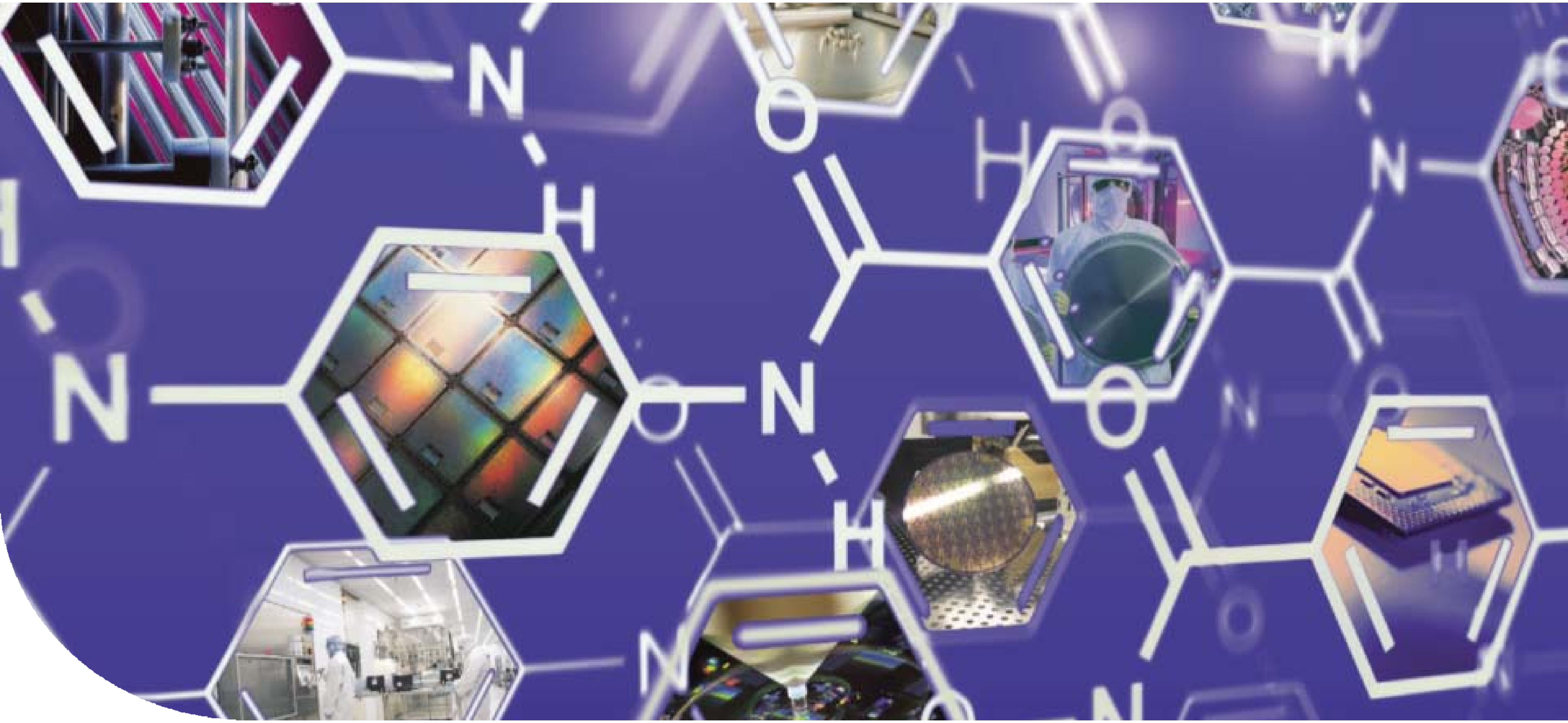
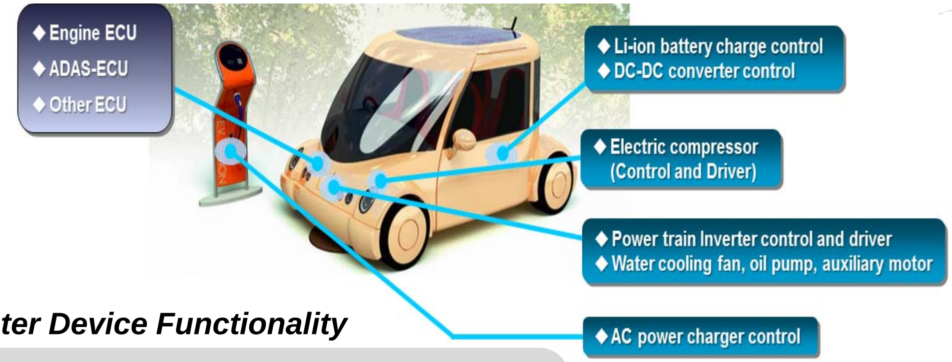


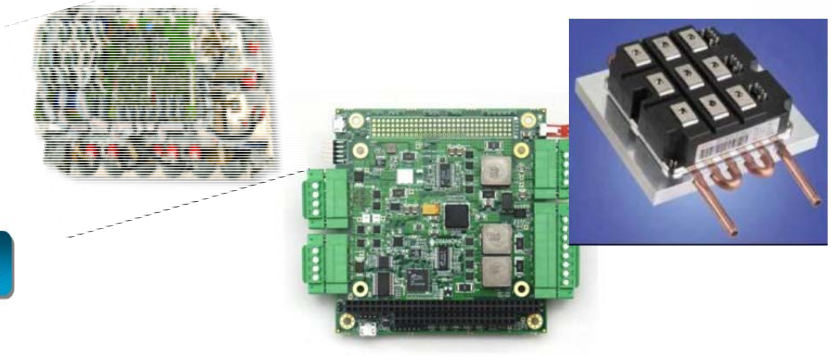
Chris Lee
Sept 14th, 2016

THERMAL INTERFACE MATERIALS (TIMS)

In Power Electronics

Industry Trend: Accelerating Power Densities



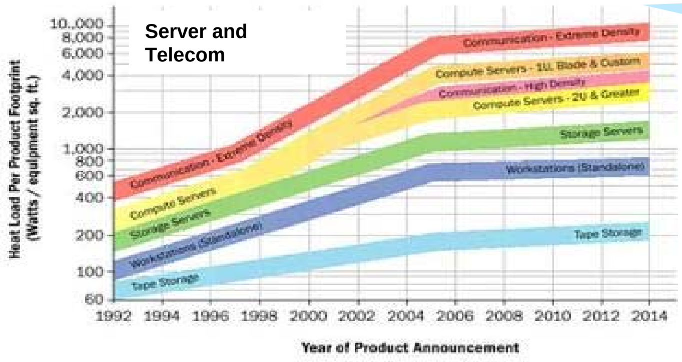


Greater Device Functionality

- Increased Power consumption
- Device / Package shrinkage
- Greater density board layout

Drive

- Higher Power densities - up to 200 W/cm^2
- Increasing Device Temperatures >150°C



Devices designed into HEV/EVs rival high end servers and computing

- Harsher Test Conditions
- Higher Operating Temperatures
- Increased Thermal Performance, Stability and Reliability

Thermal Management

Critical to Product:
- Performance
- Efficiency &
- Longevity

Rising Power Densities Drive Greater Thermal Needs

Segment Landscape

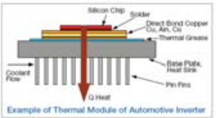
Thermal Performance: TI at T0

Notebooks, Tablets, Mobile, VGA Cards, GPU, MPU, CPU

Reliability First

Auto, Power, Telecom Infrastructures, Servers

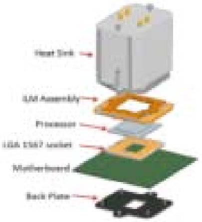
Performance & Reliability



Example of Thermal Module of Automotive Inverter

Gaming, Servers, Wireless , Power, Consumer Electronics

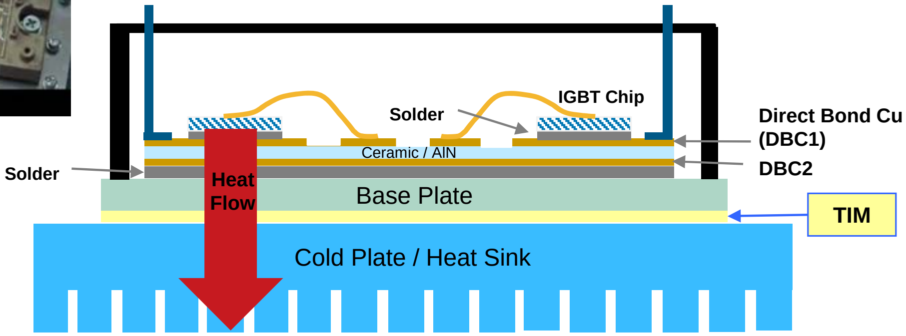
Good Enough

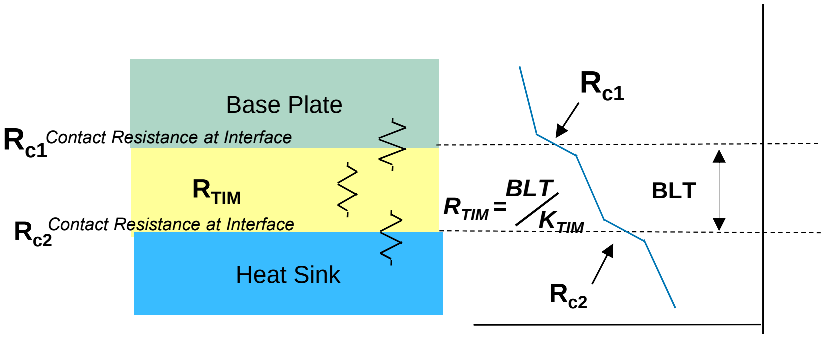


Desktop CPUs, HBLED, Consumer Electronics

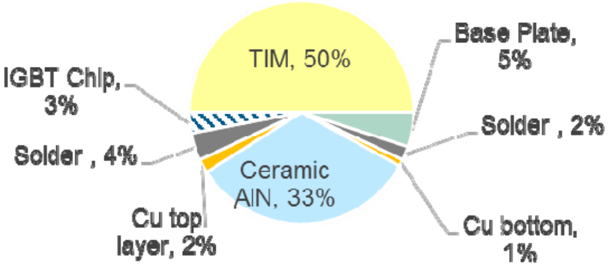
Understanding and Prioritizing Needs is Critical to the Thermal Selection

Thermal Interface Materials (TIMs) in Power Modules





Proportion of thermal resistance caused by the layers



Up to 50% of thermal resistance is from the TIM

Source: http://www.powerguru.org/heat-dissipation-and-thermal-resistance-in-power-modules/

TIM Thermal Impedance:

$$TI_T = R_{c1} + R_{TIM} + R_{C2}$$

Critical Factors

TI_T = Total Thermal Impedance
BLT = Bond Line Thickness of TIM
K = Bulk Thermal Conductivity of TIM
$R_{C1\ \&\ C2}$ = Contact Resistance at the Interfaces

Additionally:

- Load Pressure
- Interface condition / roughness
- Flatness

TIMs are Critical to the Thermal Design of Power Modules

TIMs - Thermal Needs and Requirements

#	Need	Measure	Test Conditions*
1	**Thermal Performance**	Thermal Conductivity (W/mK) Thermal impedance (TI, ^{o}C.cm^{2}/W)	• Thermal Bulk Conductivity ASTM D5470 • Laser Flash ASTM E1461 • Cut Bar TI Test ASTM D5470 • TTV and Application Set Up
2	**Thermal Stability & Reliability**	<10% Thermal Degradation or <25% Degradation	• High Temp Storage (HTS) 1000 hrs. @ 150°C • Thermal Cycling (TC), 1000 cycles -55°C to 125°C • Power Cycling (PC), 200,000 cycles 25°C to 125°C • High Humidity and Temp (THB), 1000 hrs. 85°C/85% RH • Vibration & Mechanical Shock
3	**Bond Line Thickness**	<0.2mm; 0.2mm – 1.0mm; >1.0 mm	• BLT Measurement • Gap requirements between interfaces
4	**Manufacturability & Handling**	Paste Printing & Print life Pad format	• Process window time > 30 min • User friendly process for Pad
5	**Compression & Form Factor**	Bond Line Gap Compression Need	• Deflection vs. Pressure
6	**Economics**	$/device	• Cost of Ownership Modeling

*Needs, Test Methods and Conditions vary based on customer and application

TIM Material Choices

Thermal Grease

- silicone-based, greases are non-curing, conformable
- provide low thermal resistance for applications that do not require long term reliability and thermal shock

Metallic

- all-metal (e.g., solder) or utilize a metal matrix or binder to which metallic or nonmetallic fillers have been added
- good thermal conductivity but normally contact resistance or surface wetting is not good

Thermal Adhesives

- one or two-part crosslinkable materials based on epoxies or silicones
- known for their structural support - this can eliminate the need for mechanical clamps, but cure time is required and they are not reworkable

Others

- thermal compound, tapes, films, epoxy, etc.

Gap Pad

- typically thicker (>1mm) than other TIMs and designed to have good compression properties
- however, they usually can not deliver the same level of thermal performance as other TIM materials

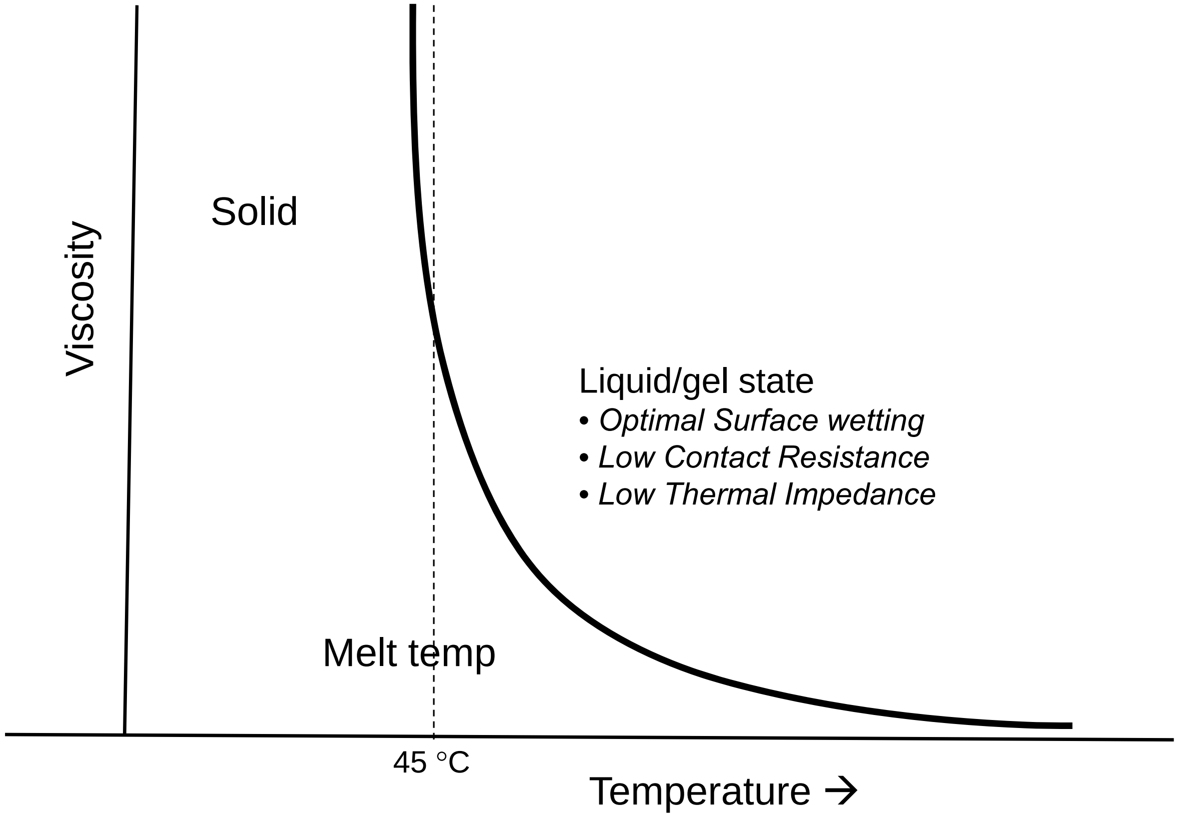
Thermal Gel

- normally is one-component, cross-linked or pre-cured gel structure
- good compressibility and dispense process automation

Phase Change Material (PCM)

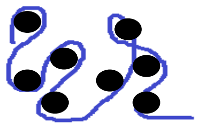
- transforms from a solid state to a liquid or gel state
- no bleed out, pump out and degradation issues normally found in thermal greases

Phase Change Materials (PCM)



Liquid/gel state
- *Optimal Surface wetting*
- *Low Contact Resistance*
- *Low Thermal Impedance*

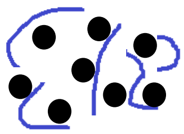
PCM



Long Chain

- **Stable and consistent filler-polymer Matrix**
- **Minimizes filler migration and separation**
- **Increase reliability performance**

Grease

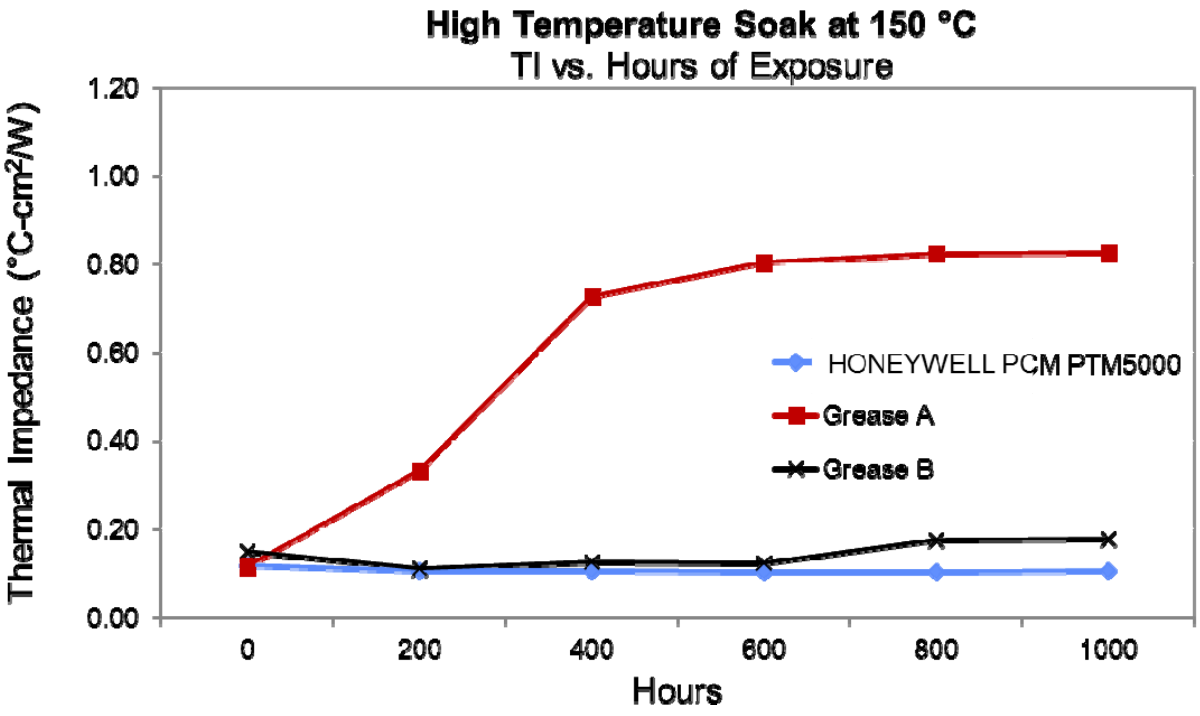


Short Chain

- **Good ‘Flow-ability’, Wetting but…**
- **Potential for Migration, Dry-Out and Pump-Out Issues**

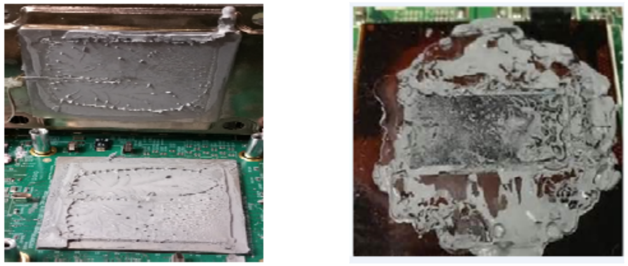
PCM Polymer Structure Enables Low Impedance and Long-Term Reliability

Phase Change Material: Thermal Reliability



Test Method: Laser Flash, ASTM E1461

TIM 2: Heat sink and ASIC lid
After HTS



HONEYWELL PCM achieves continuous interface

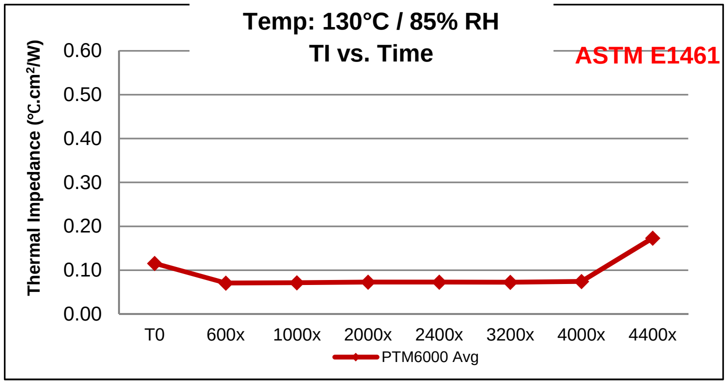
Grease A
Pump out and voids

Courtesy of Juniper Networks

Honeywell PCM Delivers Thermal Stability and Reliability

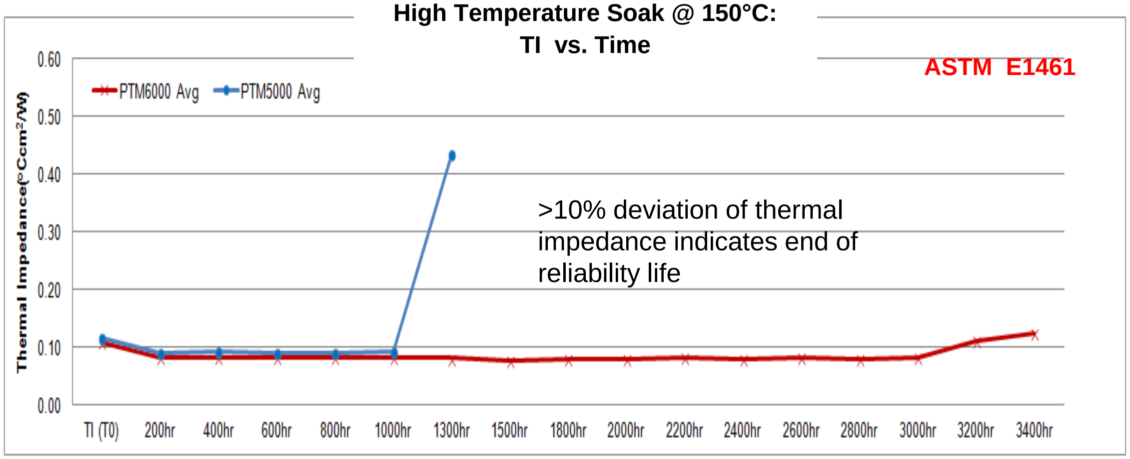
Enhanced Thermal Reliability PCM: PTM6000

- Honeywell PCM technology provides superior reliability
- Thermal Stability:
  - HTS @ 150°C >3000 hrs.
  - TCT -55°C to 125°C >4000 cycles
  - HAST 130°C/85%RH >192hrs



Temp: 130°C / 85% RH
TI vs. Time

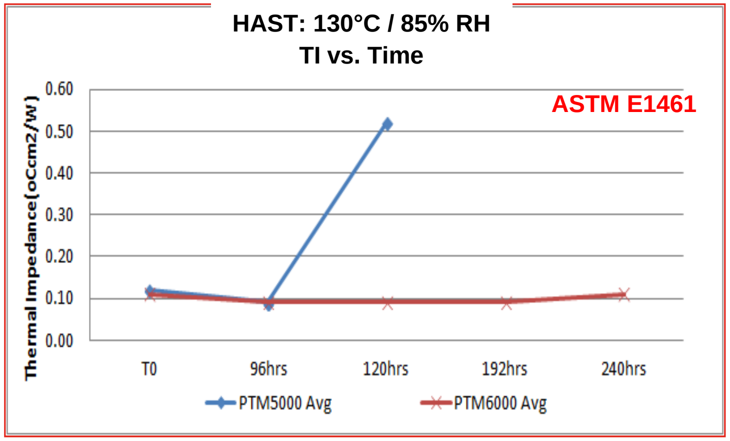
ASTM E1461



High Temperature Soak @ 150°C:
TI vs. Time

ASTM E1461

>10% deviation of thermal impedance indicates end of reliability life



HAST: 130°C / 85% RH
TI vs. Time

ASTM E1461

PTM6000 PCM Formulation Delivers Greater Reliability

Honeywell TIM Product Portfolio

Booth #1046

Product Series	Thermal Impedance (C-cm^2/W)	Thermal conductivity (W/m˚C)	Reliability High Temp Soak @ 150°C (hrs.)	Pad Thickness (mm)	Remark
	ASTM D5470	ASTM D5470	ASTM E1461		
PTM7000 Series	0.04 - 0.06	6.0 – 8.0	>1500	0.20 – 1.00	High Thermal Performance
PTM6000 Series	0.06 - 0.08	3.5 – 4.5	>3000	0.20 – 1.00	Advanced Reliability
PTM6500 Series	0.10 – 0.12	2.5 – 4.0	>1000	0.20 – 1.00	High Voltage Dielectric
PTM5000 Series	0.06 – 0.08	3.5 – 4.5	>1000	0.20 – 1.00	
TCM Series	0.12 – 0.15	2.5 – 4.5	>600	0.50 – 3.00	Compressible paste
PCM45F Series	0.09 – 0.12	2.0 – 2.5	>600	0.20 – 1.00	
LTM Series	0.12 – 0.14	1.8 – 2.4	>600	NA	Paste only

Remarks:
1. Paste Versions Available: SP – Dispense, SPM – Stencil Print
2. All TI data is collected after fully phase changed, no shim

Honeywell

THANK YOU

Booth #1046

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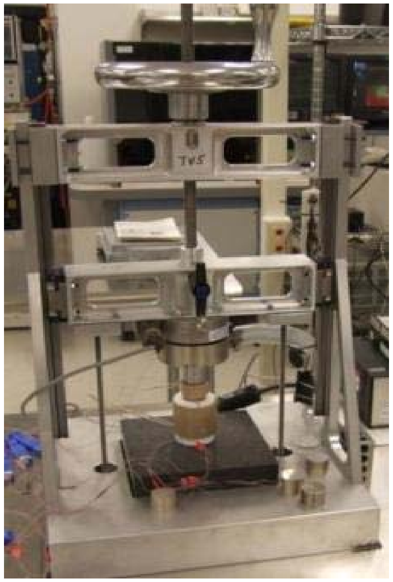
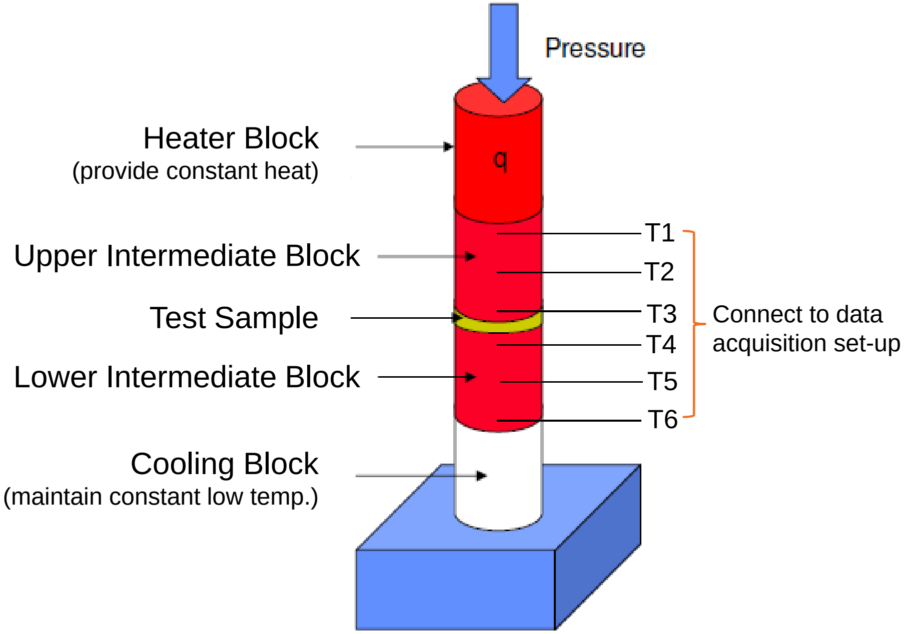
Honeywell

Thermal Impedance Test Method: Cut Bar ASTM D5470





Heater Block
(provide constant heat)

Upper Intermediate Block

Test Sample

Lower Intermediate Block

Cooling Block
(maintain constant low temp.)

Connect to data acquisition set-up

- Per Fourier’s Law of Heat Conduction:

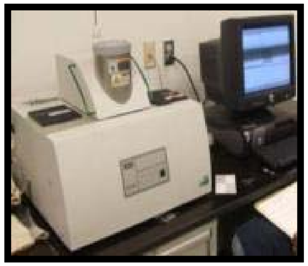
$$q = kA\frac{\Delta T}{\Delta x}$$

$$TI = \frac{\Delta T}{q}A$$

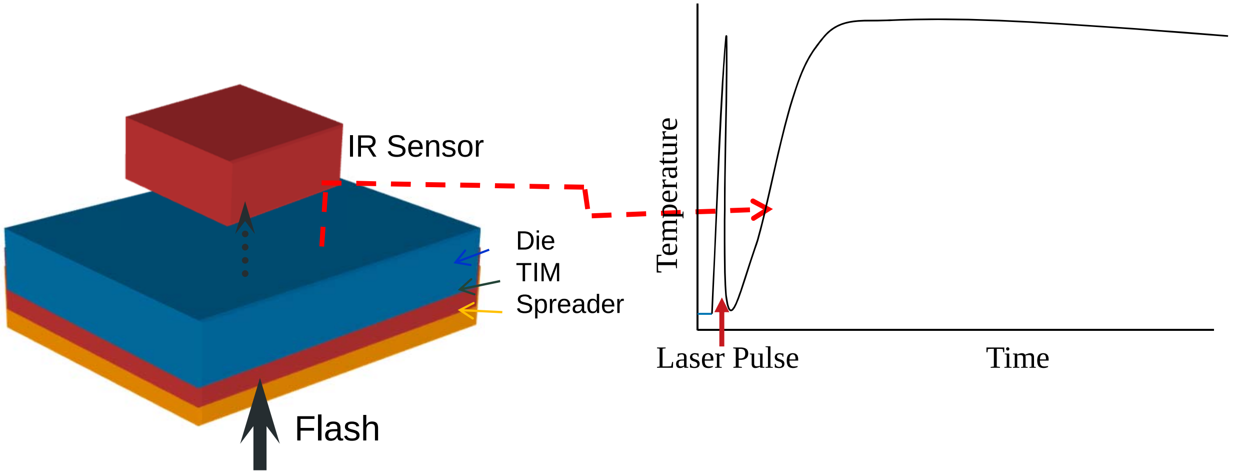
q = heat flux
K = thermal conductivity
Δx = thickness of sample
ΔT = temperature difference across sample
A = cross-sectional area of sample

- ASTM D5470
  - Destructive, one time test only
  - Fast test for immediate results
  - Most common test method

Thermal Impedance Test Method: Laser Flash
ASTM E1461



Netzsch Laser Flash™



- Determines Thermal Diffusivity
- Thermal Conductivity/Resistance Calculated

$$k = (\alpha)(C_p)(\rho)$$

k = Thermal Conductivity (W/cmK)
α = Thermal Diffusivity (cm^2/s)

$$\alpha = 0.13879 L^2 / t_{1/2}$$

L=specimen thickness, meter
$t_{1/2}$=the time required for the temperature rise to reach 50% percent of ΔT_{max}

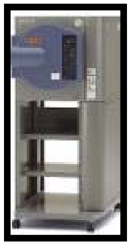
Cp = Specific Heat Capacity (J/gK)
ρ = Density (g/cm^3)

ASTM E1461

- Thermal Impedance Between Si, Ni-plated Cu Surfaces
  - Includes the CTE mismatch
  - includes actual surface finish
- Typical Coupons:
  - Ni-plate copper, 0.5”X0.5”X0.03”
  - Si, 0.5”X0.5”X0.02”
- Suitable for Accelerated Life Test

Reliability Test Condition

- **Highly-Accelerated Temperature and Humidity Stress Test (HAST)**
  - Standard: JESD22-A110-B
  - Testing Condition: 130°C, 85%RH, 96 hours
  - *Objective*: Accelerate corrosive impact of high humidity and temperature on the thermal performance of the test structure



HAST chamber

- **Temperature Cycling Test**
  - Standard: JESD22-A104C
  - Testing Condition: -55°C to 125°C (TCB), 1000 cycles
  - *Objective*: Determine the resistance of TIM to extremes of high and low temperatures, and its ability to withstand cyclical stresses

TC chamber

- **High Temperature Storage**
  - Standard: JESD22-A103
  - Testing Condition: 150°C, 1000 hours
  - *Objective*: Accelerate changes in TIM's material and performance characteristics relative to prolonged and elevated temperature

Oven