Evaluation of Cantilever Probe-Induced Dielectric Cracks in Cu/Low-k Devices

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SOUTHWEST TEST WORKSHOP

SouthWest Test Workshop - 2004

Outline

- **Objectives**
- **Background**
- **Approach**
- **Test Results**
- **Implications**
  - Card maintenance
  - Assembly and Reliability
- **Summary**

Objectives

- **Delineate multiprobe-induced crack risk to materials beneath the bond pads of Cu/Low-k devices**
  - Cantilever cards
  - Wirebond Devices

- **Show effects of varying individual parameters of needle geometries / properties**

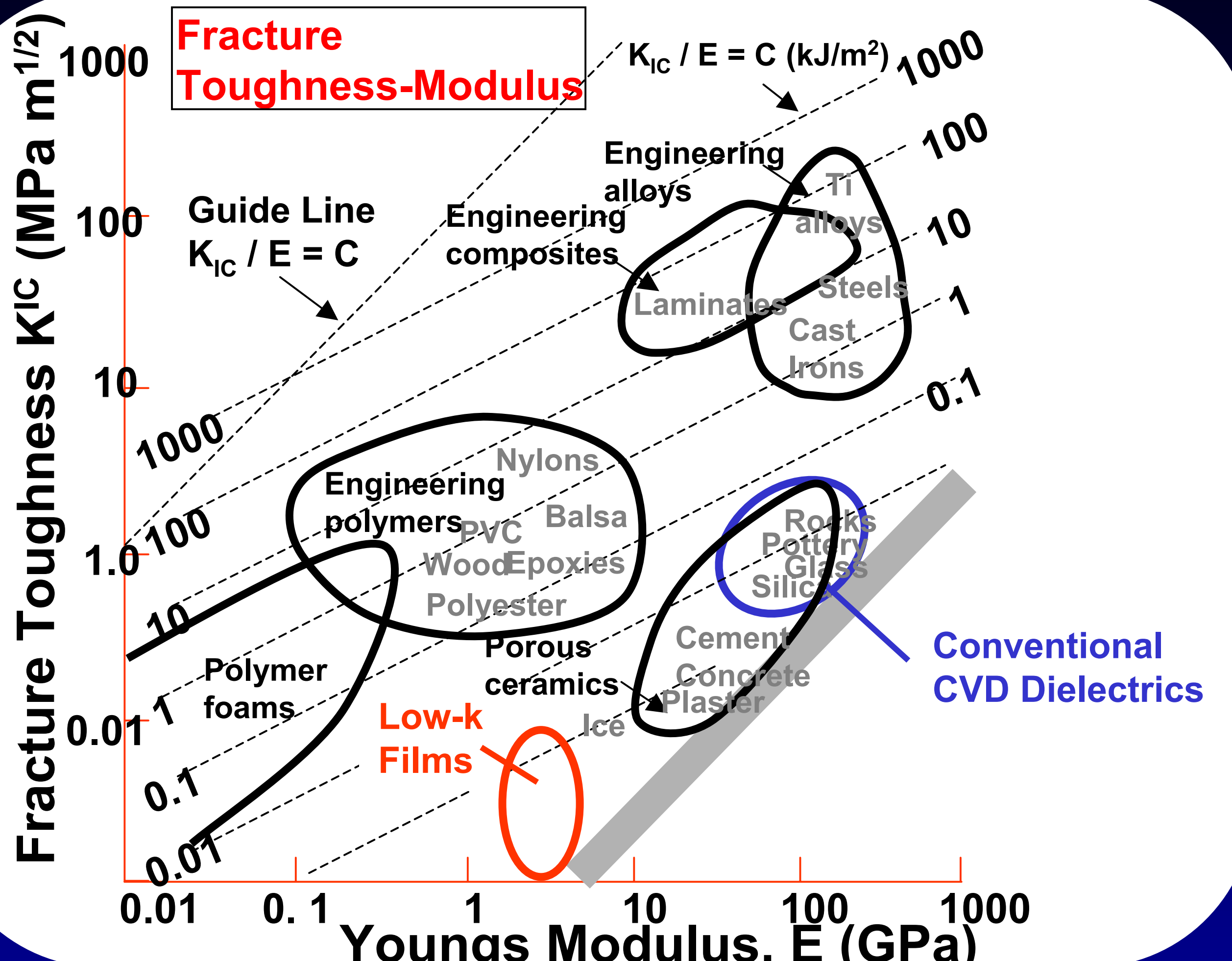
- **Make case for industry-wide attention to develop card build specifications and/or practices that will eliminate the crack risk**

Background

- **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 and hardness
  - Fracture toughness reduced; difficult to measure
- **Probe – induced cracking of devices is an ongoing test industry issue**
  - Historical Information: Aluminum – SiO2 Technology
    - TI: Metal structures changed and probing refined to eliminate probe cracks in lookahead builds, allowing successful qualification and ramp (unpublished information, ~1999).
    - Chartered: Probe-induced IMD cracks cause infant mortality failures having high resistance (ISTFA 2003).
  - Cu/Low-k Technology
    - IBM: probe damage occurs with SiLK low-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."

Background

- Low-k Dielectric Material Properties

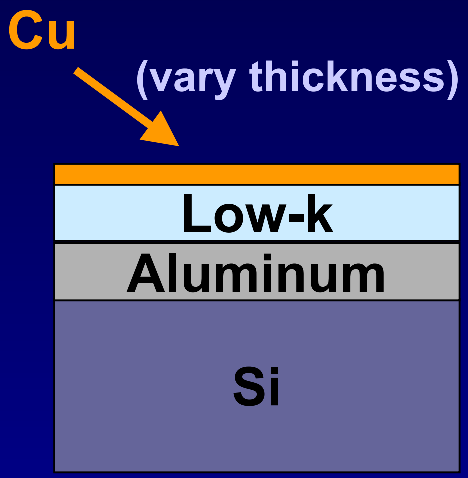


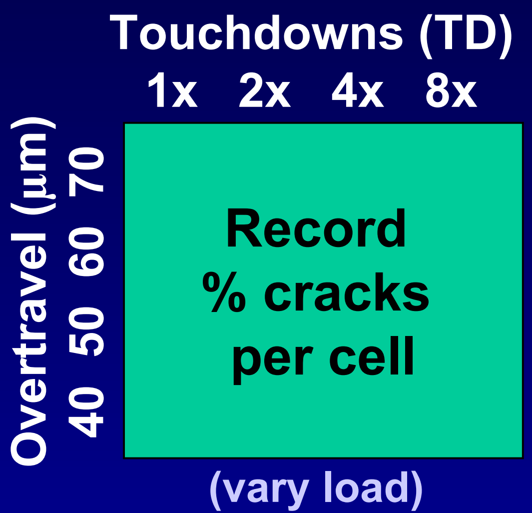
Low-k dielectrics are in a class of their own concerning combined modulus and fracture toughness properties.

Background (cont.)

Early insights: “Fracture Toughness” Probe Tests

- **No industry method available to measure low-k film fracture toughness**
- **Use multiprobe as realistic “engineering test” to compare material performance**
    - Matrix of varied touchdowns and overtravel applied to blanket films.
    - Allowed ranking of dielectric materials
    - Allowed assessment of probe-induced crack risk





Material Rank
1. OSG1
2. HSQ
3. OSG2
4. polymer

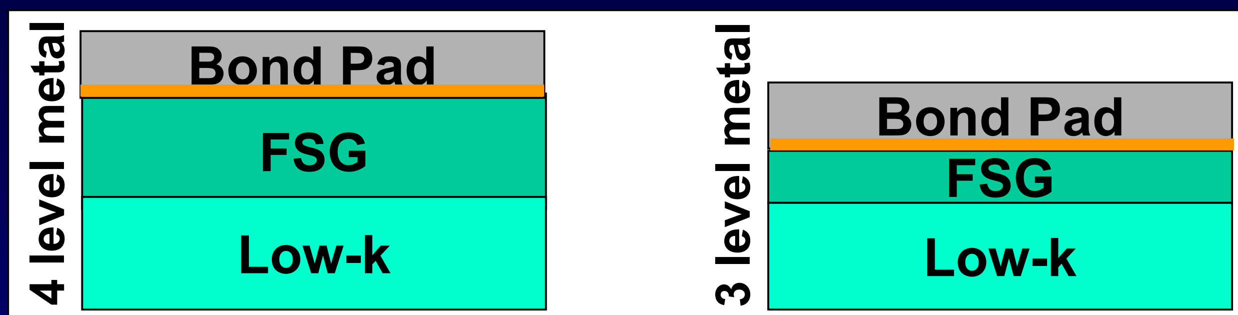
2500A Cu
BCF3.0g/mil
8x TD

0% cracks

Background (cont.)

- **Assessments of Probe Crack Risk on Full Flow Integrated Test Die**
  - Stress condition intrinsic function of integration strategy
  - More representative of true crack risk from multiprobe
    - Damage occurs at conditions that showed good results on blankets
    - Low-k devices with greater metal levels have less crack risk

DOE



	High force (2x)	Production force	High force (2x)	Production force
Touchdowns	8x	8x	1x	2x
% cracks	<2%	0%	5%	4.5%

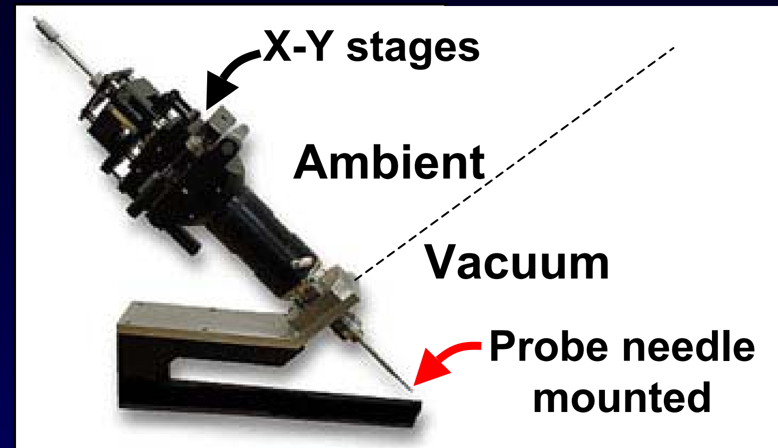
Background (cont.)

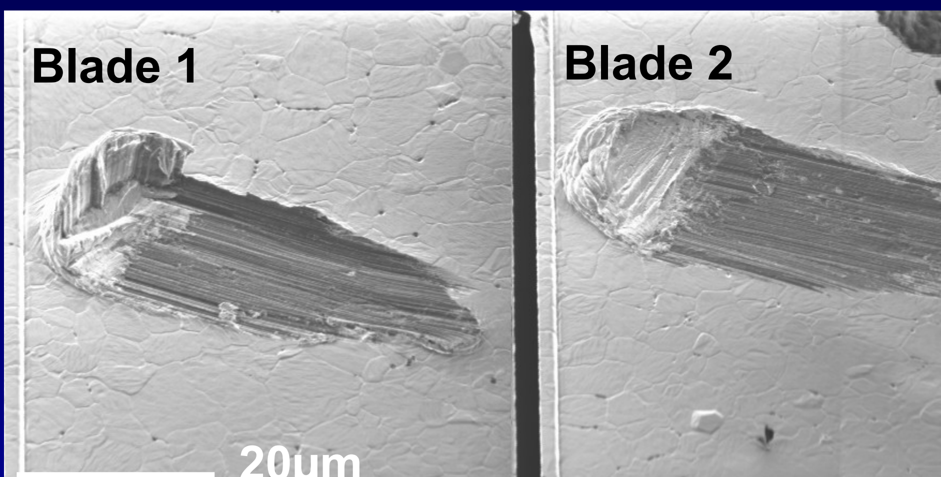
- **Experiments prove factors other than load are critical for cracks**

Micromanipulator Tests

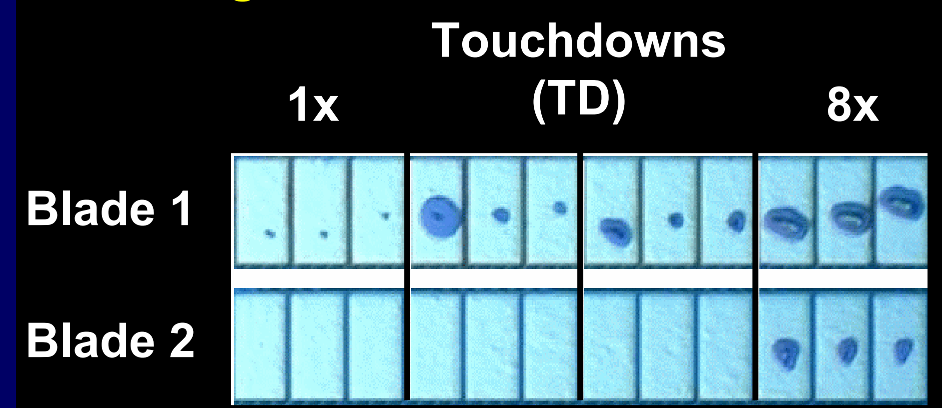
- Two blade needles
- Identical load of 2.5 g/mil
- Scrub and crack behavior different

Hartfield et al., SWTW 2003
Hartfield et al., ISTFA 2003



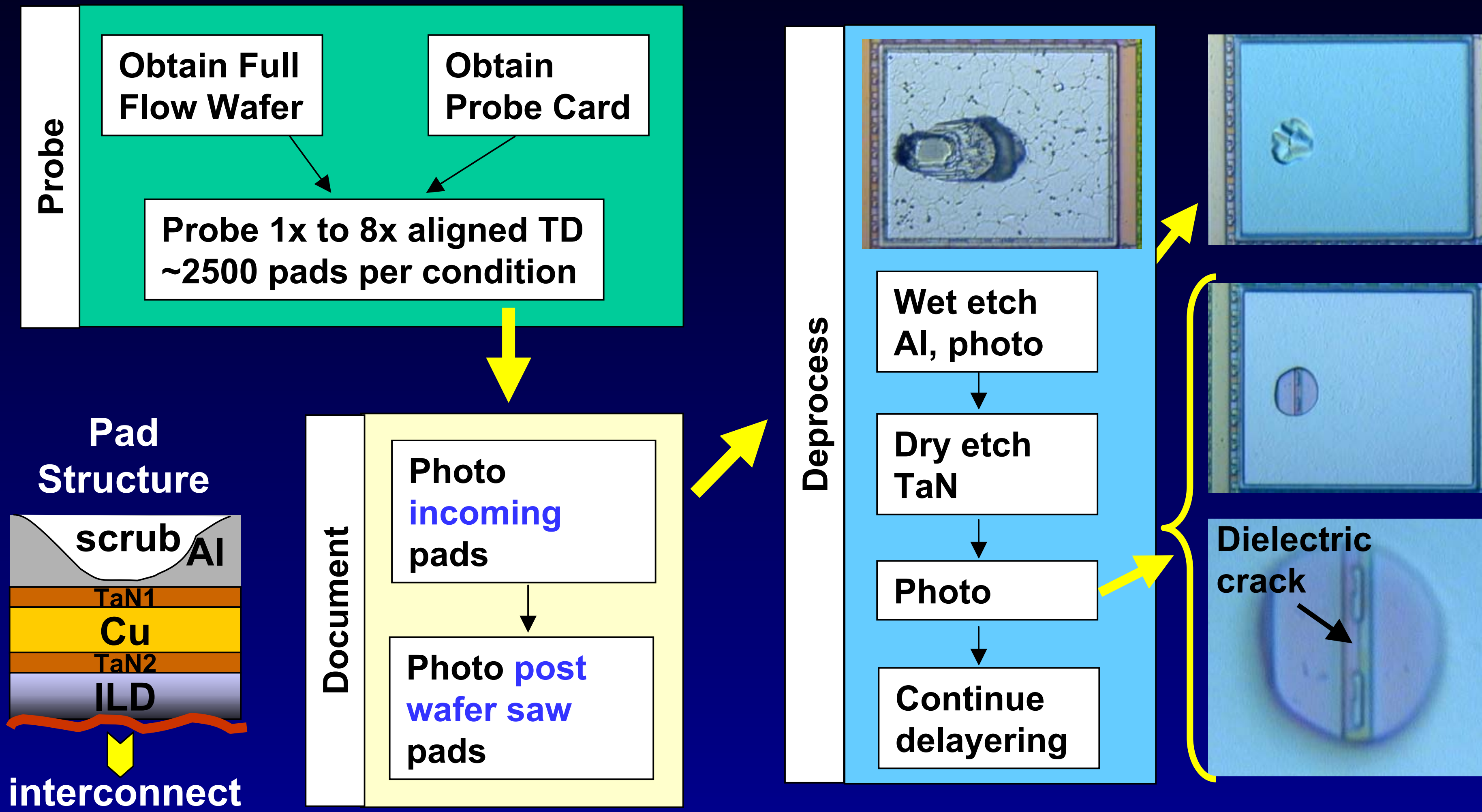


Cracking as a function of touchdowns



Approach: Identify Crack Risk

- Crack Assessment Methodology



Results – Multiprobe Assessments

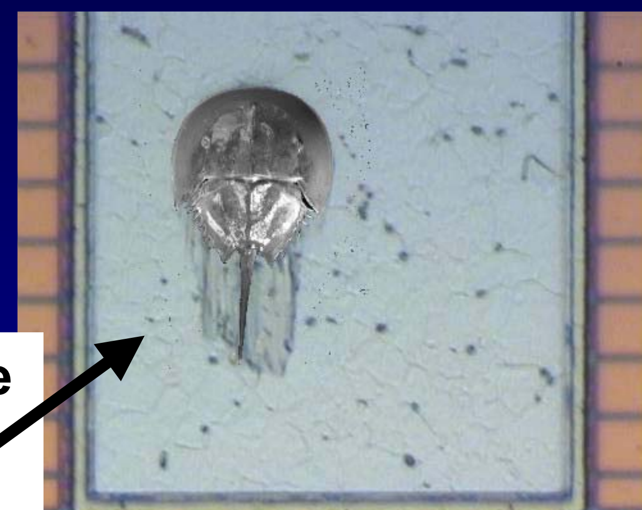
- Vendor-dependent differences at equivalent loads

	Vendor A: Load 74%*			Vendor B: Load 80%*		
	2X	3X	4X	4X	6X	8X
Qty TaN1	0	56	124	0	17	66
% Damaged	0%	2.23%	4.94%	0%	0.68%	2.63%
Est. DPPM	917	26618	55544	917	9398	30924

*Load reported as % of production load

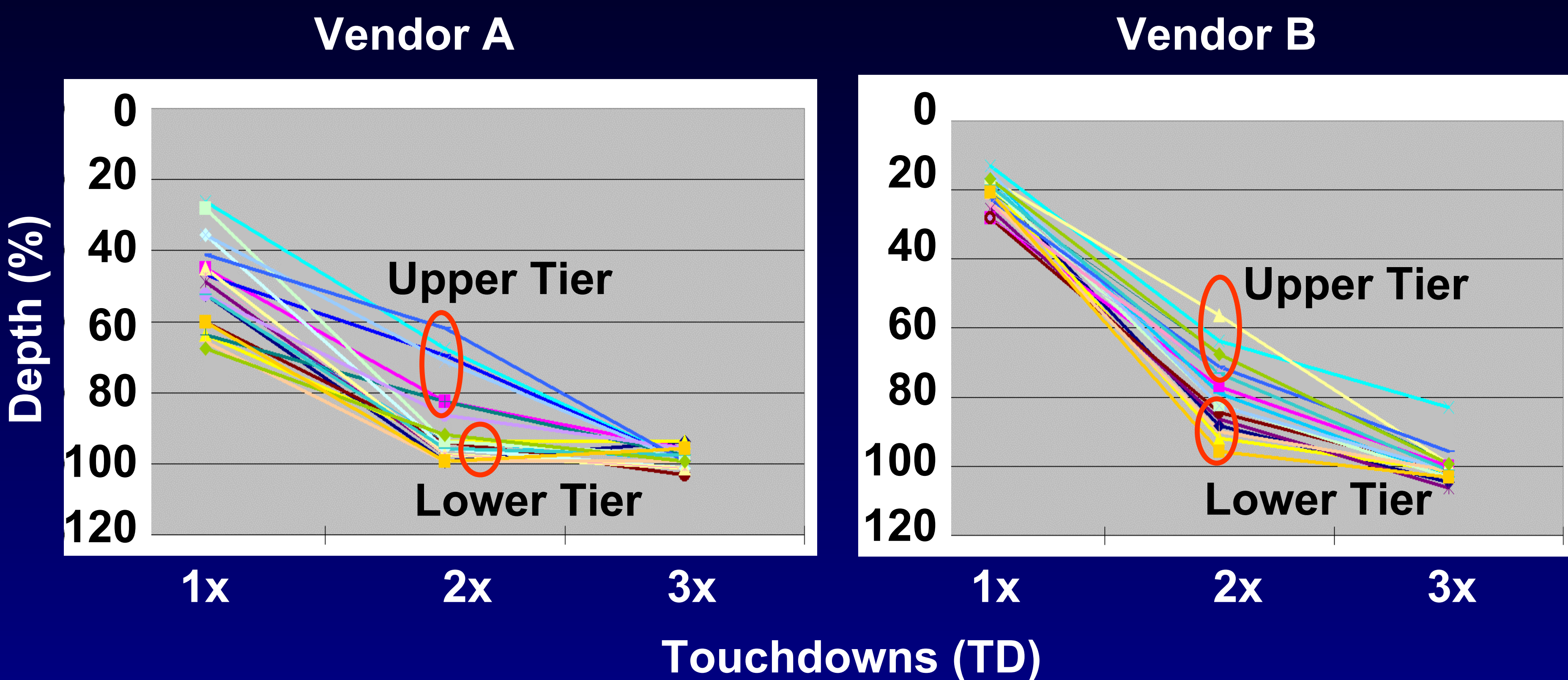
- Scrub marks indicate different “kicking action”

Horseshoe crab similarity



Results – Probe scrub depth

- Indicator of cracking risk
  - Scrub mark depth correlates to vendor crack performance

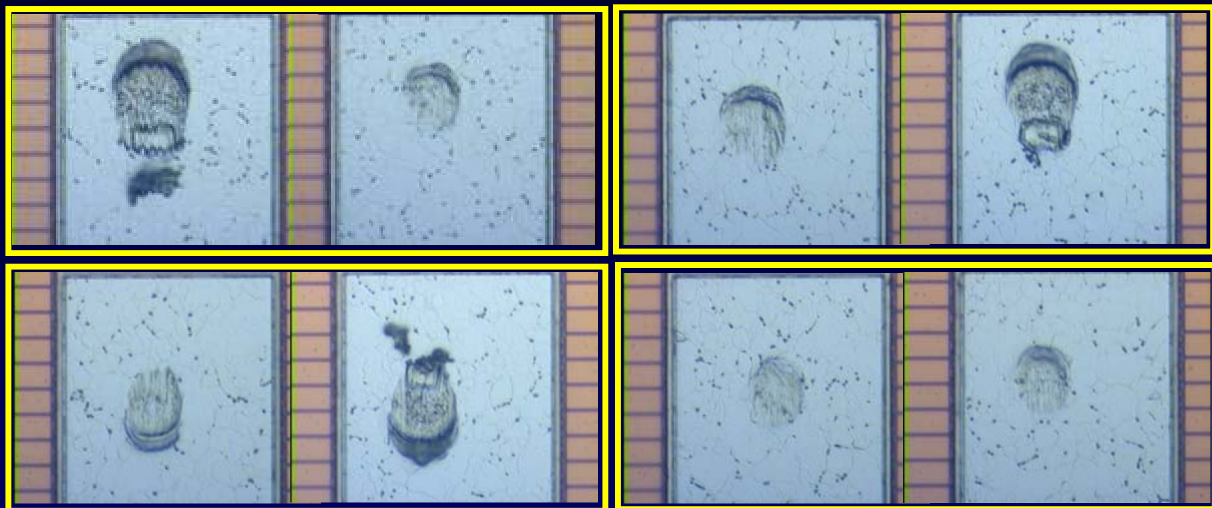


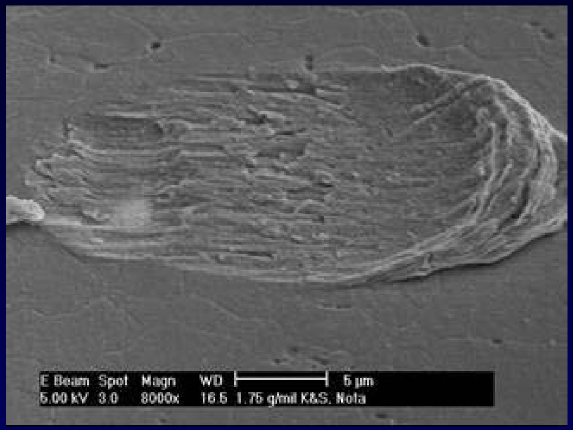
Cracks at 3x TD

Cracks at 6x TD

Results – Probe scrub depth

- Indicator of cracking risk
  - Vendor C Quad Site Card, BCF = production specification (load 100%)





All 4 sites: shallow 8x TD scrub marks, 0% cracks

Compare with 3x TD scrub from Vendor A: load 91% pdn., >6% cracks

Results – Load and Vendor Variation

- Vendor A correlates to cracks @ 3x TD regardless of load
- Other vendors crack @ 6x TD regardless of load
- Indicates geometry factor not directly tied to load plays a role

Touchdowns ▶		1	2	3	4	5	6	7	8
Vendor	Force*								
C	54	-	-	-	-	0%	0.0%	0.1%	0.3%
C	54	-	-	-	-	-	0%	0.1%	0.8%
A	74	-	0%	2.2%	4.9%	ND		ND	
C	80	-	-	-	-	-	-	0.4%	0.4%
B	80	-	-	-	0%	ND	0.7%	ND	2.6%
B	80	-	ND	-	-	-	0.0%	0.0%	ND
A	91	-	0%	2.9%	4.1%	ND	ND	ND	ND
B	100	-	-	-	-	-	-	1.4%	1.9%
A	109	-	0%	10%	20%	ND		ND	
A	109	-	0%	9.5%	16.5%	ND		ND	

% TaN1 cracks at each touchdown sector

* Force normalized to % of production force

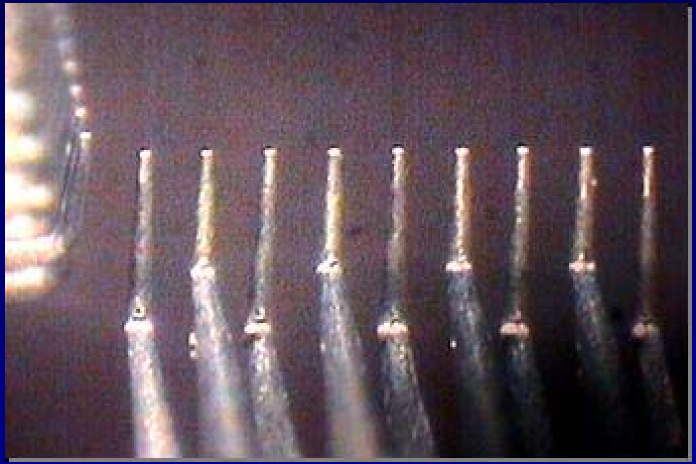
Results – Tip Shape Variation

- Tip shape affects % cracks, but does not shift crack event from 3x TD

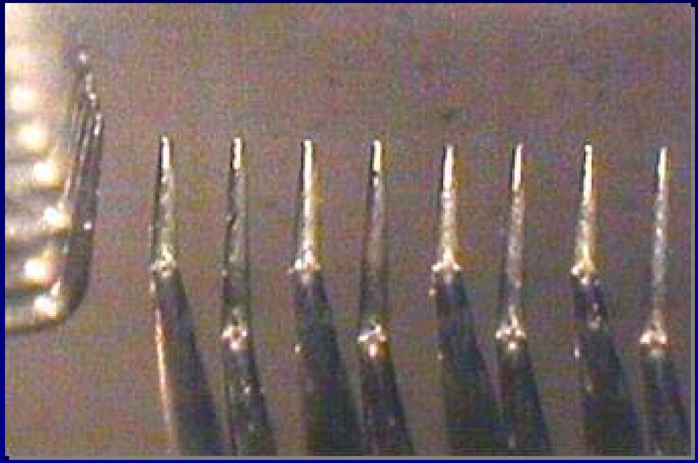
	Touchdowns ▶	1	2	3	4	5	6	7	8
	Tip Ends								
74% Pdn force	Radiused	-	0%	6.0%	12.3%	ND		ND	
	Semi	-	0%	2.2%	4.9%	ND		ND	
91% Pdn force	Flat	-	0%	0.7%	0.4%				
	Semi	-	0%	2.9%	4.1%	ND	ND	ND	ND

% TaN1 cracks at each touchdown sector

Pre-radius



Post-radius



Results – Beam Length Variation

- Beam length affects % cracks, but does not shift crack event from 3x TD

Short Beam, 100% Pdn. Force

	2X	3X	4X
Qty TaN1	0	85	233
% Damaged	0%	3.38%	9.28%
Est. DPPM	917	39044	101038

Length ~2000μm

Long Beam, 91% Pdn. Force

	2X	3X	4X
Qty TaN1	0	158	170
% Damaged	0%	6.29%	6.77%
Est. DPPM	917	69809	74825

Length ~3500μm

Results – Vendor probe test summary

- Cracking problem common among vendors

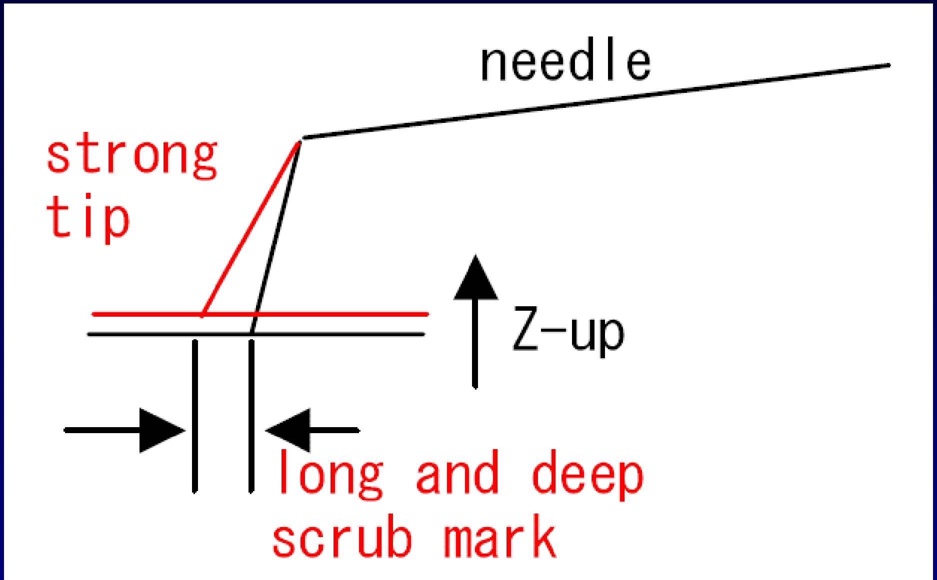
	Single Site					Dual Site		Quad Site	
Vendors	Load (%)	Cracking (TD#)		Shape Change	Cracking (TD#)	Load (%)	Cracking (TD#)	Load (%)	Cracking (TD#)
A	74	3x	→	Added radius	3x (% cracks increased)				
	91	3x	→	Flattened	3x (% cracks decreased)				
	100	3x							
B	80	6x							
	100	7x						100	6x
C	57	6x							
	80	7x						100	> 8x
D	160	4x							
E								100	6x
F						100	3x		
G						100	6x (1of 2512)		
300mm									
D						200	1x		

Load normalized to a % of production force

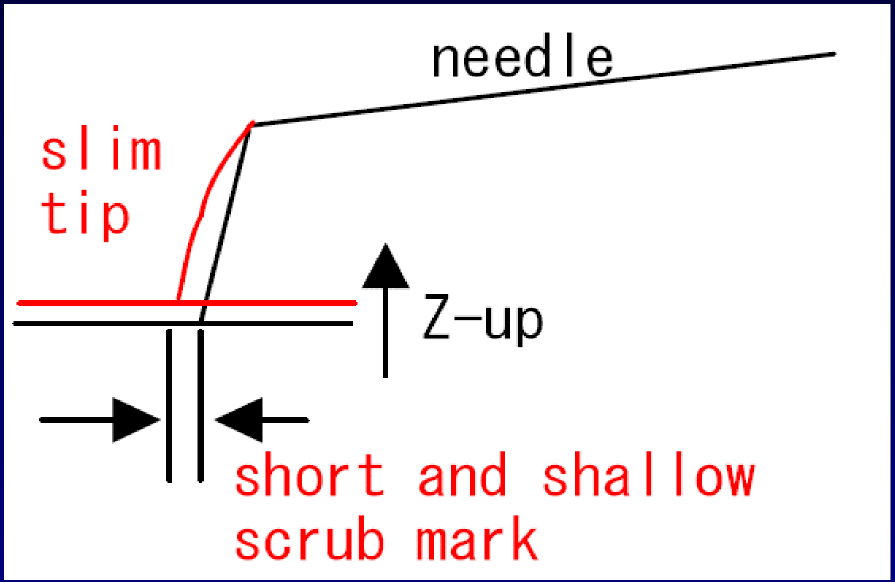
Results – New Approach

- **Design card to lessen probe depth**
  - Idea: compliant needle

Vendor A Baseline

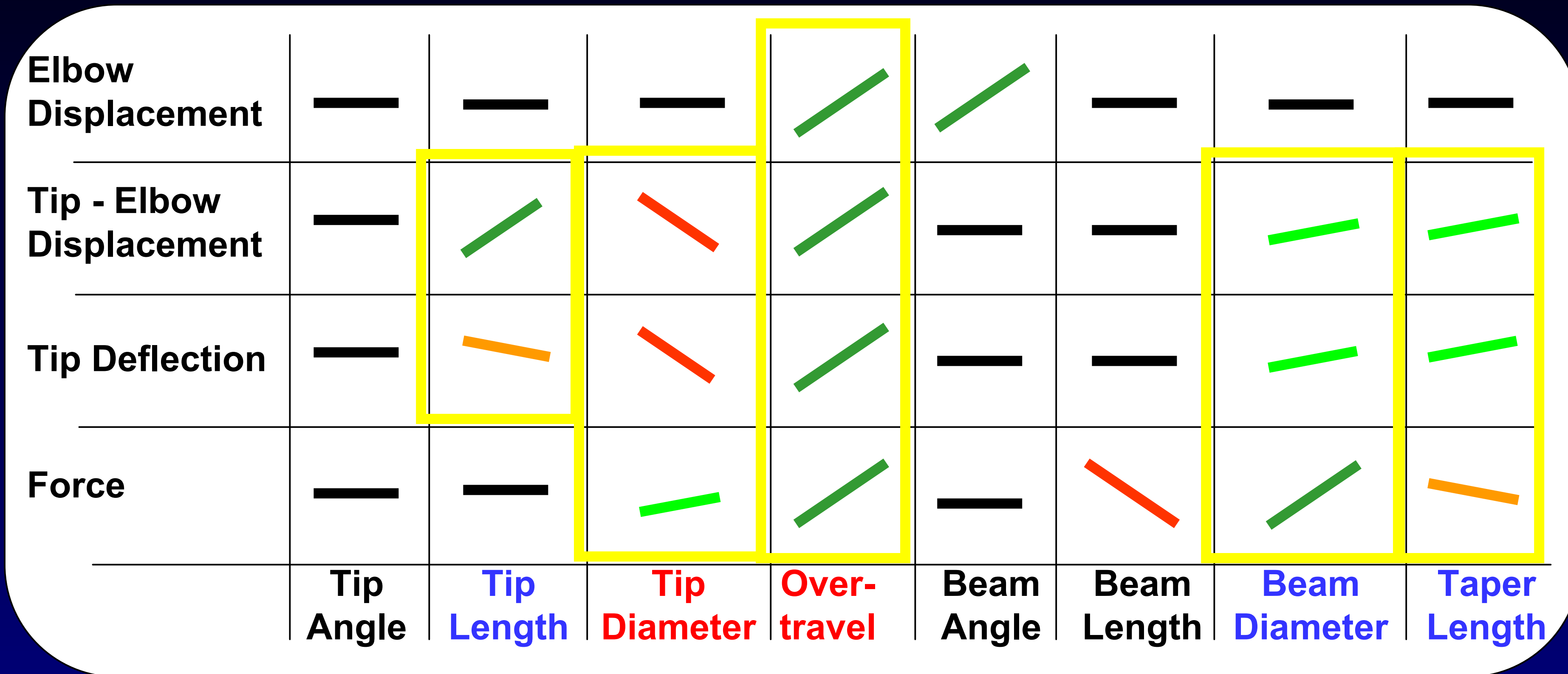


Vendor A New



Results – New Approach

- **Probe Tip Parameter Interactions** (Comeau et al., 1991)



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

Results – New Approach

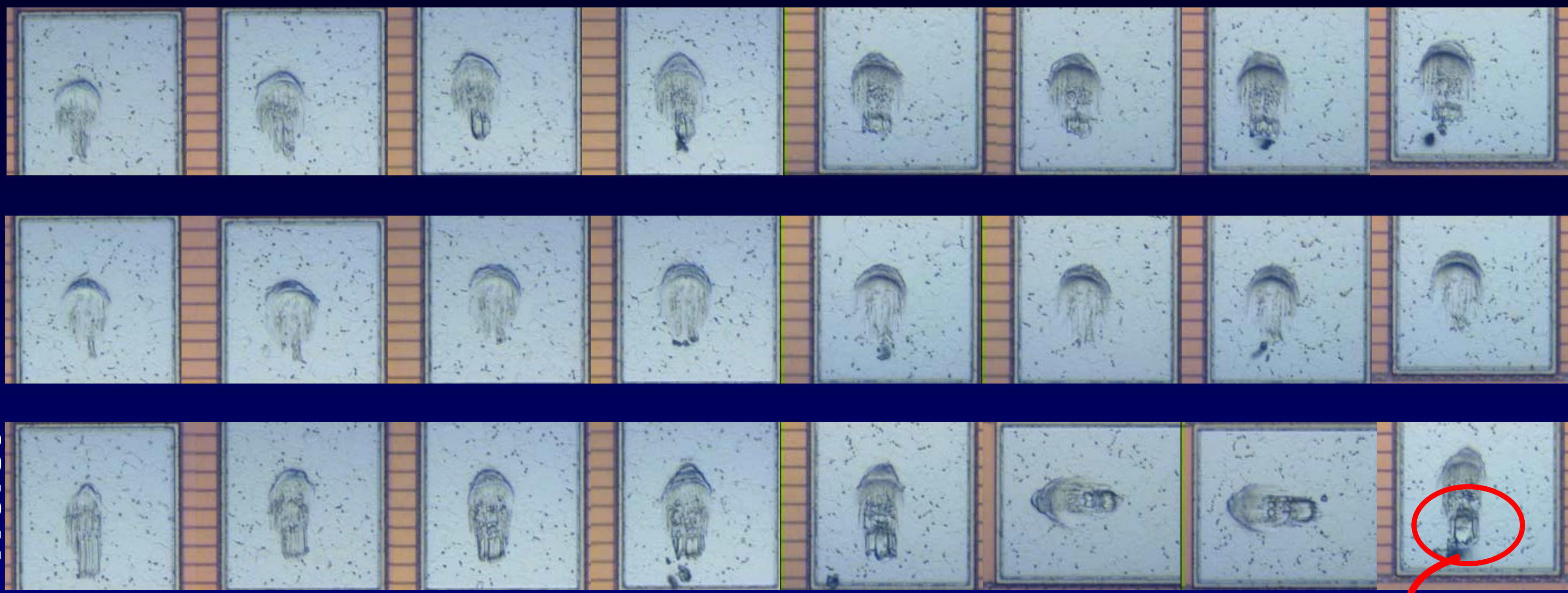
- Shallow scrubs (*mostly) obtained with new card design

1x TD 2x TD 3x TD 4x TD 5x TD 6x TD 7x TD 8x TD

Pad 1

Pad 2

Worst



Pad37 Pad37 Pad37 Pad37 Pad37 Pad39 Pad43 Pad37

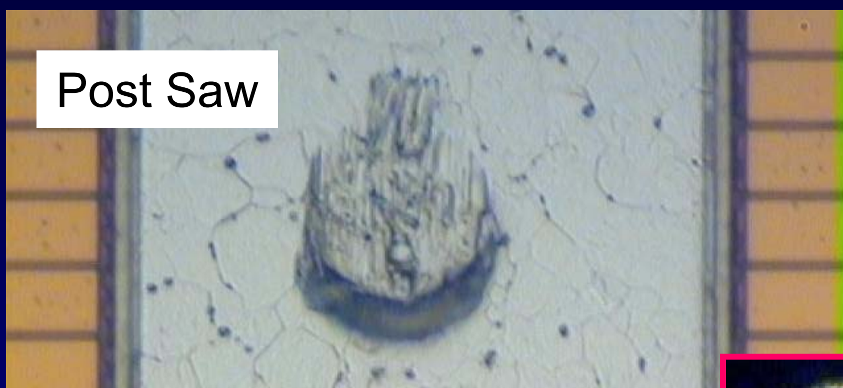
Vendor A crack threshold moved beyond 3x TD, now at 7x TD.
CRES adequate under "laboratory" conditions.

Implications: Card Design and Fabrication

- **Low-k dielectric die require new probe card design approaches.**
  - Current production specifications do not prevent design of cards that have poor cracking performance on low-k dielectric die.
  - One valid approach to design for reduction/elimination of cracks has been shown; other approaches may exist.
  - Some vendors currently capable of 8x TD, no cracks – but not on all card designs.
  - A new specification incorporating a design approach for crack reduction is difficult to create due to design parameter interactions.
    - Consider knee diameter?
    - Consider secondary measure – scrub depth?
  - Is a new specification required?
    - Vendors design for “short scrub marks” to accommodate customer demands. No specification exists.

Implications: Card IQC and Maintenance

- **More stringent probe requirements results in a more narrow "probe process window".**
  - Greater sensitivity to tip defects, cleaning residue, particles, repair….

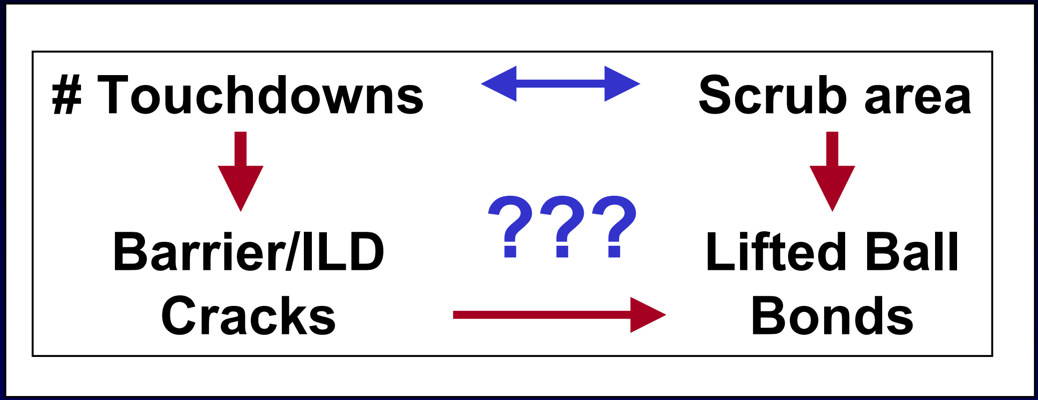


Defect of unknown origin on needle damages BEOL at 3x TD

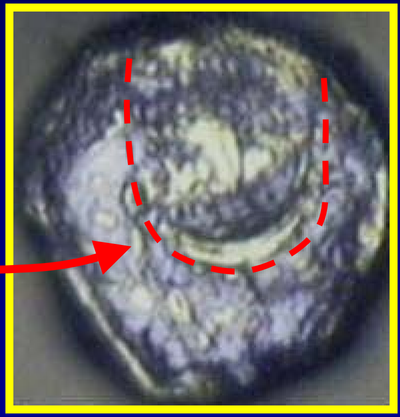
All other needles break at 6x or 7x TD

Implications: Impact on Assembly

- **Wirebond Interaction**



- **Assembly data indicates high lifted ball risk during wirebonding.**
  - Cracks result from deep scrub marks
  - Deep scrub marks result in aluminum displacement
  - No intermetallics form over the probe mark



Implications: Impact on Reliability

- Wirebond Interaction

Sample				Ball Shear Test			Wire Pull Test		
Wfr	Type	Detail	NSOP occurences	Mode 1 (LFBA)	Mode 2 (Sheared)	Mode 3 (LFML)	Mode 1 (LFBA)	Mode 2 (Break at Neck)	Mode 3 (LFML)
7	Max area scrub	60%	excessive	0	76	0	0	76	0
9		50%	19	0	76	0	5	68	3
11		40%	2	0	76	0	0	76	0
13	BL	30%	0	0	76	0	0	76	0
15	Max TD	4x TD	3	0	76	0	0	76	0
16		8x TD	51	0	76	0	21	55	0
17		12x TD	excessive	0	76	0	36	38	2

Wire Pull Test shows unacceptable lifted ball bond (LFBA) fail mode in presence of deep scrub marks.

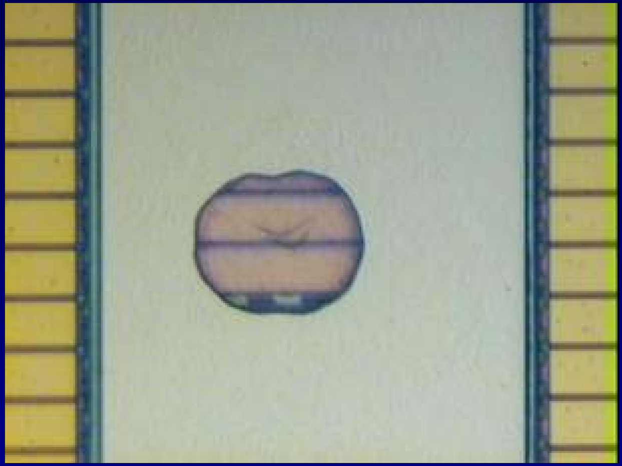
Deep marks seem to have a greater influence on LFBA than does “scrub area”.

Implications: Impact on Reliability

- **Testing Ongoing**

  Historically, probe cracks result in shifted electrical performance rather than in continuity failures.

  Purposefully cracked die are undergoing reliability tests to establish the failure mode these cracks induce in our devices.



Summary

- **Multiprobe-induced cracks on Cu/low-k die are a demonstrated concern.**
  - Occurs with cards that are built to specifications.
  - Affects assembly yield.
  - Negative implications for long-term reliability.
- **Performance among vendors is variable.**
- **Balance between non-cracking probe behavior and good contact resistance may be delicate (needs more study).**
- **New specifications to control risk are not self-evident.**
- **Scrub depth is a leading indicator of risk.**
- **Probe process window may be more narrow.**
  - Control of particles
  - Cleaning
  - Repair

Acknowledgements

We thank….

- **Our probe card vendors (A and C)**
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  - for assembly evaluations.
- **Vish Sundararaman (TI)**
  - for program support and 90nm silicon discussions.

References

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