Building the Framework of an Integral Process to Ensure Fine Pitch Probe with Fine Pitch Wirebond

Ken Thompson
Sheila Chopin
Packaging Engineering
Soosan Yong
Assembly Engineering

Semiconductor Products Sector
Motorola Inc.
Presentation Overview

– Fine Pitch Wirebond & Probe Interaction Background
  • Impact of Probe Mark on Fine Pitch Bonding
  • NPI with Fine Pitch Probe & Bonding needs

– Previous Wirebond Study with Fine Pitch NPI
  • Probe mark sizes resulting from production probe
  • Wirebond integrity degraded by probe mark size

– Current Wirebond Experiment Integrated with Controlled Probe
  • Design of Experiment, desired responses and sampling
  • Probe test settings
  • Probe tip and probe mark measurements
  • Wirebond test settings
  • Intermetallic growth results
  • Ball shear, wire pull, lifted metal, surface contamination results
  • Experiment Summary

– Successful Probe and Wirebond Integration for Fine Pitch
Probe Mark Limits Fine Pitch Bonding

“Large” Probe Mark (with target ball)

At small pad sizes the mark disturbs a significant portion of the bond area

Intermetallic (IMC) Formation Impaired by Probe Mark

The effective bond diameter (actual pad contact area) is even smaller than the ball bond diameter (BBD)

Lifted metal, as well as non-sticks and lower shear strength can result

K. Thompson, May 23, 2001, Slide 3
**NPI is Fine Pitch Bonding Challenge**

**KEY NPI FEATURES**
- Pad Opening - 60 x 90µm
- Minimum Pad Pitch - 66µm
- Minimum Wire Pitch - 63µm
- No TiN layer under Al pad

**IMPACT**
- Fine pitch wirebonding required
  - Smaller Ball Bond Diameter: 43µm
    - Accurate placement at fine pad pitch
    - Larger 50µm ball has 1.31% defect rate
  - Thinner Au Wire Diameter: 1.0mil
    - Required for fine wire pitch bonding
- Lack of TiN barrier layer may reduce pad integrity and contribute to metal lift

<table>
<thead>
<tr>
<th>Ball Size</th>
<th>Cpx</th>
</tr>
</thead>
<tbody>
<tr>
<td>43um</td>
<td>1.53</td>
</tr>
<tr>
<td>50um</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Ball placement failure

NPI Bond Pad Cross Section
MOS 13 Hip4 0.25 µm CMOS core Al technology
Prior Wirebond CZ with Probed Dice

- Uncontrolled Probe Marks Disturb Majority of a 43um ball area

<table>
<thead>
<tr>
<th>Average</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Probe Area</th>
<th>Probe/Ball Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24.3</td>
<td>46.3</td>
<td>1.7</td>
<td>1125</td>
<td>77%</td>
</tr>
<tr>
<td>Maximum</td>
<td>29.0</td>
<td>57.1</td>
<td>2.0</td>
<td>1656</td>
<td>114%</td>
</tr>
<tr>
<td>Minimum</td>
<td>20.1</td>
<td>36.3</td>
<td>1.0</td>
<td>730</td>
<td>51%</td>
</tr>
</tbody>
</table>

- Large Probe Marks Degrade Small Ball Bond Performance
  - Larger ball has greater shear strength, low occurrence of lifted metal
  - Probe Mark Limits Intermetallic Growth with Smaller ball
    - Smaller ball has a high occurrence of lifted metal
    - Smaller ball shear strength decreases after PMC
    - Further optimization decreased smaller ball lifted metal to 1.86%, though still unacceptable

<table>
<thead>
<tr>
<th>Ball Size</th>
<th>PMC</th>
<th>Shear Strength (gm)</th>
<th>Std Dev</th>
<th>Shear per Area (gm/mil²)</th>
<th>% Lifted Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td>43um</td>
<td>Before</td>
<td>20.55</td>
<td>1.8</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>18.96</td>
<td>0.7</td>
<td>6.2</td>
<td>13.8%</td>
</tr>
<tr>
<td>50um</td>
<td>Before</td>
<td>24.86</td>
<td>3.0</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>33.19</td>
<td>2.7</td>
<td>7.8</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
Controlled Probing Wirebond Experiment

Mixed Full Factorial DOE

Factors

- Ball size - 43 & 50µm
- # of probe touchdowns (0-control, 1, 3, 6)
- Cantilever probe tip hardware (0.8, 1.0, 1.2 - reference)

Sample Size

- 480 units (18 Cells)
- 3 Wafers from MOS-13

Constants

- Fine Pitch Wirebonder (43 & 50µm ball settings)
- 272 PBGA Substrates

Responses

- Probe mark size for 1, 3, & 6 touchdowns
- Ball Shear Strength - Before & after PMC
- Rip Test - Before & after PMC
- Ball Diameter - Before & after PMC
- Wirepull - Before & after PMC
- 100% Inspection (Non-stick)
- Cratering after wirebond
- % IMC
- Moisture Sensitivity (MSL 3 - 240C) - Delamination
### Test Cell Breakdown

<table>
<thead>
<tr>
<th>Cell #</th>
<th># of Probe TouchDowns</th>
<th>Probe Tip Diameter</th>
<th>Ball Bond Diameter</th>
<th># of Strips*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No PMC</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>N/A</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>N/A</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0.8</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0.8</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>1</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>1</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>0.8</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>0.8</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>1</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>1</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>0.8</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>0.8</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>unknown</td>
<td>1.2</td>
<td>43</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>unknown</td>
<td>1.2</td>
<td>50</td>
<td>2</td>
</tr>
</tbody>
</table>

* - 6 Units per Strip

3 Cases per Cell

No Probe

Worst Case
Only Case w/ Non-stick (6 Lifted Pad)

Reference
Data Collection Flow Chart

**LEGEND**
- \( \rightarrow \) Wafer Flow
- \( \rightarrow \) Die Flow
- \( \rightarrow \) Substrate/Unit Flow

**Data** Requested Data Collection

- **Surface Analysis Lab**
  - SEM Photos
  - Auger Analysis

- **U of Malaysia - KL**
  - Probe Mark Size
  - Surface Roughness

- **KLM**
  - Non-stick
  - 100% Inspect

- **KLM**
  - Heat @ 175C

- **Die for pad eval.?**
  - Yes: Go to PMC?
  - No: Die Bond

- **Die Bond**
  - Wire Bond 43 & 50

- **Mold Units?**
  - Yes: MSL 3 Testing
  - No: Perform Testing

- **Perform Testing**
  - KLM
    - Ball Shear
    - Ball Dia. (BS/A)
    - Placement Acc.
    - Intermetallic %
    - Wire Pull
    - Rip Test
    - Cratering

- **Return Die to KLM**

- **Heat @ 175C**
  - Yes: Go to PMC?
  - No: No

- **Contamination Exam at ATX**
  - Yes: Die for pad eval.?}

K. Thompson, May 23, 2001, Slide 8
### Test Case Sampling

<table>
<thead>
<tr>
<th>Test</th>
<th>Measurement</th>
<th>Instrument</th>
<th>Sampling Per Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball Shear</td>
<td>Force (gm), Mode</td>
<td>Dage 4000</td>
<td>8 Units – 40 balls/unit</td>
</tr>
<tr>
<td>Ball Placement /Diameter</td>
<td>x1, y1, x2, y2</td>
<td>Fine Focus Microscope</td>
<td>6 Units – 8 balls/unit</td>
</tr>
<tr>
<td>Rip Test</td>
<td># with Lifted Metal, # of Lifted Ball</td>
<td>Hook</td>
<td>2 Units – all wires</td>
</tr>
<tr>
<td>Wirepull</td>
<td>Force (gm), Mode</td>
<td>Dage</td>
<td>8 Units – 40 wires/unit</td>
</tr>
<tr>
<td>Intermetallic Formation</td>
<td>% IMC</td>
<td>Fine Focus Microscope</td>
<td>1 Unit – 3 balls/unit</td>
</tr>
<tr>
<td>Cratering</td>
<td># of cratered pads</td>
<td>Fine Focus Microscope</td>
<td>1 Unit – all pads</td>
</tr>
<tr>
<td>Probe Mark Size</td>
<td>dx, dy, dz</td>
<td>AFM</td>
<td>1 die/quadrant – min &amp; max mark</td>
</tr>
<tr>
<td>Probe Mark Size</td>
<td>dx, dy</td>
<td>Fine Focus Microscope</td>
<td>3 Units – 10 pads/unit</td>
</tr>
<tr>
<td>Auger Analysis</td>
<td>Contaminants</td>
<td></td>
<td>5 die/quadrant</td>
</tr>
</tbody>
</table>

**Notes:**

- 264 die pads per unit available
- Sample sizes based upon KLM NPI specifications, and the minimum necessary to gather significant data
# Test Cell Probe Settings

<table>
<thead>
<tr>
<th>Nominal Probe Tip Diameter</th>
<th>0.8 mil</th>
<th>1.0 mil</th>
<th>1.2 mil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe Tip Diameter Tolerance</td>
<td>+/- 0.3 mil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Probe Card Vendor</td>
<td>Probe Technology - Duraprobe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contact Force</td>
<td>1.3 gm/mil</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>Overdrive</td>
<td>65 µm (from 1st Touch)</td>
<td>unknown</td>
<td></td>
</tr>
<tr>
<td>Polish Frequency (Online)</td>
<td>Every 150 dice (3 touches at 25 µm)</td>
<td>unknown</td>
<td></td>
</tr>
</tbody>
</table>

- 1.2 mil Probe Card probed dice were uncontrolled and the settings unknown

**Result:** Sample 0.8 mil Probe Tip Marks

1 TD 3 TD’s 6 TD’s
**Actual Probe Tip Diameter Description**

**Probe Card Analyzer Tip Measurements**

- 0.8 mil 1.0 mil
  - Maximum 1.06 1.02
  - Minimum 0.68 0.61

- Pareto of original tip sizes unavailable
- Significant tolerance on probe tips allows for large and overlapping ranges
- Tip measurements are not consistent between analyzers, accurate values difficult to define
- 0.8 mil probe card tips worn by subsequent production use (1.0 mil card not used subsequently)

**Subsequent Tip Measurements**

- 0.8 mil 1.0 mil
  - Maximum 1.3890 1.2370
  - Median 1.0658 0.9594
  - Minimum 0.8867 0.7701
  - Mean 1.0675 0.9657
  - Std Dev 0.0747 0.0749

K. Thompson, May 23, 2001, Slide 11
Probe Mark Area Measurements

Microscope Measurements

AFM Measurements

Area correlates to tip size and number of touchdowns
Interpretation of precise AFM measurements very subjective
Uncontrolled probed wafer (1.2 mil) not the worst case as expected
Probe sizes smaller than previous probing

Test Cell (Tip - #td)

Probe Mark Area (µm²)

0 200 400 600 800 1000

0 5 10 15

% Pad Opening
Limitation of Probe Mark Measurements

- Due to expense, AFM sample size has to be limited
- Limited to six linear measurements, chosen by the operator
- AFM depth measurements inconsistent (dependent on interpretation)
- A less expensive and simpler method is needed to gather Z-direction data
**Wirebond Assembly Test Settings**

- To form 43 and 50um ball bonds, different settings were required, the resulting wirebond results may not be directly comparable

<table>
<thead>
<tr>
<th>Wirebonder</th>
<th>Fine Pitch Capable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Type</td>
<td>Gold</td>
</tr>
<tr>
<td>Wire Diameter (µm)</td>
<td>25</td>
</tr>
<tr>
<td>Ball Diameter (µm)</td>
<td>43  50</td>
</tr>
<tr>
<td>Capillary</td>
<td>414FD-2031</td>
</tr>
<tr>
<td></td>
<td>SBNE-30ZA</td>
</tr>
<tr>
<td>Ball Bond Force (mN)</td>
<td>210  190</td>
</tr>
<tr>
<td>Ball Ultrasonic Power (%)</td>
<td>12.2  10.6</td>
</tr>
<tr>
<td>Ball Impact Force (mN)</td>
<td>300  280</td>
</tr>
<tr>
<td>EFO Current (mA)</td>
<td>50.24  32.8</td>
</tr>
<tr>
<td>EFO Time (ms)</td>
<td>0.4  0.6</td>
</tr>
</tbody>
</table>

- The above table notes most of the important factors which were different for the two ball bond sizes
Intermetallics Reduced by Touchdowns

Sample
0.8 mil probed ball bonds

1 TD

3 TD’s

6 TD’s

% IMC

Probe Mark Area (um²)

No Probe
0.8 - 1
0.8 - 3
0.8 - 6
1.0 - 1
1.0 - 3
1.0 - 6
1.2 - unk

Areas without IMC

43um - Before PMC
50um - Before PMC

K. Thompson, May 23, 2001, Slide 15
**Probe Mark Area Relation to Shear Strength**

- Strength degraded by probe mark area (fine focus microscope measurements), particularly before PMC.
- Strength increases after PMC, diminishing effect of probe mark.
- 43um and 50um bond strength per unit area do not overlap, larger diameter ball has lower shear strength per unit area.

![Graphs showing relationship between probe mark area and shear strength](image)
**Further Shear Relation to Probe Mark**

- Before PMC, the 50um bond strength degrades at a smaller ratio of probe mark to ball bond area than the 43um bond (43um > 50%, 50um > 38%)
- 0.8 mil probed bonds have lower strength than 1.0 mil probed bonds for each number of touchdowns before PMC (except the 50um ball at 1 touchdown)
Wire Pull and Rip Test Results

- The Probe Mark only significantly degrades the 43um ball bond Wire Pull Strength before PMC
- Occurrence of lifted metal pads increases dramatically with Probe Mark Area (particularly over 750um²) and especially after PMC
Surface Contaminant Analysis

- Auger analysis did not reveal foreign material or contamination
- A normal thickness of Aluminum Oxide found
- Older 1.2mil probed wafer had less surface oxygen and more carbon than the newer 0.8 and 1.0mil probed wafer
Summary of Experimental Results

– Tests show degradation of wirebond strength is a function of probe mark area and ball bond size, however, the range of damage does not appear large enough to establish significant relationship
  • Non-stick at wirebond only seen on one cell (1.0mil tip, 6 td’s, 43um ball)
  • Drop in strength from no probe to max probe size not very large, minimum strength still acceptable
  • No failures found after Jedec MSL 3-240C soaking
  • Subsequent production lots revealed much larger probe marks

– The probe mark area is a function of the number of probe touchdowns
  • Limitation specification needed at probe on number of touchdowns
  • Wirebond data shows six touchdowns creates too much damage

– The 0.8 mil nominal probe tip gives smaller probe marks in most cases, versus the 1.0 mil nominal probe tip, but not all
  • Need to correlate actual probe tip to resulting mark area rather than the nominal dimension (insufficient due to wear and tolerance)
Successful Fine Pitch Deployment Requires an Integration of Probe and Assembly

- As pitch decreases, the probe tip size, number of touchdowns, and probe settings degrade the wirebond integrity
  - Assembly and Probe must characterize probe mark damage to wirebond characteristics to optimize both processes
  - Production probe specifications should be established based on fine pitch characterization to place a limit on probe tip diameter and number of touchdowns for a given pad and ball bond size
- Communication between Probe and Assembly Engineering crucial

Additional Work Required
- Establish accuracy of Wafer-level probe mark measuring system, for mark characterization at the probe floor, separate from the prober
- Establish probe contact performance of 0.8 mil and smaller probe tips
- Establish the 0.8 & 1.0 mil probe tip wear rate to define lifetime
- Gather probe damage depth and height data to further understand wirebond results
Thanks for Contributions Provided by:

**BAT-1 Probe:**
Kris Hollingsworth  
Tiffany Jackson  
Tom Scuderi

**Technology Center:**
Bill Williams  
Chris Morrow  
Chuck Miller  
Paul Laberge

**KLM PBGA Assembly:**
Dominic Koey  
Chow-Leng Lai  
Y.V. Hew  
Fuaida Harun  
Irene Wong

**Packaging Engineering:**
Ziep Tran  
Gloria Estrada