Copper Wire Bonding:
the Last Frontier of Cost Savings

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Business Development
ASE (U.S.) Inc.
April 11, 2012
Outline

- Introduction
- Fundamental Study
- Reliability Study
- Monitoring Data
- High Volume Implementation
- Summary
Introduction - ASE Cu wire-bonding history

- Fine wire active development since 2005 in ASE Kaohsiung
- ASE Chung-Li started HVM in Sep 2008
- Followed by ASE Kaohsiung, Shanghai, Malaysia, Korea and Japan.
- HVM covers:
  - 25/23/20/18 um Cu and Pd/Cu wire in QFP, SO, QFN, BGA packages.
  - wafers from ALL foundries, ALL nodes, with different structures.
- Overall yield is around 99.85%.

![Gold - London PM Fix 2000 - present](chart.png)
Introduction - ASE Production Unit Shipment

ASE Group Shipment: More than 7 Billion units up-to-date

Units: Equivalent to LQFP14x20mm 144L
Introduction - ASE Cu wire Bonders Quantity
Introduction - Production Volumes by Package Types

2009
- BGA 11%
- QFP 59%
- SOIC/PLCC 14%
- aQFN/QFN 16%
- TQFP 8%
- PQFP 8%
- FBGA 7%
- PBGA 4%

2010
- QFP 31%
- BGA 16%
- SOIC 16%
- Discrete 10%
- aQFN/QFN 27%

2011
- aQFN/QFN 35%
- BGA 14%
- QFP 23%
- Discrete 8%
- SOIC 20%
Introduction - Production Volumes by Wafer Nodes

2009

- 0.25 um: 5% (37%)
- 0.18 um: 22%
- 0.13 um: 14%
- 0.35 um: 10%
- 0.4 um: 12%
- 0.25 um: 3%

2010

- 0.25 um: 10% (18%)
- 0.13 um: 14%
- 0.18 um: 9%
- 0.35 um: 8%
- 0.4 um: 12%
- 0.25 um: 3%

2011

- 0.25 um: 8%
- 0.13 um: 14%
- 0.18 um: 42%
- 0.35 um: 6%
- 0.4 um: 4%
- 0.35 um: 10% (4%)
- 0.4 um: 11%
Introduction - Production Volumes by Applications

2009
- Consumer 54%
- Communication 21%
- Industrial 10%
- Computing 15%

2010
- Consumer 48%
- Communication (Cell Phone) 24%
- Industrial 8%
- Computing 20%
- Auto 0.2%

2011
- Consumer 51%
- Communication 24%
- Industrial 4%
- Computing 20%
- Auto 0.4%
Introduction - Production Volumes by Wire Diameters

Wire Diameter Trend

- 130nm
- 90 nm
- 65/60um
- 45/40um
- 32/28um
- 22/20um
- 60/50um
- 50/45um
- 45/40um
- 35/30um
- 32/28um
- 22/20um

Au wire
- 1.2
- 1.0
- 0.9
- 0.8

Cu wire
- 1.0-1.2
- 0.8-1.0
- 0.7

Introduction
- Production Volumes by Wire Diameters

2010
- 1.2 mil 2%
- 1.0 mil 16%
- 0.9 mil 12%
- 0.8 mil 52%

2011
- 1.2 mil 2%
- 1.0 mil 13%
- 0.9 mil 10%
- 0.8 mil 52%
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### Cu Wire vs Au Wire: Raw Material Properties

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

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

<table>
<thead>
<tr>
<th>Properties</th>
<th>Au</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic weight (g/mol)</td>
<td>197</td>
<td>64</td>
</tr>
<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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</tr>
<tr>
<td>Electrical resistivity (nΩ·m -20 °C- )</td>
<td>22.1</td>
<td><strong>16.8</strong></td>
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<tr>
<td>Thermal conductivity (W·m⁻¹·K⁻¹ -300 K- )</td>
<td>318</td>
<td><strong>401</strong></td>
</tr>
<tr>
<td>Young's modulus (Gpa)</td>
<td>79</td>
<td><strong>110–128</strong></td>
</tr>
<tr>
<td>Vickers hardness (Mpa)</td>
<td>216</td>
<td><strong>369</strong></td>
</tr>
</tbody>
</table>
Fundamental Study
Process Control:

EFO kit with Forming gas:

For Stable / Symmetric FAB:
(a) Control EFO process.
(b) Forming gas rate.

Good FAB  Void  Asymmetry  Unstable FAB
Fundamental Study

Cu Wire vs Au Wire: Hardness

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

Process Control:
Cratering / Cracking Test

Al thickness remaining: > 100nm (min)

Remained Al thickness: 277nm

Al thickness remaining should > 100nm.
Fundamental Study
Process Control:

CUP Design & LowK Wafer

- Fine Pitch
- Small Pad opening
- Circuit Under Pad
- Cu / low K

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

Defect photos
Fundamental Study

Design Guideline: CUP Bonding

- The top 2 metal layers (Top and Top-1) cannot be circuit layers.
- The top 2 metal layers (Top and Top-1) must be solid layers and must be larger than bond pads.
Reliability Test

Cu-Al IMC Inspection

OM Inspection

SEM Inspection
Reliability Test

Intermetallic Compound (IMC)


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“Cl⁻” ions reacts with IMC & creates “Al₂O₃” with high resistivity,

The mechanism for open failure in biased HAST test

\[ \text{Cu}_9\text{Al}_4 + 6\text{HCl} + 3\text{O}_2 + n\text{H}_2\text{O} \rightarrow 2\text{AlCl}_3 + 2\text{Al(OH)}_3 \ast + 9\text{Cu} + n\text{H}_2\text{O} \]
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## Monitoring Data

<table>
<thead>
<tr>
<th>Package Type</th>
<th>Body Size</th>
<th>PCT</th>
<th>TCT</th>
<th>HAST</th>
<th>HTS</th>
<th>THT</th>
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<tbody>
<tr>
<td>QFN</td>
<td>6 x 6</td>
<td>2,000</td>
<td>200</td>
<td>2,000</td>
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<tr>
<td>QFN</td>
<td>8 x 8</td>
<td>2,000</td>
<td>200</td>
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<tr>
<td>QFN</td>
<td>9 x 9</td>
<td>936*</td>
<td>6500*</td>
<td>178*</td>
<td>4500*</td>
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<tr>
<td>aQFN</td>
<td>11.5 x 11.5</td>
<td>168</td>
<td>500*</td>
<td>500*</td>
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<td></td>
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<tr>
<td>QFP</td>
<td>14 x 20</td>
<td>2016</td>
<td>6000</td>
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<td>3500</td>
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<td>QFP</td>
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<td>1272</td>
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<td>4,000</td>
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<td>LQP</td>
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<td>336</td>
<td>2,000</td>
<td>192</td>
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<tr>
<td>LQFP</td>
<td>14 x 14</td>
<td>264</td>
<td>1,500</td>
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<td></td>
<td></td>
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<tr>
<td>LQFP</td>
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<td>336</td>
<td>2,000</td>
<td>192</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>LQFP</td>
<td>24 x 24</td>
<td>264*</td>
<td>1,500*</td>
<td>144*</td>
<td>1,500*</td>
<td></td>
</tr>
<tr>
<td>TQFP</td>
<td>14 x 14</td>
<td>2,000</td>
<td></td>
<td>400</td>
<td>2,000</td>
<td></td>
</tr>
<tr>
<td>HQFP</td>
<td>14 x 20</td>
<td>336</td>
<td>1,000*</td>
<td>548*</td>
<td>3,500*</td>
<td></td>
</tr>
<tr>
<td>TFBGA</td>
<td>9 x 9</td>
<td>3,500</td>
<td></td>
<td>144</td>
<td></td>
<td></td>
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<tr>
<td>TFBGA</td>
<td>12 x 12</td>
<td>6,000*</td>
<td></td>
<td>864</td>
<td>2,000</td>
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<tr>
<td>LFBGA</td>
<td>16 x 16</td>
<td>1,500</td>
<td>168</td>
<td>1,500</td>
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<tr>
<td>HSBGA</td>
<td>27 x 27</td>
<td>336</td>
<td>4,000</td>
<td>336</td>
<td>4,000</td>
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</tr>
</tbody>
</table>

* test in progress
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Cu Wire Product/Process Qualification Flow Overview

Cu Wire Process/Package Qualification (APQP)

1. Design & Feasibility Study
   - RFQ
   - Product Design & Development

2. Process / Package Development
   - Process Design & Development
   - Qualification

3. Package / Process Qualification
   - Pre-production Monitoring
   - HVM

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1. Design Rules review
2. Products/Processes data
   Domain:
   - Wafer Tech & Bond Pad
   - Structure, BOMs, Package construction
   - device groupings
3. Electrical & Stress Modeling

1. Machine Calibration
2. Cu Wire Process
   DOE & Window Validation
3. Pre-qualification & REL assessment

1. Machine C & C
2. Qualification POR
3. Package REL & Extended REL

1. Machine C & C
2. Pre-production POR
3. Machine C & C
2. REL MON

Bonders Calibration & Correlation
Process Recipe Potability
Device Groupings & Data Base

**Wire Diameter**
- > 1 mil Diameter
- < 0.9mil Diameter
  - BPO
  - Wire Length
  - Multi-tiers

**Bondpad Structure**
- Wafer Nodes
- Via Structure
- CUP / Non CUP
- Under-layer Metal Stacking

**BOM Selection, Package StressModelling (bHAST solution)**

**Wirebonder Calibration & Correlation**

- 0.45um Al thickness

**Film Materials**
- Al Bond Pad
- Cu
- Silicon
- Mold Compound
- Cu Ball
- Al

**0.45um Al thickness**

**Accelerating Voltage**
- Length: 0.33 μm
- Length: 0.43 μm

**20um & 25um**

**Process Window**

**USG**
Cu-Wire Package In High Volume Manufacturing

Wirebond Process/Quality/Material Controls

**WB Parameters & Control**
- Locked and can be adjusted within controlled range
- 1st Bond and 2nd Bond-USG and Bond Force
- EFO Fire Time - Control the size of FAB

**Gas Flow Rate control**
- Forming Gas (Bare copper wire)
- N2 Gas (Pd coated wire only)

**Set-up/Conversion buy-off**
- Free Air Ball (FAB) – wire type change
  - WB Quality Characteristics
  - Copper wire bonder MTMV
  - Regular calibration & correlation

**WB WIP Staging Time Control**
- Plasma to WB
- WB processing time

**Cu Wire Material Controls**
- System control through MES-system Integrated Controls

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More Challenges to be addressed

- Advanced Nodes
- Legacy Products
- Automotive & Advanced Network Systems
- New Package Technologies
- Collaborative Research with Universities, suppliers, and research institutes
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Cu Wire Technology

Wafer Tech.

<table>
<thead>
<tr>
<th>Year</th>
<th>Wafer Node</th>
<th>Wafer Node (LK)</th>
<th>Wafer Node (ELK)</th>
<th>Wafer Node (ELK)</th>
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</thead>
<tbody>
<tr>
<td>2009</td>
<td>0.18um/0.15um</td>
<td>0.13um/90nm/65nm</td>
<td>45nm/40nm</td>
<td>28nm</td>
</tr>
<tr>
<td>2010</td>
<td>BPP62um/BPO55um</td>
<td>BPP52um/BPO45um</td>
<td>BPP45um/BPO40um</td>
<td>BPP40um/BPO35um</td>
</tr>
<tr>
<td>2011</td>
<td>Al wafer</td>
<td>Cu wafer</td>
<td>CUP wafer</td>
<td>NiAu/NiPd pad</td>
</tr>
</tbody>
</table>

Package Tech.

<table>
<thead>
<tr>
<th>Year</th>
<th>L/F PKG</th>
<th>Substrate PKG</th>
<th>Stack die</th>
<th>Low loop</th>
<th>FOW</th>
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</thead>
<tbody>
<tr>
<td>2009</td>
<td>In-line/Staggered</td>
<td>Tri-tier/Quar-tier</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td>Stack die</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td></td>
<td>Low loop</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td>FOW</td>
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</table>
## New wafer technology overview

<table>
<thead>
<tr>
<th>PKG</th>
<th>Production</th>
<th>Available</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGA</td>
<td>Au wire 0.13 um/ 90nm/ 65nm/ 40nm</td>
<td>28nm</td>
<td></td>
<td></td>
<td>20 nm ELK</td>
</tr>
<tr>
<td></td>
<td>Cu wire 0.13 um/ 90nm/ 65nm/ 40nm</td>
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<td>40nm</td>
<td></td>
<td></td>
<td>28 nm ELK</td>
</tr>
</tbody>
</table>

- For BGA PKG:
  - Au wire MP on 40nm wafer, available on 28nm wafer technology
  - Cu wire MP on 40nm wafer, Qual lot build on 28nm wafer, expect Qual finish on Y2012Q1
- For QFP PKG:
  - Au wire MP on 40nm wafer, under plan on 28nm wafer
  - Cu wire MP on 40nm wafer, under plan on 28nm wafer
Summary

- Fine pitch Cu wire-bonding ramped successfully into high volume production in all sites.

- Close collaboration and partnership with equipment and materials suppliers.

- Devices from advanced wafer nodes from different foundries in broad spectrum of packages.

- ASE has 6 years experience in Cu wire-bonding, total shipment will exceeded 7 billion units at end of 2011.

- Reliability demonstrated to exceeded up to 6X standard JEDEC testing and is continuing.
Thank You

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