Challenges, Requirements and Solutions for the Electronics Industry

THERMAL MANAGEMENT

Dr. Glenn Mitchell
Oct. 6, 2015

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
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
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

\[ R_{TIM} = \frac{BLT}{K_{TIM}} \]

TIM Thermal Impedance:
\[ TI_T = BLT/K + R_C \]

\( TI_T \) = Total Thermal Impedance
\( BLT \) = Bond Line Thickness of TIM
\( K \) = Bulk Thermal Conductivity of TIM
\( R_C \) = Thermal Contact Resistance at the Interfaces
# TIMs - Thermal Needs and Requirements

<table>
<thead>
<tr>
<th></th>
<th>Customer Need</th>
<th>Measure</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Thermal Performance</strong></td>
<td>Thermal Conductivity</td>
<td>Thermal Bulk Conductivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(W/mK)</td>
<td>TTV, Laser Flash ASTM E1461</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Thermal impedance</td>
<td>Cut Bar TI Test ASTM D5470</td>
</tr>
<tr>
<td>2</td>
<td><strong>“Out-of-Box” Performance @ Time 0; Withstand Temp Spikes and Bursts</strong></td>
<td>Thermal impedance</td>
<td>TTV, Laser Flash ASTM E1461</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(TI, °C.cm²/W)</td>
<td>Cut Bar TI Test ASTM D5470</td>
</tr>
<tr>
<td>3</td>
<td><strong>Longevity</strong></td>
<td>&lt;10% Thermal Degradation over</td>
<td>High Temperature Storage, Temp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ALT</td>
<td>Cycling; Highly Accelerated Stress Test (HAST)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Arrhenius Modeling</td>
</tr>
<tr>
<td>4</td>
<td><strong>Performance Under Harsh Operating Conditions</strong></td>
<td>Test Severity; temperature,</td>
<td>High Temperature Storage, Temp</td>
</tr>
<tr>
<td></td>
<td></td>
<td>humidity, shock, etc.</td>
<td>Cycling; Highly Accelerated Stress Test (HAST)</td>
</tr>
<tr>
<td>5</td>
<td><strong>Bond Line Thickness</strong></td>
<td>&lt;0.2mm; 0.2mm – 1.0mm; &gt;1.0 mm</td>
<td>BLT Measurement</td>
</tr>
<tr>
<td>6</td>
<td><strong>Compression &amp; form factor</strong></td>
<td>Bond line Compression need</td>
<td>Deflection vs. Pressure</td>
</tr>
<tr>
<td>7</td>
<td><strong>Economics</strong></td>
<td>$/device</td>
<td>Cost of Ownership Modeling</td>
</tr>
</tbody>
</table>
Understanding and Prioritizing Needs is Critical to TIM Selection

Segment Landscape

Thermal Performance: TI at T0

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

Auto, Power, Telecom Infrastructures, Servers

Performance & Reliability

Gaming, Servers, Wireless, Power, Consumer Electronics

Desktop CPUs, HBLED, Consumer Electronics

Reliability First

Good Enough
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

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

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

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

<table>
<thead>
<tr>
<th>Name of Sensor</th>
<th>Grease Application</th>
<th>Phase Change Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chip 1</td>
<td>91.0</td>
<td>92.0</td>
</tr>
<tr>
<td>Chip 2</td>
<td>92.0</td>
<td>91.2</td>
</tr>
<tr>
<td>Chip 3</td>
<td>98.0</td>
<td>97.5</td>
</tr>
<tr>
<td>Chip 4</td>
<td>100.0</td>
<td>99.0</td>
</tr>
</tbody>
</table>
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.

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

- **Melt temp**
  - 45 °C

- 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 vs. Silicone Grease

PCM Provides Stable Polymer Structure with No Pump-Out Issue

Honeywell PCM

Silicone Grease

Initial 1000 cycles

Grease breaks down

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

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

Grease TI degrades

© 2015 by Honeywell International Inc. All rights reserved.
Thermal Reliability: PCM vs. Silicone Greases

High Temperature Soak at 150 °C
TI vs. Hours of Exposure

Thermal Impedance (°C·cm²/W)

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

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

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

© 2015 by Honeywell International Inc. All rights reserved.
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

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Unit</th>
<th>TCM11</th>
<th>TCM12</th>
<th>Gap Pad A</th>
<th>Gel B</th>
<th>Putty C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Conductivity</td>
<td>W/m-K</td>
<td>4.4</td>
<td>3.0</td>
<td>3.0</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Thermal Impedance</td>
<td>C-cm²/W @2mil thickness</td>
<td>0.128</td>
<td>0.145</td>
<td>NA</td>
<td>0.393</td>
<td>NA</td>
</tr>
<tr>
<td>Thermal Impedance</td>
<td>C-cm²/W (10psi,1mm thickness)</td>
<td>0.297</td>
<td>NA</td>
<td>4.00</td>
<td>2.09</td>
<td>2.84</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>g/cm³</td>
<td>2.2</td>
<td>2.1</td>
<td>1.34</td>
<td>3.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Compressibility</td>
<td>40% deflection (Typical value)</td>
<td>14</td>
<td>8</td>
<td>26</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compressibility</th>
<th>TCM11</th>
<th>TCM12</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>10psi</td>
<td>7psi</td>
</tr>
<tr>
<td>40%</td>
<td>14psi</td>
<td>8psi</td>
</tr>
<tr>
<td>50%</td>
<td>19psi</td>
<td>10psi</td>
</tr>
<tr>
<td>70%</td>
<td>49psi</td>
<td>21psi</td>
</tr>
</tbody>
</table>

## Compression-Deflection of TCMXX vs Gap Pad
ASTMD575 1in2 sq ;2mm thickness;0.25mm/min test speed

© 2015 by Honeywell International Inc. All rights reserved.
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