Advanced Vertical Technologies for Low Damage Probing of Bumps, Pillars, and Pads

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June 4-7, 2017
Agenda

- Background
- MJC MEMS Spring Probe (MSP) for Solder Bumps, Cu Pillars, and Pads
- Qualification of MJC MSP Probe on Cu Pillar Devices at End User
  - End User Objectives
  - Qualification Test Plan
  - Results Summary
- High Volume Manufacturing Validation
- Summary / Conclusions
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Texas Test Corporation (TTC)

WHO WE ARE
Team of former Texas Instruments Engineers.

WHAT WE OFFER
The full range of product and test engineering services.

LOCATION
Headquarters: Dallas, Texas, U.S.A.
Product and Test Engineering: Sophia Antipolis, France
Manufacturing Operations: Hsinchu, Taiwan and Shanghai, China
Next Gen Requirements Create Probe Challenges

- **Bumped devices are moving from 150um pitches to 80um (and smaller) with high numbers of smaller bumps**
  - Bump pitch range from 130 to 100um today ⇒ moving into 80um (or less)
  - Bump diameters shrinking from 70um ⇒ sub-30um for certain structures
  - Reducing Cost of SoC Test is driven by large arrays for x256 multi-sites and pin-counts as high as 40,000 probes

- **Pitch reductions and minimum allowable damage for assembly and die stacks**
  - Mobile Devices ⇒ 80um
  - Automotive Devices ⇒ 65um
  - HBM Memory Devices ⇒ 50um
  - Wide I/O and Wide I/O 2 Devices ⇒ 40um

- **Electrical performance**
  - Low and stable CRES for functional test
  - Increased CCC for steady state and pulsed current
  - High speed performance testing

- **Tri-temperature characterization**
  - Demanding automotive standards
  - Multiprobe ⇒ -55C to 25C to 200C
  - Same test cell and probecard
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• **High Volume Manufacturing Validation**

• **Summary / Conclusions**
MJC MEMS Spring Probe for Solder Bumps, Cu Pillars, and Pads

MJC MEMS Spring Probe (MSP) Technology

- MEMS fabricated, non-oxidizing barrel & spring
- Proprietary fabrication process for probe architecture
- Spring force is controlled and defined by barrel geometries
- Preload at space transformer for stable contact
- On-site needle replacement capability

Flip Chip Type Device
Multi-die test of devices with Area Array (Bump / Cu Pillar)
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![MJC MEMS-SP (MSP)](image)

Flip Chip Type Device
Multi-die test of devices with Area Array (Bump / Cu Pillar)

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Spring Force can be designed to be anywhere within this range.
Plunger material and tip shape can be selected depending on the application.
Solder Bump Deformation vs. Applied Stroke (um)

- Force
- CRES

Stroke = Preload + Overtravel (micron)

Crown type

End User / TTC / MJC

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Solder Bump Probe with MJC MSP Crown Tip Plunger

Solder Bump (6gf Probe)

- Durability Evaluation [ Needle position ]
- Durability Evaluation [ p-Force ]

Solder Bump Deformation vs. Applied Stroke (um)

- Force (gram)
- Stroke = Preload + Overtravel (micron)

- Initial
- After-1M

Force vs. CRES

End User / TTC / MJC
**Cu-Pillar Bump Probe (RT) with MJC MSP Flat Tip Plunger**

**Flat type**

- **Initial**
  - Dia: 50um

**Dia_initial = 50um diameter Cu Pillar Bumps with Sn/Ag lead-free solder cap**

**Room Temp.**

<table>
<thead>
<tr>
<th>Probe Mark</th>
<th>Dia.</th>
<th>d/D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12um</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>14um</td>
<td>27%</td>
</tr>
<tr>
<td></td>
<td>15um</td>
<td>30%</td>
</tr>
</tbody>
</table>

**Graph:**

- Stroke = Preload + Overtravel (micron)
- Force [gf]
- d/D: 27%
- d/D: 30%
- d/D: 24%

**End User / TTC / MJC**
Cu-Pillar Bump Probe (RT) with MJC MSP Flat Tip Plunger

**Cu Pillar Bump (3gf Probe)**

- **Initial**
  - Dia: 50um

- **After -1M**

**Durability Evaluation [ Needle position ]**

- Probe Mark: dia. 12um, d/D: 24%
- Probe Mark: dia. 14um, d/D: 27%
- Probe Mark: dia. 15um, d/D: 30%

**Durability Evaluation [ p-Force ]**

- Dia_initial = 50um diameter Cu Pillar Bumps with Sn/Ag lead-free solder cap
Cu-Pillar Bump Probe (HT) with MJC MSP Flat Tip Plunger

Dia_initial = 90um diameter bumps (lead-free solder alloy, Sn/Ag3/Cu0.5) *SMIC_M705
MJC MEMS SP-Probe ... In the Field!

- Multisite cards with > 28K pin counts have been successfully installed.
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End User Objectives

**Improve Sort Performance over Cobra Style Vertical Card**
- Probe force consistency and “tune-ability” for uniform probe marks
- Low damage on small bumps
- Probe-to-bump alignment (PTBA)
- Stable electrical performance
- High 1st Pass Yields w/ reduced recovery test

**Reduced Cost of Ownership over Cobra Style Vertical Card**
- Reduced maintain and increased lifetime performance (MTBR and End of Life)
- Minimize test cell down due to contact related
- Easy repair and simple single pin replacement capabilities
Test Cell Overview

• **Equipment**
  – Tester = VLCT Platform
  – Prober = Accretech 300mm Prober
  – Probe Type = MEMS SP w/ flat tip plunger
  – Probe Card Test Vehicle = 1 x 4 DUT w/ 2140 pins

• **Test Conditions**
  – Test temp = 30C
  – OD = Variable as defined during testing

• **Cleaning conditions for all testing**
  – Octagonal movement
  – Cleaning Overtravel = 100um
  – Cleaning Frequency = 1 clean per 200 wafer TD
## Probe Card Test Vehicle and MSP Probe

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Material</td>
<td>Cu Pillar Bump</td>
</tr>
<tr>
<td>Minimum pitch</td>
<td>95um pitch with full array</td>
</tr>
<tr>
<td>Tip shape</td>
<td>Flat Plunger</td>
</tr>
<tr>
<td>Contact force</td>
<td>3gf / OD150um</td>
</tr>
<tr>
<td>C.C.C. (ISMI 20% force drop)</td>
<td>800 mA</td>
</tr>
<tr>
<td>Alignment</td>
<td>±15um</td>
</tr>
<tr>
<td>Planarity</td>
<td>Less than 50um</td>
</tr>
<tr>
<td>Temperature</td>
<td>-40C to 90C</td>
</tr>
</tbody>
</table>

1 x 4 DUT layout w/ 2140 pins

MEMS-Spring

Flat Plunger

Cu Pillar Bump

End User / TTC / MJC

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Qualification Test Plan

- **Contact Resistance (CRES) Assessment**
  - Determine OD to attain stable CRES
  - CRES vs. Repeated Touchdowns

- **Damage Assessment**
  - Bump Damage vs. Overdrive
  - Bump Damage vs. Repeated Touchdowns

- **Bin-to-bin Reproducibility**

- **Stable Correlation Wafer Yield Results**

- **CRES Determination and Trending**
  - MJC MSP Probe vs. Cobra Style Vertical
Overtravel to Attain Stable CRES

- **Overtravel Applied to Wafer**
  - Overtravel Range = 25 to 200um
  - Overtravel Increment = 25um
  - Single Touchdown

Stable resistance attained @ Overtravel > 50um
Overtravel to Attain Stable Correlation Yield

- **Overtravel Applied to Wafer**
  - Overtravel Range = 25 to 200um
  - Overtravel Increment = 25um
  - Single Touchdown

Stable Correlation Wafer Yield @ Overtravel > 75um

Stable Yield (~93%)
**Overtravel vs. Bump Deformation and Damage**

- At higher overtravel, the bumps are more deformed and tend to higher %-damage.
- At OD = 200um, the %-Damage is significantly less than the specification limit (% Damage < 50%).

![Cu Pillar Diagram](image)

Scrub Dia. Ratio (%) = \( \frac{d}{D} \)

---

**Cu-Pillar Bump Damage vs. Overtravel**

- **Scrub Dia. Ratio (%)**
- **Scrub Dia. (um)**

<table>
<thead>
<tr>
<th>OD (micron)</th>
<th>Scrub Diam (micron)</th>
<th>Scrub Ratio (%)</th>
<th>Scrub Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>25um</td>
<td>11.5</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>50um</td>
<td>11.5</td>
<td>23.0</td>
<td></td>
</tr>
<tr>
<td>75um</td>
<td>13.8</td>
<td>27.6</td>
<td></td>
</tr>
<tr>
<td>100um</td>
<td>14.5</td>
<td>28.9</td>
<td></td>
</tr>
<tr>
<td>125um</td>
<td>16.1</td>
<td>32.2</td>
<td></td>
</tr>
<tr>
<td>150um</td>
<td>16.8</td>
<td>33.6</td>
<td></td>
</tr>
<tr>
<td>175um</td>
<td>17.8</td>
<td>35.5</td>
<td></td>
</tr>
<tr>
<td>200um</td>
<td>18.4</td>
<td>36.8</td>
<td></td>
</tr>
</tbody>
</table>
Multi-Touchdowns vs. CRES

- **Touchdowns Applied to Wafer**
  - Overtravel = 150um
  - Number of TDs = 1 to 6
    - Function Test @ 1TD
    - CRES Test @ 2 to 6TD

- **Electrical testing performed across 10-critical pins.**

<table>
<thead>
<tr>
<th>Touchdowns</th>
<th>Electrical Tests Performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2442</td>
</tr>
<tr>
<td>2</td>
<td>2013</td>
</tr>
<tr>
<td>3</td>
<td>1583</td>
</tr>
<tr>
<td>4</td>
<td>1150</td>
</tr>
<tr>
<td>5</td>
<td>714</td>
</tr>
<tr>
<td>6</td>
<td>281</td>
</tr>
</tbody>
</table>
Multi-Touchdowns vs. Correlation Wafer Yield

- Touchdowns Applied to Wafer at OD = 150um
  - Number of Touchdowns = 1 to 6 (Function Test @ 1TD w/ retest check; CRES Test @ 2 to 6TD)

  1st Pass Correlation Wafer Yield = 91.5%
  - Re-Test Recovery
    - 13 chips were recovered
  - No further recovery for TD = 2 thru 6
  - Pass / Fail / Open of each touchdown sequence were well correlated.

<table>
<thead>
<tr>
<th>Touchdown</th>
<th>1st Pass Yield</th>
<th>1st Pass Fail</th>
<th>1st Pass Open</th>
<th>Retest Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Touchdown</td>
<td>91.5%</td>
<td>8.5%</td>
<td>0.7%</td>
<td>13 Chip</td>
</tr>
</tbody>
</table>

1st Pass Correlation Wafer Yield = 91.5%
- Re-Test Recovery ⇔ 13 chips were recovered
- No further recovery for TD = 2 thru 6
- Pass / Fail / Open of each touchdown sequence were well correlated.
Multi-TD vs. Bump Deformation and Damage

- After multiple touchdowns at OD = 150um, the bump are more deformed and have higher damage.
- After 2 x TDs, the %-Damage is remains constant and less than the specification limit (% Damage < 50%)

![Cu Pillar Bump Damage vs. Multi-Touch @ OD = 150um](image)

<table>
<thead>
<tr>
<th>Touch Down</th>
<th>Scrub Diam. (micron)</th>
<th>Scrub Ratio (%)</th>
<th>Scrub Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.1</td>
<td>32.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>20.1</td>
<td>40.1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>19.7</td>
<td>39.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>19.7</td>
<td>39.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>23.0</td>
<td>46.1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>19.1</td>
<td>38.2</td>
<td></td>
</tr>
</tbody>
</table>
Correlation Determination > 99%

- **Test Conditions**
  - Wafer Overtravel = 150um
  - Octagonal movement
  - Cleaning Overtravel = 100um
  - Cleaning Frequency = 1 clean per 200 wafer TD

Highly significant positive correlation confirmed

![Correlation Test Results](chart_image)
4 x Wafer Lot % Yield Results

- **Total Yield Average for 4-LOT**
  - First Pass Yield Target was attained and confirmed
  - MSP card had significantly better first pass yields than a comparable Cobra card.

- **MSP card had low recovery rate vs. a high recovery rate observed with the Cobra card.**
  - Recovery Rate for MJC MSP PC ≤ 0.13%
  - Recovery Rate for Cobra PC ≥ 0.50 %
MJC MSP vs. Cobra Probe CRES Trending

- **Test Conditions**

  - Wafer Overtravel = 150um
  - Octagonal movement
  - Cleaning Overtravel = 100um
  - Cleaning Frequency = 1 clean per 200 wafer TD

**Cobra Style Probe Card**

**MJC MSP Probe Card**

<table>
<thead>
<tr>
<th></th>
<th>MSP Probe</th>
<th>Cobra Probe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median</td>
<td>20.8629</td>
<td>18.321</td>
</tr>
<tr>
<td>Outliers</td>
<td>576</td>
<td>1265</td>
</tr>
<tr>
<td>StdDev</td>
<td>0.327531</td>
<td>1.16991</td>
</tr>
<tr>
<td>Var</td>
<td>0.107276</td>
<td>1.36836</td>
</tr>
</tbody>
</table>

End User / TTC / MJC
## Summary of Qualification

<table>
<thead>
<tr>
<th>Property</th>
<th>Requirement</th>
<th>Result</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRES vs. OD</td>
<td>OD = 75 to 200um</td>
<td>Stable CRES at OD ≥ 50um</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Target OD = 150um</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation Yield vs. OD</td>
<td>OD = 75 to 200um</td>
<td>Stable Yield at OD ≥ 75um</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Target OD = 150um</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bump Damage vs. OD</td>
<td>% Damage ≤ 50%</td>
<td>% Damage ≤ 40%</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>OD = 75 to 200um</td>
<td>Max. OD = 200um</td>
<td></td>
</tr>
<tr>
<td>CRES vs. TD</td>
<td>TD = 1 to 6</td>
<td>Stable CRES at Max. Allowable TD = 6</td>
<td>✔</td>
</tr>
<tr>
<td>Correlation Yield vs. TD</td>
<td>TD = 1 to 6</td>
<td>No additional recovery after 1st retest</td>
<td>✔</td>
</tr>
<tr>
<td>Bump Damage vs. TD</td>
<td>% Damage ≤ 50% at OD = 150um</td>
<td>% Damage ≤ 40% Max. Allowable TD = 6</td>
<td>✔</td>
</tr>
<tr>
<td>Test Reproducibility</td>
<td>Statistical Correlation better than 99%</td>
<td>All bins within 0.3% (R² = 0.999)</td>
<td>✔</td>
</tr>
<tr>
<td>Wafer Lot Result</td>
<td>High 1st Pass Yield</td>
<td>Recovery Rate ≤ 0.13%</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Low Recovery Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance Variance</td>
<td>Improved Stability over Cobra Type</td>
<td>Statistically Reduced Variance</td>
<td>✔</td>
</tr>
</tbody>
</table>
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High Volume Manufacturing Validation

• Production Qualification Overview
  – More than 5000 production device wafers were split across multiple test cells
  – Split Lot Ratio ⇒ MJC MSP (15%) and Cobra Style (85%)

• Production Metrics comparison for MJC MSP vs. Cobra Style
  – First Pass Yield Improvement ⇒ 0.37% increase in FPY over Cobra Style
  – Significant Reprobe Rate Reduction across 5000 wafers:

<table>
<thead>
<tr>
<th>Card Type</th>
<th>Average</th>
<th>StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>COBRA</td>
<td>0.34%</td>
<td>0.83%</td>
</tr>
<tr>
<td>MJC MSP</td>
<td>0.09%</td>
<td>0.08%</td>
</tr>
</tbody>
</table>

  – Avg. 2.69% wafer test time reduction was realized with MJC MSP Probe
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Summary / Conclusions

- Bumps, Pillars, and Pads of next-gen devices continue to shrink in size for higher pin counts with tighter pitches requiring precise and low force contact under various test conditions.

- MJC MEMS SP has “tune-ability” of probe force, plunger shape, and contactor metallurgy.
  - Engineered low probe forces facilitate high pin counts with reduced %-damage
  - Tip geometries designed for CRES stability with low %-damage after multiple touchdowns
  - Contactor shapes and metallurgies optimized for high CCC, low CRES, and %-Yield stability

- Under HVM conditions at End User, MEMS SP had superior performance over Cobra Style probe technologies.
  - A 0.37% improvement in First Pass Yield
  - Significantly reduced reprobe and recovery rates
  - Overall 2.69% reduction in average wafer test times

- Future work
  - Production probe card performance and lifetime characterization
  - Elevated temperature (125C) test conditions
Acknowledgements

- End User Probe Process Team (*Special Thanks!*)
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- Philippe Cavalier (Texas Test Corporation)
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- Keita Kudo (Micronics Japan, Co., LTD)