The High Volume Production of Cu wire Bonding

Presented by
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ASE Chung-Li
Sep.6th, 2012
Content

- Cu Wire Bonding
- Fundamental Study
- Qualification Procedure
- High Volume Production
- Summary
Gold Price and Cu wire adoption rate

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</thead>
<tbody>
<tr>
<td>Cu % (in length)</td>
<td>1%</td>
<td>10%</td>
<td>25%</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

Data source: Prismark Aug 2011 & July 2012
Cu Wire Bonding - Driving Force

- **Cost Reduction:** The main reason to use Cu wire is to reduce wire cost. The Copper cost is dramatically lower than gold cost.

31x31mm BGA 624 I/O unit price: **17% saving**

Cu Wire Bonding - Key Factors

- Key factors affect Cu wire packaging reliability

**Bond wires:** PdCu, Bare Cu

**Bonding conditions:** Bonders, kits, parameters, method, forming gas, capillary
Wire diameters,

**Bond pad structures:** Wafer nodes, lowK, surface metal pad, metal pad thickness,
metal layer number and thickness, Circuit Under Pad (CUP),
via type, via structure,

**Die attached:** Out gas, Modulus, Bond line thickness,
Die size & thickness

**Compound:** PMC, S/Br/Sb/Cl Ion, Ion catcher, pH

**Packaging:** Chip carrier material, fine pitch, warpage,
out gas, modulus, 2nd bond metal finish,

**Temperature:** Operation temp, IR reflow in PKG & PCB,
Heat from chip
Cu Wire Bonding - Material Properties

• Cu wire v.s. Au wire

Pros:
1. Lower Material Cost
2. Smaller Electrical resistivity
3. Better Thermal Conductivity
4. Better Mechanical Properties
5. Slower IMC Growth.

Cons:
1. Surface Oxidation
2. Hardness Impact Al Pad
3. EFO kit requirement
4. Inert gas requirement

<table>
<thead>
<tr>
<th>Bonding Wire</th>
<th>Au</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic weight (g/mol)</td>
<td>197</td>
<td>64</td>
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<tr>
<td>Density (g/cm-3)</td>
<td>19.3</td>
<td>8.94</td>
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<tr>
<td>Melting point</td>
<td>1066 °C</td>
<td>1085°C</td>
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<tr>
<td>Boiling point</td>
<td>2856 °C, 2562 °C</td>
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<td>Electrical resistivity (nΩ·m -20 °C-)</td>
<td>22.1</td>
<td>16.8</td>
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<td>Thermal conductivity [W/(m·K) -300K-]</td>
<td>318</td>
<td>401</td>
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<td>Young's modulus (Gpa)</td>
<td>79</td>
<td>110–128</td>
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<tr>
<td>Vickers hardness (Mpa)</td>
<td>216</td>
<td>369</td>
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</tbody>
</table>
Cu Wire Bonding - Material Properties

• Hardness: Cu Ball vs Au Ball

<table>
<thead>
<tr>
<th>Bond wire</th>
<th>Thermal Conductivity (W/m.K)</th>
<th>%</th>
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</thead>
<tbody>
<tr>
<td>Gold</td>
<td>318</td>
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<tr>
<td>Copper</td>
<td>390</td>
<td>23%</td>
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</table>

\[
\Theta_{JA} \quad 33.10 \, ^\circ C/W \rightarrow \quad \Theta_{JA} \quad 30.09 \, ^\circ C/W
\]

LQFP 28X28mm 256L  

\[
\Theta_{JA} \quad 43.17 \, ^\circ C/W \rightarrow \quad \Theta_{JA} \quad 42.50 \, ^\circ C/W
\]

PQFP 14X20mm 128L  

QFP 256L:  
20um wire/160mil length

Wire Sweep:  
Cu=2.5 %  
Au=3.7%

Source: ASE Data
Cu Wire Bonding - Material Properties

• Electrical: Cu wire v.s. Au wire

Fusing Current (A)

Au Wire and Cu Wire Resistance

Resistance: Cu < Au
Inductance: Cu ≈ Au
Capacitance: Cu ≈ Au
Cu Wire Bonding - Material Properties

• Hardness: Cu Ball vs Au Ball

Cu is Stiffer than Au
About 40-60%

Source: Johnny Yeung, Challenges for Copper Wire Bonding, KnS, 2008
**Cu Wire Bonding - Material Properties**

- **IMC: Cu wire v.s. Au wire**

  **Au-Al IMC**
  - 1 hr
  - 1500 hrs
  - 3000 hrs
  - Au ball covered with IMC

  **Cu-Al IMC**
  - 100 hrs
  - 200 hrs
  - Cu ball does not show IMC

  **Au-Al IMC growth rate** is about 10 times of **Cu-Al IMC growth rate** when the temperature is 175°C

KnS Paper @ Semicon Singapore 2005

**Cu Wire Bonding - Process Development**

- **Cu Wire Bonding**
- **Design & Feasibility Study**
- **Process Development**
- **Package Qualification**
- **Development & Qualification**
- **Mass Production**
- **High Volume Production**
Cu Wire Bonding - High Volume Production

Wire Bonding Process Control
- EFO Fire Time, Current - Control FAB size
- 1st Bond and 2nd Bond - USG, Bond Force, and Time

Inert Gas Flow Rate Control
- Forming Gas (Bare Cu wire)
- N2 Gas (Pd Cu wire)

In-Line Process Monitor
- In-line monitor
- In-line Process control

Cu Wire Bonding HVM (High Volume Mass Production)
- 1st Bond and 2nd Bond - USG, Bond Force, and Time

Parameter / Machine Set-up / buy-off
- Free Air Ball (FAB) data
- Wire pull / Ball shear / stitch pull
- Al remaining thickness
- Wire bonder characterization
- Machine maintenance

Wire Bonding WIP Stage Time Control
- Wire Spool Shelf Life
- Plasma to WB
- WB processing time
- W/M to Molding

Reliability Monitor
- Reliability Monitor
- Specific items monitor

Wire Bond Control
- Product ID System control
- BOM control: Cu Wire material, Epoxy, Compound, Lead Frame, Substrate
Content

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Fundamental Study

- Higher Hardness of Cu Wire

Hardness

Cu Wire Bonding

Au Wire Bonding

Cu Ball

Au Ball

Cu is 40-60% Stiffer than Au

Source: Johnny Yeung, Challenges for Copper Wire Bonding, KnS, 2008
Fundamental Study

• Higher Hardness of Cu Wire

- High Energy Transformation capillary
- Wire Pull / Ball shape / Ball size control.
- Process parameter optimization.
Fundamental Study

- Al thickness remain under Cu ball
Fundamental Study

- CUP Design & LowK Wafer
  - Fine Pitch
  - Small Pad opening
  - Circuit Under Pad
  - Cu / low K

- High energy transformation capillary.
- Parameter optimization.
- Ball shape control.

[Images of defect photos and diagrams related to CUP design and low-K wafer technology]
Fundamental Study

- Surface oxidation: EFO (Electronic Flame Off) kit

For Stable / Symmetric FAB:

(a) EFO process Control.
(b) Forming gas flow rate Control.

Images show voids, asymmetry, and unstable FAB.
Fundamental Study

Intermetallic Compound (IMC)


Fundamental Study

Cu-Al IMC Composition depending on aging temperature


Fundamental Study

- Al pad Corrosion and Diffusion

Mold Compound with low Cl- ion ppm and Neutral pH value

Cl⁻ + H₂O + CuAl → Cu + Al₂O₃ + Cl⁻ + HX

Cu diffusion > Al Diffusion → void formation
Fundamental Study

<table>
<thead>
<tr>
<th>pH</th>
<th>Cl-</th>
<th>10 ppm</th>
<th>25 ppm</th>
<th>50 ppm</th>
<th>75 ppm</th>
<th>100 ppm</th>
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<tbody>
<tr>
<td>6.5</td>
<td>Leg</td>
<td>Leg 6</td>
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<td>Leg</td>
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<td>Leg 2</td>
<td>Leg 3</td>
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<td>Leg 5*</td>
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<td>4.5</td>
<td>Leg</td>
<td>Leg 7</td>
<td>Leg 9*</td>
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</tr>
</tbody>
</table>

Failure rate increase as Cl- ion ppm increase

Failure rate increase as pH value reduce and Cl- ion ppm increase.

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**Qualification - Procedure**

- **Material / Tooling preparation**
  - Bonding diagram review and confirmation

  - **Phase I**
    - Wire bonding process window study
  
  - **Phase II**
    - a. Wire bonding process confirmation
    - b. Packaging process confirmation
    - c. Reliability performance confirmation

  - **Phase III**
    - Official qualification: Assembly, final test, precondition, reliability test.
Phase I: Process Parameters Study

- 1st bond study:
  - Free air ball/Wire pull/Ball shear test/Ball size/Pad cratering test.
  - Bonding parameter study / Machine stop rate verify (NSOP)

- 2nd bond study:
  - Stitch bond tail inspection/Stitch pull test
  - Stitch bond parameter study / Machine stop rate study (NSOL/SHTL)

- Wire bonding yield study:
  - Open /Short test
  - 3rd optical inspection (wire short / ball lifting / stitch lifting)
Phase II: Parameters Confirmation

Packaging assembly process window confirmation:
(Wafer Saw, Die Attach, Wire Bond, Molding and Ball mount)

- Wire bond parameters confirmation:
  - 1<sup>st</sup> bond FAB/Wire pull/Ball shear test/Ball size/Pad cratering test.
  - 1<sup>st</sup> bond parameter study / Machine stop rate verify (NSOP)
  - 2<sup>nd</sup> bond tail inspection/Stitch pull test
  - 2<sup>nd</sup> bond parameter study / Machine stop rate verification (NSOL/SHTL)

- Packaging assembly process confirmation:
  - IC packaging assembly process
  - Wafer saw, Die attached, Wire bonding, Molding, SAT, open/short test
  - SAT, pre-condition, full reliability test, reliability report
Qualification - Phase III

Phase III: Official Qualification

Open / Short Test, SAT

TCT, -65°C/150°C, 5 Cycles

Baking, 125°C, 24Hrs

Precondition Level 1
85°C/85%RH
168 hrs

Precondition Level 2
85°C/60%RH
168 hrs

Precondition Level 2Aa
60°C/60%RH
120 hrs

Precondition Level 3
30°C/60%RH
192 hrs

Solder Reflow, 260°C, 3 times

Open / Short Test, SAT

PCT
121°C/15psig
96 / 168 hrs

TCT
-65~150°C
500 / 1000 cycles

uHAST
130°C/85%RH
48 / 96 hrs

HTST
150°C
500 / 1000 hrs

THT
85°C/85%RH
500 / 1000 hrs

Open / Short Test, SAT
# Qualification - Schedule

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<thead>
<tr>
<th>Working Week</th>
<th>W01</th>
<th>W02</th>
<th>W03</th>
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</tbody>
</table>
The top 2 metal layers (Top and Top-1) can not be the circuit layer.

The top 2 metal layers (Top and Top-1) must be solid and the size must be larger than bond pad.
## Qualification - Examples

### Wire pull test

<table>
<thead>
<tr>
<th>Item</th>
<th>Max</th>
<th>Min</th>
<th>Avg</th>
<th>Sigma</th>
<th>Range</th>
<th>Cpk</th>
<th>Remark</th>
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<tbody>
<tr>
<td>Wire pull</td>
<td>11.23</td>
<td>7.86</td>
<td>10.22</td>
<td>0.67</td>
<td>3.37</td>
<td>4.09</td>
<td>&gt; 4g &amp; neck broken</td>
</tr>
<tr>
<td></td>
<td>11.45</td>
<td>8.36</td>
<td>10.29</td>
<td>0.59</td>
<td>3.09</td>
<td>4.69</td>
<td>Passed</td>
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<td>stitch pull</td>
<td>4.1</td>
<td>2.52</td>
<td>3.07</td>
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<td>1.58</td>
<td>0.897</td>
<td>&gt;2g</td>
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<tr>
<td></td>
<td>5.3</td>
<td>2.52</td>
<td>3.13</td>
<td>0.55</td>
<td>2.78</td>
<td>0.678</td>
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### Ball shear test

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<th>Max</th>
<th>Min</th>
<th>Avg</th>
<th>Sigma</th>
<th>Range</th>
<th>Cpk</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit1</td>
<td>17.17</td>
<td>13.70</td>
<td>15.20</td>
<td>1.01</td>
<td>3.47</td>
<td>2.40</td>
<td>&gt; 10g, Passed</td>
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<tr>
<td>Unit2</td>
<td>18.15</td>
<td>14.28</td>
<td>16.03</td>
<td>1.05</td>
<td>3.87</td>
<td>2.55</td>
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### Ball Size Measurement

<table>
<thead>
<tr>
<th>Type</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>Raw data (BPO = 50um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball dimension(um)</td>
<td>47</td>
<td>43</td>
<td>44.8</td>
<td>ball size control is 43~47 um</td>
</tr>
<tr>
<td>Ball thickness(um)</td>
<td>17</td>
<td>14</td>
<td>15.1</td>
<td>ball thickness control is 14~17 um</td>
</tr>
</tbody>
</table>
**Qualification - Examples**

- **Wire Looping Measurement**
  - To confirm the wire looping performance

<table>
<thead>
<tr>
<th></th>
<th>Low Loop</th>
<th></th>
<th>Height Loop</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left</td>
<td>Down</td>
<td>Right</td>
<td>Up</td>
</tr>
<tr>
<td>U1</td>
<td>4.1</td>
<td>3.9</td>
<td>4.1</td>
<td>3.8</td>
</tr>
<tr>
<td>U2</td>
<td>3.9</td>
<td>3.9</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>U3</td>
<td>4</td>
<td>4.1</td>
<td>4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The measurement data showed the looping height meet current criteria.
Qualification - Examples

Cratering test

No crack or cratering was found. It passed cratering test.

FIB Analysis

FIB analysis was performed on bond pad and no die metal layer crack was observed.
Content

- Cu Wire Bonding
- Fundamental Study
- Qualification Procedure
- High Volume Production
- Summary
Mass Production - documentation

Document & Process Ready in place
- Process control Plan
- FMEA
- OCAP (Out of Control Action Plan)
Surface oxidation Prevention:

EFO kit with Forming gas: (EFO: Electronic Flame Off)

Forming gas flow rate meter

Free Air Ball in an Oxygen Free Environment
## Au Wire Material Control

### Spool Shelf Life Control

<table>
<thead>
<tr>
<th>Wire Type</th>
<th>Condition</th>
<th>Shelf Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au Wire</td>
<td>Sealed Pack</td>
<td>No Control</td>
</tr>
<tr>
<td></td>
<td>After open seal pack</td>
<td>No Control</td>
</tr>
</tbody>
</table>

### Storage Condition

New & Partial wire kept in wire kitting room

## Cu Wire Material Control

### Spool Shelf Life Control

<table>
<thead>
<tr>
<th>Cu Wire Type</th>
<th>Condition</th>
<th>Shelf Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Cu Wire</td>
<td>Sealed Pack</td>
<td>6 mth from date of mfg</td>
</tr>
<tr>
<td></td>
<td>After open seal pack</td>
<td>7 days from open date</td>
</tr>
<tr>
<td>Pd Coated Cu Wire</td>
<td>Sealed Pack</td>
<td>6 mth from date of mfg</td>
</tr>
<tr>
<td></td>
<td>After open seal pack</td>
<td>1 mth from open date</td>
</tr>
</tbody>
</table>

### Storage Condition

New wire kept in wire kitting room

Partial wire is kept inside dry box, N2 cabinet.
Mass Production - Assembly Yield

Assembly Overall Yield

Top 5 defects

<table>
<thead>
<tr>
<th>Defect</th>
<th>PPM</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball Lift</td>
<td>550</td>
<td>29.29%</td>
</tr>
<tr>
<td>O/S fail</td>
<td>496</td>
<td>55.23%</td>
</tr>
<tr>
<td>Heal broken</td>
<td>403</td>
<td>76.33%</td>
</tr>
<tr>
<td>Foreign Matter</td>
<td>293</td>
<td>91.69%</td>
</tr>
<tr>
<td>Post Lift</td>
<td>159</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Package type: LQFP 28x28 (Wire: 20um), wire pull test

- Avg.: 8.912g
- Max.: 10.62g
- Min.: 7.2g
- Sigma: 0.651
- Cpk: 3.521
- Criteria: 4g

Package type: LQFP 28x28 (Wire: 20um), stitch pull test

- Avg.: 4.331g
- Max.: 4.94g
- Min.: 3.8g
- Sigma: 0.562
- Cpk: 2.68
- Criteria: 2g

Package type: LQFP 28x28 (Wire: 20um), ball shear test

- Avg.: 16.33g
- Max.: 21.02g
- Min.: 12.62g
- Sigma: 1.527
- Cpk: 2.628
- Criteria: 10g
Mass Production - Wire Diameters

Wire Diameter Trend

2010

- 1.2 mil (2%)
- 1.0 mil (16%)
- 0.9 mil (12%)
- 0.8 mil (52%)
- >2 mil (1%)

2011

- 1.2 mil (1%)
- 1.0 mil (13%)
- 0.9 mil (10%)
- 0.8 mil (52%)
- 0.7 mil (22%)
- >1.2 mil (2%)

Wire Diameter Trend:

- Au wire (BBP / BPO)
  - 1.2
  - 1.0
  - 0.9
  - 0.8
- Cu wire
  - 1.0-1.2
  - 0.8-1.0
  - 0.7

Mass Production - Wire Diameters:

- 130nm
- 90 nm
- 65 /60nm
- 45/40 nm
- 32/28 nm
- 22/20 nm
- 40/35um
- 35/30um
Mass Production - Cu Wire by Packages

- Cu Wire by Packages

2009
- BGA 11%
- SOIC/P LCC 14%
- aQFN/QFN 27%
- QFP 59%

2010
- BGA 14%
- SOIC/QFP 43%
- Discrete 10%
- aQFN/QFN 27%
- QFP 31%

2011
- BGA 14%
- SOIC 20%
- aQFN/QFN 35%
- QFP 23%
- Discrete 8%
Mass Production - Cu Wire by Wafer Technologies

- Cu Wire by Wafer Technologies

2009
- 0.35 um (10%)
- 0.4 um (14%)
- 0.25 um (5%)
- 0.18 um (37%)

2010
- 0.4 um (1%)
- 0.35 um (12%)
- 0.25 um (3%)
- 0.18 um (36%)

2011
- 40/45 nm (2%)
- 0.35 um (6%)
- 0.4 um (4%)
- 0.25 um (11%)
- 0.18 um (42%)
- 60/65 nm (14%)
- 80/90 nm (14%)
- 0.13 um (13%)
Mass Production - Cu Wire by Applications

- Cu Wire by Applications

2009

- Consumer 54%
- Comm 21%
- Computing 15%
- Industrial 10%

2010

- Computing 20%
- Comm (Cell Phone) 24%
- Industrial 8%
- Auto 0.2%

2011

- Consumer 51%
- Comm 24%
- Computing 20%
- Industrial 4%
- Auto 0.4%
Summary

- Fine pitch Cu wire-bonding for middle-high I/O application has been introduced successfully in high volume productions for a variety of product of lead frame and BGA families.

- Proper risk assessments in defining acceptable and reasonable criteria need be done during process characterization.

- The Cu wire-bonding has been verified to have same quality and yield as gold wire-bonding. The strict management of the manufacturing floor is a key ingredient of successes.

- The reliability has been demonstrated to exceeded 2 or 3 times standard JEDEC testing and is continuing.