Wafer probe challenges for the automotive market

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ON Semiconductor
Overview

- Automotive wafer probe requirements
- Results of experiments
- Summary
- Follow-on Work
- Acknowledgements
Automotive wafer probe requirements

- **Temperature**
  - -55°C up to 200°C
  - Probed die deliveries: Full test coverage at probe
  - Dual and tri-temp probe

- **Disturbed area on bond pad**
  - Multiple probe insertions
  - Bond pad size reduction → smaller Si area
  - Bond wire diameter in Multi Chip Modules
Impact of temperature on probe card

- PCB temperature profile
- Z movement of probes
- X-Y movement of probes
**PCB temperature**

- Radiant heat transfer
- Thermal expansion of the PCB dominates the mechanical behavior of the complete probe card assembly

<table>
<thead>
<tr>
<th>CTE XY (ppm/°C)</th>
<th>CTE Z (ppm/°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR4</td>
<td>140 to 220</td>
</tr>
<tr>
<td>Rogers</td>
<td>11 to 16</td>
</tr>
<tr>
<td>N7000</td>
<td>46 to 50</td>
</tr>
<tr>
<td>N8000</td>
<td>10 to 12</td>
</tr>
<tr>
<td></td>
<td>2,5%</td>
</tr>
<tr>
<td></td>
<td>70 to 375</td>
</tr>
</tbody>
</table>

- Temperature limitation active and passive components
  - Relays: typical maximum 85°c or 125°c
  - Active components: typical maximum up to 125°c
  - Passive components: typical maximum 125°c to 150°c
PCB temperature evolution at hot

Conclusion:

- Spider temp ≈ ½ Prober set temp
- PCB back side temp ≈ ⅓ Prober set temp
- Results independent of cantilever orientation vertical
Findings & Conclusion @ cold:
• No major difference component side ↔ wafer side
• Less temperature variation over time vs hot probe
• Results independent cantilever ↔ vertical
Z movement of probes

- **Root cause**
  - Continuous moving heat source (chuck)
  - Thermal behavior probe card assembly
  - Build quality of the spider / probe head
  - Independent of probe card type
Z deflection experiment: Initial conditions

- **Soak prior to measurements**
  - Prober soak: 2hrs after reaching set temp
  - Probe card soak: 10 min
    - After prober soak
    - Chuck centered under the probe card
    - No contact
- **Zero-level = needle position after soak**
- **Process settings**
  - Test time per wafer: 1hr 10min
  - Probe polish interval: every 100 die
  - Probe polish recipe: 25 touch downs, 20µm overdrive
Z deflection:
standard probe card at 175°C

Independent of probe card type (cantilever or vertical)
Z deflection: standard probe card at -50ºC

Independent of probe card type (cantilever or vertical)
**Z deflection:**

**High Temp probe cards at 175ºC**

- **Probe Card A:** Spider Stiffener
  - Heat shielded

- **Probe Card B:** Bridge Stiffener

- **Probe Polish:** limited impact on Z-deflection

- **Chuck:** Independent of probe card type (cantilever or vertical)

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**TESTER**

- **Start Probe**
- **End Probe**
Z deflection:
ON Semi High Temp probe cards at 175ºC

TESTER
- Start Probe
- Probe Card A: Spider Stiffener Heat shielded
- Probe Card B: Bridge Stiffener
- Probe Card C: Standard
- Probe Card D: ON Semi

Chuck
- End Probe

Test Time
Z deflection:
ON Semi High Temp probe cards at -50ºC

TESTER

Start Probe

Probe Card C: Standard

Probe Card D: ON Semi

Chuck
Independent of probe card type (cantilever or vertical)
ON Semi High Temp probe cards

- Patented design: US 7,816,930
- Bridge stiffener concept
- Allows PCB expansion without Z deflection
- Implemented on:
  - Teradyne uFLEX
  - Teradyne Catalyst
  - SZ M3650 & Falcon
  - Credence ASL1000
X-Y movement of probes

- **Root cause**
  - Build quality of the spider (cantilever)
  - Build quality of entire probe card assembly
  - Memory effect of the probes (cantilever)
  - Thermal behavior probe card assembly
Experiment: X/Y movement
Cantilever probe cards

- **Inspection limits 25 °C:**
  - +/- 7.5µm

- **Inspection limits High temp + Cold:**
  - +/- 12.5µm
Experiment: X/Y movement
Vertical probe cards

Technoprobe Wired Space Transformer (Vertical)

- Inspection limits 25 ºC: +/- 7.5µm
- Inspection limits High temp + Cold: +/- 12.5µm
Bond pad damage

- Key for probed die deliveries
- Max disturbed area
  - Diameter of entire probe mark area ≤ 28µm (≤615µm²)
- Probe depth
  - Maximum half of the thickness of top layer (T) of pad metallization
  - Maximum ≤ 500nm
- Number of probe marks
  - Number of probe insertions + 1
Experiment: Bond pad disturbance

- Evaluation disturbed area and probe depth

- Test conditions
  - Temperature: 25ºC
  - Touch count: 1
  - Overdrive Cantilever: Typical production setting
  - Overdrive Vertical: Max allowed overdrive
## Max disturbed area (≤615µm²)

<table>
<thead>
<tr>
<th>Cantilever (25 µm tip)</th>
<th>Cantilever Technoprobe - No Scrub™ (25 µm tip)</th>
<th>Vertical Technoprobe - Route 60 (13 µm tip)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>Overdrive: 30µm Disturbed area: 610 µm²</td>
<td>Overdrive: 30µm Disturbed area: 200 µm²</td>
<td>Overdrive: 100µm Disturbed area: 295 µm²</td>
</tr>
<tr>
<td>Vertical Buckling beam Vendor A (10 µm tip)</td>
<td>Vertical Buckling beam Vendor B (12 µm tip)</td>
<td>Vertical Buckling beam Vendor C (7 µm tip)</td>
</tr>
<tr>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>Overdrive: 100µm Disturbed area: 183µm²</td>
<td>Overdrive: 100µm Disturbed area: 199µm²</td>
<td>Overdrive: 65µm Disturbed area: 76µm²</td>
</tr>
</tbody>
</table>
# Probe depth

(\( \leq 500\text{nm} \) or \( \frac{1}{2} \) top metal thickness)

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<tr>
<td>![Image](Cantilever tip)</td>
<td>![Image](Cantilever Technoprobe)</td>
<td>![Image](Vertical Technoprobe)</td>
</tr>
<tr>
<td>Probe depth: 527nm</td>
<td>Probe depth: 270nm</td>
<td>Probe depth: 360nm</td>
</tr>
<tr>
<td>Vertical Buckling beam Vendor A (10 µm tip)</td>
<td>Vertical Buckling beam Vendor B (12 µm tip)</td>
<td>Vertical Buckling beam Vendor C (7 µm tip)</td>
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<td>![Image](Vertical Buckling beam Vendor A)</td>
<td>![Image](Vertical Buckling beam Vendor B)</td>
<td>![Image](Vertical Buckling beam Vendor C)</td>
</tr>
<tr>
<td>Probe depth: 430nm</td>
<td>Probe depth: 391nm</td>
<td>Probe depth: 292nm</td>
</tr>
</tbody>
</table>
Overdrive vs disturbed area

- **Cantilever (25µm tip diameter)**

<table>
<thead>
<tr>
<th>Overdrive = 15 µm</th>
<th>Overdrive = 30 µm</th>
<th>Overdrive = 60 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>130µm²</td>
<td>270µm²</td>
<td>527µm²</td>
</tr>
</tbody>
</table>

- **Vertical (10µm tip diameter)**

<table>
<thead>
<tr>
<th>Overdrive = 25 µm</th>
<th>Overdrive = 50 µm</th>
<th>Overdrive = 75 µm</th>
<th>Overdrive = 100 µm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
<tr>
<td>174µm²</td>
<td>182µm²</td>
<td>183µm²</td>
<td>183µm²</td>
</tr>
</tbody>
</table>
Number of probe marks

• **Probe mark ≠ Touch count**
  – Probe mark: Individual visible imprint of a probe
    • ≤ Number of probe insertions + 1
  – Touch count: Number of touch downs on the bond pad
    • Top metal thickness ≤5500Å: max touch count = 3
    • Top metal thickness >5500Å: max touch count = 5

• **Impact: Increased disturbed area**

• **Why multiple probe marks?**
  – Dual or tri-temp probe
  – Multi DUT probe and re-probe
  – Data retention bake → pre and post bake probe
**Probes card technology vs number of probe marks and disturbed area**

<table>
<thead>
<tr>
<th>1 Probe mark</th>
<th>2 Probe marks</th>
<th>3 Probe marks</th>
<th>≥4 Probe marks</th>
</tr>
</thead>
</table>

- Multiple DUT probe with multiple probe insertions is only possible with advance probe card technologies.
- The probe tip diameter selection is critical to comply with the max disturbed area requirement.
Impact of touch count

- **Experiment on cantilever touch count**
  - Overdrive = 75μm (worst case)
  - Increment touch count 1 to 7
  - Thin top metal: thickness ≤5500Å

- **Conclusion:**
  - Cantilever:
    - Impact on probe depth and disturbed area (scrub)
    - Aluminum build up at end of scrub
  - Vertical: main impact on probe depth
  - Touch count ≥ 5: Exposed Metal Oxide (EMO)

![Touch count images](image_url)
Cantilever probe impacts bond process

- Aluminum build up at end of probe mark
  - Build up amount driven by overdrive and touch count
  - Random height
- Intermetallics only formed at part of the bond area
- Potential risk: Bond ball lift at temperature
Summary: Temperature impact

- **Z deflection**
  - Dominated by PCB thermal behavior
  - Best result at 175ºC: 15µm
  - Best result at -50ºC: 10µm

- **XY movement of probes**
  - Cantilever:
    - Large differences depending on spider build quality
    - Difference between individual probes ➞ Swaying probes
  - Vertical:
    - Determined by probe head design
    - All probes show similar movement ➞ Probe head drift
  - Best result at 175ºC: 6µm
Summary: Bond pad damage

- Automotive requirements and multi DUT probe require more advanced probe card technologies
- Standard Cantilever probe cards
  - Disturbed area is very dependent on applied overdrive
  - Difficult to comply with automotive requirements
  - No Scrub™ (Technoprobe) is a potential alternative
- **Vertical probe cards**
  - Probe tip diameter drives the disturbed area
  - Disturbed area is less dependent on applied overdrive
  - ON Semiconductor uses ROUTE 60 ™ LL (Technoprobe) for high temp
    - Combined with ON Semiconductor patented concept for high temp cards
    - High current carrying capability: 850 mA
    - Low pad damage
    - Life time (tip length)
Future work

- Wafer probe at 200°C
- Optimize Multi DUT probe recipes to reduce number of probe marks and touch count
  - Ongoing evaluation on impact of the probe card configuration
  - Ongoing evaluation of Multi DUT probe stepping pattern
- Analyze the influence of temperature on Contact Resistance (Cres)
- Analyze behavior of probe on Over Pad Metalization (OPM)
Acknowledgements

• Frank De Ruyck
  – Equipment Engineer, ON Semiconductor

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  – Process Engineer, Technoprobe