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An Experimental work and Analysis of Vertical Cobra Probing on Low-k Wafers

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Outline

- Background
- Goals
- Experiment Plan (DOE)
- Results & Analysis
- Summary
- Follow-On Work

Background

- **Device trends**
  - ✓ Process advancement with Cu/low-k ILD materials.
  - ✓ Mass production for 65nm & 45nm processes are on track.
  - ✓ The latest 32nm process is rushing to come soon.

Table Source: ITRS 2008

90 nm	65 nm	45 nm	32nm
CVD SiOC DD (k=2.9)	→ CVD SiOC DD (k=2.9)	→ –	→ –
CVD SiOC DD (k=3.0)	→ CVD SiOC DD (k=2.75)	→ CVD SiOC DD (k=2.45)	→ –
CVD SiOC DD (k=3.0)	→ CVD SiOC DD (k=2.7)	→ CVD SiOC DD (k=2.55)?	→ CVD SiOC DD (k=2.2-2.3)?

It means to us …

Lower & lower k
(k=3 ➔2.7 ➔ 2.2 ➔…)

More weaker mechanical properties
(Young's Modulus, Fracture toughness, …)

Higher probing risk:
Pad damages
(underlying cracks)

Background (cont.)

- **Motivation**
  - ✓ Vertical probe cards are kept increasingly used in advance process node wafers with Cu/Low-k materials such as Logic, Memory, Burn In, POAA or POAC devices.
  - ✓ Lots of good practical studies contributed on "Cantilever" and "MEMS" technology probe cards for Low-k probing.
  - ✓ However, relatively few case studies available for the "Cobra Vertical" probing assessment especially on Cu/Low-k wafers.

<u>Literatures of Cu/Low k wafer probing related in SWTW</u>

Cantilever → 2003 & 2004 Hartfield et al.
2005 Stillman et al.; Tran et al.; Hwang et al.
2006 Yang et al.; Wegleitner et al.; Strom et al.
2008 Vallauri et al.

Cobra Vertical or the like → 2007 Vallauri et al.

MEMS → 2003 Martens et al.; 2004 Yorita et al.; Martens et al.;
2007 Wang et al.; Miller et al.;

Equipment / Tooling → 2004 & 2006 Collier et al.

Goals

1. Develop a DOE to investigate the probing behavior on low-k dielectric pads with 3 types of Cobra vertical probe cards.

2. Conduct probing on production test floor based on planned DOE with multiple touchdowns & overdrive.

3. Investigate the effects of DOE parameters and correlate with measurement as well as physical inspection results:
   - Probe mark (depth, length, width)
   - Underlying barrier layer images (after Al de-layered)
   - Cross sectional pad stack images (after FIB cut)

4. Identify the allowable probing window specification of Cobra VPC for safety and reliable production sort of Low-k wafers with process node 65nm.

Experimental Plan (DOE)

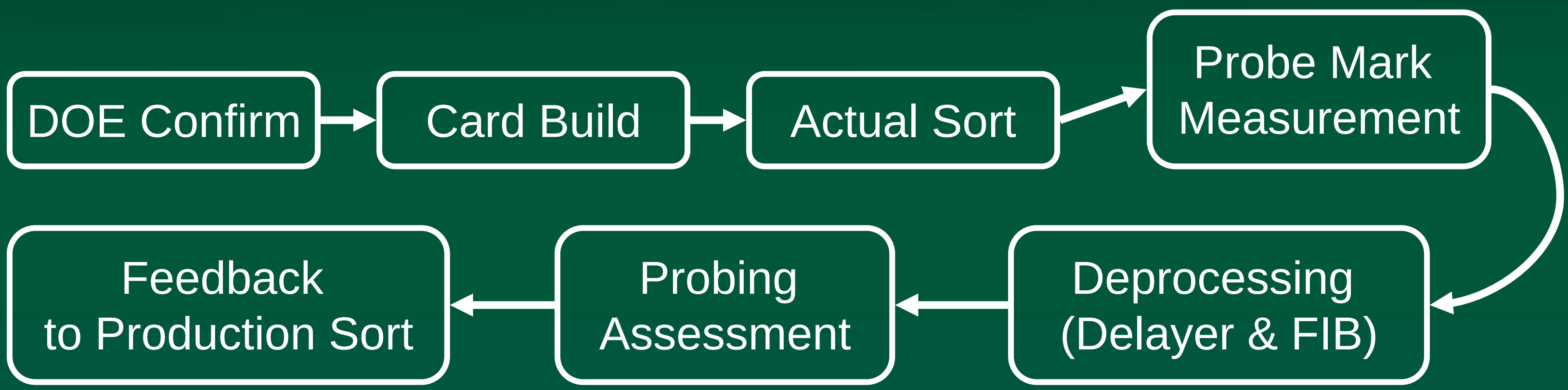
- **DOE Plan (Parameters, Evaluation & Notices)**
  - **Fixed parameters**
    - Wafer (pad material & stack up, Cu/Low-k 65nm)
    - Al pad thickness 1.2um
    - Room temperature probing
    - Chuck speed (default setting)
  - **Control parameters**
    - Overdrive (nominal, high and worst)
    - No. of Touchdown at same position (3x, 6x, 9x)
    - Cobra with various contact pressure (low, medium, high)

Experimental Plan (DOE)

- **DOE Plan (Parameters, Evaluation & Notices)**
  - **Wafer Selection**
    - Procure 2 wafers (65nm process node) from UMC production pipeline
  - **Probe Card**
    - Layout pattern based on selected devices
    - Card planarity: < 25um
    - 3 probe heads (PH) share 1 space transformer (ST)
  - **Tester, Prober & Test Program**
    - Production test floor : Advantest T2000, TEL P12XLn+, DOE program.

Experimental Plan (DOE)

- **DOE Plan (Parameters, Evaluation & Notices)**
  - **Flow**



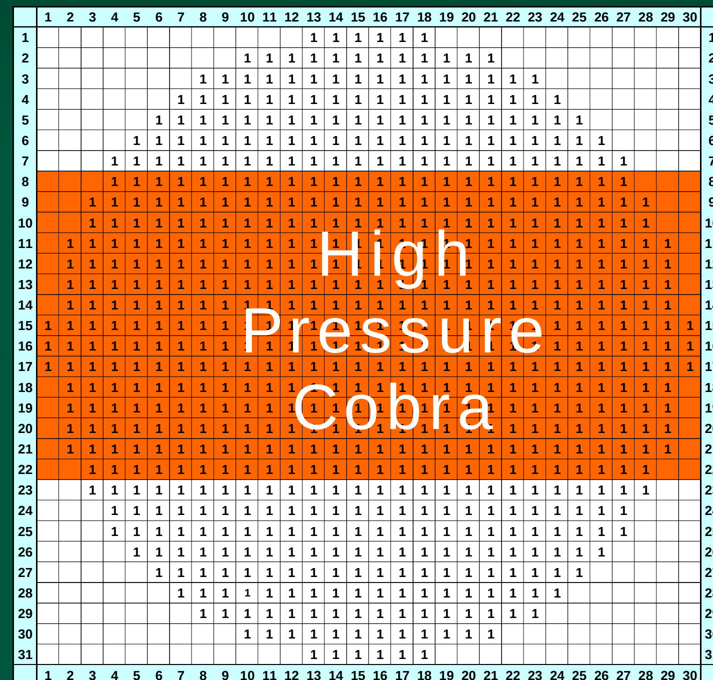
  - **Setup Conditions**
    - Production sort setup procedures
    - Use O/S program to detect 1st electrical contact
    - Multiple contact by auto mode setting at prober

Experimental Plan (DOE)

- **DOE Plan (Probing Map)**

1st Device Wafer

2nd Device Wafer



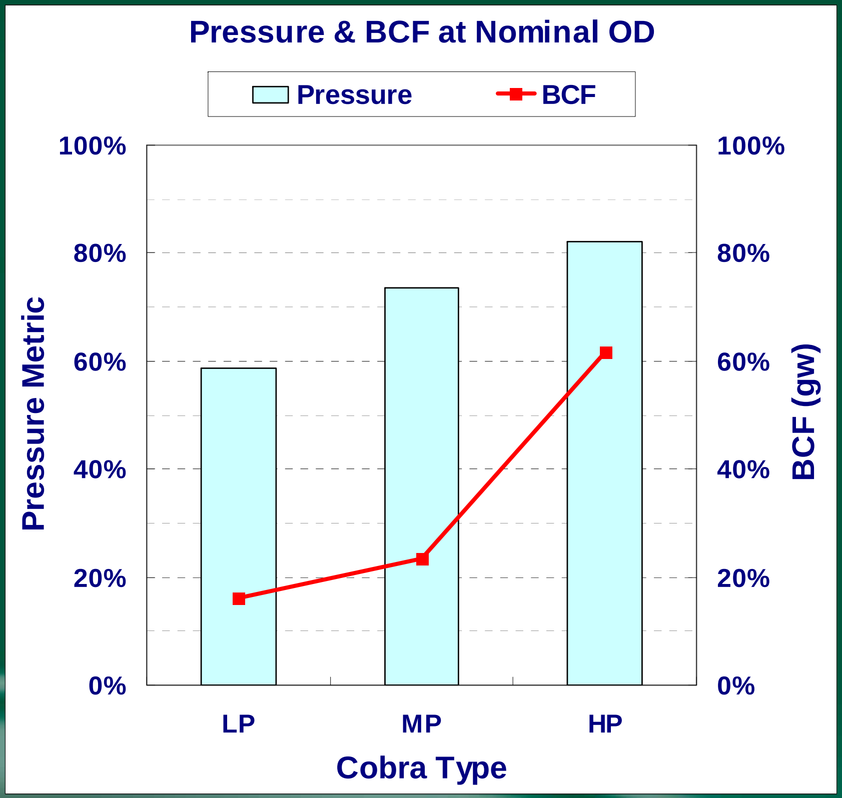
Probing settings:

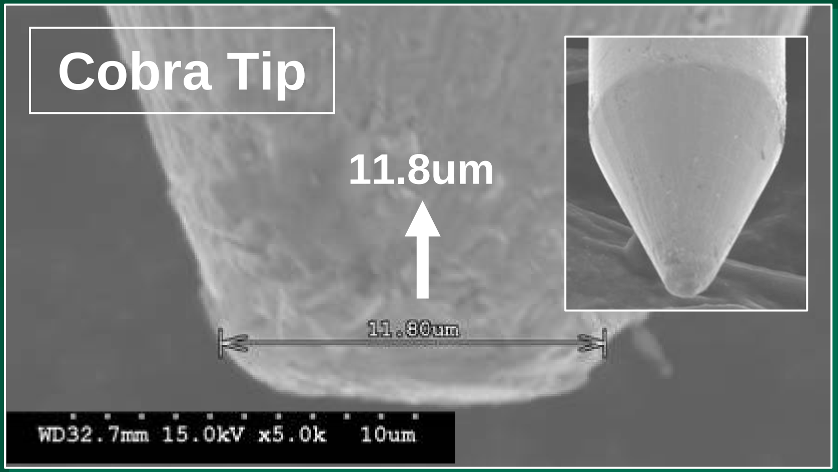
- Overdrive with nominal, high and worst condition
- Max. touchdown up to 3x, 6x and 9x

Results & Analysis

- **Probe Card (Tip diameter & Pressure Rank)**

Accurate tip diameter measurement by SEM Equipment (3xprobes/PH)



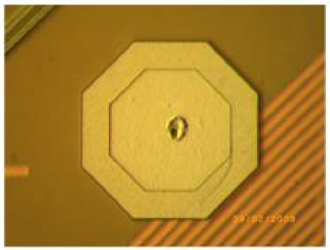
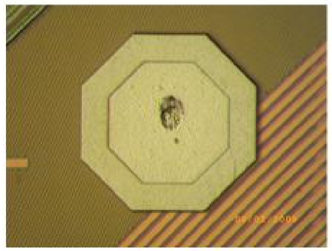
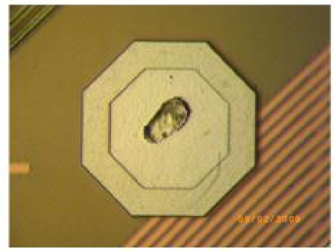
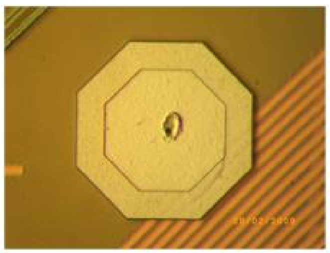
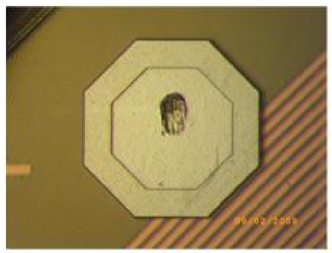
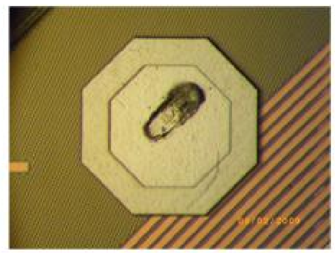
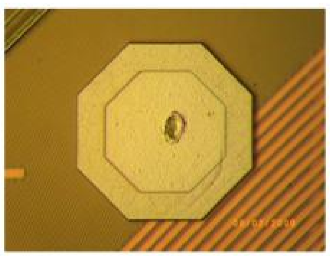
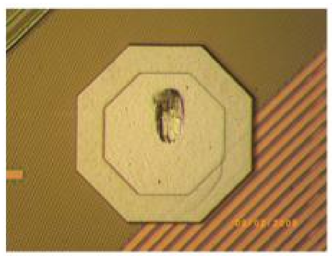
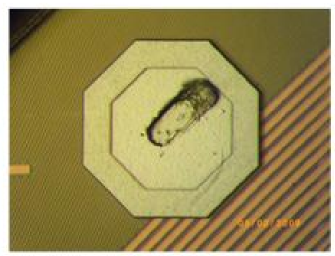


Customized Cobra Design			
Pressure Rank	Low (LP)	Medium (MP)	High (HP)
Tip dia. spec	15±5um		

Cobra design based on probe geometry, tip diameter, and contact force (BCF).

Results & Analysis

- **Probe Mark (Photos, 3D Scan, Measurement)**

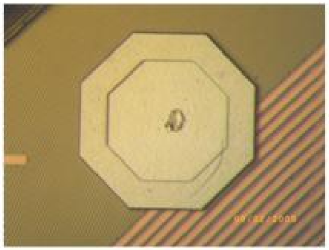
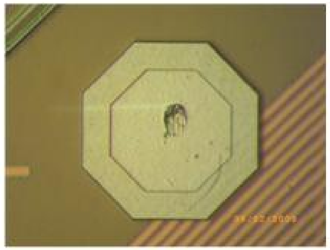
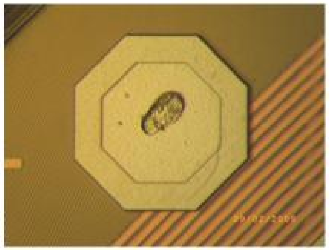
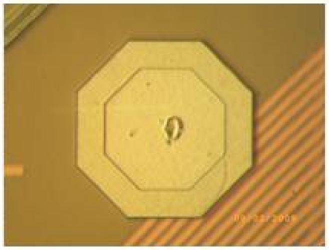
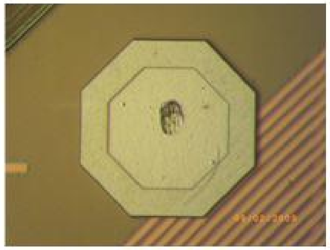
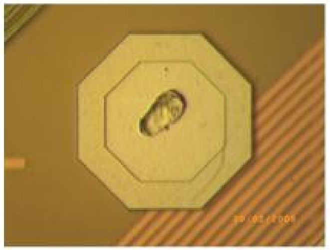
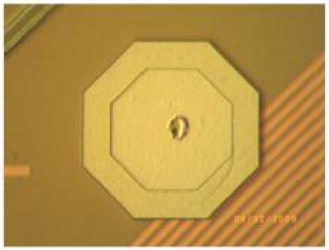
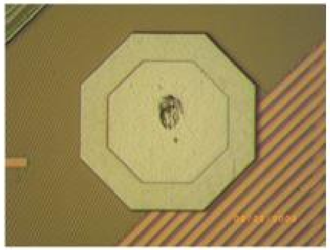
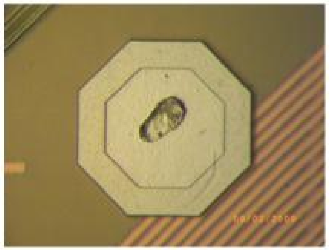
TD 9x (On each Cobra Types: LP, MP & HP)			
OD	**Low Pressure (LP)**	**Medium Pressure (MP)**	**High Pressure (HP)**
Nominal			
High			
Worst			

Effect of Increasing OD with multiple TD9x:

- ✓ No visible pad void even at worst probing condition
- ✓ Relatively more scrubbing action & piling up appeared on Medium & High pressure probe

Results & Analysis

- **Probe Mark (Photos, 3D Scan, Measurement)**

Nominal Overdrive (On each Cobra Types: LP, MP & HP)			
TD	**Low Pressure (LP)**	**Medium Pressure (MP)**	**High Pressure (HP)**
3x			
6x			
9x			

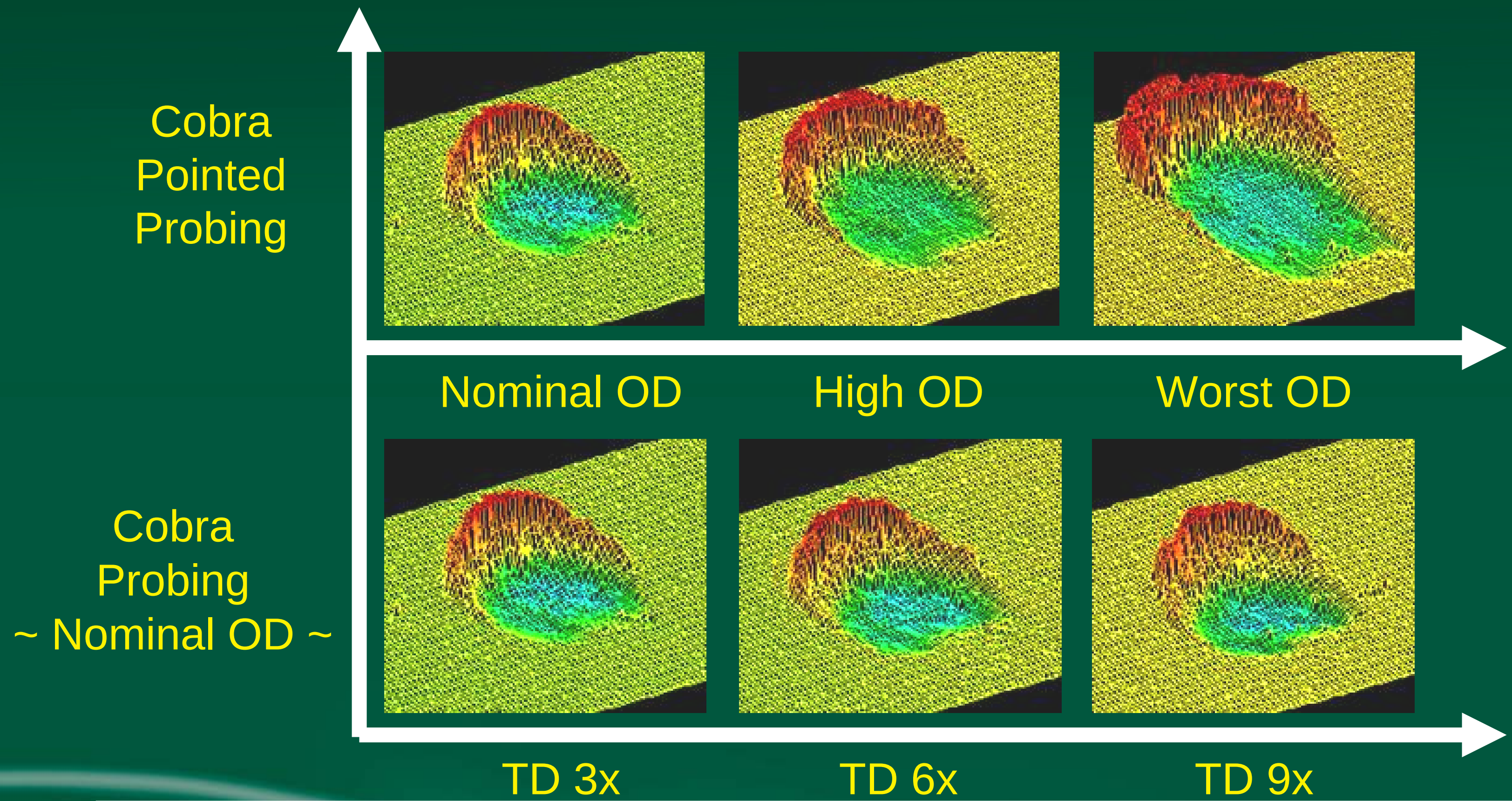
Effect of Increasing TD with nominal overdrive :

- ✓ Probe mark profile stabilized even increased multiple TD
- ✓ Largest probe mark area was resulted at High Pressure Cobra

PS: High pressure Cobra has angled probe mark due to probe assembly with 45° orientation

Results & Analysis

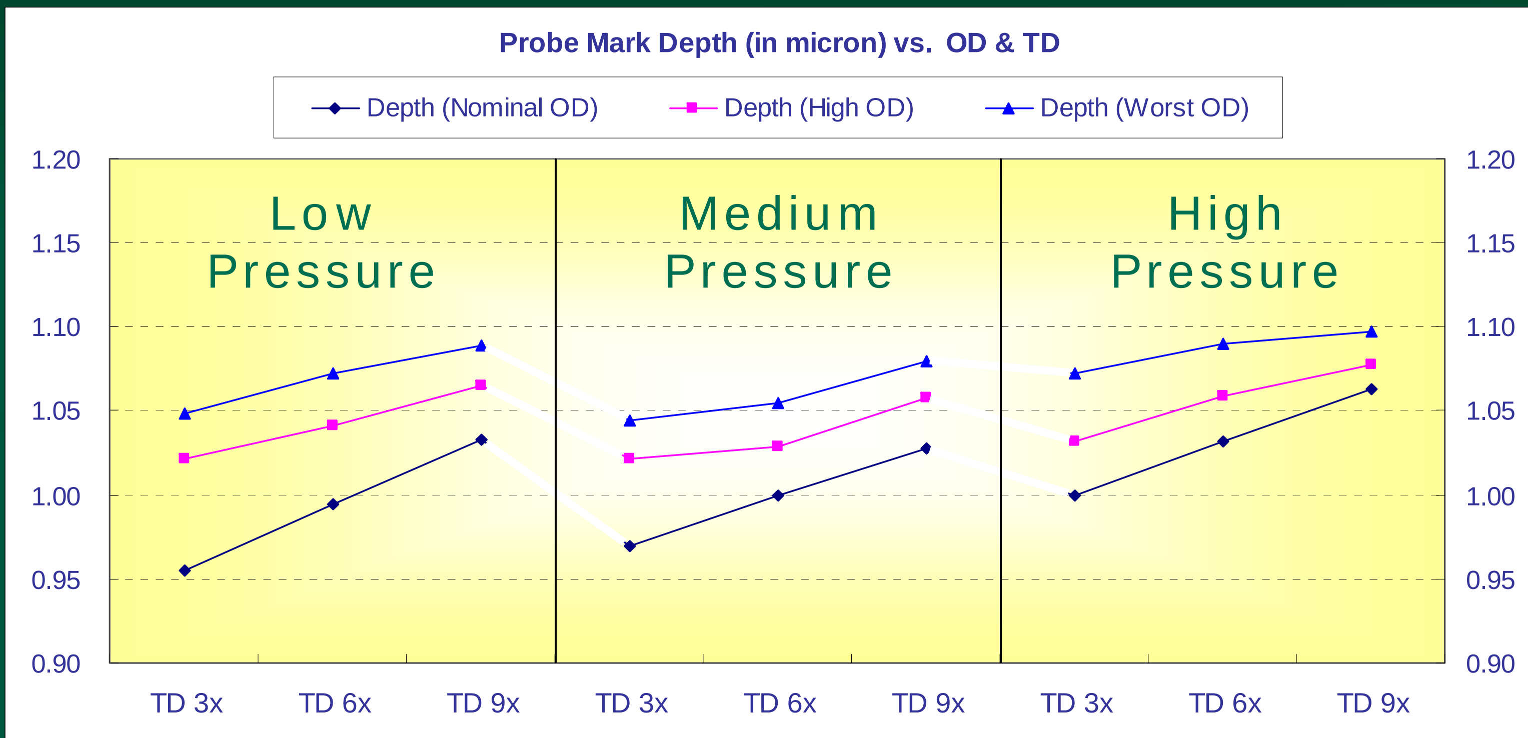
- **Probe Mark (Photos, 3D Scan, Measurement)**



All 3 Cobra designs (LP,MP, HP) showed the trends such as → Increased OD, adds more scrub to the pad, while increased TD did not add further scrubbing action.

Results & Analysis

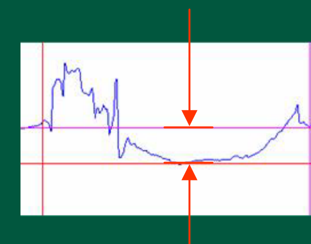
- **Probe Mark** (Photos, 3D Scan, **Measurement**)



Confocal Laser Scan

Min. sampling = 8pads

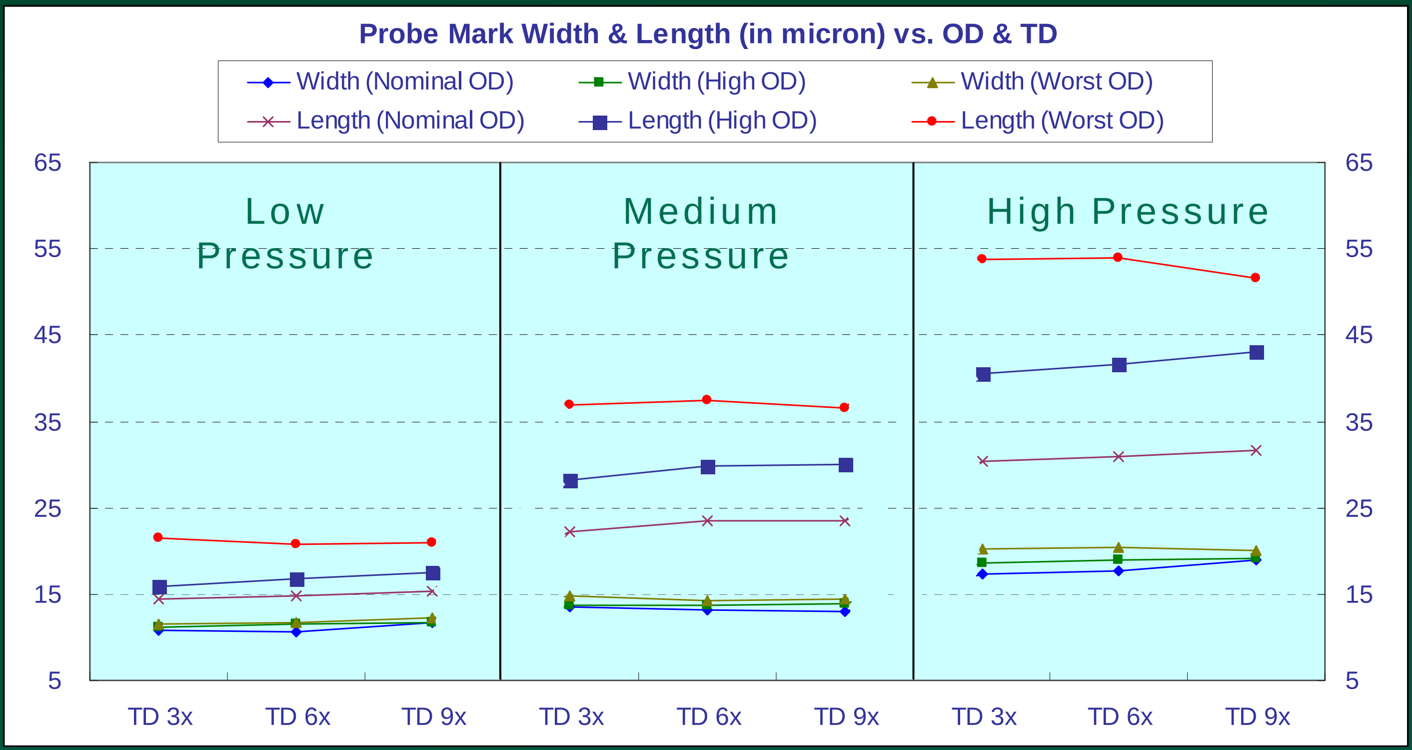
Depth



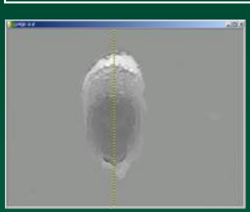
- **Trends showed larger OD & more repeated TD caused deeper probe mark**
- **Pressure magnitude is in linear correlation with the resulted probe mark depth.**

Results & Analysis

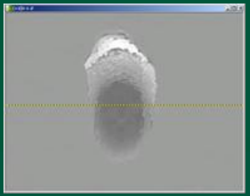
- **Probe Mark (Photos, 3D Scan, Measurement)**

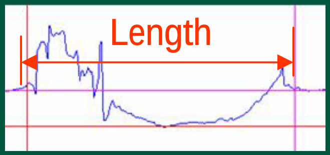


Confocal Laser Scan



Min. sampling = 8pads



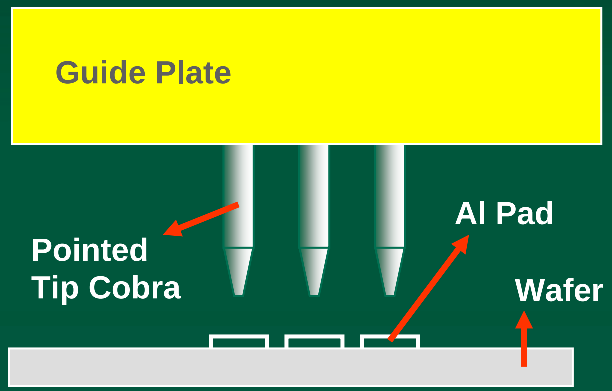


- ◆ **Probe mark width trend was stabilized while OD & TD increased**
- ◆ **Longer probe mark length whenever increasing OD, however repeated TD did not cause additional probe mark length**

Results & Analysis

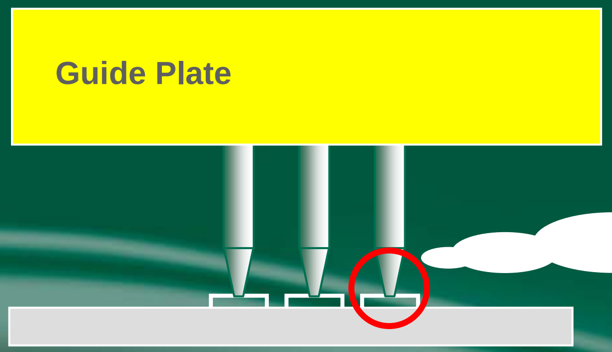
- **Prediction of Cobra Contact Behavior**

Drawing not to scale



Methods:

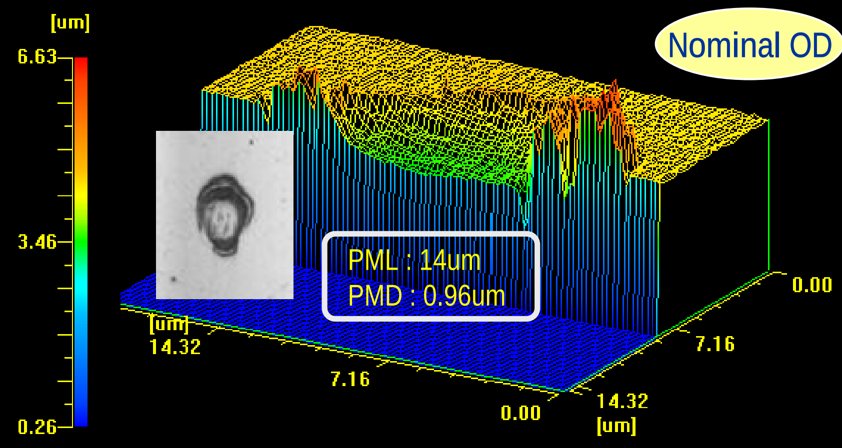
1. Collect the 2D & 3D laser scan data
2. Identify the similar patterns
3. Propose the contact mechanism
4. Real-time visualization

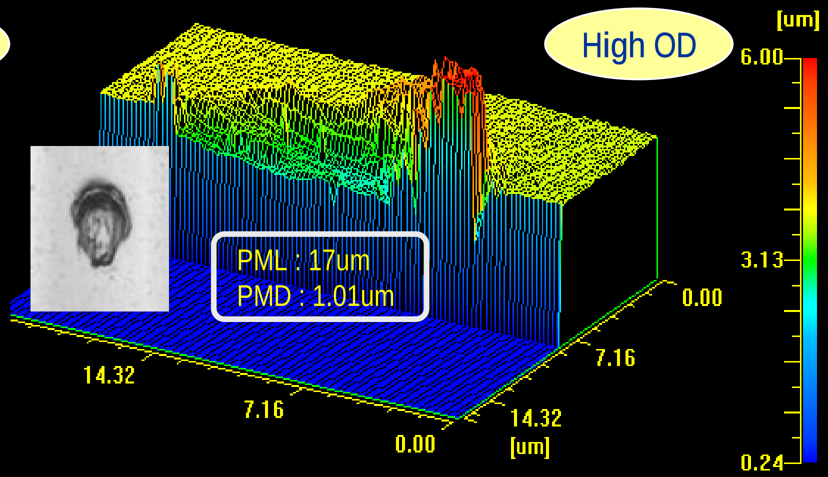


How does the probing action work ? How is the tip penetrating through oxide ? Any differences with other probe technologies ?

Results & Analysis

- **Prediction of Cobra Contact Behavior**





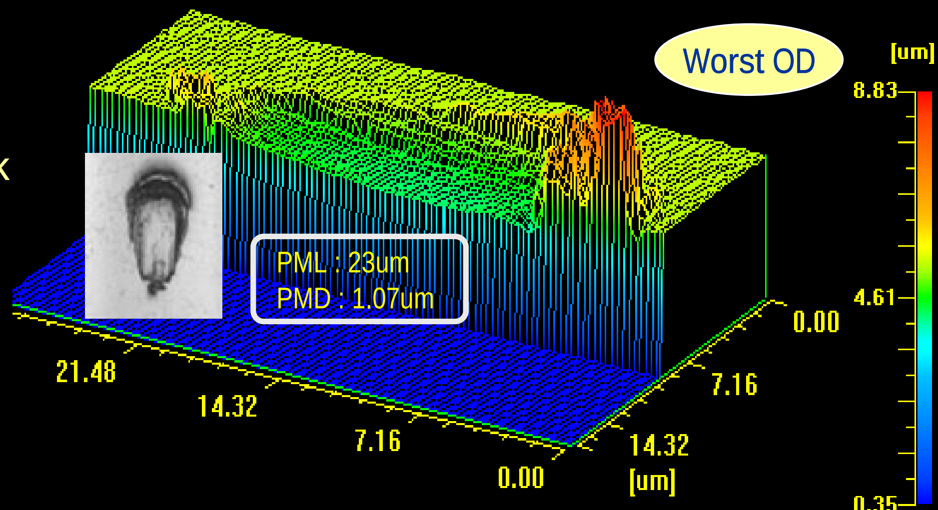
PML = probe mark length
PMD = probe mark depth

Conditions:

Pointed Cobra probing on the 65nm Cu/Low-k wafer with POAA pads (Al thick 1.2um).

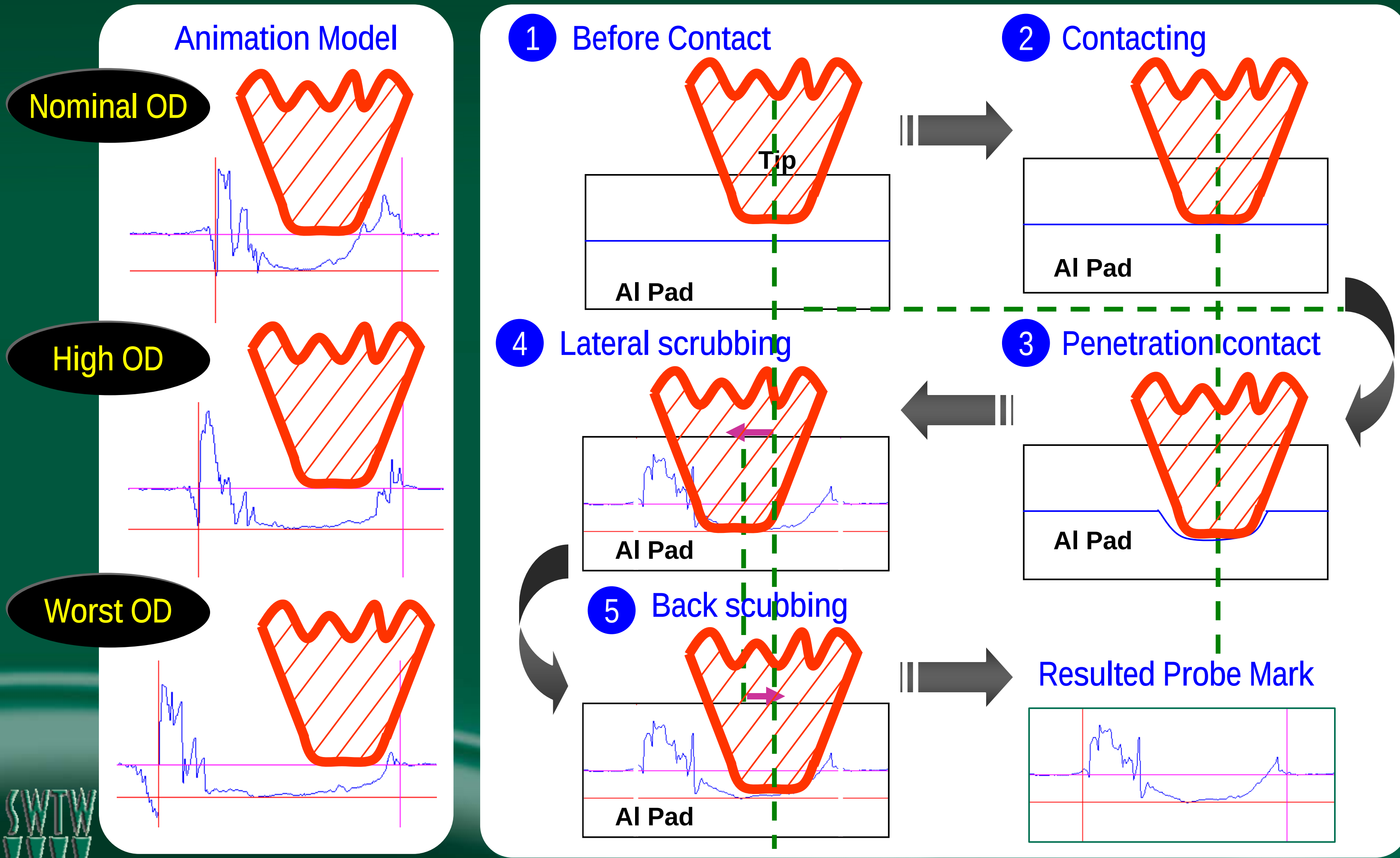
INCREASING OD, contact modes showed:

1. Penetration at certain depth
2. Scrubbing action initiated at high OD



Results & Analysis

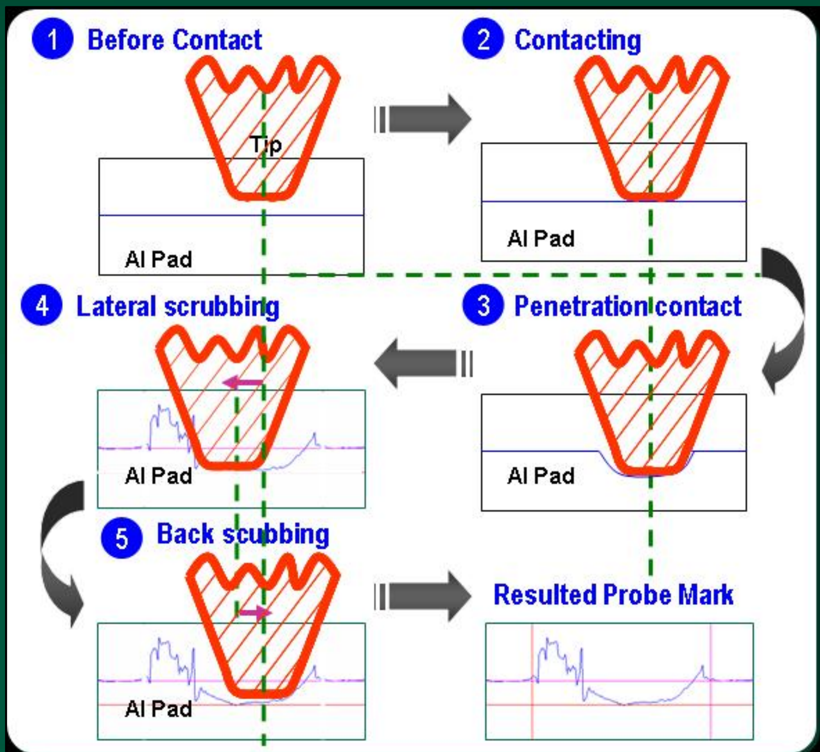
- Prediction of Cobra Contact Behavior



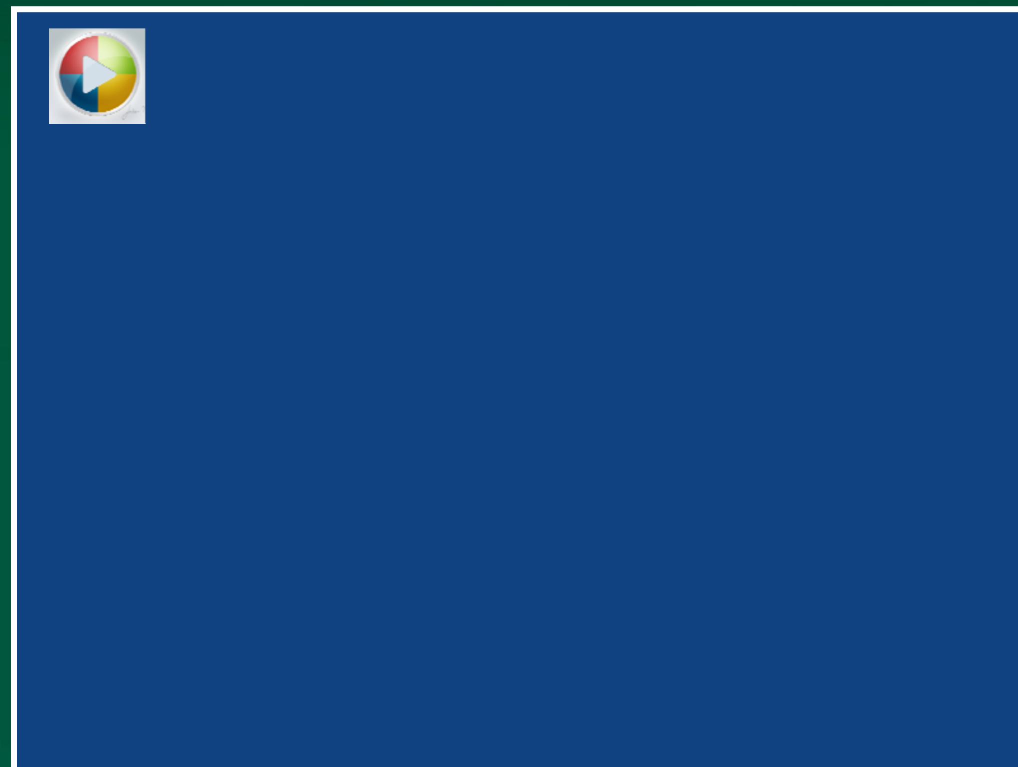
Results & Analysis

- **Prediction of Cobra Contact Behavior**

Predicted Model



Real-time visualization



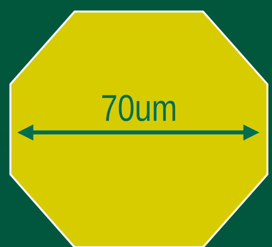
The predicted model was agreed with real-time video. The Cobra tip has tendency to SCRUB at Initial and End of contacting moments.

Results & Analysis

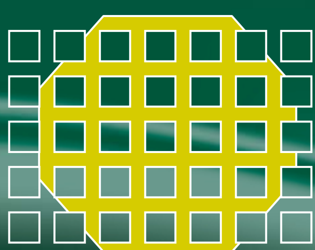
- **Deprocessing (Pad type, Delayer & Failure mode)**

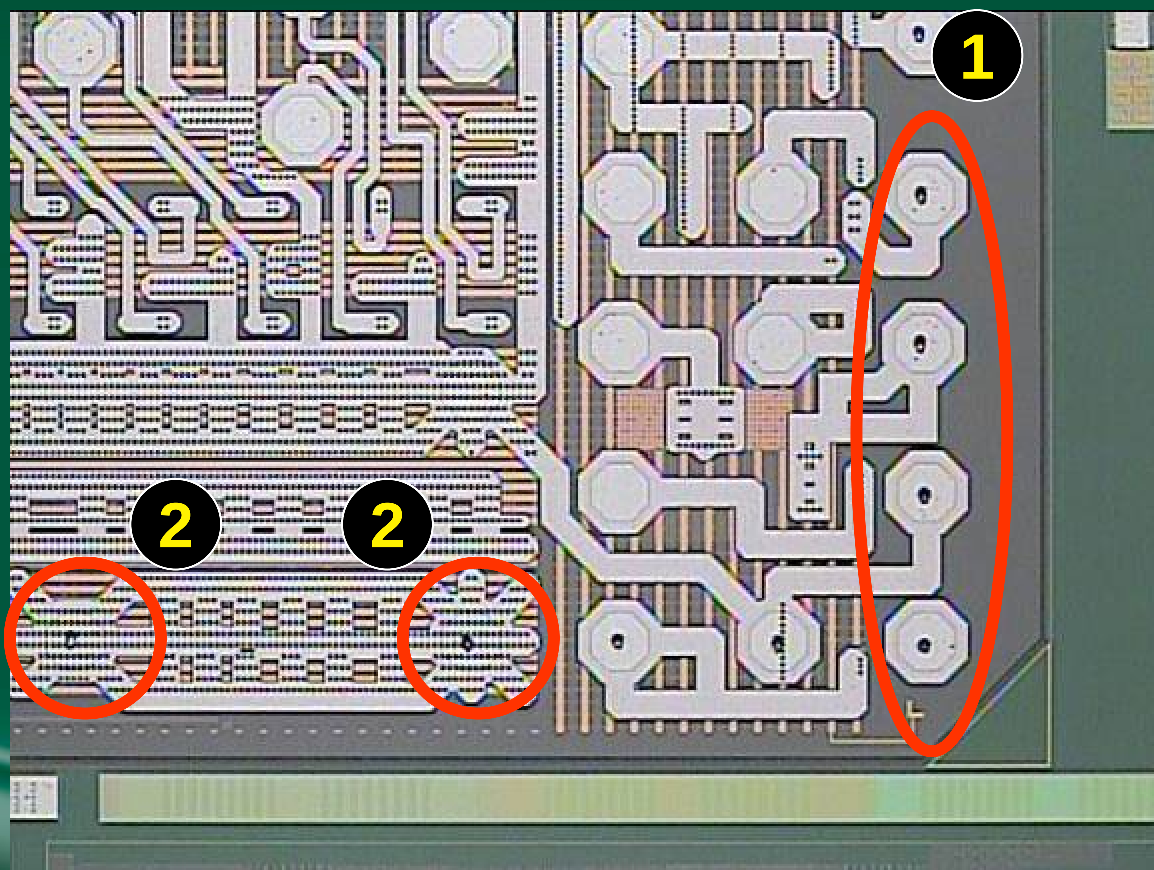
Pad Type	Actual Pads on Probed Wafer

1 Solid Pad



2 Slotted Pad

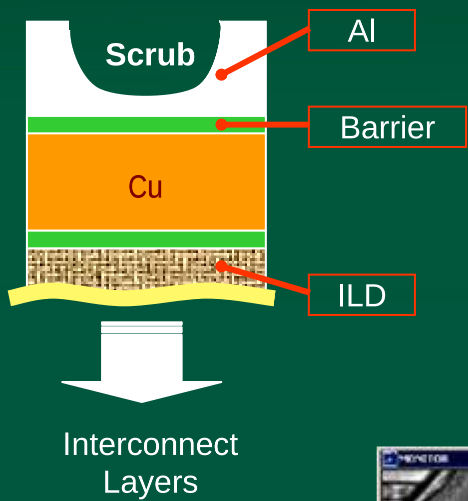




Results & Analysis

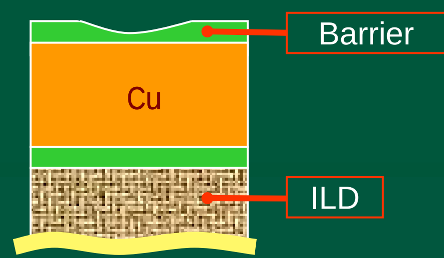
- **Deprocessing (Pad type, Delayer & Failure mode)**

Before Delayer

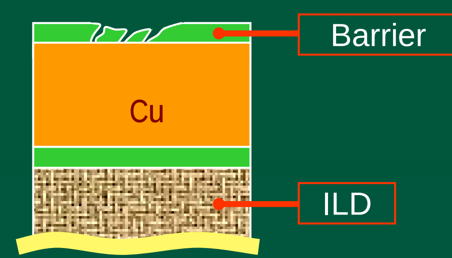


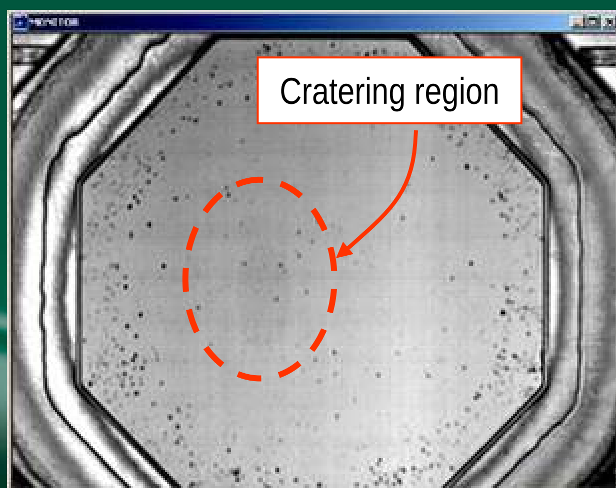
After Delayer, Check Barrier Layer

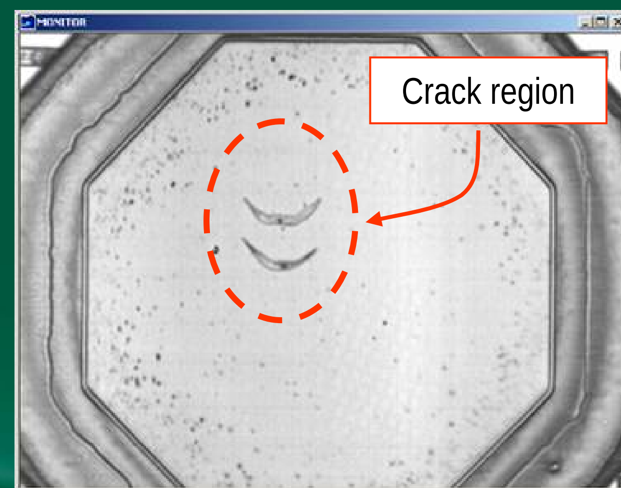
Mode 1 ~ Craters



Mode 2 ~ Cracks



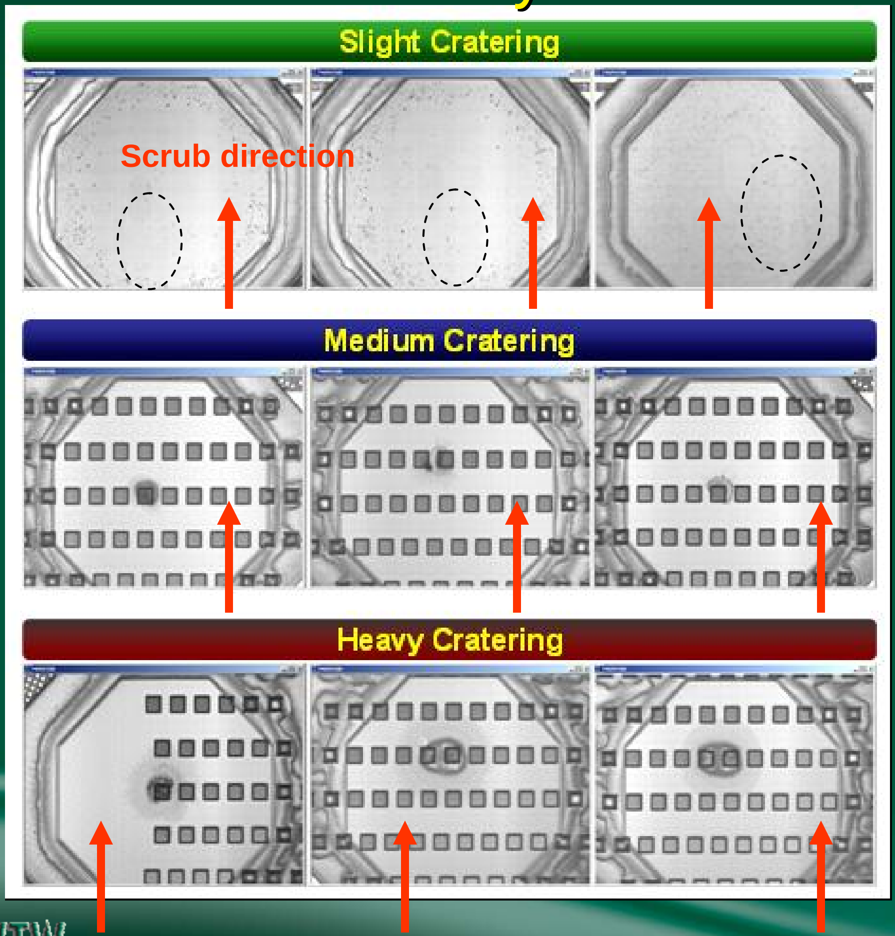




Results & Analysis

- **Deprocessing (Pad type, Delayer & Failure mode)**

"Mode-1 Barrier Layer Crater" showed 3 damage levels :



1. Shallow & small depression
2. Slight mark coloring

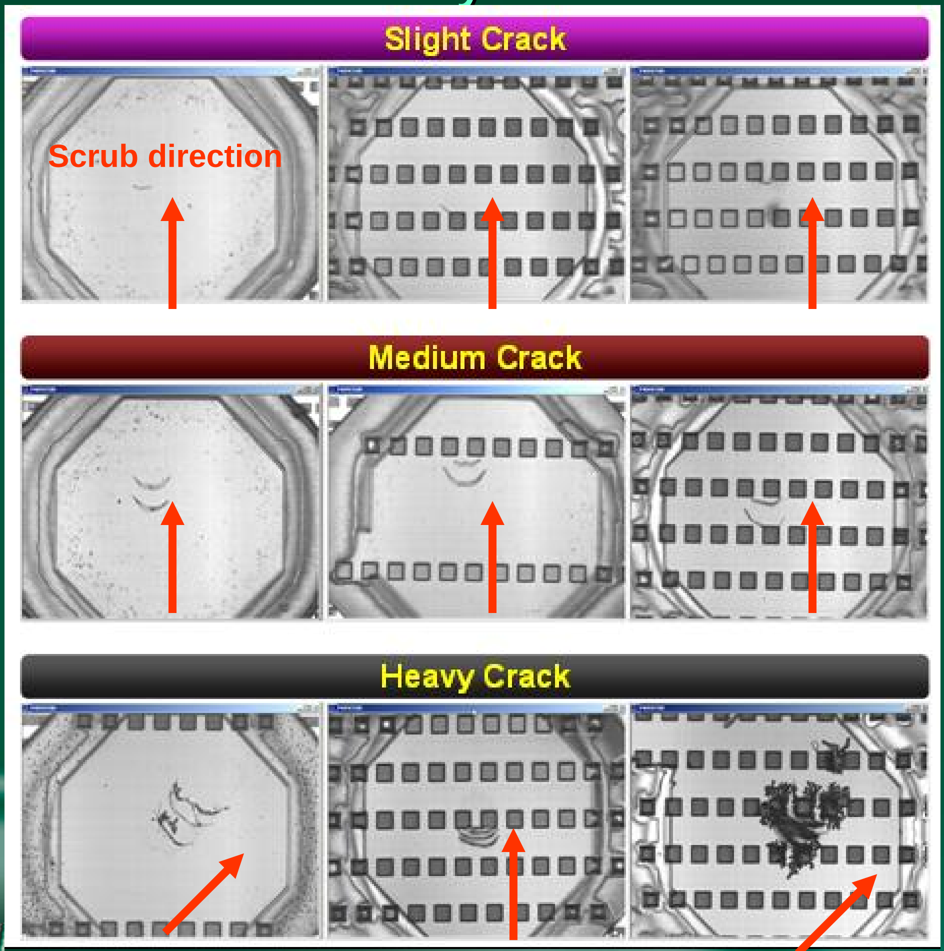
1. Medium depression area & depth
2. Darker mark coloring

1. Largest depression area & depth
2. Darkest mark coloring
3. Deformation of slotted pad wall

Results & Analysis

- **Deprocessing (Pad type, Delayer & Failure mode)**

"Mode-2 Barrier Layer Crack" showed 3 damage levels :



1. Short crack length
2. Thin crack opening

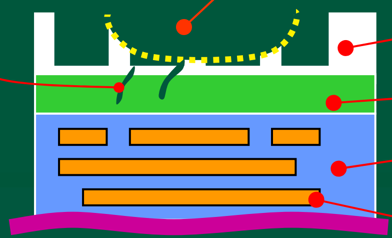
1. Longer & multiple cracks
2. Medium crack opening

1. Worst multiple cracks
2. Largest crack opening
3. Tearing off barrier layer

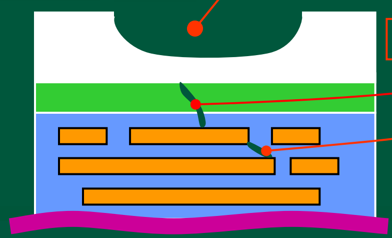
Results & Analysis

- **Deprocessing (FIB Failure Mode, Photos)**

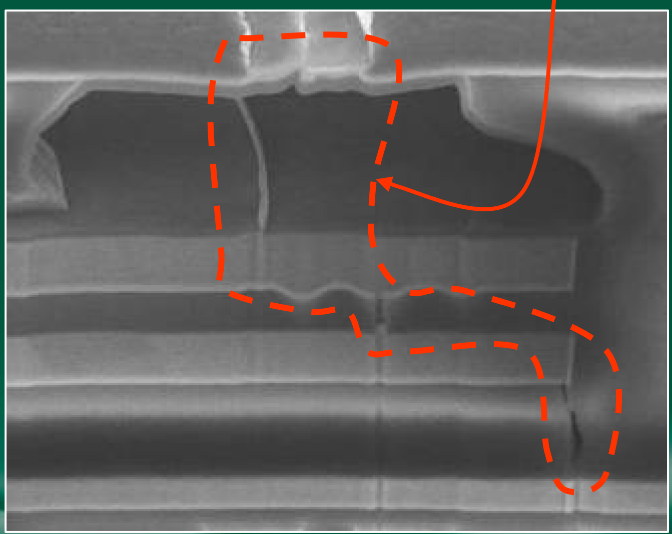
Mode 1 ~ Slot Edge Crack



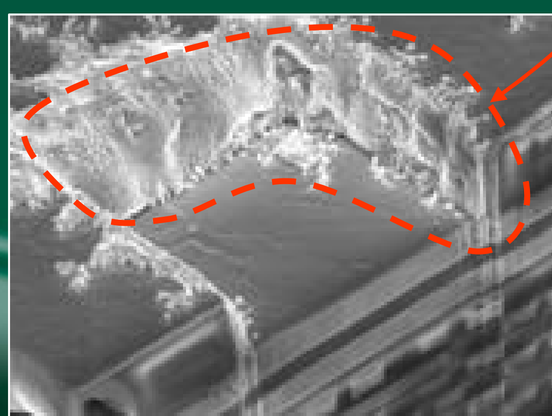
Mode 2 ~ Multi Level Crack

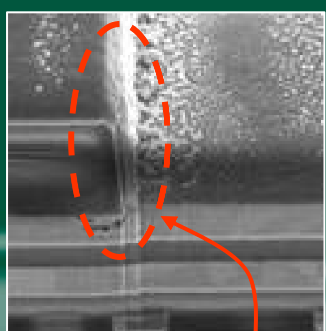


Crack propagation at underlying layers



Reactive products due to slot edge cracks

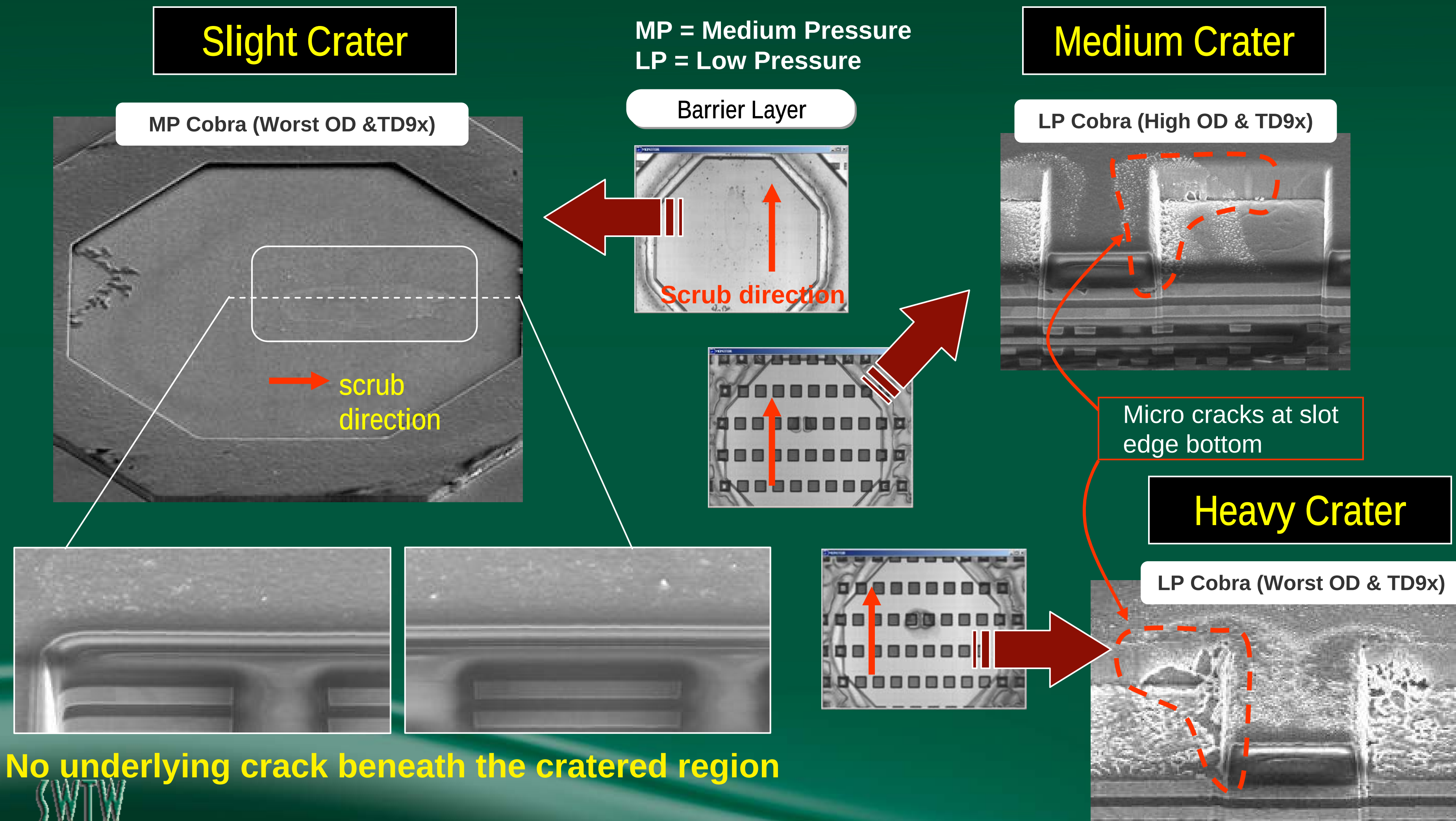




Slot edge cracks

Results & Analysis

- **Deprocessing (FIB Failure Mode, Photos)**



Results & Analysis

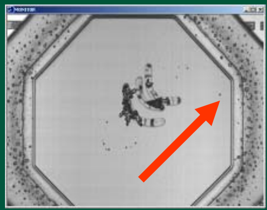
- **Deprocessing** (FIB Failure Mode, Photos)

Heavy Crack

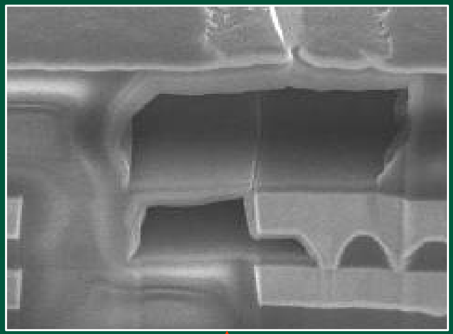
HP = High Pressure
LP = Low Pressure

No Crack

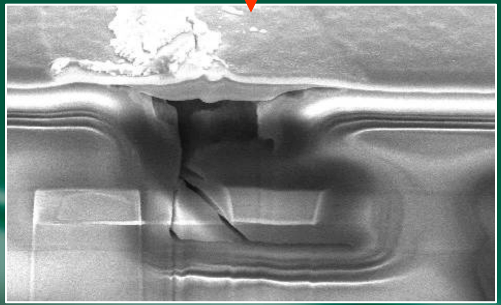
Barrier Layer



HP Cobra (Worst OD & TD6x)

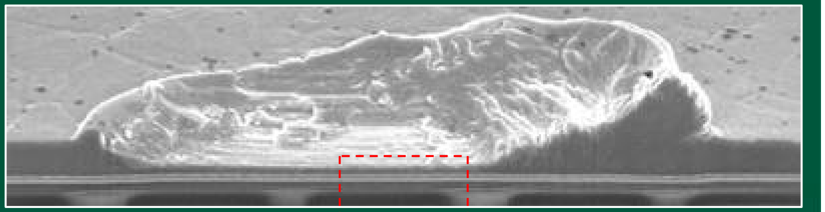


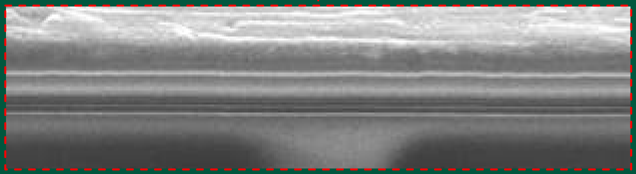
Multi-level barrier layer cracking beneath the pad



HP Cobra (Worst OD & TD9x

LP Cobra (Worst OD & TD9x)





No underlying crack beneath the probe mark

Results & Analysis

- **Overall analysis results of deprocessing**

Cobra Type (Pressure)	OD	Nominal			High			Worst		
	TD	3x	6x	9x	3x	6x	9x	3x	6x	9x
Low (LP)	% Barrier Crack on Solid Pad	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Medium (MP)		0.0%	0.0%	0.0%	0.0% (1)	0.0% (1)	0.0% (1)	0.0% (1)	0.0% (1)	0.0% (1)
High (HP)		3.0%	4.1%	5.6%	4.6%	10.6%	14.3%	6.5%	18.0%	28.6%
Low (LP)	% Barrier Crack on Slotted Pad	0.0%	0.0%	0.0%	0.0% (1)	0.0% (1)	0.0% (2)	0.0% (2)	0.0% (3)	0.0% (3)
Medium (MP)		0.0%	0.0% (1)	0.0% (1)	0.0% (1)	0.0% (2)	0.0% (2)	0.0% (3)	0.0% (3)	0.0% (3)
High (HP)		9.2%	10.8%	12.4%	13.5%	14.0%	14.6%	15.0%	19.0%	30.2%

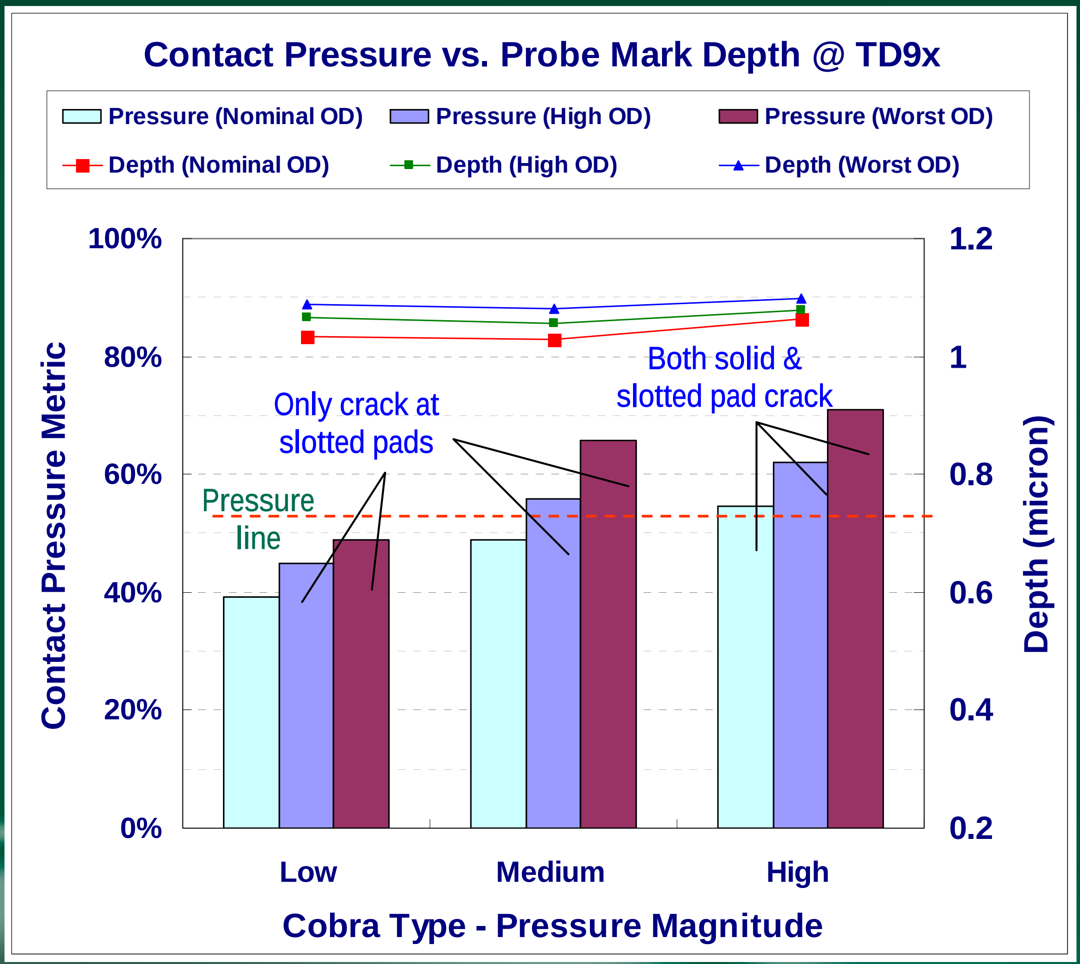
Remark

Al Pad Delayer	Safe	(1) Slight Crater	(2) Medium Crater	(3) Heavy Crater	Crack
FIB	Pass		Fail		

- Low pressure (LP) & Medium pressure (MP) Cobra design are in safety region to probe the Solid Pad, while High pressure (HP) Cobra would cause cracks on both pad types.
- FIB found the hidden micro cracks at "Top Barrier Layer" of Slotted Pad located at edge sidewall.

Results & Analysis

- **Pressure analysis (Tip Measurement, Analysis)**



Implications :

"Slotted pad" is more risky to crack than "solid pad"

Same pressure condition could lead to different results.

One critical factor is suspected to impact the probing behavior:

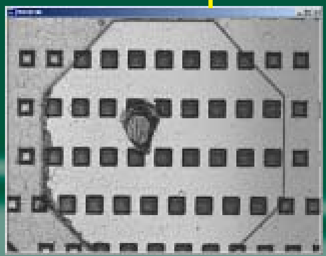
"Impulse-Momentum" effect between the pad & probe

Results & Analysis

- **Useful lessons learned (1/2)**

1. A single "Probe Mark Depth" parameter is insufficient to ensure the crack free probing. "Contact Pressure" & "Contact Momentum" should also be included.

Recommendation Probing Conditions

Pad Structure	Allowable "Top Barrier Contact Pressure"	Allowable "Contact Momentum" related parameters (BCF & chuck speed[#1])
Solid pad 	< 800 MPa (TD9x, Same Spot)	BCF < 10gw (TD9x, Same Spot)
Slotted pad 	< 550 MPa (TD9x, Same Spot)	BCF < 5.5gw (TD9x, Same Spot)

#1 default setting for present DOE

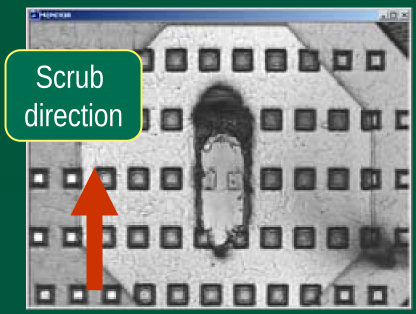
Above recommendation is based on probing results of present case study

Results & Analysis

- **Useful lessons learned (2/2)**

2. Slotted pads are more susceptible to barrier/underlying cracks due to “High Stress Concentration” resulted on relatively smaller contact area on pad.

Probe Mark



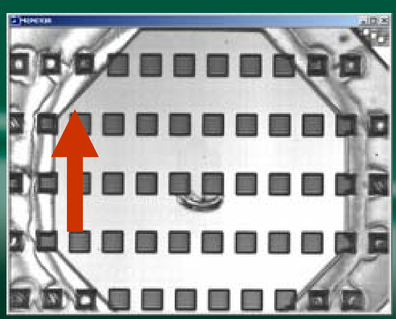
High Pressure Cobra

Worst Overdrive

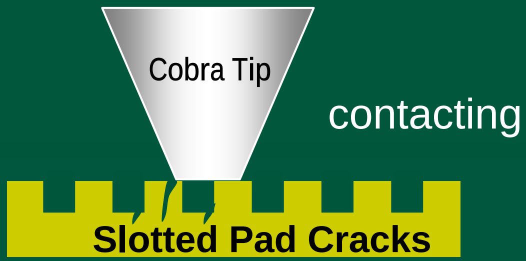
TD9x

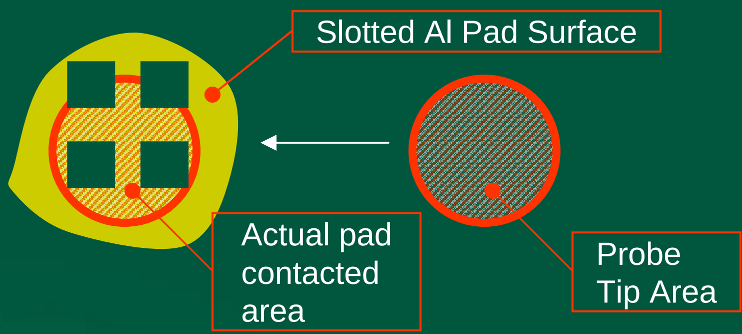
Strip off Al pad

Barrier Layer



Probing Condition





High concentrated stress effect

Summary

- A practical case study to investigate the Cu/Low-k vertical probing induced pad cracks was conducted for 65nm process node wafers.
- Probe mark geometry analysis was analyzed and correlated with various probing parameters
- Failure analysis (FA) of barrier layer and underlying pad stack damages found the key failure modes and correlated with probing parameters.
- Evaluations demonstrated :
  - Cobra contact behavior was validated with real-time visualization
  - Al "slotted Pad" type was mechanically weaker than Al "Solid Pad"
  - Probe mark depth parameter is insufficient to ensure crack free probing, other factors such as "contact pressure" and "contact momentum" must be included.
- Allowable Cu/Low-k probing window of each Cobra types were successfully determined under various overdrive and multiple TD.

Follow-On Work

- Crack probing assessment on 45nm & 32nm Cu/Low-k processes.
- Consider the additional critical parameters into DOE scope, such as :
  - ✓ Various contact pressure designs on each Cobra dimension
  - ✓ Various contact momentum related factors (chuck speed, BCF)
  - ✓ Various probing temperature (hot 85°C/110°C, cold 0°C/-40°C)
- Broaden the characterization test coverage on different pad types:
  - ✓ AlCu pad (harder structure) & Copper pad (thicker oxide)

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Q & A

Thank you very much .