Processor Performance, Packaging and Reliability Utilizing a Phase Change Metallic Alloy Thermal Interface System

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Outline

- Testing
- Performance Data
- Packaging & Reliability
- Next Steps
- Summary
Testing
Overview

- TIM1 interface tested
- Thermal Test Vehicles (TTVs)
- $\Theta_{jc}$ calculated
- Comparative data
Thermal Test Vehicles (TTVs)

- 1.4 cm² die area
- 80 Watts
- Uniform heat flux (57 W/cm²)
- FCPGA package
- Ni-plated Cu lid
Testing

Value of TTV Testing

- Actual chip and lid surface finish, flatness and composition
- Simulate processor hot spots
- Test lid attach process qualities
- Assemblies can be environmentally stressed without disturbing interface
# Testing TIMs

<table>
<thead>
<tr>
<th>TIM Type</th>
<th>Shin-Etsu X23-7783D</th>
<th>Chomerics T557</th>
<th>Enerdyne Indigo1</th>
<th>Indium Solder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>Grease</td>
<td>PSH</td>
<td>PCMA</td>
<td>Solder</td>
</tr>
<tr>
<td>Al-filled</td>
<td>PCMA within</td>
<td></td>
<td>Indium-based</td>
<td></td>
</tr>
<tr>
<td>polymer</td>
<td>polymer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase Change</td>
<td>N/A</td>
<td>43 / 65</td>
<td>~65</td>
<td>156</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impedance</td>
<td>~ 0.07 (1 mil BLT*)</td>
<td>0.0625 (70°C, 50 psi)</td>
<td>&lt; 0.04 (80°C, 40 psi)</td>
<td>0.07-0.08 (8-9 mil BLT)</td>
</tr>
<tr>
<td>(°C-cm²/W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductivity</td>
<td>6.0</td>
<td>3.0</td>
<td>&gt; 20</td>
<td>80</td>
</tr>
<tr>
<td>(W/mK)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Extrapolated from BLT vs. impedance graph
Testing Platform

 Clamp Fixture
 Leveling Foot (non-conductive)
 Cooling Block
 Foam Insulation
 Thermocouple
 TTV assembly & Socket
 Thermal Test PWB
 Clamp Pad (non-conductive)
 Thermocouple

TC Meter
Heat/Cooling H20 System
Power Supply
4 Wire Ohm
Testing

TTV Assembly

- 10 lbs force
- No lid seal
- Minimum Bondline Thickness (BLT)
- Gold metallization on Indium TTV
Testing Methodology

- Calibration
- Bias of die
- Power, diode resistance & case temperature measured
- 3 measurements / sample
- $\Theta_{jc}$ calculated
Performance Data

\[ \Theta_{jc} (^0C/W) \]

X23: 0.249
T557: 0.250
Indium: 0.267
Indigo1: 0.189
### Historic TIM Qualities

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal Grease</strong></td>
<td>High bulk conductivity</td>
<td>Pump-out</td>
</tr>
<tr>
<td></td>
<td>Conforms to surface irregularities</td>
<td>Phase separation</td>
</tr>
<tr>
<td></td>
<td>No cure</td>
<td>Migration</td>
</tr>
<tr>
<td></td>
<td>Reworkable</td>
<td></td>
</tr>
<tr>
<td><strong>Polymer-solder Hybrid (PSH)</strong></td>
<td>Good bulk conductivity</td>
<td>Cure needed</td>
</tr>
<tr>
<td></td>
<td>Conforms to surface irregularities</td>
<td>Reflow needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delamination</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-reworkable</td>
</tr>
<tr>
<td><strong>Phase-Change Metal Alloy (PCMA)</strong></td>
<td>High (metal) bulk conductivity</td>
<td>Reflow needed</td>
</tr>
<tr>
<td></td>
<td>Easy handling</td>
<td>Pump-out</td>
</tr>
<tr>
<td></td>
<td>Reworkable</td>
<td>Migration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Voiding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oxidation</td>
</tr>
<tr>
<td><strong>Indium solder</strong></td>
<td>High (metal) bulk conductivity</td>
<td>Needs Au-plate for wettability</td>
</tr>
<tr>
<td></td>
<td>Easy handling</td>
<td>Reflow needed</td>
</tr>
<tr>
<td></td>
<td>No pump-out</td>
<td>Stress cracking, delamination</td>
</tr>
<tr>
<td></td>
<td>No migration</td>
<td>Voiding</td>
</tr>
</tbody>
</table>
Packaging & Reliability

Overview

- Corrosion
- Migration
- Diffusion
Packaging & Reliability

Corrosion Mitigation

- Vent-free continuous lid seal
- Sealant with low vapor transmission rate
- Compatible with PCMA burn-in during lid attach
Packaging & Reliability
Corrosion Mitigation

- Lid seal facilitates controlled environment within lid cavity
- Vapor Phase Corrosion Inhibitor (VPCI)
- VPCI ions on PCMA surface interrupt corrosion cell

**Diagram:**
- Metal
- Anode
- Cathode
- VPCI Source
- Dissolved VPCI ions
- Molecules of VPCI in gaseous phase
Packaging & Reliability

Corrosion Mitigation

Indigo

PCMA without mitigants

1800 temp cycles

50 temp cycles

Temperature cycling—Service Condition “B”

-55°C to +125°C
Packaging & Reliability

Migration Control

- Deployment of perimeter barrier
- Secondary containment by lid seal
- Passed shock test (Service Condition “E”)
- Passed vibration test (Service Condition “4”)
Packaging & Reliability

Diffusion

<table>
<thead>
<tr>
<th>Material</th>
<th>$D_{100^\circ C}$ (cm$^2$/sec)</th>
<th>Penetration Depth after 10 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>$4.06 \times 10^{-47}$</td>
<td>&lt;1 nm</td>
</tr>
<tr>
<td>Copper</td>
<td>$1.22 \times 10^{-15}$</td>
<td>~ 10 µm</td>
</tr>
<tr>
<td>Gold</td>
<td>$1.50 \times 10^{-18}$</td>
<td>&lt; 1 µm</td>
</tr>
<tr>
<td>Indium</td>
<td>$3.30 \times 10^{-52}$</td>
<td>&lt;1 nm</td>
</tr>
<tr>
<td>Bismuth</td>
<td>$7.23 \times 10^{-60}$</td>
<td>&lt;1 nm</td>
</tr>
</tbody>
</table>

- Insufficient energy at typical operating temperatures for measurable diffusion
- Significantly more diffusion of AuSn from eutectic die bonding
Next Steps

- Complete TTV environ. tests
- Reduce voids to <2%
- Further customer qualification
- TIM2 development
PCMA Thermal Interface

Summary

- 25-30% reduction of $\Theta_{jc}$
- No chip metallization required
- Corrosion mitigation demonstrated
- Migration controlled
- Negligible diffusion in Silicon
Thank you.

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