IEEE SW Test Workshop
Semiconductor Wafer Test Workshop

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Bond Pad Damage Tutorial

Probe Pad Damage

- Damage from Wafer Sort
- The Problem and Analysis
- Initial Pad Damage Control
- Low k Dielectrics and Copper Metalization
- Controlling Damage with Probe Card Technologies
- Using the Prober to Control the Probing Process

Introduction

- Probe card technologies have become advanced; BUT, the basics of wafer sort really have not changed.

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

- "Contact and slide" is CRITICAL to break surface oxide(s), but results in localized plastic deformation, i.e. a probe mark.

- Volume of material displaced and/or transferred is a complex function of dynamic contact mechanics, metallic interactions, frictional effects, and other tribological properties.

Bond Pad Damage Overview

What is bond pad damage?

How do we define it?

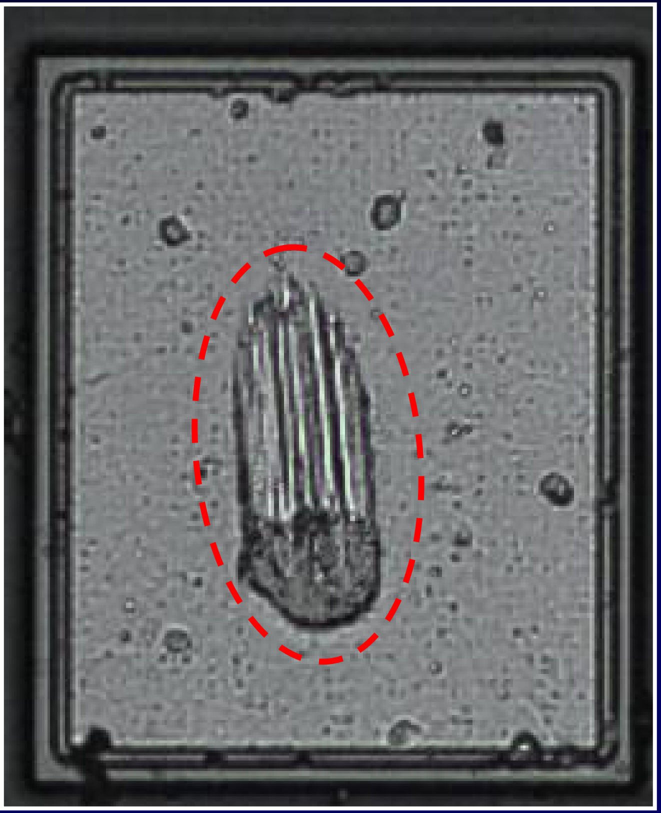
How do we measure it?

Roadmap gap assessment and industry trends

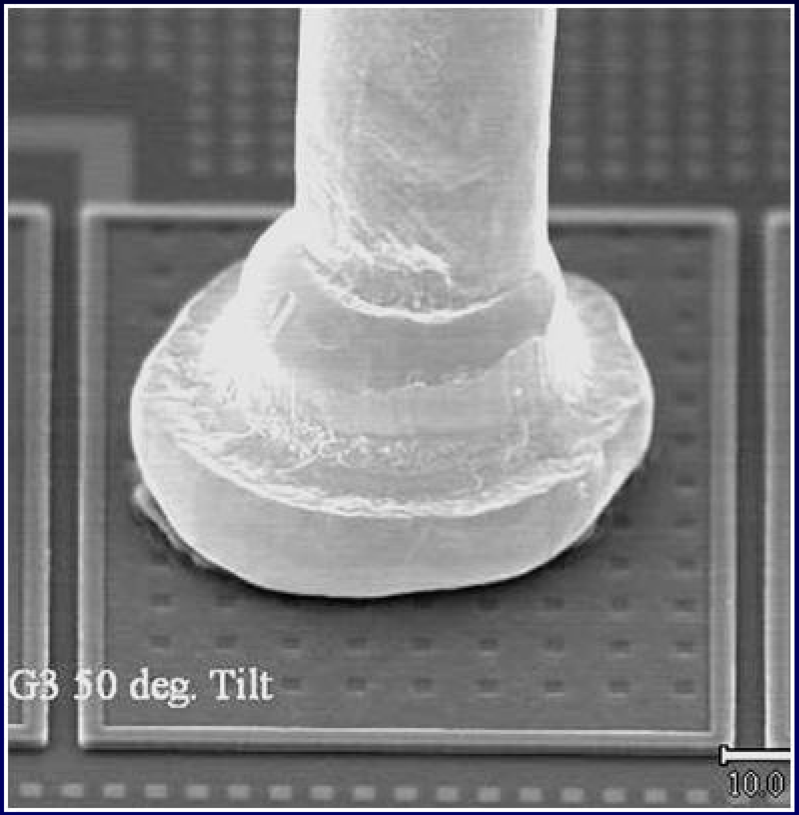
Where can I read more on bond pad damage?

Bond Pad Damage

- Excessively large scrub mark affect ball bond adhesion and cause long term reliability issues.

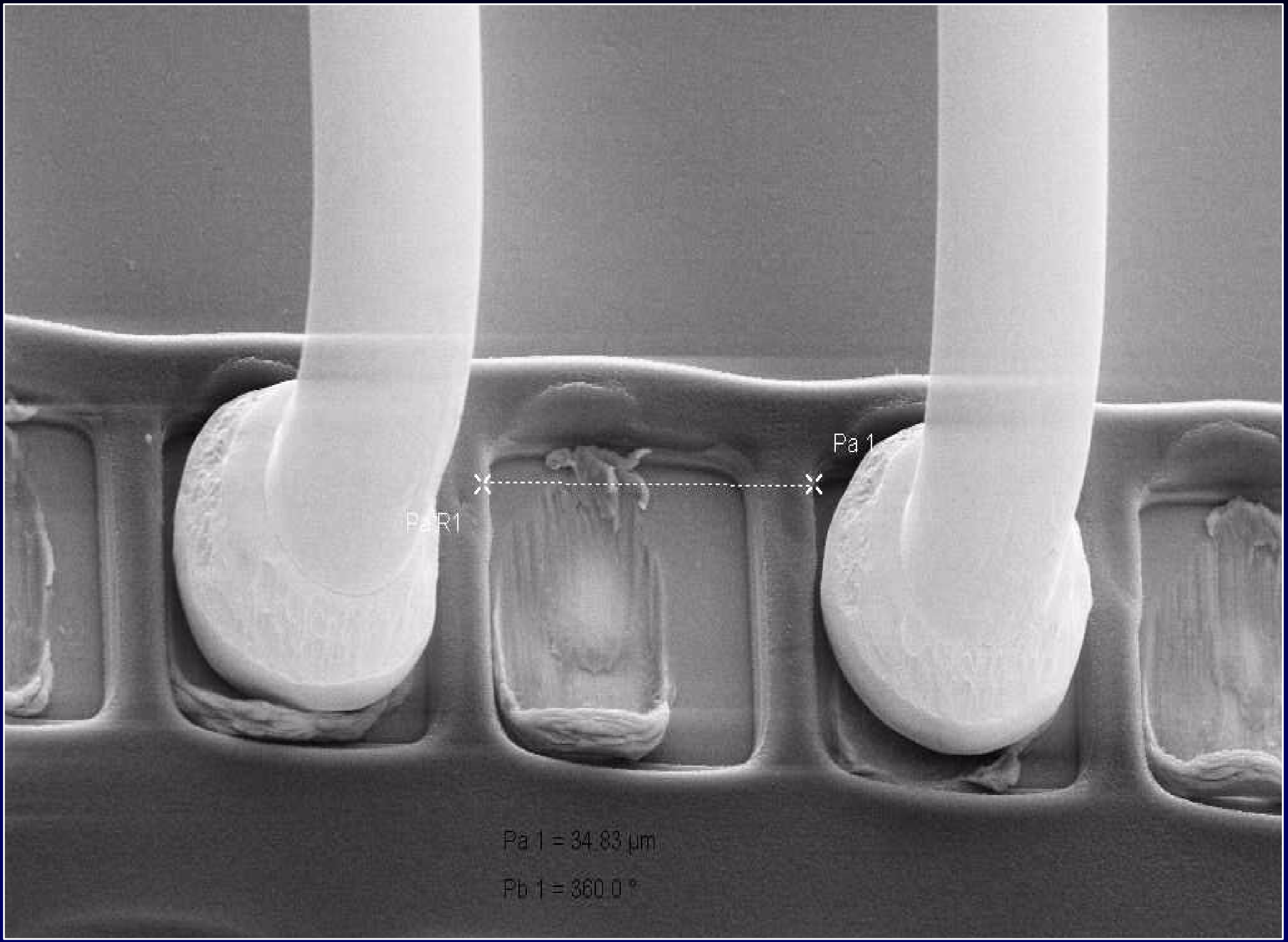


Probe Mark Size



Ball bond on probed area

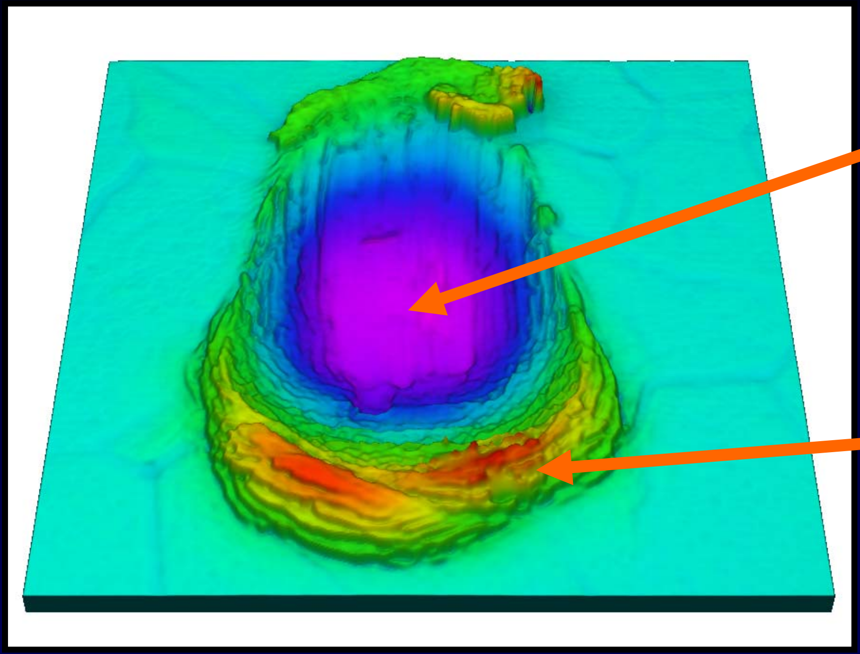
Pad size and pitch continue to shrink



Pad opening shown is 29 x 29 microns - running out of room!

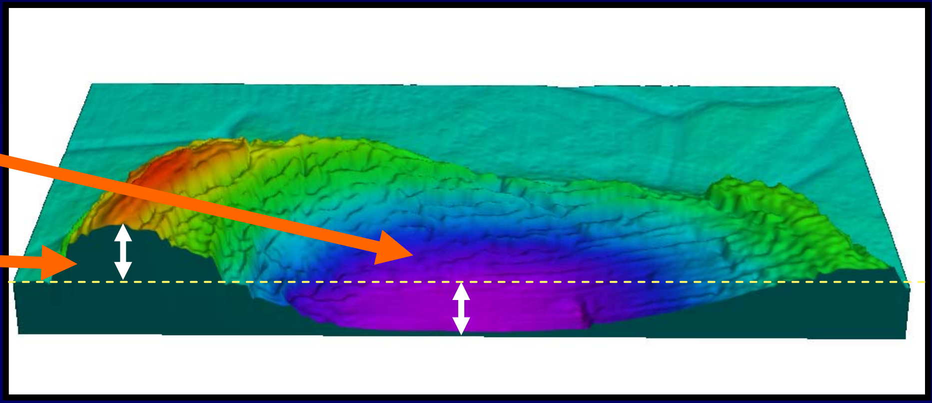
McKnight, et al., SWTW-2007

Probe Mark Anatomy



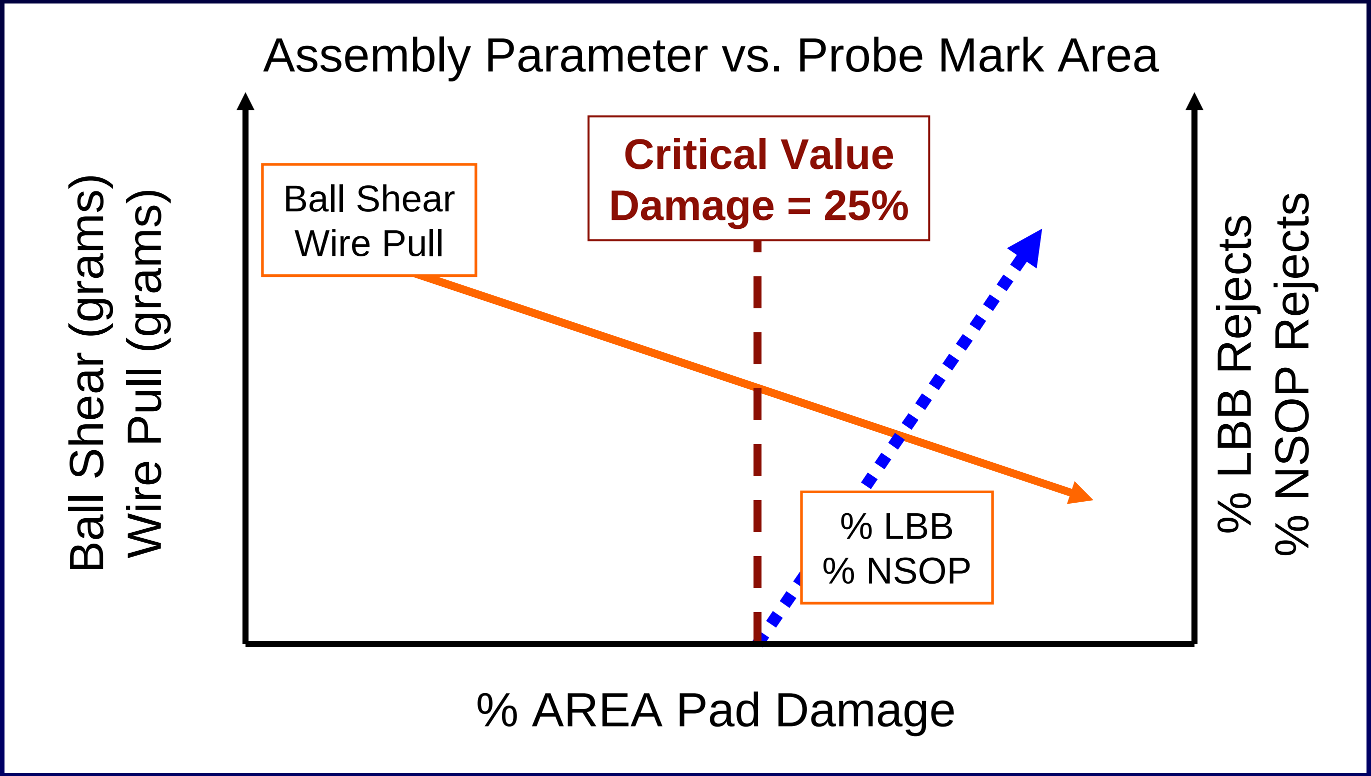
- Probe Mark
  - Area
  - Volume
- Pile-up
  - Area
  - Volume

- Probe Mark Depth
- Pile-up Height



Background – Area Effects

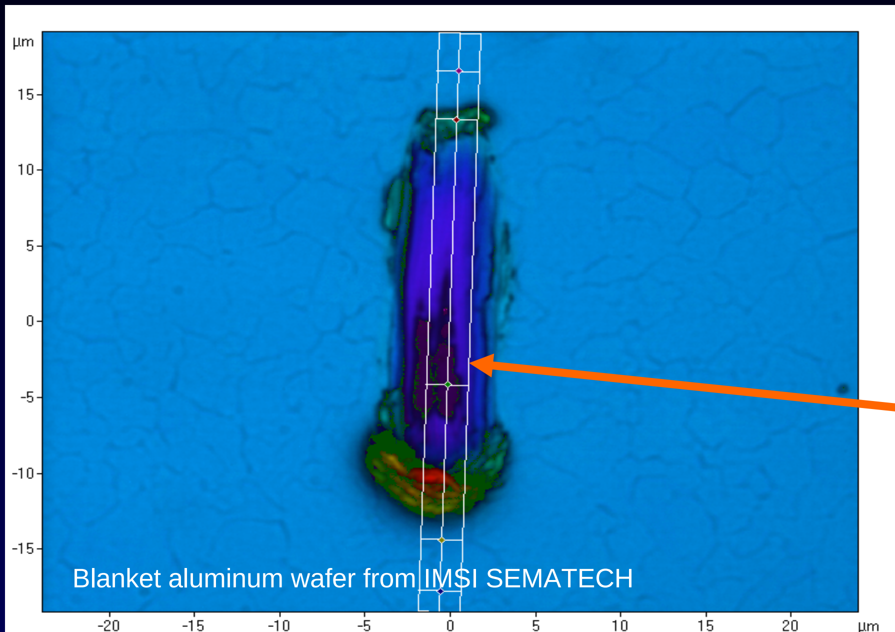
- Pad damage due to probe has been positively correlated to bondability issues.
  - Reduced ball shear strength and wire pull strength
  - Increased NSOP (no stick on pad) and LBB (lifted ball bond)



Sources …

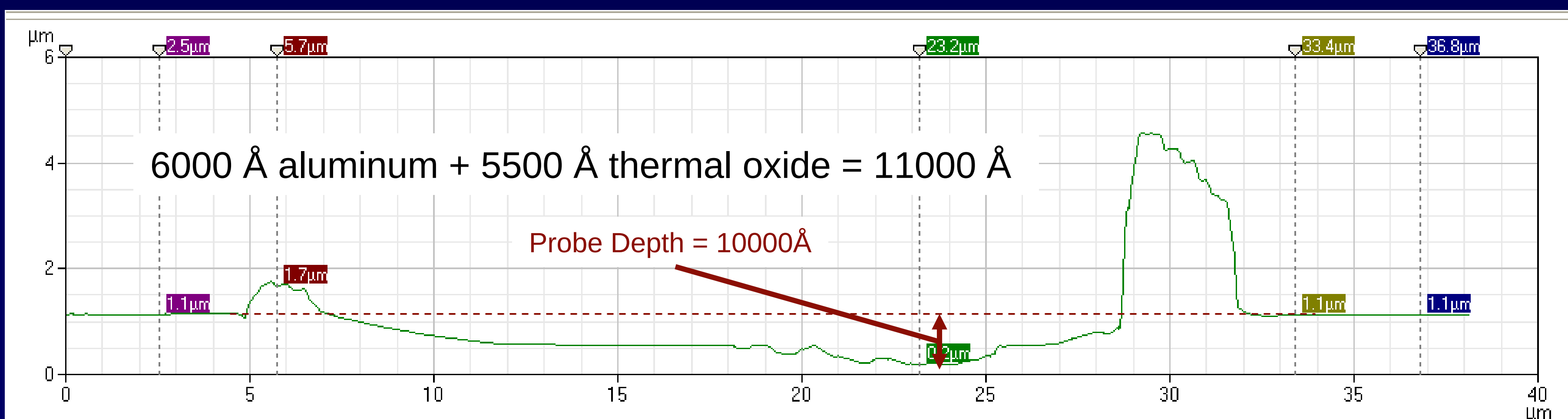
Tran, et al., ECTC -2000
Tran, et al., SWTW-2000
Langlois, et al, SWTW-2001
Hotchkiss, et al., ECTC-2001
Hothckiss, et al., IRPS-2001
Among others …

Area Effects Are Not Enough !



A probe mark can have a relatively small area of damage, but exceed the critical allowable depth.

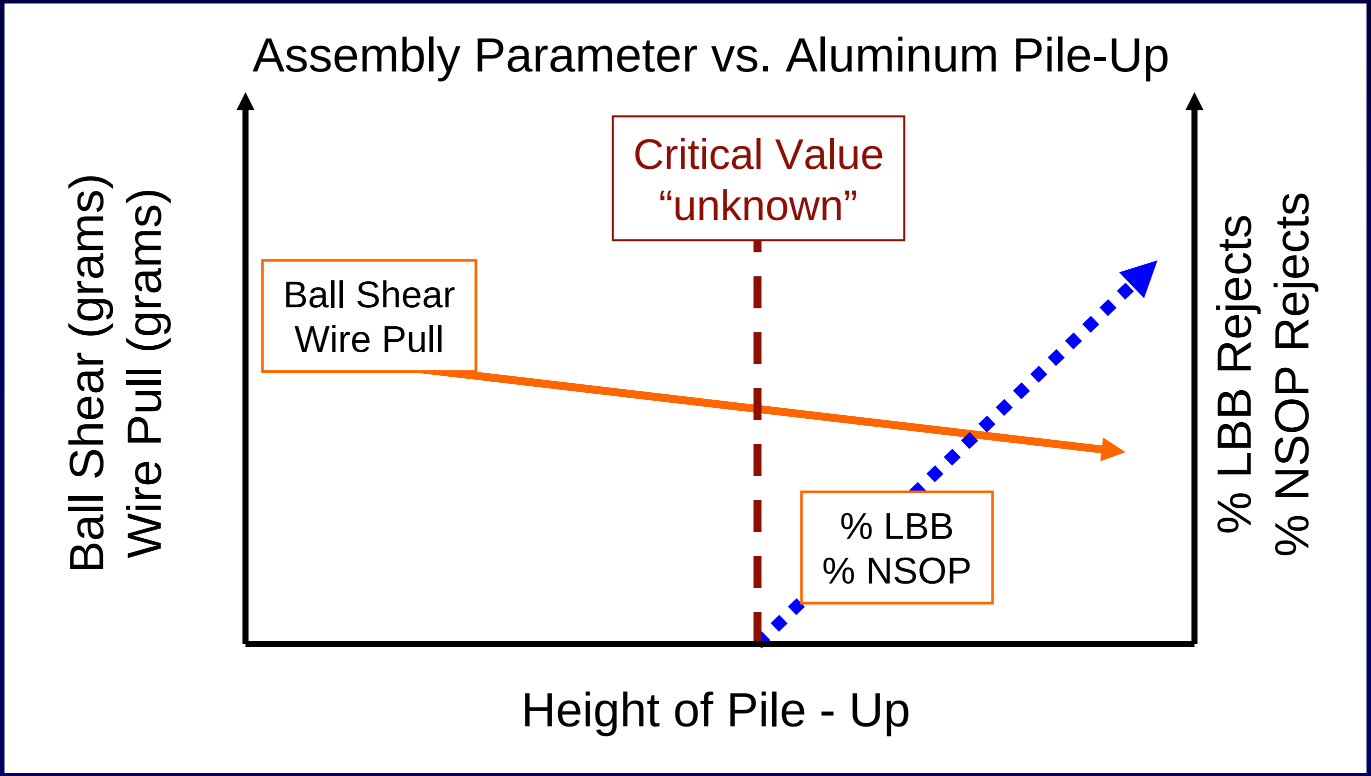
- % Area Damage = 8.8 which is within limits
- Depth = 10000Å which is excessively deep



Miller, et al., SWTW-2007

Background – Height Effects

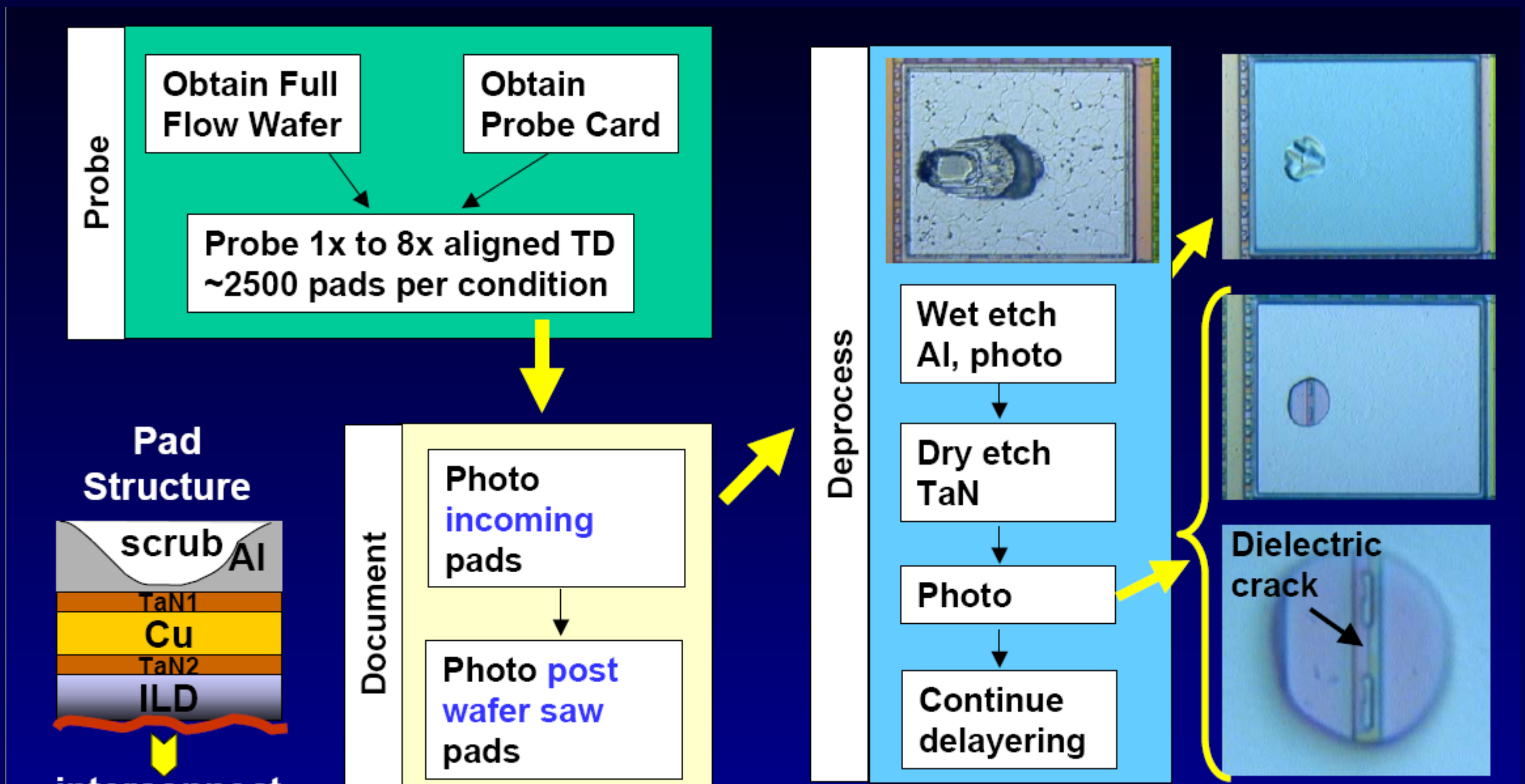
- Pad material pile-up has also been correlated to bondability issues.
  - Reduced ball shear strength and wire pull strength
  - Increased NSOP (no stick on pad) and LBB (lifted ball bond)



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

Background – Depth Effects

- Excessively deep probe marks can cause …
  - Underlying layer damage (low-k dielectric, circuitry under bond pads, and aluminum capped copper pads)
  - Bondability and long term reliability issues



Images from Hartfield, et al, SWTW-2003

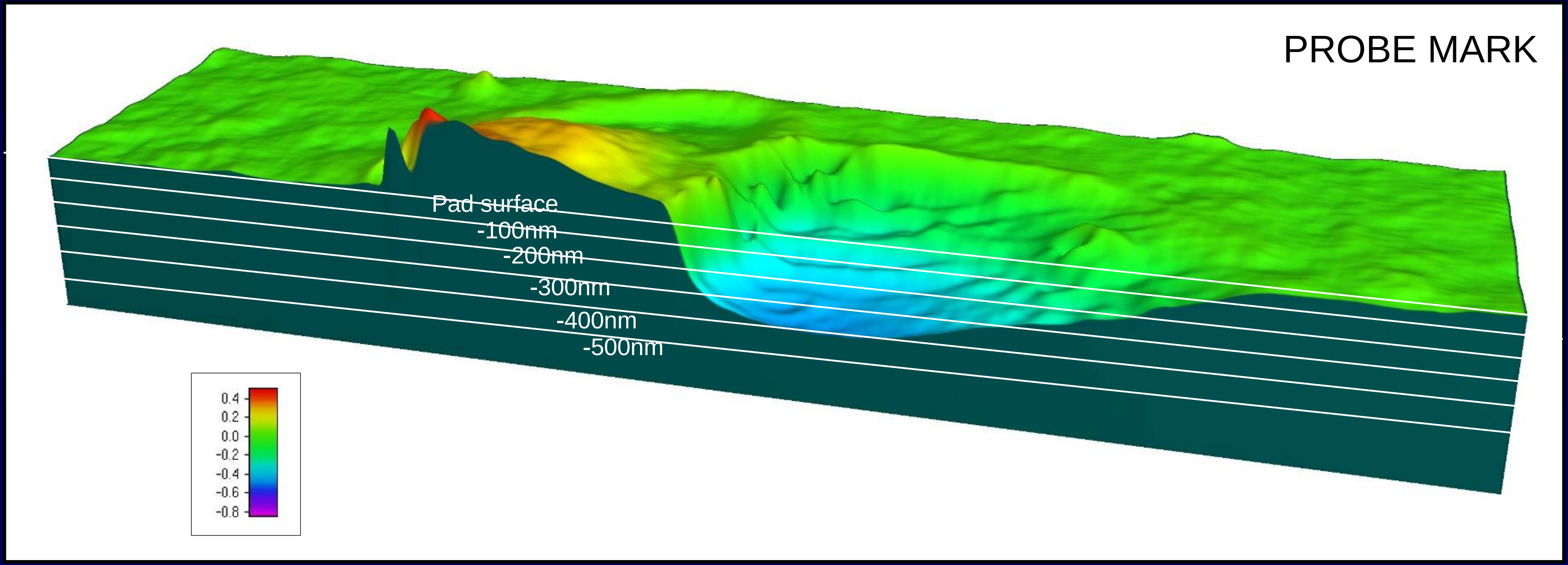
Many steps are needed to assess cracks.

Sources …

Hartfield, et al, SWTW-2003
Martens, et. al., SWTW-2003
Hartfield, et al., SWTW-2004
Stillman, et al., SWTW-2005
Among others …

Probe Mark 3D Cross Section

- From the wafer sort standpoint …
  - 3D imaging facilitates probe mark visualization
  - Displaced volume and depth can be correlated to key sort parameters, e.g. z-stage speed, overtravel, probe force, cracking, punch-through, etc.

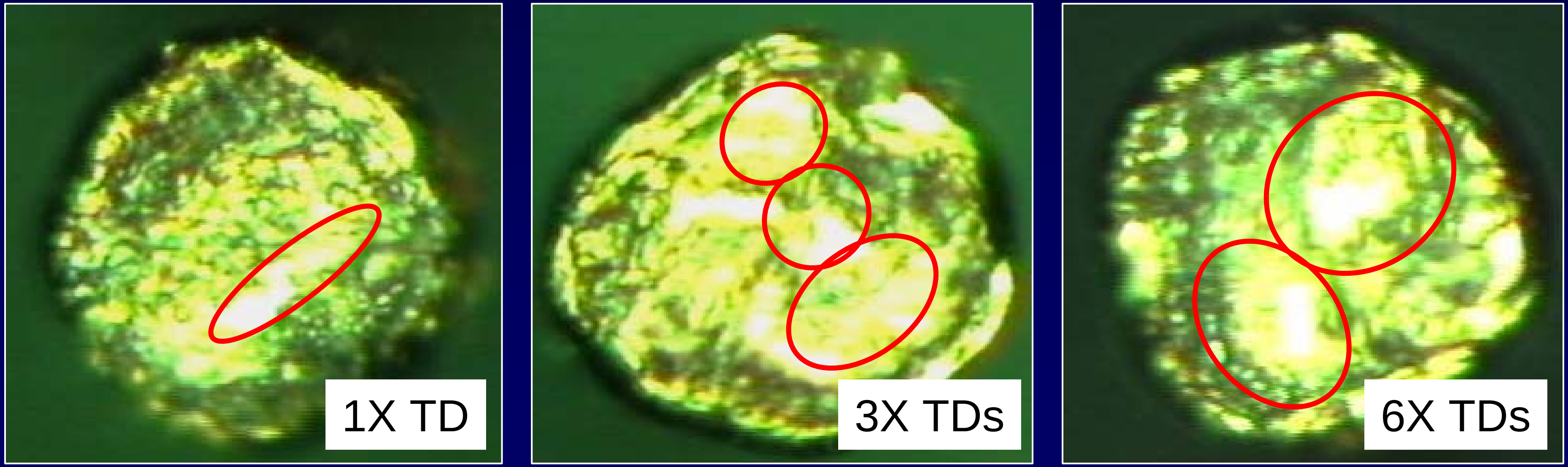


Courtesy of Hyphenated Systems, LLC.

Bonding Intermetallic Formation

- Insufficient aluminum-gold intermetallic form at the deepest portion of the probe mark.
- Bonding to pads with > 25% probe damage produces a higher incidence of lifted balls during production.

Regions of little or no intermetallic formation and voids match the locations of the probe marks



Hidden Damage

- Probe induced cracking of underlying structures is an ongoing test industry issue.

- Damage to Cu/Low-k devices during fabrication, probe, and assembly is a long-term reliability concern
  - Low-k materials tend to have lower modulus, hardness, and fracture toughness
  - Low modulus and a extremely small fracture toughness equals a high probability of cracking.

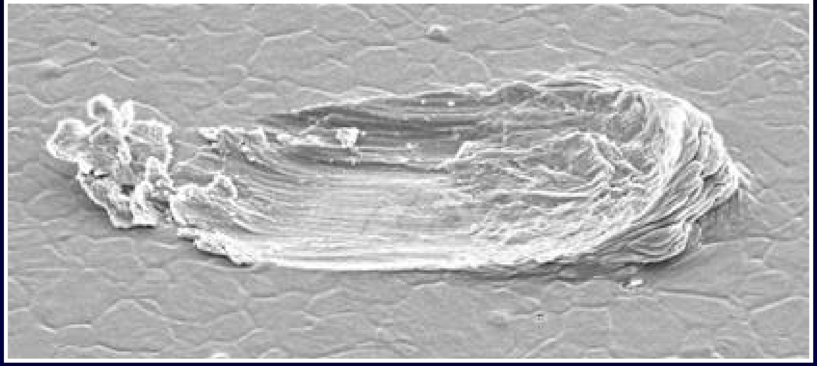
- IBM: probe damage occurs with SiLKlow-k dielectric (ISTFA 2001)
  - “The intrinsic inability to control tip contact forces with conventional tungsten tip probing techniques results in damage to the Cu interconnects and deformation of the underlying low k dielectric film.”

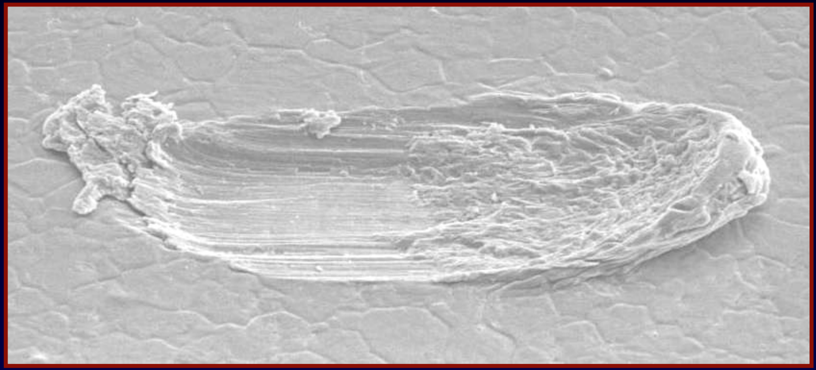
Assessing the Damage

- Traditional depth, volume, and height measurements are time consuming and can have long cycle times.
  - Probing under different conditions
  - Wafers must be scrapped
  - Careful wafer sectioning
  - Sample preparation and de-processing
  - Electron-based microscopy

Probe Card + Wafer	Manual Failure Analysis	Reporting
• Touchdowns • Variable Conditions	• Sectioning • Deprocessing • Electron Microscopy • Metrology / Correlation	**Damage Assessment** **Feedback to Production**

Hidden Deformation and Damage





BCF = 4 gw/mil
OD = 45 µm

Tip Dia. = 8 um
Probe:6 times

BCF = 4gw/mil
OD = 45µm

Tip Dia.= 14 um
Probe = 6 times

Cross Section

Al

Cu

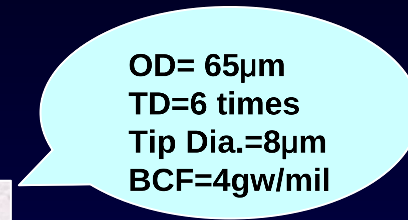
Deformation

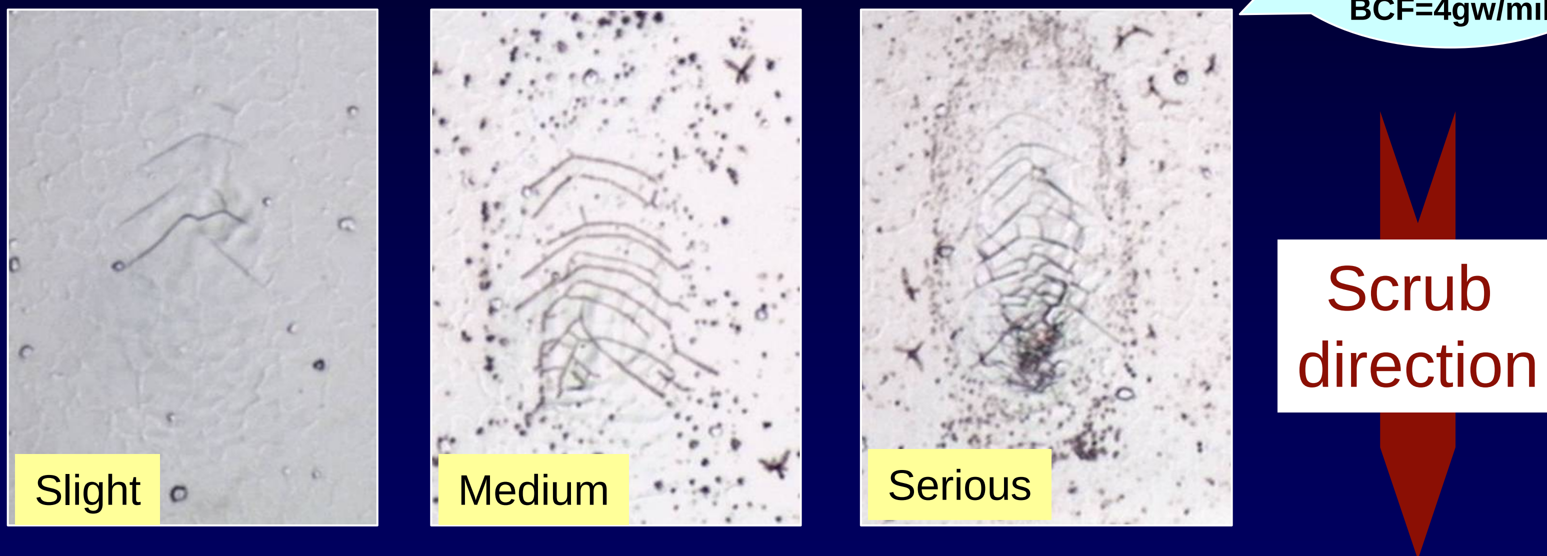
Serious "Destruction"

Hwang, et al., SWTW-2006

Assessing the Hidden Damage

- Aluminum layer was removed by deprocessing to reveal micro-scratches and cracking.





- Evaluation showed the probability of probing damage:
  - TaN Crack > Underlying Deformation > Pad Void

Hwang, et al., SWTW-2006

Dielectric Cracking DoE

4 Factors 3 Levels: 3^4

1. Over-travel
2. # of probe touchdowns
3. Dielectric thickness
4. Metal Thickness

Response:

1. # of die (out of 20) with cracks

FAB DOE – 9 Wafers

Dielectric Thk	Metal Thk
-10%	-10%
-10%	POR
-10%	+20%
POR	-10%
POR	POR
POR	+20%
+20%	-10%
+20%	POR
+20%	+20%

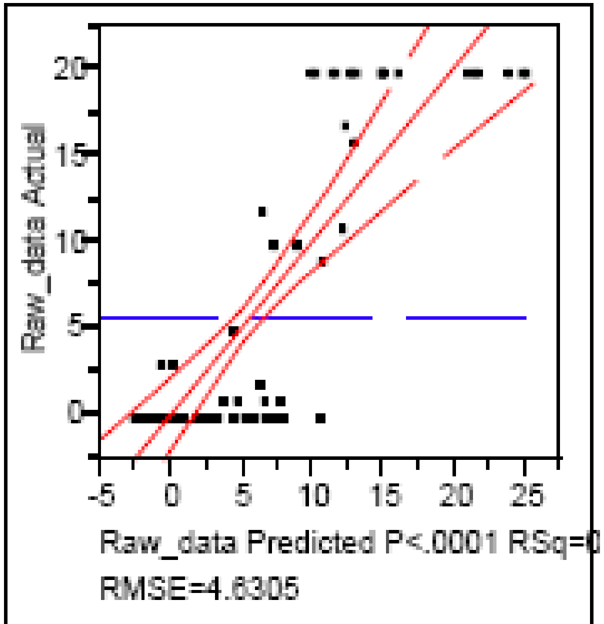
Sort DOE per wafer

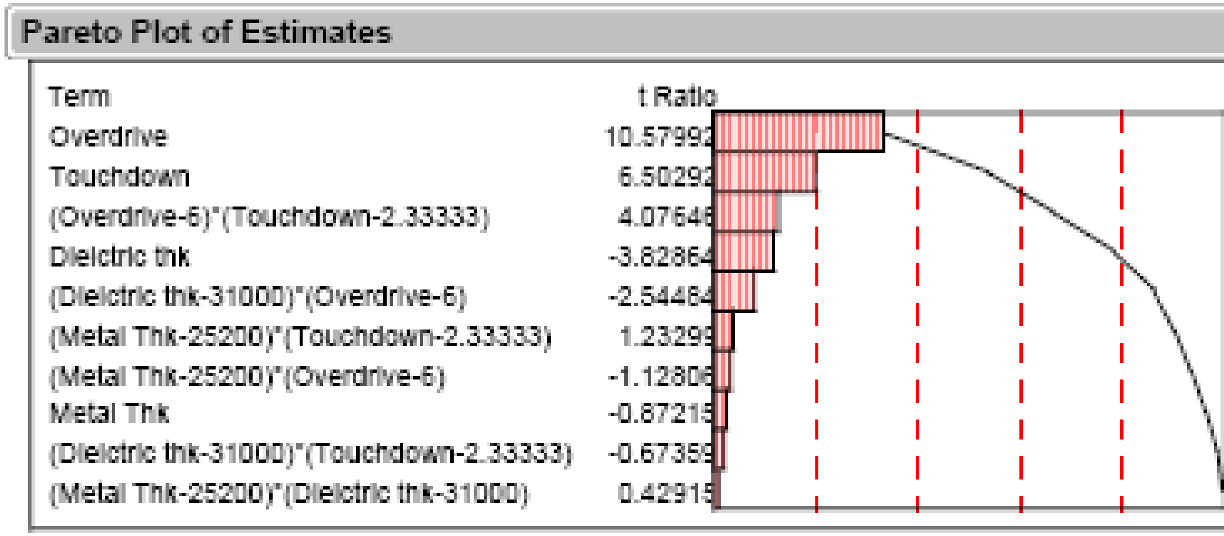
Over-Travel	Touchdowns
4mil	1X
4mil	2X
4mil	4X
6mil	1X
6mil	2X
6mil	4X
8mil	1X
8mil	2X
8mil	4X

Liu, et al., ECTC-2005

Test Results…

Probe test experiment





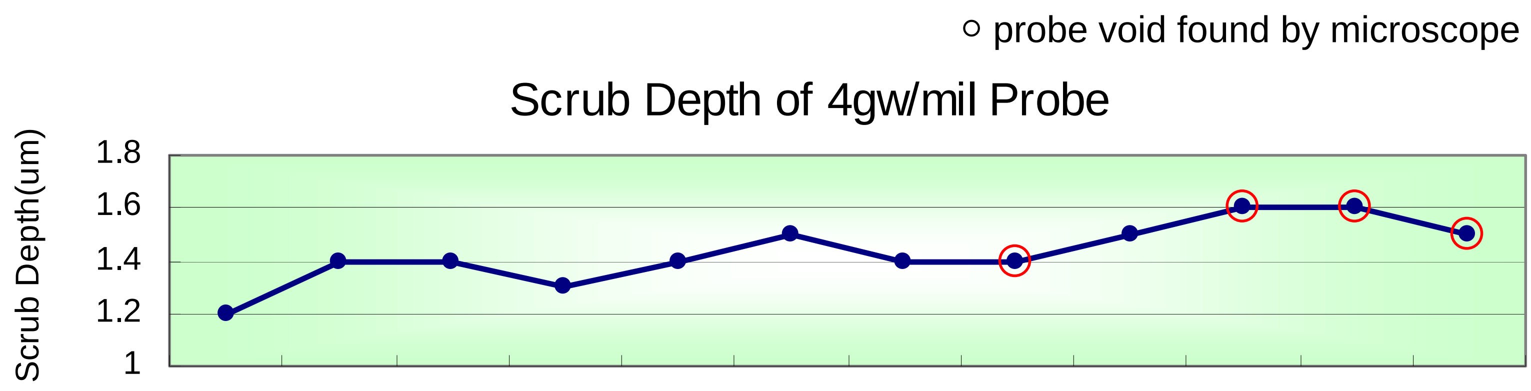
Summary of Fit

RSquare	0.737006
RSquare Adj	0.699436
Root Mean Square Error	4.630451
Mean of Response	5.703704
Observations (or Sum Wgts)	81

- Model shows that Over-travel is the first factor to control the dielectric crack
- Number of touchdowns is also the major factor
- Both OT and touch down may related to hz movement

Assessing the Hidden Damage

- Scrub Depth Correlates with Underlying Damage
- Measurements identified underlying layer deformation risk.



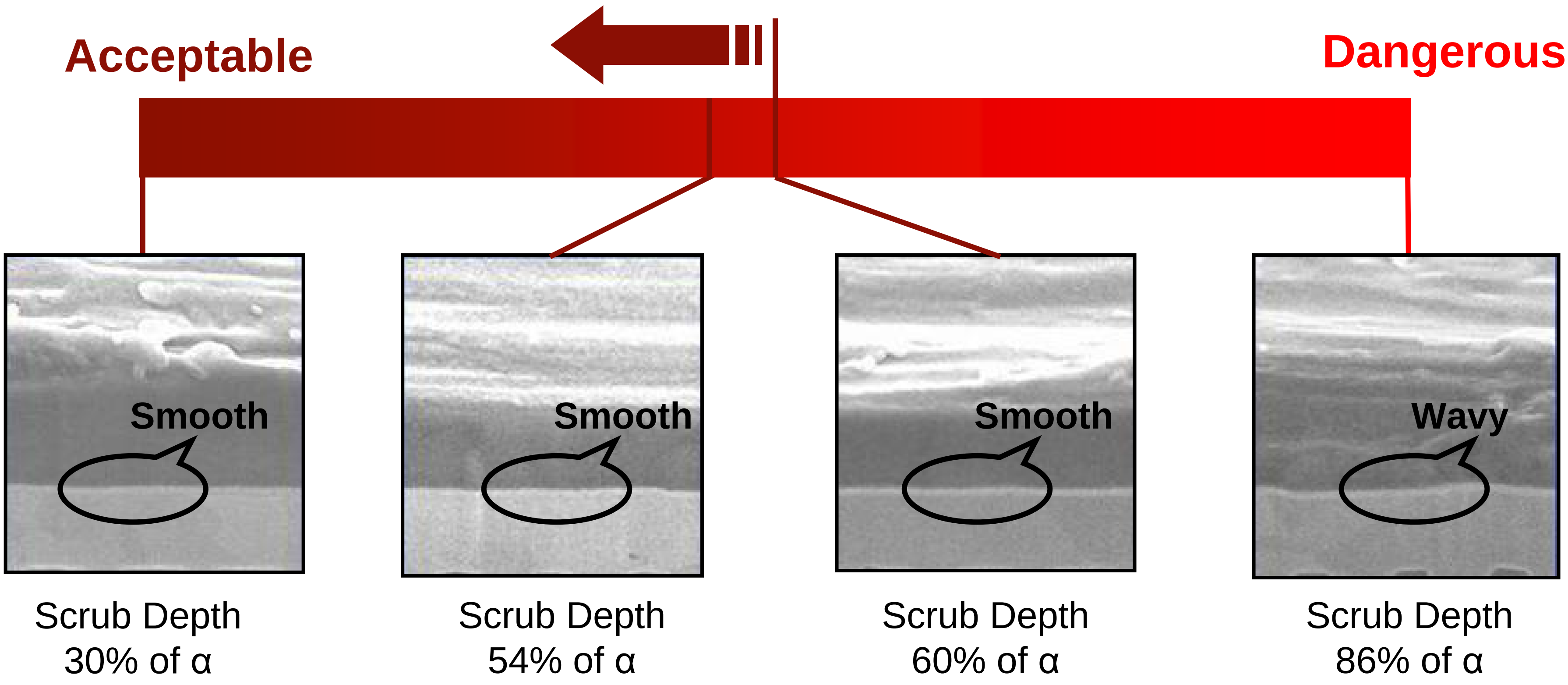
TD	2	2	2	2	4	4	4	4	6	6	6	6
OD(um)	45	55	65	75	45	55	65	75	45	55	65	75
Depth(um)	1.2	1.4	1.4	1.3	1.4	1.5	1.4	1.4	1.5	1.6	1.6	1.5

Parameters

Hwang, et al., SWTW-2006

Acceptable Scrub Depth

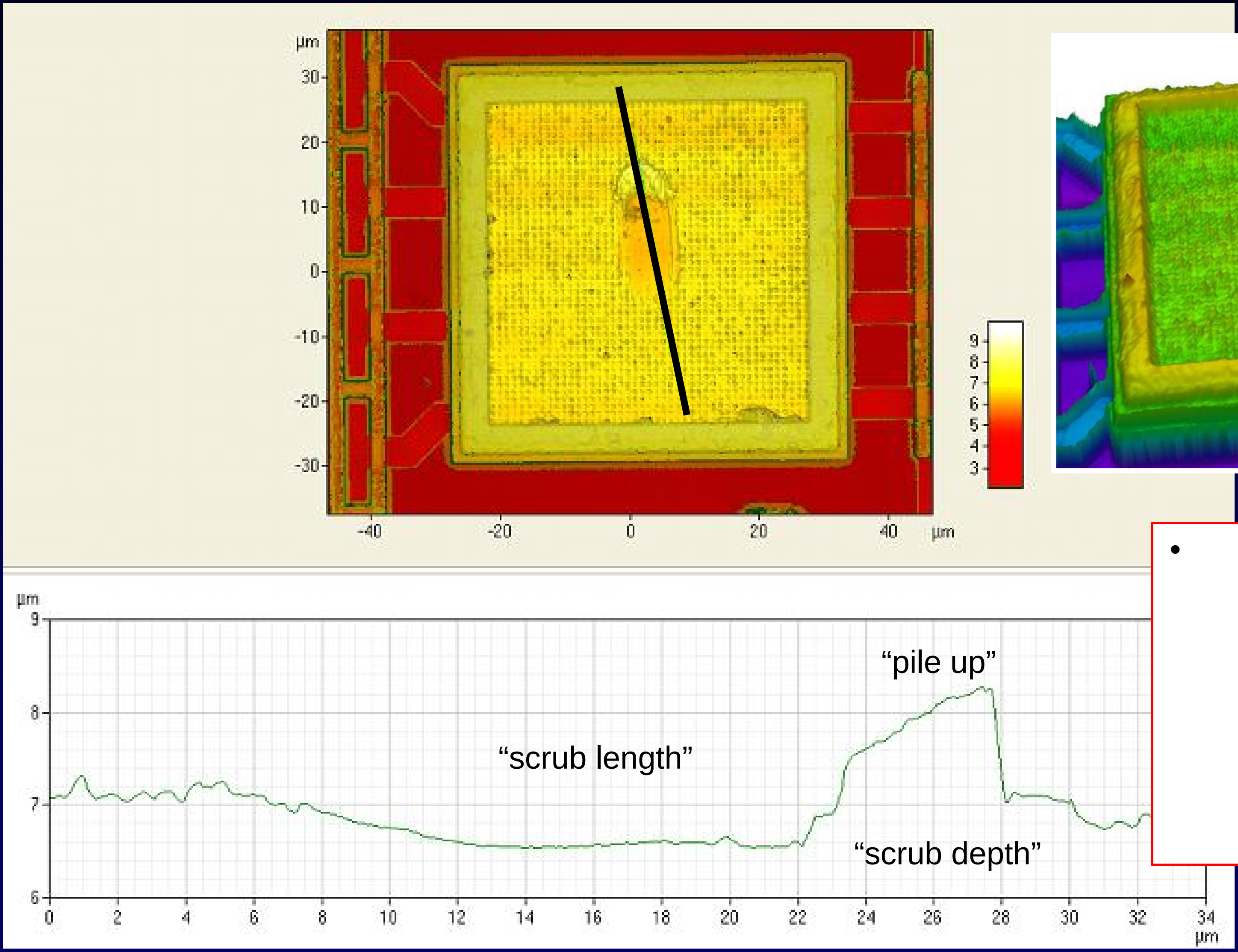
- Monitor the TaN layer integrity of shallow scrubs.

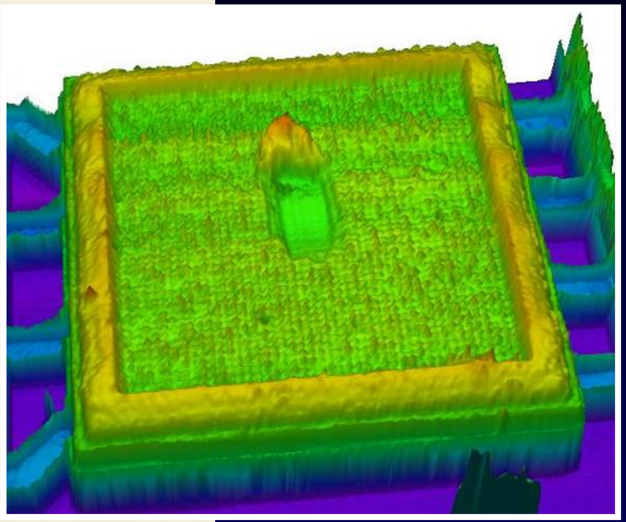


α= thickness of aluminum layer

Hwang, et al., SWTW-2006

"Fast" 3D Confocal Failure Analysis

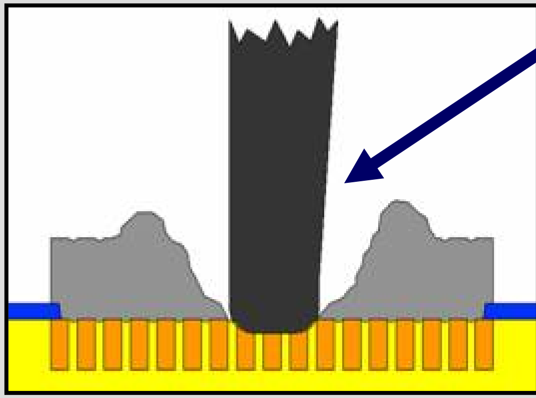




- Quickly understanding probe mark size, depth, and amount of displaced aluminum is critical for low-k dielectric, probe over active circuit, and bond ability issues (LLB and NSOP).

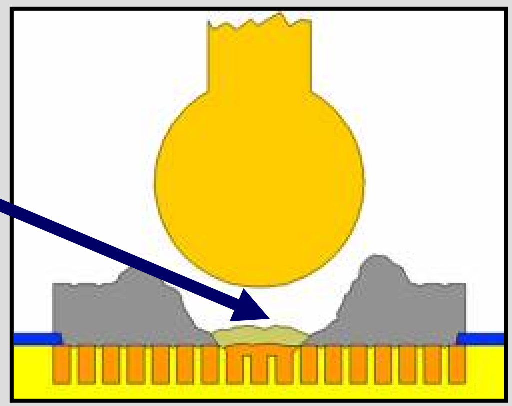
Courtesy of Hyphenated Systems, LLC.

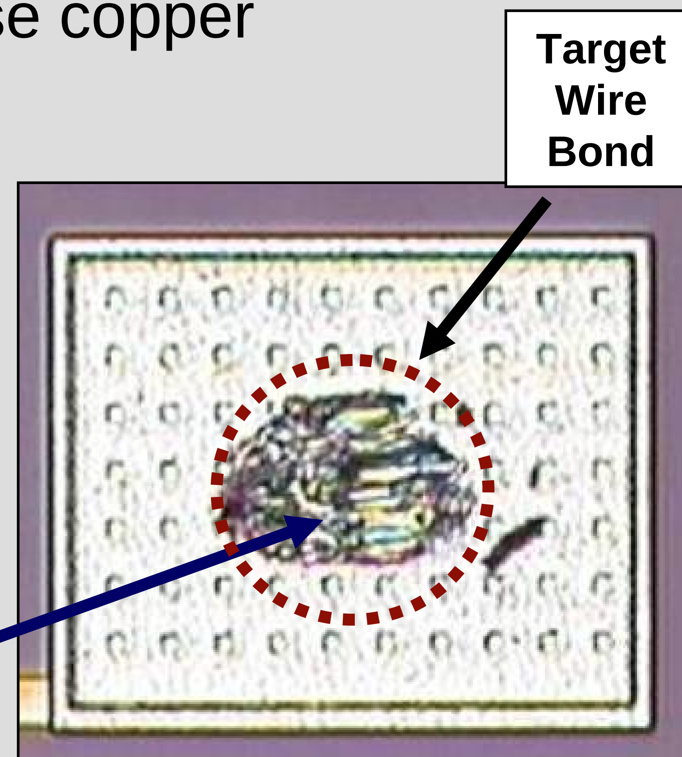
Copper Metallization Makes The Problem Even Worse …



New processes with smaller I/O pads needed smaller and sharper needles; increased chance to punch through the Al pad and expose copper

Exposed copper oxidizes fast and adversely effects the ball bonding

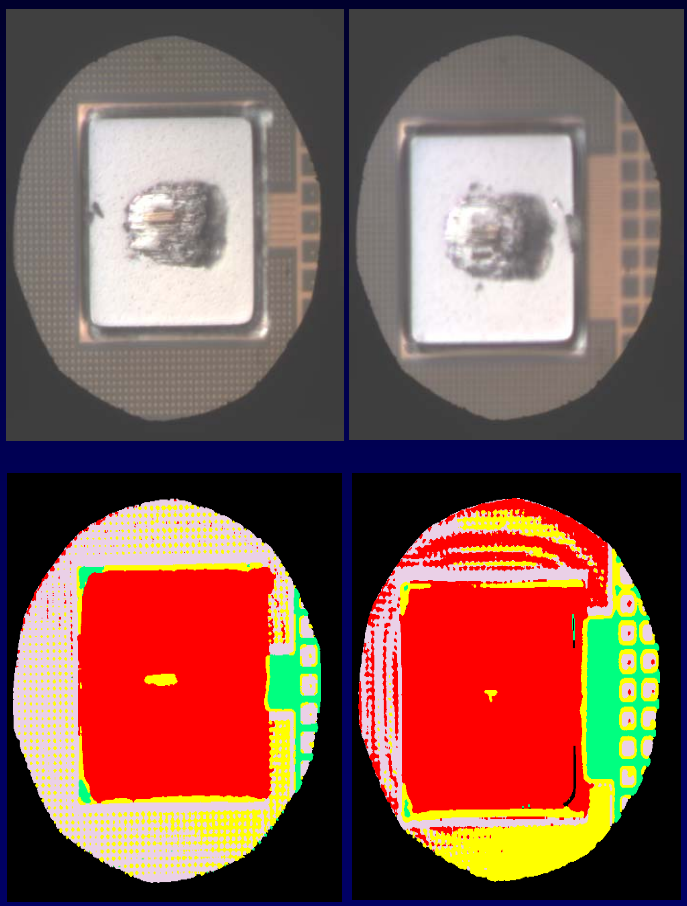




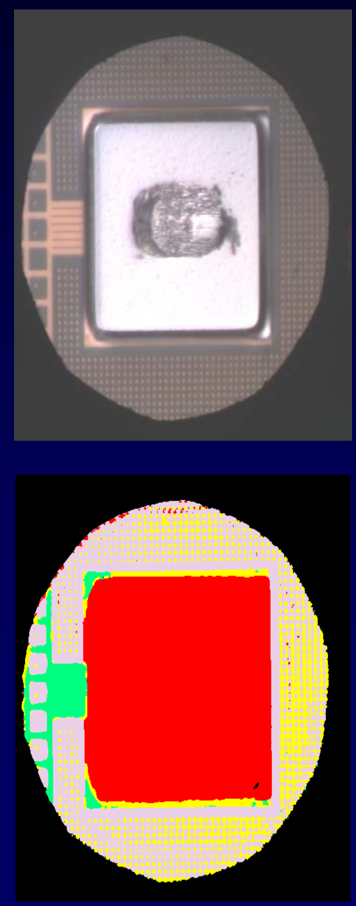
Exposed copper on I/O pad
Oxidizes causing NSOP

Punch Through

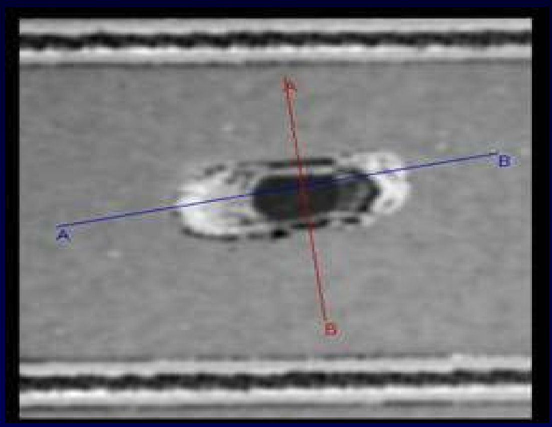
- Exposed copper identified with spectral analysis.

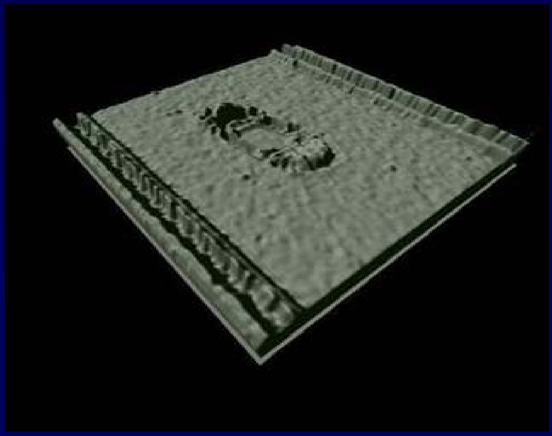


Punch Through



Okay





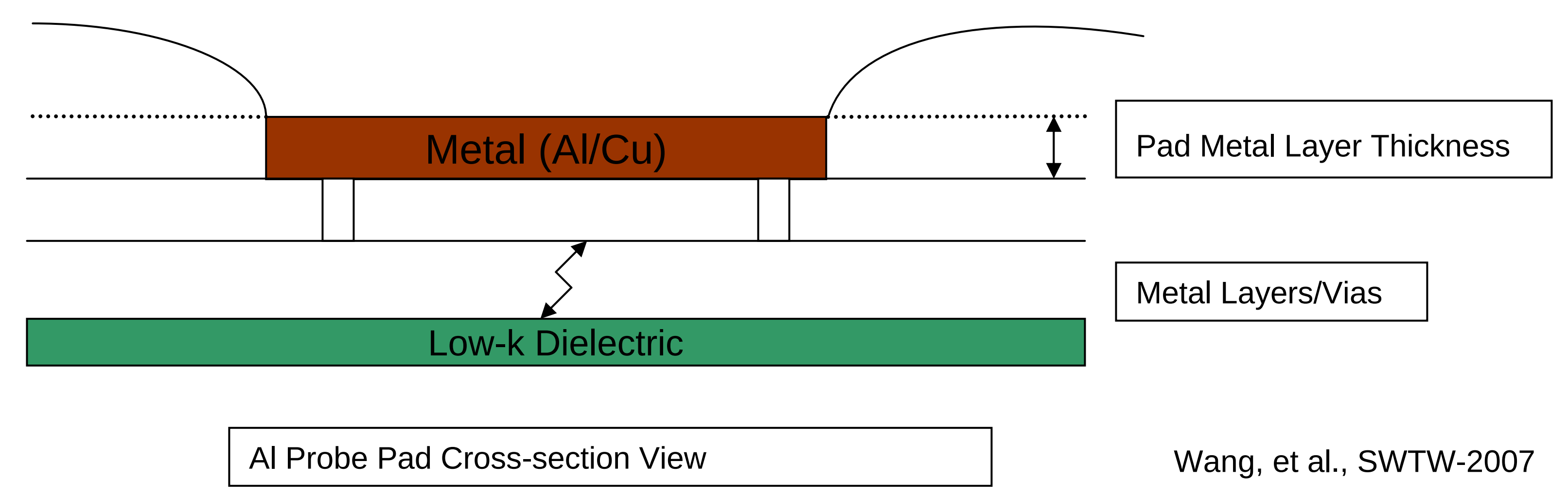
Controlling the Damage

Industry Requirements

- **Continuous shrinkage in pad dimensions**
- **Thinner pad metal layer moving below 0.7um**
- **Lower k ILD structures**

Probing Challenges

- **Minimize yield loss due to**
  - Wire-bond reliability from deep scrub and large particles
  - Probing damage at upper metal layers such as cracks

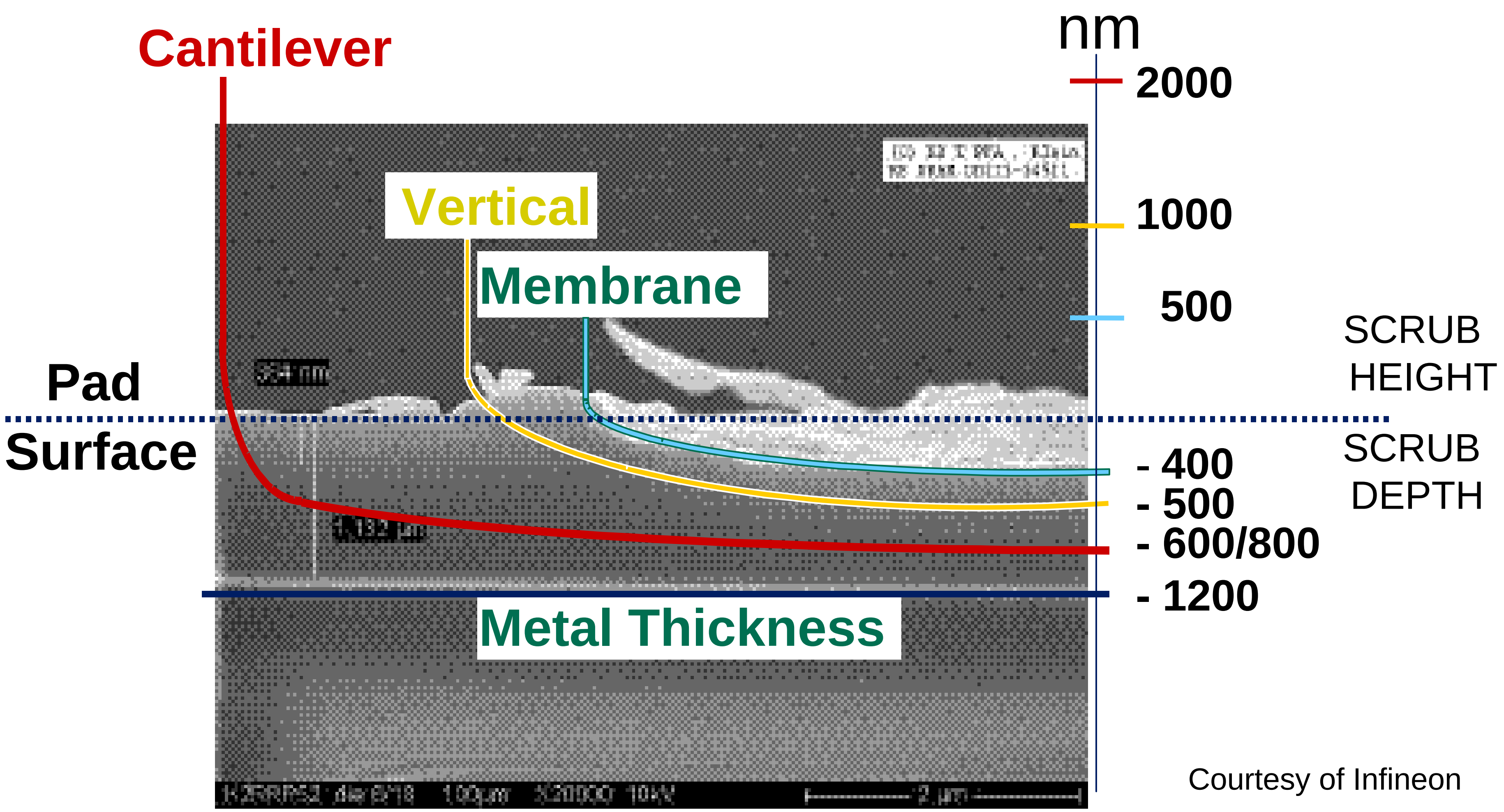


Wang, et al., SWTW-2007

Approaches to Damage Control

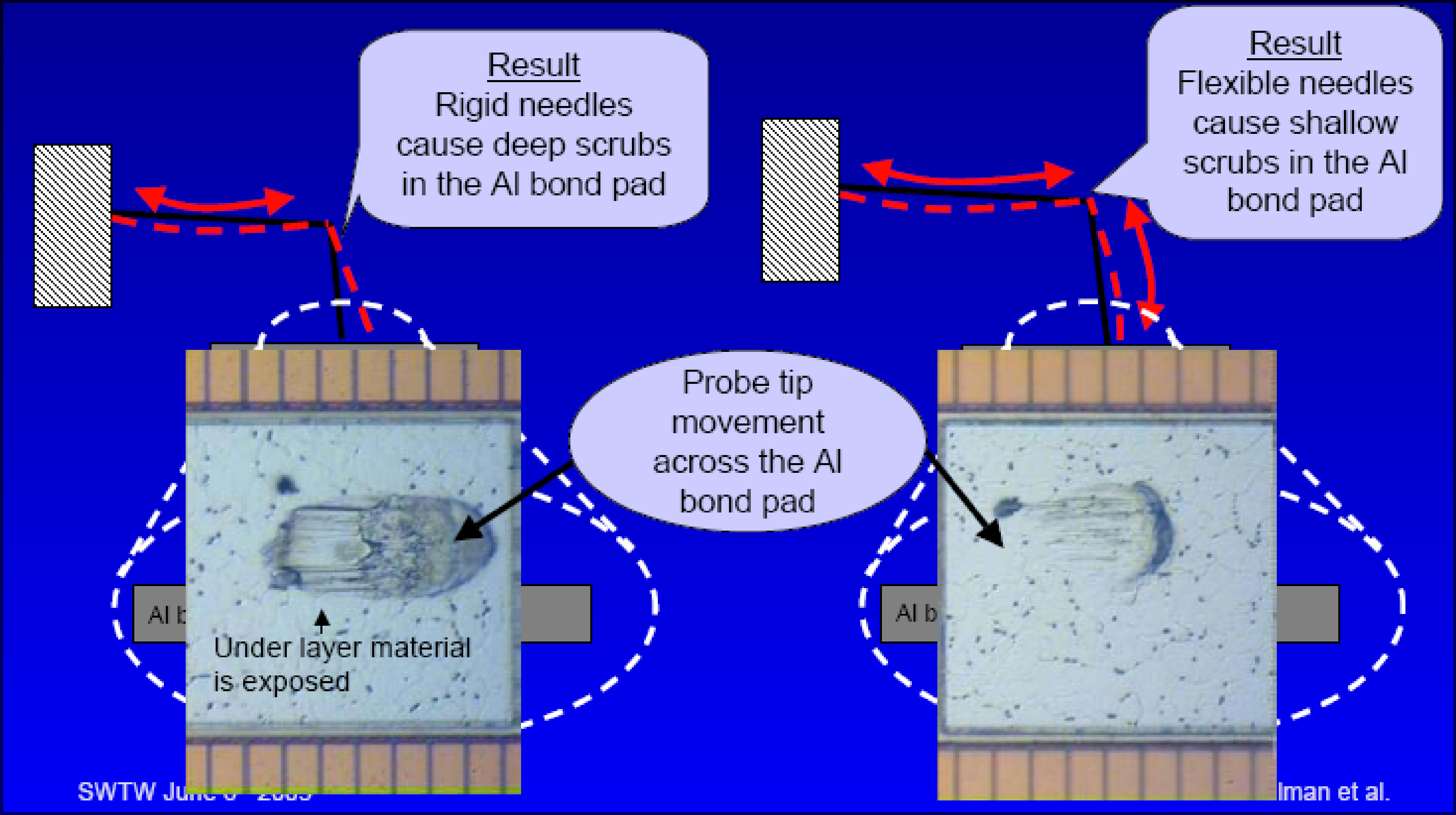
- The depth of the probe mark can be controlled with by using alternate probe card technologies
  - Tip shape and probe geometry (various manufacturers)
  - Low force probe cards (various manufacturers)
  - Optimized probe to pad interactions
- Probers can effectively change the z-stage motion just before contact and during overtravel to reduce damage
  - Variable Speed Probing by Accretech®
  - Micro-Touch™ by Electroglas®
  - 3D Probing by Tokyo Electron Limited® (TEL)

Pad Damage Versus Technology



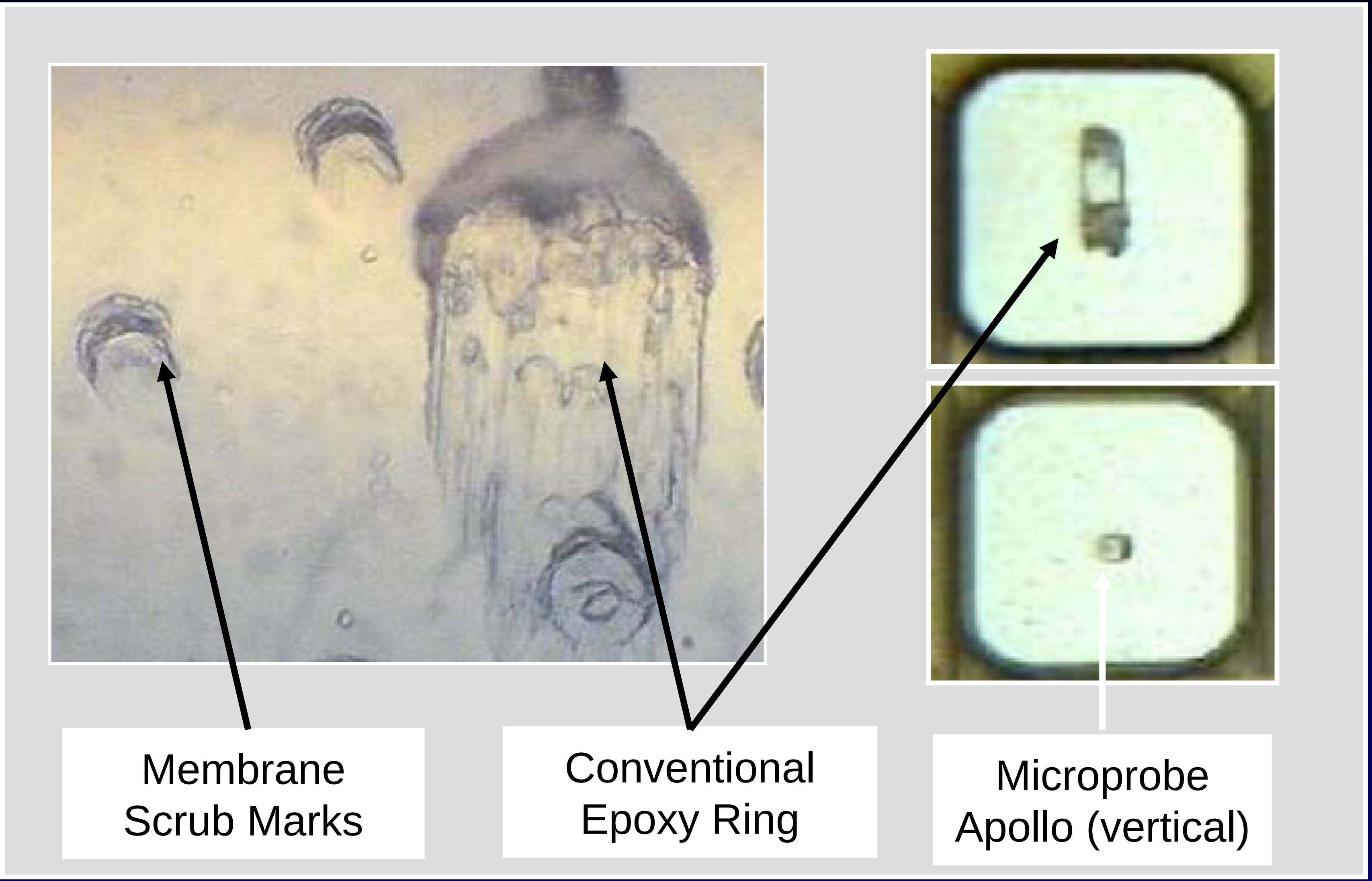
Courtesy of Infineon

Probe Needle Design Changes



Stillman, et al., SWTW-2003

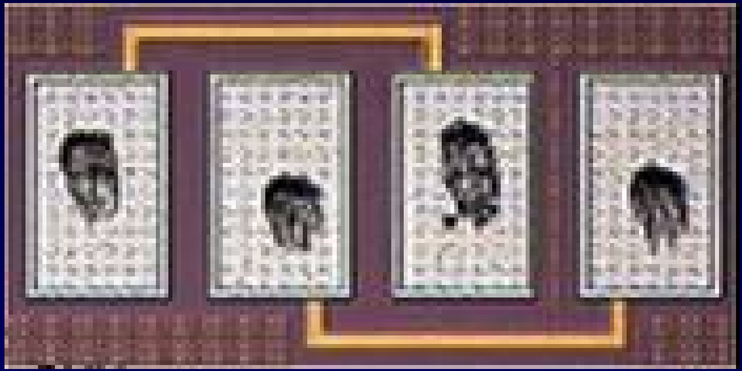
Tip Geometry Effects



Courtesy of Cascade Microtech and MicroProbe

Reduced Probe Geometry

- Reduce probe tip diameter
- Reduce spring force and overdrive
- Control number of probe passes



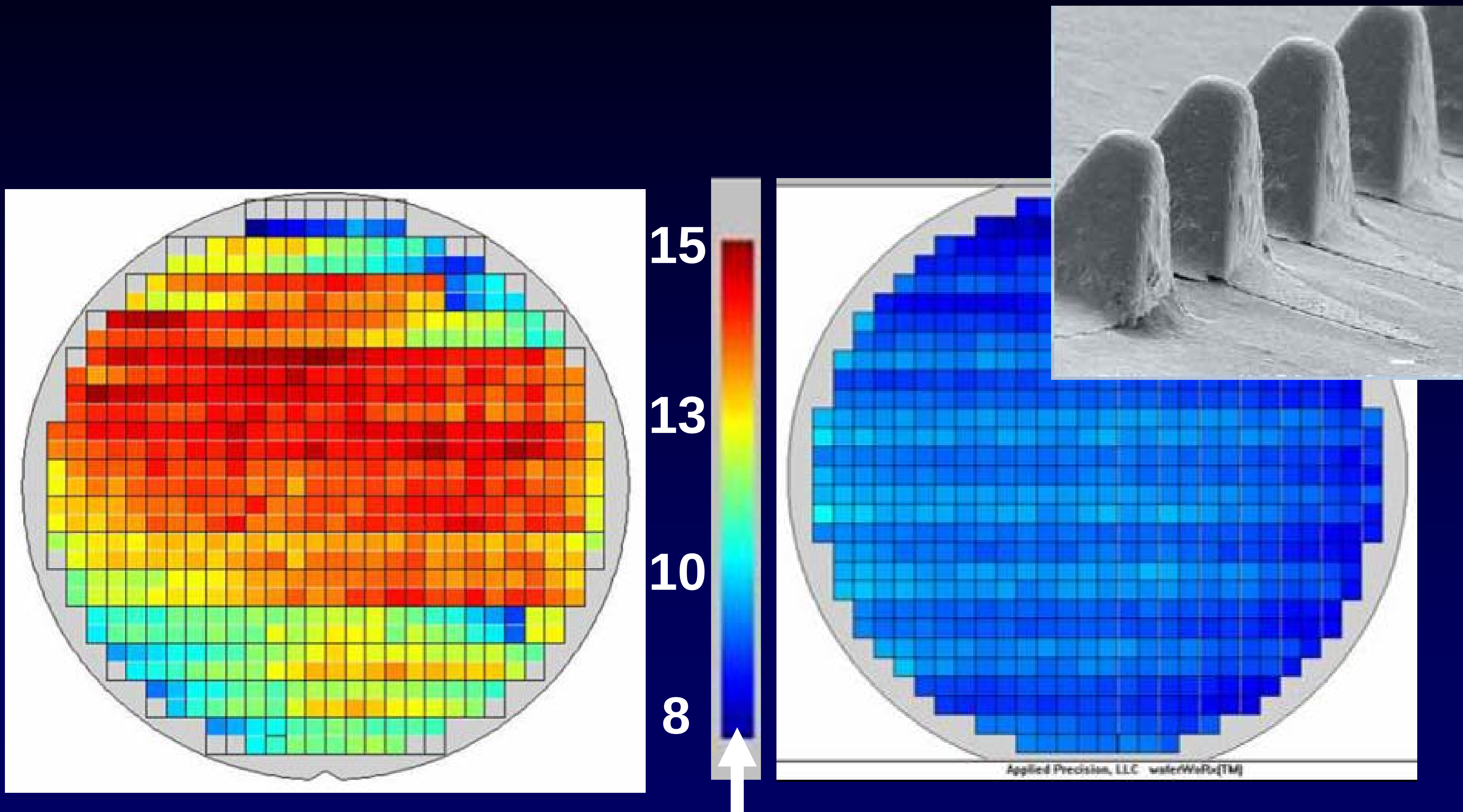
Benefits:

- Smaller probe mark
- Minimize probe size and depth

Concerns:

- Probe card fabrication
- Process control
- Reduced card life

Tip Geometry Effects

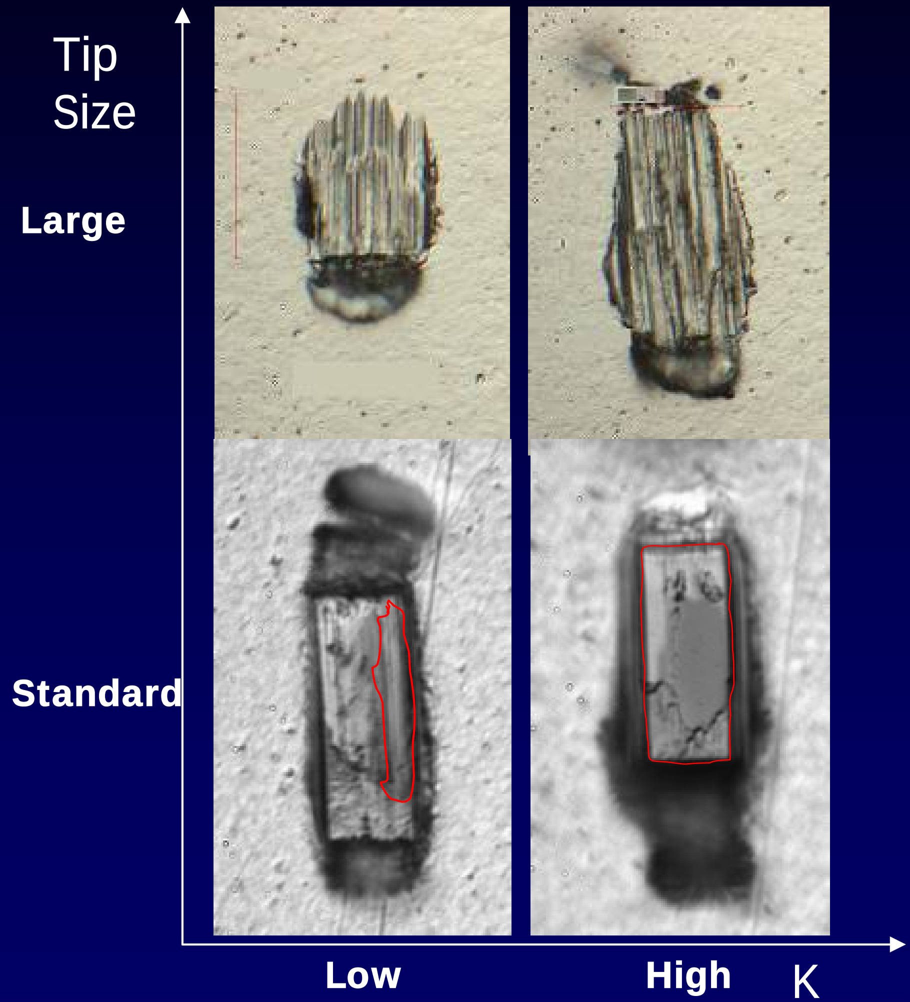


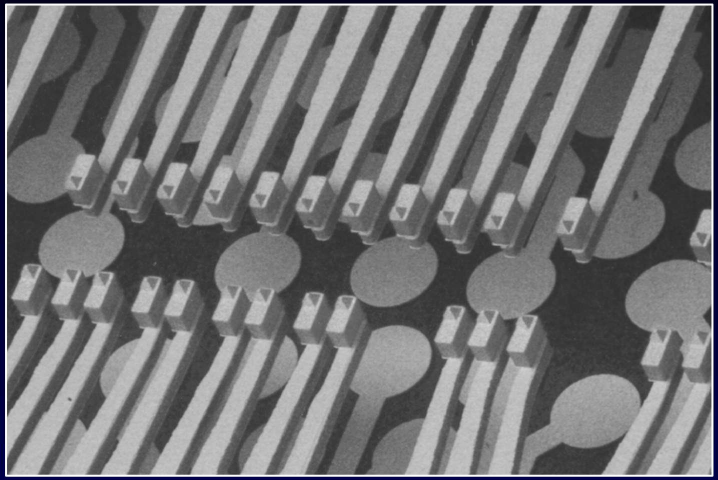
Cantilever

% Pad Damage

Membrane

Advanced Scrub Sensitivity



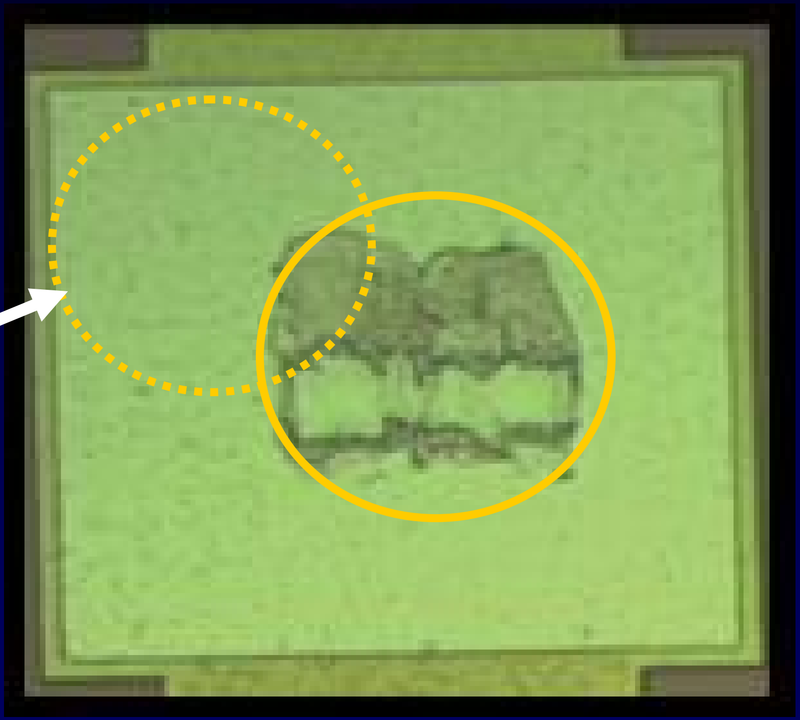


- Macroscopically, punch through level was found to be a direct function of tip pressure
  - Tip area
  - Spring constant
  - Planarity
  - Over travel

Wang, et al., SWTW-2007

Compensating for the Damage

- Offsetting the Wire Bond location
- **At Bond / Assembly**
  - Plasma clean before wire bonding
  - Optimize parameters
  - Offset wire bond location away from probe.



Benefits:

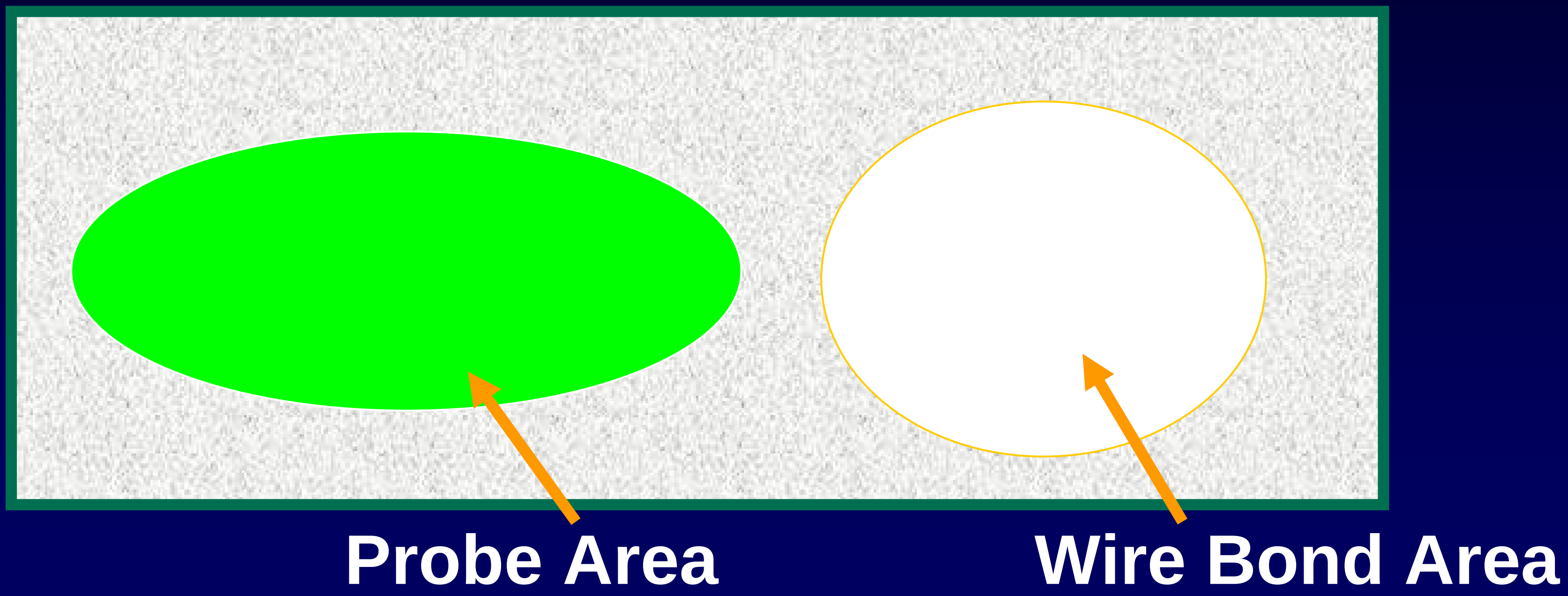
- Minimize Non Stick Bonds

Concerns:

- Difficult in small geometry

Compensating for the Damage

- Elongated or Rectangular Pad Design
  - Separate regions allocated for probe and bond



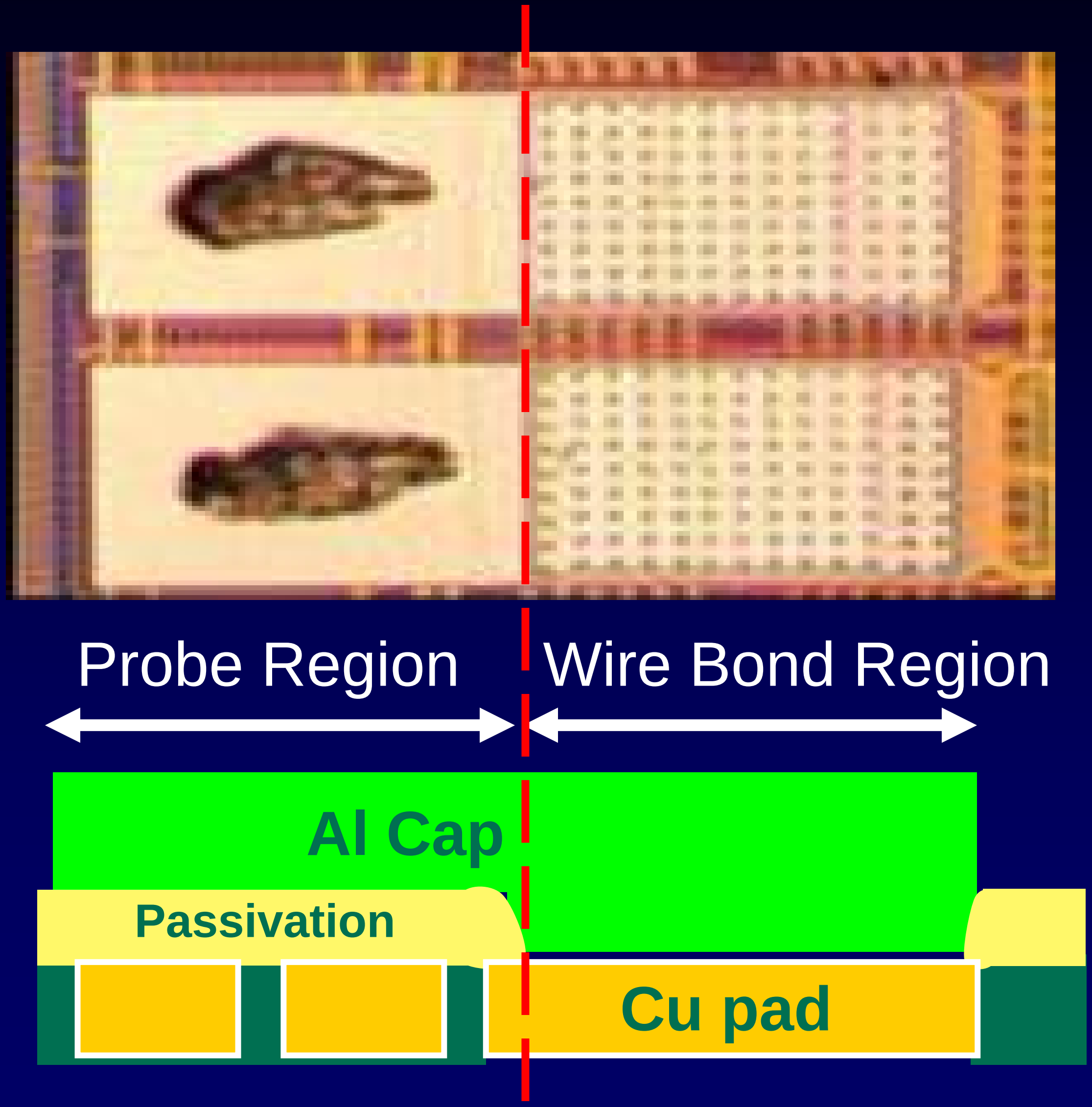
Benefits:

- Separate probe and wire bond

Concerns:

- May increase die size

Probe Over Passivation (POP)



- Eliminate probe and wire bond interference
- Creates longer bond pad but it DID NOT increase die size
  - Requires 1 mask change
- Eliminate Cu exposure due to heavy probe marks
- Ease of implementation on existing and new Cu technology products

Courtesy of Freescale Semiconductor

Benefits of “POP”

- Creates separate probe and wire bond regions without die size increase
- Totally eliminates problem of punching through to Cu and interacting with wire bond
  - No damage of passivation or Cu after 6 double-touch passes at heavy force and heavy overdrive
  - Achieved significant improvement in NSOP
  -
- New POP probe card specification can include higher spring force for better CRES performance during sort
- Numerous Freescale Cu devices at 50μm and finer pad pitches have switched to POP bond pad design

Prober Operation Performance

- Combination of vertical probe contact at over drive, coupled with horizontal chuck motion to minimize the probe mark damage

- Enabled by Intel, TEL and FormFactor for the MicroSpring™ card
  - Methodology designed to satisfy stringent requirements for low-k ILD materials

- Resulted in 10:1 reduction of probe force with consistent and low contact resistance performance.

What Steps Can I Take ?

- Can reasonable steps be taken with existing technologies (e.g., an existing probe card and a prober) to reduce pad damage in a cost-effective manner ?

- Is it possible to identify an optimized combination of prober operational settings to reduce the overall area and volumetric probe damage, i.e. disturbed pad area ?

Key Prober Operational Settings

- Number of Touchdowns
  - Single vs. Double
- Overtravel Magnitude
  - Low (50um) vs. Middle (63um) vs. High (75um)
- Undertravel Magnitude
  - Low (0um) vs. Middle (10um) vs. High (20um)
- Pin-Update Execution
  - Abbreviated pin alignment to compensate for thermal movement
  - On vs. Off
- Wafer Chuck Speed
  - Low (6000 um/sec) vs. High (18000 um/sec)
- Chuck Revise Execution
  - Re-zero of the wafer chuck to compensate for thermal movement
  - On vs. Off

Major Contributors to Damage

- Primary Responses for Area and Volume
  - Single vs. Double Touchdown
  - Minimum vs. Maximum Overtravel

- Secondary Responses
  - Wafer chuck speed
  - Undertravel

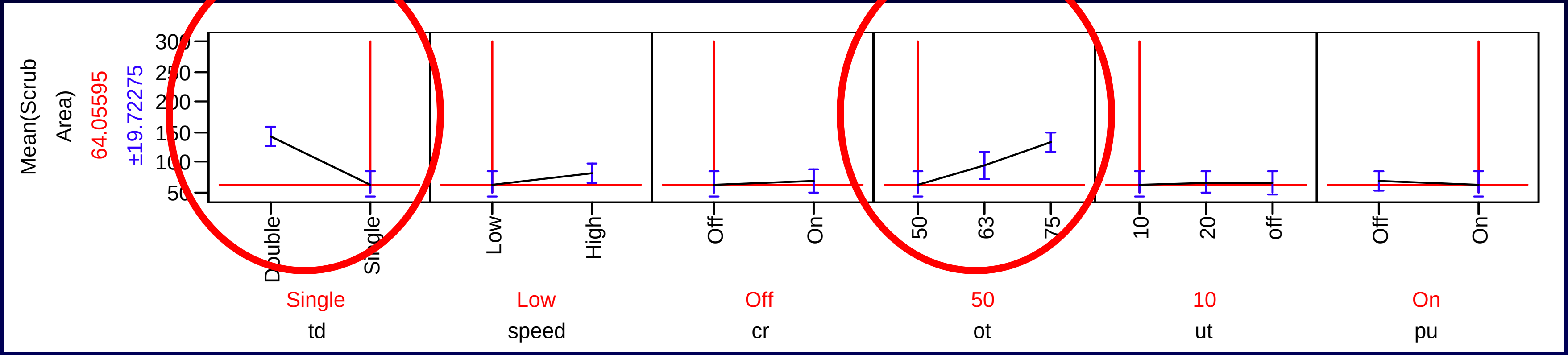
- The influence of second order factors for fine-tuning the operational parameters can be performed using modeled response data.

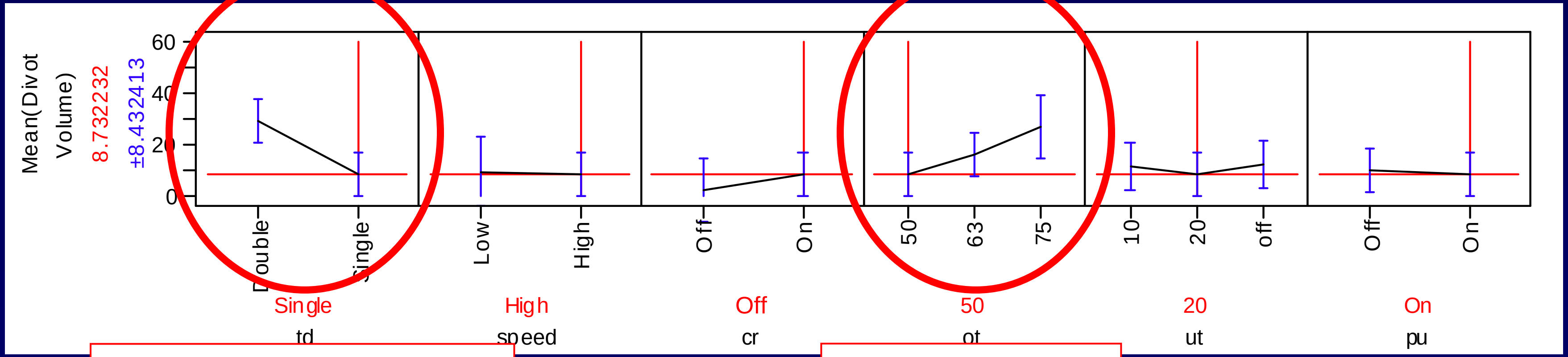
- Other contributors for consideration
  - Small sample size effects
  - Operator-induced variability
  - Probe tip diameter variations
  - Probe gram force variations

Best Case Combinations

Modeled response data can be used to investigate the effects of changing one parameter and keeping the other constant.

- Slopes of the lines can give some indication of sensitivity to the change.





Number of TDs

Overtravel

Miller, et al., SWTW-2007

Effects of Reprobe on Pad Damage

Intuitively we know the 2D effects of reprobe or multiple probe steps diminish with each touchdown but at what rate?

One model:

$$A_d = \sum_{n=1}^{TD} \frac{1}{a^{n-1}} A_s$$

Where:

A_d - disturbed area

TD - touchdowns

a - scaling coefficient

A_s - scrub mark 2D size

Pad Damage: Actual Versus Model

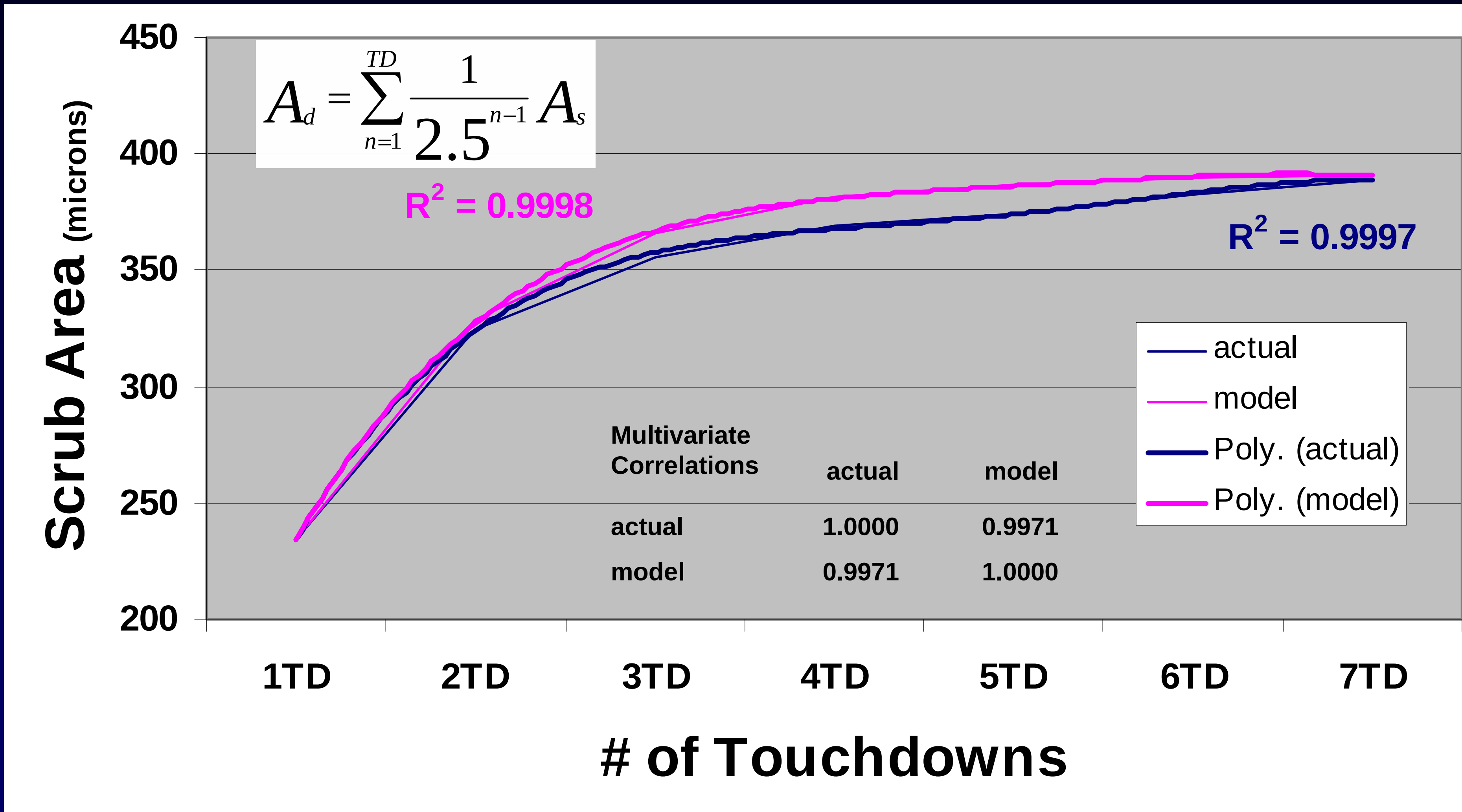
The goal of the design of experiment would be to hold everything constant and only change the number of touchdowns.

<u>DoE</u>

- multiple wafers
- one probe card
- one test cell
- one operator
- same setup each time
- fully disturbed wafers
- fully disturbed probe card
- seven cumulative touchdowns

Millions of scrub marks!

Actual Versus Model: Results

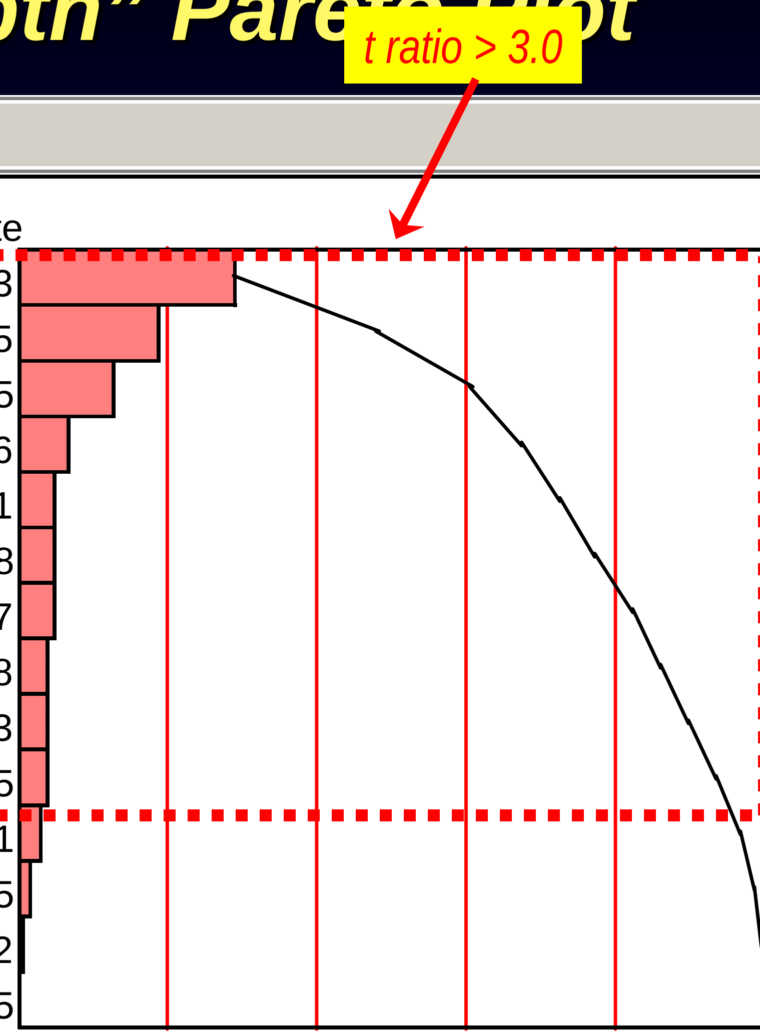


Scrub Sensitivity Analysis DOE

Results: "Scrub Depth" Pareto Plot

Pareto Plot of Transformed Estimates

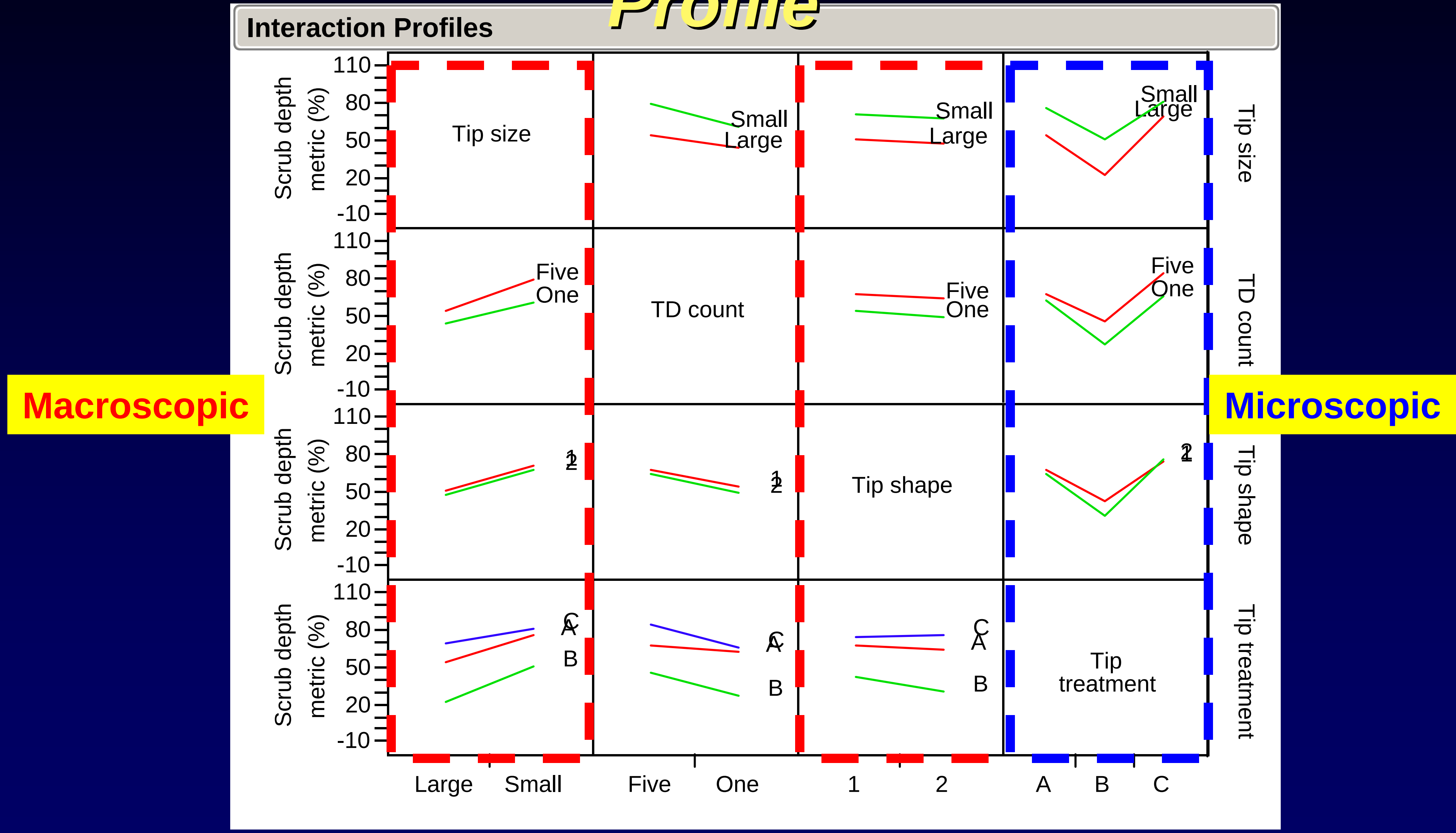
Term	Orthog Estimate
Tip treatment[B]	-15.99093
Tip size[Large]	-10.28125
TD count[Five]	6.95375
Tip treatment[A]	-3.80436
Tip size[Large]*Tip treatment[B]	-2.77981
Tip shape[1]*Tip treatment[B]	2.66668
TD count[Five]*Tip treatment[A]	-2.59187
Tip size[Large]*TD count[Five]	-2.19958
Tip size[Large]*Tip treatment[A]	-2.06523
Tip shape[1]	2.06375
TD count[Five]*Tip treatment[B]	1.71031
Tip shape[1]*Tip treatment[A]	1.01195
TD count[Five]*Tip shape[1]	-0.50792
Tip size[Large]*Tip shape[1]	0.10375



Significant factors for scrub depth: Tip conditions, tip size, TD count, and Interactions

Wang, et al., SWTW-2007

Scrub Sensitivity Analysis DOE
Results: "Scrub Depth" Interaction Profile



Macroscopic, microscopic factors and their interactions all impact scrub depth

Wang, et al., SWTW-2007

Scrub Sensitivity Analysis DOE

Results: "Prow Height" Pareto Plot

Pareto Plot of Transformed Estimates

Term	Orthog Estimate
Tip treatment[B]	-15.99093
Tip size[Large]	-10.28125
TD count[Five]	6.95375
Tip treatment[A]	-3.80436
Tip size[Large]*Tip treatment[B]	-2.77981
Tip shape[1]*Tip treatment[B]	2.66668
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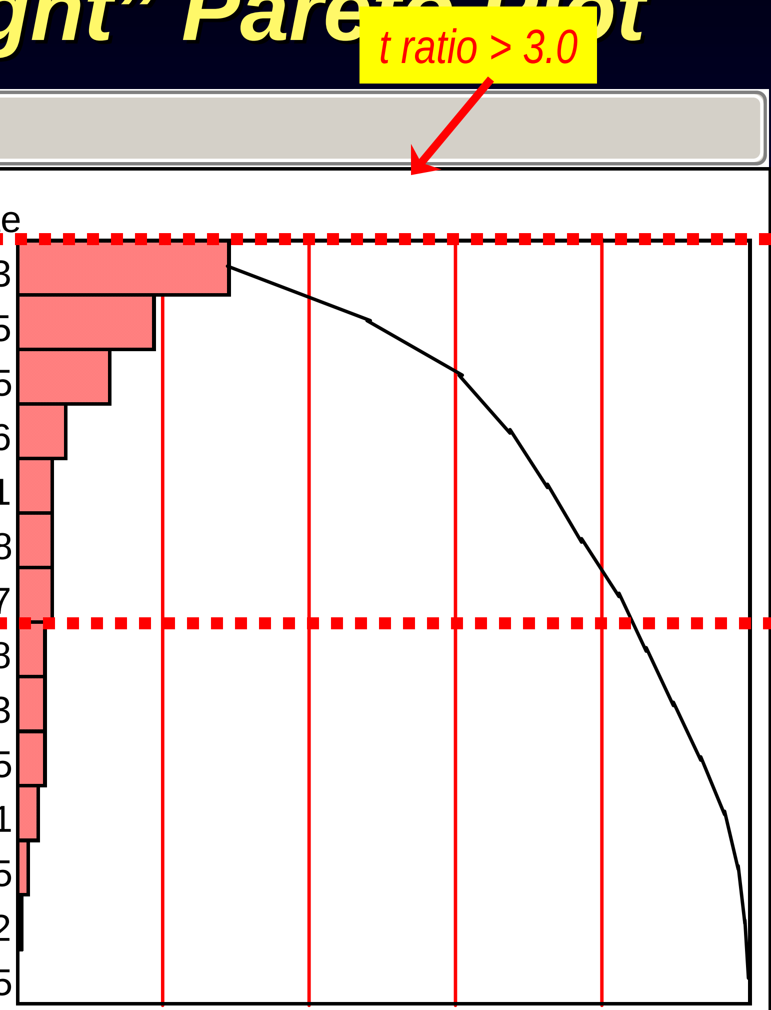
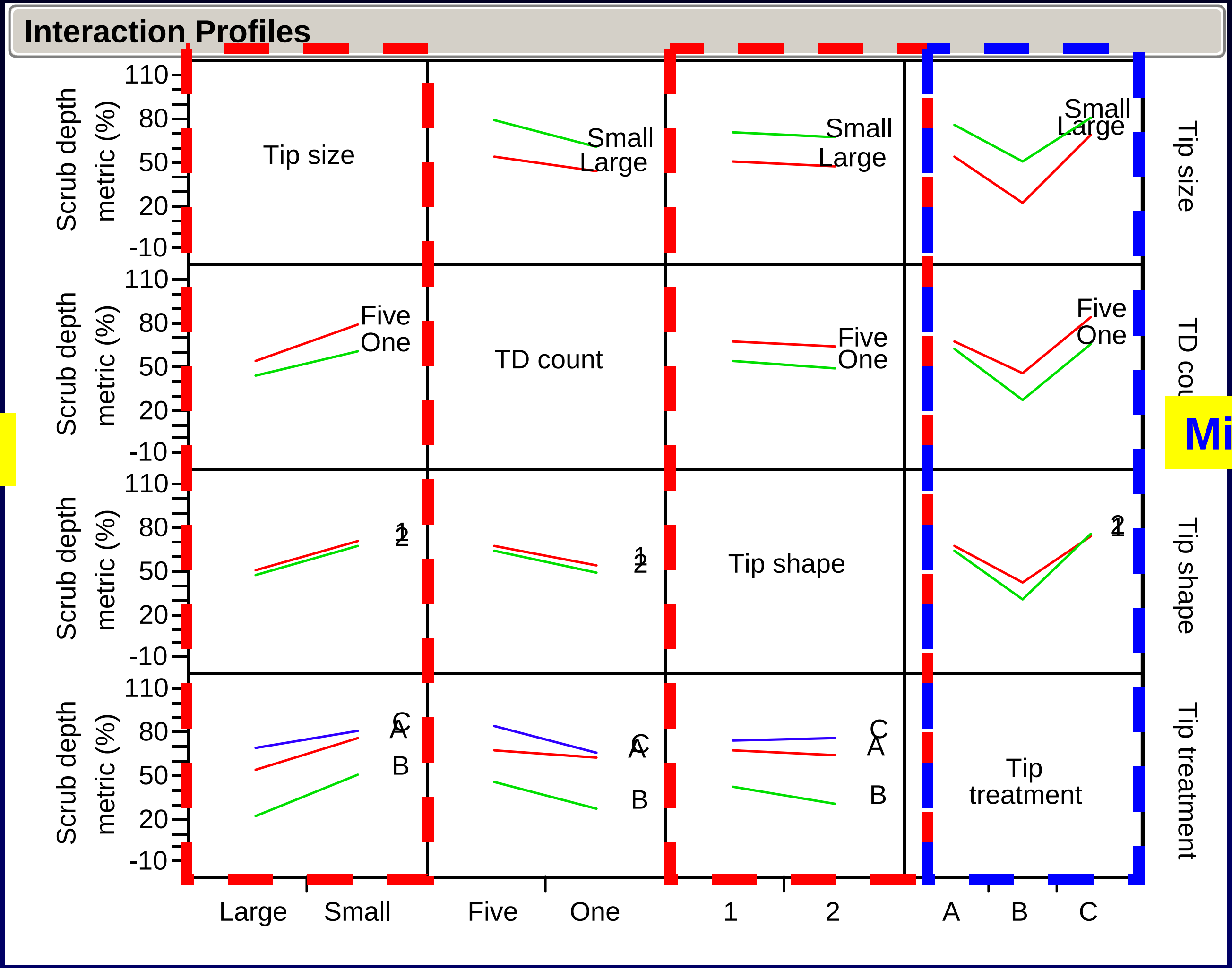


TD count, tip conditions, and tip size all contribute to the prow height metric

Wang, et al., SWTW-2007

Scrub Sensitivity Analysis DOE
Results: "Prow Height" Interaction Profile



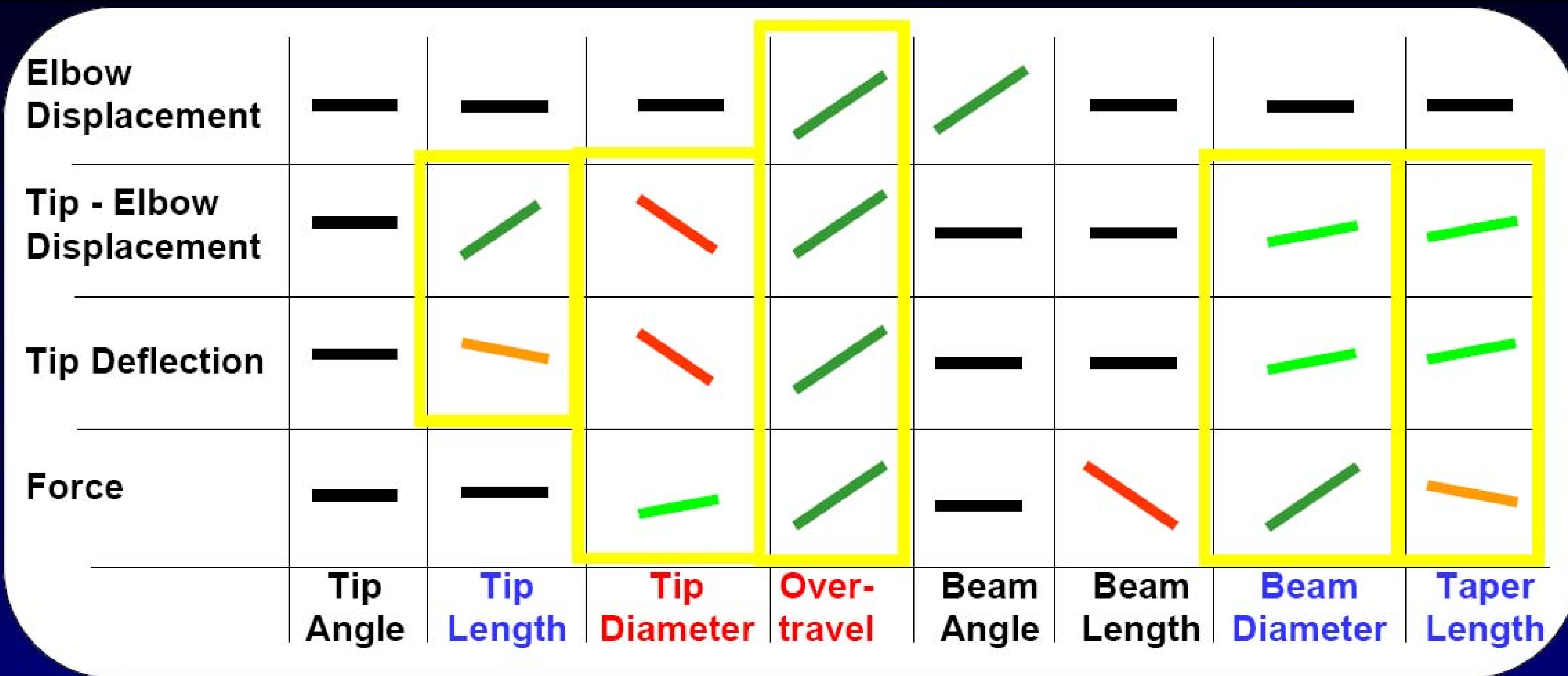
Macroscopic

Microscopic

The trends are similar to that of depth metric

Wang, et al., SWTW-2007

Conventional Cantilever Design Considerations



Design targets for modification to improve crack problem → **Reduce beam diameter**
Increase taper length
Increase tip length

Hartfield, et al., SWTW-2004

Summary

- I/O pad damage has been aggravated by smaller pads, sharper needles, and new process node technologies.
- Changes and improvements to probe card specification have been developed to mitigate some of the problems.
- Significant new probe methods, new probe card technologies, and design and layout tricks are now being implemented.
- Reasonable steps can be taken with “existing” hardware to reduce pad damage in a cost-effective manner.

Acknowledgements

- Special thanks to Dr. Jerry Broz and Bill Mann for their significant contribution!!!
- Thanks to the SWTW Program Committee for their contribution and critique