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MEMS Technology - Enabling Design Flexibility for Fine Pitch Probing

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Outline

- ☐ **Introduction**
  - ➢ Emerging fine pitch peripheral & array test requirements at 60µm pitch
    - ➢ Design perspective & probing multiple DUTs by cantilever vs. vertical probe
    - ➢ Contact model for vertical probe contacts to control bond pad damage

- ☐ **Method & Systems for Characterization**
  - ➢ Hertzian contact mechanics & Holm electrical contact model
  - ➢ Instrumentation & software

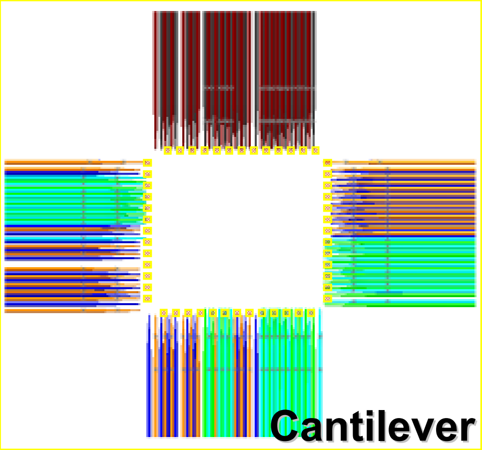
- ☐ **Test Results & Analysis**
  - ➢ MEMS-based vertical technology contact performance for various contact metallurgies on wafers
    - ➢ Contact on aluminum, copper & lead-tin
    - ➢ Contact resistance as a function of contact force & current

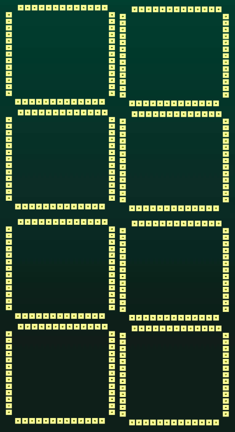
- ☐ **Summary & Follow-on Work**

Fine Pitch Probing

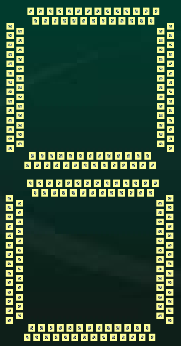
- **Cantilever probing approaches, both traditional & MEMS-cantilever, have limitations for multidut probing at 60µm-pitch :**
  - Number of rows of bond pads are limited, dependent heavily on pad density
  - Corner keep-out in device layouts
  - Requires skip-DUT configurations, compromising test stepping efficiency
- **Vertical probing technology approaches allow more rows of peripheral pads & array patterns**

Probing Technology & Design Capability

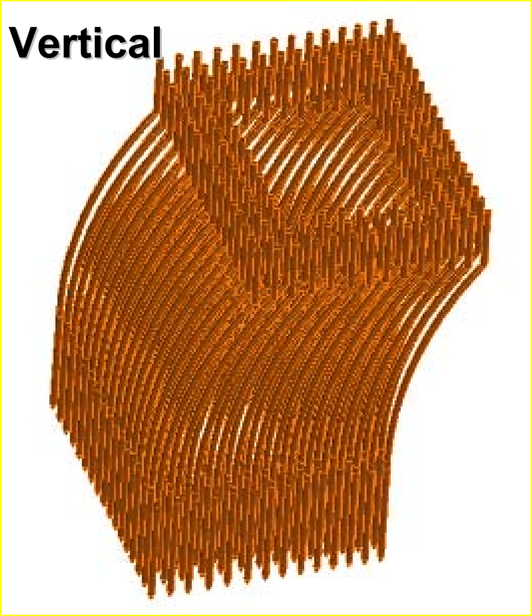


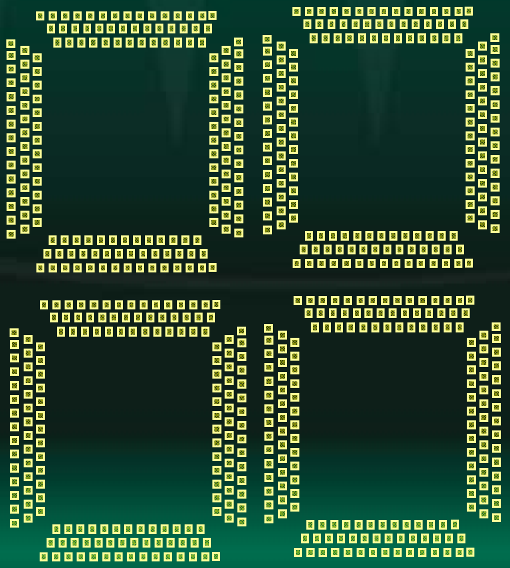


1-row Peripheral
Multi-dut

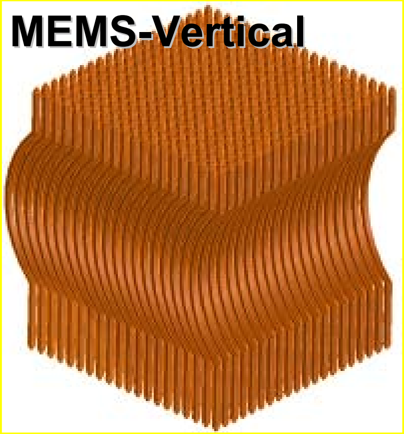


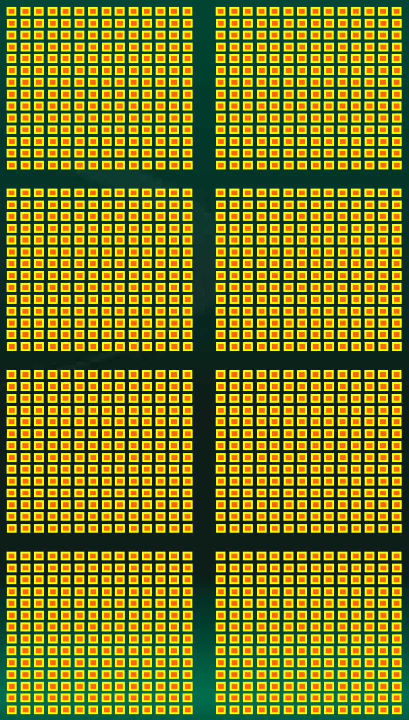
1, 2 Row Peripheral Layouts





3 Row Peripheral layouts

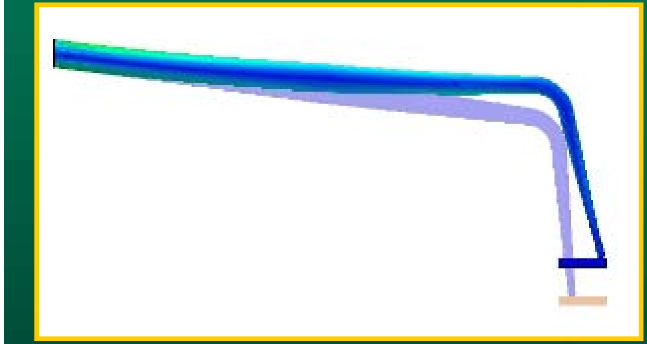


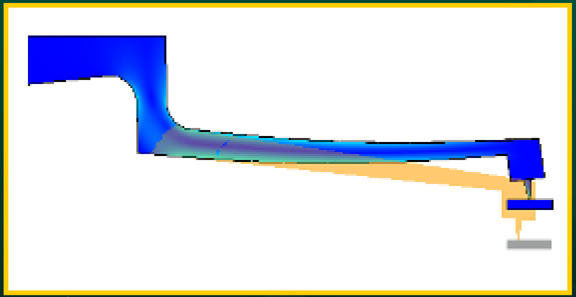


Array Layouts

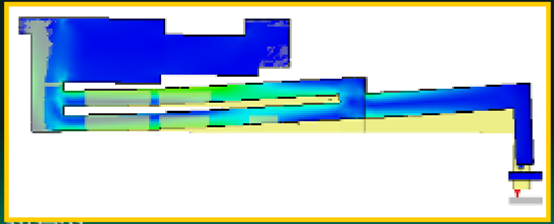
Probing Technology & Scrub on Pads

Cantilever Technologies

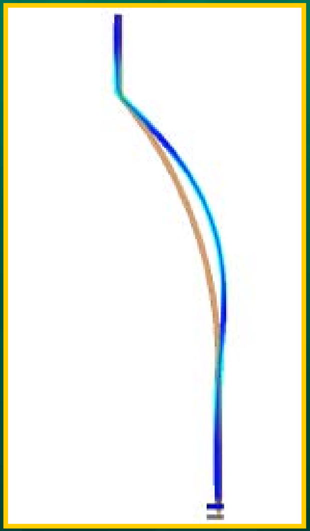


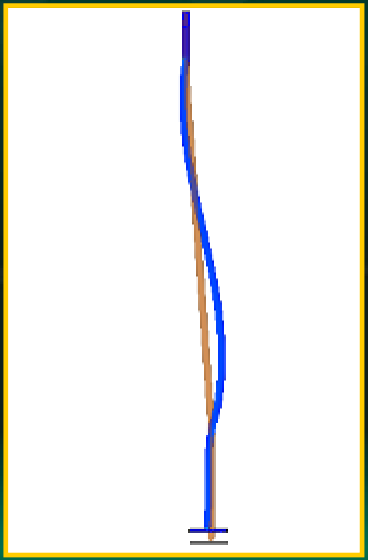


MEMS Cantilever

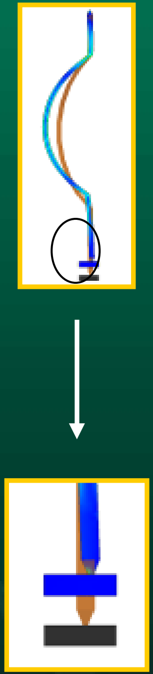


Vertical- Buckling Beam





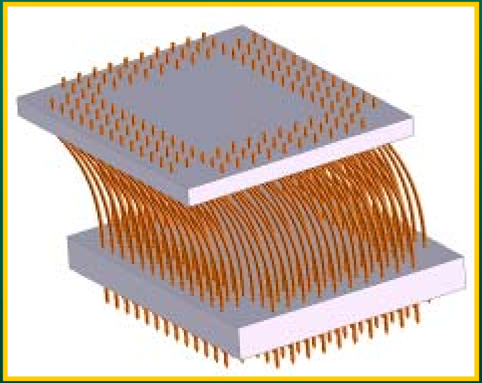
MEMS Fine Pitch Vertical



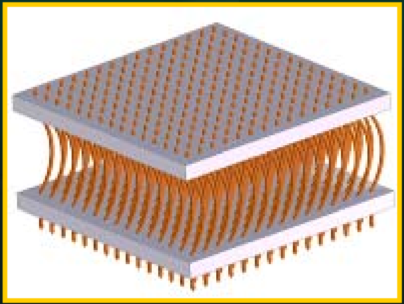
Fine Pitch Probing

- ☐ **Fine pitch probing requires precise control of alignment at pad sizes of 45µmx45µm**
  - ➢ Contact model for vertical probe contacts is different than cantilever style beams
    - ➢ Scrub marks generated by cantilever beams by design is typically longer than marks by vertical probes
  - ➢ Accurate guiding of probes permits finer controls & precise scrub marks for Vertical. The tolerances on guiding holes as well as probes are critical for positions
- ☐ **Probe action, scrub mark size & depth must be precisely controlled to prevent damage to bond pads & low-k dielectrics**
  - ➢ Study scrub behavior, determine scrub length, width, depth & also the debris pile created

Vertical- Buckling Beam



MEMS Fine Pitch Vertical

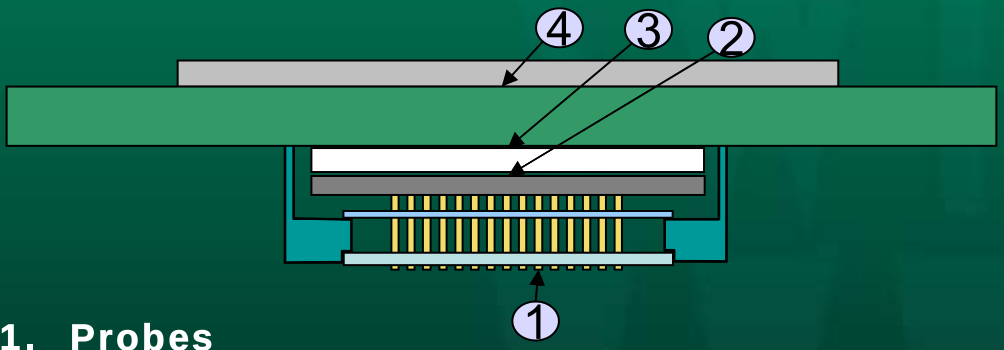


Methodology for Analysis

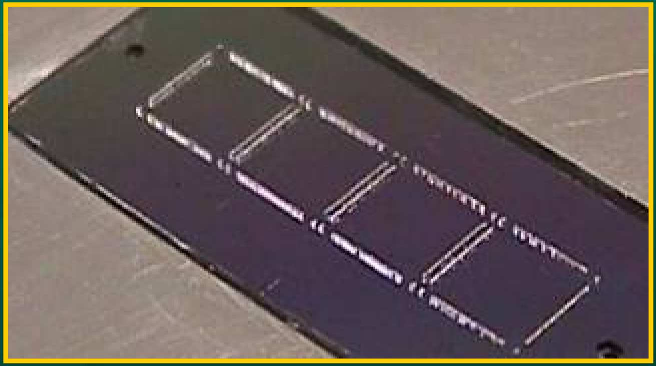
- ☐ **Contact Model**
  - ➢ Hertzian Contact Mechanics
    - ➢ Software model is developed for predictive scrub behavior on various wafer pad metallurgies, based on VB code
    - ➢ Simplified Holm electrical contact model

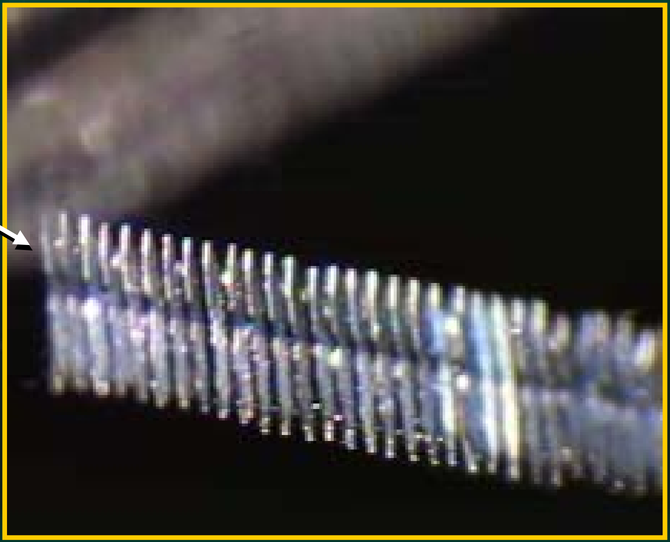
- ☐ **Test systems for scrub mark & contact resistance characterization**
  - ➢ Instrumentation
    - ➢ Probe: TEL P12 XLn
    - ➢ Keithley Tester & Source Meter
    - ➢ Nikon Optical Inspection System
    - ➢ Veeco Profilometer
    - ➢ Test Wafers: Al, Cu, PbSn
    - ➢ Probing Technology: MEMS-Fine Pitch Vertical Technology (LogicTouch™)

MEMS-Fine Pitch Vertical Probing Technology for Contact Study



1. **Probes**
2. **Space Transformer (MLC)**
3. **Interposer**
4. **PCB**

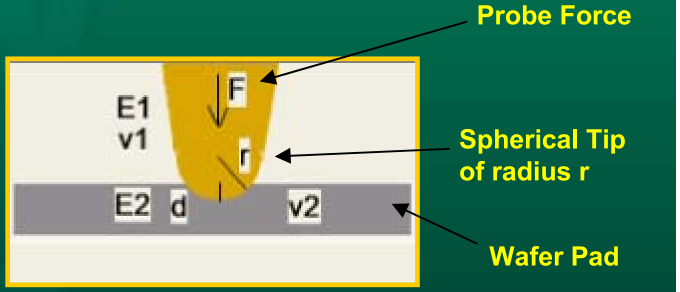




- ➢ 60/30µm layout is shown
- ➢ Technology scalable to 50µm & 40µm pitch
- ➢ Supports much higher speeds & bandwidth compared to cantilever technologies

Probe Contact

- ❑ **Contact Model**
  - **Hertzian Contact Mechanics: Hertz**'s classical solution provides the foundation in contact mechanics of solid pairs (of two surfaces). The size & depth of an indentation of a probe into a flat surface can be estimated by Hertz contact stresses. GW model based on Hertz theory is assumed where the probe tip of radius r indents a flat plane to depth d, creates a contact area of radius a = √rd . The force equation

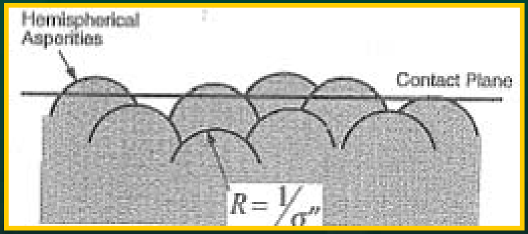


$$\mathbf{F = 4/3\ Er^{1/2}\ (z_s - d)^{3/2}}$$

Where z_s is the normalized summit height & elastic modulus E of the equivalent surface is given as

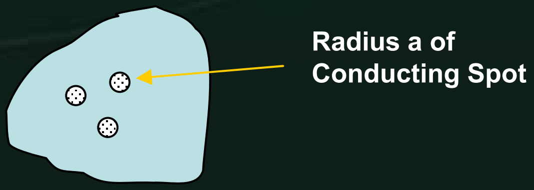
$$\mathbf{1/E = (1-v_1^2)/E_1 + (1- v_2^2)/E_2}$$

Where v is the Poisson's ratio & two bodies of 1 & 2



Model of Surface Roughness

  - Surfaces are rough & the apparent contact area between a probe tip & the pad is not the actual load bearing area due to asperities. The real area of contact is found as, $\mathbf{A_r/A_a = 1 - 3\%}$
  - Metallic surfaces also have insulating films. Real intimate contact & load bearing area is actually much smaller & the electrical conduction is achieved through these a-spots, conducting contact areas. **Holm** defined the electrical contact model using this constriction resistance, $\mathbf{R_f = \rho/A_c}$, between contacting members by extension of Ohm's law.



- ❑ **Predict scrub mark by known properties of probe materials, pad materials & geometry**

Contact Model Results for Aluminum

Input Parameters

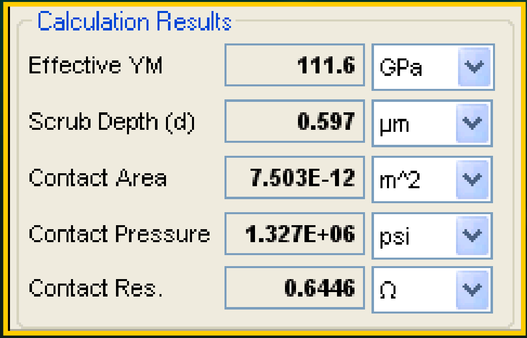
FPV Probe tip: 4um radius

Overdrive: 63.5um

Force: 7 g

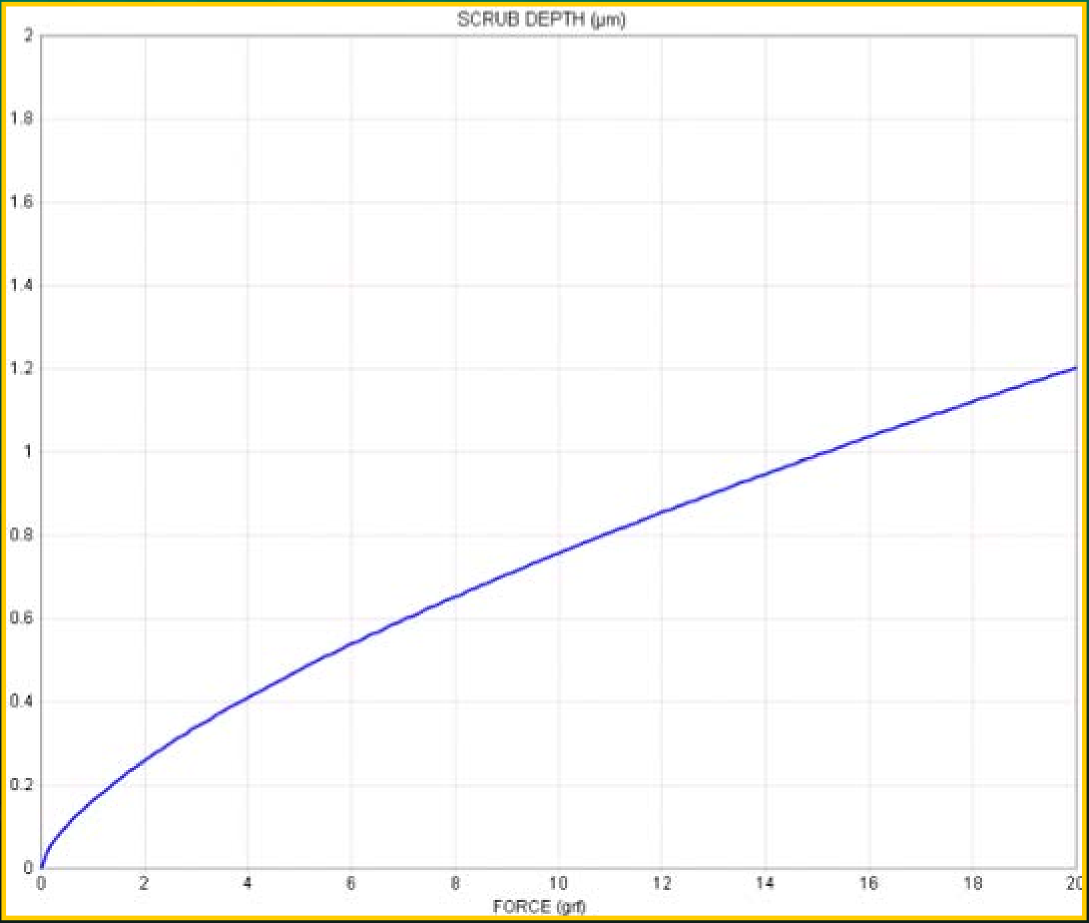
Pad: Al

Results



Calculation Results

Effective YM	111.6	GPa
Scrub Depth (d)	0.597	µm
Contact Area	7.503E-12	m^2
Contact Pressure	1.327E+06	psi
Contact Res.	0.6446	Ω



Scrub depth as a function of probe force. Assumes a hemispherical probe tip.

Contact Model Results on Copper

Input Parameters

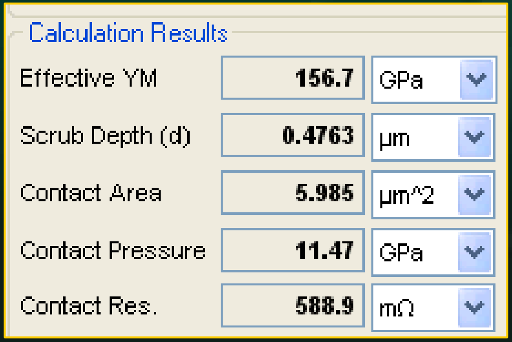
Probe tip: 4um radius

Overdrive: 63.5um

Force: 7 g

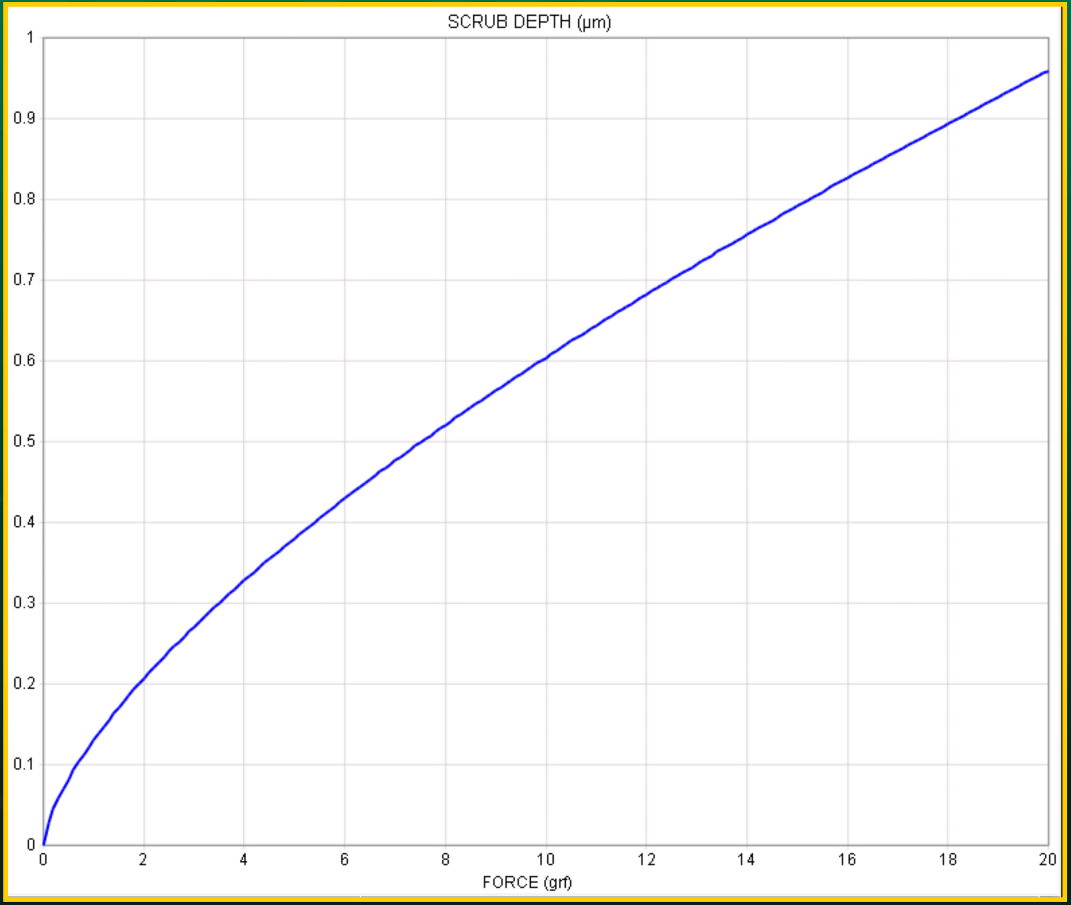
Pad: Cu

Results



Calculation Results

Effective YM	156.7	GPa
Scrub Depth (d)	0.4763	µm
Contact Area	5.985	µm^2
Contact Pressure	11.47	GPa
Contact Res.	588.9	mΩ



Scrub depth as a function of probe force. Assumes a hemispherical probe tip.

Contact Model Results on PbSn

Input Parameters

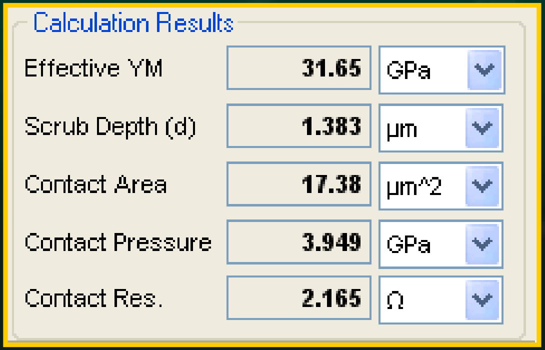
Probe tip: 4um radius

Overdrive: 63.5um

Force: 7 g

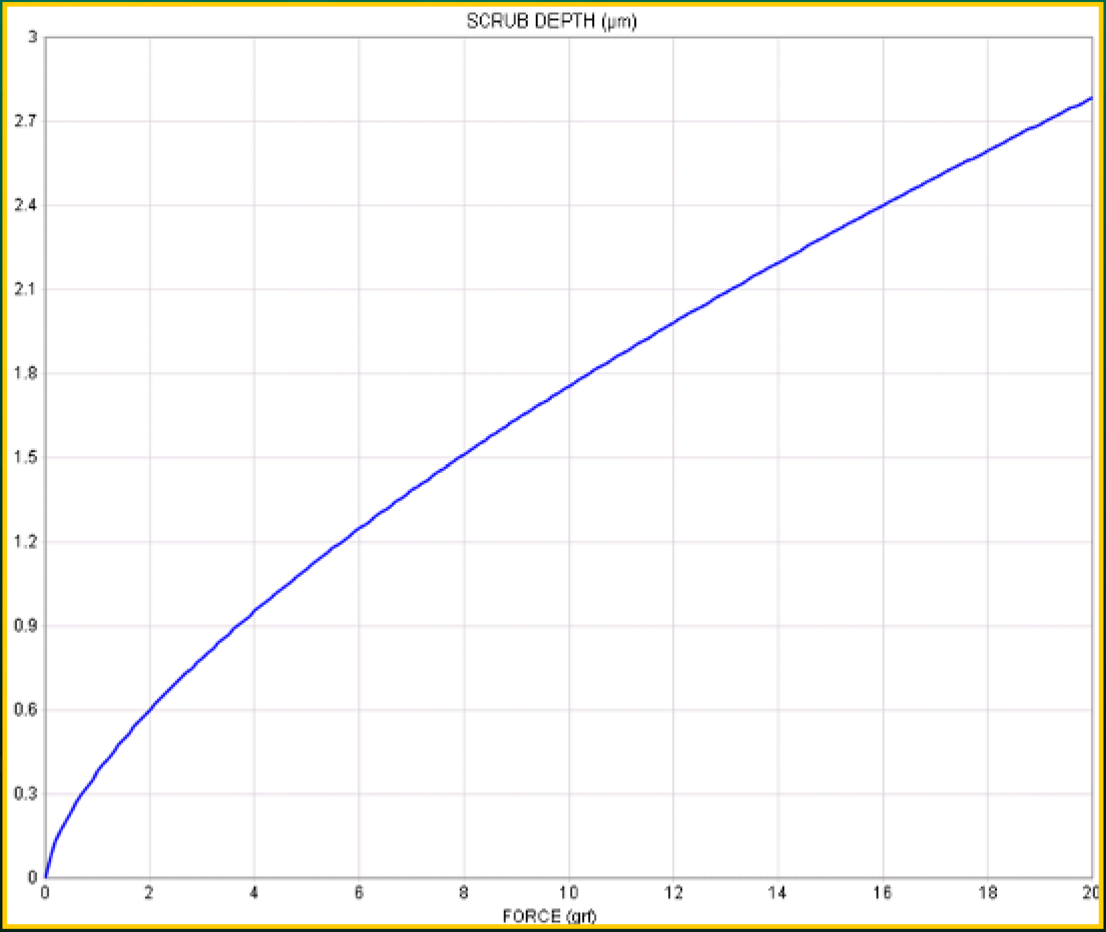
Pad (Bump): PbSn

Results



Calculation Results

Effective YM	31.65	GPa
Scrub Depth (d)	1.383	µm
Contact Area	17.38	µm^2
Contact Pressure	3.949	GPa
Contact Res.	2.165	Ω



Scrub depth as a function of probe force. Assumes a hemispherical probe tip.

Experimental Scrub Characterization

- **Scrub marks by standard cantilever & vertical technologies**
- **FPV Scrub Characterization**
  - Comparative study of multiple TDs on Al & Cu pads
    - Scrub dimensions were measured
    - Two different tip diameters were studied
  - Contact resistance behavior was also investigated
    - Contact resistance (Cres) was measured per TD & as a function of overdrive to determine the onset of fritting
    - Cres was measured during lifecycle experiments monitoring stability for Al, Cu as well as PbSn

Cantilever Technology Scrub Marks

<u>Conditions:</u>

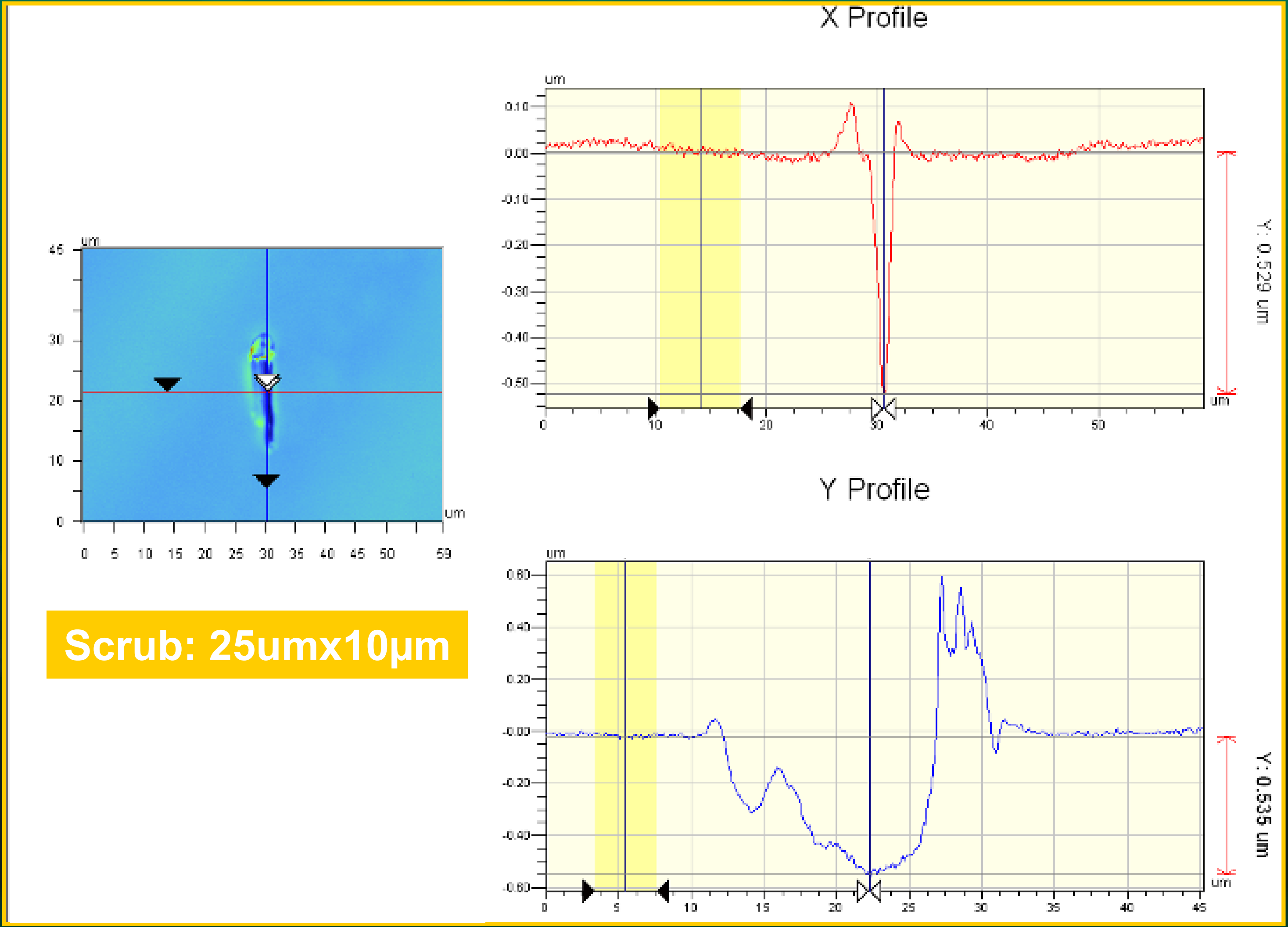
50µm O.D

Force: 2.3 g @ 50µm

3-milØ WRe

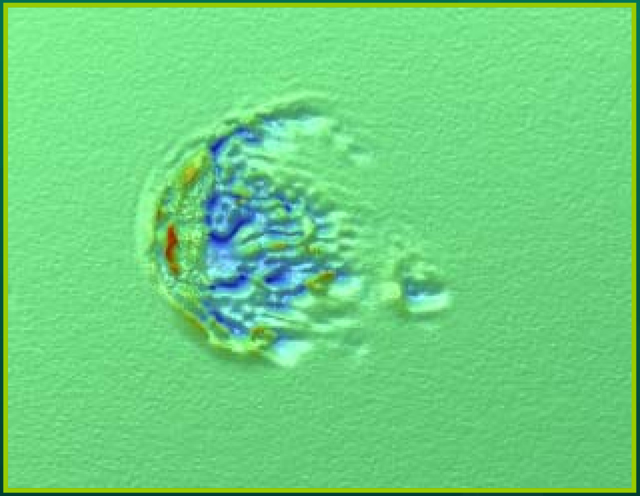
10µm Tip Diameter

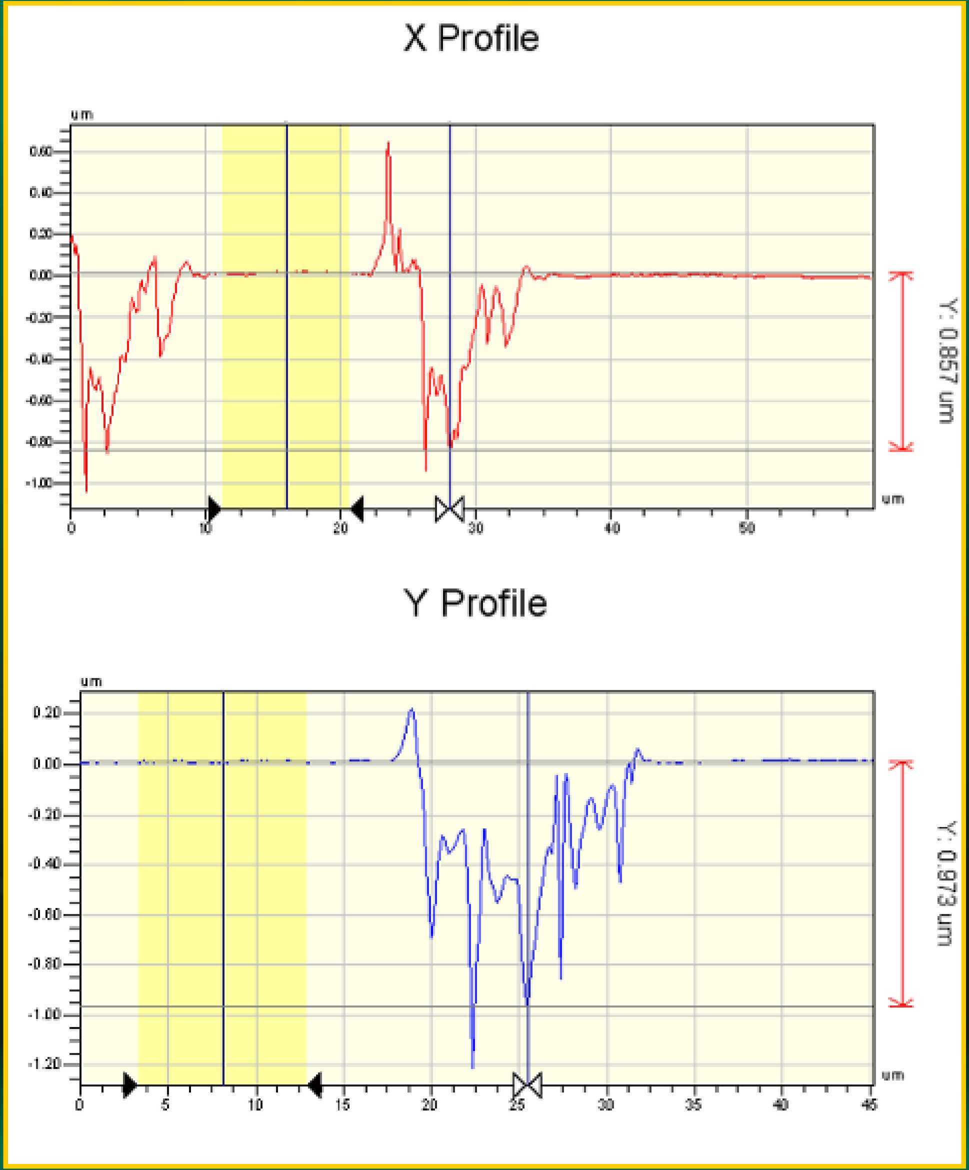
Aluminum Wafer



Scrub: 25umx10µm

Vertical Technology Scrub Marks





Conditions:

125 µm O.D

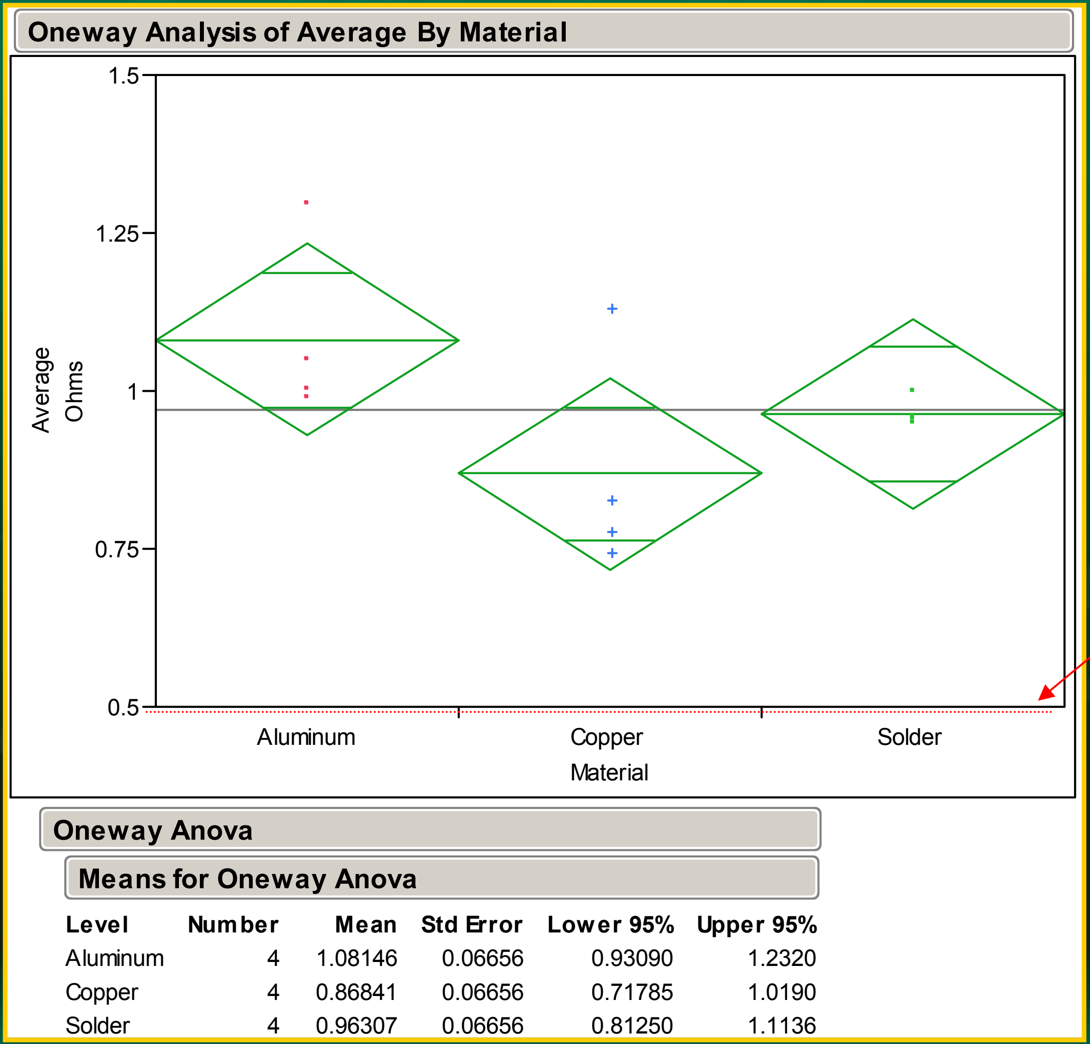
3-milØ Pointed Probe

13 µm Tip

Aluminum Wafer

Test Results for FPV: Resistance Comparison for Different Pad Materials

Contact resistance values are path resistance measurements & not normalized



Oneway Analysis of Average By Material

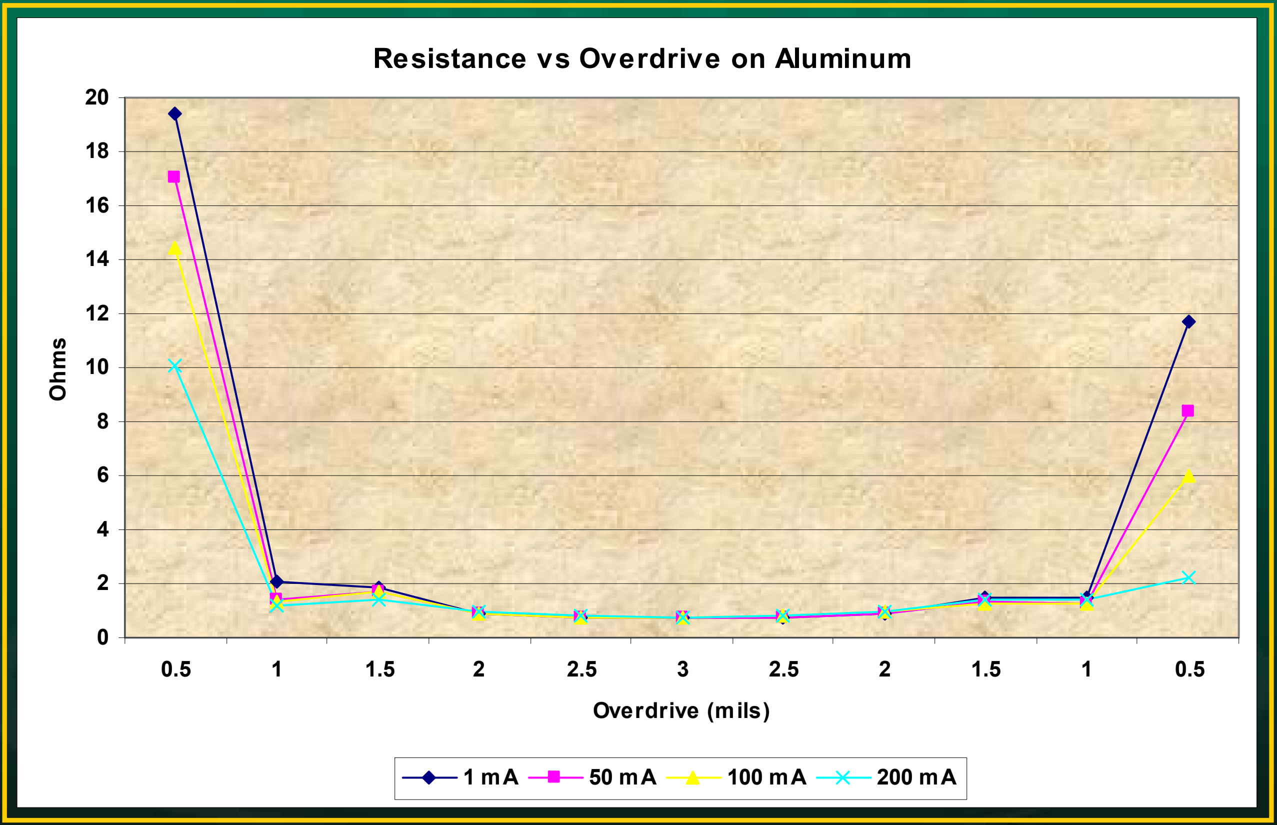
Baseline Resistance

Oneway Anova

Means for Oneway Anova

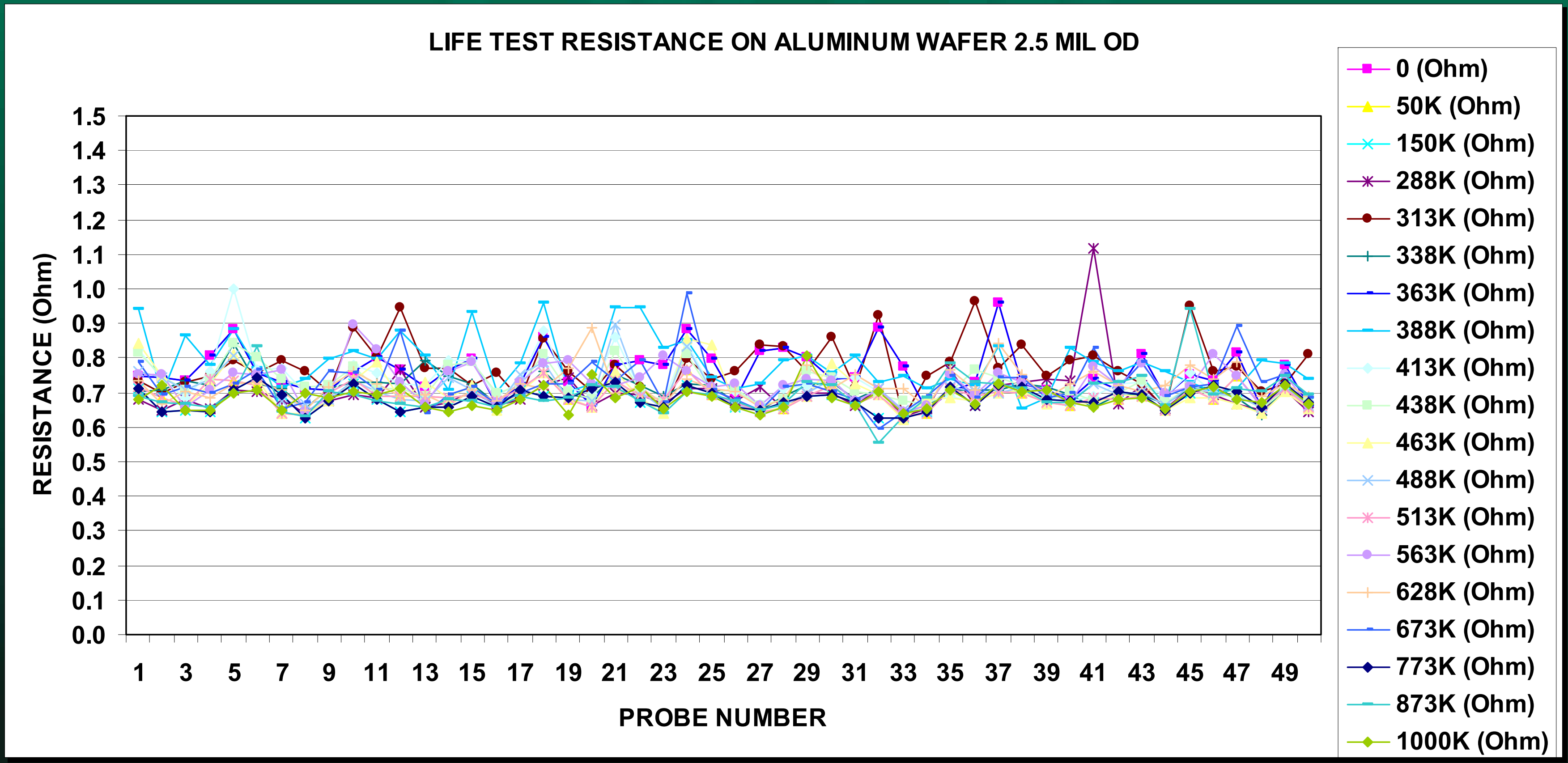
Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Aluminum	4	1.08146	0.06656	0.93090	1.2320
Copper	4	0.86841	0.06656	0.71785	1.0190
Solder	4	0.96307	0.06656	0.81250	1.1136

Cres Behavior on Al



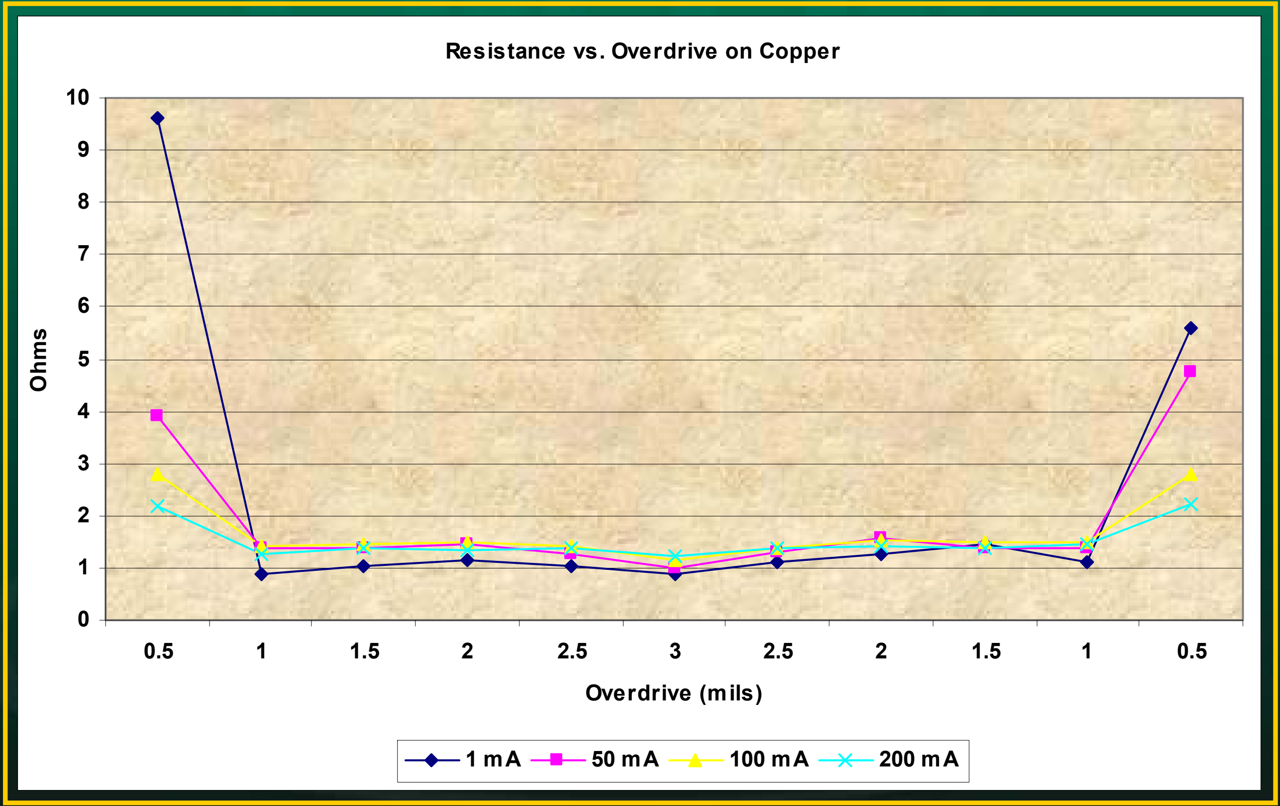
Contact resistance as a function of overdrive for current values of 1, 50, 100 & 200 mA. It appears that the fritting takes place below 1 mil OD, the fritting ratio drops as the OD increases.

Cres Testing on Al



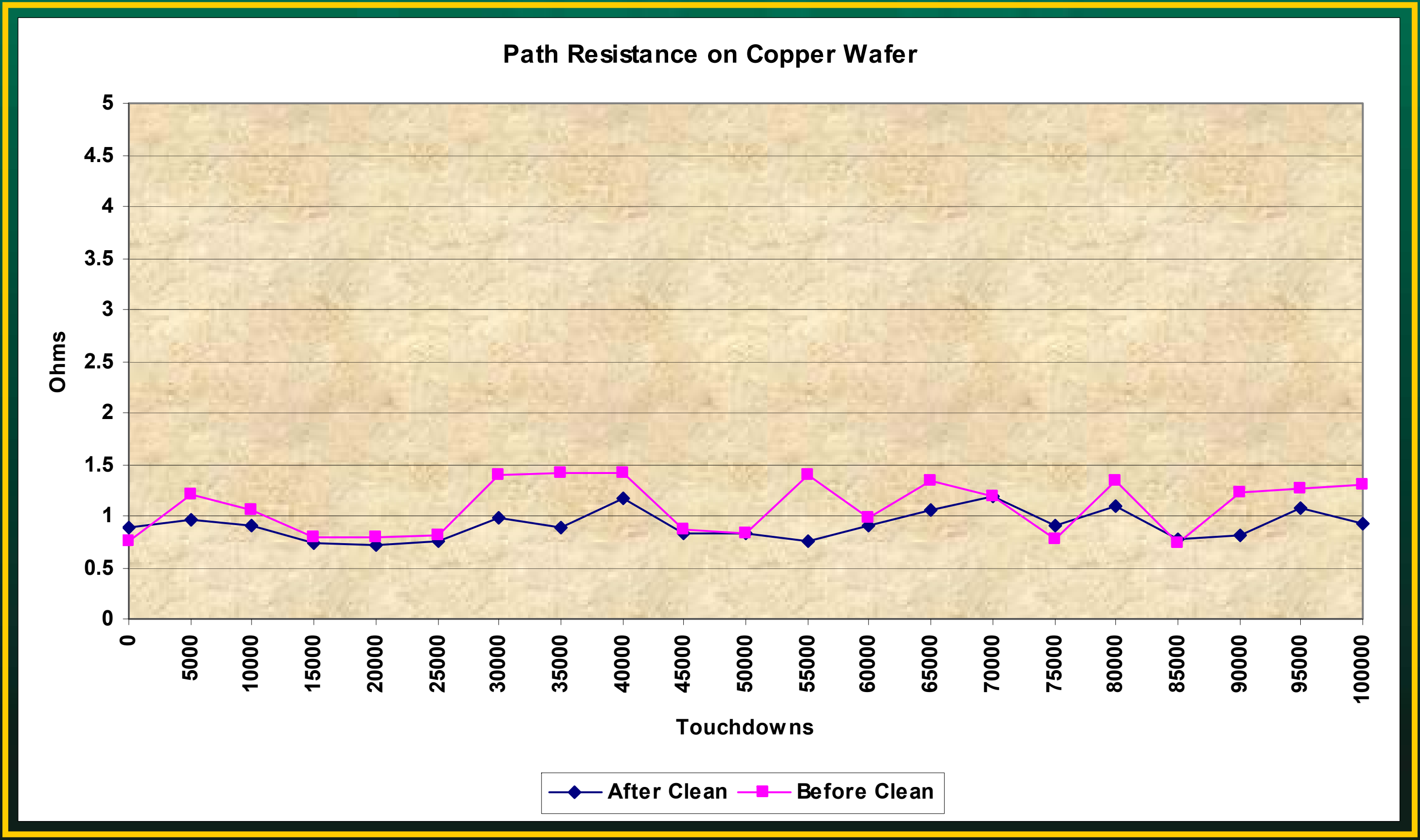
Contact resistance results up to 1M TDs. Resistance is the path resistance including the Cres.

Cres Behavior on Cu



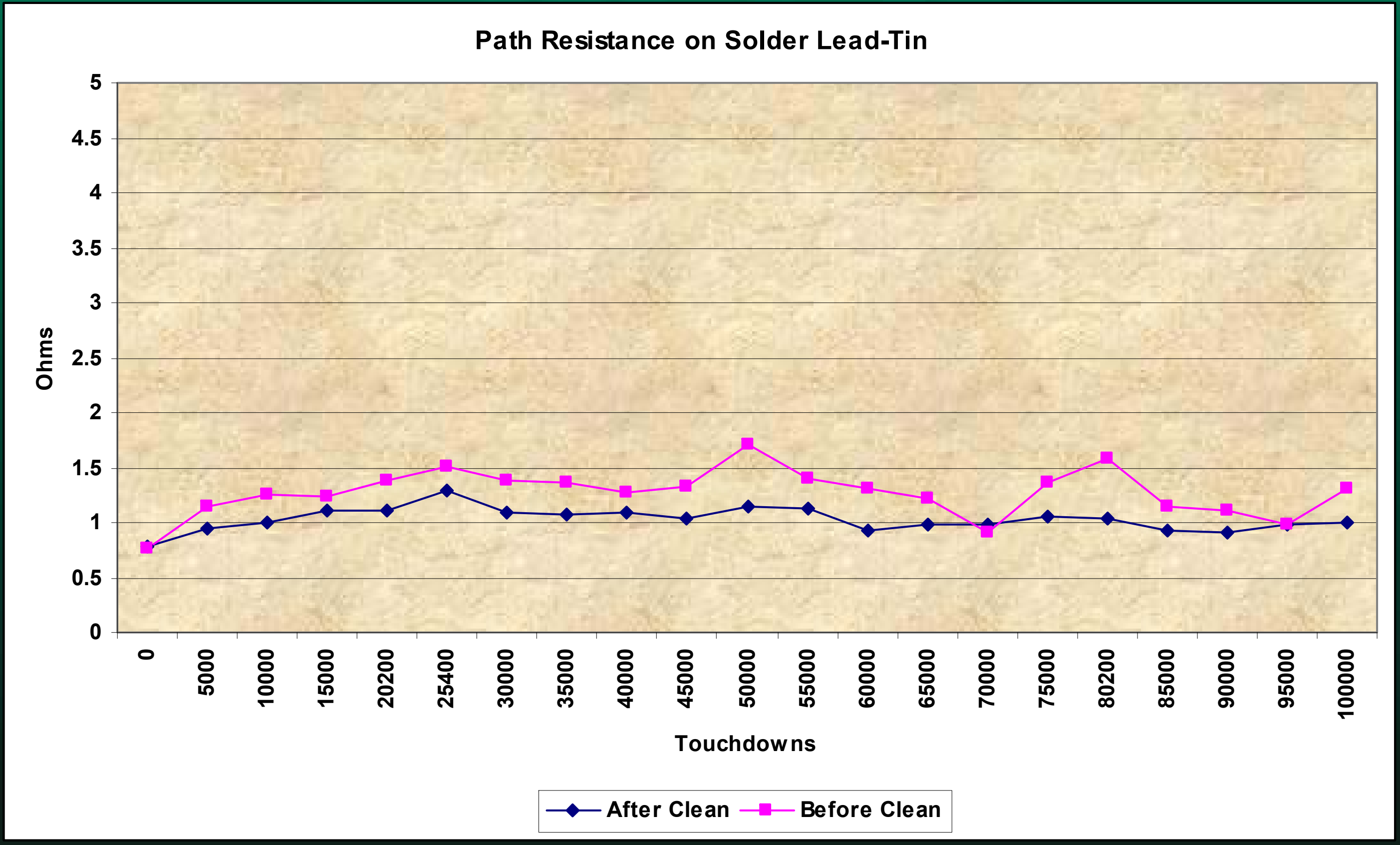
Contact resistance as a function of overdrive for current values of 1, 50, 100 & 200 mA. Resistance is the path resistance including the Cres. Cres unstable below 1 mil OD & stabilizes at higher OD.

Cres Testing on Cu



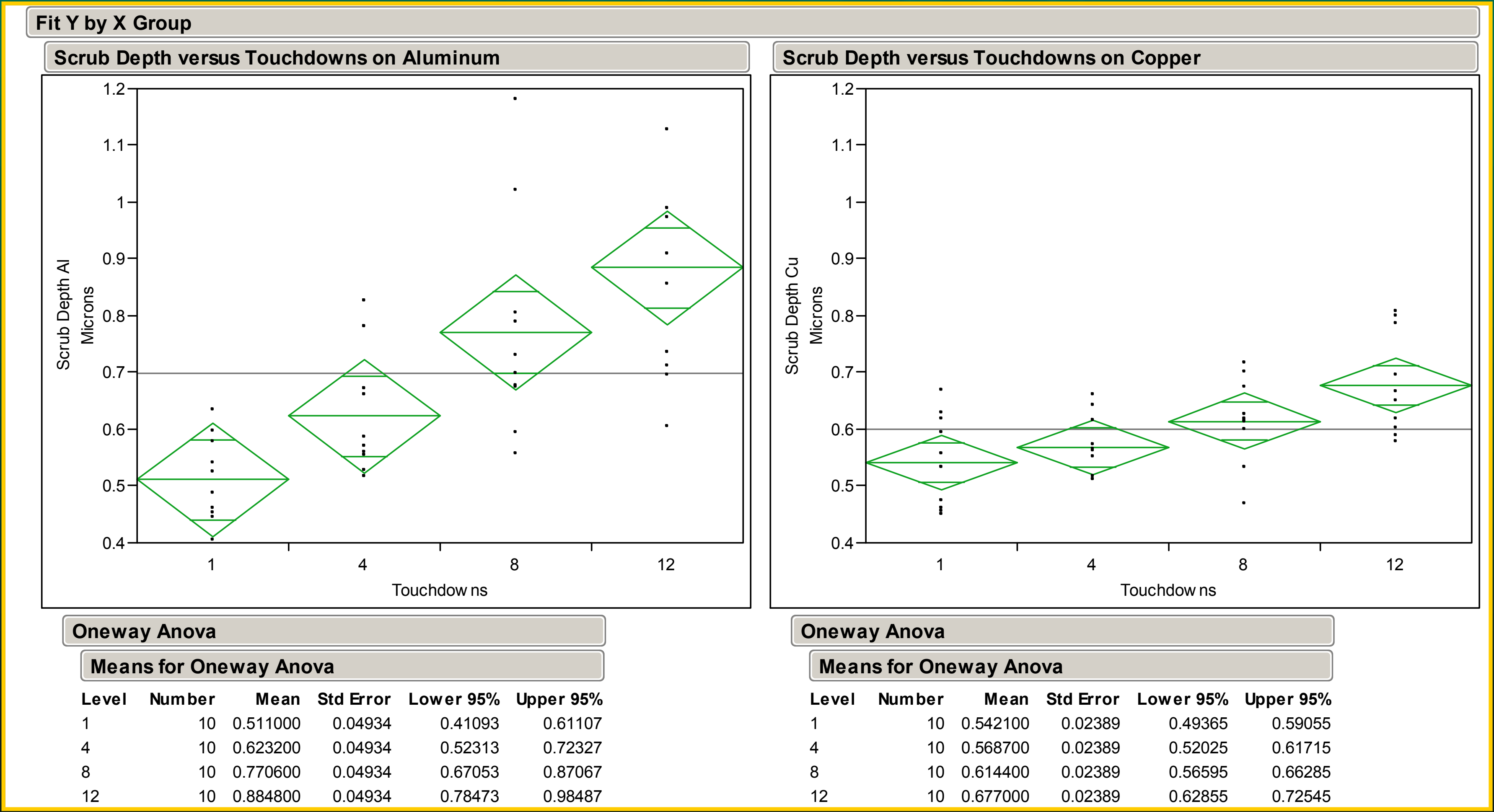
Contact resistance results up to 100K TDs. Resistance is the path resistance including the Cres.

Cres Testing on PbSn



Contact resistance results up to 100K TDs. Resistance is the path resistance including the Cres.

Comparing Means of Scrub Depth for Al & Cu



Fit Y by X Group

Scrub Depth versus Touchdowns on Aluminum

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	0.511000	0.04934	0.41093	0.61107
4	10	0.623200	0.04934	0.52313	0.72327
8	10	0.770600	0.04934	0.67053	0.87067
12	10	0.884800	0.04934	0.78473	0.98487

Scrub Depth versus Touchdowns on Copper

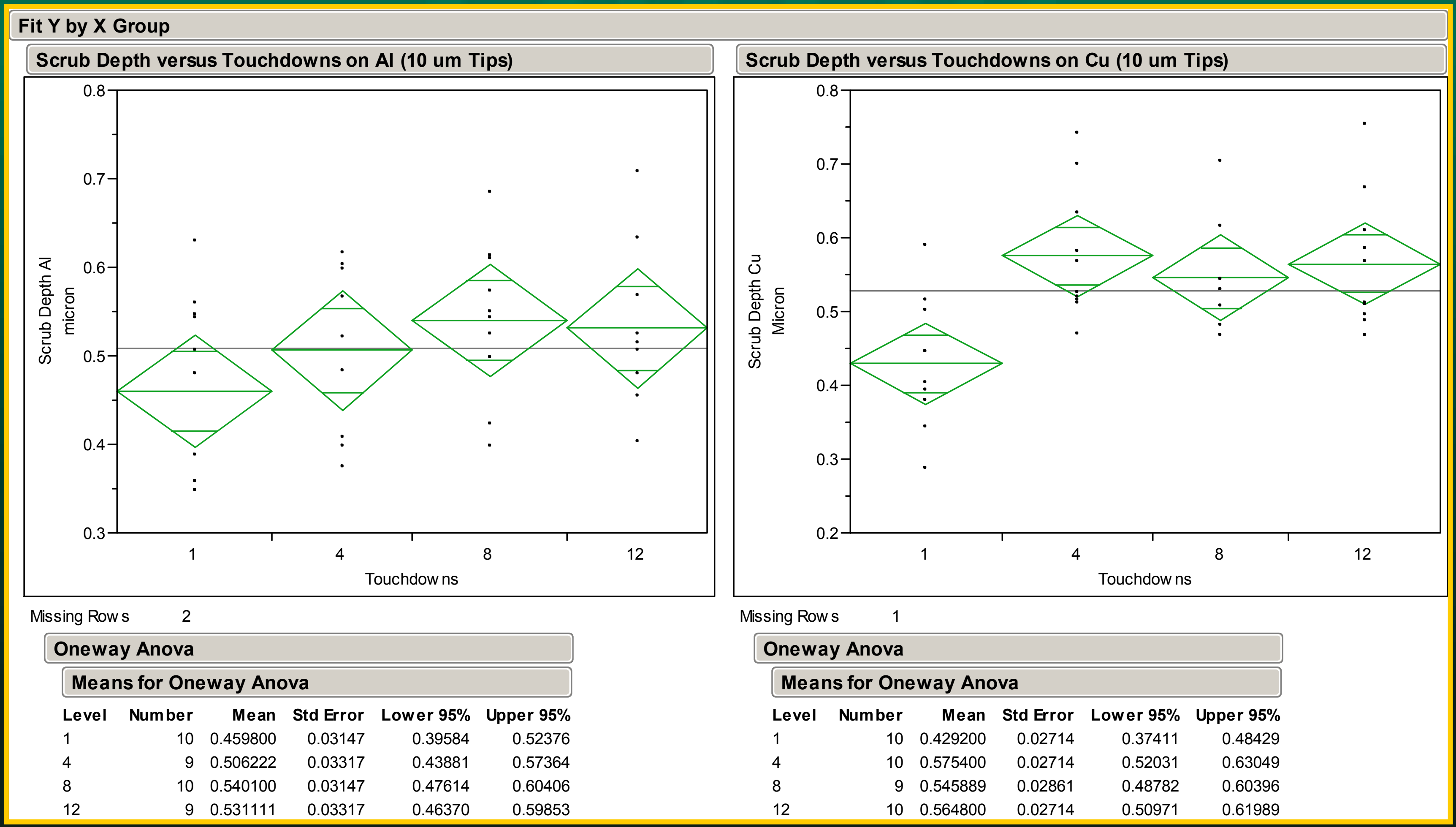
Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	0.542100	0.02389	0.49365	0.59055
4	10	0.568700	0.02389	0.52025	0.61715
8	10	0.614400	0.02389	0.56595	0.66285
12	10	0.677000	0.02389	0.62855	0.72545

Scrub depth on Al & Cu for 1, 4, 8 & 12 TDs on the same spot. Probe tip diameter is 8 µm.

Comparing Means of Scrub Depth



Fit Y by X Group

Scrub Depth versus Touchdowns on Al (10 um Tips)

Missing Rows 2

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	0.459800	0.03147	0.39584	0.52376
4	9	0.506222	0.03317	0.43881	0.57364
8	10	0.540100	0.03147	0.47614	0.60406
12	9	0.531111	0.03317	0.46370	0.59853

Scrub Depth versus Touchdowns on Cu (10 um Tips)

Missing Rows 1

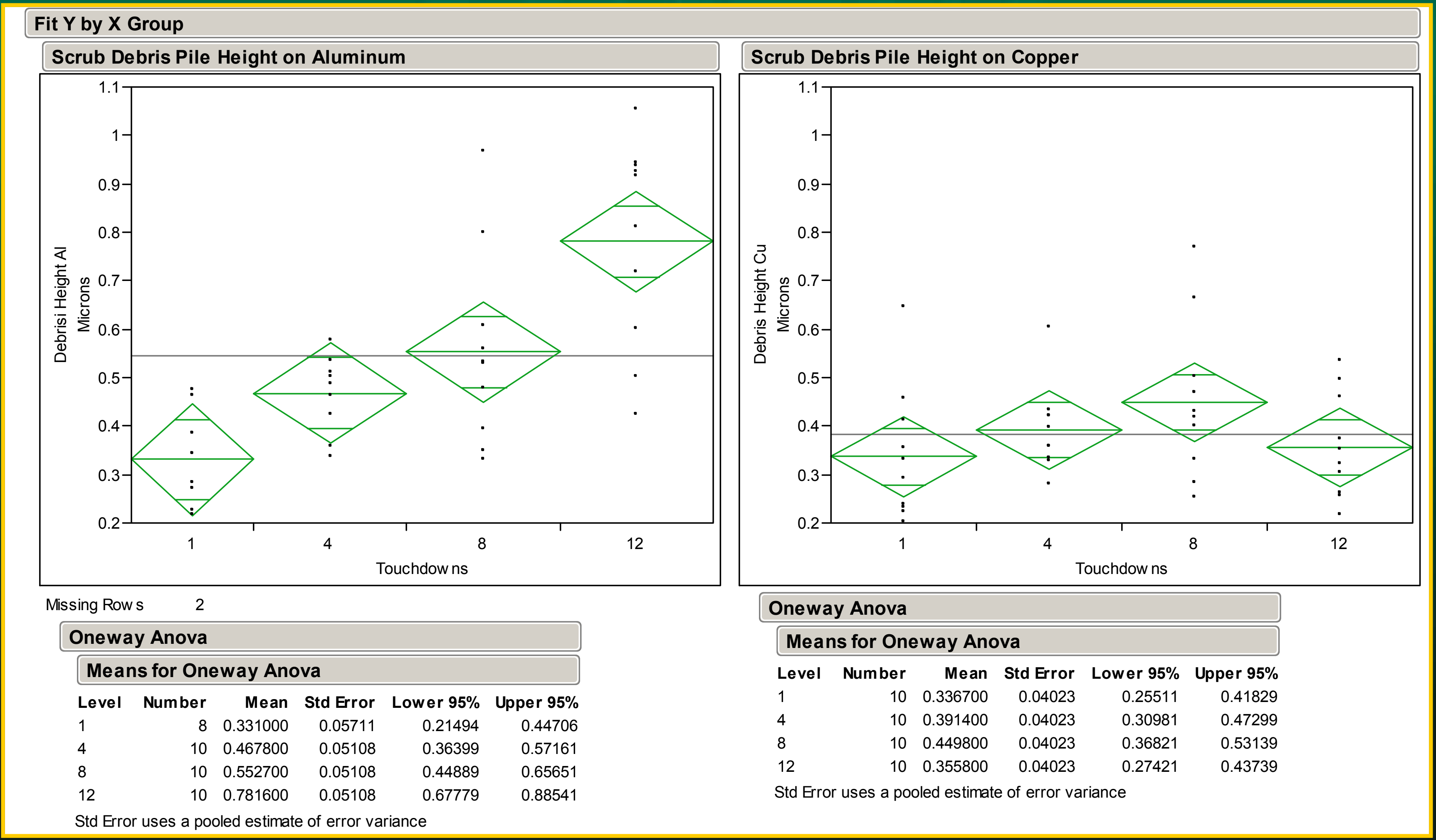
Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	0.429200	0.02714	0.37411	0.48429
4	10	0.575400	0.02714	0.52031	0.63049
8	9	0.545889	0.02861	0.48782	0.60396
12	10	0.564800	0.02714	0.50971	0.61989

Scrub depth on Al & Cu for 1, 4, 8 & 12 TDs on the same spot. Probe tip diameter is 10 µm.

Comparing Means of Debris Pile Height



Fit Y by X Group

Scrub Debris Pile Height on Aluminum

Missing Row s 2

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	8	0.331000	0.05711	0.21494	0.44706
4	10	0.467800	0.05108	0.36399	0.57161
8	10	0.552700	0.05108	0.44889	0.65651
12	10	0.781600	0.05108	0.67779	0.88541

Std Error uses a pooled estimate of error variance

Scrub Debris Pile Height on Copper

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	0.336700	0.04023	0.25511	0.41829
4	10	0.391400	0.04023	0.30981	0.47299
8	10	0.449800	0.04023	0.36821	0.53139
12	10	0.355800	0.04023	0.27421	0.43739

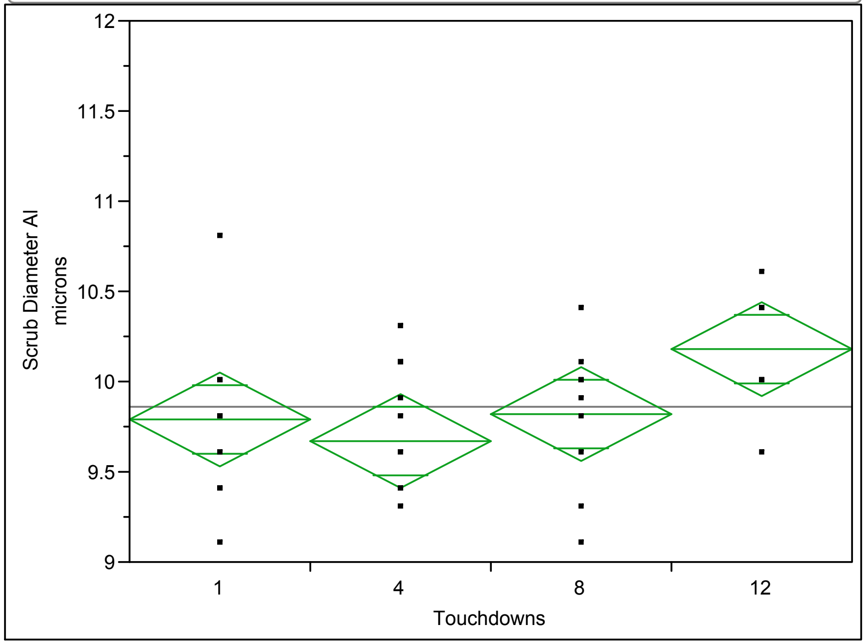
Std Error uses a pooled estimate of error variance

Scrub pile height on Al & Cu for 1, 4, 8 & 12 TDs on the same spot. Probe tip diameter is 8 µm.

Comparing Means of Scrub Diameter

Fit Y by X Group

Scrub Diameter versus Touchdowns on Aluminum



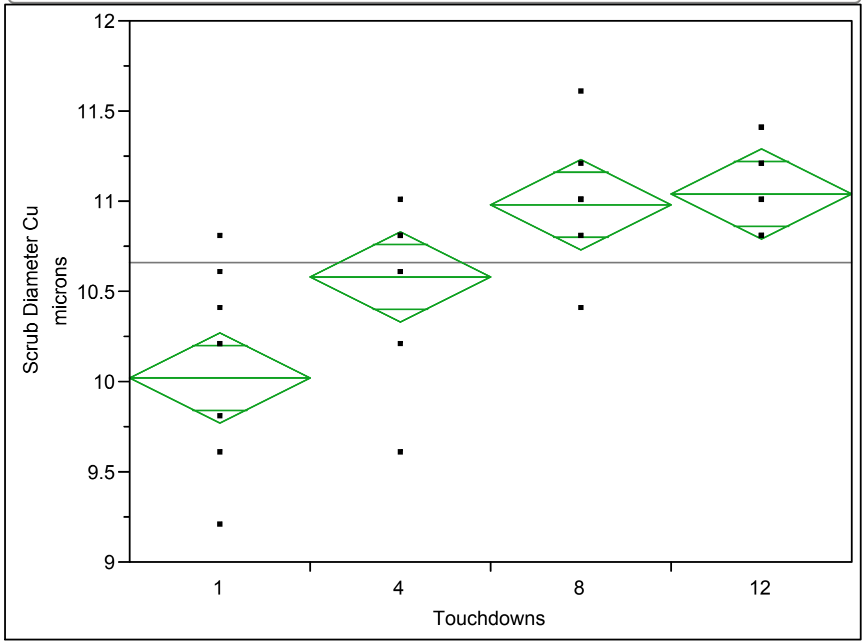
Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	9.7900	0.12955	9.5273	10.053
4	10	9.6700	0.12955	9.4073	9.933
8	10	9.8200	0.12955	9.5573	10.083
12	10	10.1800	0.12955	9.9173	10.443

Std Error uses a pooled estimate of error variance

Scrub Diameter versus Touchdowns on Copper



Oneway Anova

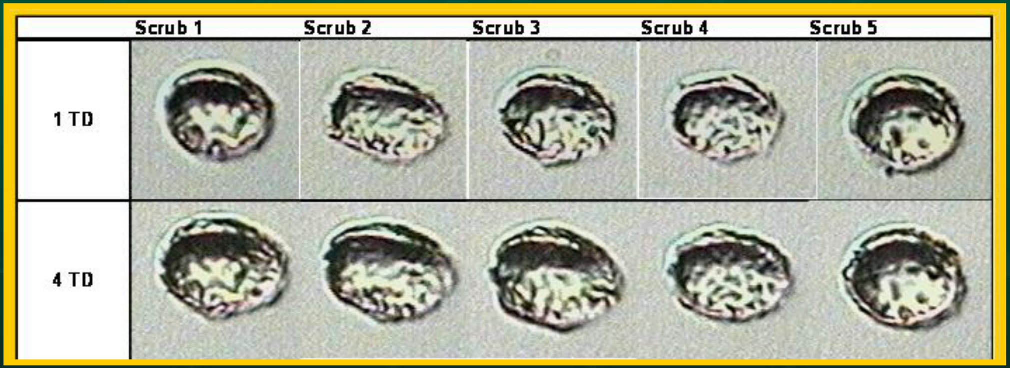
Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	10	10.0200	0.12486	9.767	10.273
4	10	10.5800	0.12486	10.327	10.833
8	10	10.9800	0.12486	10.727	11.233
12	10	11.0400	0.12486	10.787	11.293

Std Error uses a pooled estimate of error variance

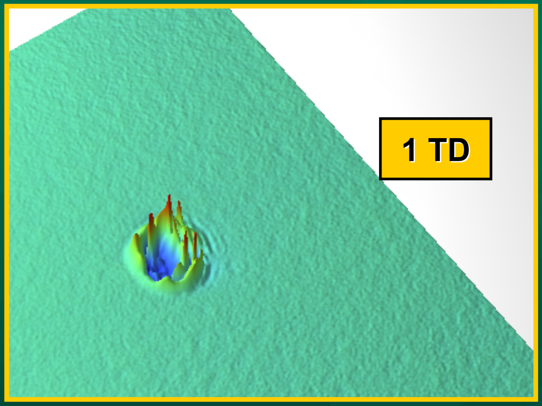
Scrub diameter on Al & Cu for 1, 4, 8 & 12 TDs on the same spot. Probe tip diameter is 8 µm.

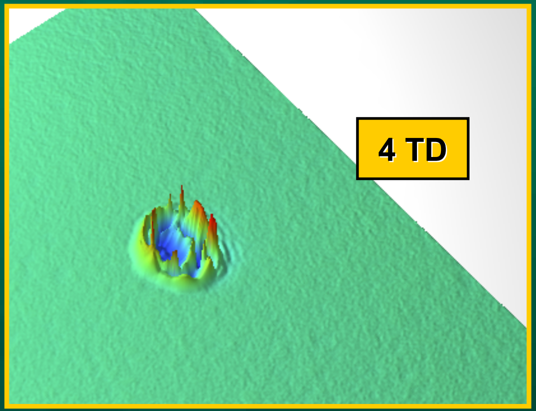
Scrub Optical Images on Al at 1 vs 4 TDs

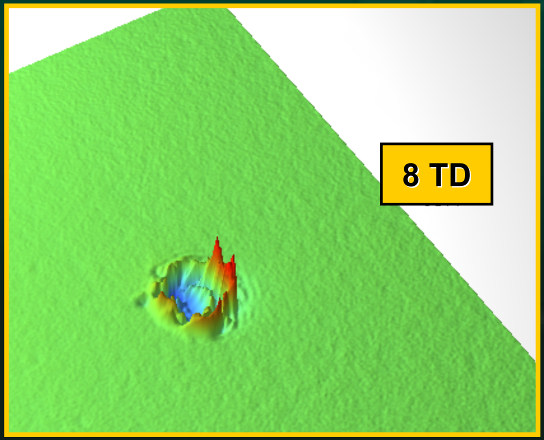


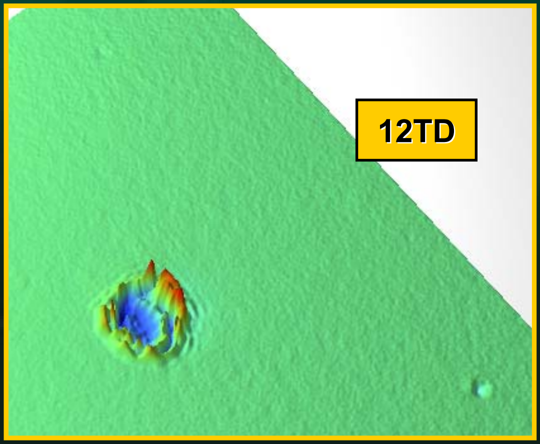
Scrub marks on Al imaged optically

3D Scan for Multiple Touchdowns on Al



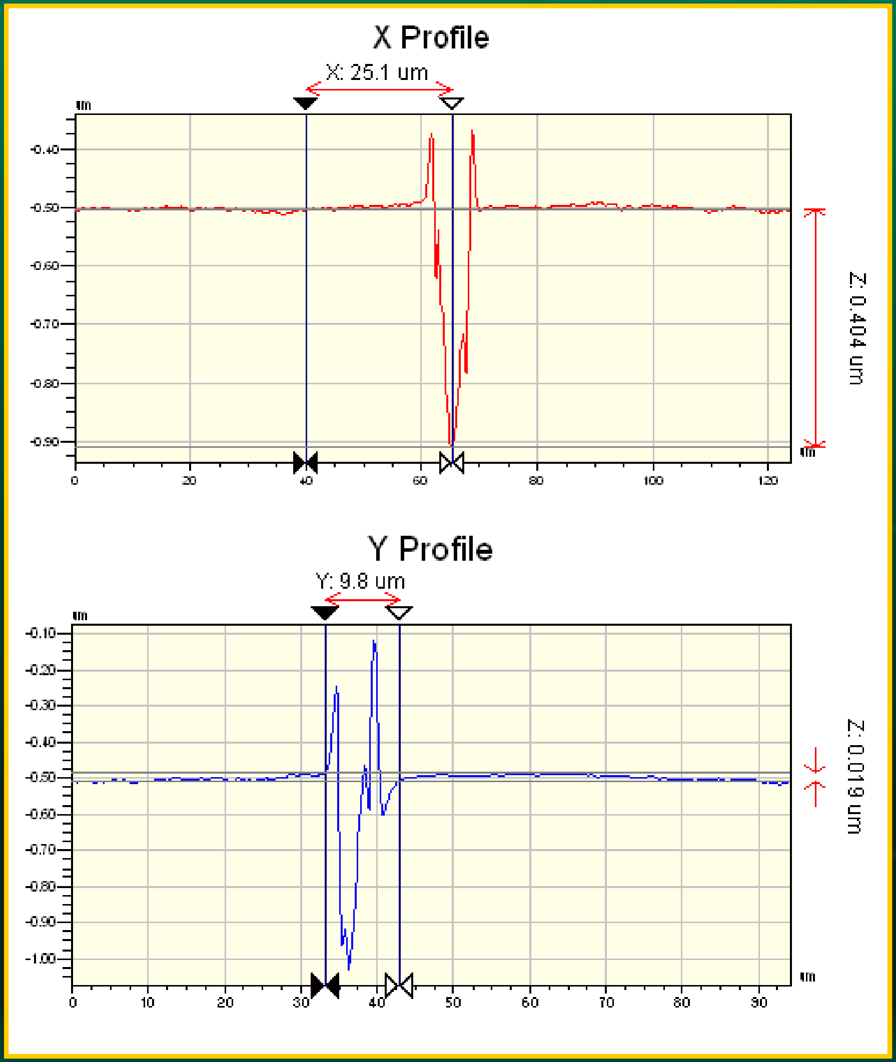




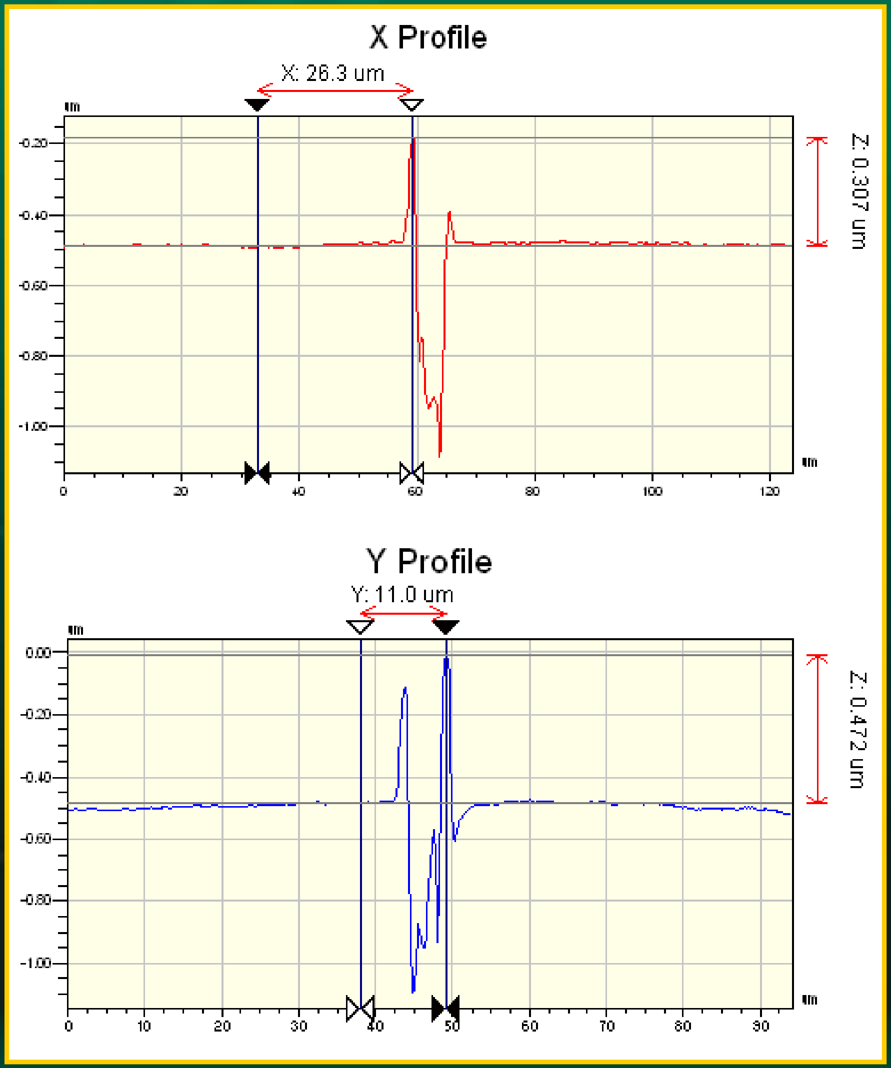


2D Scan 1TD Case for Al

Depth

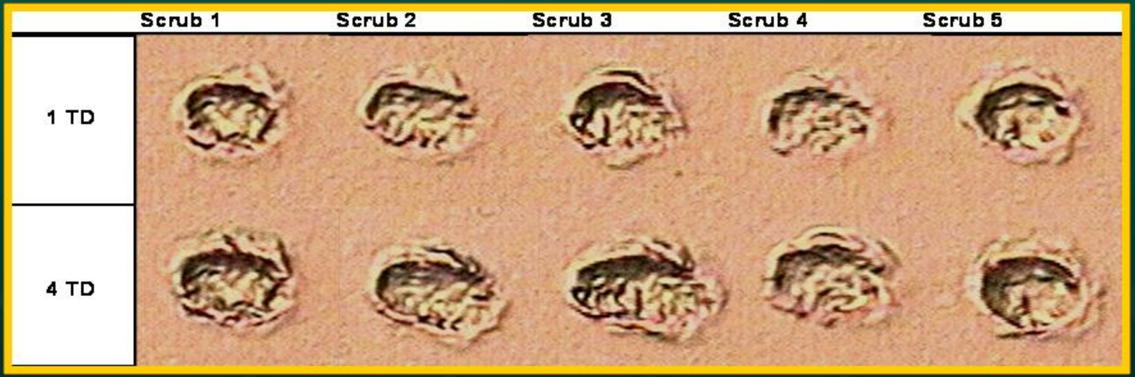


Debris Height



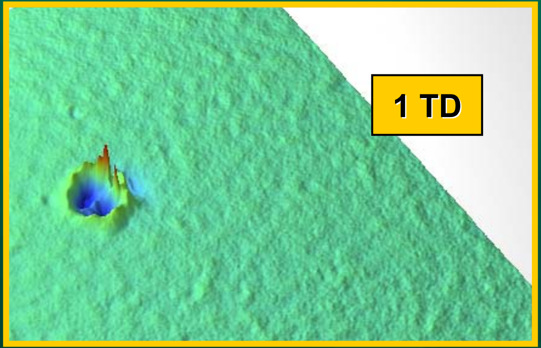
Diameter

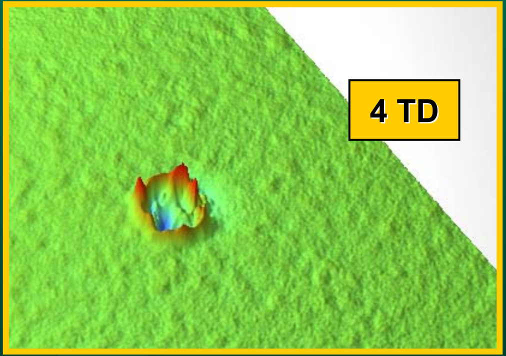
Scrub Optical Images on Cu at 1 vs 4 TDs

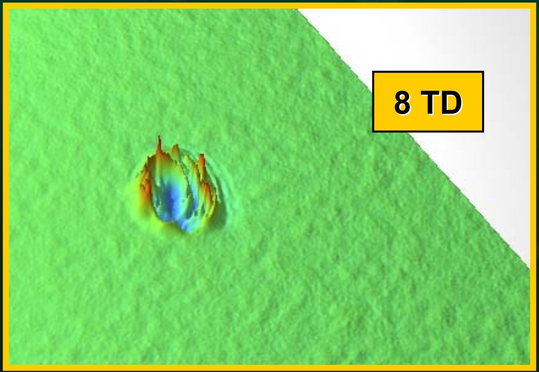


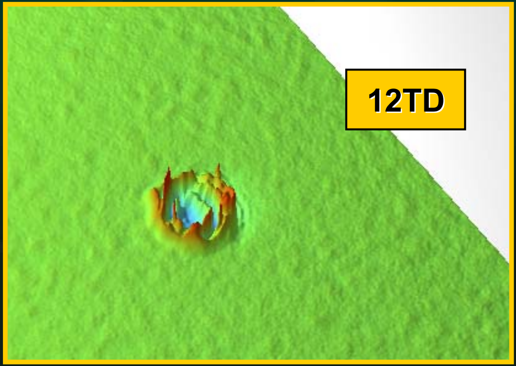
Scrub marks on Cu imaged optically.

3D Scan for Multiple Touchdowns on Cu









Summary

- ❑ **For fine pitch multidut requirements, vertical probe technologies provide advantages over cantilever approaches with design flexibilities**
  - ➢ MEMS-based vertical technology has an edge over buckling beam technologies for design flexibility for highly parallel peripheral devices as well as accuracy of scrub signatures required for smaller pad sizes
- ❑ **Contact mechanics for MEMS-based fine pitch vertical technology is studied on various contact metallurgies.**
  - ➢ Calculations for scrub depth correlate well for aluminum and copper pad contacts in experimental results. It appears that the modeling can also predict contact resistance for these pad metallurgies. This allows predictive performance of contact pin & pad materials of choice.
  - ➢ Contact resistance is studied as a function of test parameters. Stable contact resistance is achieved for three types of pad/bump metallurgies.
- ❑ **Initial results were presented for solder bump probing.**
  - ➢ More scrub analysis and characterization on different solder metallurgies on copper pillars are needed.

References

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❑ Acknowledgments

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