Construction Analysis of Plastic Encapsulated Microcircuits Containing Copper Bond Wire

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NSWC Crane has been developing processes and performing construction analyses on plastic encapsulated microcircuits containing copper bond wires (Cu-PEM’s) since 2015.

NSWC Crane has independently shown correlation between Cu-PEM specific process indicators discovered during DPA and failures modes observed during wire pull:

- Evaluated over 40 unique part numbers including a range in manufacturer, package style, and part functionality.
- Summary report available for distribution in both Dist A (public release) and Dist D (DoD and DoD contractors).
Construction Analysis of Cu-PEM’s at NSWC Crane

• Fluid transition dates
  – Manufacturers estimate transition dates on PCN’s but actual transition may occur months to years afterwards
  – Manufacturers reserve the right to transition between copper and gold

• Non-destructive screening
  – A qualified x-ray technician can discern the difference between gold and copper bond wires via real-time x-ray

• Multiple detection techniques for common process indicators
  – Correlation between dielectric cracking in cross-section, wire pull failure mode, and force to failure
  – Correlation between bond floor morphology, wire pull failure mode, and force to failure

• 17 of 41 parts contained processes indicators not typically observed on PEM’s with Au wire bonds
  – Includes direct comparison of same part numbers in gold and copper
Examples of Findings

• All the following examples were performed at NSWC Crane:
  – All parts tested in the as-received condition
    • Smaller parts were hand soldered to substrates
  – All parts were chemically decapsulated, exposing the entire bond wire
  – All wire pulls were performed with the hook located between the apex and the ball (near center)
Significant Findings: Example 1: Cracked Dielectric

• MA-16-008-01 (Crane Analysis #)
  – Low-cost commercial FPGA
  – Significant dielectric cracking observed in cross section
  – 16 of 134 (12%) of wires pulled failed via die bond lift
  – 20% reduction in pull strength correlated to die bond lift failure mode, including one <1g force to failure (shock and vibe concern)

• Manufacturer contacted concerning results. Per manufacturer:
  – Part is intendent to be a low-cost commercial FPGA
  – Manufacturer maintains a gold-wire alternative for automotive industry to meet the automotive reliability requirements
**Significant Findings:**

**Example 2: Manufacturer Comparison**

- Comparison of components MA-16-008-02 (Comp A) and MA-16-008-25 (Comp B) from same manufacturer
  - Both use palladium coated copper wire
  - Both bonded to aluminum with intermetal dielectric
  - Comp A had ‘ideal’ ball bond morphology without dielectric cracking; comp B had an uneven bond floor with dielectric cracking
  - Comp B exhibited multiple die bond lifts; comp A did had none

- Use of palladium coated copper does not guarantee manufacturing success

- Correlation shown between bond morphology and wire pull force to failure/failure mode for other components, including bonds to Al on Si, Al on W on Si, and Al on SiO₂ to Si
  - Not a function of manufacturer (i.e. manufacturer and past experience cannot necessarily be used a predictor of quality)
Significant Findings:

Example 3: Die Bond Pad Adaptation for Copper Wire

- MA-16-008-14
  - Thick copper pad grown on die, finished with palladium on nickel
  - Thicker pad would accommodate higher bonding forces without damaging underlying silicon
- Unexpected failure modes related to die bond lifts were observed including:
  - Incomplete bonding between ball and pad at the bond center
  - Incomplete bonding between the ball and pad along an axis
  - Lifting of the nickel plating from the copper pad
- Adapting the die for copper bond wire does not guarantee success and may introduce new failure modes
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- Adapting the die for copper bond wire does not guarantee success and may introduce new failure modes
• The transition date to copper bond wires cannot be determined from manufacturer’s product change notifications
• It cannot be assumed that once a manufacturer transitions to copper bond wires, future productions runs will use copper wires or that that determination that a date code with gold wires exonerates previous date codes as having copper wire
• Additional changes to the packaging may occur with the transition to copper bond wires
• X-ray inspection is an effective technique to non-destructively determine if a component has copper or gold bond wires
• The current state of the copper wire bonding process results in manufacturing process indicators and defects not typically seen from the gold wire bonding process
• Construction analysis is capable of detecting process indicators specific to the copper wire bonding process including defects at the die and lead frame bonds
Difficulties in Application

• Accessing copper wire bond quality requires looking at inspection criteria on the aggregate
  – Enough samples to establish confidence in coverage of the processing margins
    • Supported by AEC-Q-006 & IBM 57G9271
    • Requires testing more parts than may be used in the production run
  – Inspection criteria becomes weighted decision points instead of black and white pass/fail criteria though some hard fail criteria remains
    • Supported by AEC-Q-006 & IBM 57G9271
    • Requires back-and-forth between government authority and the contractor
    • Requires environmental stress data to drawdown risk

• How bad is bad enough when weighing cost and schedule?
Difficulties in Application
Ex. Cracked dielectric with ball lifts

• Cu on Al-IMD on Si
  – Cracked dielectric observed in cross section and wire pull (rejection criteria)
  – Standard Deviation > 10% average (rejection criteria)
  – 2x failure to meet enhanced pull criteria
  – 1x failure to meet 883 criteria
• Should this lot be rejected?
  – What if SN1 and SN3 weren’t tested?

Cracked dielectric

Ball bond lift with cracked dielectric: Force to failure, 1.3gf.
Difficulties in Application
Ex. Non-standard bond pad with ball lift

• Cu on Pd on Ni
  – No IMC formation between Cu and Ni (cannot inspect to IMC criteria)
  – Ball lift shows an effective bonding area of 55% (rejection criteria: <75%)
  – Ball lifted (rejection criteria: any failure mode but span) but exceeded minimum enhanced pull strength by over 2x

• Should this lot be rejected?
Difficulties in Application
Ex. Less than ideal ball bond formation and bonding

- **Cu on Al on Si**
  - Aluminum thickness reduced to less than 200nm as observed in cross section, rejection criteria
  - Standard deviation exceed 10% of the average, rejection criteria
  - Non-span, ball neckdown failure modes, rejection criteria
  - All pull forces exceed enhanced criteria by at least 2X

- **Should this lot be rejected?**

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>Minimum, gf</th>
<th>Average, gf</th>
<th>Standard Deviation, gf</th>
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<tr>
<td>Overall</td>
<td>67</td>
<td>6.3</td>
<td>9.6</td>
<td>1.2</td>
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<tr>
<td>Ball Neckdown</td>
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<td>6.9</td>
<td>9.1</td>
<td>1.1</td>
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<tr>
<td>Span</td>
<td>50</td>
<td>6.3</td>
<td>9.8</td>
<td>1.2</td>
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</table>
Difficulties in Application

Ex. Gold and copper comparison with non-span failure modes

- **Cu vs Au Comparison**
  - Ball neck and wedge neck breaks observed in both Au and Cu packages (Cu specific reject criteria)
  - All pulls (Au and Cu) exceeded enhanced pull force requirements

- **Should this lot be rejected?**

<table>
<thead>
<tr>
<th>Failure Mode</th>
<th>Copper: 64 Wires Pulled</th>
<th>Gold: 64 Wires Pulled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>Ave, gf</td>
</tr>
<tr>
<td>All</td>
<td>--</td>
<td>12.42</td>
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<tr>
<td>Ball Neckdown</td>
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<td>12.78</td>
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<tr>
<td>Span</td>
<td>16%</td>
<td>13.25</td>
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<tr>
<td>Die Bond Lift</td>
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<tr>
<td>Frame Bond Lift</td>
<td>0%</td>
<td>--</td>
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<tr>
<td>Die Metal Lift</td>
<td>0%</td>
<td>--</td>
</tr>
<tr>
<td>Frame Metal Lift</td>
<td>0%</td>
<td>--</td>
</tr>
<tr>
<td>Die Fracture</td>
<td>0%</td>
<td>--</td>
</tr>
<tr>
<td>Frame Fracture</td>
<td>0%</td>
<td>--</td>
</tr>
<tr>
<td>Wedge Neck</td>
<td>70%</td>
<td>12.16</td>
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</tbody>
</table>
Difficulties in Application
Ex. Gold and copper comparison wire specific concern

• Cu vs Au Comparison
  – Ball neck and wedge neck breaks observed in both Au and Cu packages (Cu specific reject criteria)
  – Wire dependent low force to failure and exclusive wedge neck failure mode (rejection criteria captures in standard deviation requirements)
  – All pulls (Au and Cu) exceeded enhanced pull force requirements
• Should this lot be rejected?

Distribution Statement A: Approved For Public Release
Summary

- NSWC Crane has been conducting construction analysis of Cu-PEM’s since 2015 and a summary document is available in both Dist A (public) and Dist D (DoD and DoD Contractors).

- Construction analysis of Cu-PEM’s can detect process indicators with correlation between indicators and detection methods.

- Further understanding of how processes indicators correlate to simulated life failure modes is need to find the line between needed confidence and over test.
  - Test parts with known process indicators and test to failure with different accelerated life conditions to establish failure modes and acceleration factors.
  - Establishing surveillance programs for configuration control, baseline construction analysis, and analysis of failed parts when removed from circuit card assemblies.