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Oct. 6, 2015

# THERMAL MANAGEMENT

## Challenges, Requirements and Solutions for the Electronics Industry

Honeywell

# Agenda

- Introduction
- Thermal Industry Trends
- TIM Challenges, Needs & Criteria
- TIM Industry Solutions
- Summary
- Questions

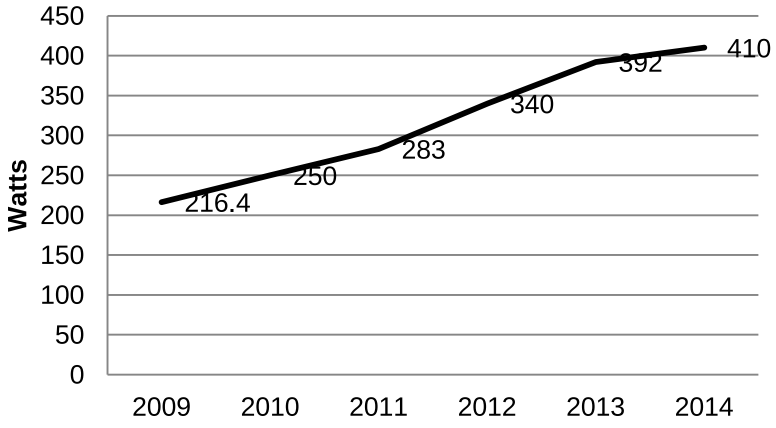
# Thermal Management Industry Trends

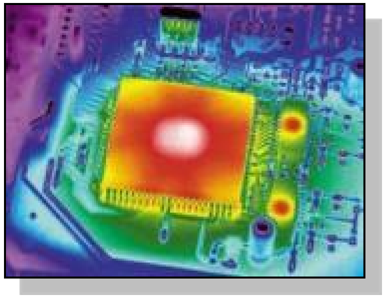
# Industry Trend: Power Densities Accelerating

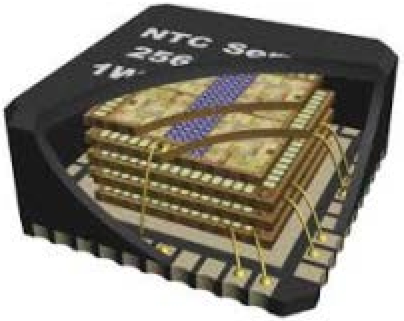
Market Dynamics

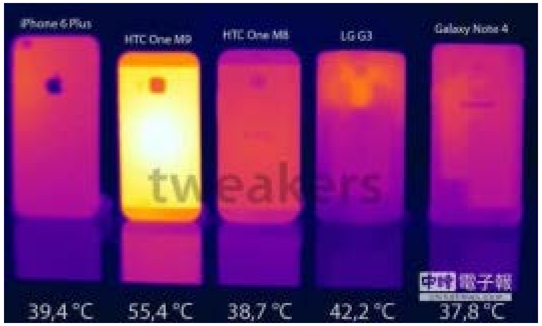
- Increasing power consumption for CPU, APU, GPU, and chipsets
- Thermal performance & reliability becoming increasingly important across more applications

## VGA Power Consumption

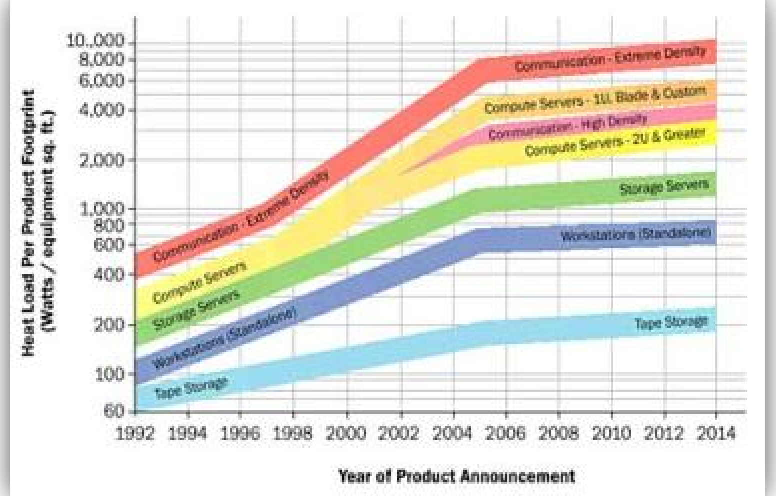






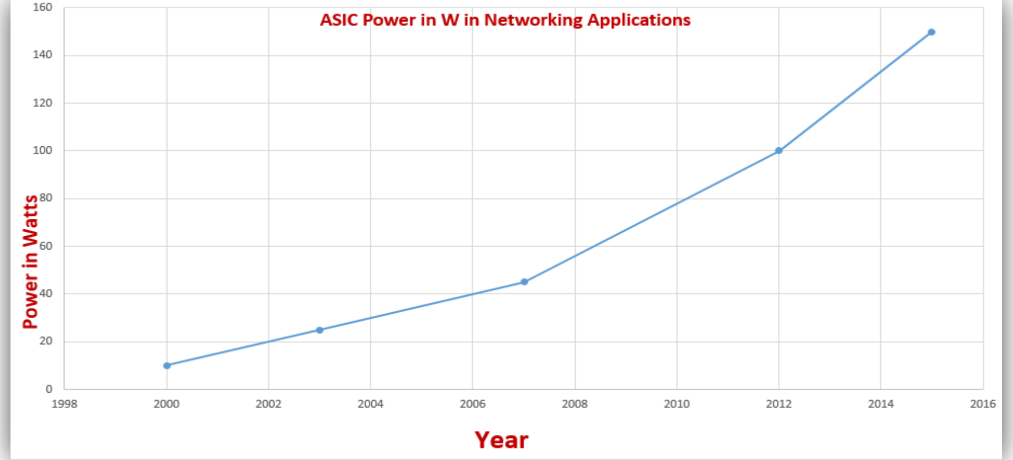


## Server and Telecom Heat Load

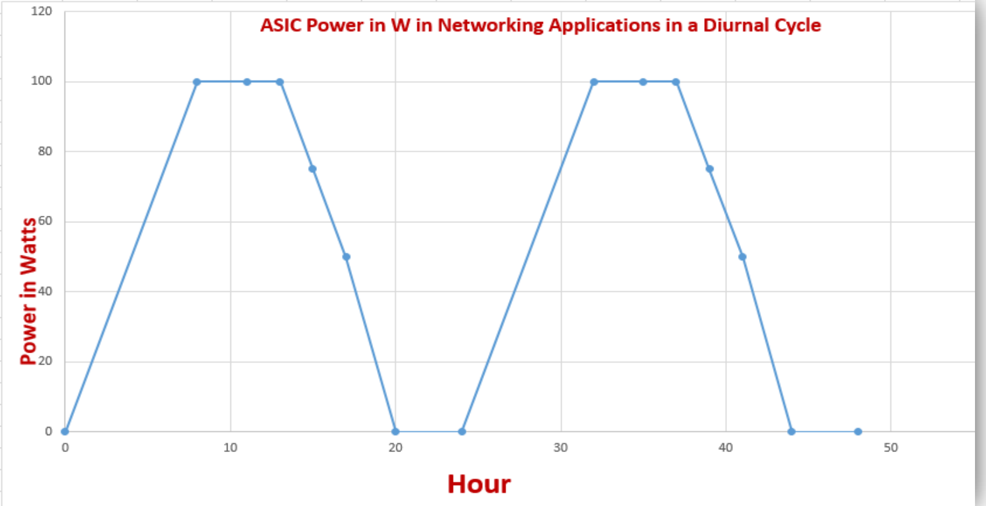


**Rising Power Drives More Emphasis on Reliability**

# Merchant Silicon Power in Networking Applications



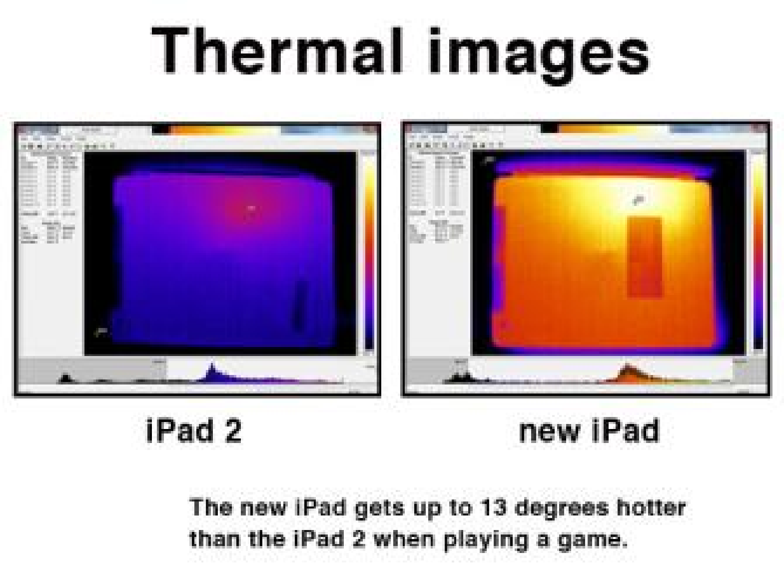
- Power increases more than seven times after the year 2000



- Power cycling trends in networking applications

# TIMs – Crucial for Thermal Management

- Product Performance
  - Increasing power densities
  - High density board layout
  - Higher Device Temperatures
  - Lower Thermal Impedance
  - Increased Thermal Stability and Reliability
  - Harsher Test Conditions
- Customer Satisfaction
  - Reliable product performance for demanding users
- Result of Incorrect TIM
  - Device failure and performance degradation



The new iPad gets up to 13 degrees hotter than the iPad 2 when playing a game.

**Real Potential to Impact Customer Satisfaction and Brand**

# Thermal Management Challenges, Needs & Criteria

# Key Thermal Properties of TIM

## Bulk Thermal Conductivity (W/mK)

- Material property only
- Does not consider:
  - Interface contact resistance
  - Bond line thickness

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

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

k: thermal conductivity

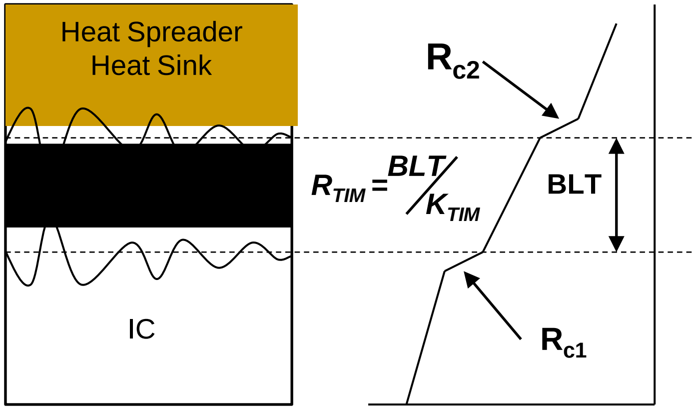
$\Delta x$: thickness of sample

$\Delta T$: temperature difference across sample

A: cross-sectional area of sample

## Thermal Impedance (°C.cm2/W)

- Thermal bulk resistance + interface contact resistance
- Bond line thickness



TIM Thermal Impedance:

$$\mathbf{TI_T = BLT/K + R_C}$$

**$TI_T$ = Total Thermal Impedance**

BLT = Bond Line Thickness of TIM

K = Bulk Thermal Conductivity of TIM

$R_C$ = Thermal Contact Resistance at the Interfaces

**Thermal Impedance Most Critical to Thermal Dissipation and Performance**

# TIMs - Thermal Needs and Requirements

| | | | |
|---|---|---|---|
| 1 | **Thermal Performance** | Thermal Conductivity (W/mK)<br>Thermal impedance (TI, $^oC.cm^2/W$) | Thermal Bulk Conductivity<br>TTV, Laser Flash ASTM E1461<br>Cut Bar TI Test ASTM D5470 |
| 2 | **"Out-of-Box" Performance @ Time 0; Withstand Temp Spikes and Bursts** | Thermal impedance (TI, $^oC.cm^2/W$) | TTV, Laser Flash ASTM E1461;<br>Cut Bar TI Test ASTM D5470 |
| 3 | **Longevity** | <10% Thermal Degradation over ALT | High Temperature Storage, Temp Cycling; Highly Accelerated Stress Test (HAST)<br>Arrhenius Modeling |
| 4 | **Performance Under Harsh Operating Conditions** | Test Severity ; temperature, humidity, shock, etc. | High Temperature Storage, Temp Cycling; Highly Accelerated Stress Test (HAST) |
| 5 | **Bond Line Thickness** | <0.2mm; 0.2mm – 1.0mm; >1.0 mm | BLT Measurement |
| 6 | **Compression & form factor** | Bond line<br>Compression need | Deflection vs. Pressure |
| 7 | **Economics** | $/device | Cost of Ownership Modeling |

# Segment Landscape

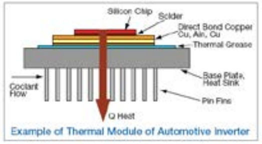
## Thermal Performance: TI at T0

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

## Reliability First

*Auto, Power, Telecom Infrastructures, Servers*

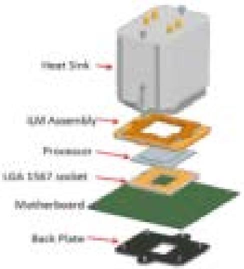
## Performance & Reliability



Example of Thermal Module of Automotive Inverter

*Gaming, Servers, Wireless , Power, Consumer Electronics*

## Good Enough

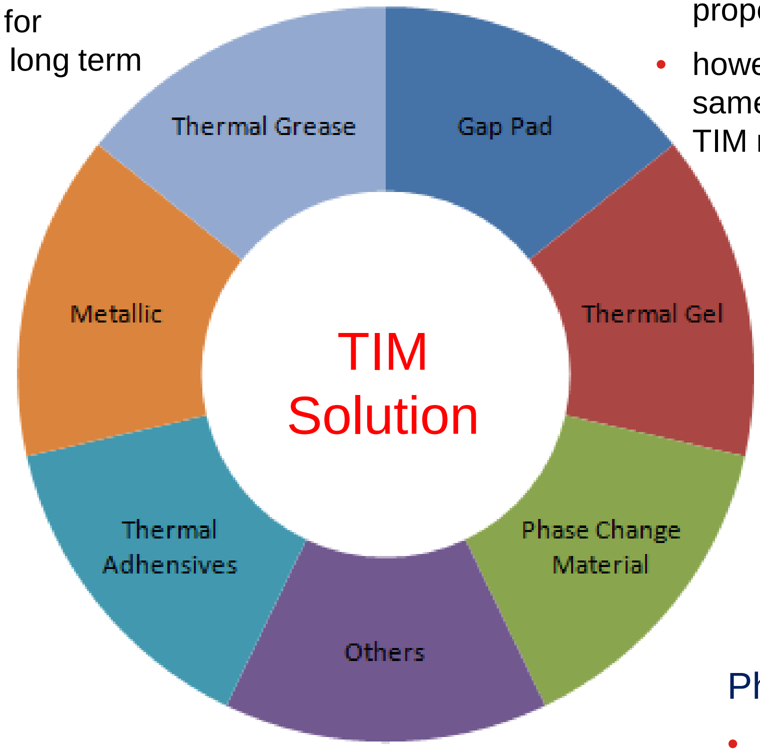


*Desktop CPUs, HBLED, Consumer Electronics*

**Understanding and Prioritizing Needs is Critical to TIM Selection**

# TIM Industry Solutions

# 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

## 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

## 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 Gel

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

## 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.

## 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

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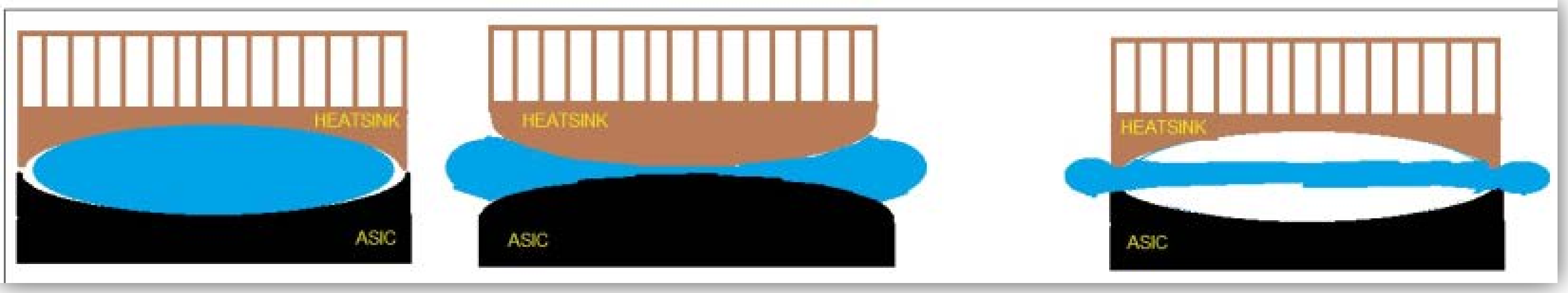
# Greases in Power Cycling Applications

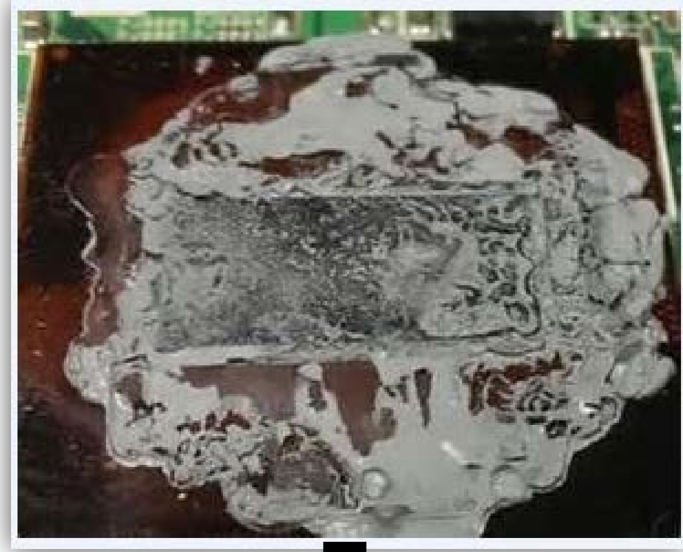
- Greases
  - Subject to thermal expansion of the heat sink and ASIC lid during power cycling
  - Can cause pump out and result in dry-out scenarios of the interface between the heat sink and the chip



| Name of Sensor | Grease Application | Phase Change Application |
|---|---|---|
| Chip 1 | 91.0 | 92.0 |
| Chip 2 | 92.0 | 91.2 |
| Chip 3 | 98.0 | 97.5 |
| Chip 4 | 100.0 | 99.0 |

**PCM Can Provide Equal Thermal Performance as Grease w/o Issue**

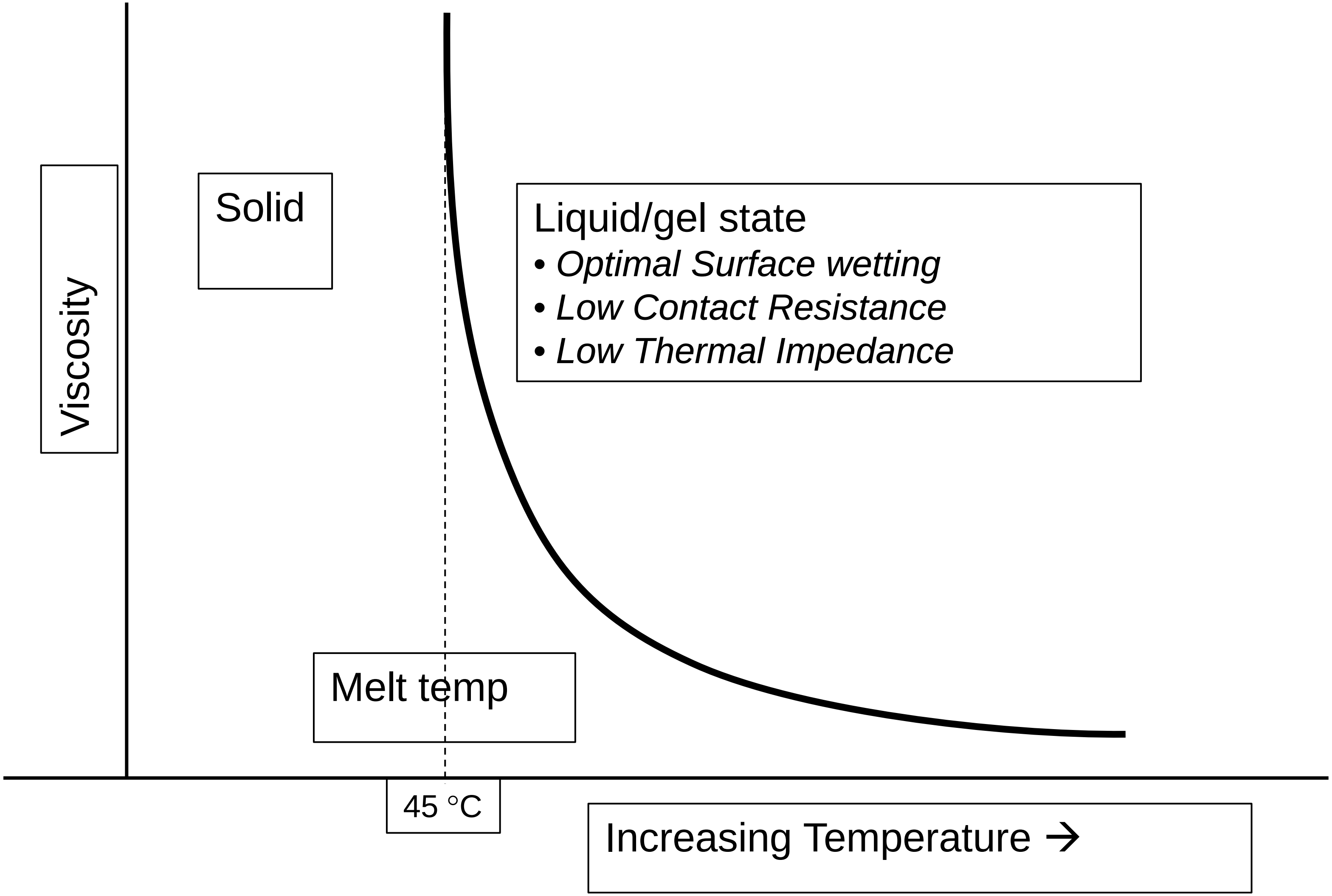
# Illustration of Pump Out



Grease pump out and creation of voids

Phase change application forming a continuous interface between heat sink  and ASIC lid

# Theoretical Curve: PCM Viscosity vs. Temp.



Lijquid/gel state

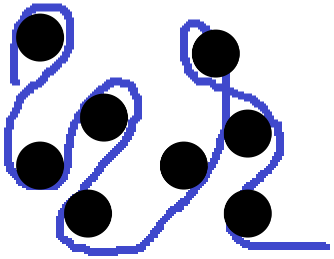
- *Optimal Surface wetting*
- *Low Contact Resistance*
- *Low Thermal Impedance*

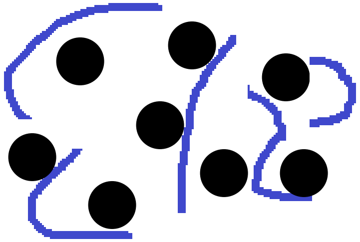
Increasing Temperature →

# PCM Polymer

- Higher Molecular Weight
  - Structural integrity
- Long Chain Polymer Structure

**PCM** vs. **Grease**





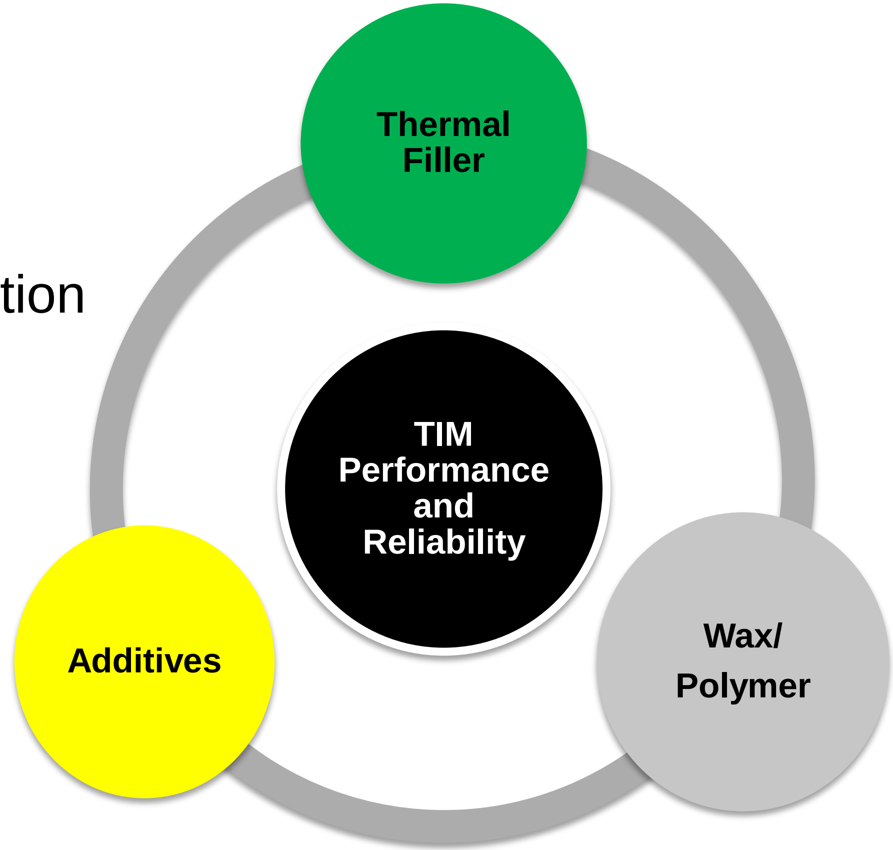
- Long Chain
- Stable and Consistent Filler
- Minimizes Filler Migration / Separation Over Accelerated Life Test (HTB, Temp Cycle)

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

**PCM Polymer Structure Enables Reliable, Long-Term Performance**

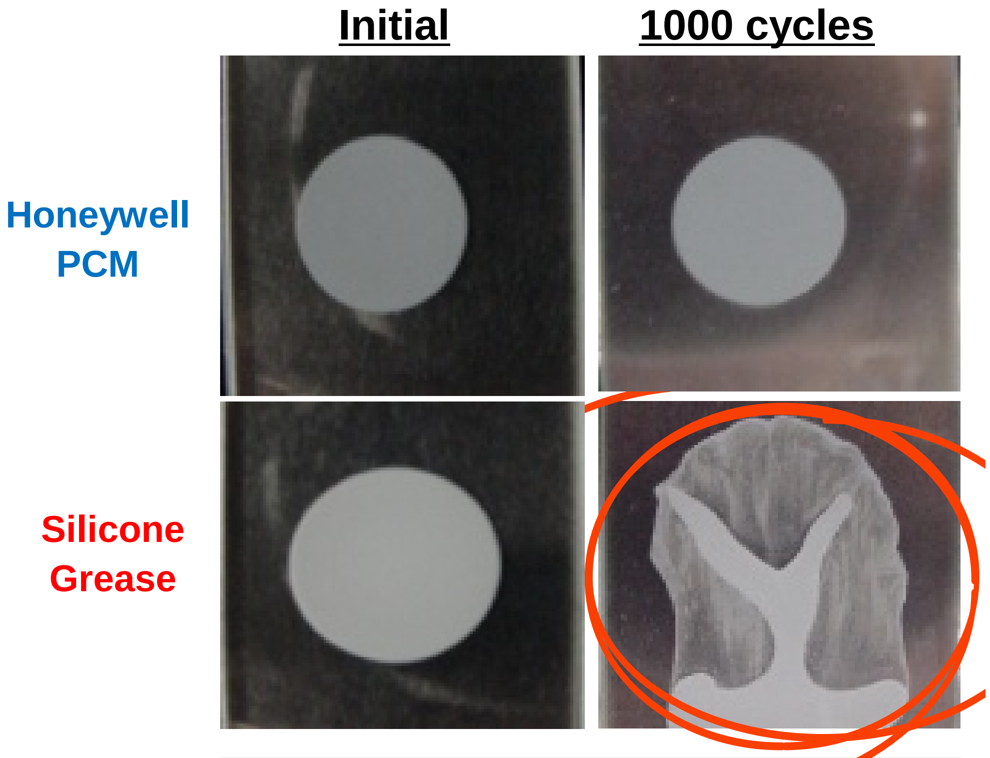
# PCM Technology

- Fundamentally three primary components in PCM
- Each are vital to robust polymer matrix integrity and filler optimization
- Filler
  - Thermal
- Wax/Polymer
  - Structural integrity
- Additives
  - Cross linking



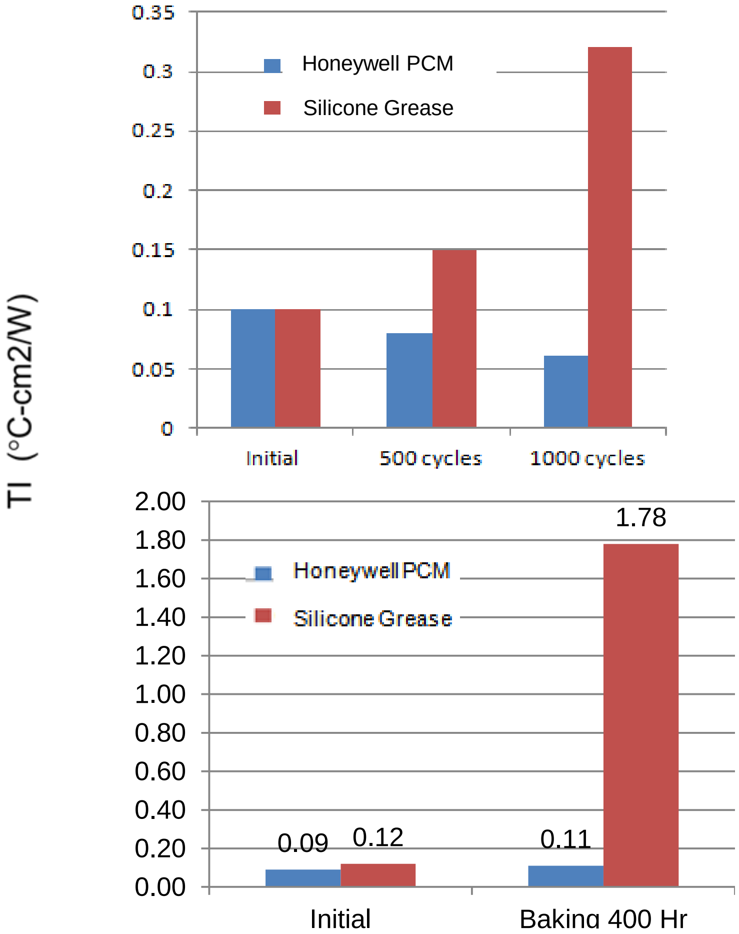
**PCM Formulation is Critical to Performance**

# PCM vs. Silicone Grease



**Grease breaks down**

Thermal Cycle (-55 °C to 125 °C) vs. Grease



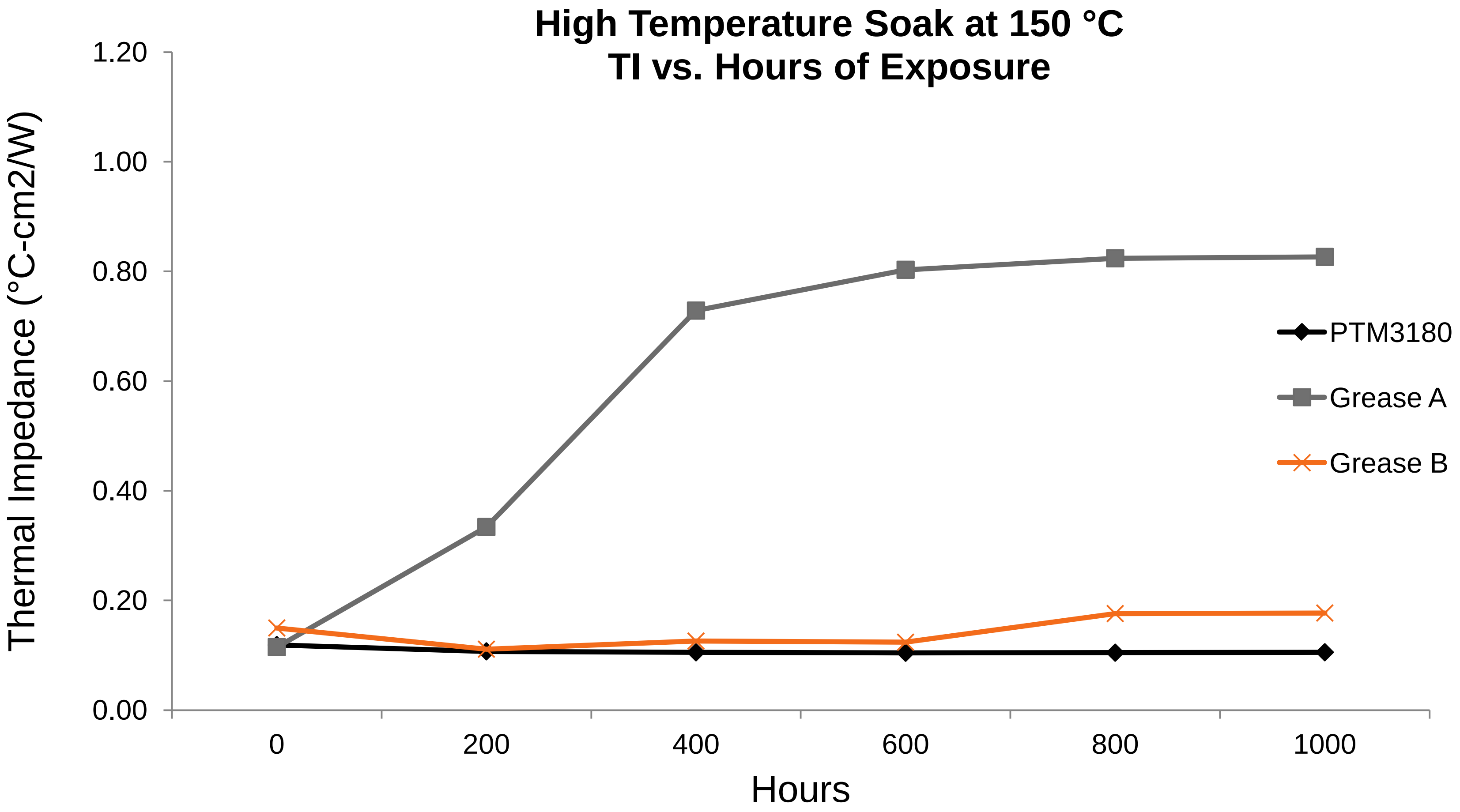
**Grease TI degrades**

**Thermal Cycling Test Condition:**

- -55˚Cx10min + 125˚Cx10 min, for 500 to 1000 cycles
- Sandwich PCM & grease between aluminum and glass plates set at 200µm gap
- TI Test : ASTM D5470

**PCM Provides Stable Polymer Structure with No Pump-Out Issue**

# Thermal Reliability: PCM vs. Silicone Greases

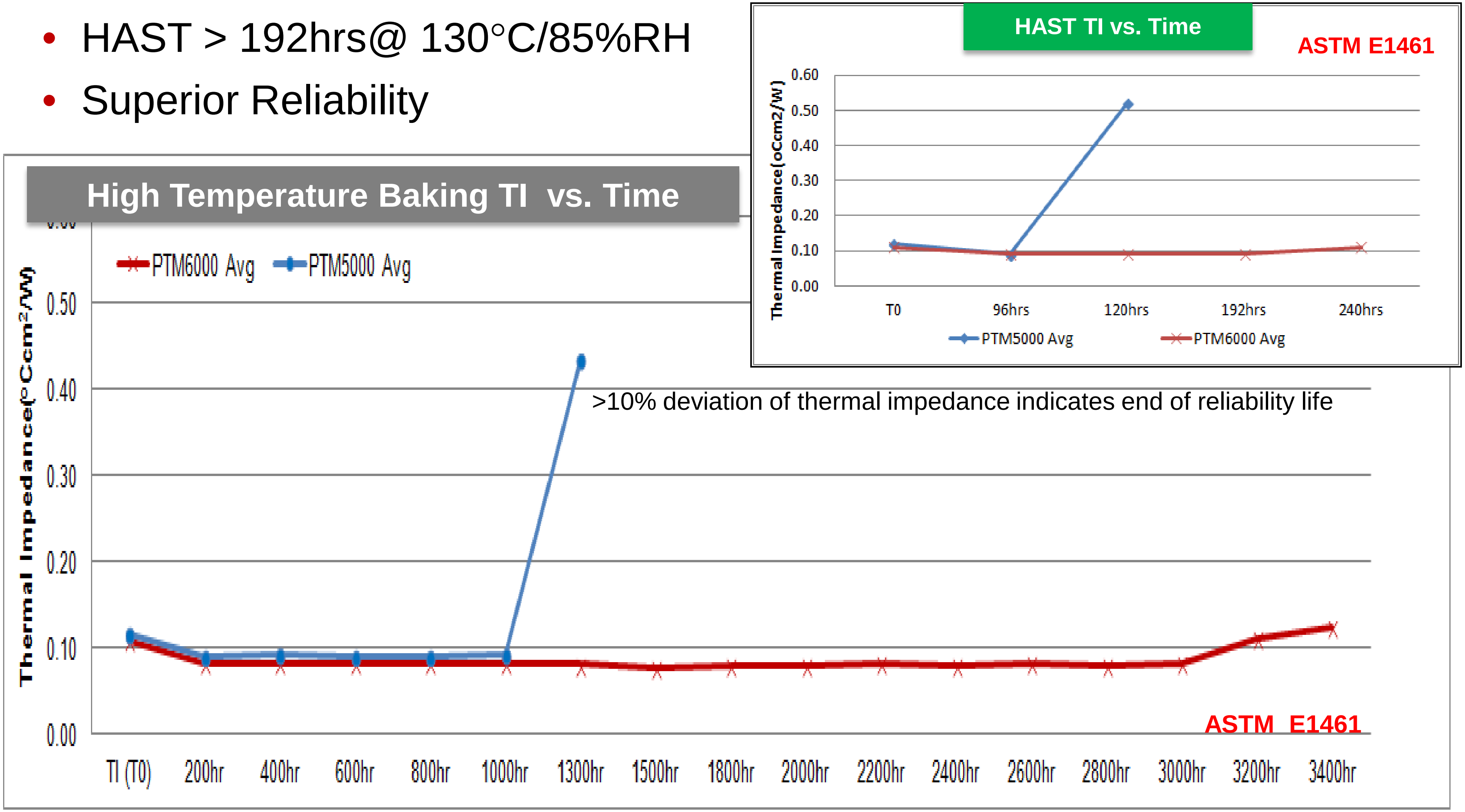


**Test Condition: 150°C continuous baking**
**Test Method: Laser Flash, ASTM E1461**

**Significantly Better Reliability Than Silicone Grease**

# Extended Reliability - PCM

- Thermal Stability >3000 hrs @ 150°C
- HAST > 192hrs@ 130°C/85%RH
- Superior Reliability



HAST TI vs. Time

ASTM E1461

High Temperature Baking TI vs. Time

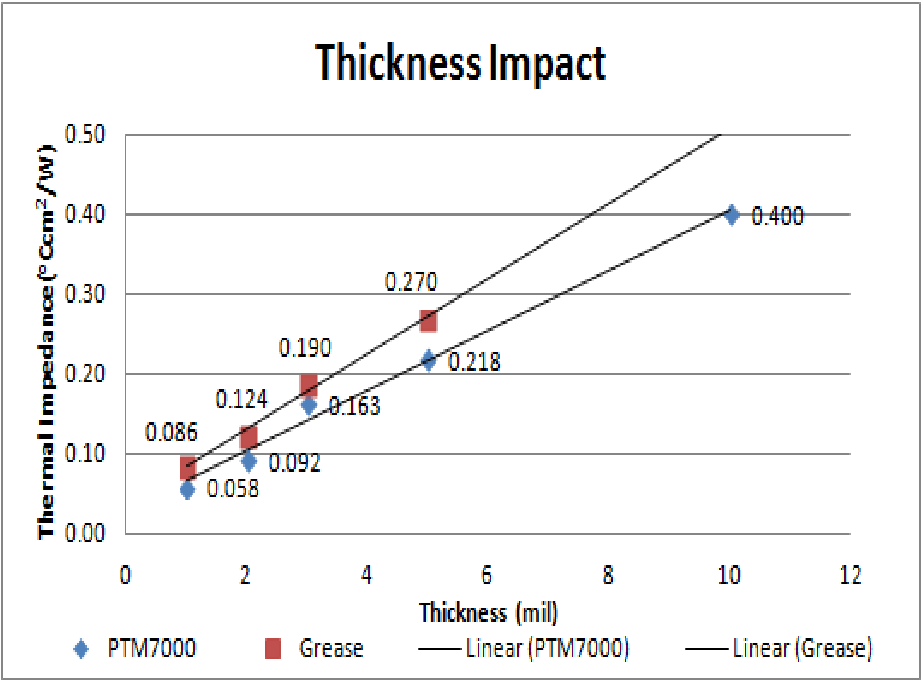
>10% deviation of thermal impedance indicates end of reliability life

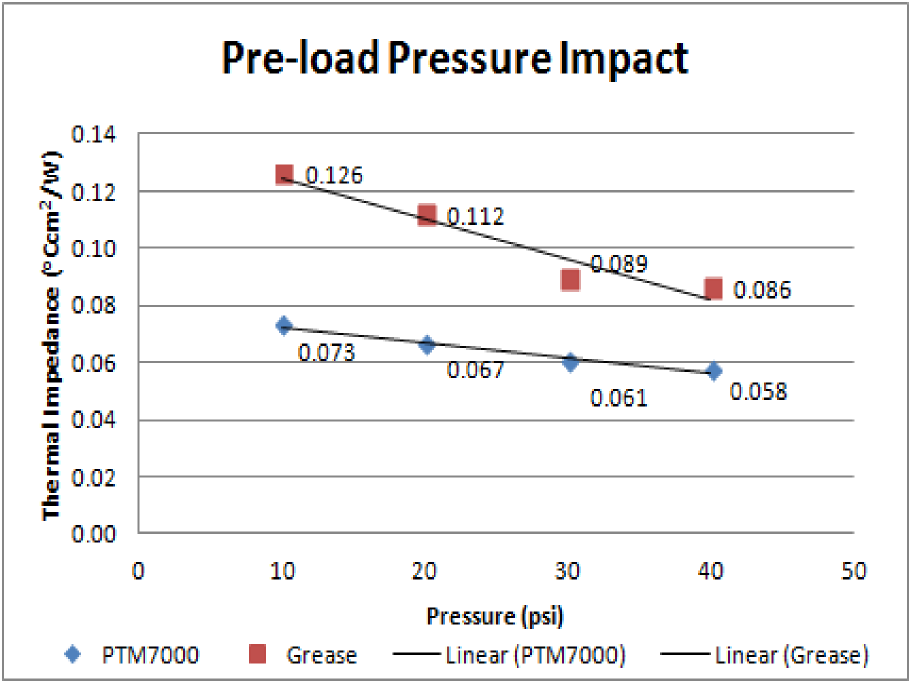
ASTM E1461

**Polymer Chemistry Enables Improved Reliability**

# Improved Thermal Impedance - PCM

- Lower Thermal Impedance: <0.06 °Ccm²/W
- As much as 30% Improvement at 20 um Bond Line
- Wider Process Window for Pre-Load Pressure Range

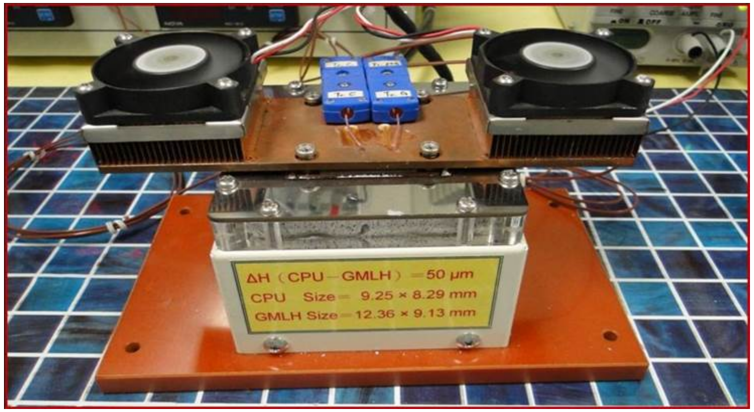


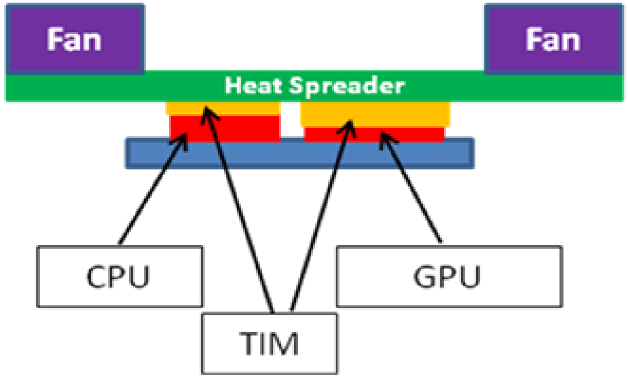


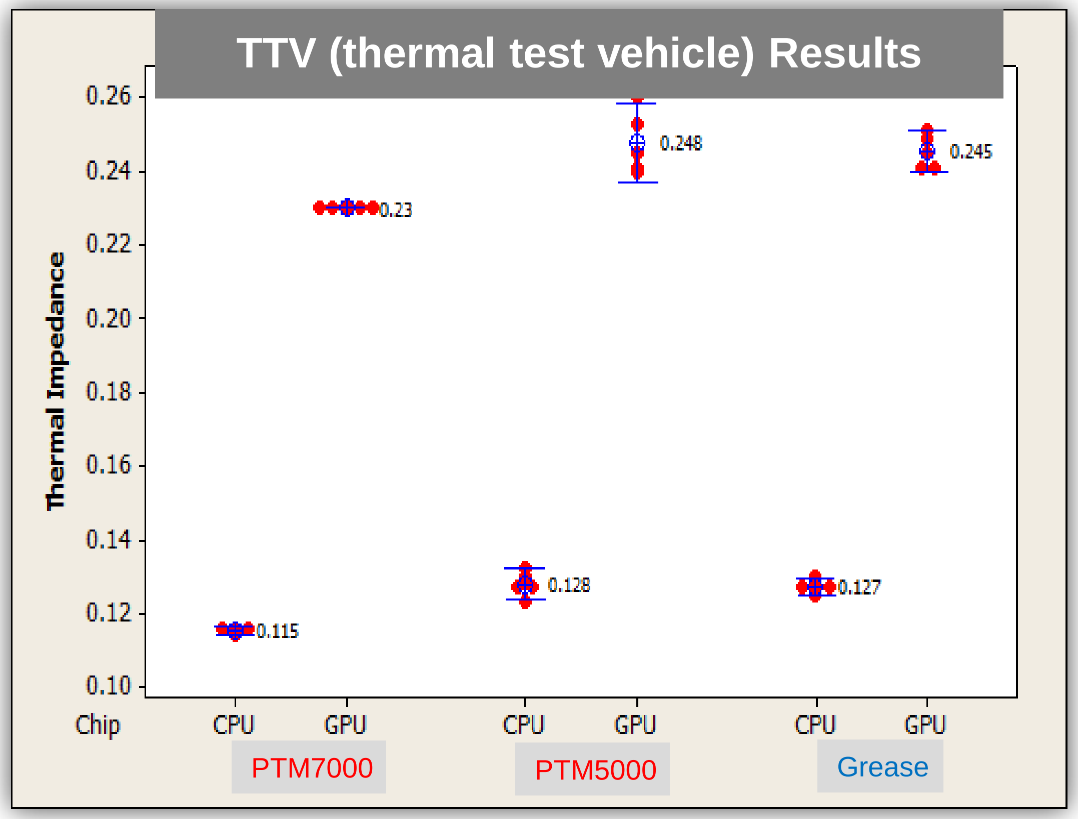
Test Method: Cut bar, ASTM D5470

**New PCM Material Demonstrates Lower Thermal Impedance**

# Thermal Test Vehicle (TTV) Study







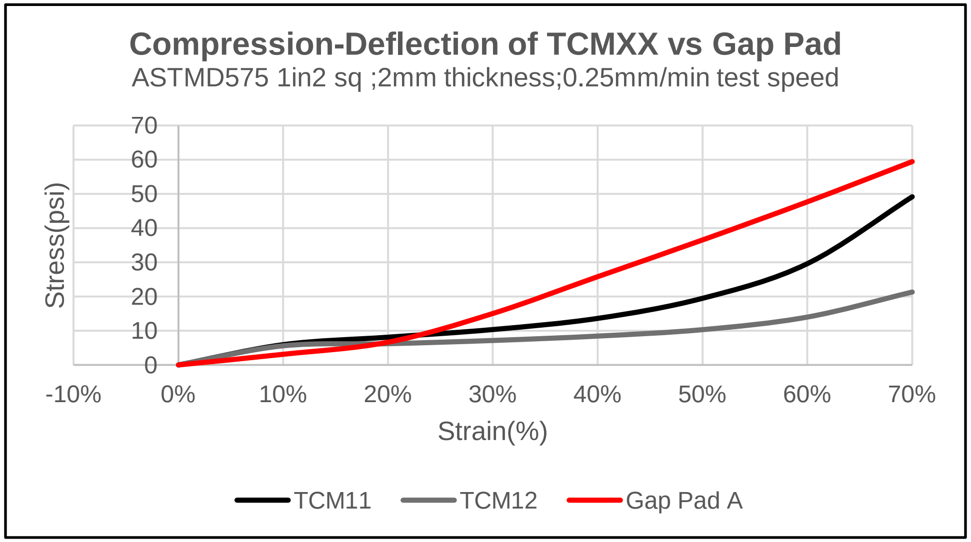
CPU device: = 9.25 mm x 8.29 mm
GPU device: 12.36 mm x 9.13 mm

# High Compressibility – TCM Series

- Feature
  - Integrates gap pad, putty material and thermal gel
  - No rebound, low spring back force
- Performance
  - Lower TI vs. gap pads, putty or gels with better wetting and no bleeding, no pump out
- Reliability
  - Equal to PCM45 and PTM5000
- Form Factor
  - Both Pad and paste available

| Physical Property | Unit | TCM11 | TCM12 | Gap Pad A | Gel B | Putty C |
|---|---|---|---|---|---|---|
| Thermal Conductivity | W/m-K | 4.4 | 3.0 | 3.0 | 3.5 | 3.0 |
| Thermal Impedance | ℃-cm$^2$/W @2mil thickness | 0.128 | 0.145 | NA | 0.393 | NA |
| Thermal Impedance | ℃-cm$^2$/W (10psi,1mm thickness) | 0.297 | NA | 4.00 | 2.09 | 2.84 |
| Specific Gravity | g/cm$^3$ | 2.2 | 2.1 | 1.34 | 3.2 | 1.7 |
| Compressibility | 40% deflection (Typical value) | 14 | 8 | 26 | 5 | 5 |

| Compressibility | TCM11 | TCM12 |
|---|---|---|
| **30%** | **10psi** | **7psi** |
| **40%** | **14psi** | **8psi** |
| **50%** | **19psi** | **10psi** |
| **70%** | **49psi** | **21psi** |


**Compression-Deflection of TCMXX vs Gap Pad**

ASTMD575 1in2 sq ;2mm thickness;0.25mm/min test speed

**New TCM Material: High Compressibility & Thermal Performance**

# Summary

- Increased device power densities challenge the performance and reliability of Thermal Interface Materials

- Application needs and requirements as well as accelerated life tests are critical to TIM selection criteria

- The robust polymer chemistry of Phase Change Materials enables low thermal impedance with proven long term thermal stability and reliability

# Questions