ADDRESSING CHALLENGES IN DUAL SIDED SIP THERMAL BUDGET

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Heraeus Electronics
AGENDA

1. Introduction
   - System In Package for 5G applications
   - Thermal Budget Challenge In Dual-sided SiPs

2. Low Temperature Solder Material
   - Tin-bismuth-silver (Sn-Bi-Ag) low temperature alloy properties
   - Solder bump microstructure and Intermetallic phase development with thermal aging
   - Thermal cycling and mechanical drop tests

3. Targeting Ultra-fine Pitch Application
   - Paste formulation- powders and flux

4. Q & A
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RF FRONT-END MARKET OPPORTUNITIES

Source: Yole Developpement Sept 2020

Addressing Challenges in Dual Sided SiP Thermal Budget | 18th Device Packaging Conference | Heraeus Electronics
SYSTEM-IN-PACKAGE (SIP) MODULES FOR 5G APPLICATIONS

- System-in-Package technologies’ flexibility enables heterogenous integration for functional performance and faster time-to-market
- SiP modules consist of flip chips (filters, PA, LNA, etc.) and passive components of various sizes
- SiP can be dual sided and subjected to multiple reflows
THERMAL BUDGET CHALLENGE IN DUAL-SIDED SIPS

A Case study of dual sided Antenna-in-package (AiP)

1st reflow (260°C for SAC305) and underfill/molding

2nd reflow (260°C for SAC305)

Lower the thermal budget during 2nd reflow by using a low temperature solder material
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# SOLDER ALLOY PROPERTIES

<table>
<thead>
<tr>
<th>Solder Type</th>
<th>Melting Point, °C</th>
<th>Electrical Resistivity, μΩ.cm</th>
<th>Young's Modulus, GPa</th>
<th>0.2% Proof Stress, N/mm²</th>
<th>Tensile Strength, N/mm²</th>
<th>Elongation, %</th>
<th>Impact Energy, J</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAC305</td>
<td>223</td>
<td>10.9</td>
<td>45.6</td>
<td>35.8</td>
<td>46.6</td>
<td>44.6</td>
<td>69</td>
</tr>
<tr>
<td>Sn-Bi57-Ag1</td>
<td>138</td>
<td>34.8</td>
<td>41.5</td>
<td>63.0</td>
<td>78.0</td>
<td>22.8</td>
<td>0.88</td>
</tr>
<tr>
<td>Sn-Bi48-Agₓ</td>
<td>145</td>
<td>29.0</td>
<td>42.2</td>
<td>60.6</td>
<td>80.6</td>
<td>24.0</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Bi-Sn alloys are known to be more brittle than SAC305
SN-57BI-1AG SOLDER BUMP MICROSTRUCTURE

Solder bumps are formed with a Type 6 printing solder paste in a no clean chemistry.

Sn-Bi57-Ag1 solder bump printed on ENIG plated surface (Au/Ni)

White (S125): pure bismuth phase, 100% Bi
Grey (S124): primary tin phase (βSn), Sn-5wt%Bi
S123: Intermetallic compound (IMC) with ENIG substrate
Growth of interface IMC layer thickness over thermal aging at 75°C is more obvious for Cu OSP and ENIG substrate surfaces.
**INTERFACE IMC ON ENIG SUBSTRATE SURFACE**

**ENIG-SnBi solder interface**

<table>
<thead>
<tr>
<th>Spots</th>
<th>Elements</th>
<th>SEM-EDX, Wt%</th>
<th>Reference-Phase Diagram</th>
<th>Molecular weight, g/mol</th>
<th>Mole fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Ni</td>
<td>29.4</td>
<td>Ni$_3$Sn$_4$ (Sn 70 – 75 wt%)</td>
<td>191.36</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>70.6</td>
<td></td>
<td>459.54</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ag</td>
<td>68.5</td>
<td>Ag$_3$Sn (Sn 25-30 wt%)</td>
<td>302.95</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>27.2</td>
<td></td>
<td>120.41</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Au</td>
<td>37.9</td>
<td>AuSn$_2$ (Sn 60-65 wt%)</td>
<td>164.8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>62.1</td>
<td></td>
<td>270.02</td>
<td>2</td>
</tr>
</tbody>
</table>
## INTERFACE IMC ON CU OSP & ENEPIG SUBSTRATE SURFACE

### Cu OSP-SnBi solder interface

<table>
<thead>
<tr>
<th>Spots</th>
<th>elements</th>
<th>Wt%</th>
<th>Typical Intermetallics</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>Cu</td>
<td>37.9%</td>
<td>Cu₆Sn₅</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>62.1%</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Ag</td>
<td>70.3%</td>
<td>Ag₃Sn</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>23.7%</td>
<td></td>
</tr>
</tbody>
</table>

### ENEPIG-SnBi solder interface

<table>
<thead>
<tr>
<th>Spots</th>
<th>elements</th>
<th>Wt%</th>
<th>Typical Intermetallics</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Ni</td>
<td>28.5%</td>
<td>Ni₃Sn₄</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>70.2%</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ag</td>
<td>72.0%</td>
<td>Ag₃Sn</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>28.0%</td>
<td></td>
</tr>
</tbody>
</table>
THERMAL AGEING (75°C)- SN-BI COARSENING (OSWALT-RIPENING)

- **Oswalt Ripening**: Obvious coarsening of Bi and Sn phases noticed.
- **Sn-Bi interface is stable** without any significant changes in microstructure.

- Sn-Bi eutectic phases are evident:
  - S73: pure bismuth phase (100% Bi)
  - S72: primary tin phase (100% (βSn))

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Oswalt Ripening Effect

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Sn and Bi phases become coarser and more inhomogenously distributed over aging time.
Shear strength remains high without significant degradation over 1000Hr aging at 75°C

Effect of interface IMC growth and Sn-Bi coarsening on shear strength is minimal
### STUDY 1- THERMAL CYCLING TESTS

#### Low Temp. Solder Alloys

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solder A</strong></td>
<td>SnBi57Ag1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solder B</strong></td>
<td>SnBi48Agx</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solder G</strong></td>
<td>SAC305</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solder J</strong></td>
<td>SnBi48Agx + dopants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Conditions:** **Thermal cycling profile:** -40/125°C with 16.5 minutes ramps up and down (10°C per minute) and 15 minutes dwell time at 125°C and 10 minutes dwell time at -40°C. Recorded continuously the electrical connectivity of the solder joints. ENIG plated test boards.

<table>
<thead>
<tr>
<th>Paste</th>
<th>A (SnBi57Ag1)</th>
<th>B</th>
<th>G (SAC305)</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>CABGA208</td>
<td>SMR</td>
<td>CABGA208</td>
<td>SMR</td>
</tr>
<tr>
<td>Total Test Components</td>
<td>18</td>
<td>36</td>
<td>18</td>
<td>36</td>
</tr>
<tr>
<td># of failed components until 1500 cycles</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>% failure until 1500 cycles</td>
<td>5.56%</td>
<td>0.00%</td>
<td>11.11%</td>
<td>0.00%</td>
</tr>
<tr>
<td>1st Failure</td>
<td>1240</td>
<td>0</td>
<td>275</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Sn-Bi57-Ag1** showed comparable TCT performance to SAC305, and best among all low temperature solder pastes tested.
STUDY 2- MECHANICAL DROP TEST

- Sn-Bi57-Ag1 (Solder A) showed drop characteristic life of >100 drops
MECHANICAL DROP TEST – CRACK ALONG BI PHASE

- Agglomerated large bismuth phase accelerated crack propagation via weak Sn-Bi eutectic interface.

- Scattered fine bismuth phase prolong the crack propagation via Sn eutectic (grain) boundaries.
Study 3 - Mechanical Drop Test with Underfill

With underfill, Sn42-Bi57-Ag1 (BU) showed >5X increase in drop characteristic life. Applicable for SiP modules with underfill and molding.

- Deviation in drop test characteristic life as compared to Study 2 without underfill.
- Further Investigations in progress on:
  - Substrate condition
  - Reflow profile control
  - Paste volume control
  - Flux formulation control
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SOLDER PASTE FORMULATION FOR FINE-PITCH SIP APPLICATION

Fine-pitch Solder Paste Formulation:

- **Fine-pitch Powder**
  - Type 6, 7, 8 and beyond
  - Alloys: SAC305, SnBiAg
  - Made with unique Welco™ technology

- **Flux System**
  - Designed to work with fine pitch powders for optimal paste performance

- **Solder Paste for SiP**
  - Consistent paste release at ultra-fine pitch printing
  - Minimal voids & beading
  - Long stencil life & staging
SUMMARY

• Low temperature solder paste material can effectively address thermal budget challenges in dual-sided SiPs for 5G applications (RFFE, AiP, etc.)

• Low temperature alloy Sn-Bi57-Ag1 demonstrated best reliability performance for thermal aging (75°C), thermal cycling and drop tests

• Key to have the right solder paste formulation for ultra-fine pitch SiP applications
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