Introduction of High Reliability Copper Bonding Wire for High Rel Industrial, A&D and Automotive Applications

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<table>
<thead>
<tr>
<th>MICROCHIPS</th>
<th>Level 1</th>
<th>Level 2</th>
<th>ELECTRONICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>IC Packaging</td>
<td>Circuit Board Assembly</td>
<td>System</td>
</tr>
</tbody>
</table>

Our Industries
In Global Electronics the most emphasized precious metal is Gold.

Vehicles
Mobile phones
PCs
LCD TVs
etc.

Electronic devices

Precious metal
Ruthenium
Rhodium
Platinum
Silver
Palladium
Gold

Electrical properties, high corrosion resistance
Question is how to cut the device cost while using Gold (Au) metal?

1. Reduce the thickness of Au plating on the substrate

2. Use alternative metals instead of Au wire

Target is to optimize the combination between the Surface finish material and Wire bond material

Reduce the material cost of PKG
Bonding Wire Transition Gold => Copper

Flawless Transition?
Copper vs. Gold

Advantages

- **Low Material Cost** (Approx 30-50% lower than Au)
- **Better Conductivity** (Approx 20% better than Au)
- **Higher Fusing Current** (Approx 30% higher than Au)
- **Low Reaction Rates** (Cu/Al IMC @ 150-300C 10x slower Au/Al)

Disadvantages

- **Need N2 or Forming Gas** (Gas necessary for Copper wb)
- **Higher Mechanical Strength** (FAB hardness, Work Hardening)
- **Narrow parameter window at 1st & 2nd bonding process**
- **Require halogen free resin**
- **Need additional investments** (Cu bonder, Forming gas piping)
Gold & Copper Comparisons

1.0 mil copper wire and gold wire properties comparison.\textsuperscript{3, 4}

<table>
<thead>
<tr>
<th>Property</th>
<th>Cu wire</th>
<th>Au wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Resistivity, uohm-cm</td>
<td>1.7</td>
<td>2.3</td>
</tr>
<tr>
<td>FAB Hardness, Hv</td>
<td>~80</td>
<td>~60</td>
</tr>
<tr>
<td>Ball Bond Hardness, Hv</td>
<td>~128</td>
<td>~80</td>
</tr>
<tr>
<td>Tensile Strength, gms</td>
<td>8 – 15</td>
<td>10 – 15</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>8 – 16</td>
<td>2 – 6</td>
</tr>
</tbody>
</table>

Figure 1a. EFO assembly for gold wire.  
Figure 1b. EFO assembly with forming gas supply for copper wire.
# Gold & Copper Comparisons

Cu/Al vs. Au/Al IMC reaction rate comparison.

<table>
<thead>
<tr>
<th>Temperature (deg C)</th>
<th>Cu/Al, K (cm²/s)</th>
<th>Au/Al, K (cm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>1.878 x 10⁻¹⁶</td>
<td>1.1 x 10⁻¹⁴</td>
</tr>
<tr>
<td>280</td>
<td>2.645 x 10⁻¹³</td>
<td>2.4 x 10⁻¹¹</td>
</tr>
<tr>
<td>350</td>
<td>3.747 x 10⁻¹²</td>
<td>3.9 x 10⁻¹⁰</td>
</tr>
</tbody>
</table>

Au/Al IMC growth after assembly

Cu/Al IMC growth after assembly

Au/Al IMC growth after 1000hrs HTS @ 150C

Cu/Al IMC growth after 1000hrs HTS @ 150C

Au/Al vs Cu/Al IMC growth rate comparison.
Copper Wire Challenges (US/Mex Customers)

Challenges of Bare Copper Wire

- Copper Wire is Hard
- Die pad crack
- Al pad splash
- Narrow process windows (Short tail, fish tail, lifted bonds)
- FAB (Forming Gas N2H2)
- Capillary life
- Reliability (PCT/HAST Failures, Oxidation)
1) Copper wire is harder than Gold wire
2) Copper processes have work hardening issues during looping formation
Existing Common problem in Cu bonding

Short tail / No tail issue
**More Common problems in Cu bonding**

1) Die pad-to-pad shorting (Al splash) high parameters
2) Lifted metal occurs at lower side of optimum parameters
How to achieve process window closer to Au wire and solve Cu wire surface oxidation?
**Palladium Coated Wire:**

![Diagram showing a cross-section of a palladium coated wire with labeled parts: 4N Bare Cu wire and Thin Coated layer.]

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longer Spool Lengths (1km – 5km/spool)</td>
<td>Price is higher than bare copper</td>
</tr>
<tr>
<td>Wider 2nd bond window/Higher 2nd bond pull</td>
<td>(Au relative value 1.0, bare Cu 0.2, PdCu 0.4 in HVM)</td>
</tr>
<tr>
<td>Chemical Stability</td>
<td>FAB is harder (possible pad damage)</td>
</tr>
<tr>
<td>Better HAST (BGA)</td>
<td>Capillary Life</td>
</tr>
<tr>
<td>Longer shelf life; 6 months after manufacturing date, 1 month after opening package (bare Cu 1-week after opening)</td>
<td></td>
</tr>
</tbody>
</table>
Palladium Coated Copper Wire

- Atomic # 46 Member of the Platinum Group Metals (PGM)
  - ½ world's supply goes into catalytic converters
  - Palladium is used as an oxidation catalyst
  - Palladium has lowest melting point of the PGM’s
    - It is soft and ductile when annealed and greatly increases its strength and hardness when it is cold-worked
  - 3N Copper FAB is 30% harder than Au FAB
  - PdCu alloy FAB harder than bare Cu FAB

- Oxidation Free (longer storage/shelf & bonder life)
- Palladium Copper bonded products are ‘one-to-one’ pin compatible with Au bonded products.
  - No form, fit or function change
- SMT and System level customers do not need to do anything different in receipt and use of the Palladium Copper products
Au/Cu/PCC Hardness & Compression Comparisons

 créer une zone de croix de section Hv dureté de FAB

Compression Stress of FAB est squashed side direction

[FAB Making condition]
- Wire: φ20 µm
- FAB: 40 µm
- Bonder: Maxum plus
- Gas: N₂-5%H₂

[Measurement Equipment]
- Hardness Tester: MVK-3 (AKASHI)

[Measurement condition]
- Force: 2 gf
- Press Speed: 3 µm/sec
- Hold time: 10 sec
- Measurement count n=5 each

[FAB Making condition]
- Wire: φ20 µm
- FAB: φ40 µm
- Bonder: Shinkawa UTC-1000
- Gas: N₂-5%H₂

[Measurement Equipment]
- Compression Tester: MCT-W500 (SHIMADZU)
- Measurement count n=10 each

[Measurement Conditions]
- Compression speed: 100mN/sec
- Maximum Load: 1000mN

Graphs showing hardness and compression stress comparisons between 4N-Au, Bare Cu, and PCC.
Cu Wire is applied even to high pin counts packages
Reliability

- Process Equipment Change
- PCB Component Change
- Pb-free Reliability Concern
- Problems on Lead free Reliability
- Lead free Reliability Qualification
- Alloy Change
Mechanism of HAST/PCT failures-BGA w/Copper Wire

- Cu/Al boundary attacked by moisture on HAST/PCT test of BGA.
- Main failure comes from the corrosion of the First Bond interface leading to crack along the copper ball bond and aluminum bondpad.
- This is called ‘Galvanic’ corrosion which is between Cu-Al IMC and copper bonded ball
- It is presumed that the possibility of preventing moisture attack is HIGH if Pd exists on the copper surface.
How to prevent corrosion

1. Improve Pd distribution
2. Alloying core Cu

During reliability test, Al diffuse into Cu and the weakest interface move up to Cu side. Therefore, Pd and alloy element α exist around the weakest interface.
# High reliability PCC wire type

<table>
<thead>
<tr>
<th>Wire type</th>
<th>Electrical resistivity ($\mu\cdot\Omega\cdot\text{cm}$)</th>
<th>Improve Pd distribution</th>
<th>Better looping</th>
<th>Alloying core Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>PdCu</td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4N core</td>
<td>1.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3N core</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2N core</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reliability Results of HTS 200degC

- CHR type showed best performance amongst all samples

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Bonding</th>
<th>EFO Current</th>
<th>Wire Dia</th>
<th>Deformed Ball</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBGA</td>
<td>PRO Cu</td>
<td>65mA</td>
<td>18um</td>
<td>36um &amp; 9um</td>
</tr>
<tr>
<td>Halogen Free</td>
<td>Wire Dia</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph showing failure ratio (%) vs. time [hr] for different materials:
- Bare Copper
- Cu Alloy
- Cu High Rel
- PCC
Reliability Results of HAST 130degC 85%RH

- CHR type showed best performance amongst all samples

<table>
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<tr>
<th>Substrate</th>
<th>Bonding</th>
<th>EFO Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBGA</td>
<td>PRO Cu</td>
<td>65mA</td>
</tr>
<tr>
<td>Resin : with Halogen</td>
<td>Wire Dia : 18um</td>
<td>Deformed Ball : 36um &amp; 9um thickness</td>
</tr>
</tbody>
</table>

- Graph showing failure ratio over time for different materials.
  - Bare Copper
  - Cu Alloy
  - PCC

4N Cu High Rel
3N “
2N “
# Benefit Comparison Summary

<table>
<thead>
<tr>
<th>Categories</th>
<th>Items to compare</th>
<th>Bare gold</th>
<th>Bare copper</th>
<th>PdCu Wire</th>
<th>Comments (on copper and/or PdCu Wire)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enabling capability</td>
<td>Material storage, bonder life, long spool lengths</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>General benefits from PdCu wire (robust bonding process, no oxidation, etc.)</td>
</tr>
<tr>
<td>Economics</td>
<td>Cost savings (wire cost)</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>Lower material cost</td>
</tr>
<tr>
<td></td>
<td>Extra cost for wire bonding</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Copper kit and use of forming gas during bonding</td>
</tr>
<tr>
<td>Performance</td>
<td>Electrical resistivity</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>About 20% lower</td>
</tr>
<tr>
<td></td>
<td>Long term reliability</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>Slow IMC formation</td>
</tr>
<tr>
<td></td>
<td>Heat dissipation</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
<td>Higher thermal conductivity</td>
</tr>
<tr>
<td></td>
<td>Wire bonding (first bond)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Cratering on pad structure</td>
</tr>
<tr>
<td></td>
<td>Wire bonding (second bond)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Narrow bonding window bare copper on some surfaces</td>
</tr>
<tr>
<td></td>
<td>Capillary life</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Could be improved with PdCu wire</td>
</tr>
</tbody>
</table>

**X**: Worse, **✓**: Better, **△**: Potential improvement compared to bare copper
Thank You For Your Attention!