SWTW

IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

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Transverse Load Analysis For Semiconductor Applications

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UNR Owen Stedham Award

- **Awarded by the UNR Mechanical Engineering Department to the best Senior Capstone Team and Project that exemplifies high levels of ingenuity, acumen, and professionalism.**

2D-LC Capstone Team
Front: Soheil Khavandi, Jordan James, Parker Fellows
Back: Robert Hartley, Aaron Lomas

Overview

- Introduction
- Motivation
- Objectives /Approach
- Methodology
- Characterization/Results
- Summary / Future Work
- Acknowledgements

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Introduction

- **Probe card technologies are more advanced; however, the contact basics of wafer sort really have not changed.**

- **ALL probe technologies have a contact area substantially harder than the pads, solder balls, or pillars of the device.**

- **"<u>Contact and slide</u>" is CRITICAL to break through oxides, but results in localized plastic deformation.**

- **Volume of material displaced during the slide is a function of probe contact mechanics, metallic interactions, frictional effects, and tribological properties between the pad and contact.**

Controlled Contact is a TOP GOAL

- **To control wafer test is to control the mechanical contact and the electrical contact between the probes and the DUT.**

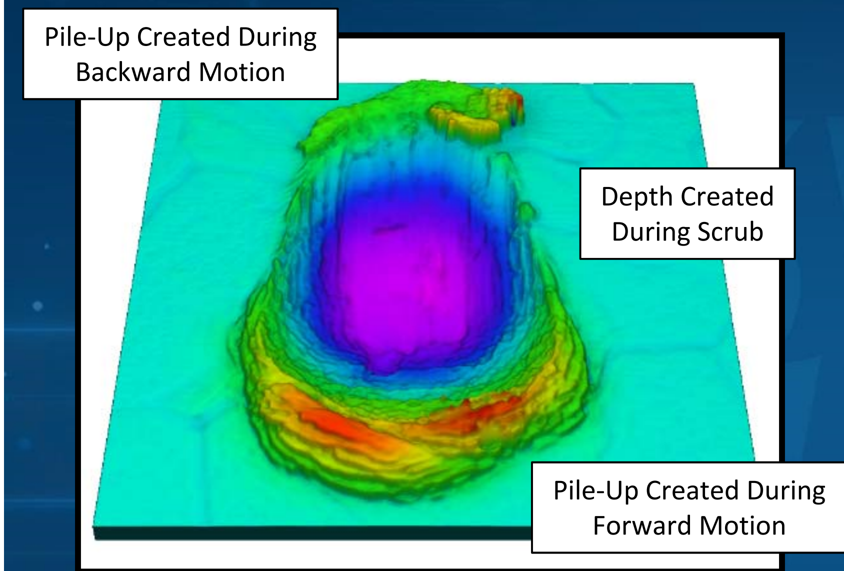
- Control Variables
  - Probe Force
  - Overtravel
  - Probe Placement (XYZ)
  - Current / Duration
  - Temperature
  - Cleaning Execution

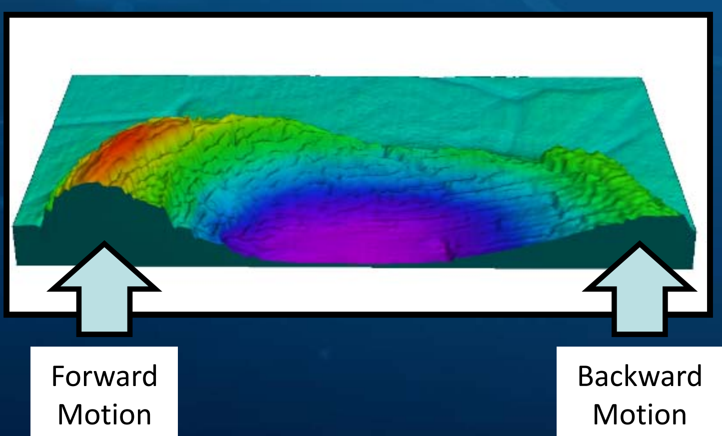
- Process Monitors
  - Probe Yield
  - Binout Metric
  - Contact Resistance
  - Probe Mark
  - Re-Probe / Re-Test
  - Pad and Bump Damage

Apply the least contact that ensures reliable electrical connection.

Plastic Deformation (Probe Marks)

Probe Mark Anatomy

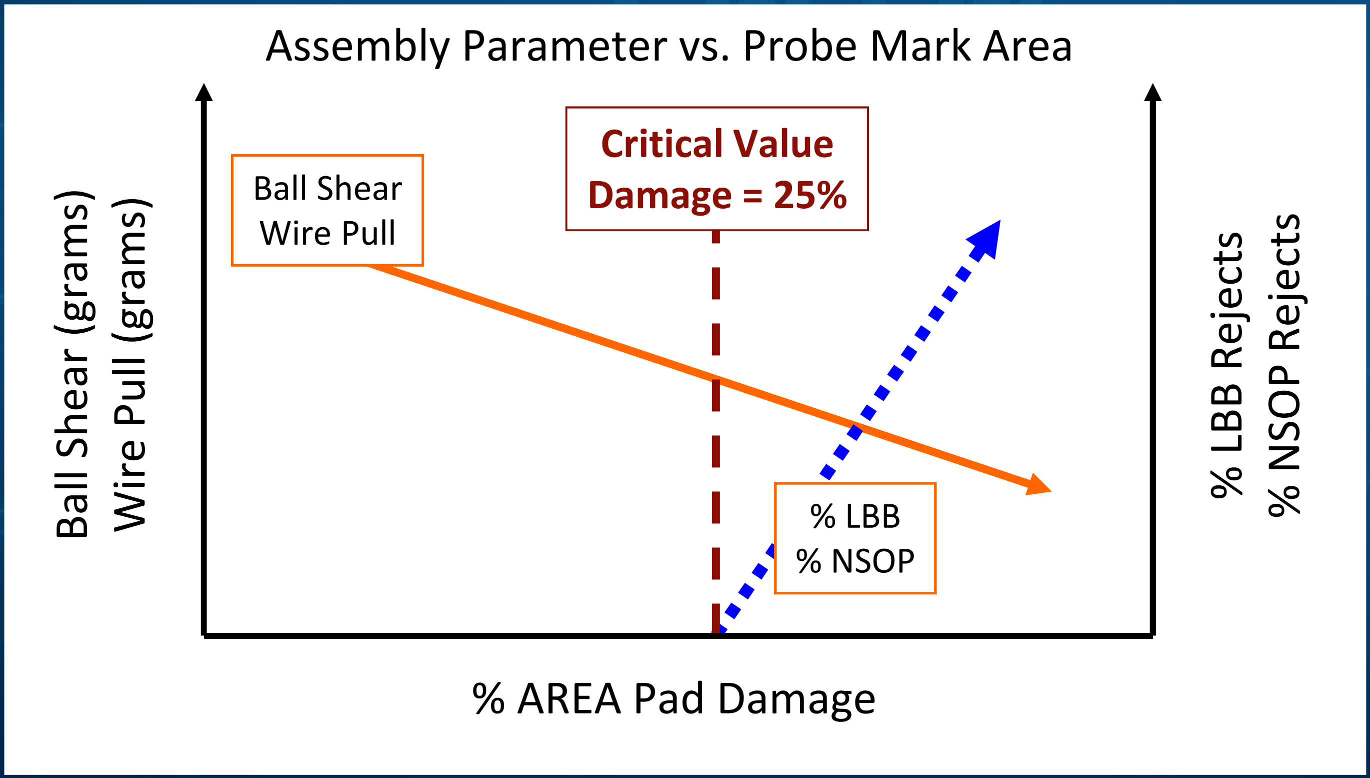




- Stress distribution during the scrubbing has been shown by cause underlying damage and cracking.
- Repeated probing has been shown to displace material and create under pad damage.

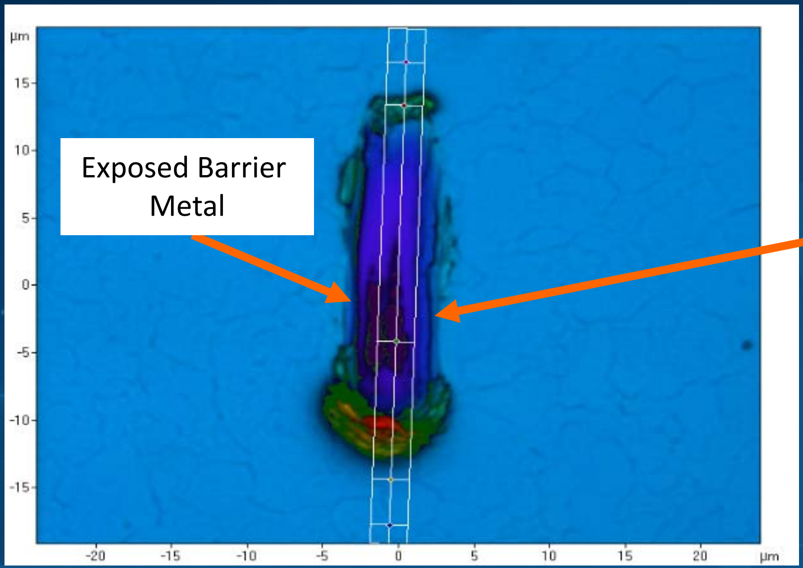
Area Effects

- **Probe Mark Area positively correlated to bondability issues.**
  - Reduced ball shear strength and wire pull strength
  - Increased NSOP (no stick on pad) and LBB (lifted ball bond)



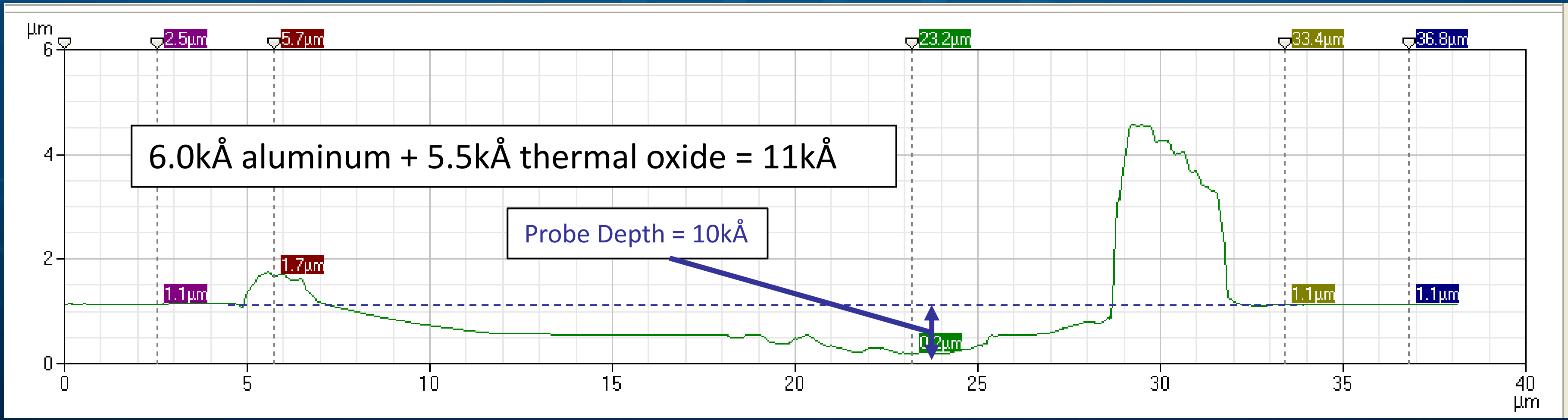
Sources …
Tran, et al., ECTC -2000
Tran, et al., SWTW-2000
Langlois, et al, SWTW-2001
Hotchkiss, et al., ECTC-2001
Hothckiss, et al., IRPS-2001
Among others …

Area Effects Are Not Enough !



- **A probe mark can have a small area of damage, but exceed critical depth.**
  - % Damage < 9 % (which is within limits)
  - Depth = 10kÅ (which is excessively deep)

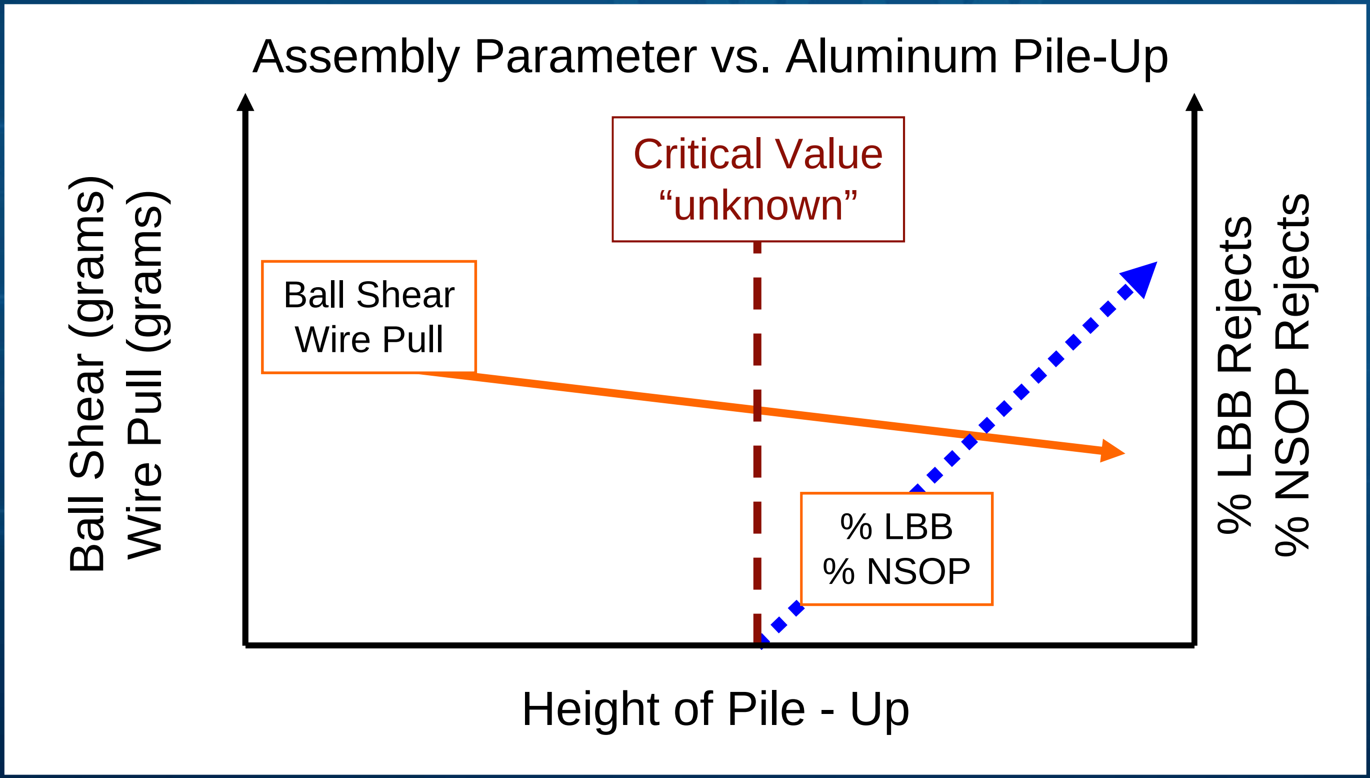
- **Multiple touchdowns will further displace the pad material and expose the barrier metal**



Miller, et al., SWTW-2007

Height Effects

- **Pile-up has been correlated to bondability issues.**
  - Reduced ball shear strength and wire pull strength
  - Increased NSOP (no stick on pad) and LBB (lifted ball bond)



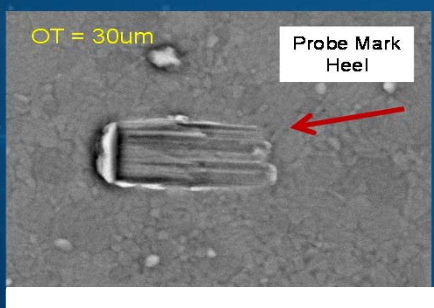
Sources …
Langlois, et al, SWTW-2001
Among others …

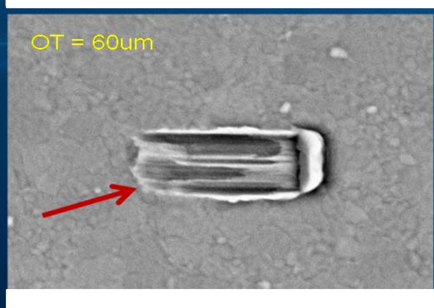
Metal Thickness Affects Probe Mark Properties

6kÅ Wafer

- OT = 30um
- Length = ~10 to ~14um
- Depth = ~3.5 to ~3.8kÅ

- OT = 60um
- Length = ~18 to ~20um
- Depth = ~5.0 to 5.4kÅ

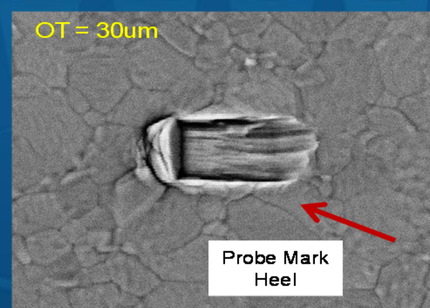


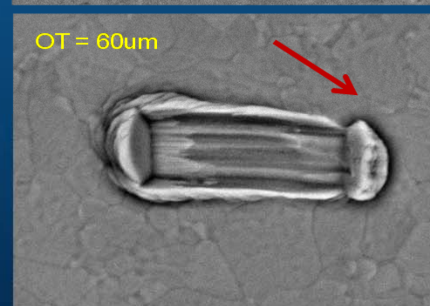


15kÅ Wafer

- OT = 30um
- Length = ~12 to ~14um
- Depth = ~8.0 to ~8.3kÅ

- OT = 60um
- Length = ~20 to ~22um
- Depth = ~12.0 to 12.3kÅ

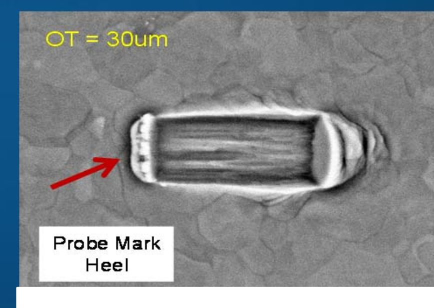


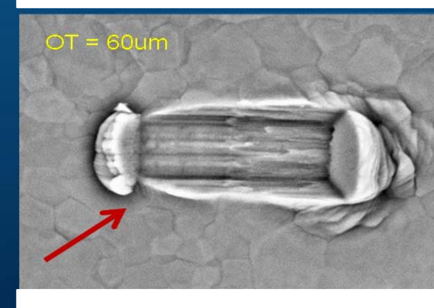


30kÅ Wafer

- OT = 30um
- Length = ~16 to ~18um
- Depth = ~14.6 to 16.2kÅ

- OT = 60um
- Length = ~22 to ~24um
- Depth = ~20.0 to 22.3kÅ

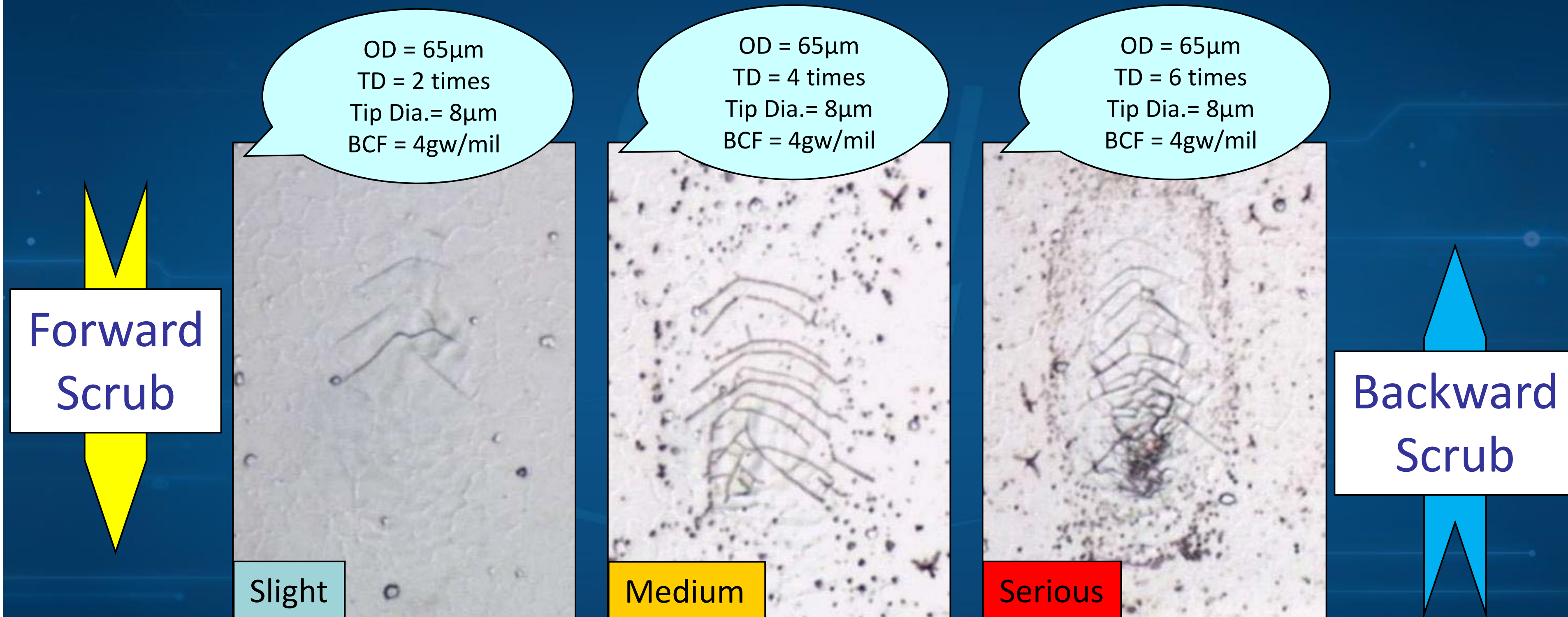




Bischoff, et al., SWTW-2012

Hidden Damage due to Probe

- **Under-layer micro-scratches and cracking attributed to probe.**



Hwang, et al., SWTW-2006

- **TaN Crack > Underlying Deformation > Pad Void**
- **z-Force is well determined from probe needle properties.**
- **Transverse loading conditions were not characterized.**

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Motivation

- Probe induced cracking of underlying structures is an ongoing test industry concern.
- Damage to underlying structures and circuit under pad (CUP) during wafer test, re-probe, and assembly affect reliability.
- Previous work has focused on high force / overtravel, tip shape, and multi-touchdowns without a “resistance to scrub” characterization.
- Little information on transverse / shear load effects during probe scrub on semiconductor wafers is available.

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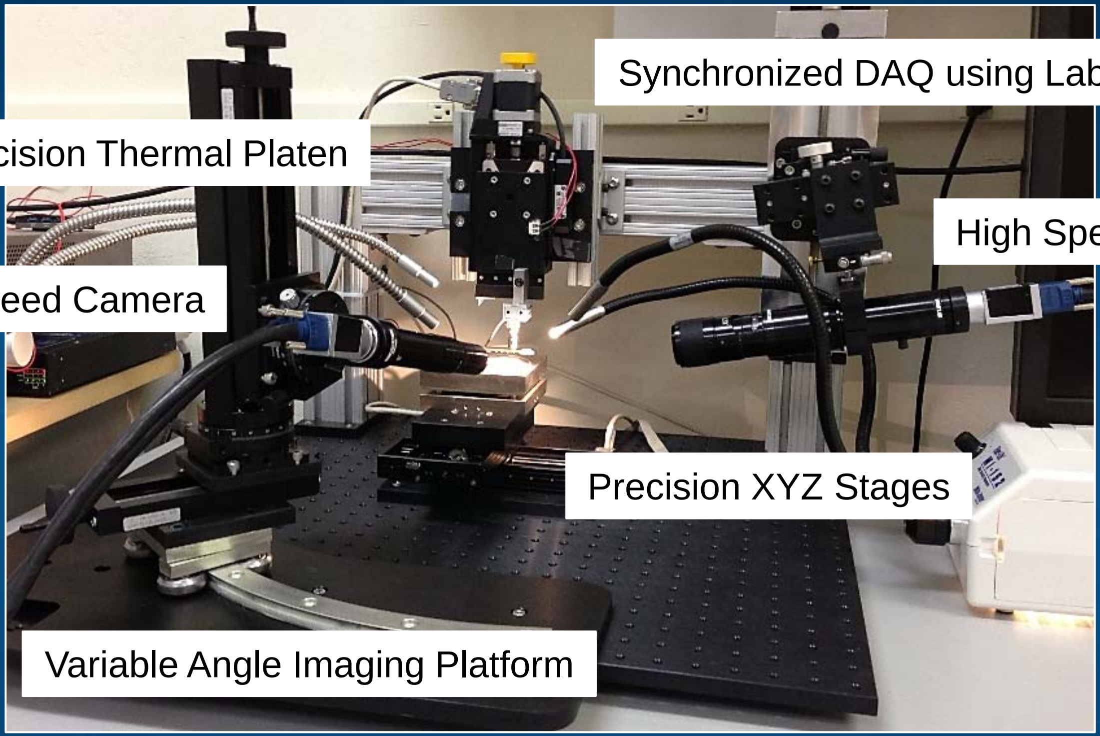
Objectives / Approach

- **Develop a methodology to study the "resistance to scrub"**
  - Design novel fixturing to simultaneously monitor xyz-Forces during probe
  - Determine changes in stress conditions on forward / backward scrub
  - Quantify metallization effects on xyz-Forces during probe
- **Apply Controlled Test Conditions with a Benchtop System**
  - z-probe force vs. z-Overtravel to assess performance consistency
  - xy-probe force vs. z-Overtravel to assess "resistance to scrub"
  - xyz-probe force vs. z-Overtravel vs. CRES for basic contact studies

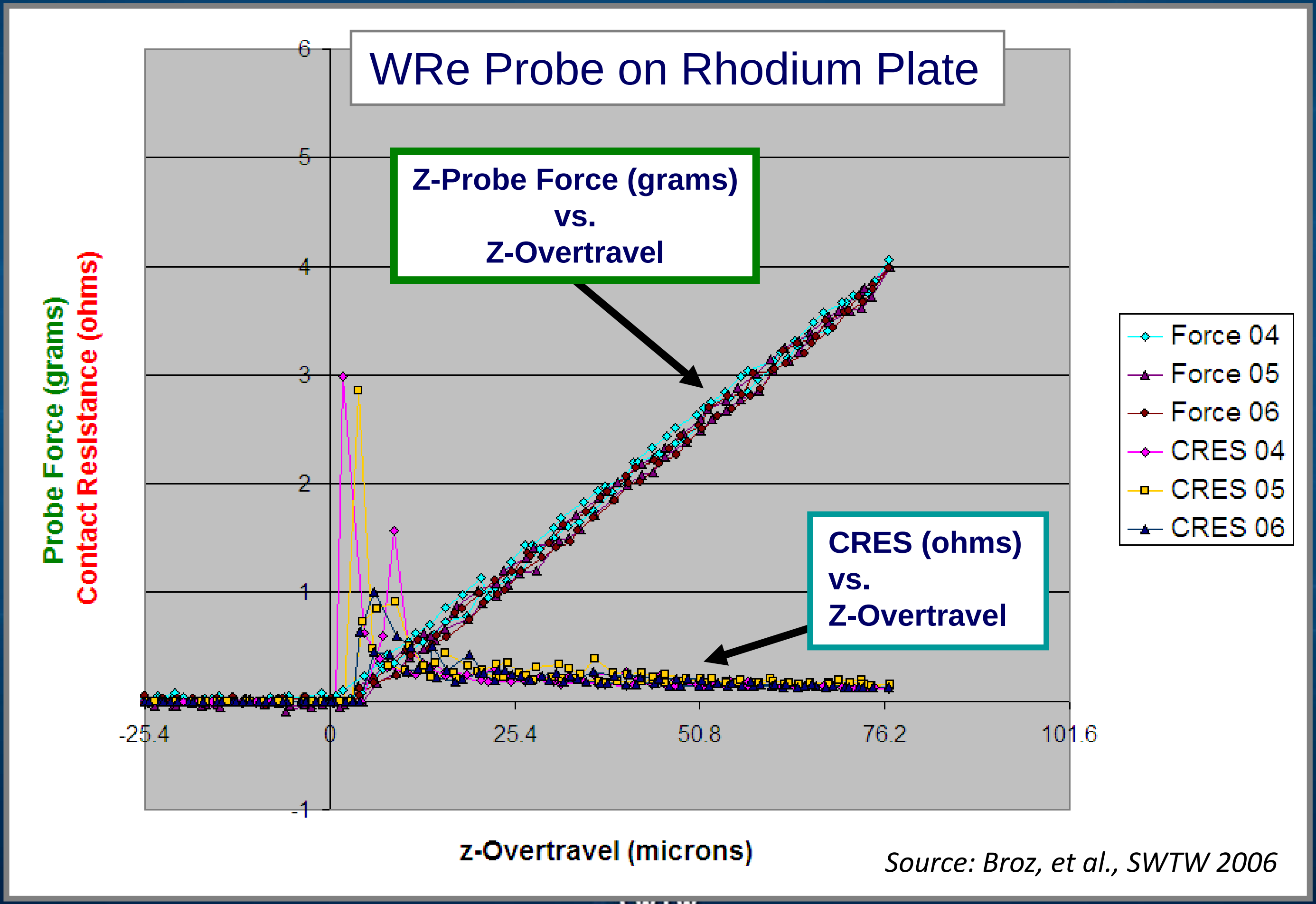
Controlled Test Conditions



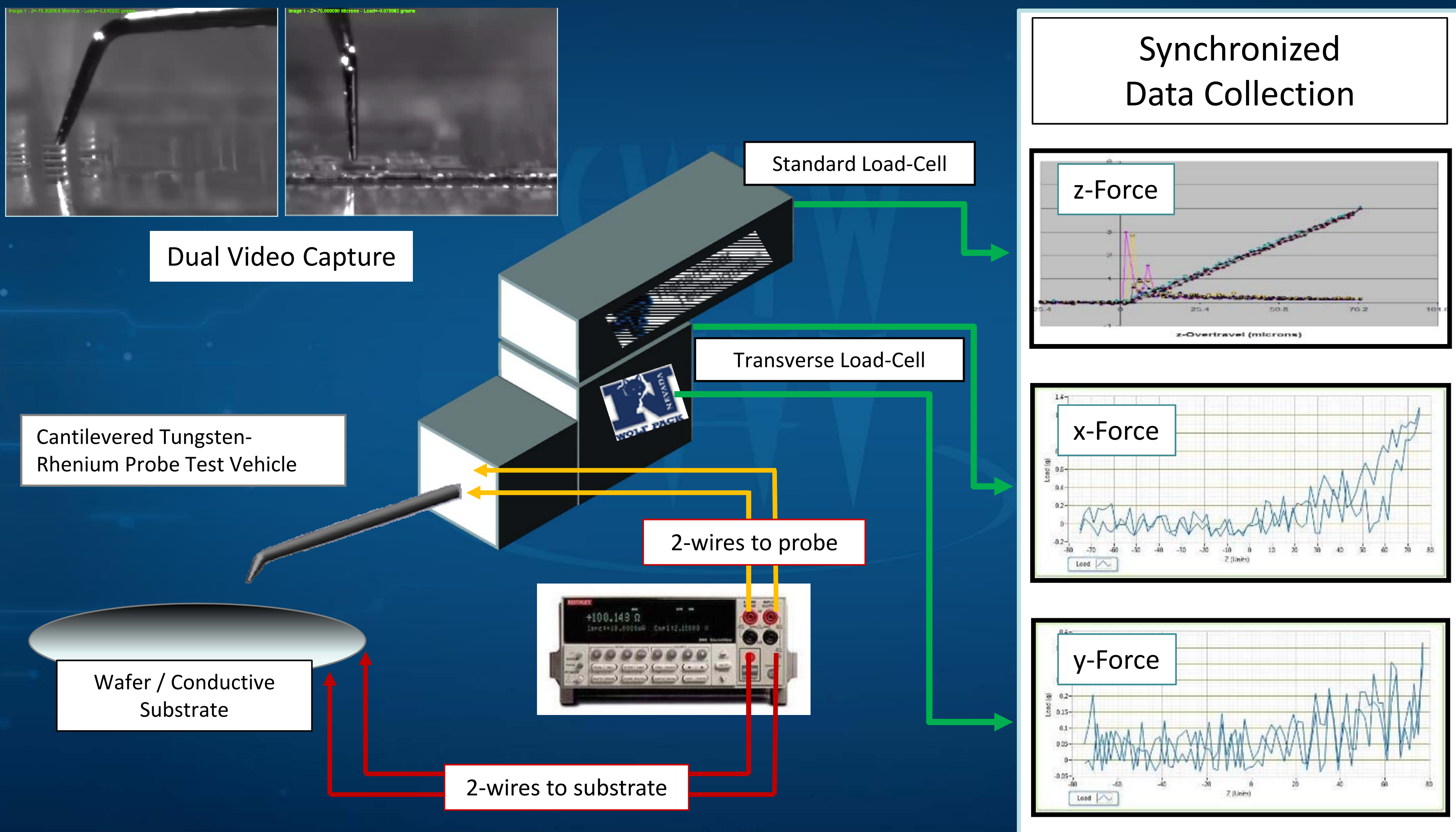
- Dual high speed cameras with for high resolution video imaging
- Synchronized load vs. overtravel vs. CRES acquisition vs. dual video capture
- z-Stepping and xy-indexing for cleaning recipe development

Basic Contact Mechanics and CRES

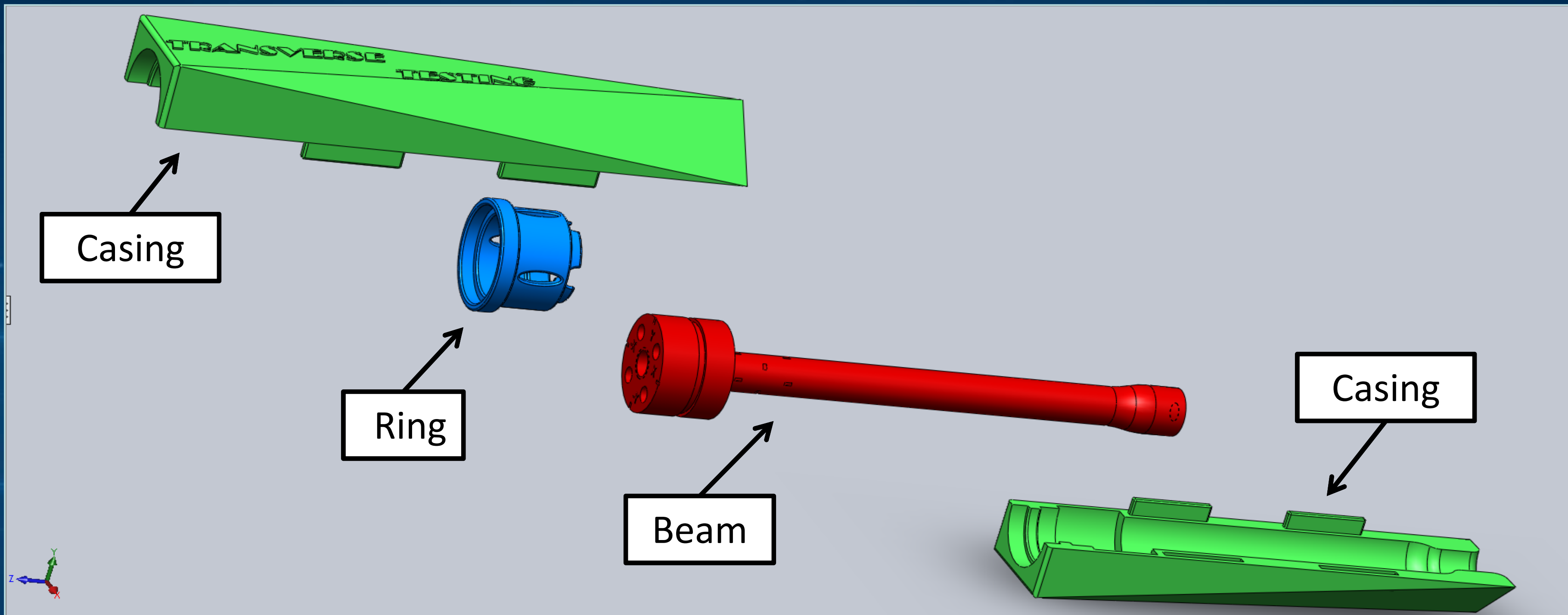
- **z-Probe Force vs. z-overtravel vs. CRES for contact assessment**

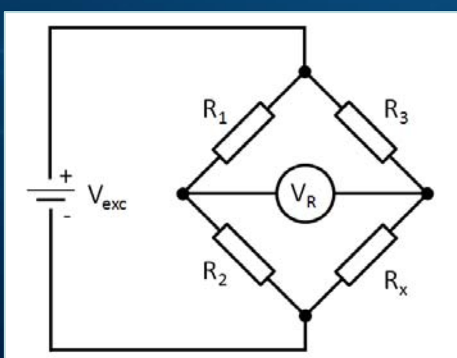


Transverse p-Force Testing



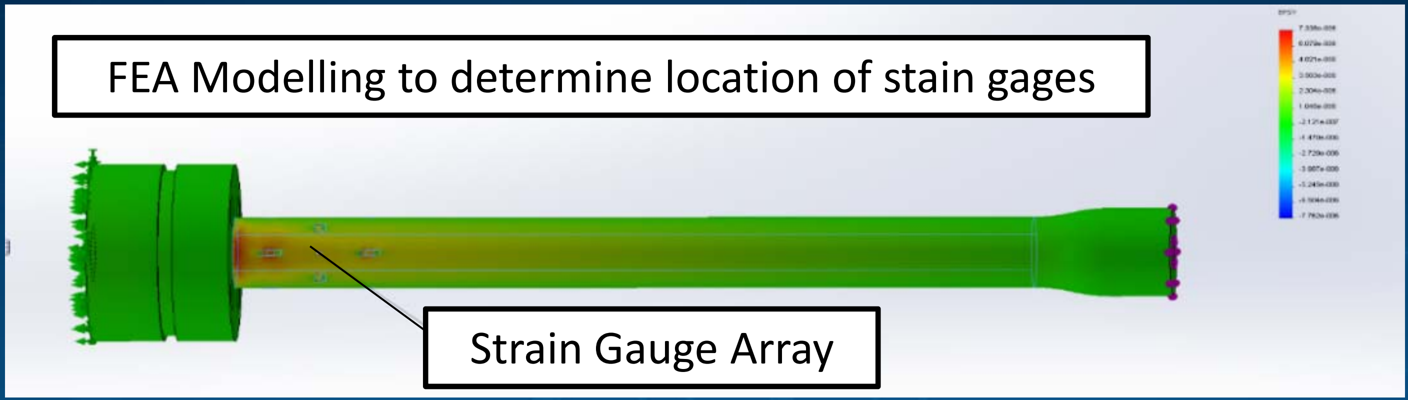
Transverse Load Cell Design





- Custom load cell instrumented with precision strain gauges in a Wheatstone bridge configuration.
- LabVIEW 2013 VI's developed for data collection, test system control and de-convolution to resolve xy force calculations.

Load Cell Development (FEA)



- Key Formulas

1. $F = \dfrac{4V_g I}{EV_{in}G_f Lh}$

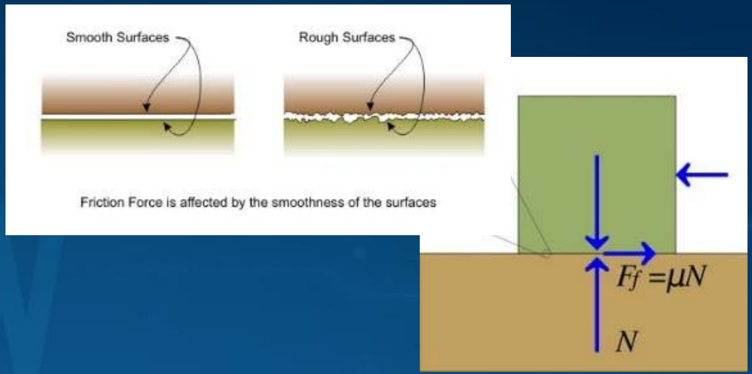
2. $\sigma = \dfrac{2V_g}{EV_{in}G_f}$

3. $\dfrac{\Delta R}{R} = \dfrac{\sigma G_F}{E}$

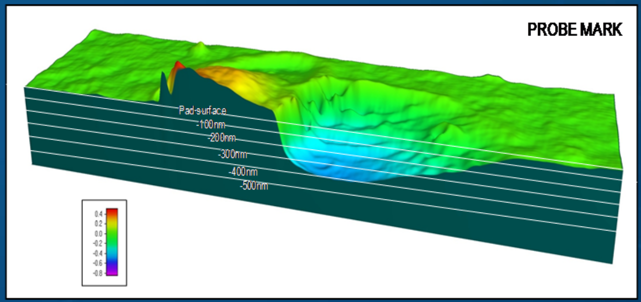
- $F = force$
- $V_g = voltage\ gain$
- $I = area\ moment\ of\ inertia$
- $V_{in} = initial\ voltage$
- $G_f = gauge\ factor$
- $L = Length$
- $h = height$
- $\sigma = bending\ stress$
- $E = modulus\ of\ elasticity$
- $\Delta R = change\ gauge\ resistance$
- $R = unstrained\ gauge\ resistance$

Approach

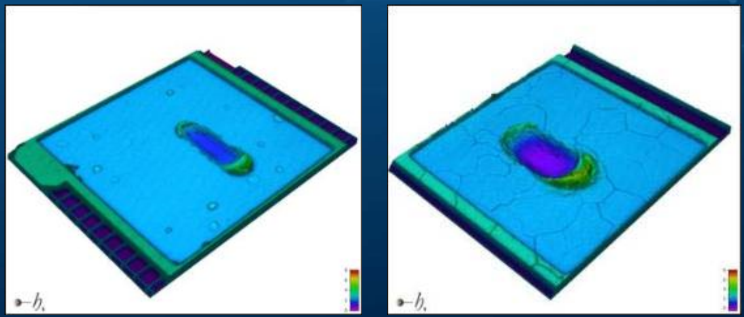
- **Proof of Concept**
  - Validate xyz p-Force measurements
  - Smooth surface vs. Rough surface



- **Investigate effects of aluminum thickness**
  - Resistance to scrub due to metal properties
  - Resistance to scrub due to contact texture



- **Aluminum Pads of Devibe**
  - Aluminum pads for xyz assessment



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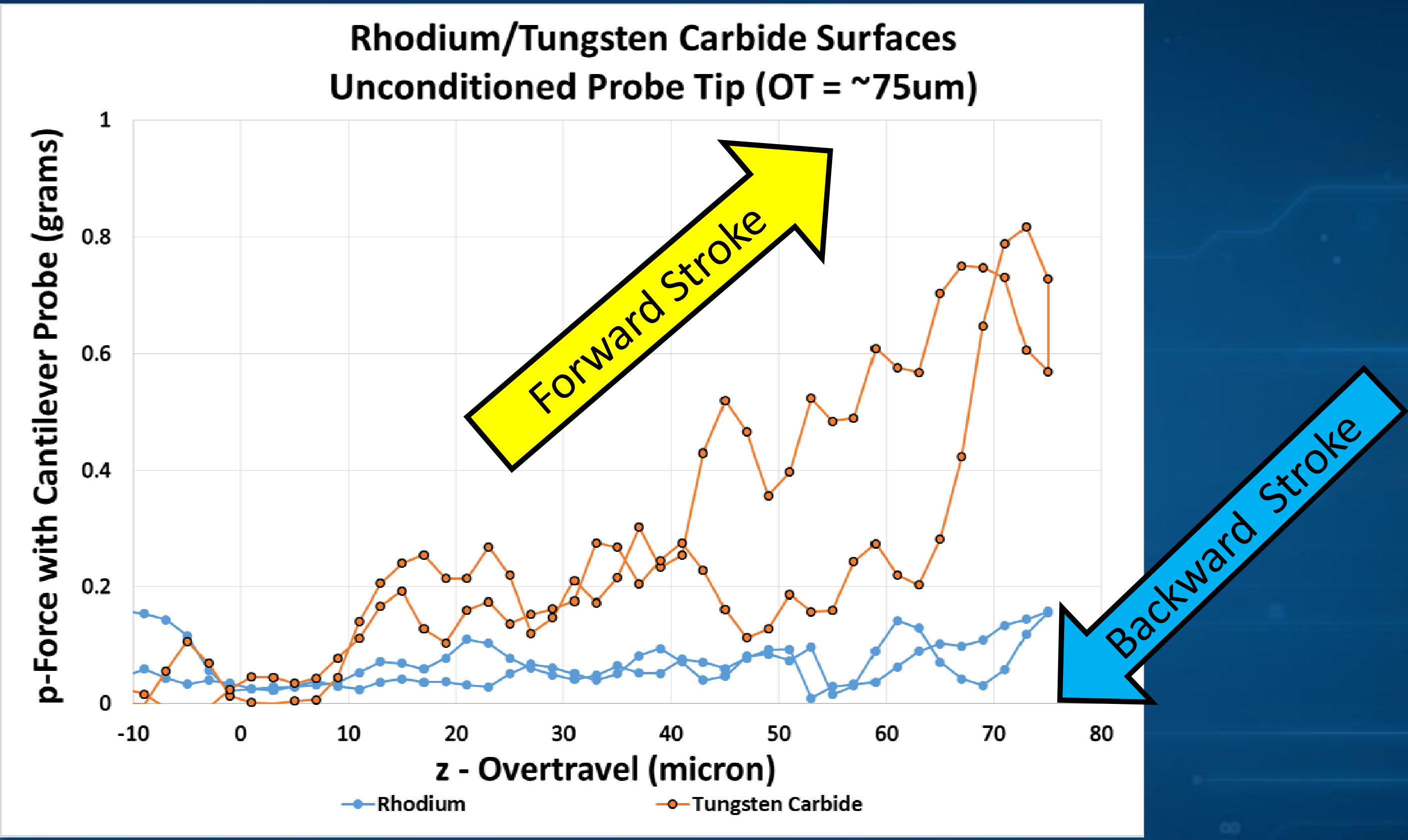
Methodology (Proof of Concept)

- **Materials**
  - Tungsten-rhenium, cantilever probe test vehicle
    - Initial = smooth surface as received from PC supplier
    - Conditioned = surface textured with ITS Probe Lap abrasive film
  - Substrates
    - Tungsten carbide plate used with PC analyzer at OT = 75um
    - Rhodium substrate with a polished surface at OT = 75um

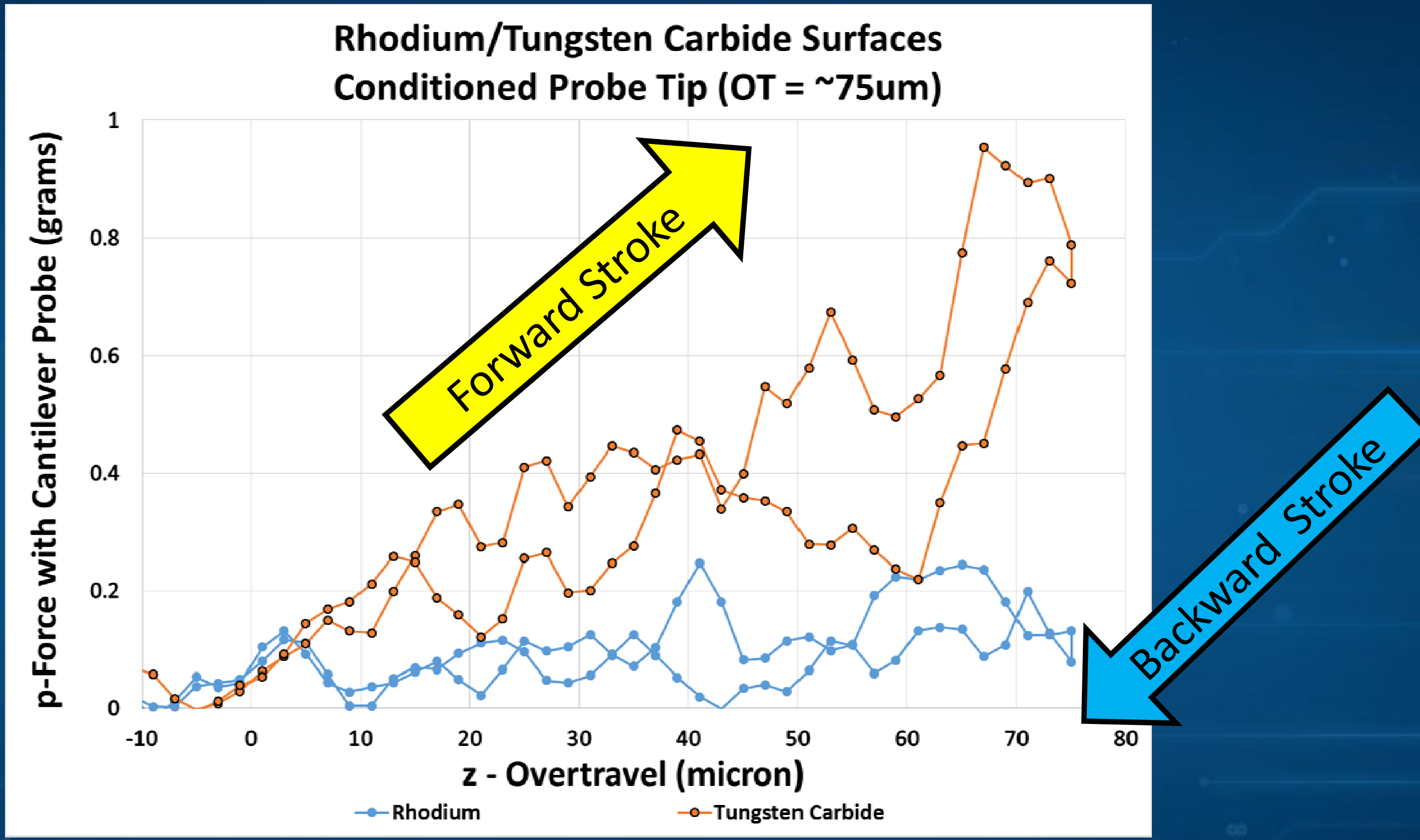
- **Methods**
  - Assess effects of substrate finish on xy transverse load
  - Assess effects of tip texturizing on xy transverse load

Substrate Characterization
(Unconditioned Probe Tip)



- **WC plate had a higher "resistance to scrub" (due to surface roughness).**
- **Signal-to-Noise for xy load cell was sufficient to clearly differentiate between the different surface conditions.**

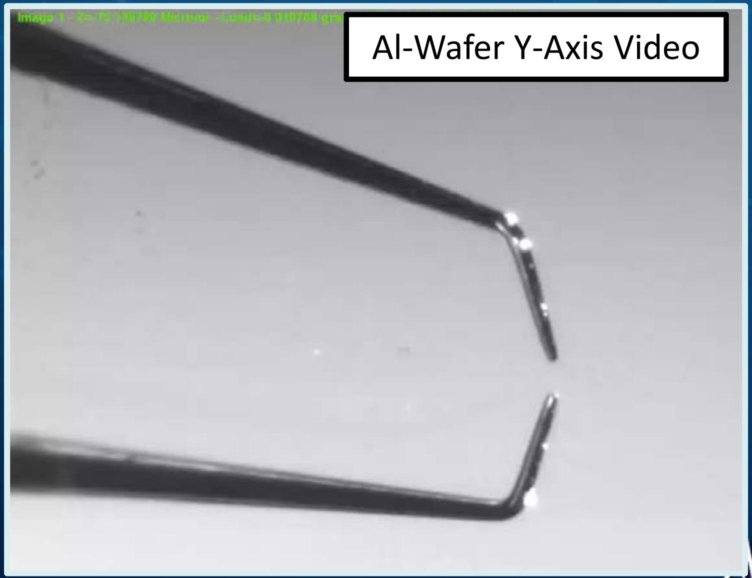
Substrate Characterization
(Textured Probe Tip)



- **“Resistance to scrub” increased since contact area now has a texture.**
- **xy load cell has sufficient sensitivity for identifying small changes in the “resistance to scrub”.**

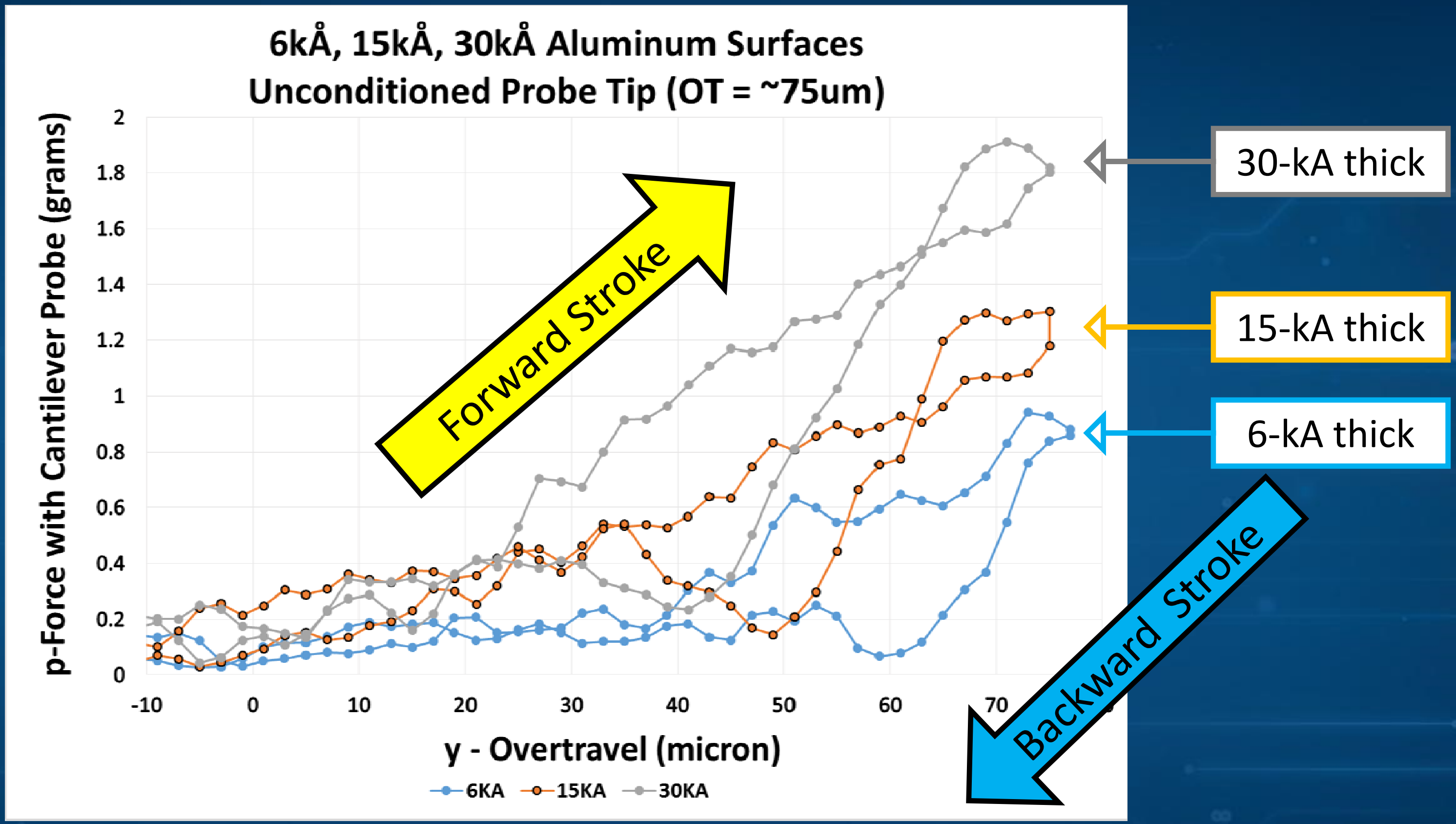
Methodology (Al-Thickness Effects)

- **Materials**
  - Tungsten-rhenium, cantilever probe test vehicle
    - Initial = smooth surface as received from PC supplier
    - Conditioned = surface textured with ITS Probe Lap abrasive film
  - 3 x Wafers with Al-layer thickness = 6kÅ, 15kÅ, and 30kÅ (*Bischoff et al., SW Test 2012*)
    - 6kÅ = Small grain structures with hillock-like features
    - 15kÅ = Medium grain structures
    - 30kÅ = Large grain structures
- **Methods**
  - Assess effects of Al-layer thickness on for xy transverse load state at OT = 75um
  - Assess effects of tip texturizing on xy transverse load state at OT = 75um



Transverse p-Force

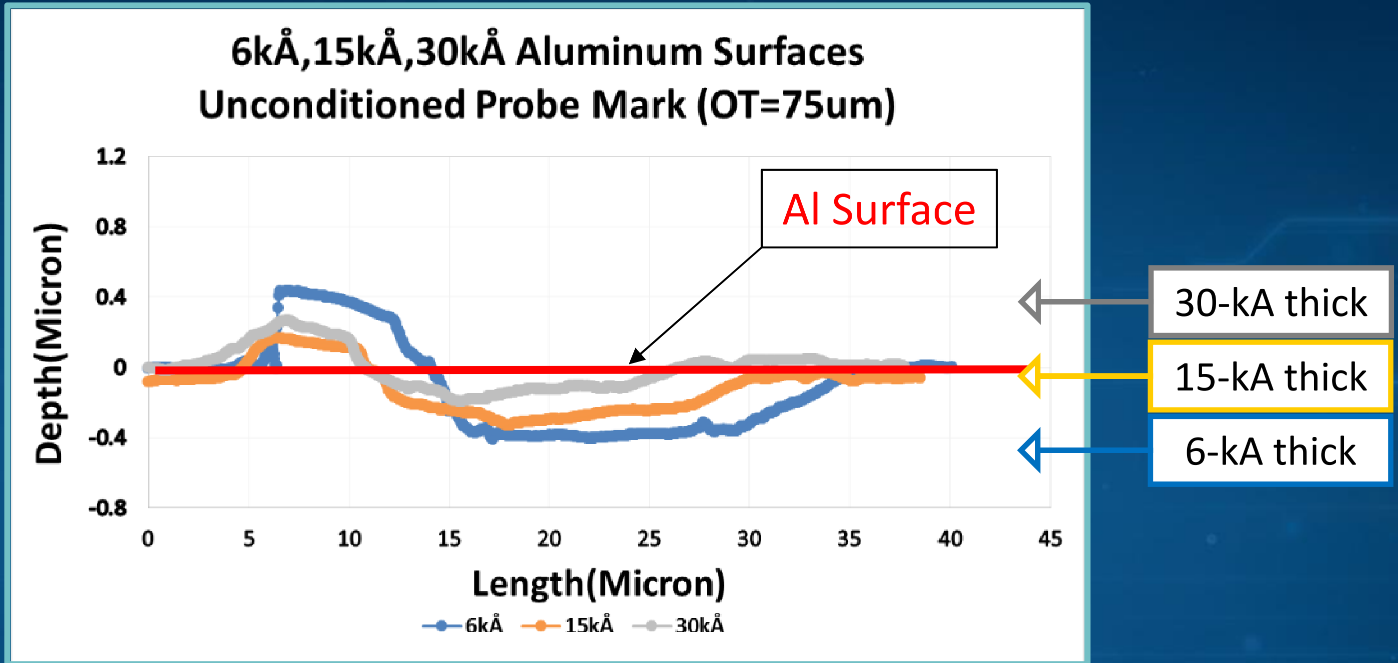
(Smooth Probe Tip)



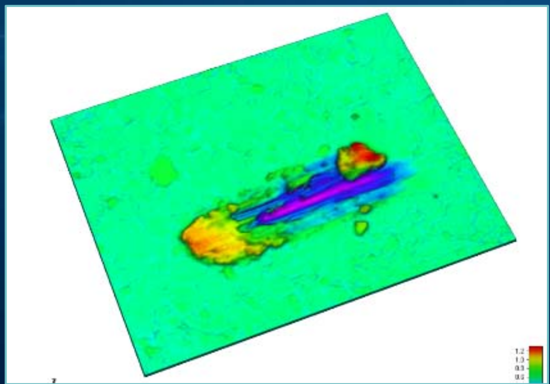
- 30-kA thick aluminum (large grains, soft surface) had the highest “resistance to scrub”.
- 15-kA thick aluminum (medium grains) had an intermediate “resistance to scrub”.
- 6-kA thick aluminum (small grains, hard surface) had the lowest “resistance to scrub”.

Probe Mark Depth

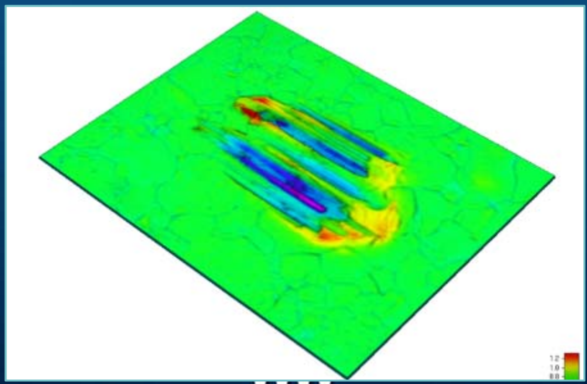
(Smooth Probe Tip)



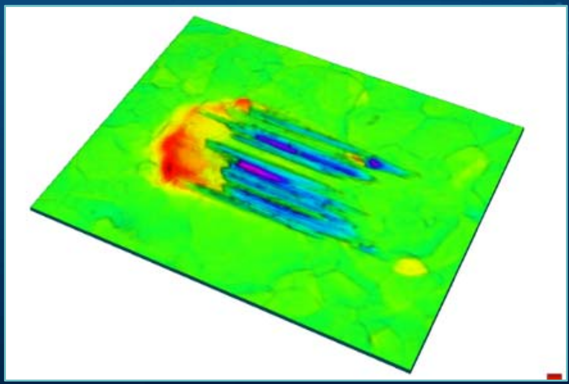
6kÅ Wafer



15kÅ Wafer

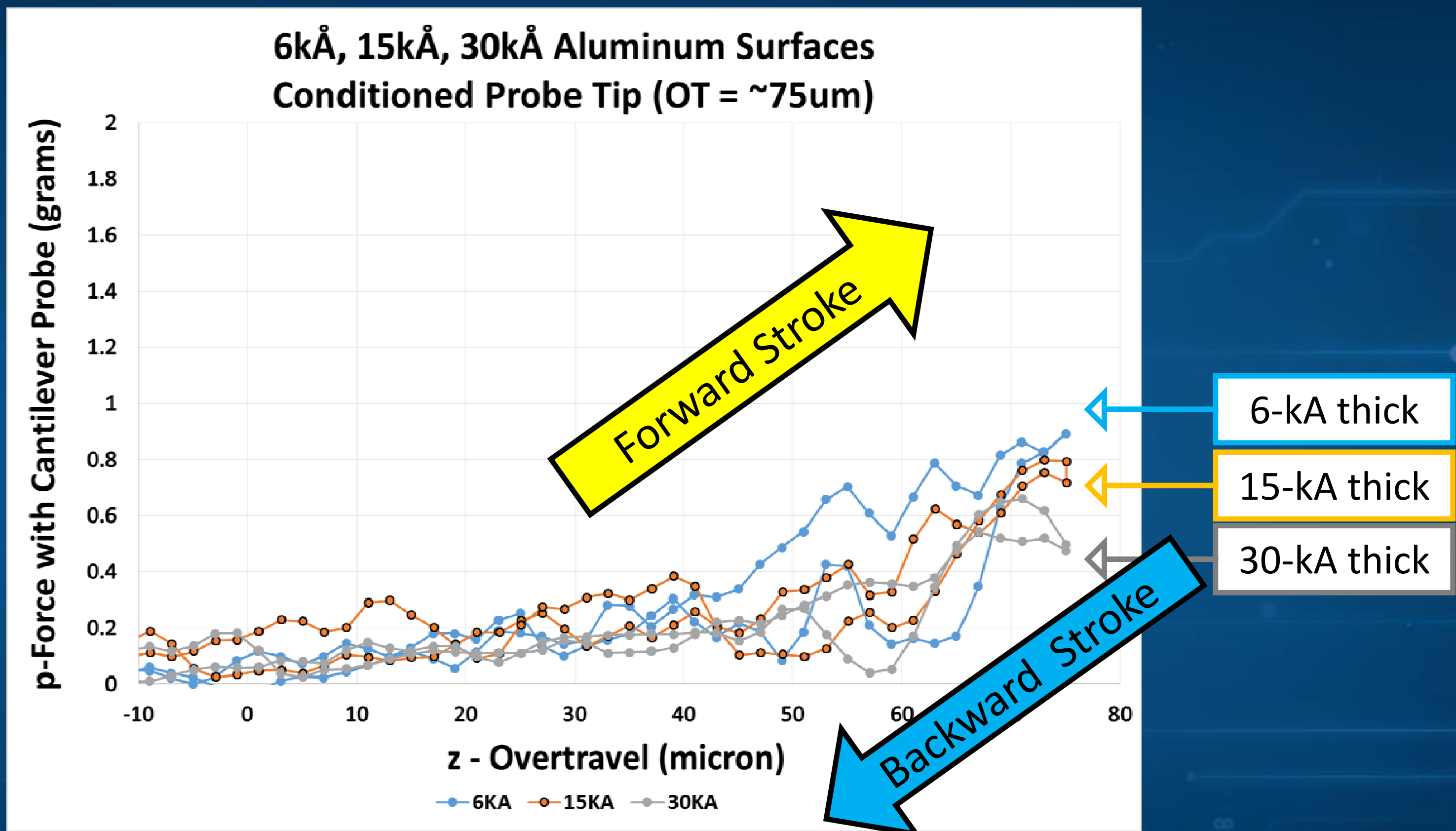


30kÅ Wafer



Transverse p-Force

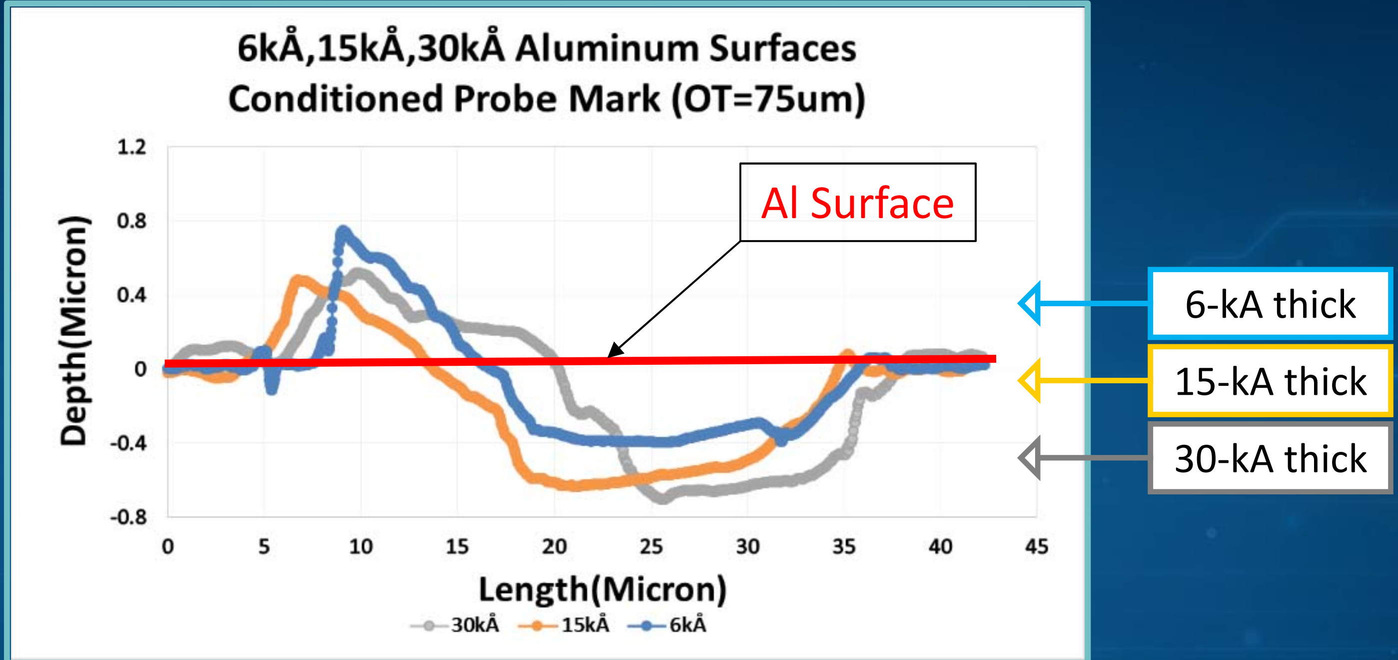
(Textured Probe Tip)



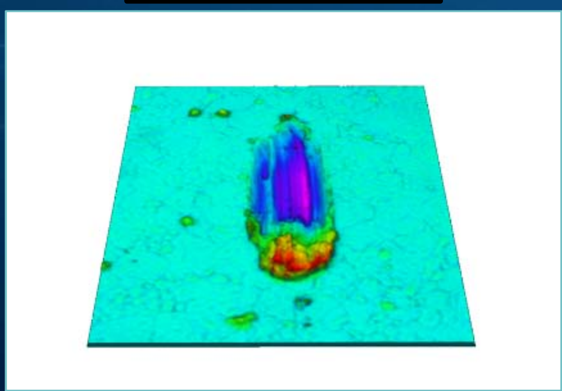
- 6-kA thick aluminum (small grains, hard surface) had the highest “resistance to scrub”.
- 15-kA thick aluminum (medium grains) had the intermediate “resistance to scrub”.
- 30-kA thick aluminum (large grains, soft surface) had the lowest “resistance to scrub”.

Probe Mark Depth

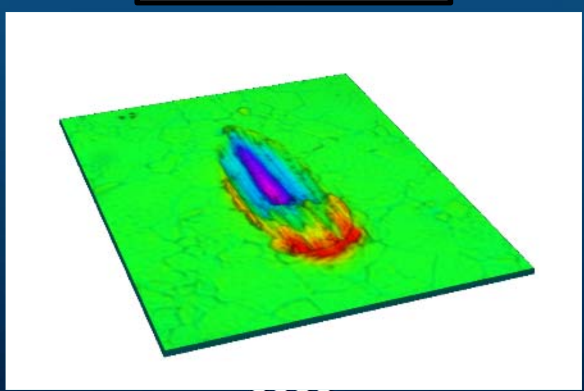
(Textured Probe Tip)



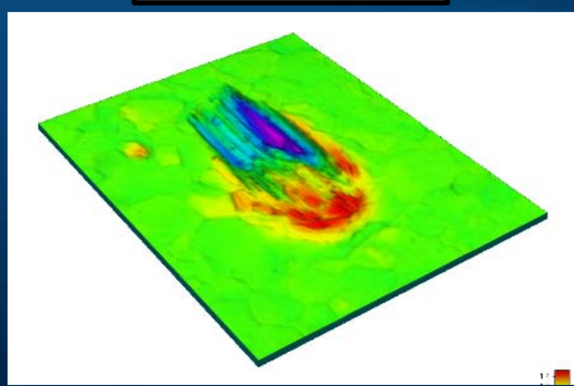
6kÅ Wafer



15kÅ Wafer



30kÅ Wafer

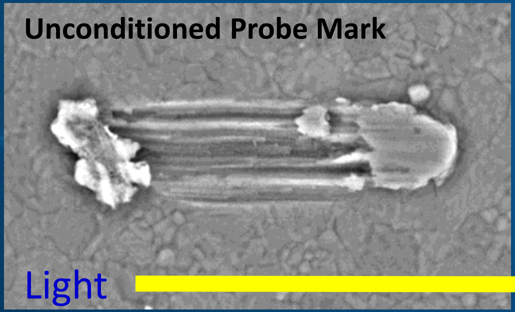


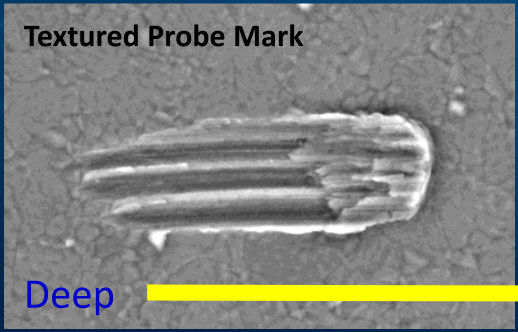
Probe Mark Size and Depth

6kÅ Wafer

- Unconditioned Probe Mark
- Length = 32~34 um
- Depth = ~ 4kÅ

- Conditioned Probe Mark
- Length = 28~30 um
- Depth = ~ 4kÅ

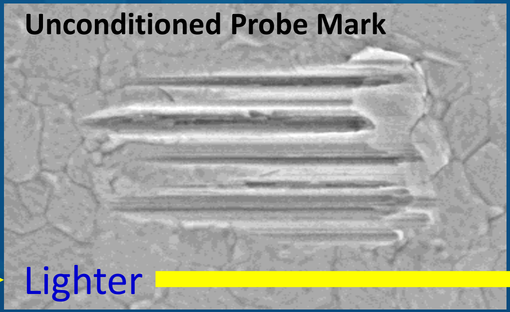


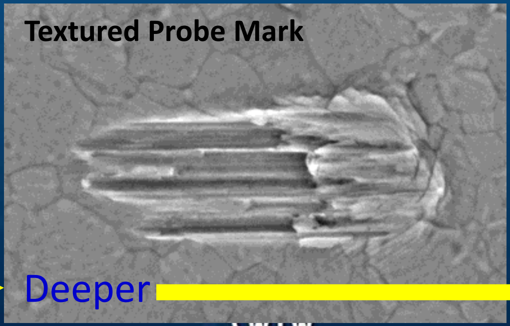


15kÅ Wafer

- Unconditioned Probe Mark
- Length = 29~31um
- Depth = ~3kÅ

- Conditioned Probe Mark
- Length = 29~31um
- Depth = ~6kÅ

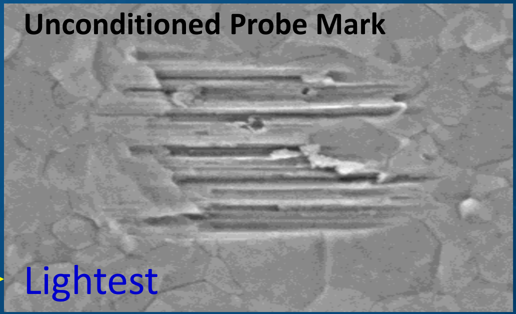


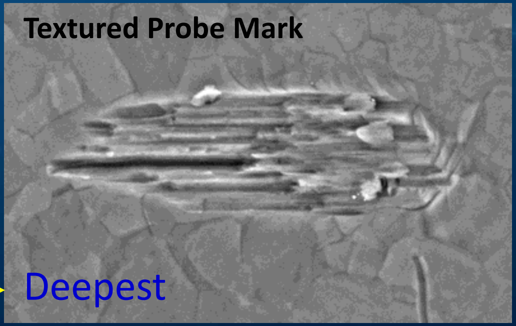


30kÅ Wafer

- unconditioned Probe Mark
- Length = 28~30um
- Depth = ~2kÅ

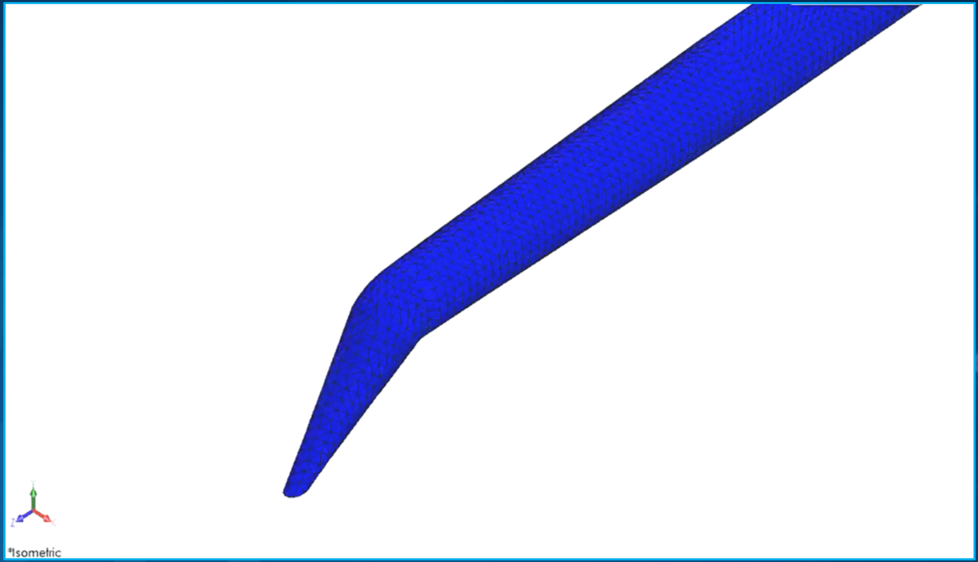
- Conditioned Probe Mark
- Length =32~34um
- Depth = ~7kÅ

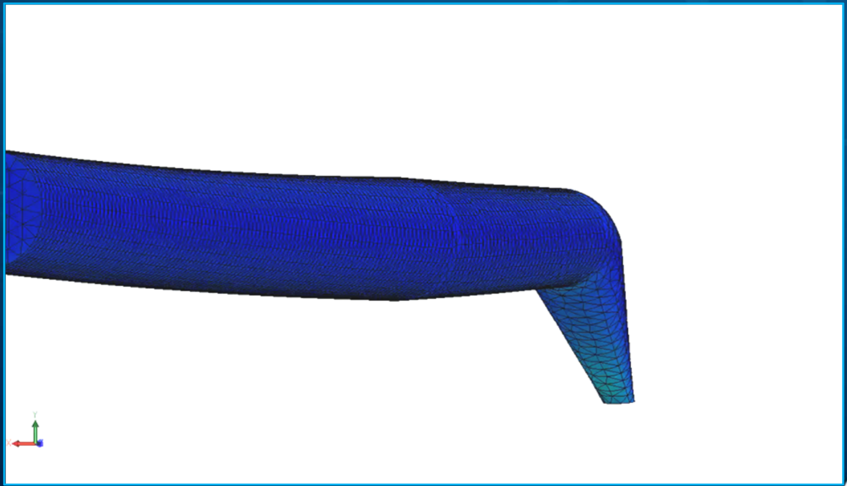


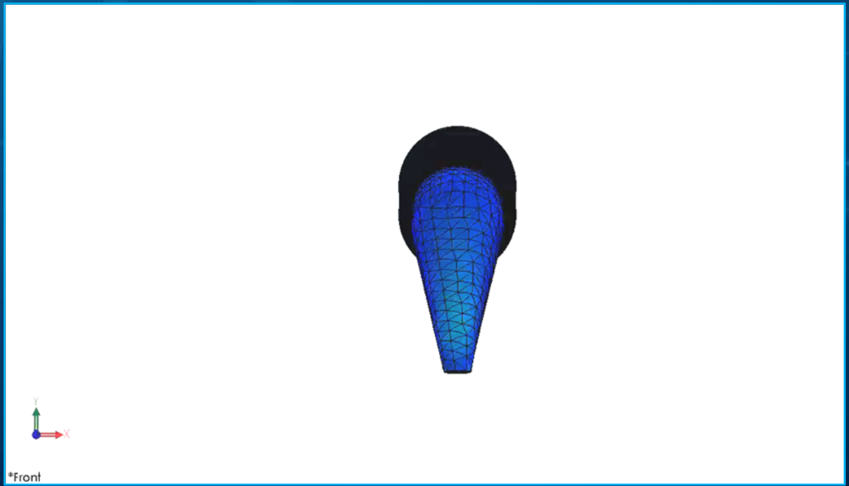


Probe Mechanics Simulation

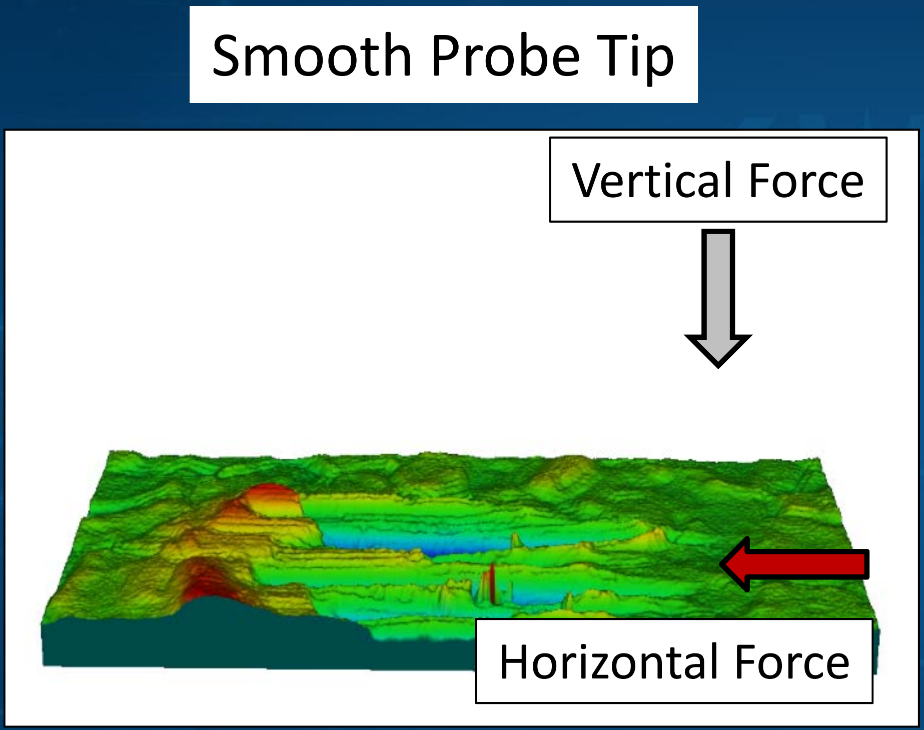
Basic FEA Model of probe needle was developed to visualize the moment created during overtravel.

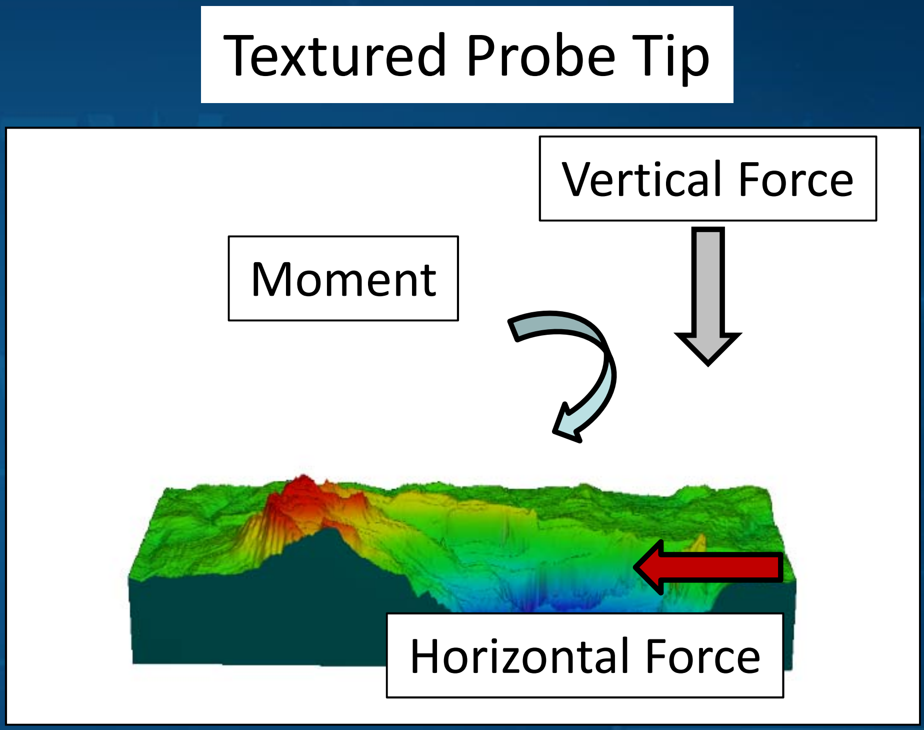






Probe Mark Creation
(Example: 15kA Al-thickness)





- Textured probe tips "dig into" the aluminum layer; while smooth probe tip "skate" across.
- As the textured surface resists the forward scrub of the tip, a moment is generated and the heel of the probe penetrates the surface of the pad.

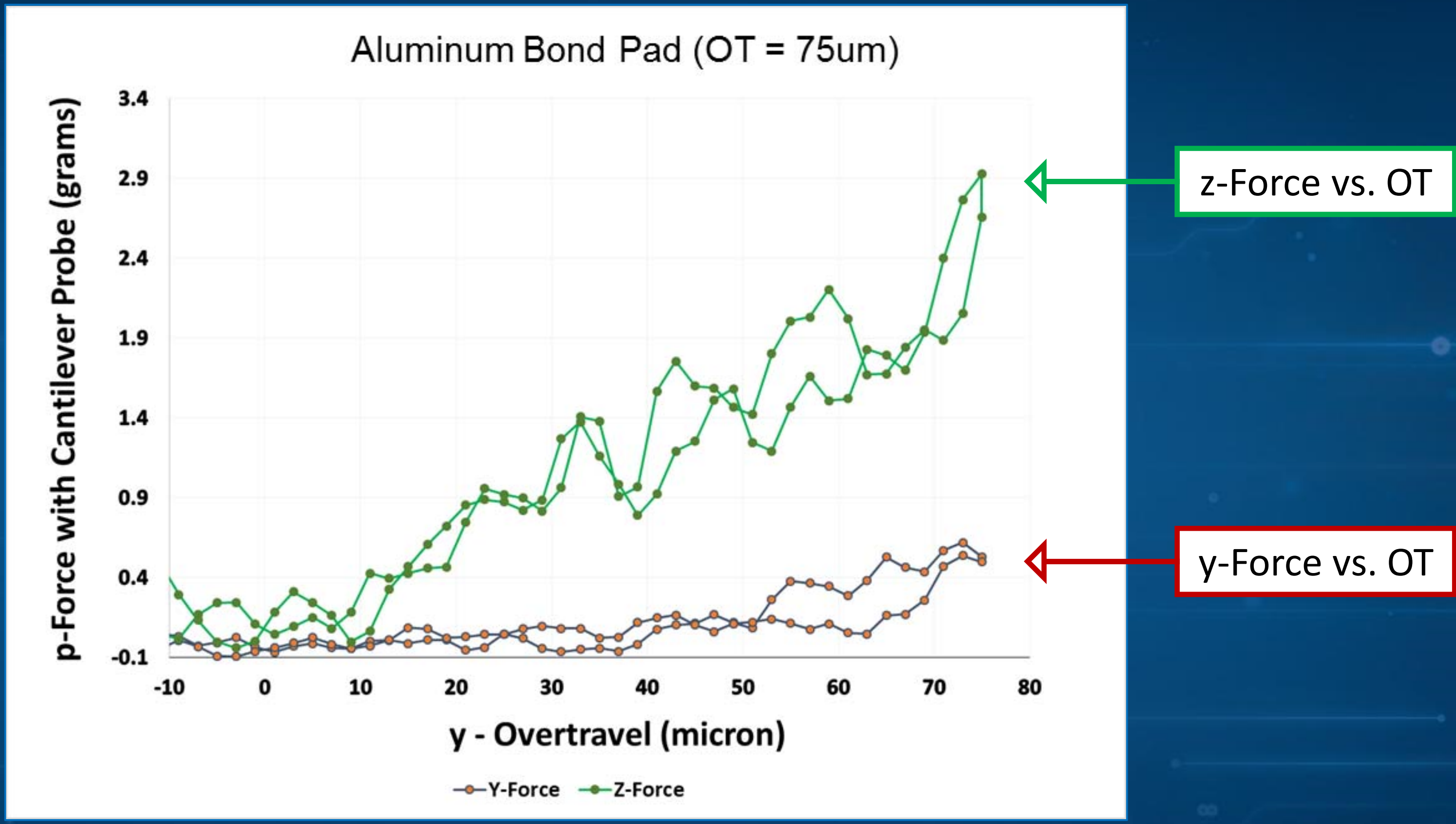
Methodology (Al-pads of Device)

- **Materials**
  - Tungsten-rhenium, cantilever probe
    - Initial = as received from PC supplier
    - Condition = surface textured with ITS Probe Lap abrasive film
  - Aluminum pads from actual device
- **Methods**
  - Apply overdrive (OT = 75um) to different substrates
  - Assess effects of substrate finish on xy transverse load
  - Assess effects of tip texturizing on xy transverse load

Methodology (Al-pads of a Device)

- **Materials**
  - Tungsten-rhenium, cantilever probe test vehicle
    - Conditioned = probe tip textured with ITS Probe Lap abrasive film
  - Device with aluminum bond pads
- **Methods**
  - Assess xy transverse load state at OT = 75um
  - Assess effects of tip texturizing on xy transverse load state at OT = 75um

Initial Results: Al-pad of a Device



- **z-Force vs. OT and y-Transverse are clearly differentiated.**
- **Currently, there is ongoing testing to assess and compare the "resistance to scrub" for Al-pads obtained from different semiconductor devices.**

Overview

- Introduction
- Motivation
- Objectives /Approach
- Methodology
- Characterization/Results
- **Summary / Future Work**
- Acknowledgements

Summary / Conclusions

- Methodologies and custom hardware were developed and validated to characterize the "resistance to scrub" using transverse (xyz) p-Force measurements.

- "Resistance to Scrub" was experimentally quantified under controlled conditions for different substrates, probe tip conditions, and aluminum layer thicknesses.

- Based on the preliminary results, the method has utility to gain insights into the complex scrubbing action and localized stress states during wafer test.

- Further work is needed to investigate the applicability of this method for predicting under-layer damage caused during wafer test.

Future Work

- “Resistance to scrub” characterization for Al-pads from different semiconductor devices.
- Multiple probe mark effects on “Resistance to scrub”.
- Transverse load analysis of different probe technologies, e.g., vertical probes.

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Questions?