A Novel *In-situ* Methodology to Characterize Bond Pad and Dielectric Mechanical Behavior during Wafer Level Test

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Outline

- Objectives
- Background
- Approach
- *In-situ* Methodology Development
- Application of Methodology
- Summary

Objectives

- **Develop a methodology to assess the *in-situ* mechanical behavior of a bond pad metal stack**
  - Evaluate the elastic and plastic deformation of bond pads during wafer level testing
  - Determine the deformation limits of the low-k dielectric layers
    - Impact of bond pad reinforcement structures
    - Impact of various bond pad metals
- **Visualize the probe process in real-time as the probe tip scrubs across a bond pad**
- **Correlate the probe scrub action with contact resistance, overtravel, and applied strain**

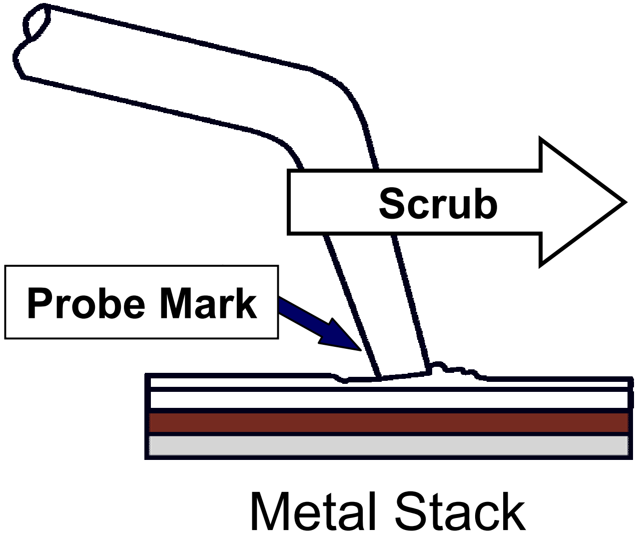
Background

- **Semiconductor device development and scaling**
  - Conversion from aluminum to copper traces and from SiO_2 to lower dielectric constant materials
  - Metal stack is a complex multi-layered “sandwich” of metal conductor traces and insulating dielectric materials
- **Potential for damage during fabrication, probe, and assembly may cause long term reliability issues**
  - Low-k materials tend to be fragile and susceptible to damage
    - FSG, k~3.3: Modulus 50GPa
    - HSQ, k~3.1: Modulus 4GPa
- **Knowledge of the dielectric / metal stack characteristics and acceptable damage limits are critical**
  - Defining wafer level test practices of advanced IC technologies
  - Synergy between test and assembly, i.e., optimized probe practices facilitate improved assembly yield

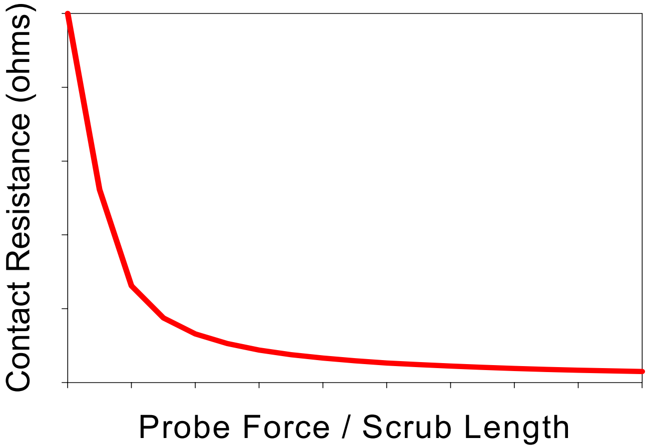
Background (cont.)

- Overtravel is required to reduce contact resistance (CRES) to an acceptable level during test
- At the end of overtravel, a small contact area imparts large stresses on the bond pad and the dielectric stack
  - Applied stress can be 75-400 MPa range for various tip sizes (0.6mil – 1.2mil) using 64um overtravel, 1.75BCF card

Probing an Al-Bond Pad

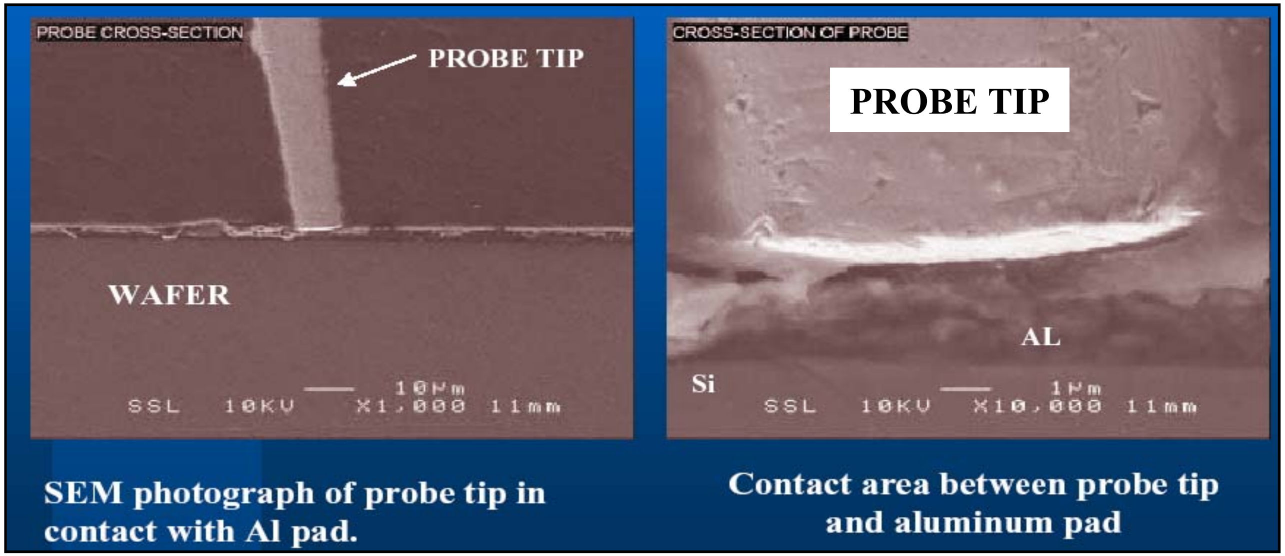


CRES During Probe



Background (cont.)

- *In-situ* visualization of the “scrubbing action” during wafer test is extremely difficult
  - Previous work used an SEM approach with an embedded probe



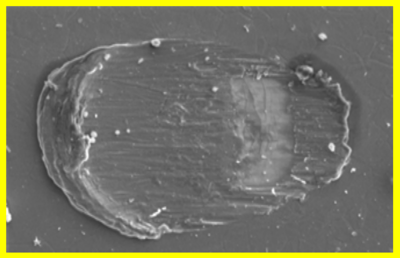
SEM photograph of probe tip in contact with Al pad.

Contact area between probe tip and aluminum pad

Kister, et al., 2000

- Want to correlate REAL-TIME in-situ “scrubbing action” with CRES

Background (cont.)



- **Current methods of assessing dielectric damage**
  - “Lab Tests” that vary the probe conditions

    PROS
    - High volume, statistically relevant sample size easily generated
    - Easy to generate data on variety of materials (full flow, blanket films)
    - Easy to extrapolate data to test floor

    CONS
    - Data analysis tedious and time-consuming
    - Dielectric cracks can be difficult to identify on fully processed material and correlate to probing conditions
    - “Production” may have weaknesses not uncovered by “lab tests”
    - High % uncertainty due to wide std .dev. (wide range probe specs)
  - FEM

    PROS
    - Can run new “test conditions” without generating new Si

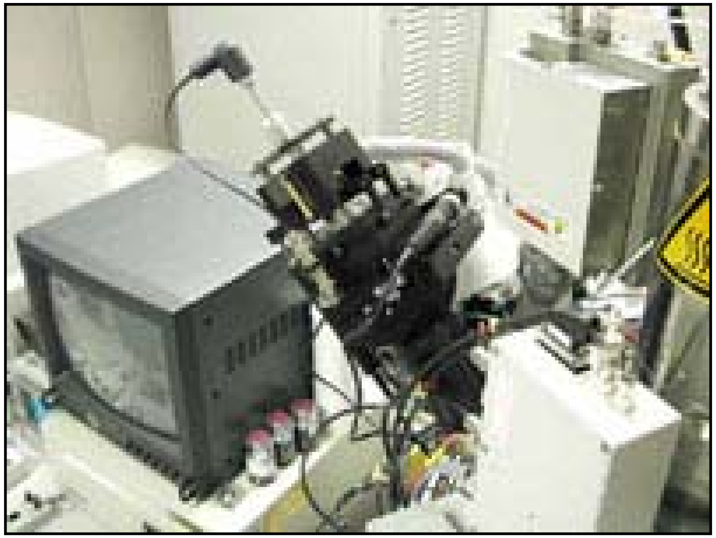
    CONS
    - Model only as good as the input variables.
    - Often relies on data provided by mechanical tests of dielectric films

Approach

- **Utilize the capabilities of the Omniprobe Analytical Tool**
  - Micromanipulator enabled for vacuum environments
  - Configured for mechanical tests using various tungsten probe tips
  - Electrical test resistance and contact resistance
  - Real time video image capture in a Focused Ion Beam (FIB) instrument
  - Applied strain sensing / load monitoring

Omniprober Model 100.5

Omniprober mounted on FEI DB235 FIB



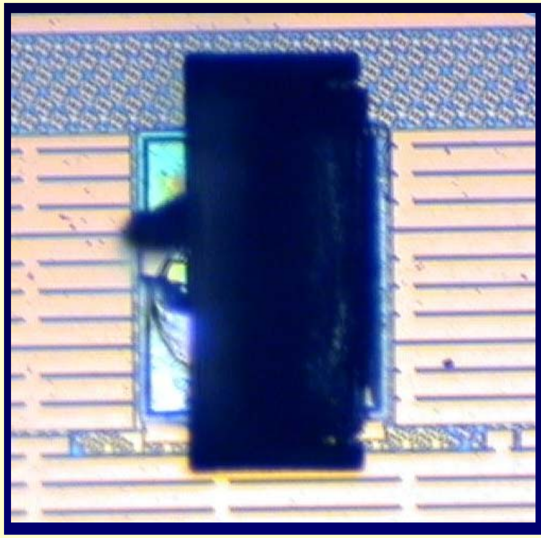
Approach (cont.)

- **Video capture and still images**
  - Scanning Electron Microscope (SEM) videos synchronized with overtravel experiment
  - Experiments conducted within single beam FIB instrument
  - High resolution SEM images at critical points
- **Overtravel and Fixturing**
  - Precise 3-D translational control
  - Customizable “test probe” holding fixtures
- **Electrical Resistance**
  - Electrical continuity detection
  - Contact resistance monitoring
- **Strain sensor**
  - Applied probe force monitoring
  - High sensitivity to loading changes
- **In-Situ “Lift-Out” for Transmission Electron Microscope (TEM)sample prep and inspection**
  - Determine presence of material cracking
  - Reliable, site-specific capability of the Omniprobe tool

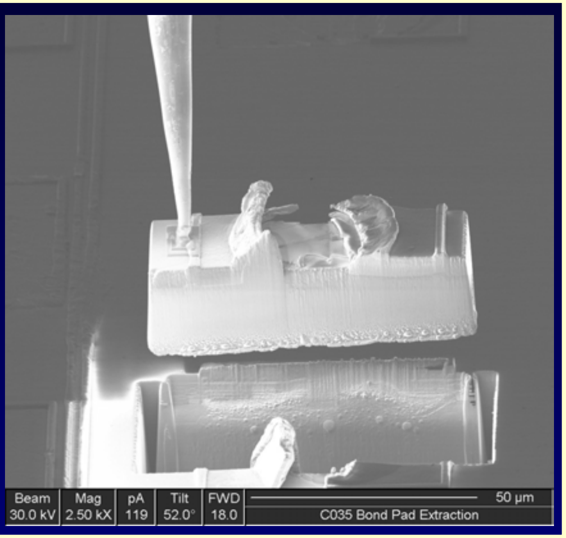
Approach (cont.)

- *In-Situ* Lift-Out to assess dielectric stack cracking

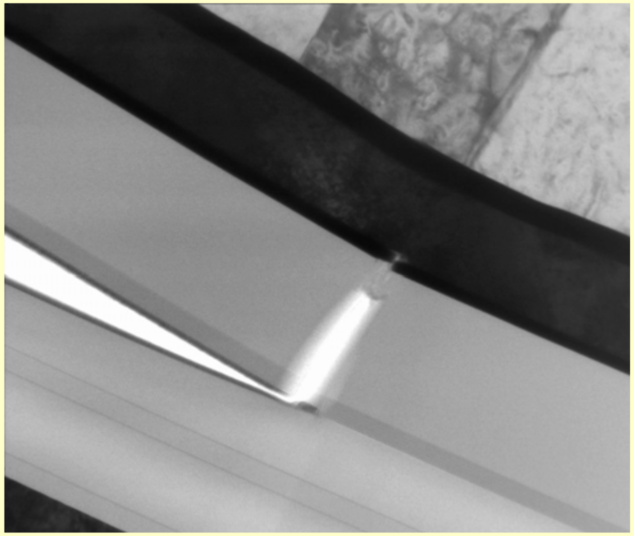
65um wide section removed by lift-out method → TEM Inspection



Optical image



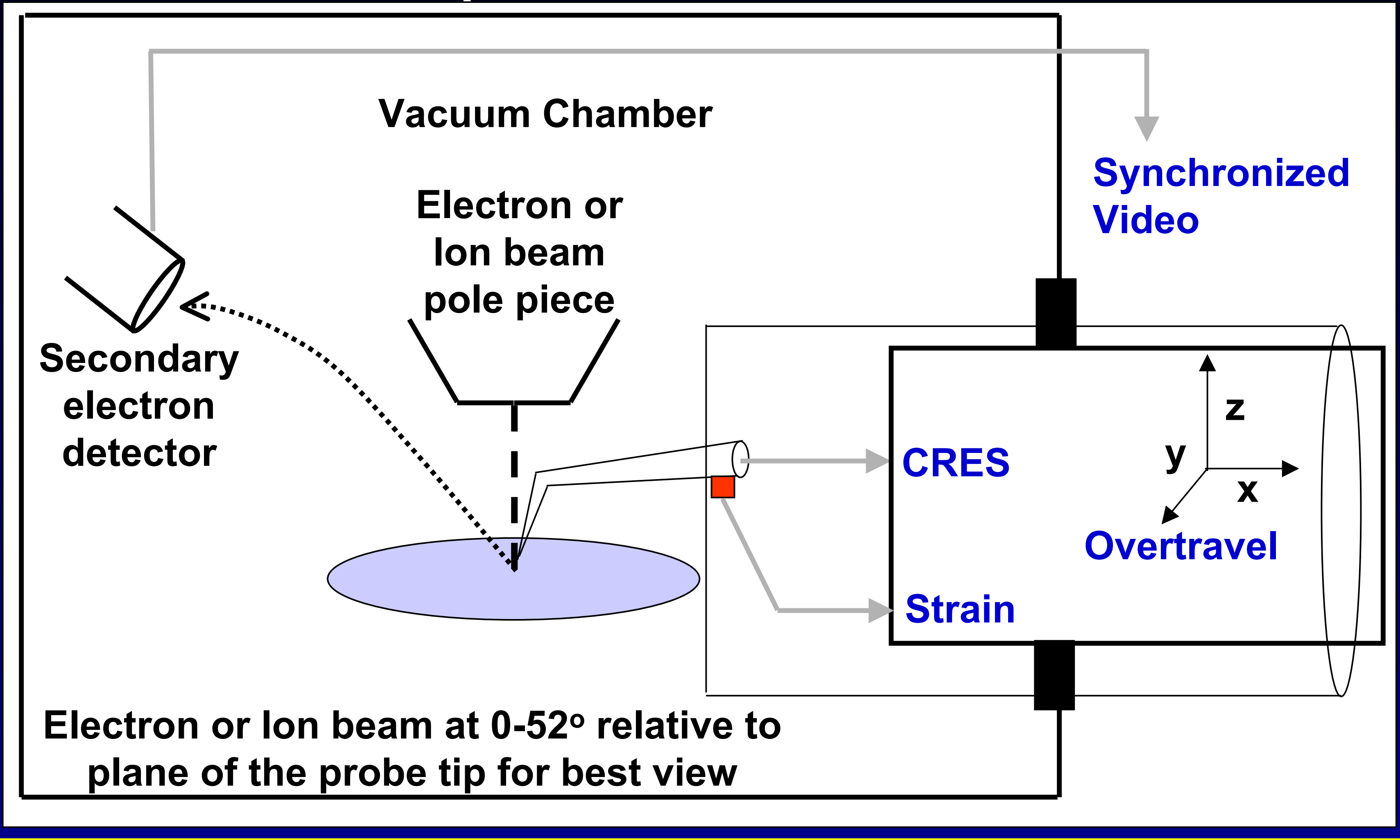
FIB image



TEM image

Approach (cont.)

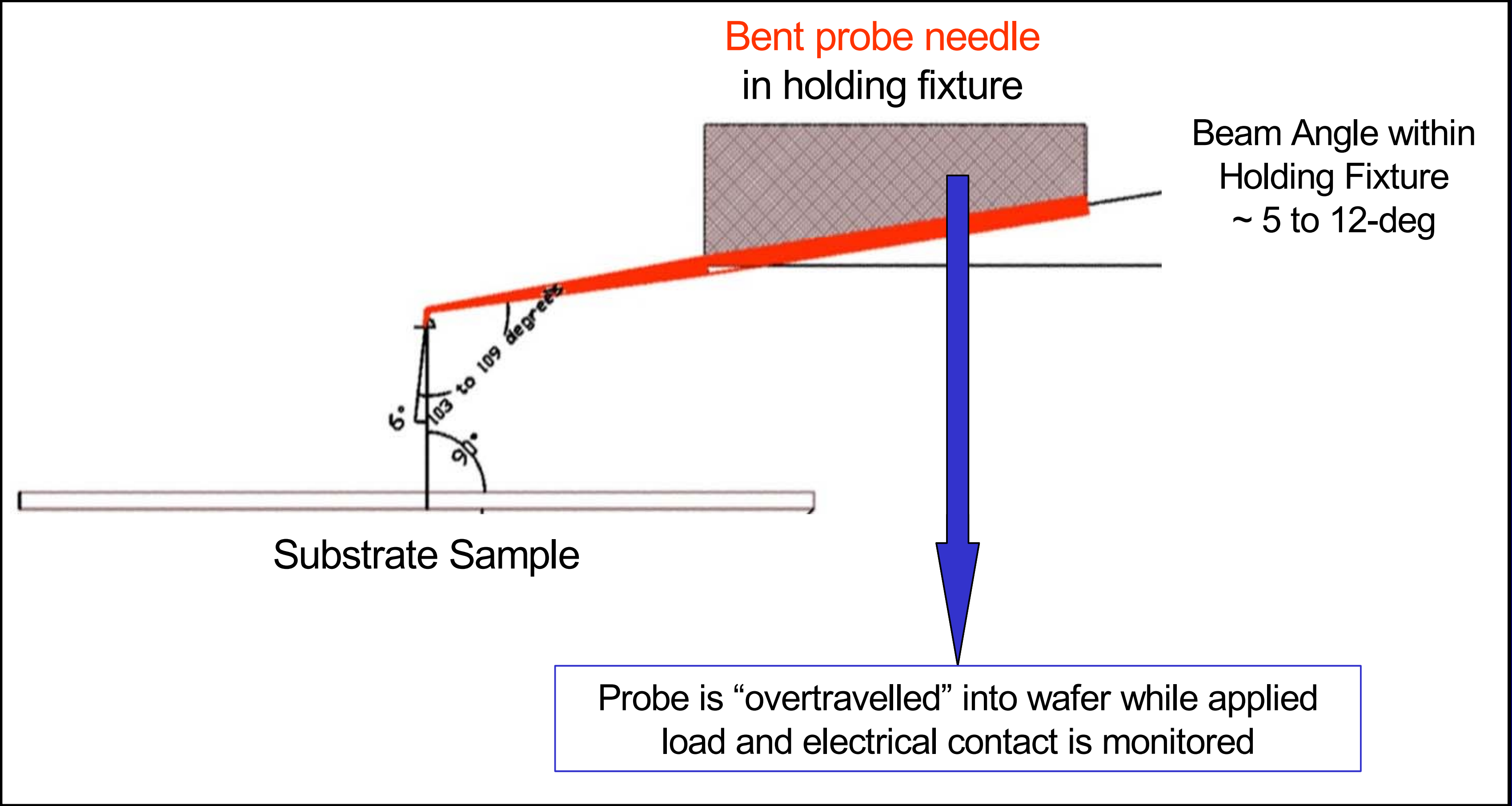
- Overview of Experimental Hardware



Electron or Ion beam at 0-52° relative to plane of the probe tip for best view

Approach (cont.)

- **Approximate probe orientation in FIB chamber**



Bent probe needle
in holding fixture

Beam Angle within
Holding Fixture
~ 5 to 12-deg

Substrate Sample

Probe is “overtravelled” into wafer while applied load and electrical contact is monitored

Proof of Concept Applications

- **Evaluation of inter-layer dielectrics covered by thin film blanket Cu**
  - Three low-k dielectric materials with different mechanical and material properties

- **Evaluation of aluminum capped test die**
  - Bond pads with a double thick dielectric
  - Bond pads with dense metal structures

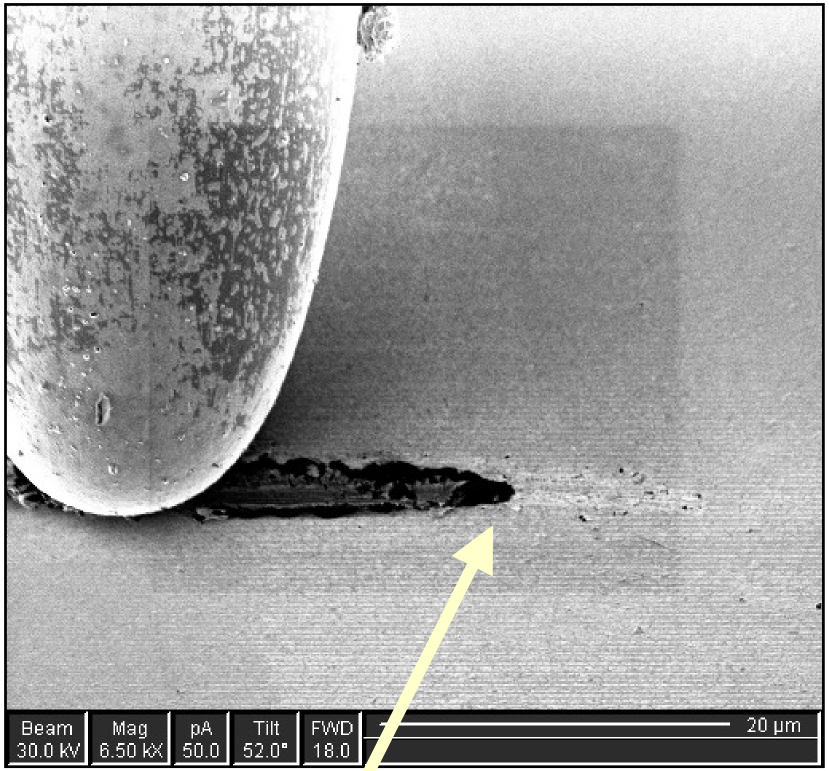
- **Multiple touchdowns on a blanket low-K dielectric material layered on top of silicon**

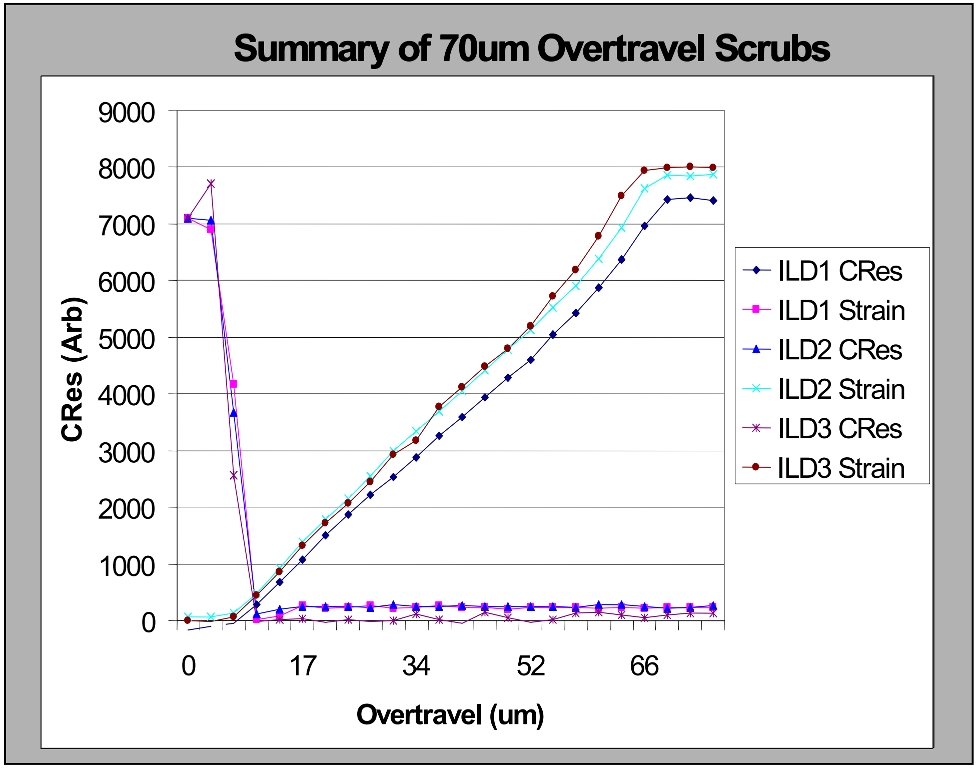
Methodology Details

- **Electrochemically polished tungsten probes were mounted into the Omniprobe holding fixture.**
  - The probes were bent with a 8-mil tip length
  - The probe tips were electrochemically radiused
  - Tip diameter is less than 1 mil

- **Synchronized data collection**
  - Real-time scrubbing action correlated with overtravel, strain, and electrical resistance
  - Wafer is stationary, probe z-axis height adjusted to apply overtravel
  - Surface contact detected with strain gauge and verified with in-situ visual observation
  - Overtravel is initiated 0.1um above the surface

Results - ILD Materials (cont.)

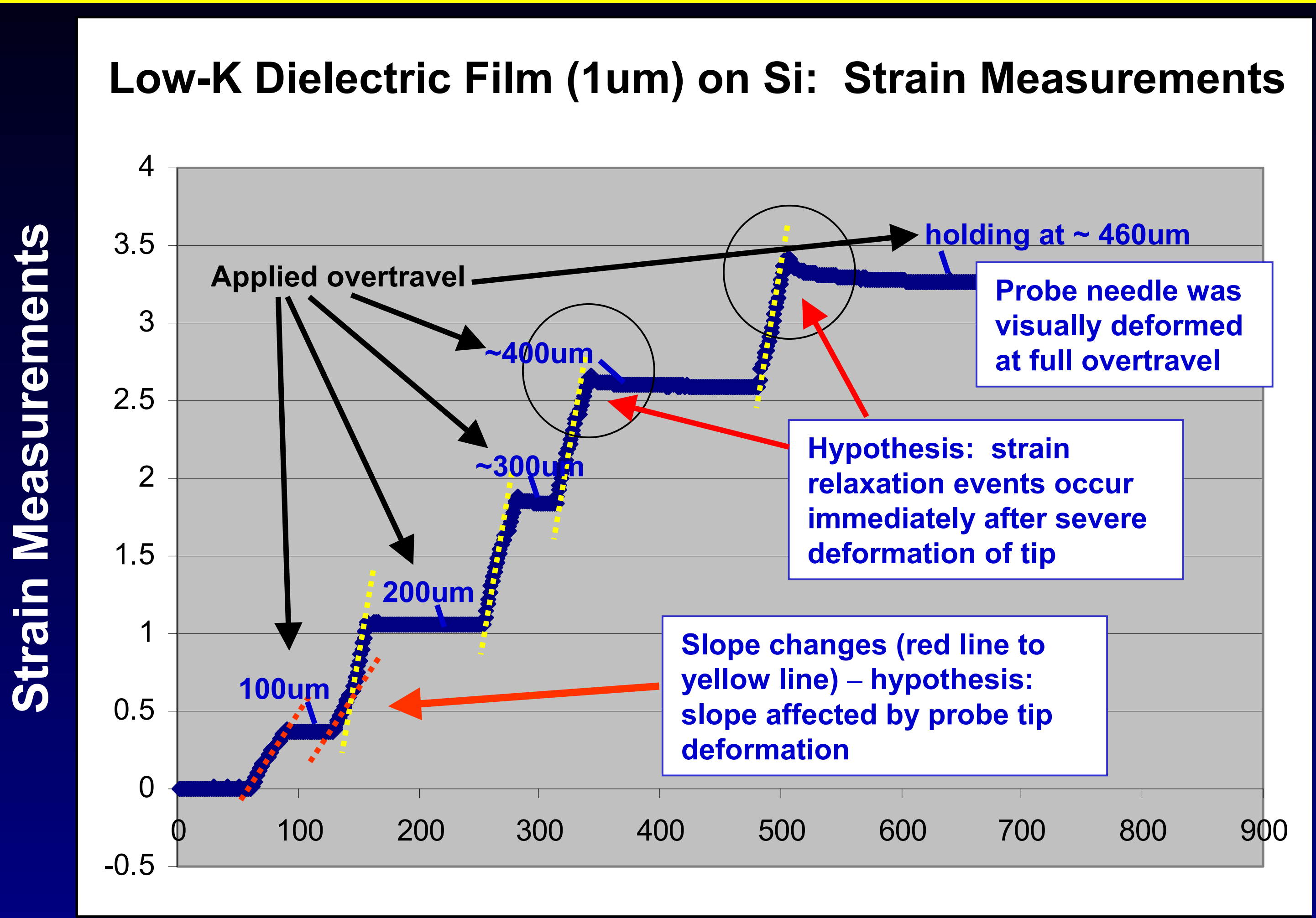




Breaking through metal surface layer

Comparison of 3 ILD Mat'l Strain and CRES

Results - Excessive Overtravel Test



Low-K Dielectric Film (1um) on Si: Strain Measurements

Probe needle was visually deformed at full overtravel

Hypothesis: strain relaxation events occur immediately after severe deformation of tip

Slope changes (red line to yellow line) – hypothesis: slope affected by probe tip deformation

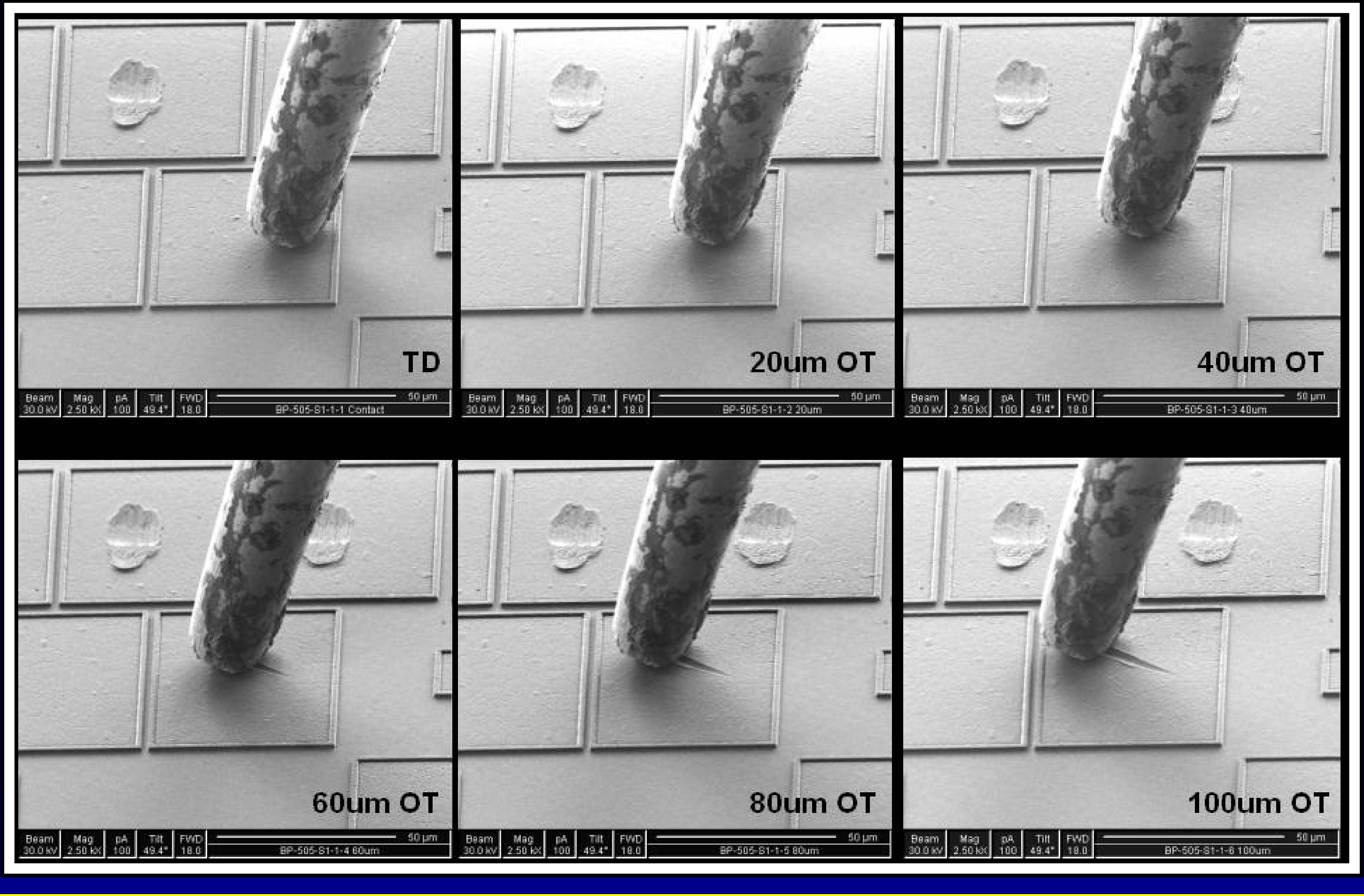
Strain monitored while overtravel applied in successive forward steps.

Tip is already into Si well before 100um overtravel.

Strain data may be able to reveal when probe tip deformation occurs.

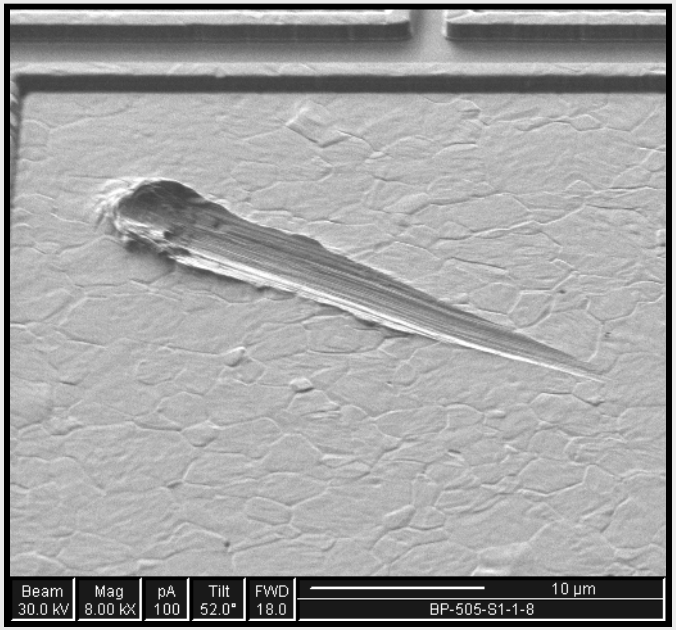
Results – Aluminum Bond Pads

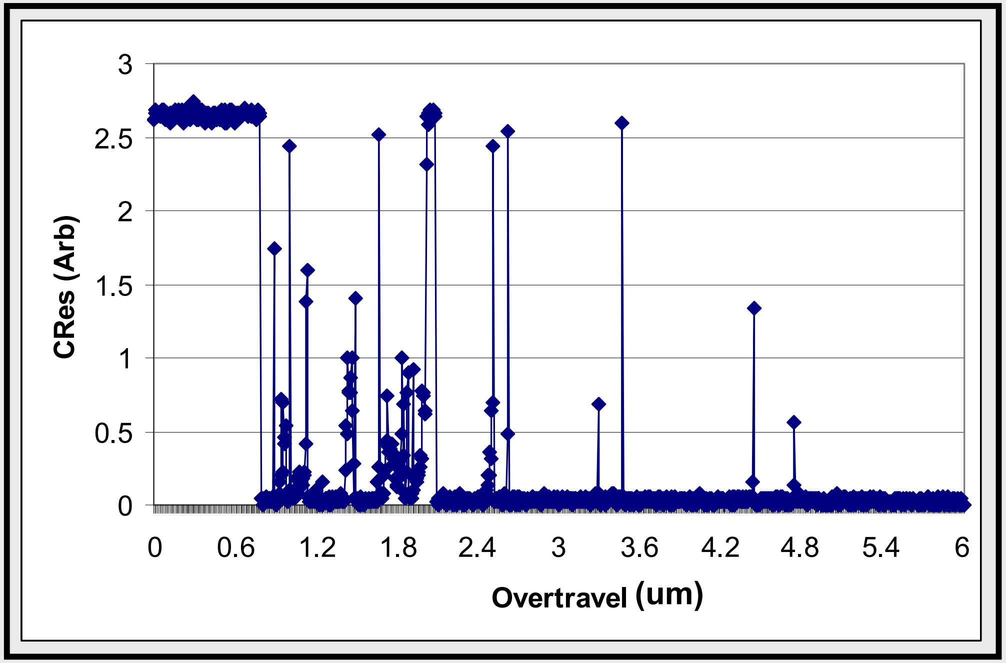
- High Res SEM images – 0 to 100um of overtravel



Results – Aluminum Bond Pads

- Scrub mark visualization and CRES vs. Overtravel





Stable contact occurs at ~6um overtravel with a clean radiused tip

Results – Metallized Substrate (cont.)

Real-time probe scrub visualization on a non-aluminum metallized substrate

Results – Metallized Substrate (cont.)

Probe on
Metallized
Substrate

Results – Copper Substrate (cont.)

Real-time probe scrub visualization on Cu showing electrostatic debris interactions

Results – Copper Substrate (cont.)

Multiple Probe on Copper Substrate

Results – Aluminum Bond Pads (cont.)

Real-time probe scrub visualization on an aluminum capped bond pad

Results – Aluminum Bond Pads (cont.)

Probe on
Aluminum
Bond Pad

Conclusions / Future Work

- **A methodology has been developed for *in-situ* probe scrubbing action visualization combined with synchronized force and electrical measurements.**

- **Using this method a clearer understanding of probe effects to the materials under test as a function of material (probe or sample) composition, probe tip shape, etc., can be developed.**

- **Future work……**
    - Calibration of strain
    - *In-situ* crack detection
    - Blade assemblies with variable probe force (0.5 – 3 g/mil)
    - Flat tip vs. radius tip shape comparison
    - Scrubbing behavior on Al, Cu, and Au pad comparison
    - Continuing Low-K studies

Acknowledgements

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