Degradation Characterization of Thermal Interface Greases

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ITHERM 2017

June 2, 2017

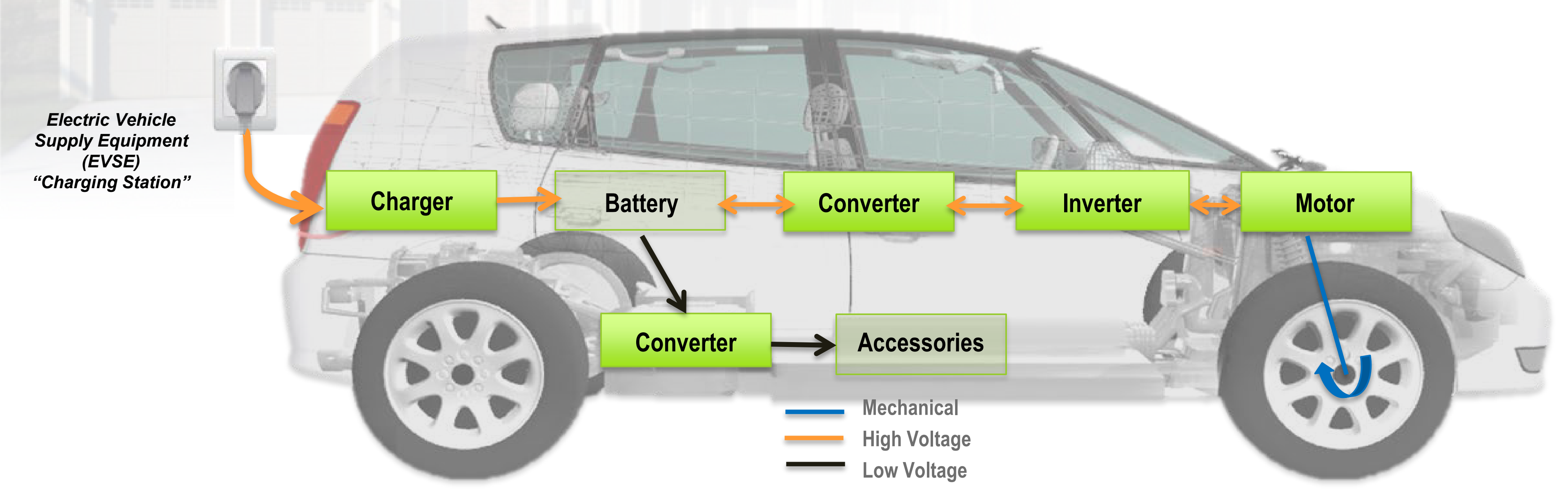
NREL/PR-5400-70012

Outline

- Relevance of work
- ASTM D5470 best practices
- Steady-state measurements
- Large-area fixtures
- Reliability analysis

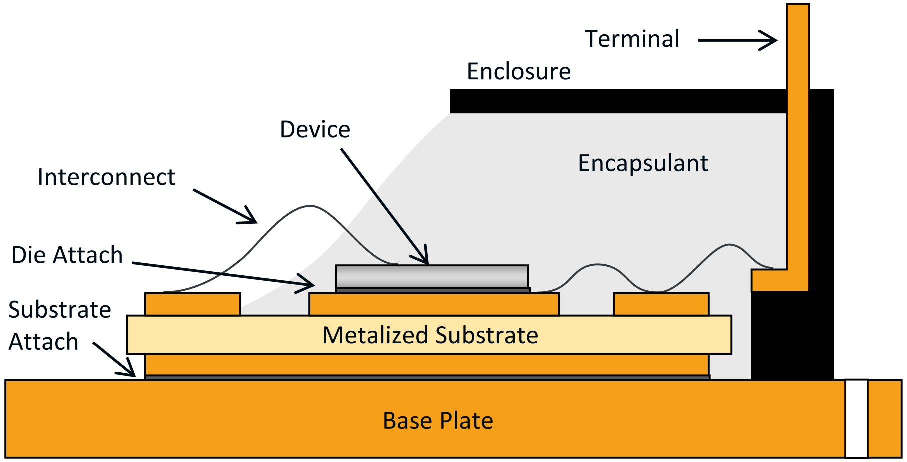
Background – Electric Vehicle Powertrain

- Power electronics systems are widely employed for efficient control of energy generation, distribution, and use
- Degradation occurs from environmental conditions such as:
  - Thermal cycling
  - Vibrations
  - Exposure to humidity
  - Exposure to reactive chemicals
  - Peaks/transients in the operating temperature, voltage, and current

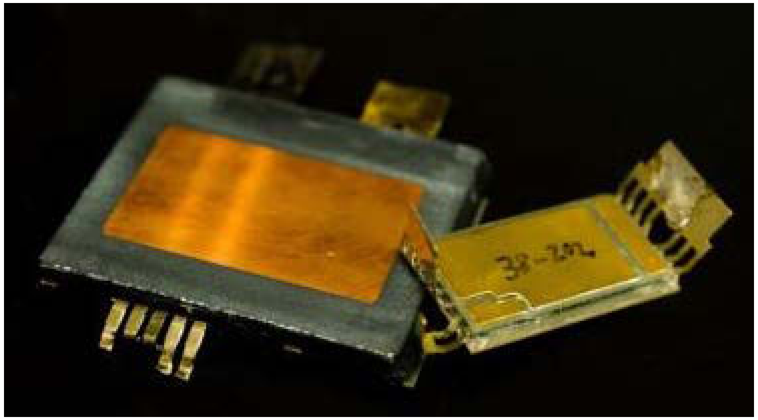


Background – Power Electronics Components

- Packaging designs must thermally allow for:
  - High operating temperatures
  - High heat fluxes
  - Hot spots
- Thermal grease is used at the junction between the package and a cold plate to aid in the transfer of heat away from the device



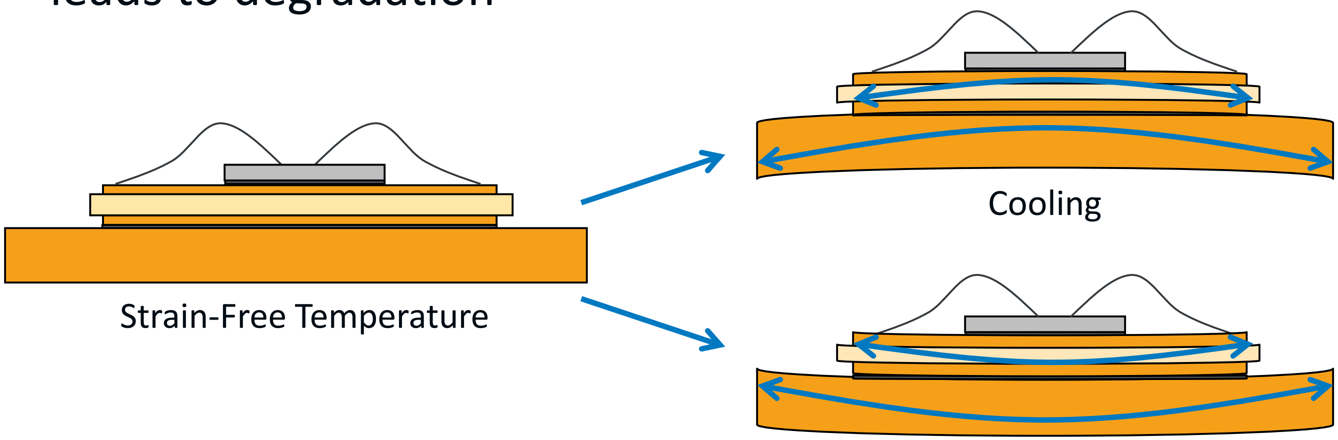
Traditional Power Electronics Package



State-of-the-Art Packages

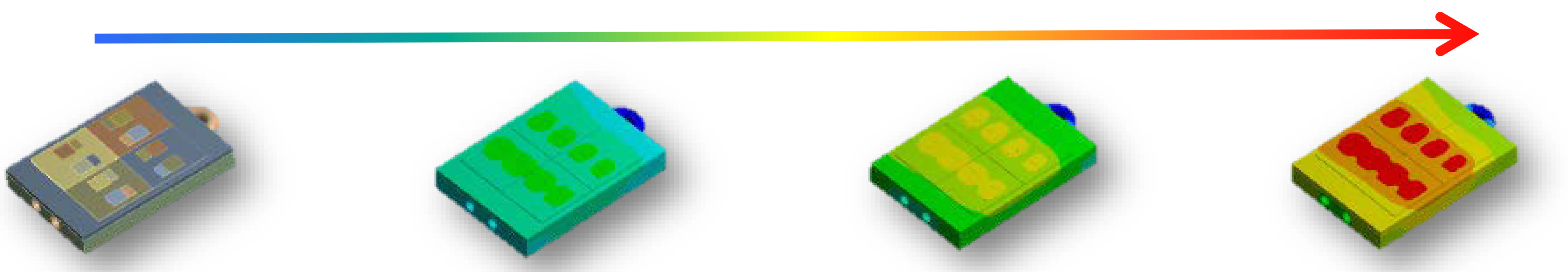
Background – Common failure mechanisms

- Because the mismatch in the coefficient of thermal expansion (CTE) within the package and high temperature conditions, thermal grease is subject to stress that leads to degradation



CTE ($\times 10^{-6}$ / K)
Silicon: 2.6
AlN: 4.5
Si_3N_4: 3.2
Copper: 16.5
Aluminum: 22.7
Sn63/Pb37 Solder: 24.7
Silver: 19.5

As the grease degrades, the junction temperature at the device rises



Model of temperature rise of electronics as thermal resistance increases

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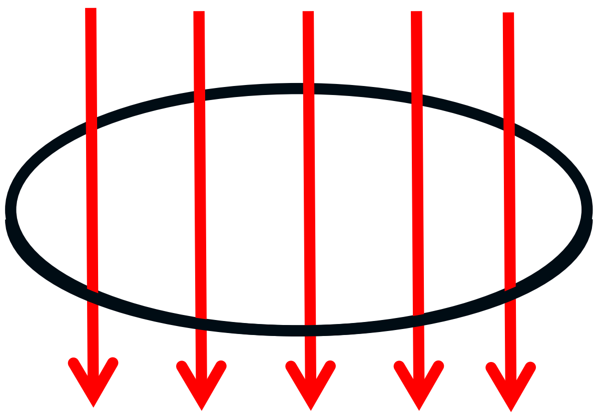
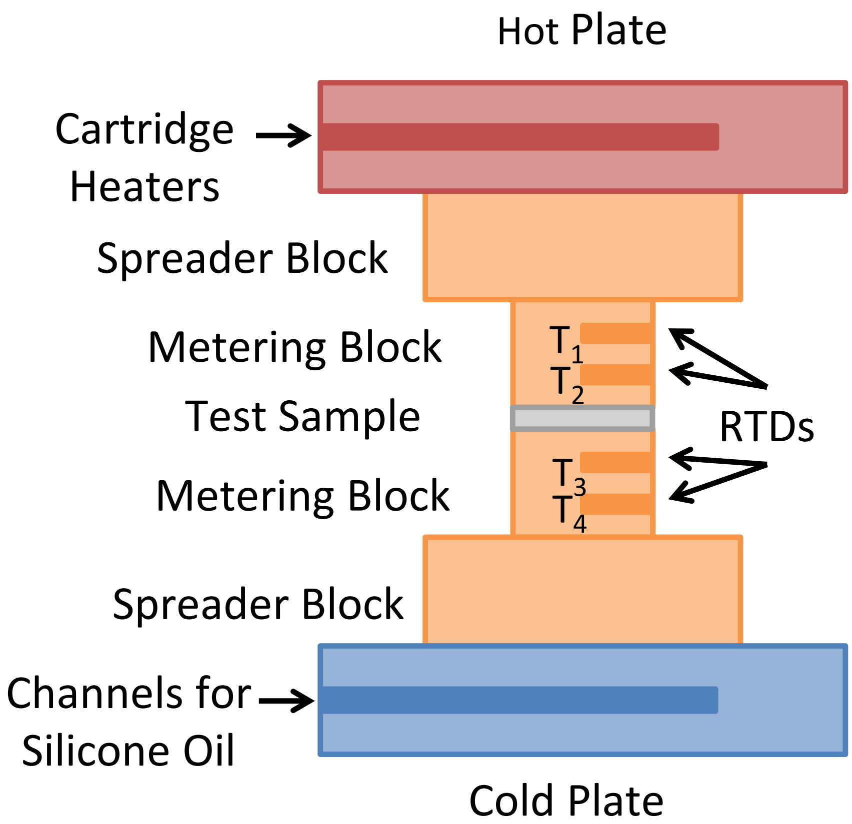
ASTM D5470

- The ASTM D5470 standard is used to test the thermal characteristics of the thermal interface material (TIM)
- Common sources of error include:
  - Resistance Temperature Detectors not making sufficient contact with the meter block
  - Inaccurate bondline thickness measurements



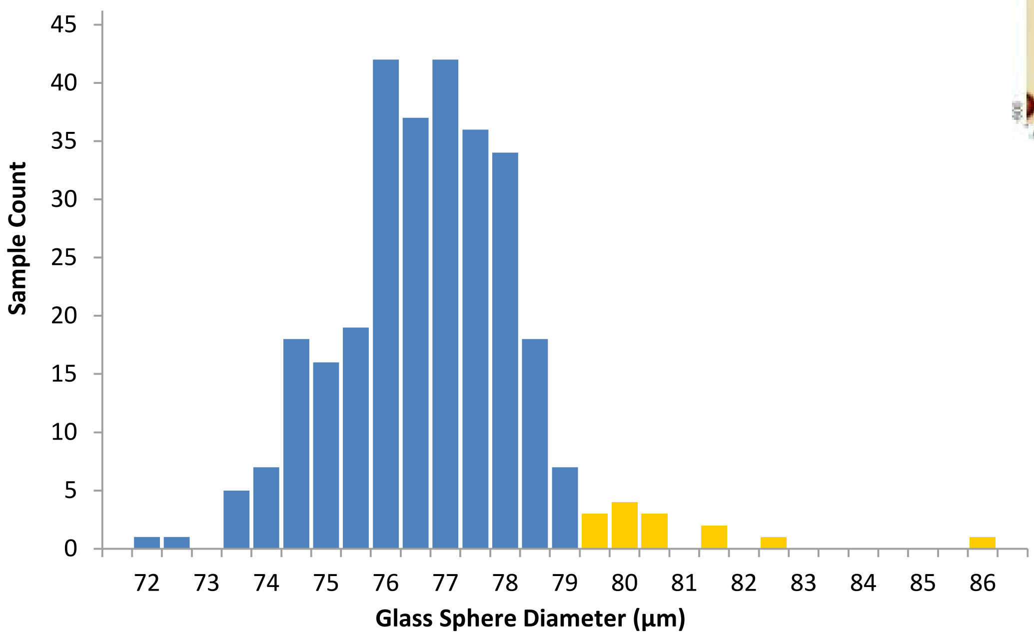
Direction of heat flow through the meter blocks



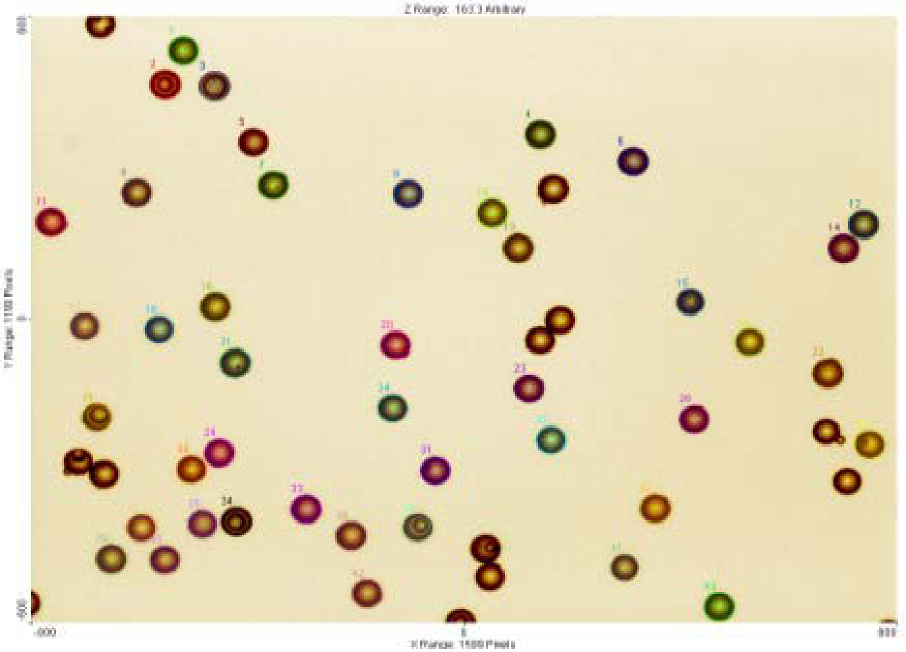
D5470 test stand diagram

Bondline thickness spacers (glass sphere distribution)

- Glass spheres used as bondline spacers were analyzed to determine the largest 95th percentile diameters
- SPIP* by image metrology was used to analyze the diameter of each sphere within a sample batch



*SPIP™ is an advanced software package for processing and analyzing microscopy images at nano- and microscale



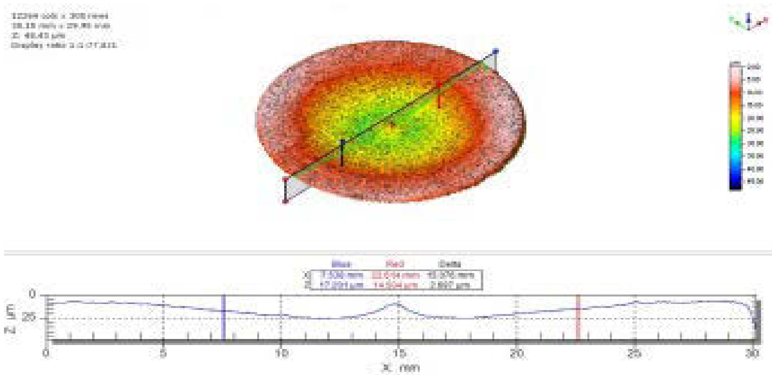
Bondline spheres images processed in SPIP

Nominal Sphere Diameter (µm)	Mean Sphere Diameter (µm)	95th Percentile Diameter (µm)
23-27	25.5	29.0
47-50	50.5	52.0
75	76.5	78.5
123-127	123.5	125.5
150	152.5	158.0
190-197	193.0	196.0
250	257.0	266.0

Comparison of nominal sphere diameter reported by the manufacturer with measured sphere diameter

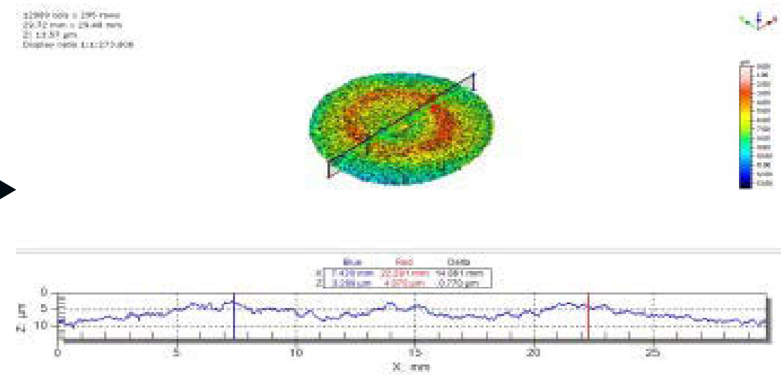
Meter block surface polishing

- The machining process for the meter block's mating surfaces was not adequate to achieve the flatness tolerance required
- A process known as 'lapping' was used to smooth out the mating surfaces



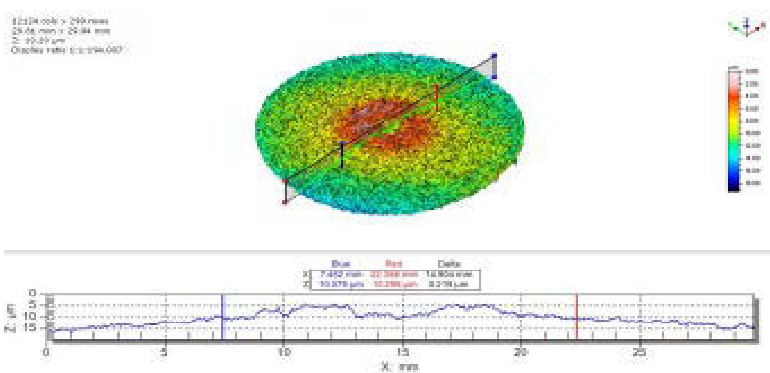
Pa	5.72 µm	Average Roughness
Pq	6.41 µm	RMS Roughness
Pt	30.35 µm	Peak to Valley Height

25 µm lapping paste →



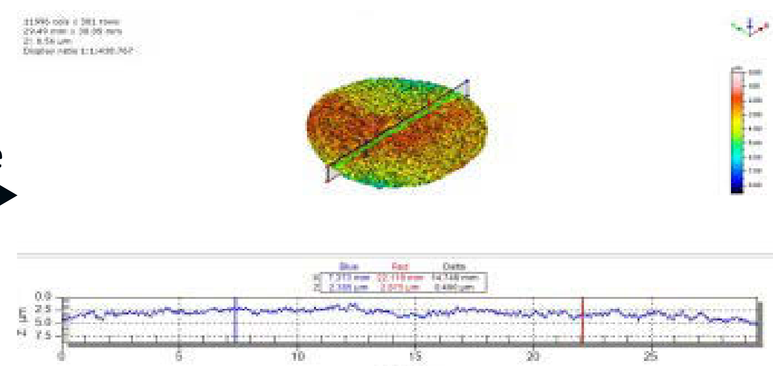
Pa	2.48 µm	Average Roughness
Pq	2.99 µm	RMS Roughness
Pt	12.20 µm	Peak to Valley Height

10 µm lapping paste



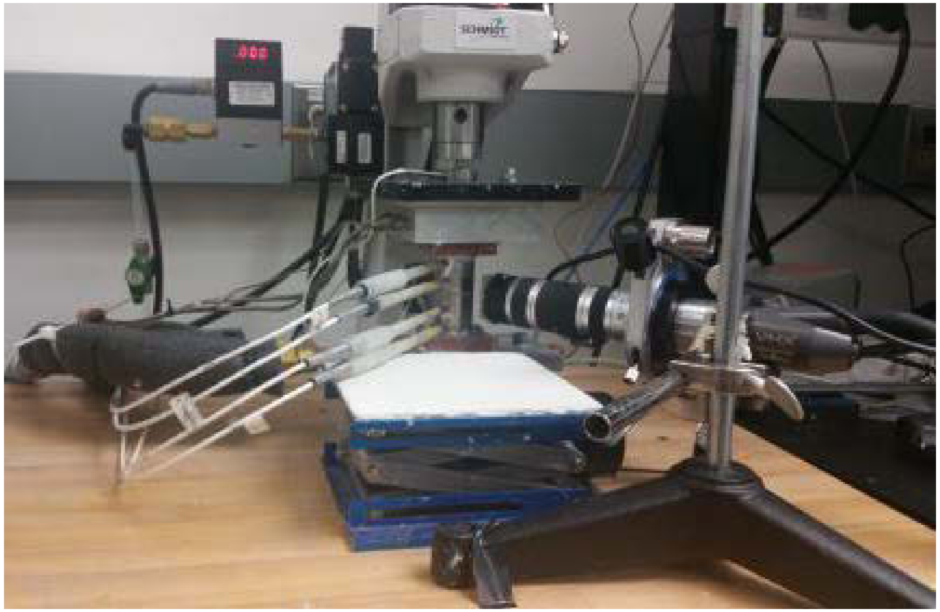
Pa	1.54 µm	Average Roughness
Pq	1.81 µm	RMS Roughness
Pt	8.29 µm	Peak to Valley Height

4 µm lapping paste →



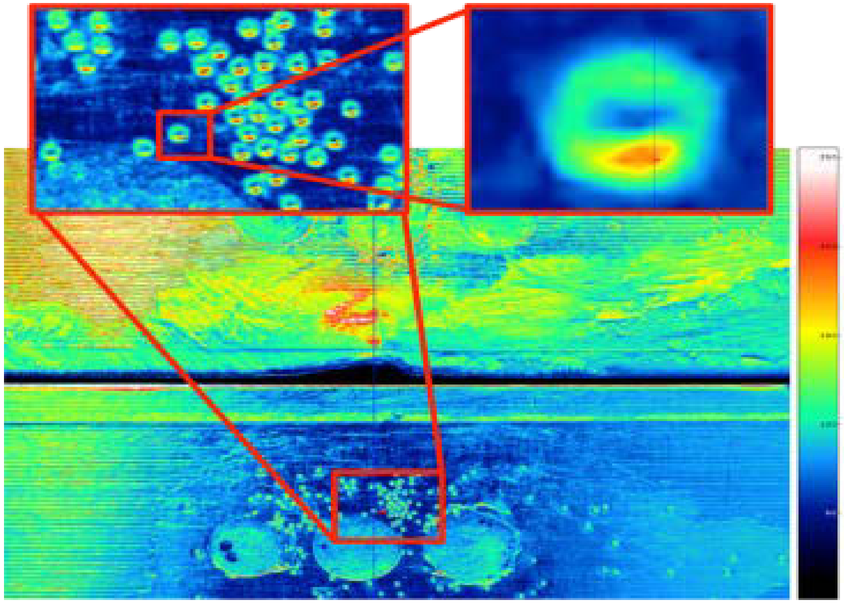
Pa	0.53 µm	Average Roughness
Pq	0.67 µm	RMS Roughness
Pt	4.32 µm	Peak to Valley Height

Bondline thickness measurement



- During testing, a high resolution microscope was used to capture images of the actual bondline thickness
- 50 µm glass spheres were attached to the side of the meter blocks to be used as fiducial markings

- The glass spheres produced repeatable reflections that were consistent through multiple tests
- SPIP was used to process the images
- This process produced bondline measurements accurate up to +/- 5 µm



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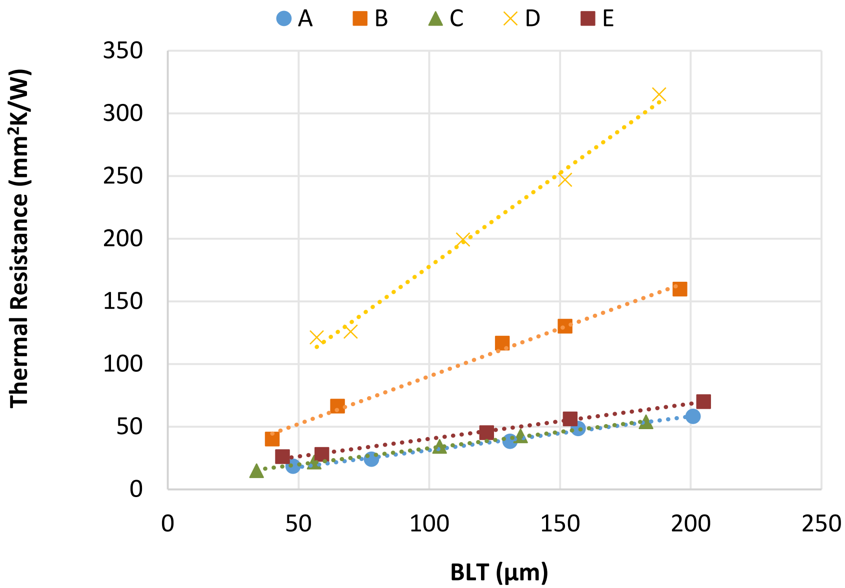
TIM stand results



Thermal resistances of greases as a function of BLT

Grease	Thermal Conductivity (W/m-K)	Contact Resistance (mm²K/W)	R^2
A	3.7	4.2	0.992
B	1.3	14.1	0.993
C	3.8	6.6	0.998
D	0.7	28.3	0.991
E	3.6	12.2	0.996

Bulk thermal conductivity, contact resistances, and R^2 value

- Each set of test results conformed to the linear regression equation

  $$y = a*x + b$$

  where the inverse of *a* is the bulk thermal conductivity, *x is the* bondline thickness, and *b* is the contact resistance

- Greases A, C, and E showed similar thermal performance while greases B and D had significantly higher thermal resistance across all bondline thicknesses
- The improved test processes yielded R^2 values approaching 1.0

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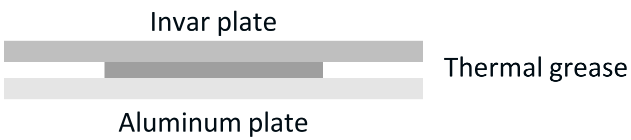
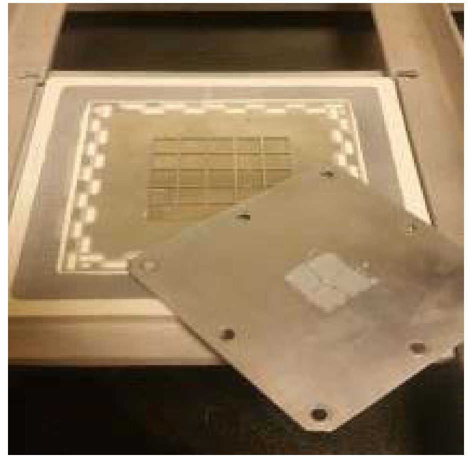
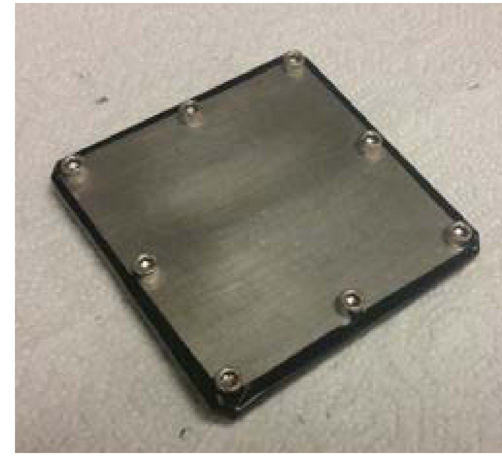
Large area fixture assembly process

- A test was devised to subject the grease to pump-out and dry out conditions by thermally cycling a large area fixture containing the grease
- The fixture was made of Invar and Aluminum due to their CTE mismatch
- The test involves a 4 step process :
  - Grease application
  - Fixture assembly
  - Acoustic scanning
  - Thermal cycling

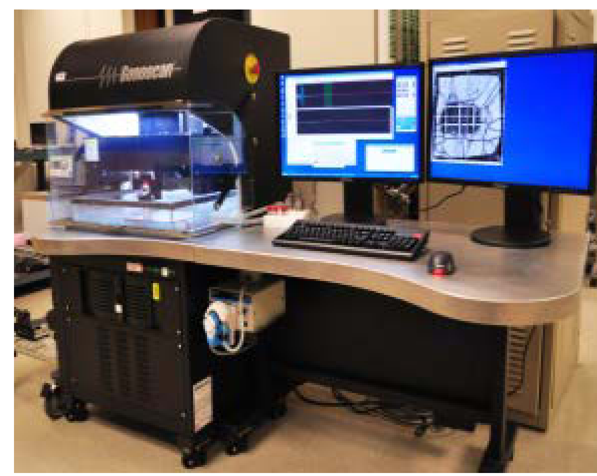




Grease application



Fixture assembly



Scanning acoustic microscopy

Thermal cycling

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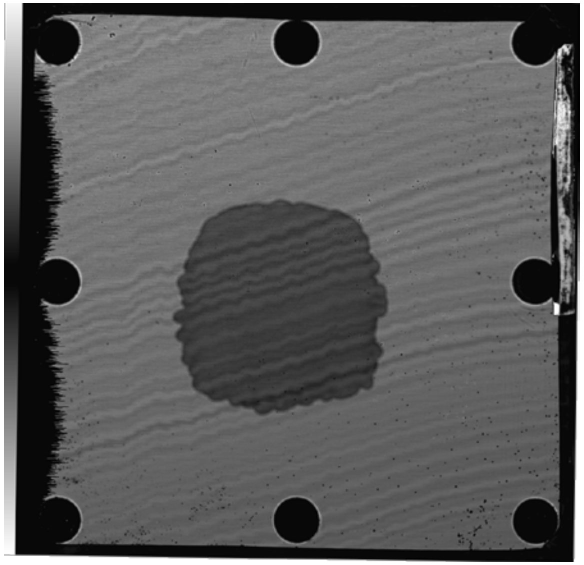
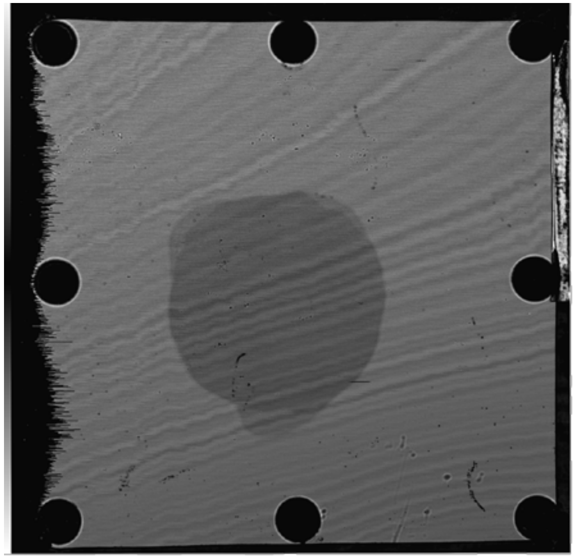
Reliability Analysis

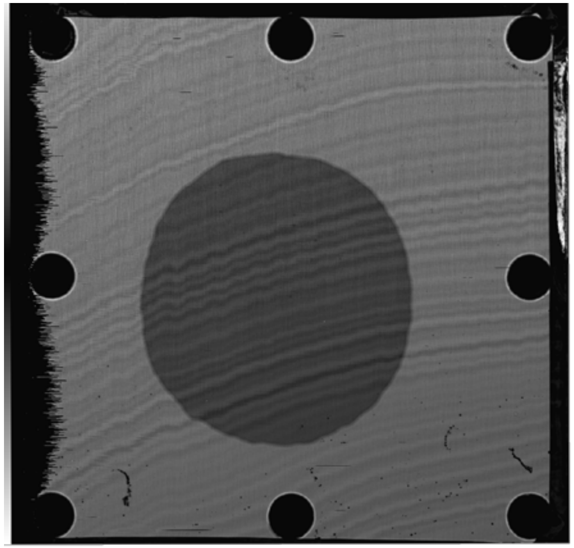
- The fixtures were cycled from -40°C to 125°C for 100 cycles and imaged using a scanning acoustic microscope every 10 cycles.
- The images show at least three unique failure conditions:
  - Void formation
  - Separation
  - Migration



Grease ‘A’: Void formation



Grease ‘B’: Separation



Grease ‘D’: Migration

Summary

- This project refined techniques to increase the reproducibility in measurements between different ASTM D5470 test setups
- Rigorous care taken to accurately measure bondline thicknesses greatly increases the accuracy of the test
- Several silicone and non-silicone greases were compared and a large-area pump out procedure was developed to test the reliability of each grease
- Rigorous testing of TIMs will allow for educated selection of materials for a variety of electronics package designs where managing heat is a primary concern

Questions?

Team members and acknowledgements

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Sreekant Narumanchi *
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Gregory Blackman**
Arnold Wong**
Jeffery Meth**

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