SW Test Workshop
Semiconductor Wafer Test Workshop

Effects of Probe Marks on Wirebonding

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A tutorial, summarizing work of ON Semiconductor and BYU-Idaho since 2010

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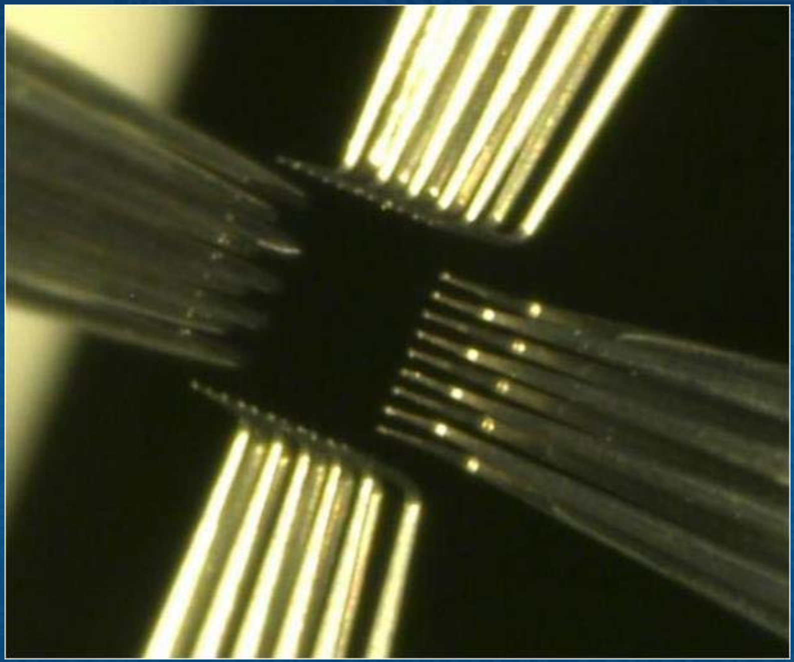
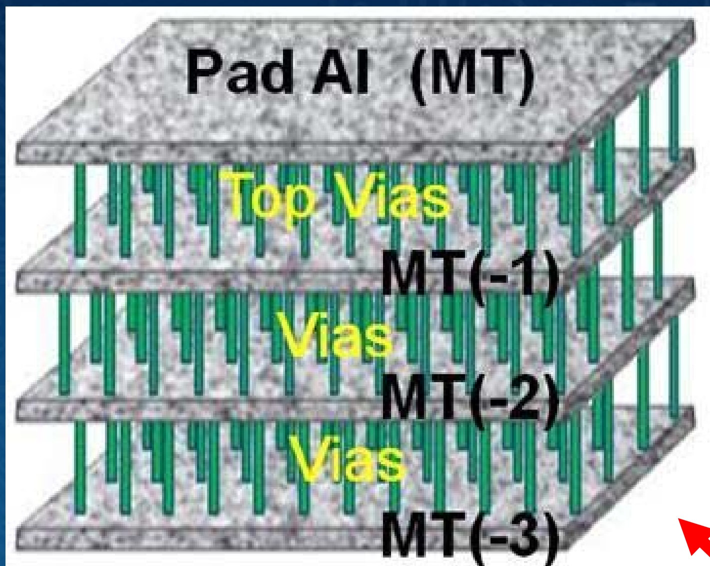
Overview

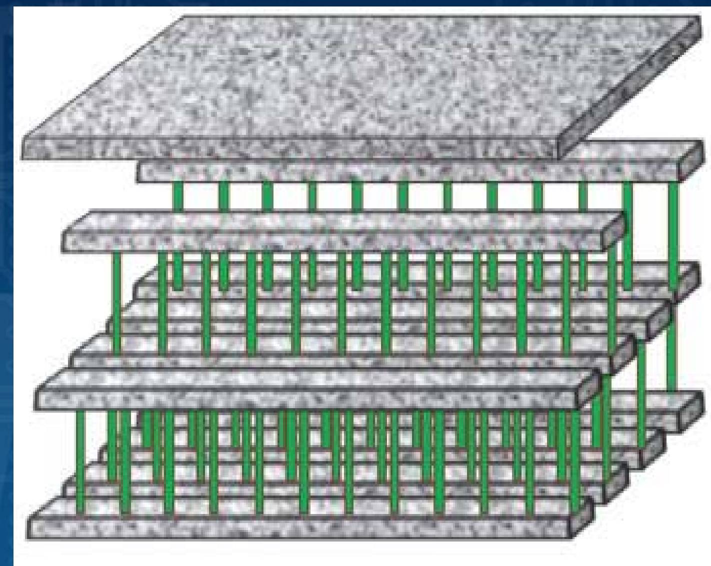
- **Probing**
  - Can cause or lead to cracking in pad sublayers
  - Deforms the pad Al surface
  - Less invasive probe marks are best
- **Wirebonding**
  - Bond energy will *extend* probing cracks
  - Bond energy can *cause* cracks in probing-weakened pad structure
    - Cracked bond pad can cause short or open, and is unreliable
  - Forms an intermetallic with the pad Al surface
    - Probe mark can interfere with the bond strength



Probing on Al Pads

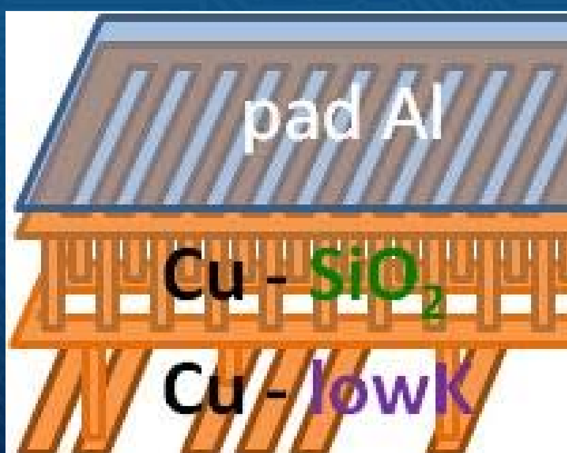
Bond Pad Structure Examples



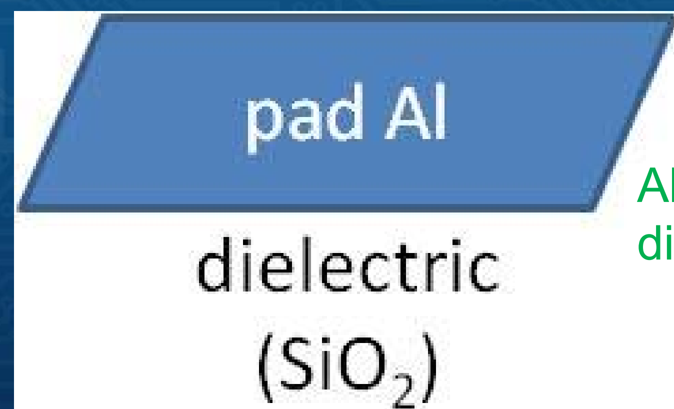


Circuit Under Pad (CUP)

"Traditional Bond Pad" is structurally weak



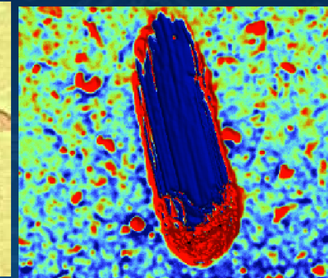
Cu-lowK CUP



Al over dielectric

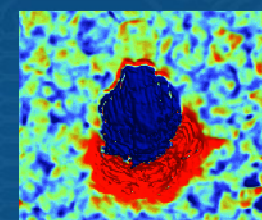
Example Cantilever Probe Marks

Example Cantilever Probe Marks



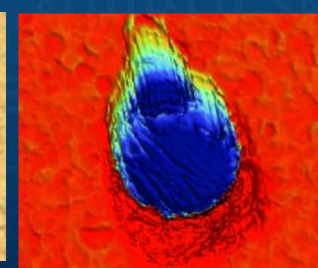
Probe tips

- Various shapes
- Small or large diameter
- Smooth or rough
- Low or high force
- Vertical or cantilever
- Scrubbing or no scrub



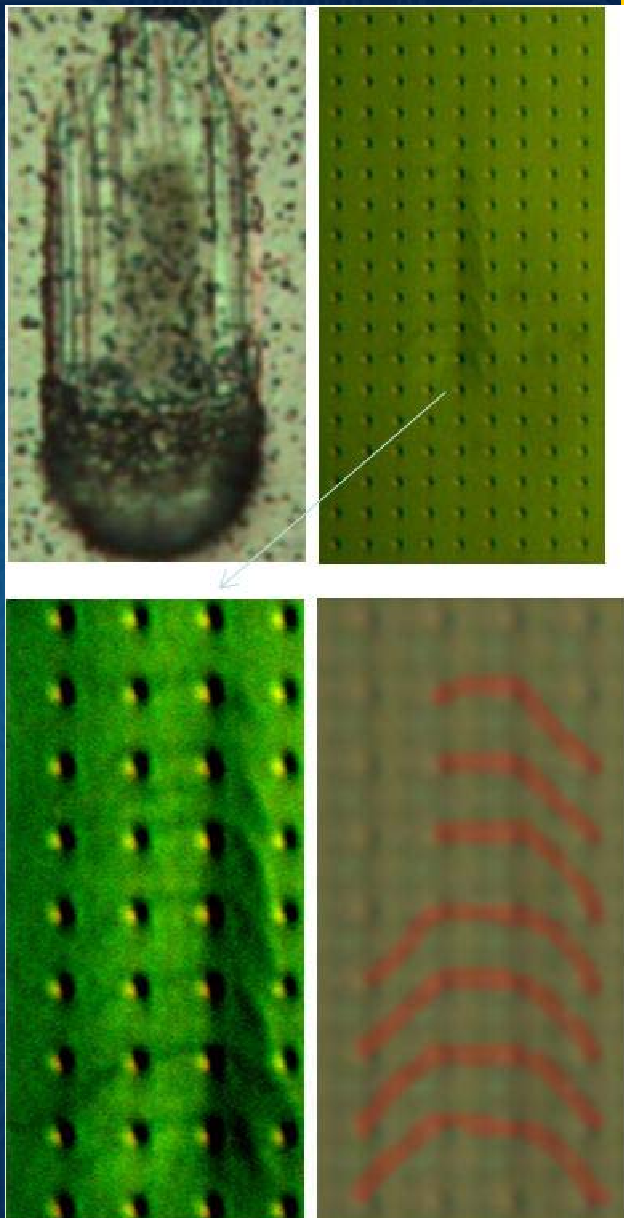
Bond pad

- Small or large pad size
- Thin or thick Al
- Other metals added instead of Al
  - *(out of scope for this presentation)*



Small Tip Cantilever Probe Damage

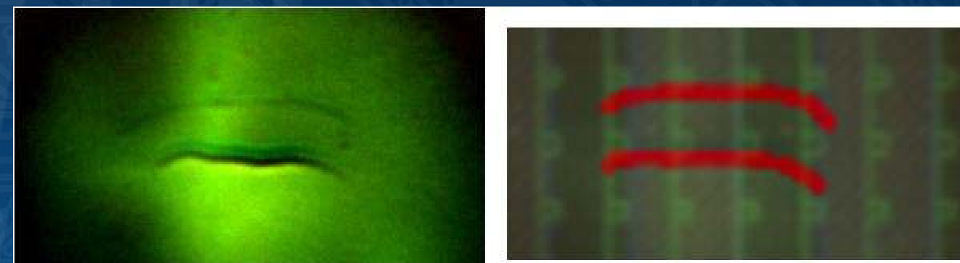
1



Pad Cracks and Sublayer Patterns

Probe
Direction

2



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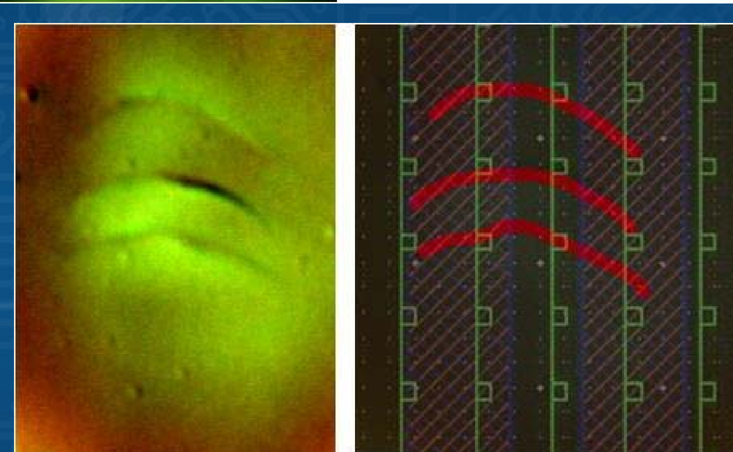

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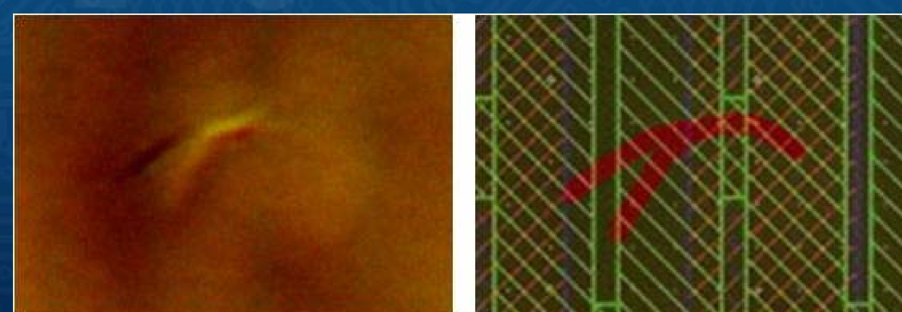
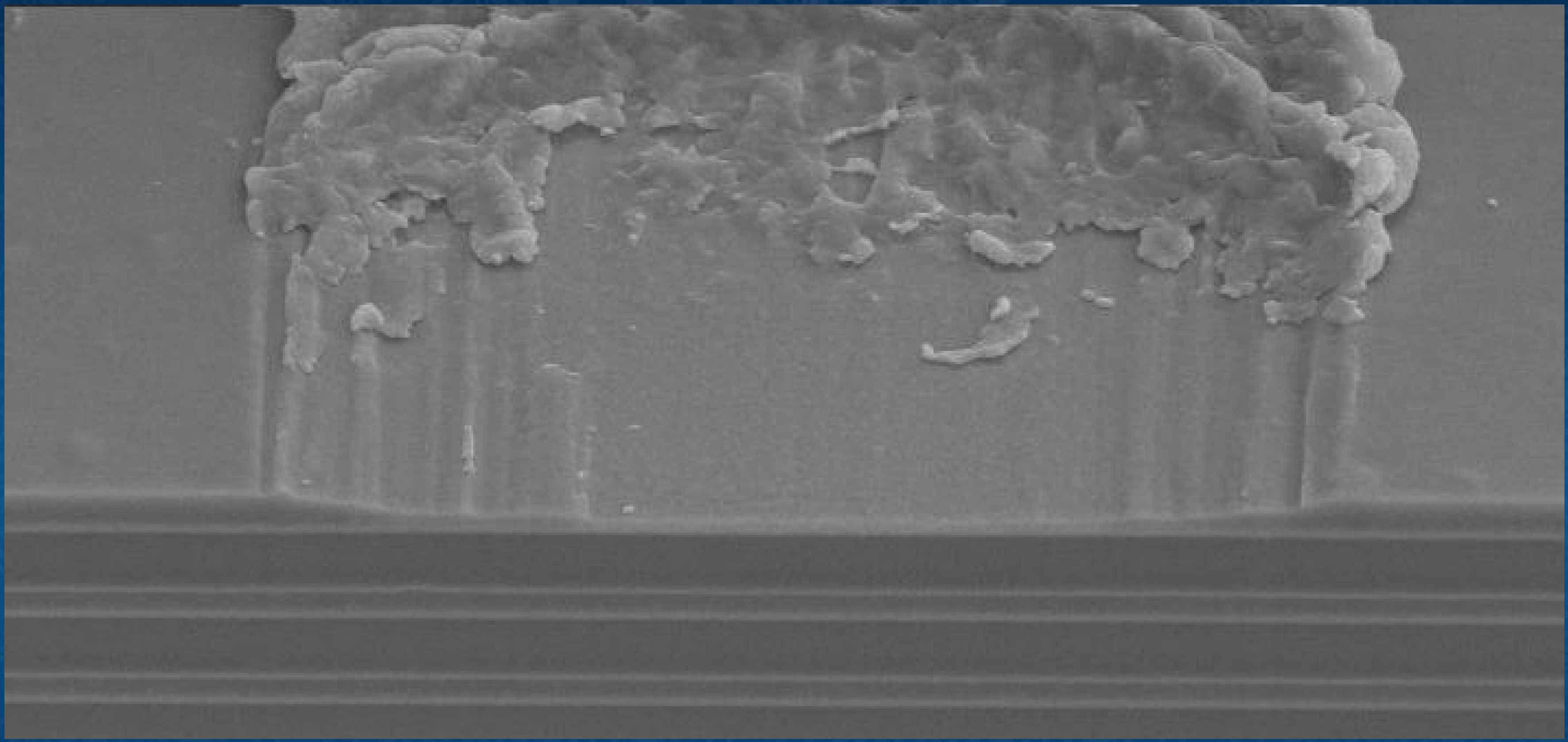


Hunter, Brown,
Wynder

FIB of Cantilever-Probed Traditional Pad



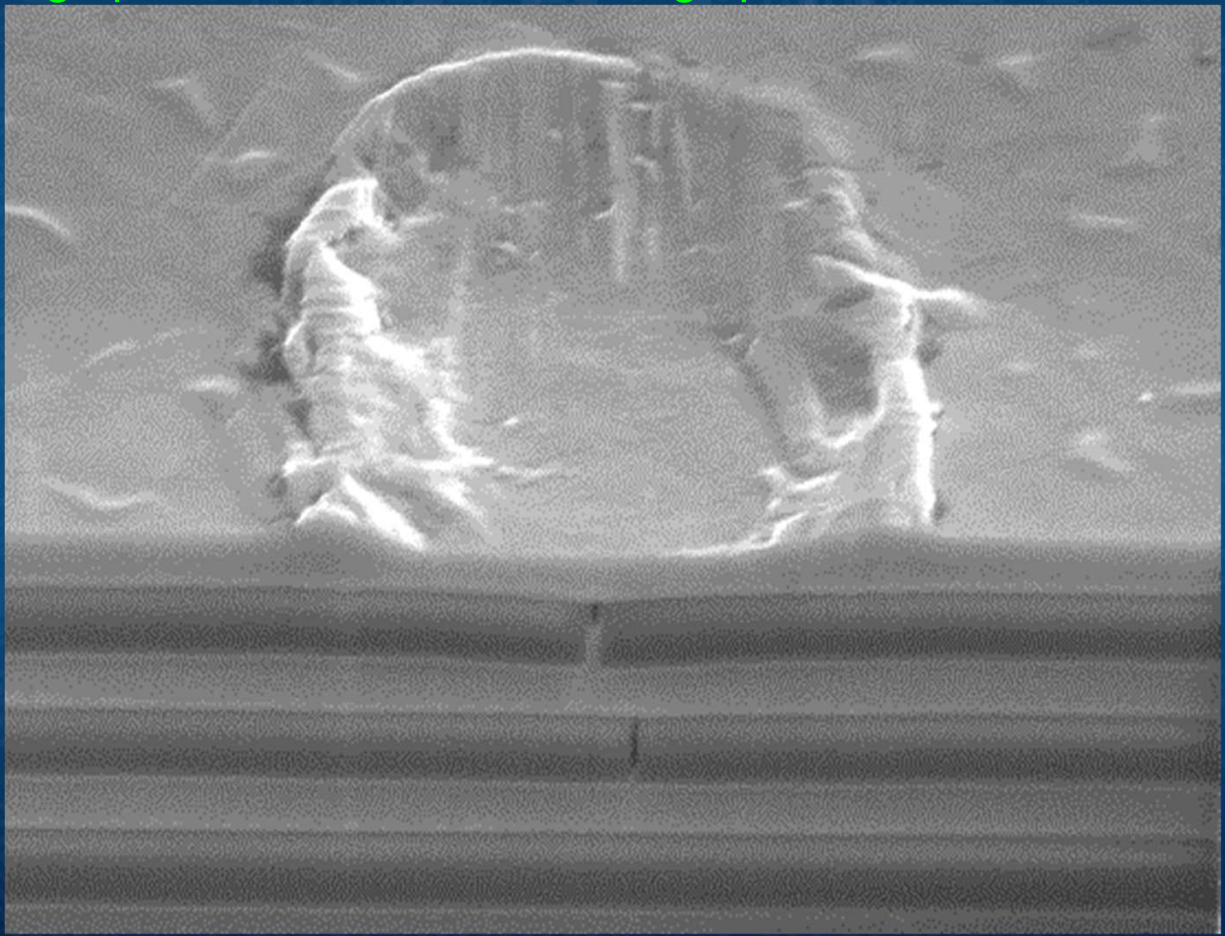
A focused ion beam (FIB) cross section through a harsh probe mark

- Almost no pad Al thickness remaining in the deep scrub region
- Displaced Al in the “prow” is not continuous and is somewhat oxidized
- High risk of sublayers deformation and cracks

FIB of Vertical-Probed Traditional Pad

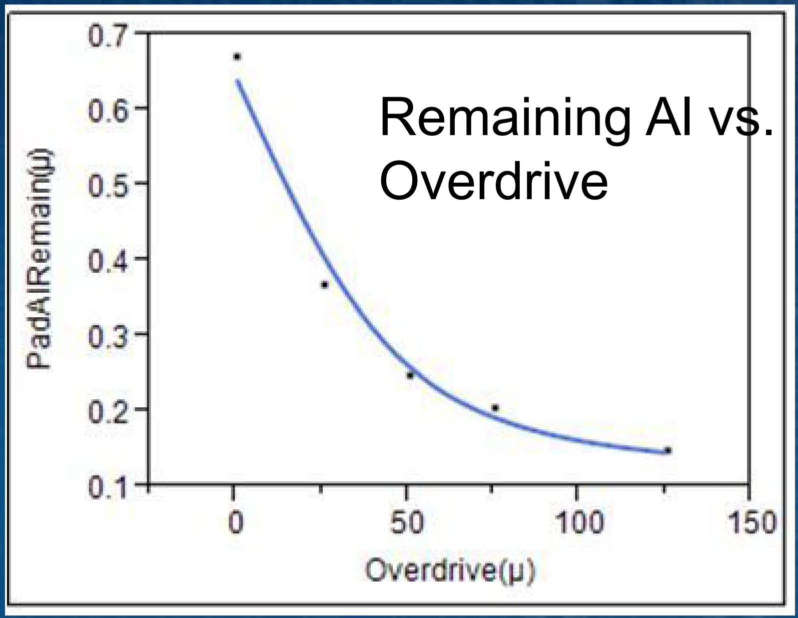
FIB through a harsh probe mark made by a vertical probe

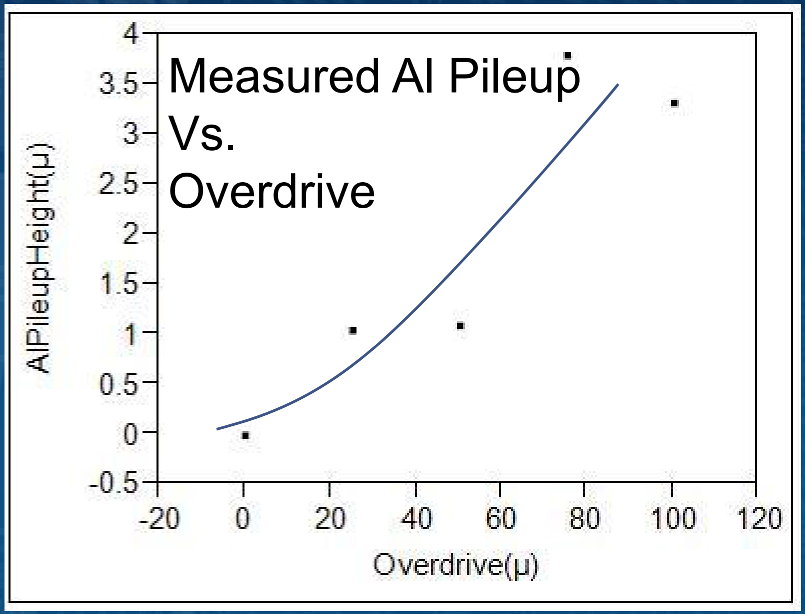
- Deep depression in pad Al, high "splash"
- Sub-layer films show local ripple and cracks
- Cracking in lower SiO_2 film is unusual, caused by the high pressure at small tip area
- Al extruding up in to the cracks due to high pressure

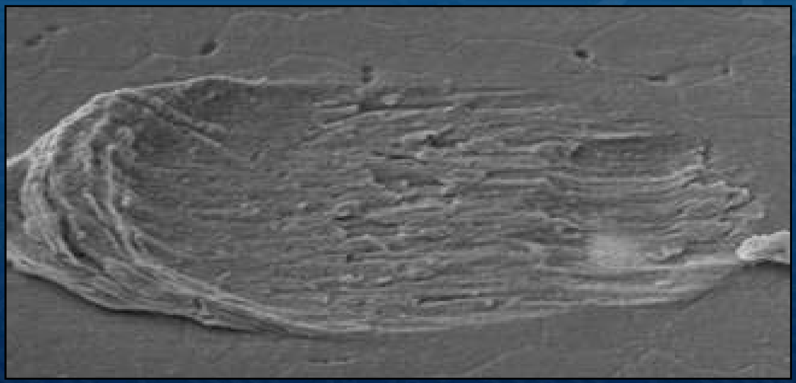


Pad Al Remaining, Prow Height

Overdrive on prober is the most significant factor for probe marks area and Al deformation







Hunter, Brown, Wynder

Summary of Probe Damage to Bond Pads

- **Probing causes issues on the pad Al surface**
  - Surface deformation
  - Probe mark area
  - Depth of gouge
  - Height of prow or splash

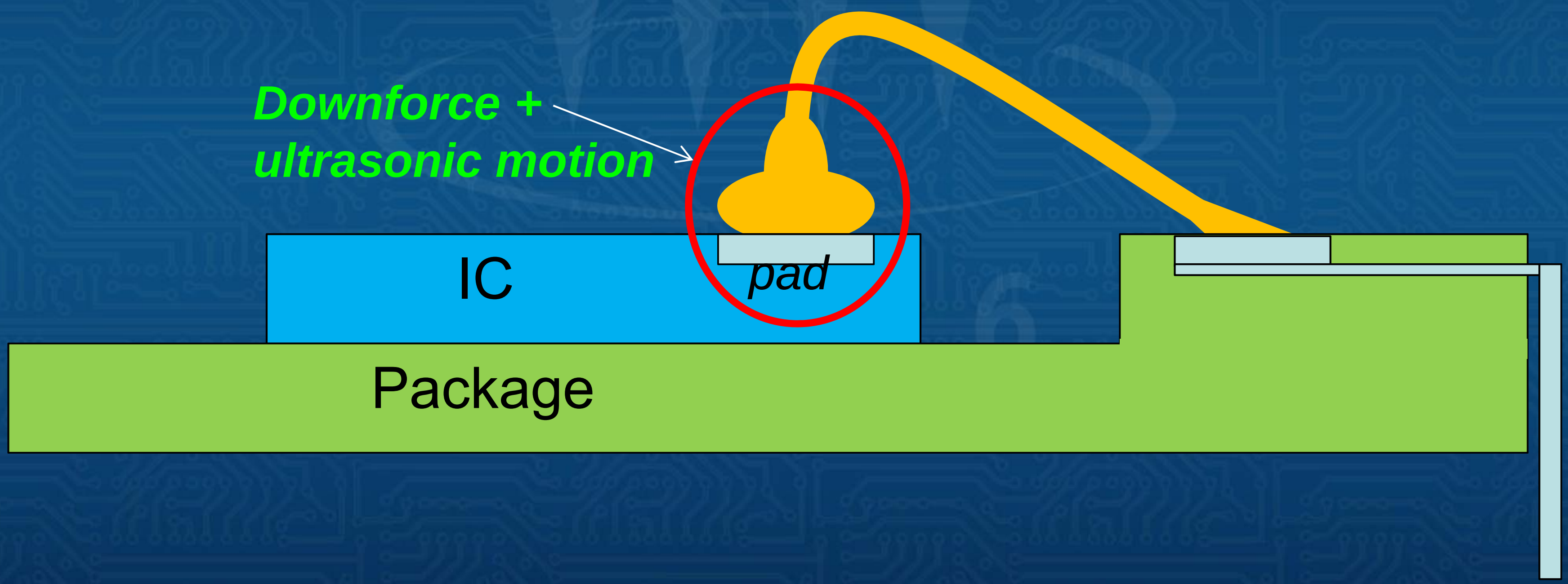
- **Probing can cause deformation and cracking in the pad sub-layers**
  - cracks increase for increased overdrive and touchdowns, or short probe tips
  - cracks decrease for thicker pad Al
  - traditional pad designs, especially with dense top vias, are the weakest structures in terms of resistance to crack formation
  - cracks are facilitated by the presence of a ductile material (Al) beneath SiO_2

Wirebonding on Al Pads

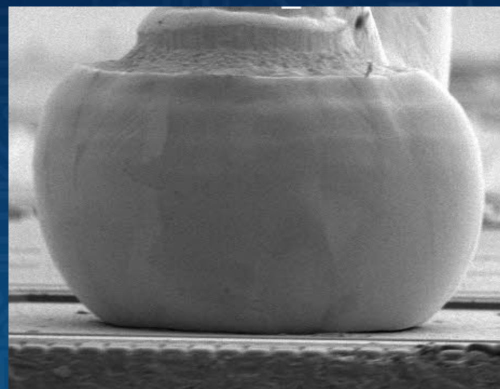
Au Wire Ball Bonding

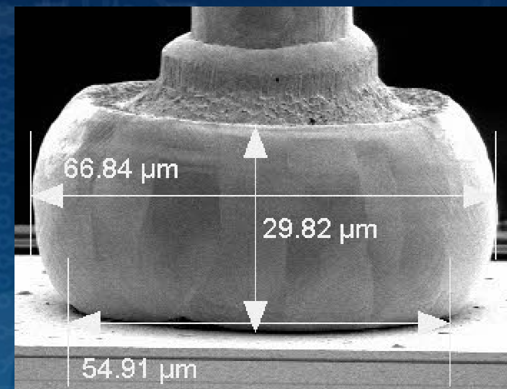
- A ball is formed at the end of a Au wire, then the ball is squashed onto the Al pad surface and welded by ultrasonic energy

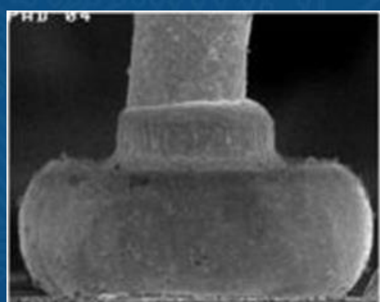
- The second bond of the same wire piece is a “wedge” bond

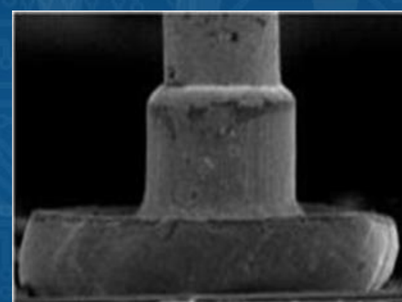


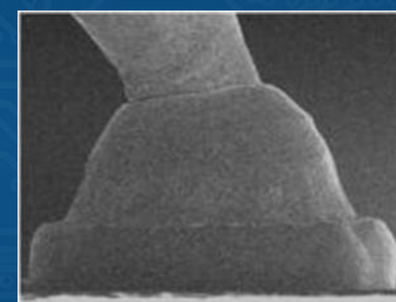
Bond Ball SEM Photos

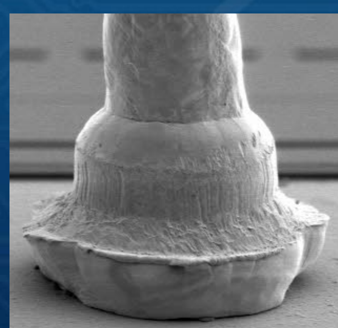


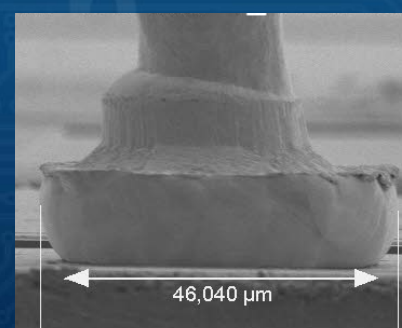












Ripple Effect from Wirebonding

Cratering Test after harsh ball bonding:

- Remove the ball bonds and the pad Al
- Inspect by microscope to look for "ripple", cracks, damage
- Large ripple implies cracks in sublayers

Traditional Pad (cracks easily) | Structurally robust pad (no ripple, no cracks) | Traditional Pad (cracks easily)

Bonding Cracks, after Crater Etch

Can’t see any ripple in these pads…

…these pads were actually cracked *due to severe ripple*

>> crater etch solution seeped into the cracks and etched away some sublayers!

Potential for damage in probing followed by wirebonding

Pad Cracking: *Unreliability* Process Flow

Wafer probe (electrical test) → **Wirebond** → **Packaging** → **Operation**

Wafer probe (electrical test)
1. Compressive stress from probe force
2. Lateral stress from scrub
3. Multiple touchdowns

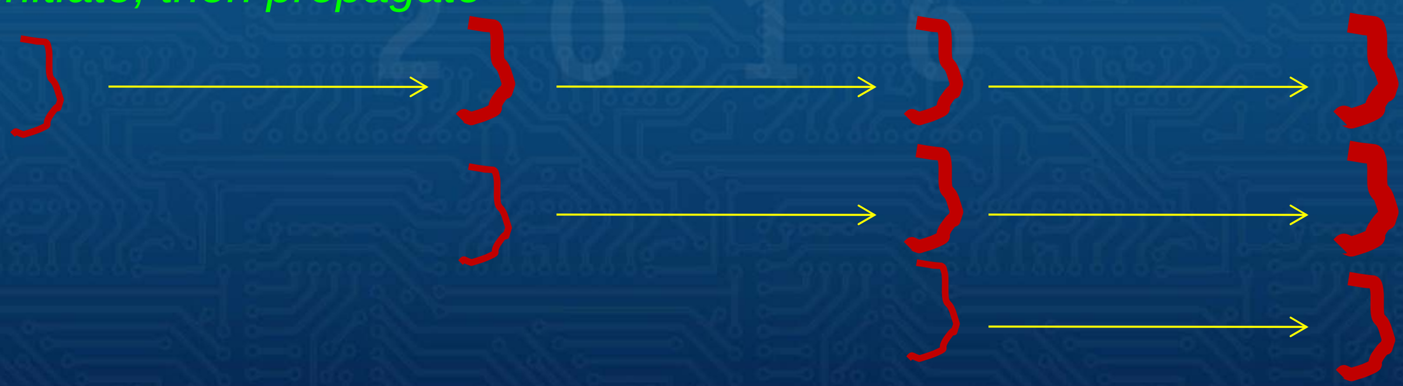
Wirebond
1. Compressive stress from C/V + downforce
2. Lateral stress from ultrasonic

Packaging
1. Thermal cycling
2. Stresses from packaging

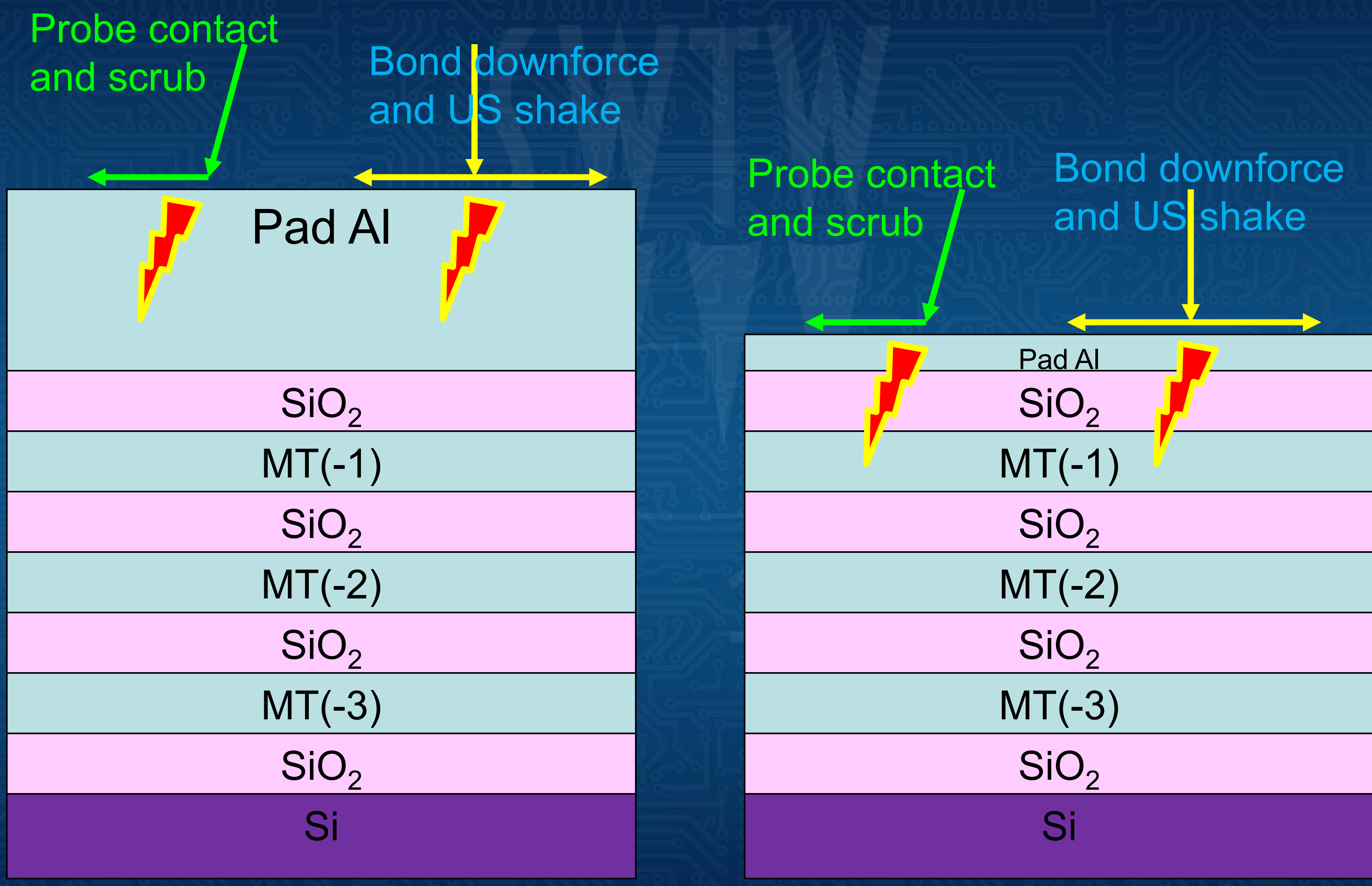
Operation
1. Use conditions
2. Thermal cycling

Cracks initiate, then propagate

(crack)



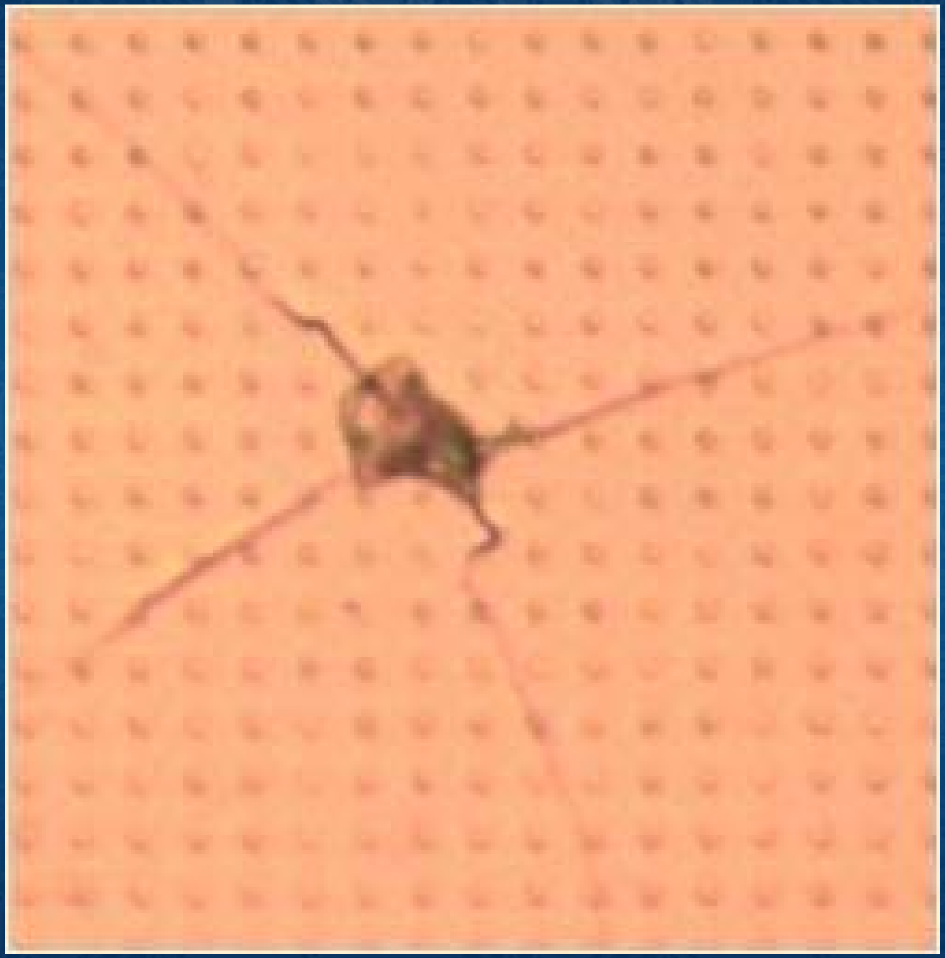
Thin Pad Al Reduces Bond Pad Margins



Wirebond Over Probe Cracks

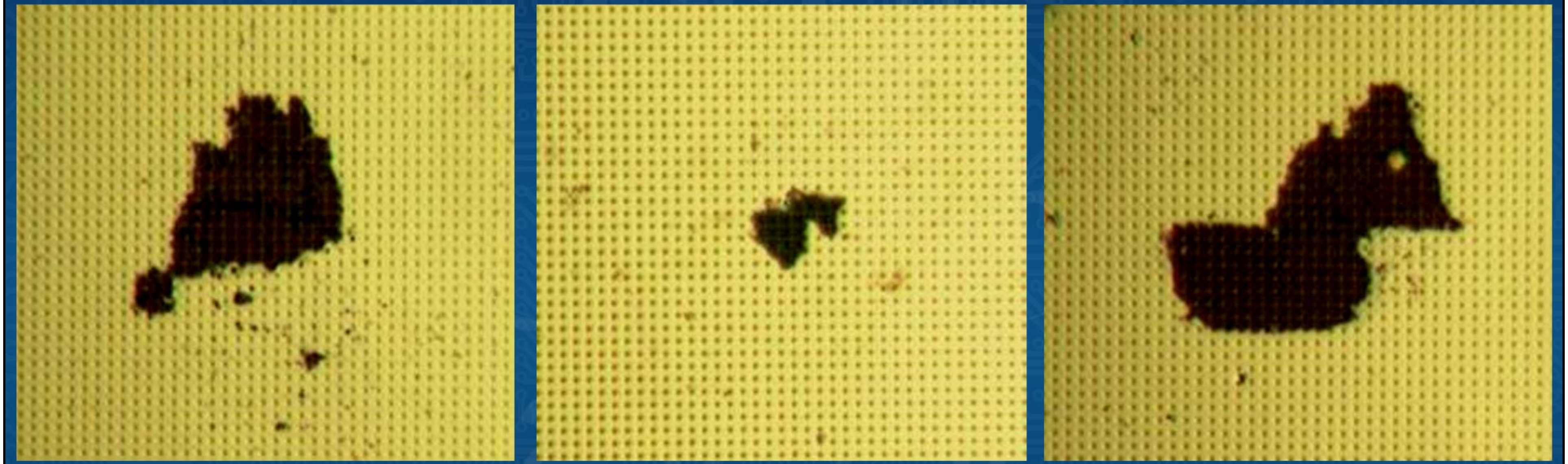
What happens to probe cracks during wirebond?

Probe Damage Propagated in Wirebond



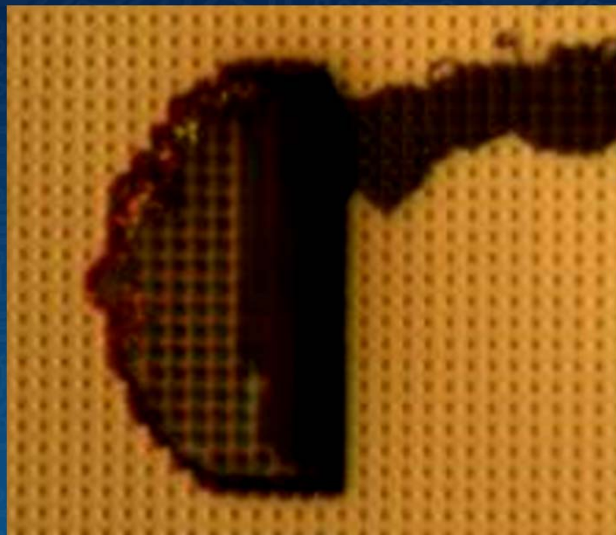
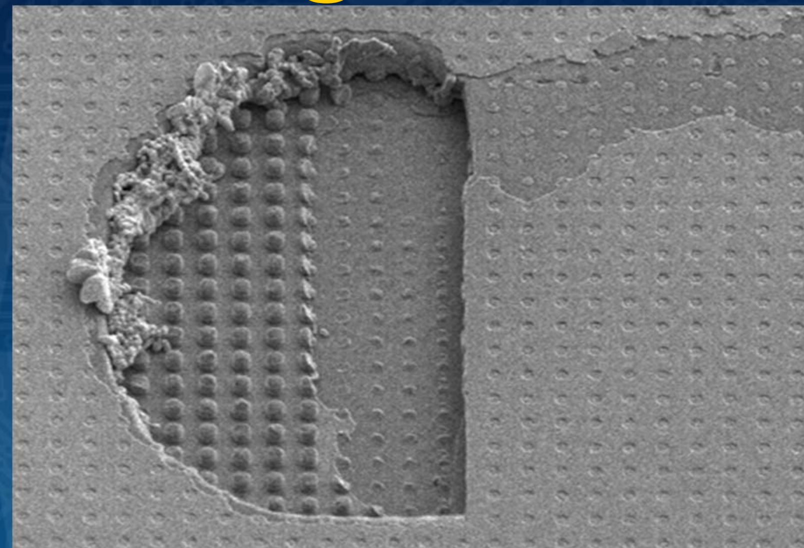
Additional Pad Damage Due to Wirebond

Probe damage, …after wirebond

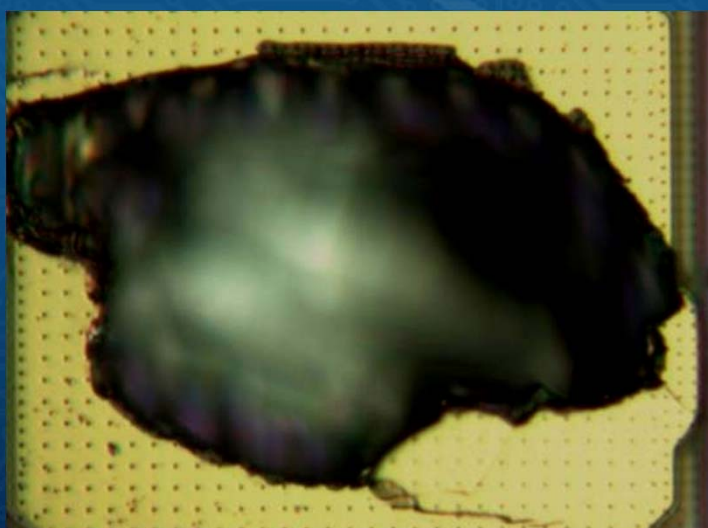
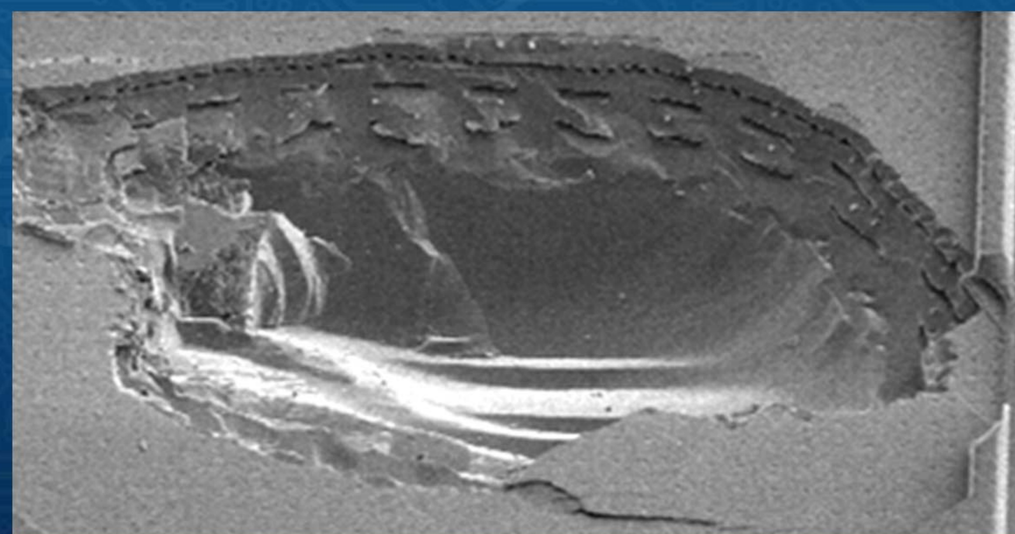


Cracking and sublayers lifting in the cratering test

Additional Pad Damage Due to Top

Probe damage, …after wirebond

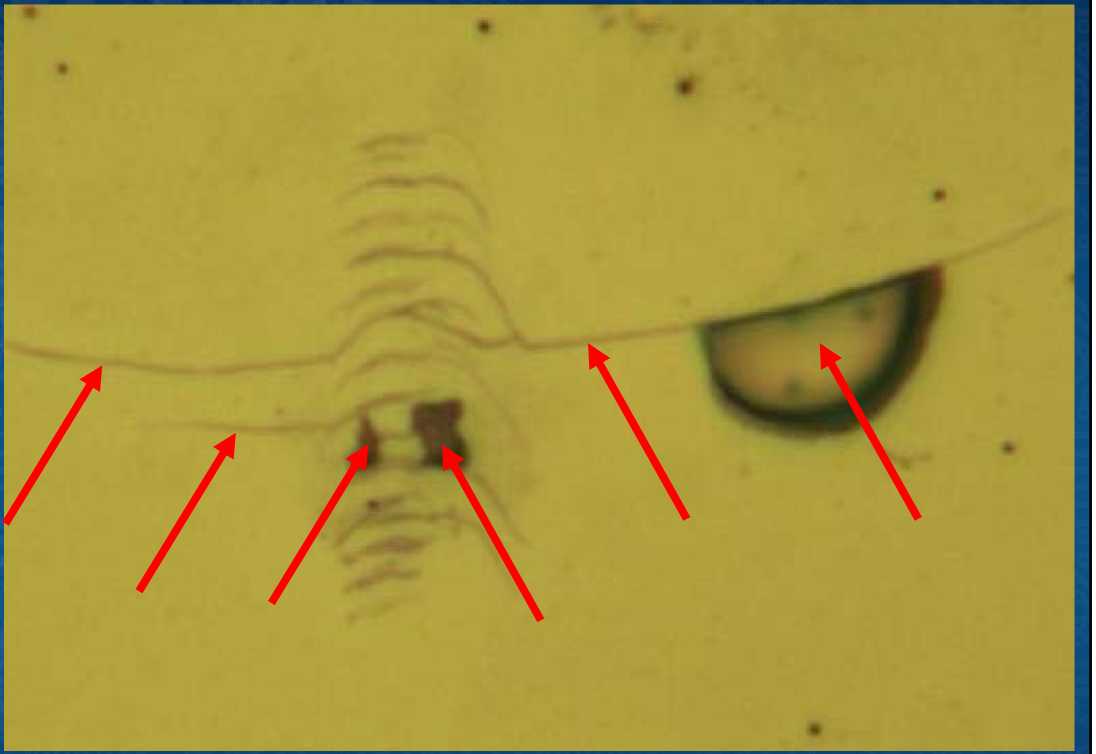
Probe Cracks, then more Cracks after Wirebond

Crater Test *after probe*

Crater Test *after bond*

Probe Cracks, then more Cracks after Wirebond

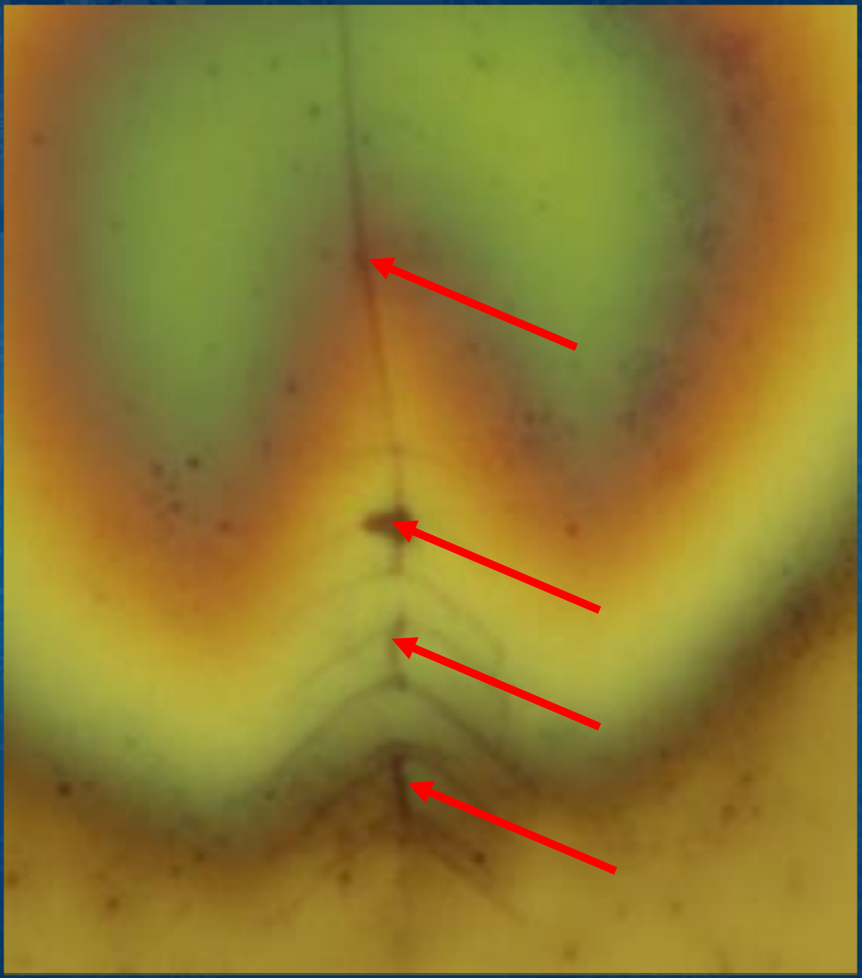
Crater Test *after probe*



Crater Test *after bond*

Probe Cracks, then more Cracks after Wirebond

Crater Test *after probe*



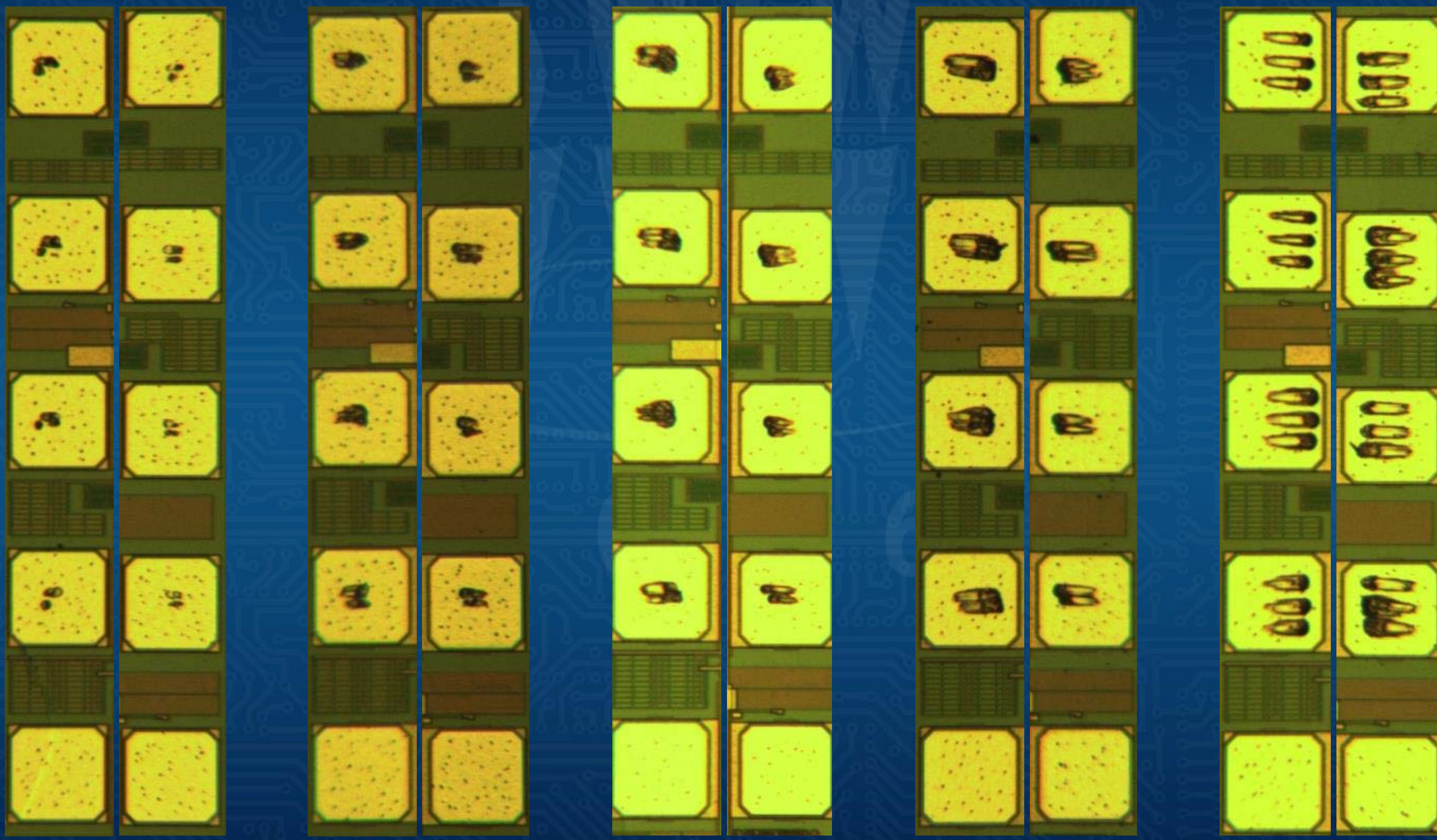
Crater Test *after bond*

Au Wirebond Over Probe Marks

"Detune" the Au wirebond process to reveal the probe mark effect on bond pull strength

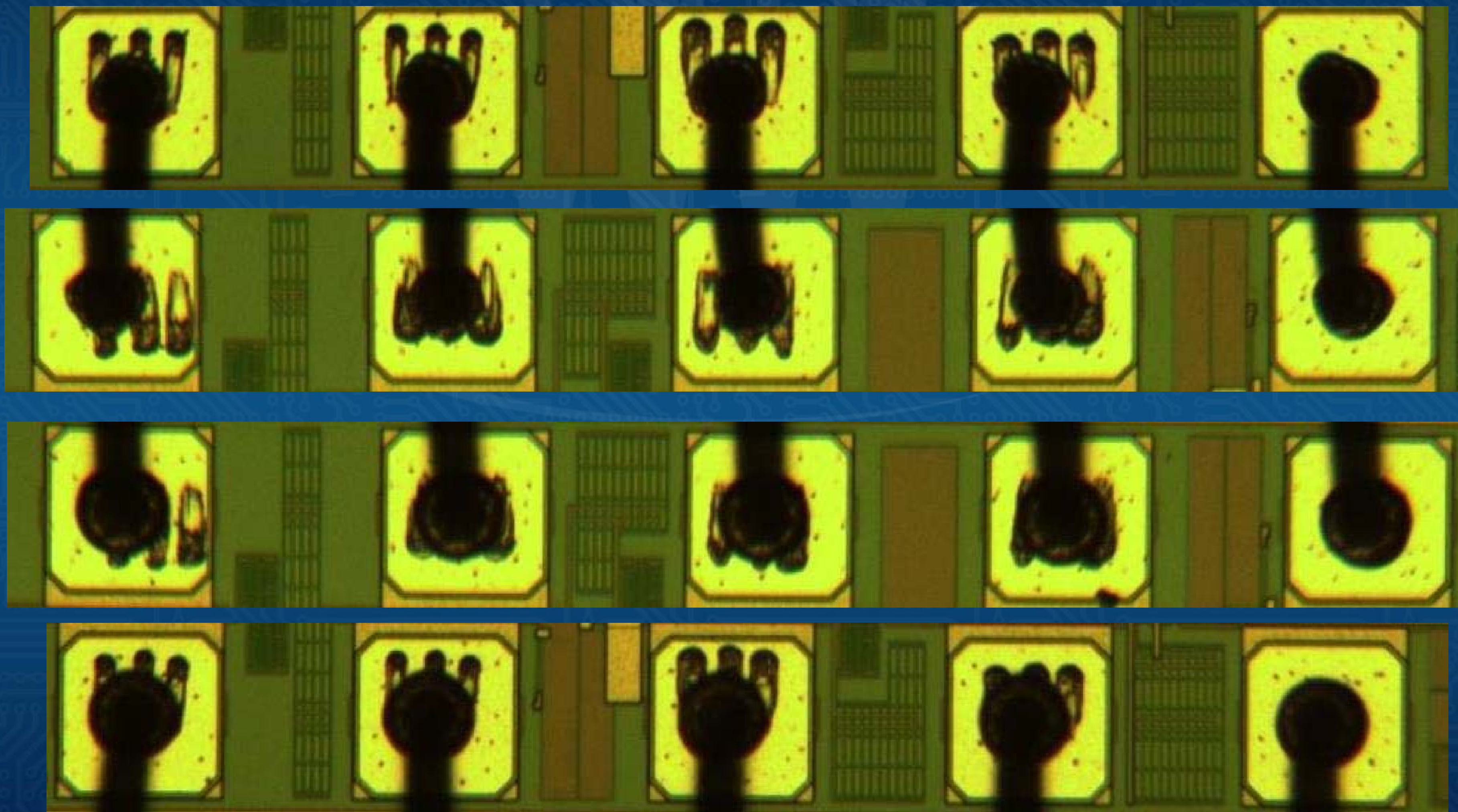
A Variety of Probe Marks

- Au wirebonds in 2 different ball diameters will be bonded over these marks

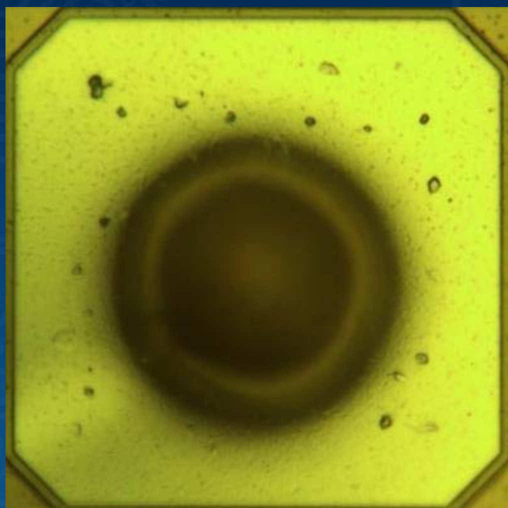


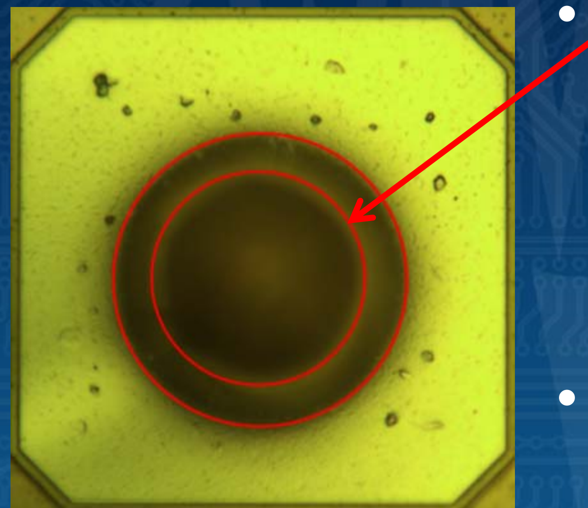
Au Ball Bonds over Probe Marks

- Reduced ultrasonic energy on some bonding to “detune”
- Bonds slightly more susceptible to “ball lift” in pull test

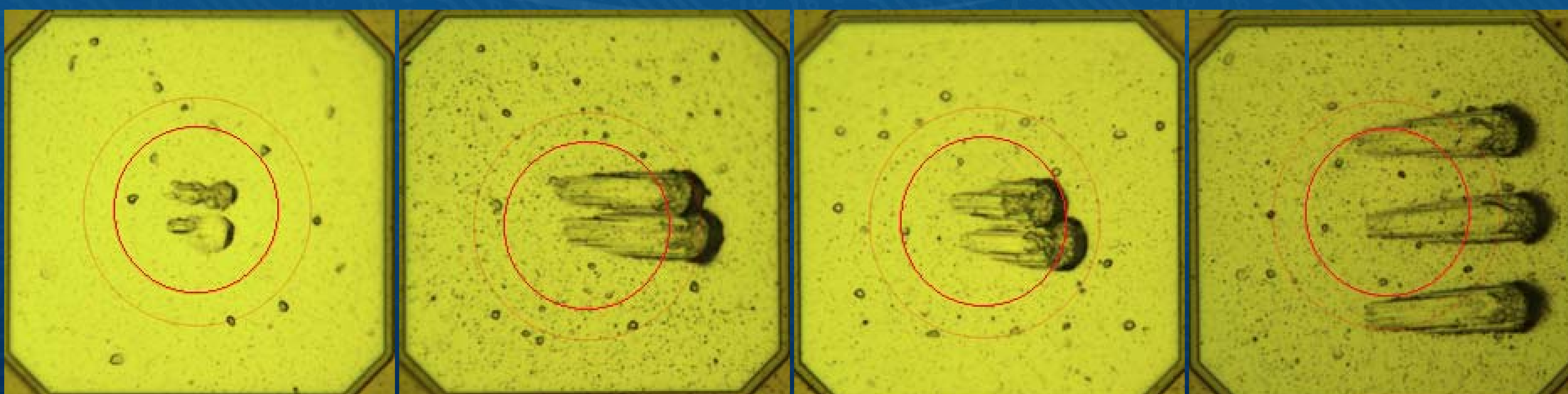


% Bond Contact Area Measurement



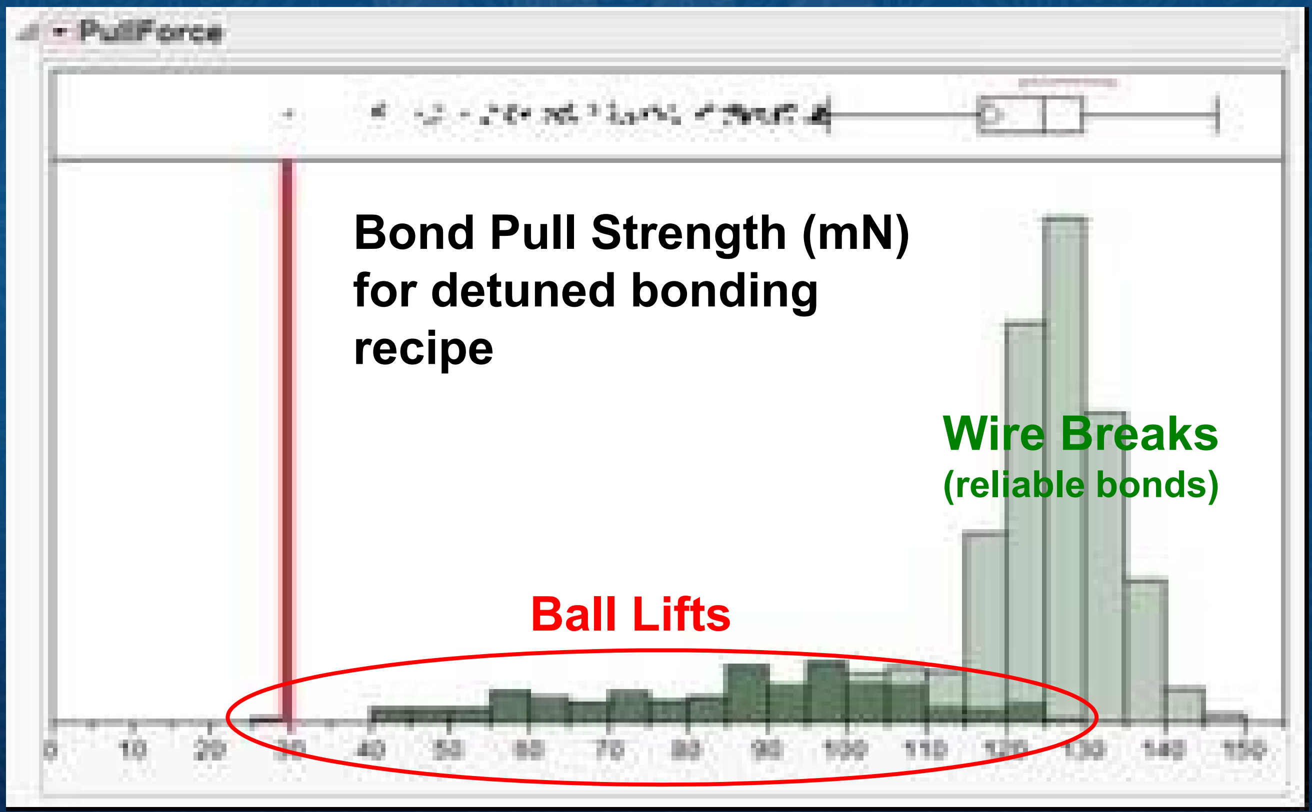


- Inner circle is an estimate of the contact area, drawn on the optical microscope photo
- For each pad, estimate the area of bond contact on the probe marks



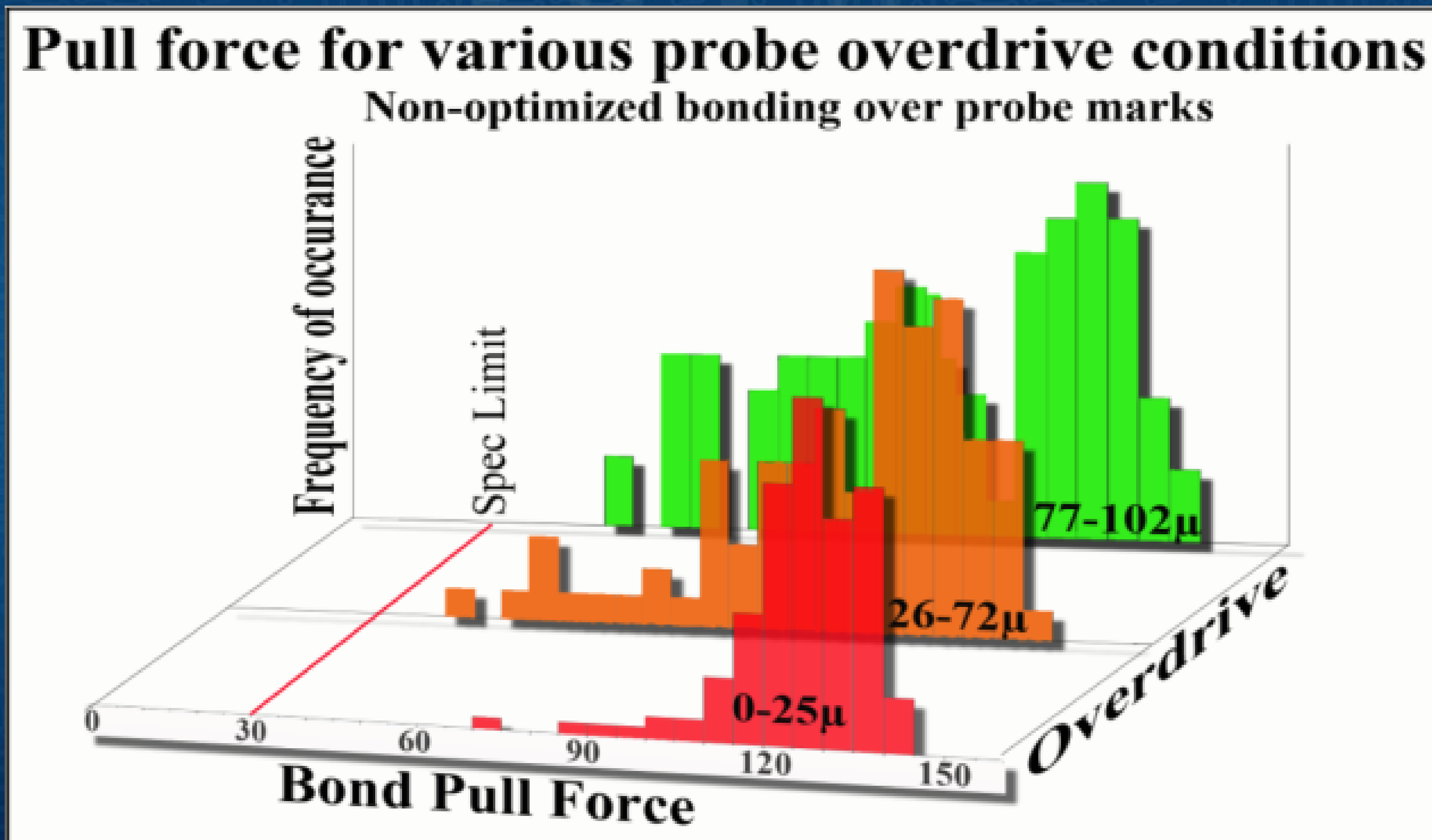
Au WireBond Pull Strength (mN)

- No ball lifts for standard Au wirebond
- Some ball lifts on detuned bonding recipe, over probe marks



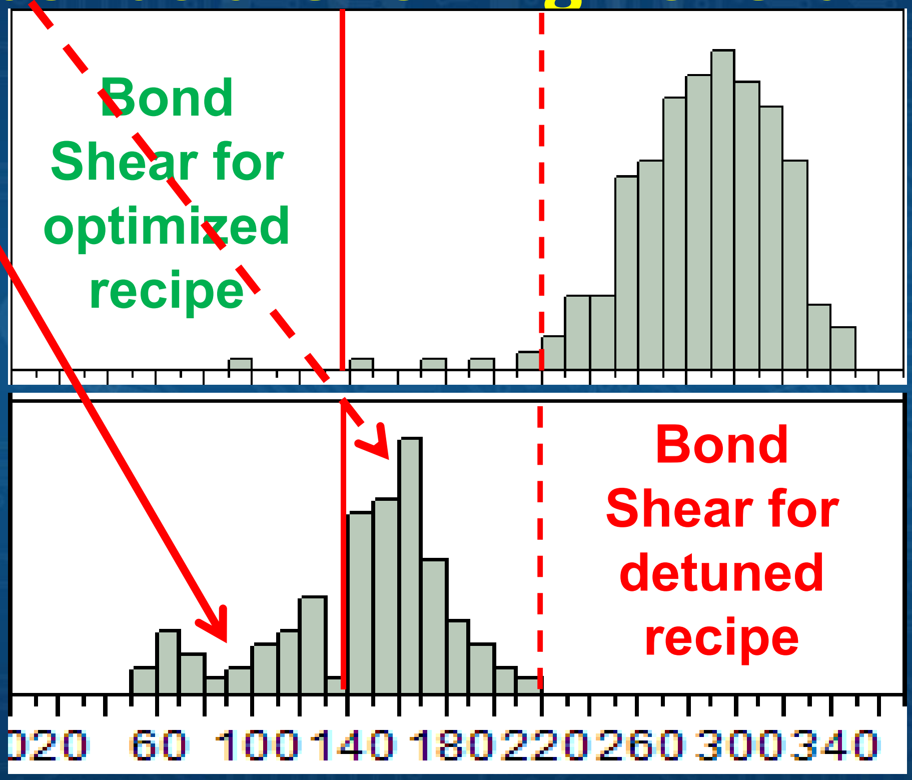
Au Wirebond Pull Strength (mN)

- **Increasing Ball Lifts with higher probe overdrive, due to larger, deeper marks**



Au Wirebond Shear Strength (mN)

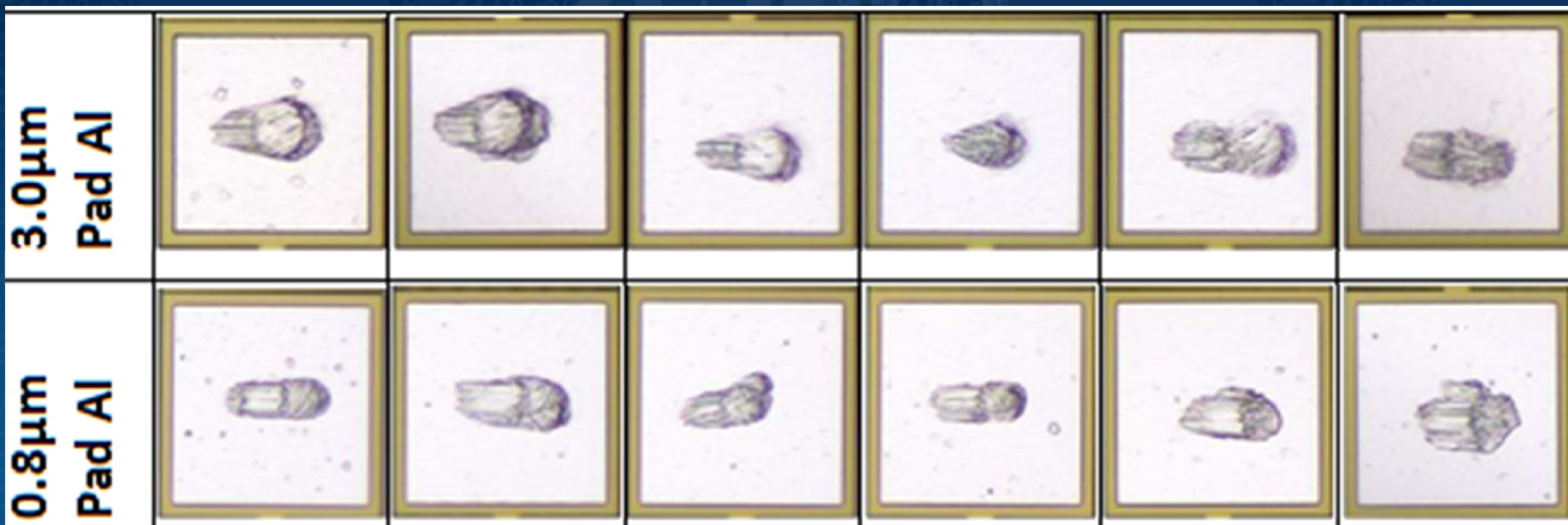
- **Weaker bonds on un-optimized recipe over probe marks**
- **Weakest bonds are for high overdrive values**



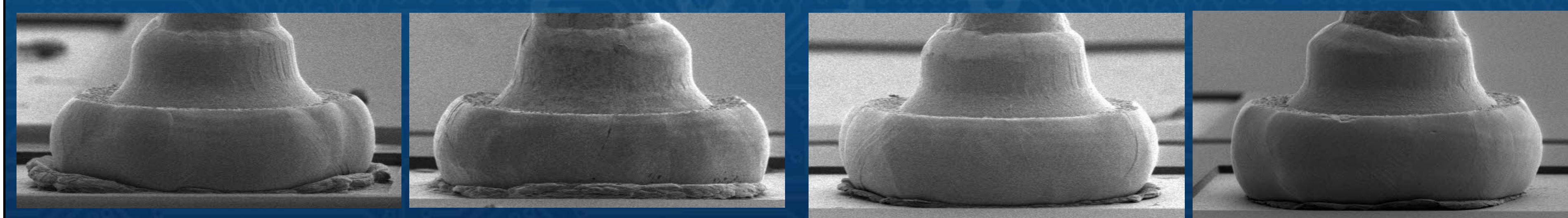
- For a detuned Au wirebond process, bonds are unreliable
- ***Au bonds over invasive probe marks are weakest***

Cu Wirebond over Probe Marks

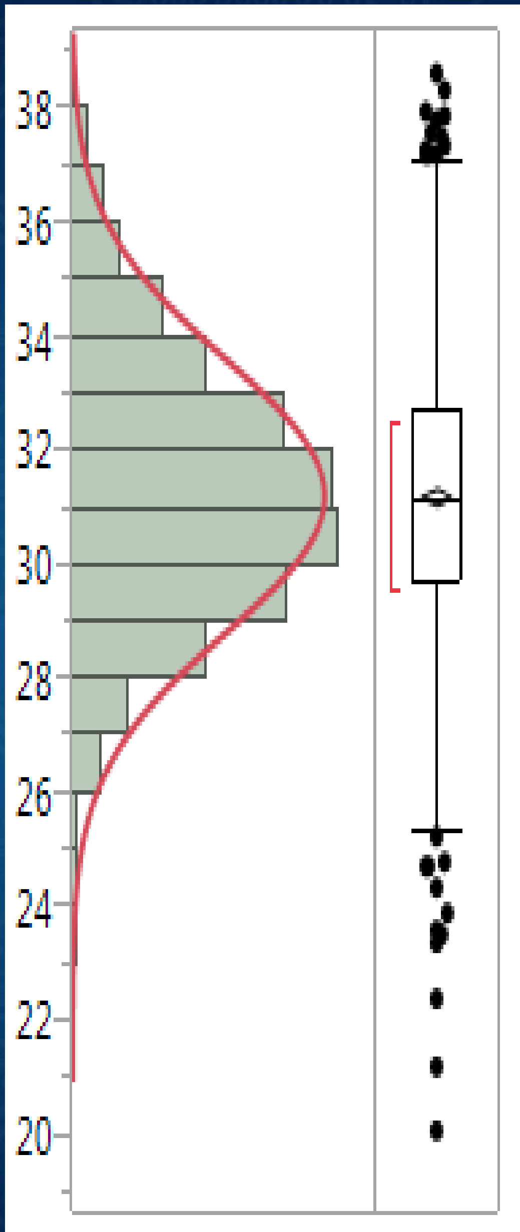
Probe Marks in 2 Pad Al Thicknesses

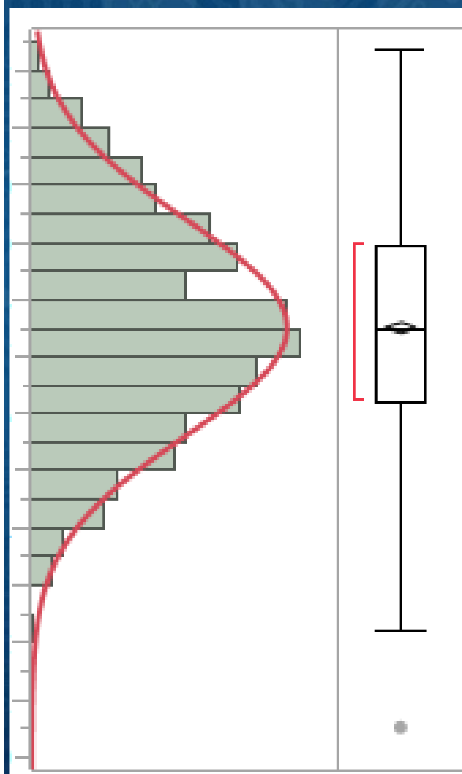


Cu ballbond profiles on thick, and thin pad Al



Shear Test Distributions on Thick and Thin Pad Al





- **3.5 gF lower shear values on thin pad Al for same bonding recipe**
  - About 11% less strength
- **Assume high energy ultrasonic required for thick pad Al is too high for the thin Al**

Other Shear Test Results for Cu Bonds

Summary from measurements of Cu wirebonds on *thick pad Al*:

- **It matters whether the shear force is *parallel or perpendicular* to the bonding ultrasonic vibrations**
  - About 3.5% less strength when shear testing parallel to the ultrasonic direction
- **The presence of an invasive probe mark further weakens the shear strength *when the scrub is parallel with the ultrasonic***
  - Large area, deep marks and high prows contribute to low shear values
  - Shearing from the “prow” side is worst, suggesting that the prow region is the weakest part of the bond
- **Small probe marks, and probe marks on thin pad Al in general had no effect on Cu wirebond shear strength in this experiment**

Summary of Probe Effects on Wirebonding

Based on research of BYU-Idaho students and ON Semiconductor:

- **Wafer probing can cause cracking in bond pad sublayers**
  - Especially when tip exerts high pressure on the pad
  - Some bond pad structures are more robust to cracking than others
  - Cracked bond pad is less reliable mechanically
- **Wirebonding over cracked bond pads causes crack propagation and may lead to cratering**
  - Cracks from wafer probe become worse from wirebonding
  - Pad structure weakening due to probe damage can become cracks during wirebond

Summary of Probe Effects on Wirebonding, cont

Based on research of BYU-Idaho students and ON Semiconductor:

- **Probe marks can cause weaker Au wirebonds**
  - Demonstrated clearly using "detuned" Au wirebond recipe
  - Large, deep marks with high prows have largest effect
  - *Did not observe any effect from small probe marks*
- **Probe marks can cause weaker Cu wirebonds**
  - Demonstrated with bond over marks on thick pad Al
  - Large area marks with high prow are worst
  - Adverse effect is most observable for large scrub marks when wirebond ultrasonic is parallel to the scrub, with shear test also parallel
  - *Did not observe any effect from small probe marks*

Conclusions

1. **Reliable wirebonds require low pressure, low deformation probe marks**

2. **Bond pad structure and pad Al thickness are important factors, along with good wirebonding recipe**

References
(Selected BYU-Idaho & ON Semiconductor research)

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