Converting High Volume IC Manufacturing to Cu wire packaging

Larry Bright
Assembly Engineering Manager

September 2013
Agenda

- Overview
  - Cost and Ramp
- Benefits and Concerns
  - Benchmark, Motivation, 4 corners
- Preparing for Manufacturing
  - Wire Type, Characterization, Qualification
- Factors affecting Cu Wire Reliability
  - Halogens, CTE mismatch
- Discussion and Techniques
- Conclusion
About Microsemi Corporation

- Global provider of semiconductor solutions for applications focused on delivering power, reliability, security and performance.

- High-value, high barrier-entry markets:
  - Communications
  - Defense & Security
  - Aerospace
  - Industrial

- FY 2012 Revenue: $1 billion
About Microsemi Corporation

### Acquisitions

- **Maxim, Inc.** Jan, 2012  
  - (Timing, Synchronization and Synthesis Business)
- **Zarlink, Inc.** Oct, 2011
- **Brijot Imaging** Jul, 2011
- **ASIC Advantage** Jul, 2011
- **AML Comm.** May, 2011
- **Actel (SOC)** Nov, 2010
- **Arxan Defense** Sep, 2010
- **VT Silicon** Sep, 2010
- **White Electronics** May, 2010
- **Nexsem** Jun, 2009
- **Endwave Defense** Apr, 2009
- **Spectrum** Apr, 2009
- **Babock** Oct, 2008
- **T.S.I Microelect.** Jan, 2008
- **MDT** Nov, 2007
- **PowerDsine** Jan, 2007
- **APT** Apr, 2006
- **Compensated** Aug, 2001
- **New England** Aug, 2001
- **Infinesse** Feb 2000
- **Narda** Jun, 1999
- **Linfinifty** Apr, 1999
- **BKC Semi** May, 1998
- **PPC Products** Sep, 1997
- **SGS Thomson** Oct, 1996  
  - Radio Frequency
- **Unitrode** Jul, 1992  
  - Semiconductor Division
History of Integration

1960: Microsemi founded in California as a power conditioning equipment manufacturer.
1969: Standard Resources acquires the company.
1969: AMD founded

1970: Mitel founded

1973: Mitel founded

1980:

1981: The company goes public.
1983: The company shortens its name to Microsemi Corporation.

1980:

2000:
The company begins making semiconductors for cell phones and other types of handheld devices.

2000:

2001: Zarlink Semiconductor created from Mitel’s Telephony-based Communications Systems Business
2000: Legerity created (AMD Spin-off)

2002: Legerity acquires Agere’s voice interface business

2007: Zarlink acquires Legerity

2010:

2011: Microsemi acquires Zarlink

Power Matters.
Major Market Segments and Usage

14% CAGR Ethernet Mobile Backhaul [2012 – 2016]

11% CAGR Service Providers Routers & Switches [2012 – 2016]

17% CAGR OTN Infrastructure Equipments [2011-2016]
Primary Package Profile

**Leaded packages**
- QFN
- PDIP
- SSOP
- PLCC
- QFP
- LQFP / TQFP-EP

**BGA packages**
- LBGA
- PBGA
- SiP - LGA
- CSBGA
- HSBGA

Source: ASE Packaging Roadmap
Overview

- In 2008-2009 our organization embarked on a relatively aggressive Copper-wire conversion program.
- By CYQ410, half of Production was converted to copper and by CYQ211 we were at 95% copper (Cu) and have remained at ~98% copper since.
By the time gold (Au) doubled from $800 to $1,600, Microsemi was well on its way out of Gold.

Gold adder cash spend dropped 92% saving millions of dollars annually.
Industry Benchmark

In early 2009, over 10 packaging subcontractors in seven countries were benchmarked for Cu-wire production status.

<table>
<thead>
<tr>
<th>Country</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Malaysia</td>
<td>Qualified QFNs in bare Cu, but looking to convert to PdCu, no production volume</td>
</tr>
<tr>
<td>2 Taiwan</td>
<td>Promoting PdCu, several customers under evaluation, no production volume</td>
</tr>
<tr>
<td>3 China</td>
<td>Promoting bare and PdCu, several customers under evaluation, no production volume</td>
</tr>
<tr>
<td>4 Taiwan</td>
<td>Promoting bare and PdCu, several customers under evaluation, ~200K/mth QFN &amp; QFP</td>
</tr>
<tr>
<td>5 Indonesia</td>
<td>TSSOPs @MSL1, QFNs @ MSL3. BGAs under evaluation, ~2KK/week in Production</td>
</tr>
<tr>
<td>6 Malaysia</td>
<td>QFNs @ MSL3 and running in production</td>
</tr>
<tr>
<td>7 China</td>
<td>Ongoing internal qualification, production ramp schedule starting to be formulated</td>
</tr>
<tr>
<td>8 Singapore</td>
<td>BGAs running several years, L/F packages &lt;1yr, Cu-wire &lt;5% of total production</td>
</tr>
<tr>
<td>9 Korea</td>
<td>Using only bare copper, characterization and evaluations ongoing, no HVM</td>
</tr>
<tr>
<td>10 Philippines</td>
<td>Using bare copper 0.8-2.0mil, 2.0mil Cu wire in production 100-300K/wk, &lt;2.0mil in qual</td>
</tr>
</tbody>
</table>
Converting to Cu Wire

**Motivation to use Copper**

**Benefits of Cu Wire**
- High Conductivity: 23% Increase
- Cost Saving
- Flexible Design: Stiffer Loop
- Better HTS Performance: Moderate IMC Growth

**Concerns**
- Oxidation
- Workability, UPH lower
- Concerns about Long Term Reliability
- AI Splash

Source: Amkor Customer Symposium 2012
Benefits

- Cost is driving the move to copper

<table>
<thead>
<tr>
<th>Metal</th>
<th>Price 2013</th>
<th>% Au</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>$1,452</td>
<td>-</td>
</tr>
<tr>
<td>Copper</td>
<td>$0.22</td>
<td>0.015%</td>
</tr>
<tr>
<td>Silver</td>
<td>$23.68</td>
<td>1.63%</td>
</tr>
<tr>
<td>Palladium</td>
<td>$687</td>
<td>47.3%</td>
</tr>
</tbody>
</table>

1 troy ounce = 1.09714286 ounces
Benefits

- **High Conductivity**
  - Copper wire is ~26% more conductive than Gold
  - Thermal properties improved by ~21%

<table>
<thead>
<tr>
<th>Property</th>
<th>Cu</th>
<th>Au</th>
<th>Al</th>
<th>Ag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Conductivity (W/m-K)</td>
<td>393</td>
<td>317</td>
<td>222</td>
<td>419</td>
</tr>
<tr>
<td>Electrical Resistivity (uOhm/cm)</td>
<td>1.7</td>
<td>2.3</td>
<td>2.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

- **Stiffer Loops**
  - 40-60% stiffer wire reduces wire sweep

Source: K&S; Cutting Edge in Copper Wire Bonding
Benefits

- Better High Temp Storage (HTS) Performance
  - Slow diffusion rate of the CuAl intermetallic
    - Very stable bond
  - Post 1000hr HTS 98% coverage

- Moderate IMC Growth
  - Intermetallic compound (IMC) growth comparing
    - Au-wire at 500 hrs
    - Cu-wire at 1000 hrs

Source: Tech Search International
Concerns

- **Oxidation**
  - To ensure consistent bonding the FAB (Free Air Ball) must be created in an inert environment

- **Forming Gas**
  - An exclusion zone is created using 95% N₂ and 5% H₂
  - Early studies used 80/20
Concerns

- Inert Gas Mixing Station

- N2 piped in from main tank

- H2 piped in from local bottles

- Control panel monitors gas flow
  - 5% Hydrogen
Concerns

- Hydrogen Tanks
  - Piped into mixing tank
- Pre-mixed Tanks
  - Back up system

- Control Panel Flow Meters
- \( \text{H}_2 \) monitor
Concerns

- Lower Productivity
  - Capillary usage is one of the top reasons for lower productivity in cu-wire bonding

<table>
<thead>
<tr>
<th>Wire Type</th>
<th>Capillary</th>
<th>Capillary Touchdown Control</th>
<th>Capillary Cost (USD)</th>
<th>UPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>Smooth Finish</td>
<td>2,000K</td>
<td>~ $6.00</td>
<td>~ 5-6 wires / sec</td>
</tr>
<tr>
<td>Copper</td>
<td>Rough Finish</td>
<td>500K</td>
<td>~ $4.00</td>
<td>~ 4-5 wires / sec</td>
</tr>
<tr>
<td>Remarks</td>
<td>Au Cap – Build Up Cu Cap – Worn Out</td>
<td>Cu Cap with higher cost</td>
<td>15-25 % drop in Productivity</td>
<td></td>
</tr>
</tbody>
</table>
Concerns

- Aluminum Splash
  - The hardness of Cu displaces the softer Al under the ball and creates an “aluminum” splash

- Cratering
  - A larger “splash” typically leaves less Al under the ball and can lead to cracks on the bond pad or “cratering”
Concerns

- **Long Term Reliability**
  - Extended reliability through TC4000, HTS4000, and PCT336 showed no copper-related bond integrity failures

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Microsemi

Power Matters. 20
Preparing for Manufacturing

Wire Type

- One of the great debates was whether to use bare copper (Cu) or Palladium-Coated Copper (PdCu).

The Pd coating is typically 0.1-0.2um and costs about 2-3 times bare copper.

- $N_2$ could be used in place of forming gas ($H_2/N_2$).
- Harder on 1st bond, better for 2nd bond.

Source: Tanaka; New Evolution of Copper Wire.
Preparing for Manufacturing

- Based on wafer technologies, product mix, and package type the matrix to the right was created.

- Standardized QFN and BGAs to PdCu for the wider 2nd bond process window.

Source: Tanaka; New Evolution of Copper Wire
Preparing for Manufacturing

- Characterization is key!

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Target Range</th>
<th>Average</th>
<th>Std. dev.</th>
<th>Min.</th>
<th>Max</th>
<th>Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free Air Ball Diameter</td>
<td>1.2 ~ 1.5 mils</td>
<td>1.38</td>
<td>0.04</td>
<td>1.31</td>
<td>1.43</td>
<td>0.12</td>
<td>Passed</td>
</tr>
<tr>
<td>Bonded Ball Size</td>
<td>X</td>
<td>1.67</td>
<td>0.04</td>
<td>1.60</td>
<td>1.76</td>
<td>0.16</td>
<td>Passed</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>1.64</td>
<td>0.04</td>
<td>1.55</td>
<td>1.74</td>
<td>0.19</td>
<td>Passed</td>
</tr>
<tr>
<td></td>
<td>XY</td>
<td>1.66</td>
<td>0.03</td>
<td>1.60</td>
<td>1.73</td>
<td>0.13</td>
<td>Passed</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>0.43</td>
<td>0.01</td>
<td>0.41</td>
<td>0.47</td>
<td>0.06</td>
<td>Passed</td>
</tr>
<tr>
<td>BAR (Ball Aspect Ratio)</td>
<td>20% ~ 30%</td>
<td>0.26</td>
<td>0.01</td>
<td>0.24</td>
<td>0.28</td>
<td>0.04</td>
<td>Passed</td>
</tr>
<tr>
<td>Aluminum Splash Out</td>
<td>Within BPO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Passed</td>
</tr>
<tr>
<td>Loop Height</td>
<td>4.0 ~ 6.0 mils</td>
<td>4.46</td>
<td>0.19</td>
<td>4.15</td>
<td>4.82</td>
<td>0.67</td>
<td>Passed</td>
</tr>
</tbody>
</table>

**Destructive Test: (S/S: 25)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Spec Limit</th>
<th>Average</th>
<th>Std. dev.</th>
<th>Min.</th>
<th>Max</th>
<th>Range</th>
<th>Cpk</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck Pull/Wire Pull</td>
<td>Min 3 gms</td>
<td>11.37</td>
<td>0.61</td>
<td>9.98</td>
<td>12.35</td>
<td>2.37</td>
<td>4.56</td>
<td>Passed</td>
</tr>
<tr>
<td>Ball Shear</td>
<td>Min 8 gms</td>
<td>25.53</td>
<td>1.45</td>
<td>23.27</td>
<td>28.19</td>
<td>4.92</td>
<td>4.02</td>
<td>Passed</td>
</tr>
<tr>
<td>Stitch Pull</td>
<td>Min 3 gms</td>
<td>5.51</td>
<td>0.50</td>
<td>4.56</td>
<td>6.25</td>
<td>1.69</td>
<td>1.68</td>
<td>Passed</td>
</tr>
</tbody>
</table>

**Mold Response: (S/S: 25)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Spec Limit</th>
<th>Average</th>
<th>Std. dev.</th>
<th>Min.</th>
<th>Max</th>
<th>Range</th>
<th>Cpk</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Sweep</td>
<td>Max 15%</td>
<td>2.66</td>
<td>0.67</td>
<td>1.30</td>
<td>4.40</td>
<td>3.10</td>
<td>6.11</td>
<td>Passed</td>
</tr>
</tbody>
</table>
Preparing for Manufacturing

- **Characterization**
  - The Free Air Ball (FAB) should be round and shiny – pre bond
  - Examples of deformed FABs that are shown below need to be avoided
  - A good example of the Ball Aspect Ration (BAR) is show below (post bond)

![BAR Diagram]

Given the equation: 
\[ \text{BAR} = \frac{z}{xy} \]
Preparing for Manufacturing

- Characterization
  - Aluminum Splash should be minimized
    - Well within the bond pad structure
  - Excessive force can lead to “cratering” in the bond pad and below
Preparing for Manufacturing

- Qualification
  - Preconditioning 192 Hours
  - Pressure Cooker Test (PCT) 168 Hours
  - Temperature Cycling (TC) 1000 cycles
  - High Temperature Storage (HTS) 1000 Hours

- Conditional Qual is achieved after QRB approval of 96 PCT 500TC, and 500HTS
- PCN is prepared for PCN Board review
- Samples Ready
- Full Qual within the 90-Day window

<table>
<thead>
<tr>
<th>Reliability Stress</th>
<th>CSAM Results</th>
<th>Test Results QUAL</th>
<th>Test Failures QUAL</th>
<th>Test Results CONTROL</th>
<th>Test Failures CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Assy (0 hour)</td>
<td>0 / 10</td>
<td>92.54% (1377/1486)</td>
<td>Bin 5 – 75u Bin 6 – 27u Bin 8 – 5u VM – 4u</td>
<td>92.74% (496/496)</td>
<td>Bin 5 – 29u Bin 6 – 4u VM – 3u</td>
</tr>
<tr>
<td>MSL 3 Precon (30°C/60%RH/192hrs/3x CR@260°C)</td>
<td>0 / 10</td>
<td>100% (450/450)</td>
<td>N/A</td>
<td>100% (150/150)</td>
<td>N/A</td>
</tr>
<tr>
<td>TC'C 1000cycles (160°C to -65°C)</td>
<td>n/a</td>
<td>100% (150/150)</td>
<td>N/A</td>
<td>100% (50/50)</td>
<td>N/A</td>
</tr>
<tr>
<td>PCT 168hrs (121°C/100%RH/15psi)</td>
<td>n/a</td>
<td>100% (150/150)</td>
<td>N/A</td>
<td>100% (50/50)</td>
<td>N/A</td>
</tr>
<tr>
<td>HTS 1000hrs (150°C)</td>
<td>n/a</td>
<td>100% (120/120)</td>
<td>N/A</td>
<td>100% (39/39)</td>
<td>1u Bin5 during HTS500 so qty is 49 only</td>
</tr>
</tbody>
</table>
Factors Affecting Cu Wire Reliability

- Halogens such as Chlorine (Cl-)
- Target Mold with <10PPM Cl- & <7.0pH

Higher Cl⁻ content compounds failed more.
Higher pH reduced failure.
Cl⁻ content is main factor and pH is sub factor.

Source: Hitachi Chemical Co., Ltd.

Source: bizzoe.net
Factors Affecting Cu Wire Reliability

- bHAST – Mechanism of Failure

Hast Condition - RH 85% / 130 deg C / 1.9V

Forward Bias - Positive Pad

Inferior Bond Quality + Vapor Pressure + Cl = bHAST failure

Source: ASE
Factors Affecting Cu Wire Reliability

- Controlling Ion Mobility
  - Organic substrates have much higher Cl- content

*Key Factor: Ion mobility in compound*

*Idea:*
1. Less free volume resin system
2. Better Cl ion catching system

Source: Hitachi Chemical Co., Ltd.
Factors Affecting Cu Wire Reliability

- **CTE Mismatch**
  - Two trends have highlighted a potential reliability issue
    - Green Compound
    - Copper Wire

  ![CTE Mismatch Diagram]

- **Extended Reliability**
  - 1,600 units passed 4,000 Temp Cycles with no bond fatigue failures
  - Loop profiles help minimize the stress

Source: iNEMI Webinar 2013
### Defining Superior Bonding

#### Good Bond Criteria

<table>
<thead>
<tr>
<th>Item</th>
<th>Desired Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMC Coverage</td>
<td>Minimum 70% with no localized voiding</td>
</tr>
<tr>
<td>Al Thickness remaining</td>
<td>Min 0.2um or 20% of original Al thickness</td>
</tr>
<tr>
<td>FAB Shape (pre bond)</td>
<td>Round and Shiny</td>
</tr>
<tr>
<td>FAB Shape (post bond)</td>
<td>Flat with uniform IMC layer</td>
</tr>
</tbody>
</table>
Discussion and Techniques

- The Industry is showing improvement in cu-wire processing. Most factories tend to follow the same basic techniques, but have their own “artistic” tweaks to fit their line and their customers product.
- In just a few years since attaining +95% copper, there has been significant improvements in the quality of copper wire bonding.

Source: ASE
Converting to Cu Wire

### Conclusion

- Development began as early as the late 1980’s
  - At that time, risks outweighed the cost advantages
- As Gold prices broke through $800 and headed towards $1,600, the risk/reward balance shifted
- The Concerns that outweighed the benefits needed to be and have been addressed
  - Oxidation, Aluminum splash, long-term reliability issues, and productivity losses continue to mature and improve
- There is a process to a successful paradigm shift from gold to copper-wire bonding for IC packaging
Converting to Cu Wire

- Acknowledgements
  - John Kelly & Ninete Pascua
  - CMPG Quality Organization
  - ASEM Cu-wire team
  - Carsem, Suzhou Cu-wire team
  - Unisem, Chengdu Cu-wire team
  - PC Lim, ASE Sunnyvale
  - Cheryl Tulkoff, DfR
Thank You!

Questions?