EFFECTS OF SUBSTRATE MATERIAL AND PACKAGE PAD DESIGN ON SOLDER-JOINT RELIABILITY OF 0.8MM PITCH BGA

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Agenda

- Introduction / Background
- Package Description
- Experiment Description
- Package Characterization
- Temperature Cycling Results
- Crack Analysis
- Summary and Conclusions
Introduction

- Application
  - Automotive under-the-hood applications
  - 0.8mm pitch BGA packages
  - Temperature Cycling on Board -40°C to +125°C
  - >3000 cycle to first failure

- Objectives
  - Demonstrate 0.8mm BGA meet 3000+ cycles
  - Quantify effects of key parameters:
    - Package pad design type: SMD vs. SMD/NSMD Hybrid
    - Substrate dielectric material: Standard vs. Low CTE
Derivation of Hybrid Concept

292MAP NSMD Trace Crack Failures

Unit 1

Trace Crack

Flat Section with substrate removed

Unit 2

Cu trace crack

NSMD Soldermask opening

Flat Section with substrate removed

Unit 3

Trace Crack

Flat Section with substrate removed

Unit 4

Trace Crack

Flat Section with substrate removed

Failure of NSMD pads always occurred under the die!
Package Case Outline
Package Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>512TEPBGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Size</td>
<td>25mm x 25mm</td>
</tr>
<tr>
<td>BGA Pitch</td>
<td>0.8mm</td>
</tr>
<tr>
<td>Mold Size</td>
<td>22.5mm x 22.5mm</td>
</tr>
<tr>
<td>Mold Thickness</td>
<td>1.15mm</td>
</tr>
<tr>
<td>Mold Material</td>
<td>Epoxy $a_1=9$ppm/°C</td>
</tr>
<tr>
<td>Substrate Thickness</td>
<td>0.56mm, 4 layer</td>
</tr>
<tr>
<td>Substrate Material</td>
<td>Variable – See Table</td>
</tr>
<tr>
<td>Die Size</td>
<td>8.1mm x 9.6mm x 0.28mm</td>
</tr>
<tr>
<td>Package Pad Design</td>
<td>Variable – See Footprints</td>
</tr>
<tr>
<td>Package SRO</td>
<td>0.45mm</td>
</tr>
<tr>
<td>Pad Finish</td>
<td>Electroplated Ni/Au</td>
</tr>
<tr>
<td>Sphere Diameter</td>
<td>0.50mm</td>
</tr>
<tr>
<td>Sphere Alloy</td>
<td>Sn 3.5Ag</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cell</th>
<th>Design</th>
<th>Substrate Dielectric Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SMD</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Hybrid-A</td>
<td>Standard $a_1=16$ppm/°C</td>
</tr>
<tr>
<td>3</td>
<td>Hybrid-B</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SMD</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Hybrid-A</td>
<td>Low CTE $a_1=11$ppm/°C</td>
</tr>
<tr>
<td>6</td>
<td>Hybrid-B</td>
<td></td>
</tr>
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</table>
Methodology

- **PCB**
  - 8-up Daisy-chain
  - 1.56mm thick, 4-layer
  - 0.4mm NSMD OSP pad

- **SMT**
  - Stencil aperture 0.4mm
  - Stencils thickness 0.1mm
  - SAC305 Paste
  - Reflow peak 235°C - 240°C

- **Cycling**
  - Dual Chamber (AATS)
  - 1 cycle/hour
  - Dwell set 30min, actual ~25min
  - Monitor in-situ
  - 10 events >300ohms is a failure
Ball Geometry Measurements

- Component before mounting to board
- RVSI LS8000 scanner at 25°C
- Uncompensated NSMD pads predicted to be 22um shorter
- Actual compensated NSMD Ball Height ~6um shorter
- No difference in Ball Diameter
Component before mounting to board, solder balls removed

Akrometrix TherMoire PS400

Pad design has no effect (expected)

Low CTE substrate dielectric lower warpage at lower temperatures
Electrical Test Results

- Ranked results, best to worst:
  - Cells 5 & 6
  - Cells 2, 3 & 4
  - Cell 1

- Low CTE dielectric or hybrid design offered improvement

- Combining was best

- 16 units/cell, cycled to ≥75% failure rates
Electrical Test Regression Analysis

Change in solder-joint lifetime (# of cycles)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Change</th>
<th>1st Fail</th>
<th>Eta</th>
<th>1% fail cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Material</td>
<td>Standard → Low CTE</td>
<td>1195</td>
<td>958</td>
<td>979</td>
</tr>
<tr>
<td></td>
<td>SMD → Hybrid-A</td>
<td>1153</td>
<td>1221</td>
<td>962</td>
</tr>
<tr>
<td></td>
<td>SMD → Hybrid-B</td>
<td>1242</td>
<td>1323</td>
<td>866</td>
</tr>
<tr>
<td></td>
<td>Hybrid-A → Hybrid-B</td>
<td>89*</td>
<td>102*</td>
<td>-96*</td>
</tr>
<tr>
<td>Dielectric + Design</td>
<td>Std + SMD → Low CTE + Hybrid</td>
<td>2392</td>
<td>2230</td>
<td>1892</td>
</tr>
</tbody>
</table>

Change in solder-joint lifetime (%)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Dielectric Material</td>
<td>Standard → Low CTE</td>
<td>43%</td>
<td>22%</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>SMD → Hybrid-A</td>
<td>41%</td>
<td>28%</td>
<td>39%</td>
</tr>
<tr>
<td></td>
<td>SMD → Hybrid-B</td>
<td>45%</td>
<td>30%</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>Hybrid-A → Hybrid-B</td>
<td>2%*</td>
<td>2%*</td>
<td>-2%*</td>
</tr>
<tr>
<td>Dielectric + Design</td>
<td>Std + SMD → Low CTE + Hybrid</td>
<td>86%</td>
<td>51%</td>
<td>76%</td>
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</table>

- Linearly regressed Weibull results vs. test parameters
- Eta:
  - Low CTE added ~1000 cycles
  - Hybrids add 1200~1300
  - Hybrid A and B the same

* not statistically significant at the alpha=0.05 level
Crack Analysis by Dye-and-pry

- Random sampling at 4013 cycles
- Images are PCB view, on top of BGA ball attached to PCB pad after pry
- Fracture surface is between solder ball and package BGA pad
- Red area was fractured during cycling
- Shinny area was still intact
Crack Analysis by Dye-and-pry

- Less Cracking Hybrid vs. SMD; Less cracking Low CTE vs. Standard
- Hybrids show less cracking in outer rows (NSMD)
Cell 5 (Hybrid-A, Low CTE) First failure at 4954 cycles

- Solder-joint AF02 (an NSMD pad) was 100% cracked: this caused the unit to fail electrically.
- One solder-joint in the thermal array – T19 (an SMD pad) was 90% cracked
- Distribution of cracking more balanced between perimeter rows and thermal array than for pure SMD designs.

- BGA map shows area % cracking on the package side of the solder-joint.
- Image is PCB view, on top of BGA ball attached to PCB pad after pry
- Fracture surface is between solder ball and package BGA pad
- Red area was fractured during cycling
- Shinny area was still intact
Crack Analysis by Cross-section

- Random sampling at 3000 cycles
- SMD joints primarily failing on package side
- NSMD joints mixed

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<td>SMD</td>
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Pad type denoted by (S) or (N)
Random sampling at 3000 cycles
SMD joints primarily failing on package side
NSMD joints mixed
Crack Analysis by Cross-section mapping @ 3000 cycles

- Less cracking in hybrid designs vs. SMD designs
- Most advanced cracking under die edge
Discussion

- **Design Type**
  - Component coplanarity can be controlled
  - Electrical test clear indication of improvement
    - Eta increased 1200~1300 cycles
  - FA showed solder-joint fatigue, not trace crack
  - Crack analysis – limited sample size
    - Less cracking in hybrid designs vs. SMD designs
    - Cracks formed on both sides of NSMD solder-joints
    - Less cracking in perimeter rows of hybrid designs

- **Substrate Dielectric Material**
  - Lower warpage at low temperature
    - CTE matching of substrate to mold compound
  - Electrical test clear indication of improvement
    - Eta increased ~1000 cycles
  - Crack analysis – limited sample size
    - Dye-and- pry showed less cracking in Low-CTE solder-joints
Summary

- **Conclusions**
  - Mixing SMD and NSMD pads on the same package is feasible for manufacturing and can improve solder-joint life.
  - Lowering the package substrate dielectric CTE can improve solder-joint life.
  - Greater than 3000 cycles to first failures was achieved for the 512TEPBGA package in -40°C to +125°C.

- **Future Work:**
  - Comparison of Hybrid to pure NSMD design.
  - Confirmation evaluation with additional first failure FA.
  - Better understanding of failure mechanics at the die edge.
  - Robustness of NSMD for other stresses (shock, handling).
## Acknowledgements

<table>
<thead>
<tr>
<th>Component Assembly</th>
<th>BY Low Peng Peng Ng</th>
</tr>
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<tbody>
<tr>
<td>Board Assembly &amp; SJR testing</td>
<td>Andrew Mawer Paul Galles Thomas Koschmieder</td>
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<td>Lab Analysis</td>
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<td>Project Support</td>
<td>John Arthur Matt Zapico</td>
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<tr>
<td>Modeling &amp; Simulation</td>
<td>Betty Yeung</td>
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