IN-LINE PROBING OF BARE COPPER PADS

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Overview

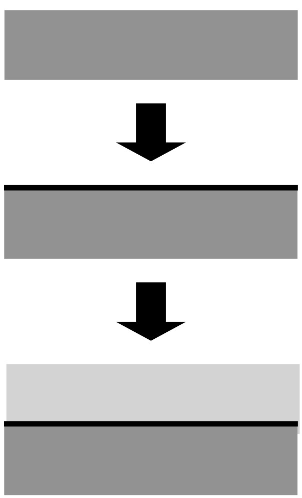
- Parametric Probe Objectives
- Aluminum (Al) vs. Copper (Cu) Pad Fabrication
- Brief Overview of E-Test (In-line) Probing
- Expectations Probing Cu
- Difficulties Probing Cu
- “Have We Lost the Recipe?!?”
- Cu Pad Characteristics
- Electrical Characteristics
- Next step - Cleaning Procedures
- Conclusions

Parametric Probe Objectives

- Reliably probe slotted and unslotted bare copper pads
- Characterize probe needle performance
  - Scrub marks
  - Contact resistance (C_{RES})
- Optimize overtravel and touchdown combinations
  - C_{RES} stability
  - Probe needle life
- Develop cleaning protocols

Typical Aluminum Pad Formation (Historical)

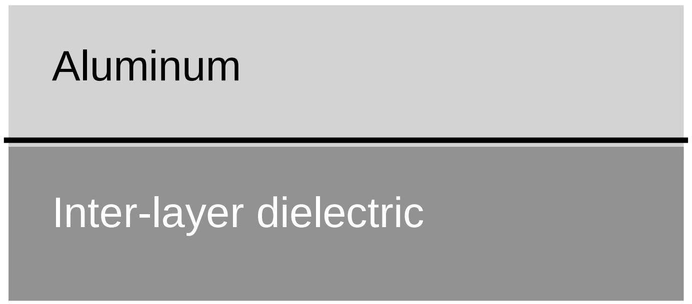
Aluminum Process



Inter-layer dielectric (ILD) over silicon

Barrier-Seed (Ti/TiN)

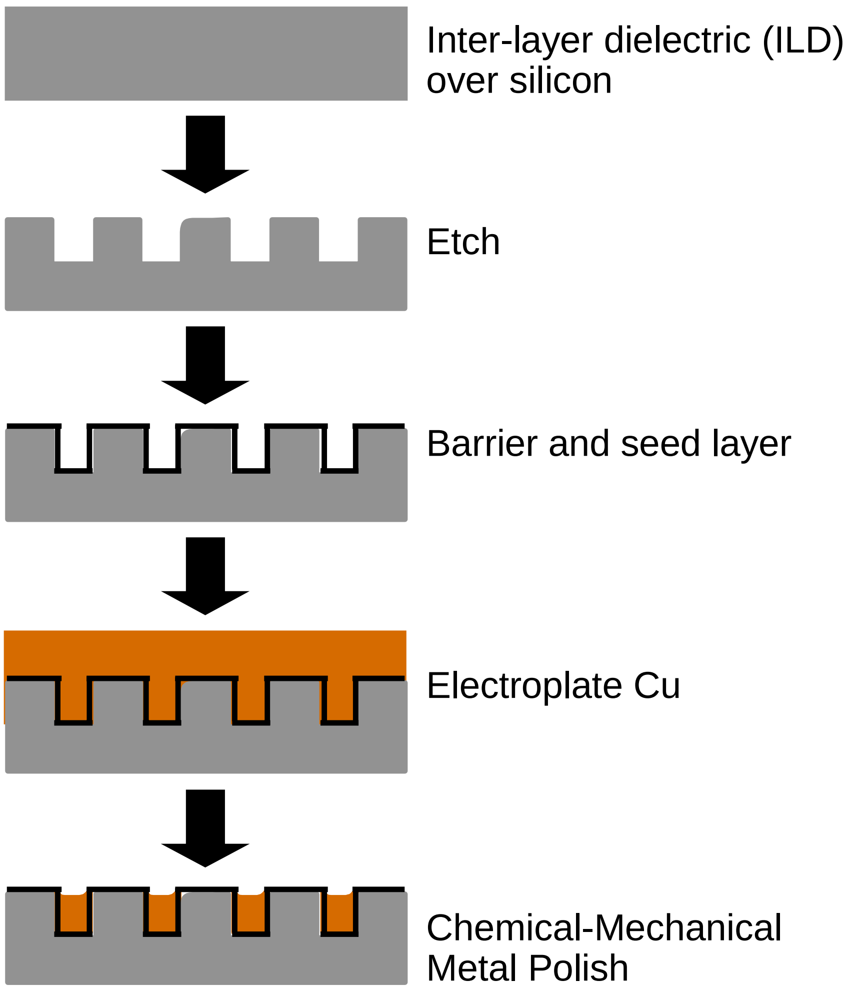
Al deposition

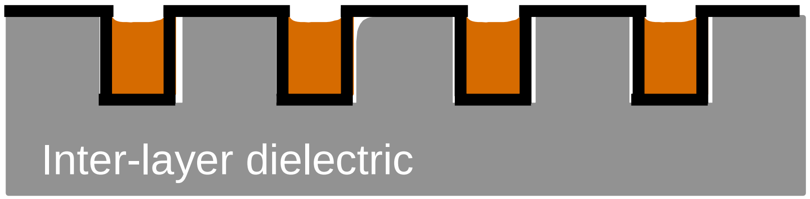


Resultant Aluminum Pad:

- Metal sits above ILD
- Surface is soft and conductive

Industry-Typical Copper Dual Damascene Process





Resultant “slotted” copper pad:

- Metal is recessed beneath Inter-Layer Dielectric (ILD)
- Metal in a matrix of ILD
- Surface is hard and non-conductive
- Striped or checkerboard geometry

Brief Overview of E-Test (In-line) Probing

- Purpose of E-Test
  - Developmental - Fab process characterization and control
  - Production - Test structure integrity for wafer-level dispositioning
- **NOT** measuring the chip functionality
  - Area sampling on a wafer - typically 5 to 16 sites per 200-mm wafer
- Measurements of parametric test structures
  - Threshold voltage
  - Capacitance
  - Sheet resistance
- Reliable and stable C_{RES} is critical for “good” measurements

Typical E-Test Probe Cards

- Tungsten (W) or tungsten-rhenium (WRe) probes
- Epoxy ring or ceramic blade construction
- Relatively loose pitch (~100 μm)
- Relatively large pad dimensions (~70 to 90 μm)
- Low leakage current requirements (pico- to femtoamps)
- Low pin counts
  - Intel: 2×15 (development) and 1×25 (production)
  - TI: 2×10 (development) and 1×20 (production)

Cu Parametric Probing Expectations

- Bulk Copper is softer than bulk Aluminum
  - Probing Cu-pads will be similar to Al-pads
  - Low and stable C_{RES} will be attainable
- TI and Intel had done little E-test probe development in 15 years
- Expected little (if any) development work in changing to Cu

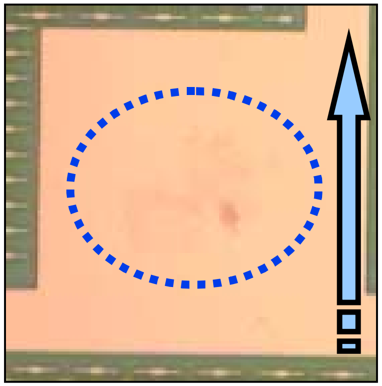
"This should be easy!"

Summary of Cu Pad Probing Difficulties

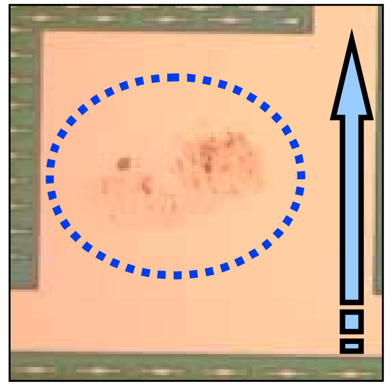
- Poor results when probing with W and WRe-probes
- Unstable and high contact resistance
- Probes “stick” rather than slide across the pad
- Nearly invisible scrub marks
- Increasing the overtravel and/or BCF had little to no effect
- Interactions between tungstenates and cupric oxides (both grow at ambient temperatures)
  - Initial cupric oxides form quickly on pad surface
  - Cupric oxides have different properties than Al_2O_3

TI: Solid Pad Characterization

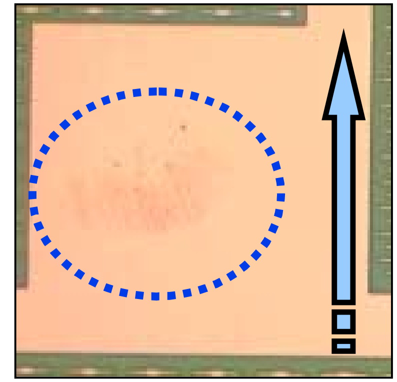
- Scrub mark evaluation with WRe-probes



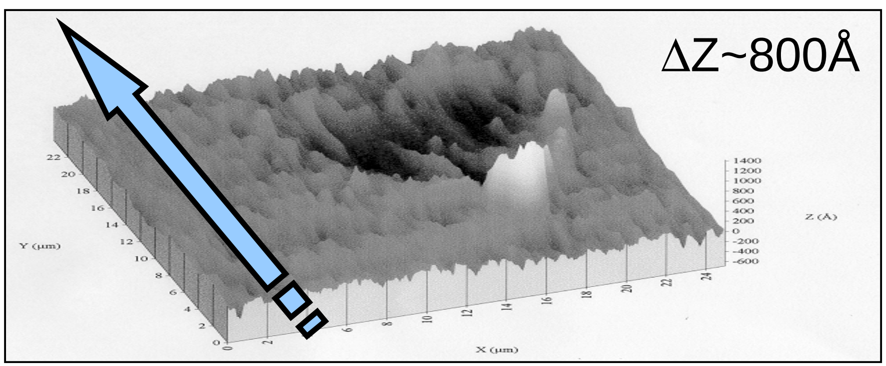
Scrub Mark at 40 µm (1.6 mil) overtravel



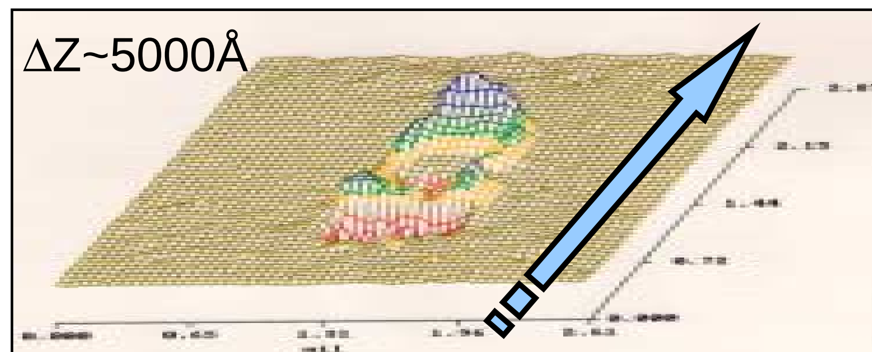
Scrub Mark at 80 µm (3.2 mil) overtravel



Scrub Mark at 120 µm (4.7 mil) overtravel



Cu-Pad scrub mark at 80 µm overtravel



Al-Pad scrub mark at 80 µm overtravel

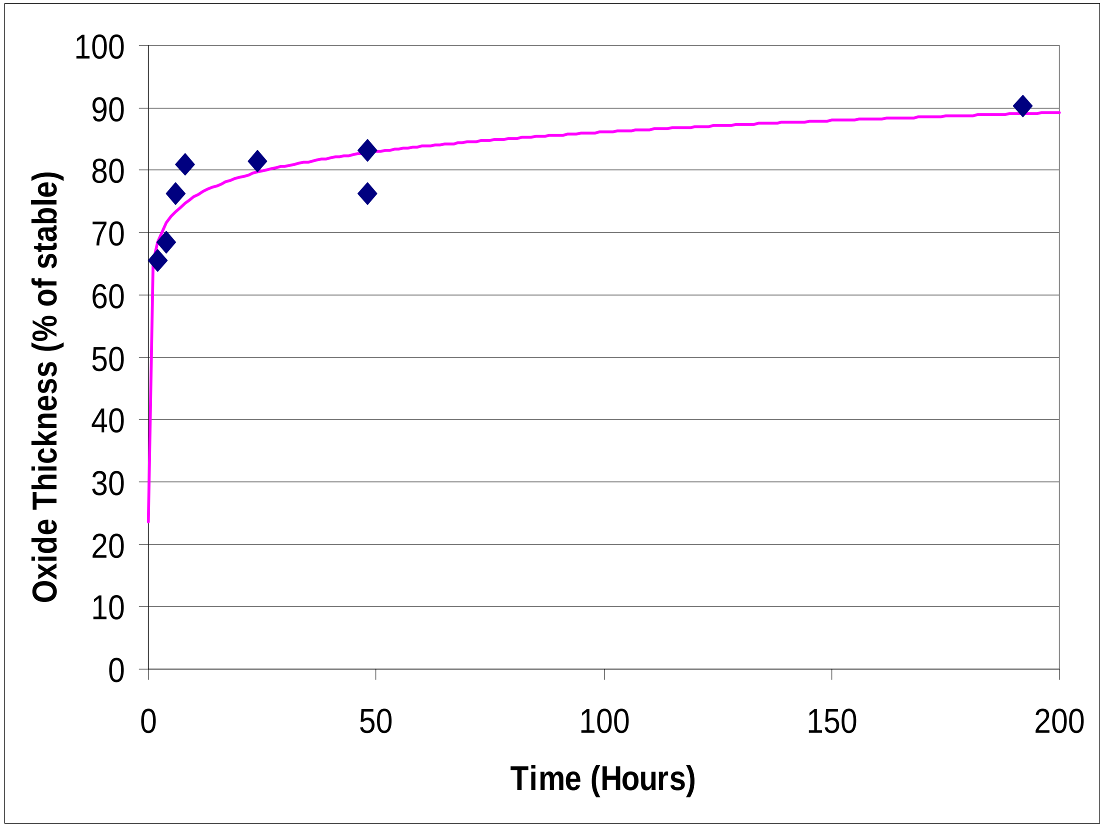
“Have We Lost the Recipe?!?”

- Traditional, tungsten-based needle materials did not work with any probing parameters
- Full-scale development effort needed
  - Probe-pad interactions (oxide formation)
  - Probe needle material alternatives (non-oxidizing alloys)
  - Cu-pad material hardness
- Probe process **MUST** work on both solid and slotted pads

Copper Pad Oxidation

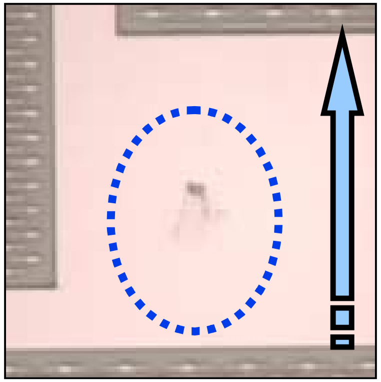
- Cupric-oxides on the pad surface under ambient conditions (V. Dubin, Intel, 2000)

Time (hours)	Thickness (nm)	% of final thickness
2	1.41	65.6%
4	1.47	68.4%
6	1.64	76.3%
8	1.74	80.9%
24	1.75	81.4%
48	1.79	83.3%
48	1.64	76.3%
192	1.94	90.2%
2400	2.15	100.0%

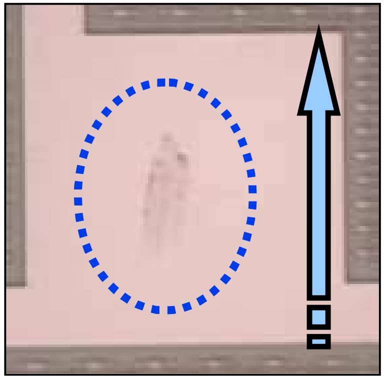


TI: Solid Pad Characterization

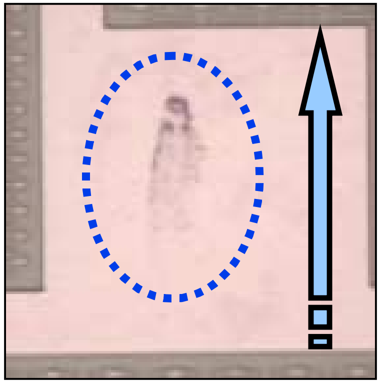
- Scrub mark evaluation with metallic alloy and BeCu probes



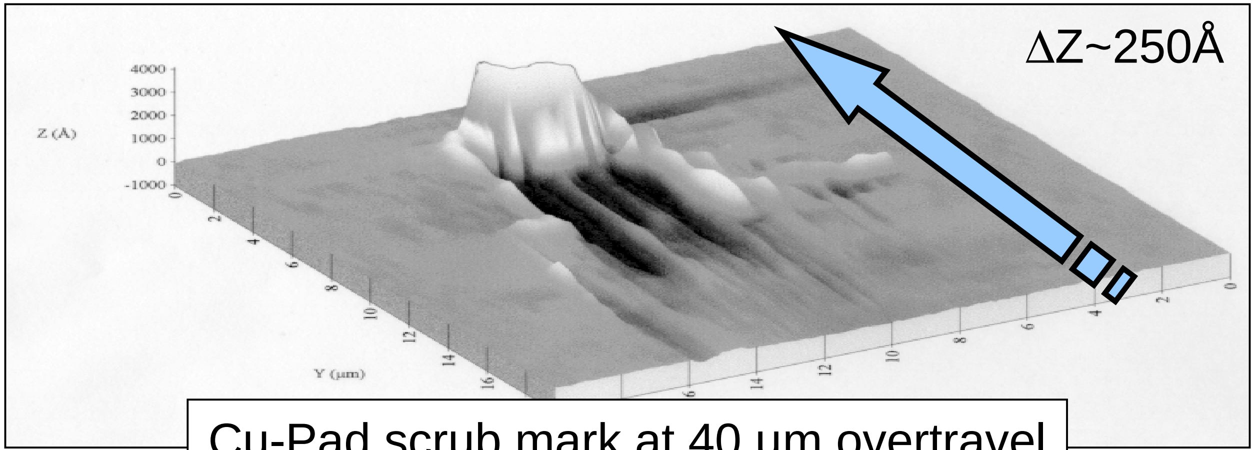
Scrub Mark at 40 µm (1.6 mil) overtravel



Scrub Mark at 60 µm (2.4 mil) overtravel



Scrub Mark at 80 µm (3.2 mil) overtravel

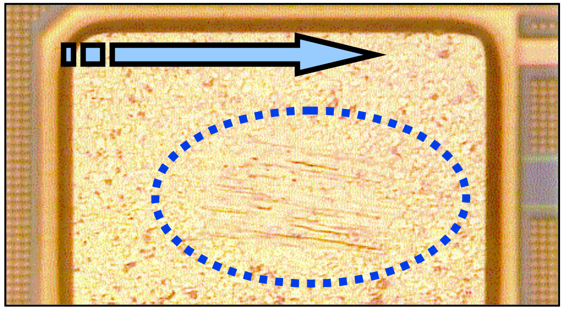


Cu-Pad scrub mark at 40 µm overtravel

Intel: Solid Pad Characterization

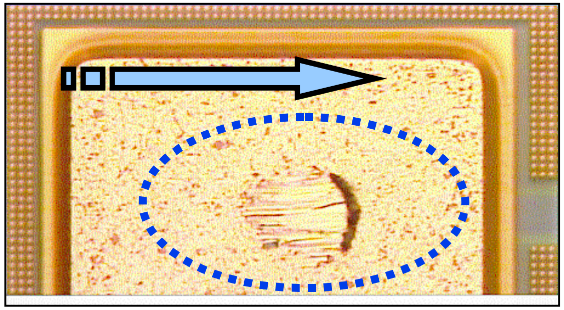
- Scrub mark evaluation - *standard probing process for all probe materials*

Tungsten probes

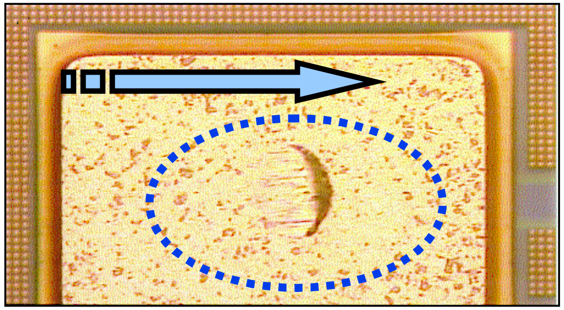


Scrubs marks made with 2 TDs at 100 μm overtravel

Metallic alloy probes



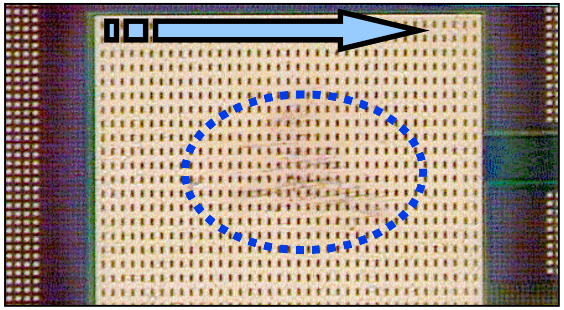
Beryllium-copper probes



Intel: Slotted Pad Characterization

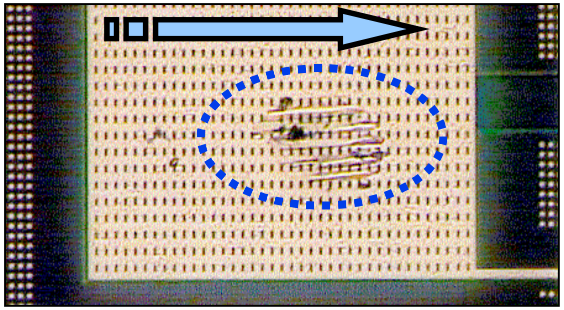
- Scrub mark evaluation - *standard probing process for all probe materials*

Tungsten probes

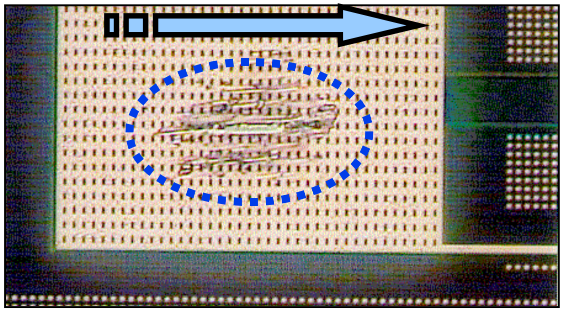


Scrubs marks made with 2 TDs at 100 µm overtravel

Metallic alloy probes



Beryllium-copper probes



Copper Pad Hardness

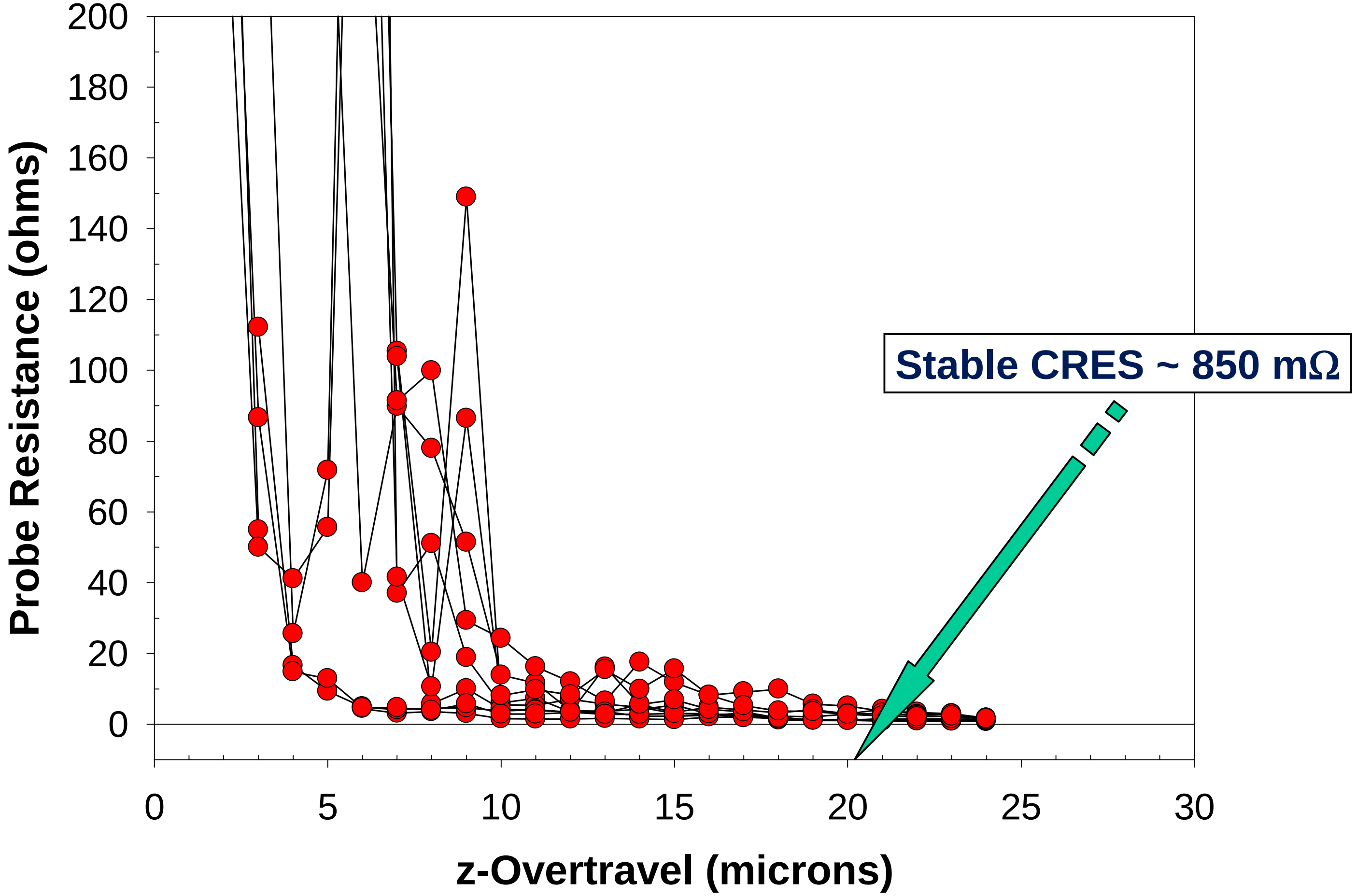
- Electroplated Cu hardness is sensitive to conditions such as:
  - Current density
  - Bath chemicals
  - pH acidic or basic
  - Annealing
- Material hardness: *(from "Properties of Electro-deposited Metals and Alloys")*
  - Electroplated Cu = 0.5 up to 3.4 GPa.
- Solid Cu pad:
  - Intel - approximately 2X Al pads
  - TI - approximately 2.5X Al pads
- Slotted Cu pad:
  - Intel - approximately 18X Al pads
- Hardness of the slotted pad is dominated by the SiO_2
  - SiO_2 is ~ 9.5 GPa

Scrub Marks on Copper Pads

- Cu pad metal is significantly harder than Al pad metal
- Cupric oxides form quickly on the pad surface
- Non-oxidizing probe materials scrub through the cupric oxides
- “Good” scrub marks can be obtained low BCF and overtravel

**“We’re not in the scrub mark business,
we’re in the electrical measurement business…..”**

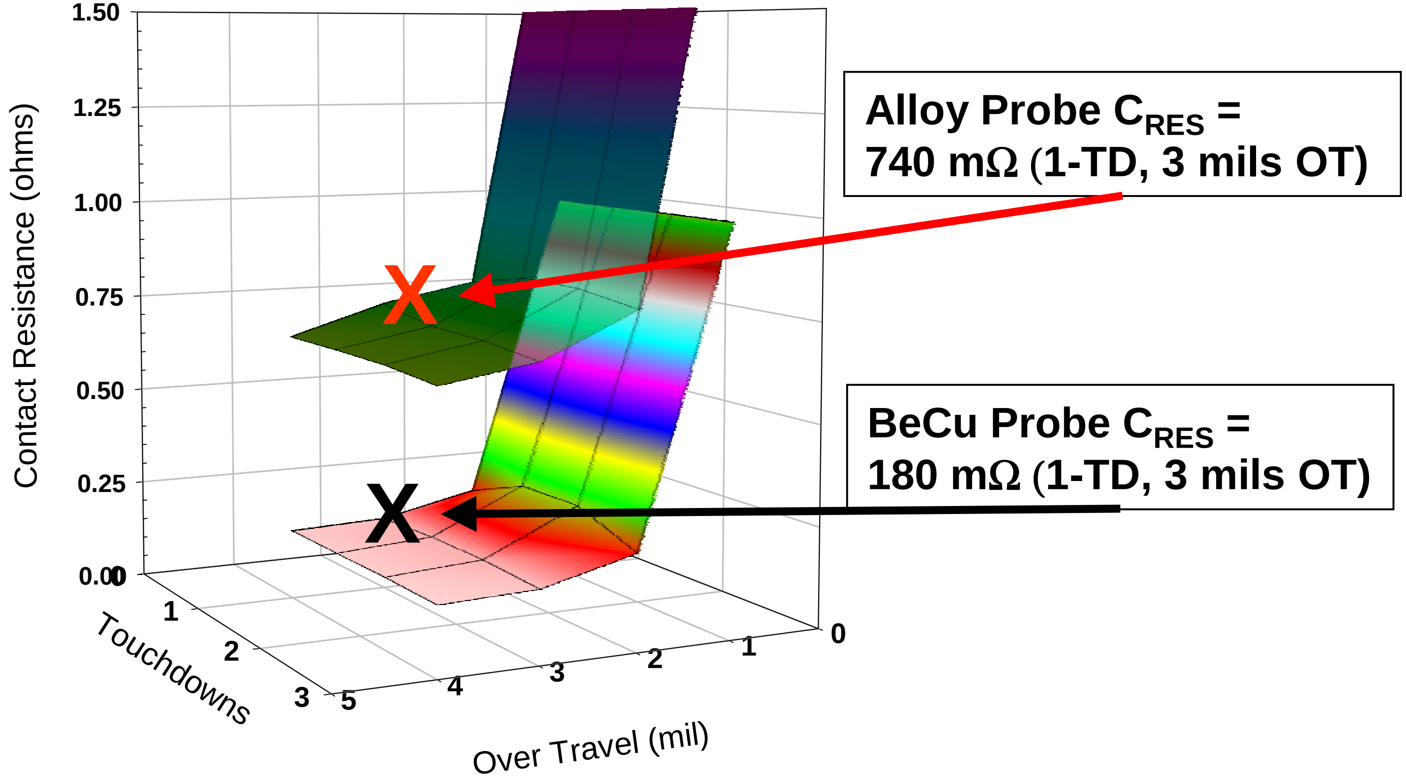
TI: Overtravel vs. C_{RES} on Copper Pads



- BeCu probes at 1.25 grams/mil of overtravel

Intel: Solid Pad Characterization

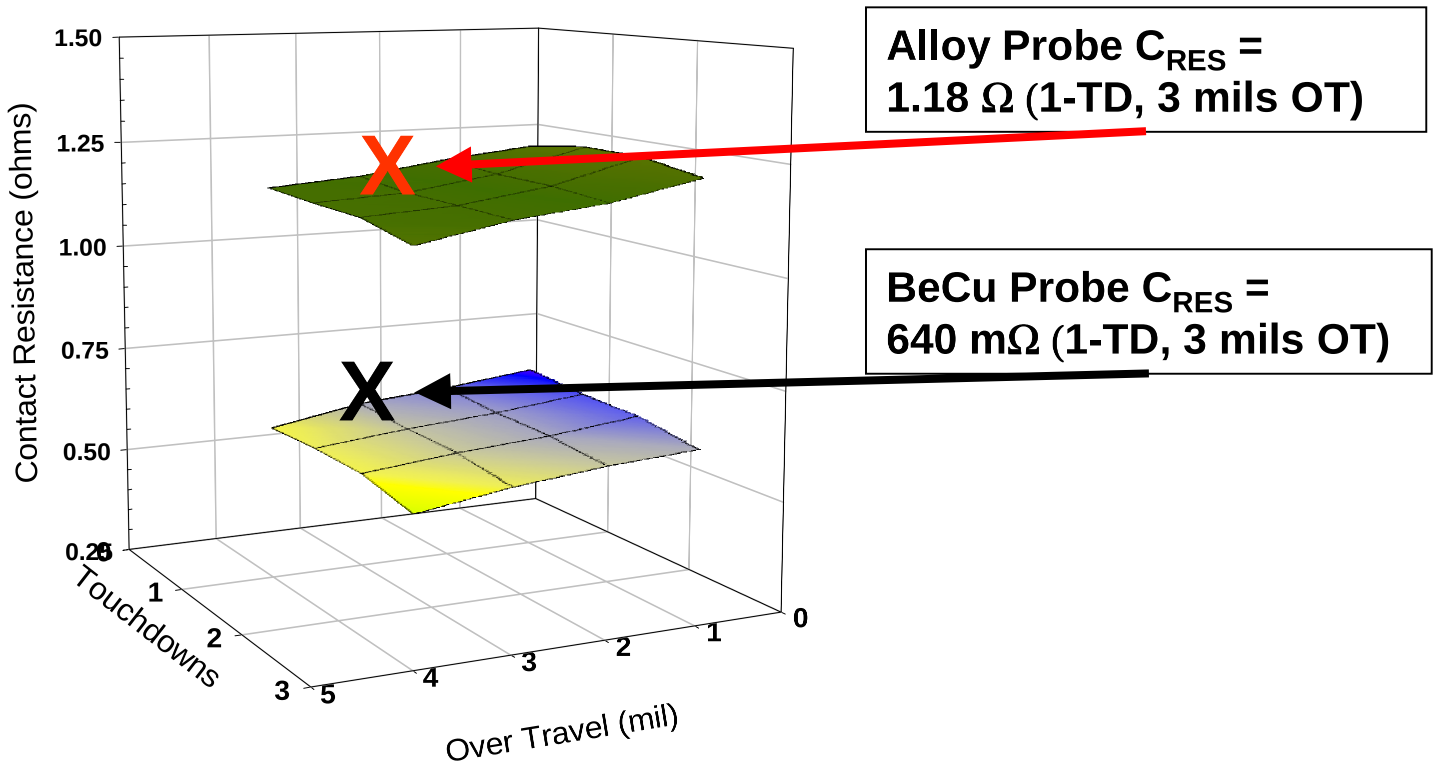
- Overtravel and touchdown evaluation



- C_{RES} differences attributed to higher bulk resistivity of metallic alloy probes
- Total resistance measurement of two probes and two adjacent shorted pads
- Note: Tungsten C_{RES} is approximately 670 mΩ

Intel: Slotted Pad Characterization

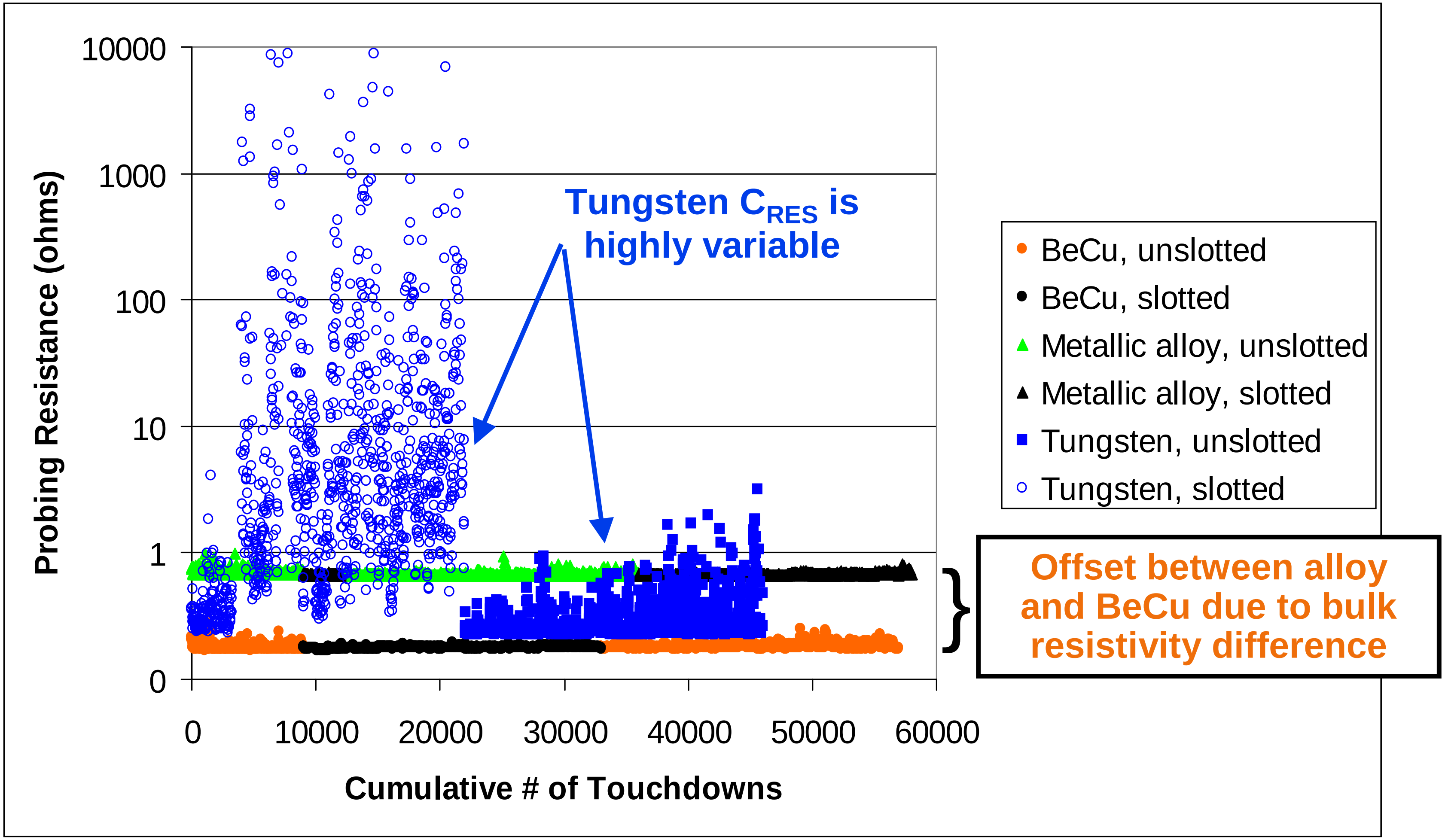
- Overtravel and touchdown evaluation



- C_{RES} for all data points is shows low variability and “near” to tungsten values
- Single touchdown processes give good results -- test time and probe-card lifetime extender opportunities

Intel: Contact Resistance Behavior

- C_{RES} measured every 20-touchdowns



Next step - Cleaning Procedures

- Intel and TI plans are similar:
  - Looking at various cleaning substrates
    - Ceramics
    - Metals
    - Polymers
  - Various grit sizes
  - Cleaning process
    - Number of touchdowns
    - Overtravel
    - Scrub shape
  - Determine optimal cleaning frequency

Conclusions

- Hardness of the Cu-pads is higher than that of Al-pads and affects the ability of the probes to leave scrub marks
- Tungsten based probes do not provide stable contact resistance values or make good scrub marks on copper
- Interactions between probe and pad are presumably causing the problem, possibly tungstenates on the probes or a higher friction coefficient
- Probing with the non-oxidizing materials easily resolves the issue at lower BCF and reduced over-travel
- The non-oxidizing probe materials gave a tremendous C_{RES} improvement
- BeCu probes provided the best scrub marks and had the lowest mean and variability of C_{RES}
- More work on the probe cleaning process needed