC between temperatures of 30°C and –50°C, using a cooling rate of 5°C/minute and holding for 5 minutes at –50°C, under nitrogen purge gas.

The cooling plot in figure 12 demonstrate that no phase change event (solidification of the fillers) occurs at temperatures above -50°C. This supercooling behavior of TIMbber™ makes it adaptable for extremely low temperature conditions.

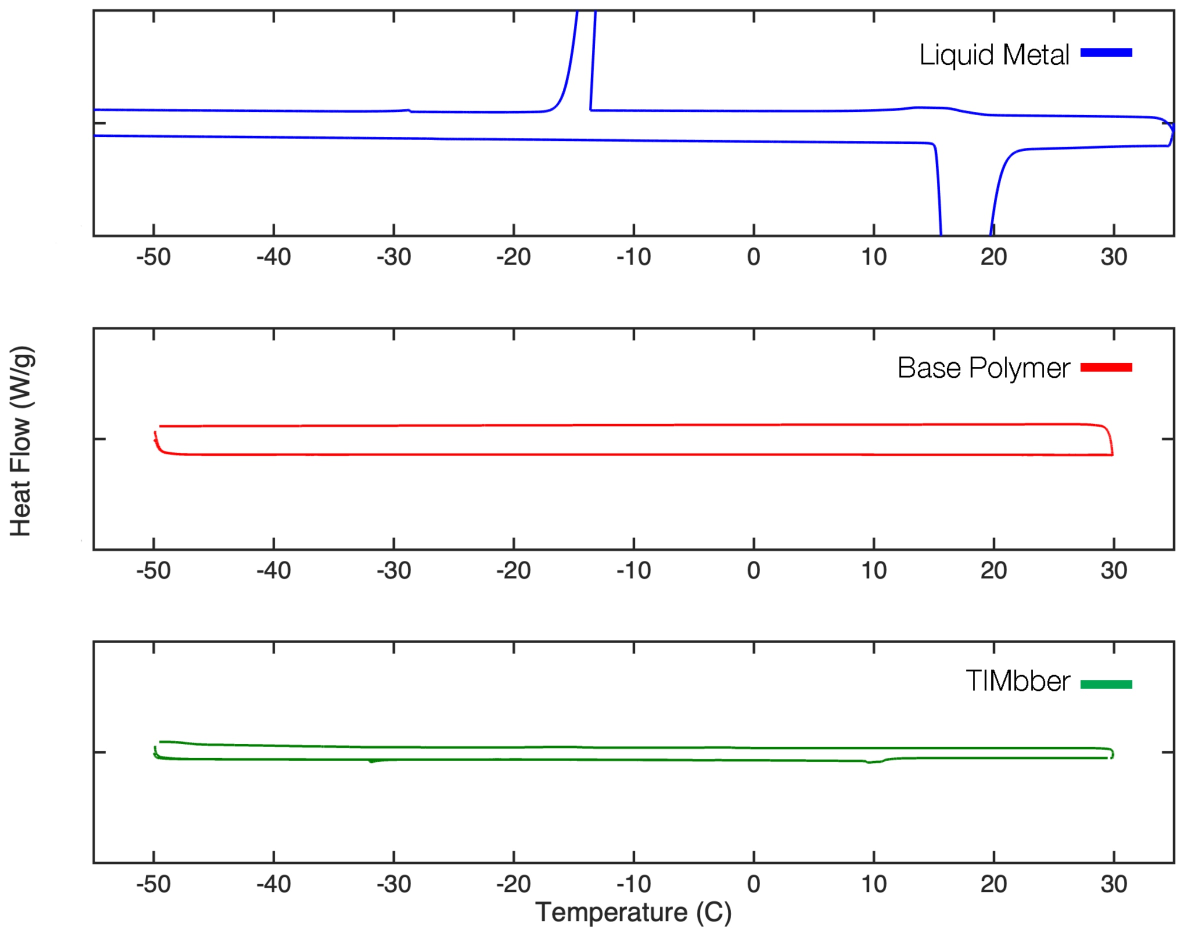


Figure 12. Comparison of DSC plots of bulk liquid metal and unfilled base polymer along with TIMbber™. TIMbber shows no phase change between –50°C to 30°C.

Viscosity

The Viscosity of TIMbber™ is compatible with high volume manufacturing Polymer-TIM dispensing tools. The range of viscosity measured by Ametek Brookfield cone-plate viscometer is between 100-500 Pa.s.

The material properties for various formulations are summarized in Figure 13 below.

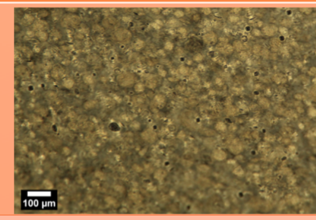
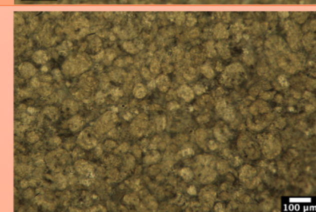
Formulation	Loading	Particle size (µm)	Stress (kPa) @ ε=200%	Strain at Break (%)	Viscosity (Pa.s)	Adhesion (N/m)	
ALT-303-60	57% vol 88.9% wt	58 ± 12	718 ± 30	259 ± 6	236	Ni: 40 (nom)	
ALT304-90	65% vol 91.8% wt	77 ± 20	524 ± 9	270 ± 11	193	Ni: 40 (nom) Si: 150 (nom)	
ALT-305-90	70% vol 93.4% wt	68 ± 27	460 ± 30	259 ± 7	223	Ni: 40 (nom)	

Figure 13: TIMbber Material Properties

Preliminary Reliability

The ALT family is designed for large integrated circuits (IC) that consume high power and are expected to have a reliable working lifetime of many years. One of the cautions in designing products with ultra-low bond line thicknesses (BLT) is that reliability performance could be unacceptably compromised. Reliability performance is highly package and application dependent, and final reliability can only be validated by the manufacturer. However, Arieca has performed a preliminary reliability test, on a limited number of samples, to demonstrate baseline reliability.

Test were performed on a commercially available TTV (11mm x 13mm active die) with 5 temperature sensor diodes places in the center, off-center, and corner of the die. An image of the TTV is shown in figure 14.

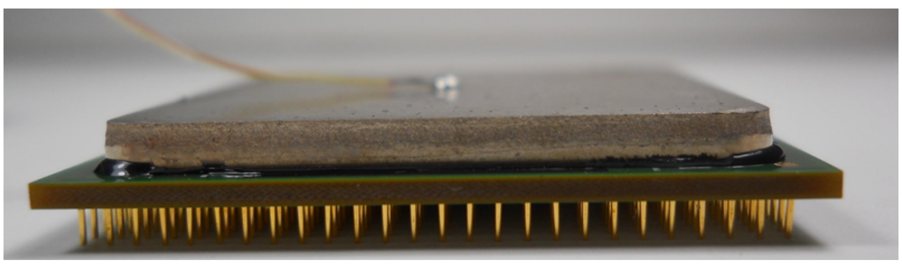


Figure 14: TTV Used for Reliability Testing

The reliability tests were chosen to validate critical performance parameters of a TIM in a high-performance (low thermal resistance) application. These are:

- JEDEC22-A 108 HTOL – High Temperature (125C) storage for 1000h to ensure that the encapsulating polymer matrix prevents the liquid metal from excessive oxidation and drying out.
- JEDEC22-A 110 HAST – Highly Accelerated Stress Test (85C/85% RH) to ensure that the encapsulating polymer matrix prevents the liquid metal from oxidizing in a humid environment.
- MIL-STD 883 Thermal Shock – Alternating soaking (15 minute dwell) of the device in -55C and 125C to ensure that the TIM does not delaminate with device warpage.

Reliability testing is still in progress. The first test conducted was thermal shock, as delamination is a possible failure point for thin BLT TIM packages. The thermal shock profile is shown in figure 15, and the thermal shock performance of the center diode is shown in figure 16. This plot shows the measured thermal resistance after each 100 cycles of shock. The graph is normalized to the T0 (initial) thermal resistance measurement.

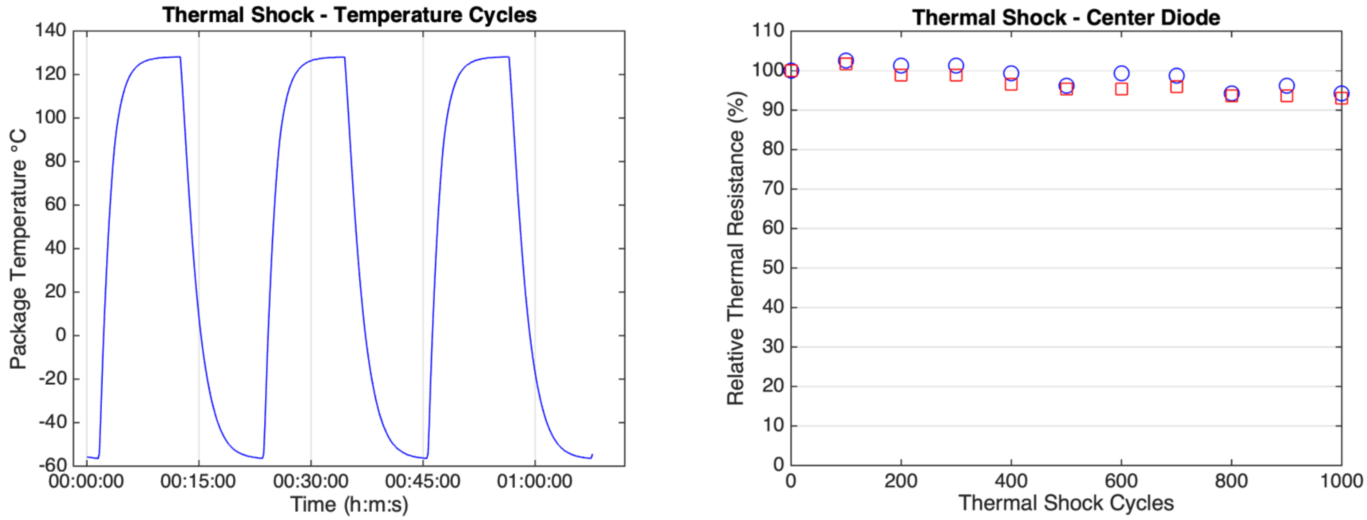


Figure 15: Temperature cycles and center diode thermal performance during Thermal Shock reliability tests

The thermal shock results (Figure 15) show that over 1,000 cycles there is no degradation in TIM thermal performance.

High Temperature storage is currently at 700 hours. The thermal resistance is measured after each 100 hours of storage. Figure 16 shows the thermal resistance of the center diode, normalized to the T0 reading. Thermal performance is stable over the tested 700 hours.

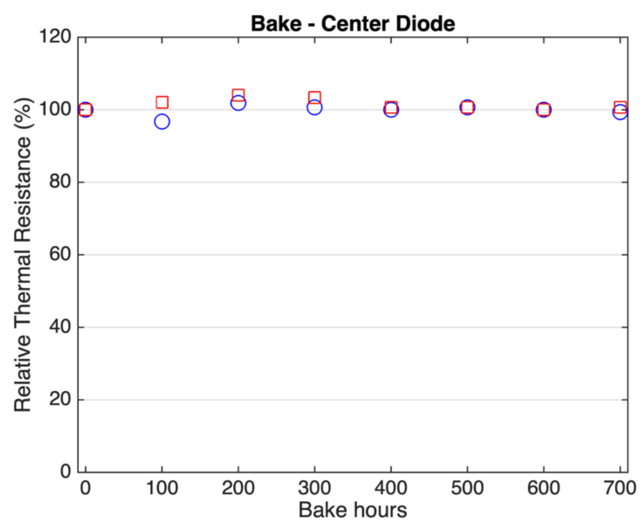


Figure 16: Center Diode Performance Over Time

Our evaluation lab does not have the capability to perform UHAST. Hence, we are conducting the HAST (85C/85%RH) over a longer duration. HAST is currently at 500h. The thermal resistance is measured after each 100 hours of storage. Figure 17 shows the thermal resistance of the center diode, normalized to the T0 reading. Thermal performance is stable over the tested 500 hours.

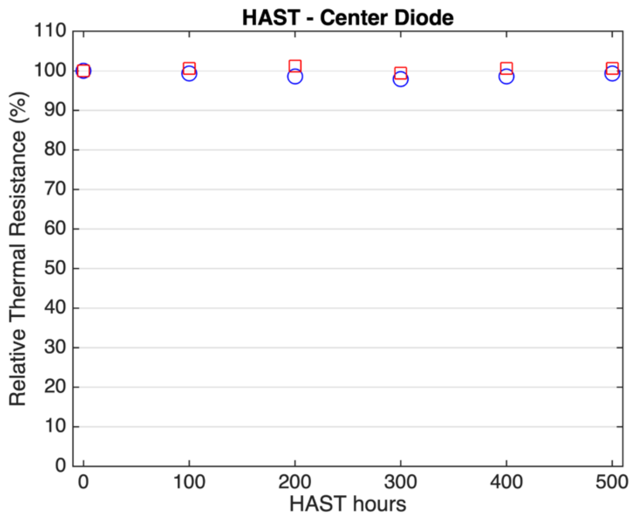


Figure 18: Center Diode Performance Over Time

Availability

TIMbber^{TM} is currently produced on a pilot production line in our Pittsburgh laboratory for evaluation purposes. Arieca is eager to engage with industry partners so that the formulations can be optimized for performance and manufacturing needs for commercial applications.

A Preliminary Technical Data Sheet (PTDS) is available under NDA.
Evaluation samples require an NDA.