Probe Needle Wear and Contact Resistance

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Participants

- SEMATECH
  - Probes PTAB

- Probe Needles
  - Advanced Probing Systems, Inc.

- Probe Cards
  - CerProbe Corporation
  - JEM America
  - Micro-Probe, Inc.
  - Probe Technology Corporation
  - Wentworth Laboratories

- Testing Facilities
  - Applied Precision, Inc. (John Strom, Kenneth Sokol, Bryce Ekstrom)
  - Sandia National Laboratories (David Monroe, Scot Swanson)
Research Objectives

- **No Benchmarking**
  - Probe card construction was specified for this study
  - Overall performance between cards WAS NOT compared

- **Quantify abrasive cleaning effects**
  - Probe tip wear due to burnishing
  - Appropriate cleaning procedures

- **Evaluate probe needle wear behavior**
  - Room and elevated temperature touchdown testing
  - Appropriate probe needle metal system
Research Focus

- SEMATECH 1997 Development Roadmap
  - Room temperature (hot chuck at 30°C)
  - Elevated temperature (hot chuck at 85°C)

- “Practice” for probe card cleaning
  - 3-µm grit burnishing pad (hot chuck at 30°C)

- “Practices” used for 70 µm pitch probe cards
  - Tungsten and tungsten-rhenium probe materials
  - 0.005” and 0.007” diameter probe needles
  - Three-tiered epoxy ring probe cards
  - For this presentation only Tier 1 behavior will be discussed
Probe Needles

● Testing Environments
  – Abrasive cleaning
  – Room temperature (30°C)
  – High temperature (85°C)
  – “Low” forcing current (50 mA)

● Focus on “Primary” Probe Needle Properties
  – Material
  – Probe and probe tip diameter
  – Etch length
Probe Card

- Consistent “Secondary” Probe Needle Variables
  - Balanced contact force
  - Overtravel
  - Beam angle
  - Tip angle
  - Etc…. 
Probe Needle Specifications

- **Isolinear™ Probe Needles**
  - Known probe tip geometry
  - Tip diameter and length mathematically related

<table>
<thead>
<tr>
<th>Probe Needle Diameter</th>
<th>Etch Length (inch)</th>
<th>Etch “Rate” (deg)</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-mil</td>
<td>0.070</td>
<td>4.1</td>
<td>Tungsten (W): Matte</td>
</tr>
<tr>
<td></td>
<td>0.080</td>
<td>3.6</td>
<td>Tungsten-Rhenium (WRe): Polish</td>
</tr>
<tr>
<td></td>
<td>0.090</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>7-mil</td>
<td>0.090</td>
<td>4.5</td>
<td>Tungsten (W): Matte</td>
</tr>
<tr>
<td></td>
<td>0.100</td>
<td>4.0</td>
<td>Tungsten-Rhenium (WRe): Polish</td>
</tr>
<tr>
<td></td>
<td>0.110</td>
<td>3.6</td>
<td></td>
</tr>
</tbody>
</table>
## Probe Card Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Board Style:</strong></td>
<td>HP 4062, 4&quot; PCB</td>
</tr>
<tr>
<td><strong>Test Temperature:</strong></td>
<td>25° to 85°C</td>
</tr>
<tr>
<td><strong>Tip Diameter:</strong></td>
<td>1.2 ± 0.1 mils</td>
</tr>
<tr>
<td><strong>Tip Shape:</strong></td>
<td>Flat</td>
</tr>
<tr>
<td><strong>Tip Angle:</strong></td>
<td>103 ± 3 deg.</td>
</tr>
<tr>
<td><strong>Beam Angle:</strong></td>
<td>10 deg.</td>
</tr>
<tr>
<td><strong>Pad Material:</strong></td>
<td>Aluminum</td>
</tr>
<tr>
<td><strong>Fanout:</strong></td>
<td>0 ± 3 deg.</td>
</tr>
<tr>
<td><strong>Probe Depth:</strong></td>
<td>150 mils</td>
</tr>
<tr>
<td><strong>Ring Material:</strong></td>
<td>Ceramic</td>
</tr>
<tr>
<td><strong>Overdrive:</strong></td>
<td>3 mils</td>
</tr>
<tr>
<td><strong>Planarity:</strong></td>
<td>± 0.5 mils</td>
</tr>
<tr>
<td><strong>Alignment:</strong></td>
<td>± 0.5 mils</td>
</tr>
<tr>
<td><strong>Leakage:</strong></td>
<td>100 nA</td>
</tr>
<tr>
<td><strong>Contact Resistance</strong></td>
<td>1.5 to 2.0 Ω</td>
</tr>
<tr>
<td><strong>Gram Force:</strong></td>
<td>2 grams/mil</td>
</tr>
<tr>
<td><strong>BCF:</strong></td>
<td>± 20%</td>
</tr>
</tbody>
</table>
60-Pin Configuration

X - Location (µm)

Y - Location (µm)

- TIER 1
- TIER 2
- TIER 3

- Tungsten 5-mil diameter
- Tungsten-Rhenium 5-mil diameter
- Tungsten 7-mil diameter
- Tungsten-Rhenium 7-mil diameter
Probe Card
Test Wafers

- **Abrasive Testing**
  - 6-inch “scrap” metallized wafer
  - 3-µm abrasive pad, i.e. “the pink stuff”

- **Touchdown Testing**
  - 8-inch metallized wafer manufactured by SEMATECH
  - Titanium-nitride substrate
  - 1-µm thick Aluminum layer
Stepping Pattern
Test Equipment

- **ElectroGlas-4080 Tester with “Hot Chuck”**
  - Burnishing pad touchdown testing
  - Metallized wafer touchdown testing at 30°C and 85°C

- **HP4062 Parametric 48-Channel Analyzer**
  - On-line contact resistance measurements

- **Applied Precision PRVX$_2$-Probe Card Analyzer**
  - Probe tip diameter
  - Contact resistance
  - Balanced contact force
Touchdown “Test Flow”

- **3-µm Abrasive Pad**
  - 3.0-mil overtravel, linear mode, double-touchdown mode
  - PRVX$_2$ metrology performed after 0, 7.5K, and 15K touchdowns
    - Contact resistance
    - Tip diameter

- **Metallized Wafer at 30° and 85°C**
  - 3.0 mil overdrive, double-touchdown mode (8 touchdowns/second)
  - Contact resistance measurements every 5K touchdowns
  - PRVX$_2$ metrology performed after 0, 250K, and 500K touchdowns
    - Contact resistance
    - Tip diameter
3-μm Abrasive Pad
3-μm Abrasive Pad

- **Tungsten vs. Tungsten-Rhenium**
  - Abrasive particles are considerably harder than both probe materials
  - No “significant” differences between materials in amount of tip length removed

- **5-mil vs. 7-mil Diameter Probe Needles**
  - Amount of tip length removed from the 5-mil probes was greater than that of the 7-mil probes

- **Contact Resistance Measurements**
  - Baseline (“as delivered”) and post-touchdown $C_{RES}$ values were higher than expected
  - Cleaning was performed and $C_{RES}$ values were considerably reduced
  - Contamination on probe tip surface - tungsten-oxide? other residue?
3-μm Abrasive Pad

- “Approximate” Wear Rates
  - Changes in tip geometry occur with each touchdown
  - Wear rate = \( f(\text{overtravel, scrub length, BCF, etch length, contact materials}) \)
  - Conservative “first approximation” of abrasive wear rates

<table>
<thead>
<tr>
<th>Diameter</th>
<th>0 to 7.5K</th>
<th>0 to 15K</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-mil</td>
<td>38 Å per touchdown</td>
<td>52 Å per touchdown</td>
</tr>
<tr>
<td>7-mil</td>
<td>35 Å per touchdown</td>
<td>48 Å per touchdown</td>
</tr>
</tbody>
</table>
Al-Wafer at 30° and 85°C

- **Probe Tip Wear Characteristics**
  - Isolinear™ taper shape was used to calculate average tip length changes

- **Contact Resistance**
  - Box plots were used to show the range and mean of $C_{RES}$ values for material
**Probe needle tip length (Tier 1 design specification = 7-mil)**

- Dark grey: Material worn away by touchdown on aluminum at 30 °C with 3-mil overdrive

### Probes

- W5
- WRe5
- W7
- WRe7

#### Data

- **250K Touchdowns on Aluminum**
  - W5: 0.6
  - WRe5: 0.4
  - W7: 0.5
  - WRe7: 0.3

- **500K Touchdowns on Aluminum**
  - W5: 1.4
  - WRe5: 1.1
  - W7: 1.2
  - WRe7: 0.8
Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 30°C)
Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 30ºC)
Al-Wafer at 30ºC

- **Wear and \( C_{RES} \)**
  - 7-mil WRe-probes demonstrated significantly lower \( C_{RES} \) values than 7-mil W-probes
  - Differences between the 5-mil probes were not as significant
  - Microhardness values of the probes

<table>
<thead>
<tr>
<th></th>
<th>W005</th>
<th>WRe005</th>
<th>W007</th>
<th>WRe007</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHN</td>
<td>738 ± 47</td>
<td>736 ± 33</td>
<td>718 ± 45</td>
<td>804 ± 23</td>
</tr>
<tr>
<td>(kg/mm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **\( C_{RES} \) on “Virgin” vs. “Scrubbed” Aluminum**
  - \( C_{RES} \) response of the WRe-probes unaffected by wafer surface condition
  - On the other hand, the W-probes demonstrated marked differences
Probe needle tip length (Tier 1 design specification = 7-mil)
Material worn away by touchdown on aluminum at 85 °C with 3-mil overdrive

250K Touchdowns on Aluminum
W5  WRe5  W7  WRe7
1.4  1.0  1.1  0.6

500K Touchdowns on Aluminum
W5  WRe5  W7  WRe7
2.1  1.4  1.8  1.1
Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 85°C)

- **5-mil Tungsten Probes**
- **5-mil Tungsten-Rhenium Probes**

**Contact Resistance (ohm)**

**Touchdowns (x 1000)**

**Tungsten-Rhenium Probes on Stepping Pattern Leading Edge**

**Tungsten Probes on Stepping Pattern Leading Edge**
Tier 1 Contact Resistance on Wafer
(3-mil overtravel at 85°C)
Al-Wafer at 85ºC

● **Wear and C<sub>RES</sub>**
  - Reductions in WRe-probe tip lengths were significantly less than those of the W-probes
  - Overall, the WRe-probes demonstrated lower and “more stable” C<sub>RES</sub> behavior

● **Temperature Effects**
  - Metallurgical fact - materials soften with increased temperature
  - Rhenium stabilizes small diameter wire grain structure at high temperatures
  - Grain structure affects hardness and wear characteristics of probe needles
  - The “softening rate” of WRe-probes differs from that of W-probes
Application of Results
“A Thought Experiment”

- Probe card required to test 500K die
- Testing performed at room and high temperature
- “Triple Hit” cleaning every 100 die
  - 7.5K cleaning touchdowns after 250K die
  - 15K cleaning touchdowns after 500K die
- Can an estimate be made of the probe service life?
  - Reduction in tip length
  - Increase in tip diameter
Probe needle tip length (Tier 1 design specification = 7-mil)
Material worn away by touchdown on aluminum at 85 °C with 3-mil overdrive
Material removed by abrasive cleaning with 3-mil overdrive in linear mode

Original Probe Tip Length

W5  WRe5  W7  WRe7

250K Touchdowns on Aluminum
7.5K Touchdowns on 3-μm Abrasive

W5  WRe5  W7  WRe7

500K Touchdowns on Aluminum
15K Touchdowns on 3-μm Abrasive
Summary
TIER 1 ONLY

- No Benchmarking

- Probe Needle Wear
  - Abrasive Cleaning
    - Cleaning pad material is dramatically harder than both probe materials
    - No significant differences in the amount of tip length removed
    - Wear rate “first approximations” based on 15K cleanings: 52 Å and 48 Å per touchdown for 5-mil and 7-mil probes, respectively
    - Wear rate $= f(\text{overtravel, scrub length, BCF, etch length, contact materials})$
Summary

• **Probe Needle Wear**
  - Aluminum-wafer at 30°C
    - Difference in wear behavior were observed for the 7-mil probes and not as severe for the 5-mil probes
    - Wear rate “first approximations” based on 500K touchdowns: 700, 560, 600, and 380 Å per 1K-touchdowns for W005, WRe005, W007, and WRe007, respectively
    - Hardness values of the 7-mil WRe-probes were significantly higher than those of the W-probes
    - The 5-mil probes had comparable hardness values and hence demonstrated similar wear characteristics
    - As the diameter of the probe needles decreases, the hardness of tungsten and tungsten-rhenium become similar
Summary

- **Probe Needle Wear**
  - Al-Wafer at 85°C
    - Wear differences were exacerbated by the higher temperature
    - Wear rate “first approximations” based on 500K touchdowns: 1100, 700, 900, and 560 Å per 1K-touchdowns for W005, WRe005, W007, and WRe007, respectively
    - Increased temperature results in a thicker Al-oxide layer and a reduction in the probe needle hardness
    - Changes of the WRe-probe tip lengths were significantly less than those of the W-probes
    - Alloying with rhenium stabilizes the grain structure and hardness at high temperatures
    - The temperature dependent “softening” of WRe-probes is different than that of W-probes
Summary

● Contact Resistance

  – Al-Wafer at 30°C
    ○ $C_{RES}$ consistency of the W-probes was affected by the wafer surface condition
    ○ W-probes demonstrated higher $C_{RES}$ values on the “scrubbed” portion
    ○ WRe-probes demonstrated consistent $C_{RES}$ values regardless of the wafer surface, i.e. “virgin” vs. “scrubbed”

  – Al-Wafer at 85°C
    ○ $C_{RES}$ variance of all probe needles was greater at higher temperature
    ○ $C_{RES}$ consistency of the W-probes was affected by the wafer surface condition; but not as dramatically as at room temperature
    ○ $C_{RES}$ behavior of the WRe-probes was unaffected by the wafer surface condition
    ○ Overall, the WRe-probes demonstrated lower and consistent $C_{RES}$ values
Summary

● Probe Service Life Estimates
  - “First approximations of the service life” for Tier 1 were made
  - Differences in probe tip wear are over-shadowed by abrasive cleaning
  - Service Life = f(temperature, current, overtravel, scrub length, BCF, cleaning frequency, and contact material)
  - The results indicate that WRe-probes would provide a longer service life than W-probes at high temperatures

● Benefits of Tungsten-Rhenium
  - At room temperature, WRe-probes provide $C_{RES}$ consistency with slight improvements in wear that over-shadowed by abrasive cleaning
  - At high temperature, WRe-probes provide $C_{RES}$ consistency and significant improvements in wear
Side Bar

● **Additional Observations**
  - $C_{\text{RES}}$ values of probes that never touched a wafer were higher than expected
  - Cleaning was performed and $C_{\text{RES}}$ values were considerably reduced
  - Contamination on probe tip surface - tungsten-oxide? other residue? who really knows?

● **Future Work**
  - Analysis of Tier 2 and Tier 3 behavior