NINETEENTH ANNUAL

BiTS

Burn-in & Test Strategies Workshop™

March 4 - 7, 2018

Hilton Phoenix / Mesa Hotel
Mesa, Arizona

Archive

COPYRIGHT NOTICE

www.bitsworkshop.org

Mechanical Insertion and Thermal Performance Testing Evaluation of Metallic TIMs for Semiconductor Test and Burn-in Applications

David L. Saums
DS&A LLC

Tim Jensen, Ron Hunadi, & Carol Gowans
Indium Corporation

Mohamad Abo Ras
Berliner Nanotest und Design GmbH

BiTS Workshop
March 4 - 7, 2018

Purpose: TIM Contact Cycle Testing for Semiconductor Test

This presentation describes a reliability testing program for thermal interface materials (TIMs) for semiconductor test and burn-in applications:

- Mechanical contact cycling and thermal resistance measurement of TIMs;
- Three program test phases to test under increasingly rigorous cycling;
- Phase I test results;
- Analysis.

The overall purpose of this test program is to evaluate durability of selected TIMs under mechanical contact cycling equivalent to semiconductor test.

Purpose: TIM Contact Cycle Testing for Semiconductor Test

Test program with three phases for TIM thermal and reliability testing specific to semiconductor test and burn-in:

Table 1. Thermal /Mechanical Cycling Test Program Design

Program Phase	Purpose	Test Head Configuration*	Operating Temperature (°C)	Data Output
I	Baseline Values	Parallel	70 – 95	R_{th}**, Thickness Change,** * Cycle Count
II	Strike Angle	Upper Body: Strike Angle	70 – 95	R_{th}**, Cycle Count
III	Strike Angle/Elevated Temperature	Upper Body: Strike Angle at Elevated Temperature	125	R_{th}**, Cycle Count

*Notes: * Test head configuration and test system design per ASTM D 5470-12 thermal interface material testing methodology. Use of this test system and methodology is intended to provide industry-standard baseline thermal performance values.*

*** Thermal resistance value is the principal thermal performance value for a TIM and uniform, stabilized values indicate an appropriately stable testing system.*

**** Thickness change data is intended to provide indication of a stable test cycling process for baseline data.*

Thermal Interface Materials

Thermal interface materials (TIM) are integral to adequate heat transfer from a semiconductor source to an external environment.

- Required for many different types of component interfaces.

Specialized TIM materials are selected for challenging requirements for critical applications, including:

- Required thermal resistance value to meet a package heat transfer goal
- Suitability for applicable surface flatness, roughness, available clamping force, operating environment

Thermal Interface Materials

TIM application requirements (continued):

- Required product life and reliability
- Suitability for an intended handling, placement, and assembly process
- Ease of rework
- Zero residue or marking of DUT for semiconductor test applications

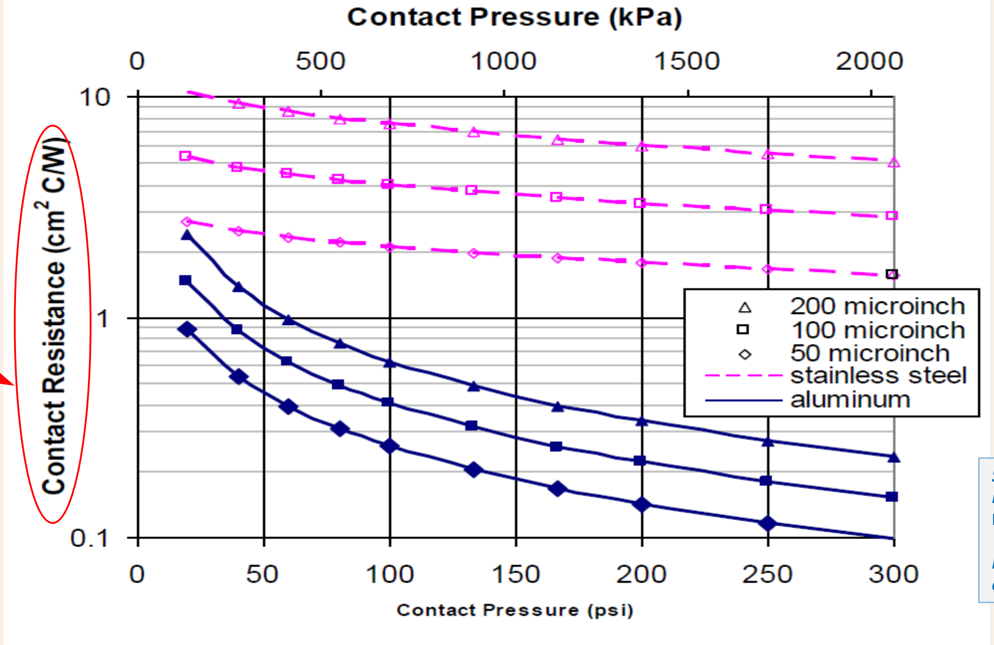
Proper TIM testing is critical to proper selection for each application.

Specific testing methods are needed to understand performance in unusual conditions for semiconductor test and burn-in applications.

Thermal Interface Materials: Why Are These Needed?

Metal-to-metal surface contact resistance – comparison of two metals, three surface finishes (roughness), under load:

The primary function of a TIM is to minimize the thermal contact resistance between two mating surfaces



Source: M. Yovanovich, et al., "Calculating Interface Resistance", Electronics Cooling Magazine, *May 1997, Vol. 3, No. 2.*

Note: 100 microinch = 2.54 microns. Values are RMS values.

"Well-Performing" TIMs

What is meant by "well-performing"?

1. An application for a thermal interface material in a given high-performance design must be assessed against a defined list of specialized criteria in addition to bulk thermal conductivity alone.
2. These specialized requirements may include, for example:
   - Higher operating temperature range;
   - Minimized thermal resistance, with 100% surface wetting;
   - Higher dielectric properties with improved thermal resistance (if a dielectric function is required);
   - Durability to resist cycling;

"Well-Performing" TIMs

What is meant by "well-performing"? (Continued)

- *No* compound run-out due to temperature
- *No* dry-out of a carrier compound due to temperature
- *No* compound pump-out due to mechanical stress
- *No* silicone bleed, outgassing, or redeposition on critical system elements.

Thermal Interface Materials: Development Requirements

Table 2. TIM Typical Development Parameters	
Thermal Impedance	Dielectric Strength**
Bond Line Thickness Post-Assembly	Cut-Through Resistance**
Thermal Conductivity	Thermal Cycling
Clamping Force Applied	Power Cycling
Wettability	Humidity and Bake
Thixotropicity	HAST
Dispensing/Placement Process Automation	Shock and Vibration
Cure Schedule*	Flammability
Adhesion, Peel Test*	Working Life
Contaminants	Storage/Transit Temperature Range (As Supplied)
Modulus of Elasticity	Shipment/Storage Temp Range (Complete Assembly)
Material Stability	Removability and Rework Process
Silicone Stability	Environmental and Recycling Process
Flammability	Cost

*Notes: *Applies only to adhesive TIMs. **Applies only to dielectric TIMs.*

Semiconductor Test Cycling Parameters

Semiconductor test engineers were surveyed to determine test parameters:

Table 3. Thermal /Mechanical Cycling Test Parameters

Organization	Test Pressure Reported (PSI)	Test Temperature Range Reported (°C)	Dwell (Seconds)
Company A	170	25**/100	60
	170	100	60
Company B	100	-	60
Company C	-	120	-
Company D	-	100	-
Company E	-	80	60
Company F	60/100*	105**/125	-
	100*	105**/125	-

*Note: * Pressure applied dependent upon die or package contact area. ** Initial value. Source: DS&A LLC.*

Thermal/Mechanical Test System Design

Testing utilized a commercial ASTM D 5470-12 (modified) test stand:

Table 4. Thermal /Mechanical Cycling System Design

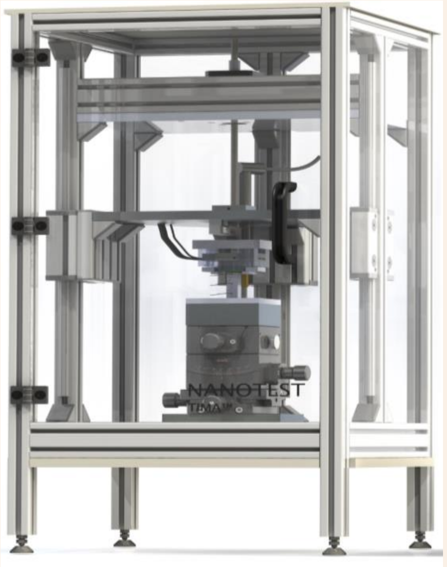
Property	**Value**
System	Berliner Nanotest TIMA6
Upper Reference Body (Heater Bar)	125°C
Lower Reference Body (Liquid Cold Plate)	75°C
Sample Temperature	95°C
Clamping Force Method	Servo Automated
Clamping Force Applied	500kPa (72PSI)
Temperature Measurement	In situ
Thickness Measurement Under Force Applied	In situ

Note: Uniform single clamping force applied for all materials. Source: Berliner Nanotest und Design GmbH.

Thermal/Mechanical Test System Design

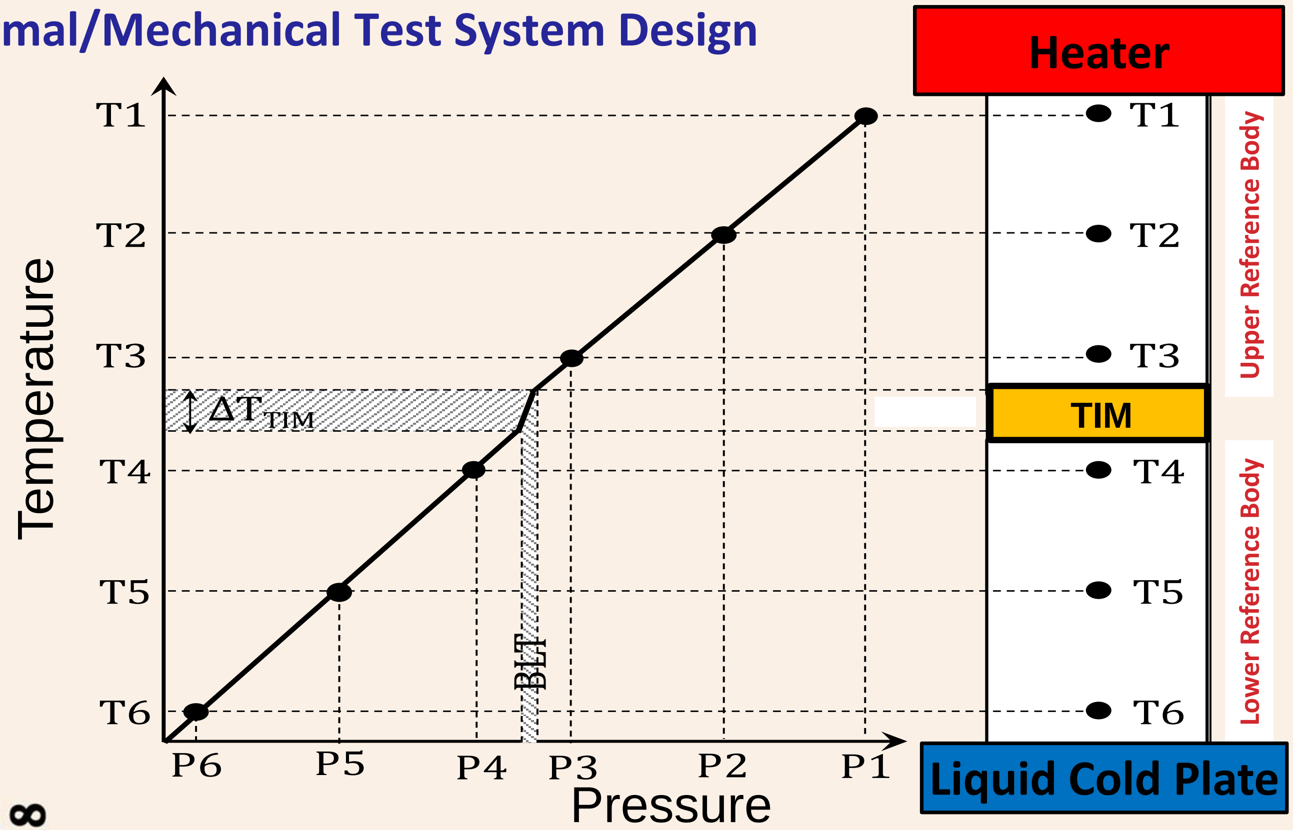
Berliner Nanotest commercial ASTM D 5470-12 TIM test stand utilized:

- ASTM D 5470-12 is the industry standard test methodology for comparative TIM testing;
- System measures force applied, power (heat), temperature, thickness – with precise and uniform heat flow.
- Measures thermal conductivity and force applied and provides calculated thermal resistances.



Note: ASTM D 5470-12 methodology may be purchased for a nominal fee from ASTM International. Information can be found at www.astm.org

Thermal/Mechanical Test System Design



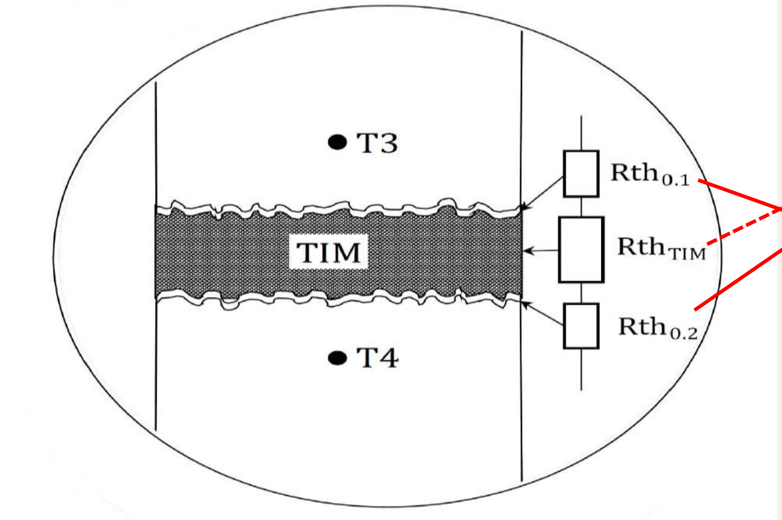
Note: ASTM D 5470-12 methodology may be purchased for a nominal fee from ASTM International. Information can be found at www.astm.org

Thermal/Mechanical Test System Design

Thermal interface material testing with ASTM D 5470-12:

- Provides measurement of a thermal resistance value that is the sum of three constituent values:

The TIM thermal resistance *total* (R_{th}) is the important value, in practice.



TIM Bulk Resistance

+

(2) Interfacial Contact Resistances (Calculated)

=

TIM Thermal Resistance (Total)

Phase I System Test Design: Parallel Test Heads

Reliability test data:

- The first phase of this test program is intended to establish a baseline of mechanical data with three types of TIMs
- *Parallel* test heads
- TIM (material under test) temperature: 95°C
- Phase I testing includes three commercial TIM products designed to meet semiconductor test and burn-in market requirements.
- Success of Phase I program will determine if other TIM products will subsequently be tested.

Phase I System Test Design: Parallel Test Heads

Test heads were adapted for this mechanical cycling test program to fit an existing test stand. Test head values are shown:

Table 5. Thermal /Mechanical Cycling Test Head Design

Property	**Value**
Material	Aluminum Alloy (AlMgSi1)
Contact Area	17.5mm x 17.5mm (306mm^2)
Contact Surface Roughness	Rz $\leq$ 1µm
Sample Temperature	95°C
Upper Reference Body (Heater Bar)	125°C
Lower Reference Body (Liquid Cold Plate)	75°C
Temperature Measurement	In situ
Thickness Measurement Under Force Applied	In situ

Note: Uniform single clamping force and temperature applied for all materials.

Phase I System Test Design: Test Sample Materials

TIM commercial products developed for semiconductor test requirements, included in Phase I test program:

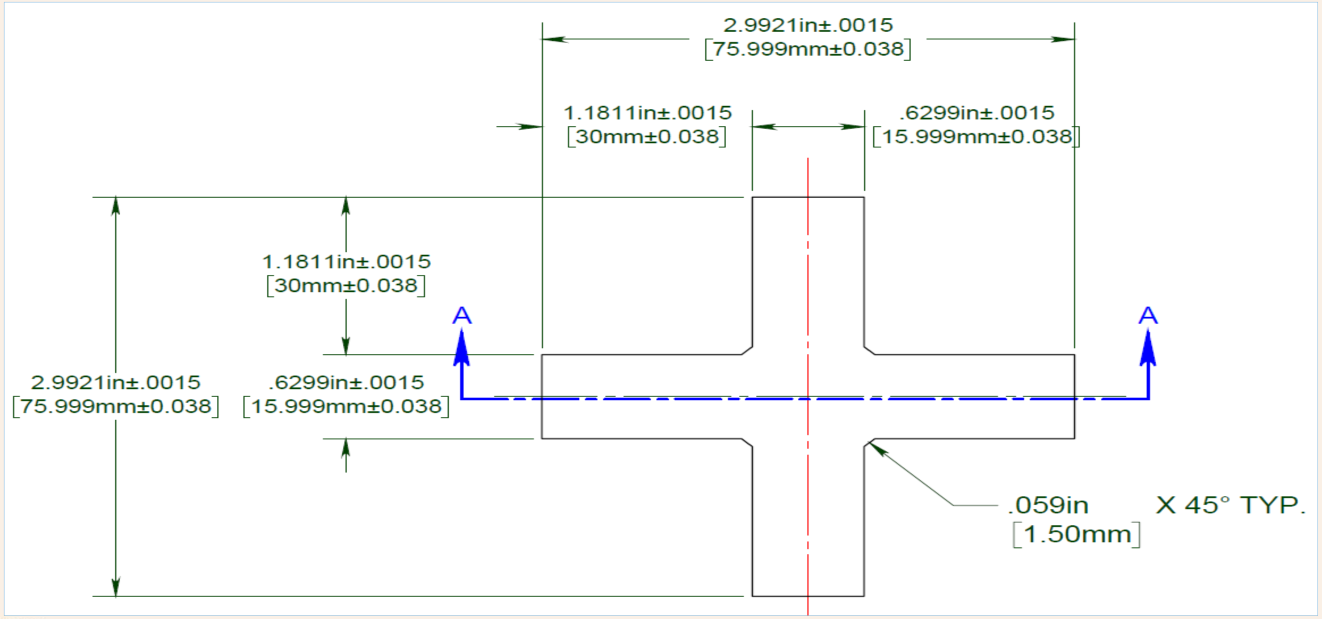
Table 6. Thermal Interface Materials Tested

Graph Key	Description
CLAD	Indium (99.99%) flat foil, clad one side (0.0005”) aluminum
CLAD HSK	Indium (99.99% foil, clad one side (0.0005”) aluminum, HSK pattern applied*
HSMF-OS	Aluminum foil (0.002”), coated one side with dry thermal compound**

*Note: * Indium Corporation Heat-Spring® HSK. ** Indium Corporation HSMF-OS.*

Phase I System Test Design: Test Sample Format

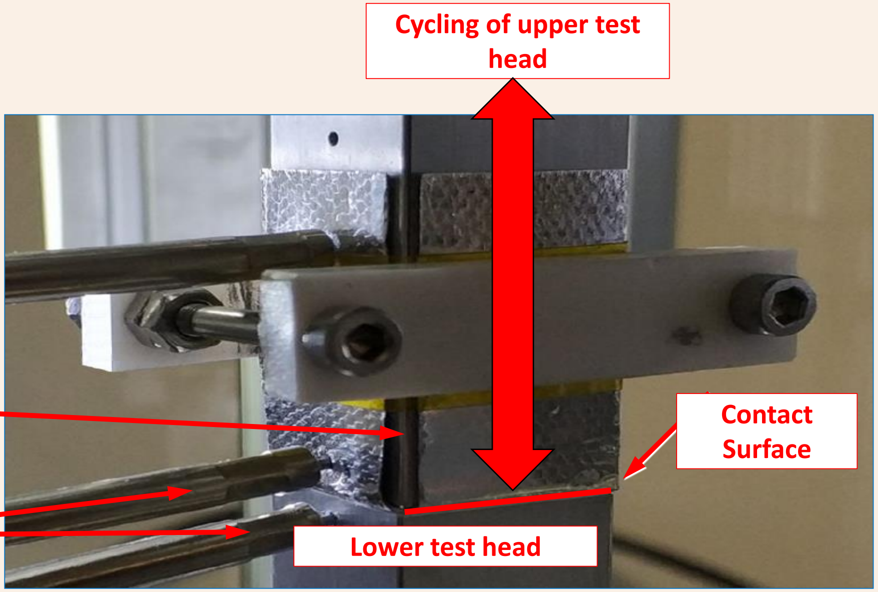
“Red Cross” test material designed for head attachment:



Phase I System Test Design: Parallel Test Heads

Test heads were adapted for this mechanical cycling test program to fit an existing test stand.

- Test assembly shown with TIM under test applied
- Heat-Spring® HSK aluminum-clad patterned indium alloy TIM applied to upper test head



Cycling of upper test head

Upper test head with HSK aluminum-clad patterned indium foil TIM applied

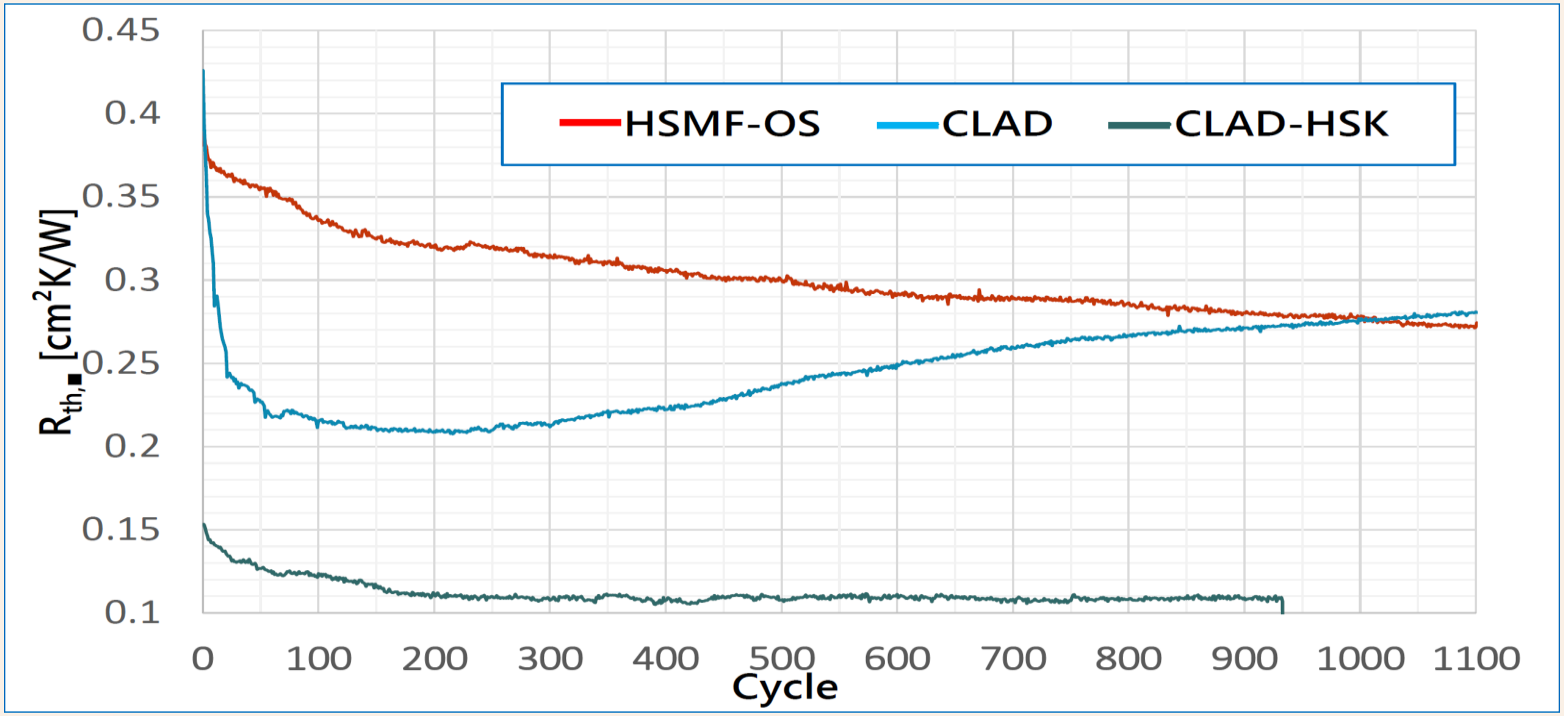
Contact Surface

RTDs inserted into test heads (3 places shown)

Lower test head

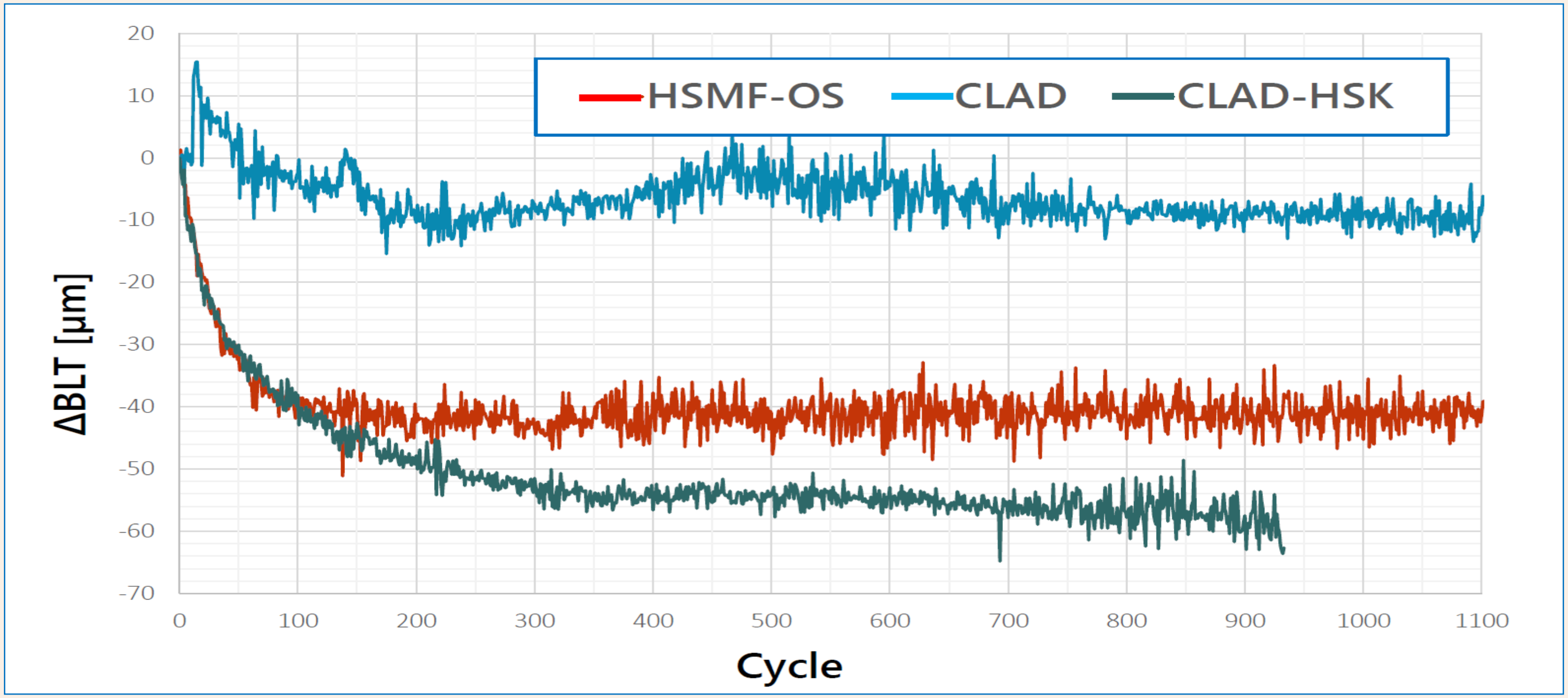
Note: Uniform single clamping force and temperature applied for all materials.

Test Data, Phase I: Thermal Resistance vs. Contact Cycling



Source: Berliner Nanotest und Design GmbH. January 12, 2018.. Note: Power supply failure at 940 cycles, CLAD-HSK material; test currently being re-run.

Test Data, Phase I: Thermal Resistance vs. Thickness Change



Source: Berliner Nanotest und Design GmbH. January 12, 2018.. Note: Power supply failure at 940 cycles, CLAD-HSK material; test currently being re-run.

Test Data, Phase I: Analysis

Phase I testing is intended to establish a baseline set of date to demonstrate:

- Mechanical cycling results with parallel test head surfaces, the most common application characteristic for semiconductor test.
- Thermal resistance values during cycling, with stabilization.
- Thickness measurement during cycling, stabilized.
- Stabilized thermal resistance and thickness values are important indicators of:
  - Test platform and procedure
  - Thermal and mechanical performance for test applications.

Test Data, Phase I: Analysis

Phase I testing of all three TIM types successfully passed 1,300 cycles:

- HSMF-OS: 0.004” (0.102mm)-thick aluminum foil, coated one side only with non-silicone thermal compound. Applied with Al surface facing DUT.
- 99.99% flat indium foil [0.012” (0.30mm) thickness, including clad one side only with 0.0005” (0.0001mm) aluminum]. Applied with Al surface facing DUT.
- Indium Corporation Heat-Spring® HSK patterned 99.99% indium foil, clad one side only with 0.0005” (0.0001mm) aluminum . Total thickness: 0.0220” (0.559mm). Applied with bare Al surface facing DUT.

Test Data, Phase I: Observations

- Phase I testing has demonstrated:
- Stable thermal resistance values achieved during mechanical cycling demonstrated required durability for all three baseline materials tested;
- Visual inspection indicated no visible marking and zero residue on lower body test head surface (equivalent to the case or die surface of DUT);
- Stable thermal and thickness values indicate success of each material type for long-term cycling without tearing or marking.

Summary

- Thermal interface materials (TIM) are integral for adequate heat transfer from a semiconductor source to an external environment.
- Specialized TIM materials can be characterized as “well-performing” when measured against challenging requirements for critical applications.
- A range of metallic TIMs have been developed, for specialized applications requiring performance and reliability in challenging conditions.

Summary

- A test stand designed per ASTM D 5470-12 has been utilized with test heads adapted for a test program in three phases, per requirements for semiconductor test and burn-in applications.
- Phase I baseline test results for a mechanical contact cycling test program have been described. All three materials met the baseline test targets.
- Next steps:
  - Phase II – Introduction of strike angle at constant temperature.
  - Phase III – Introduction of strike angle and elevated temperature conditions.