Integrating Micro Hardness Testing Into IC Evaluation

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CVI customers, value and improvement

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- Low-K
- Hardness Testing and In-Process Quality Assurance (Pad Morphology)
- Cleaning, CRES and Friction
- Flip Chip (PbR - PbF)

Background

The Need For Electro-Mechanical Analysis

- **Low-k Fracture!**
- Probe Card Design
- **Bond Pad/Scrub Analysis!**
- In-Process QA
- **PbR to PbF Conversions!**
- Accurate Measurement of Contact Force
- **Timely and Low Cost Solutions!**

Why the MHT:

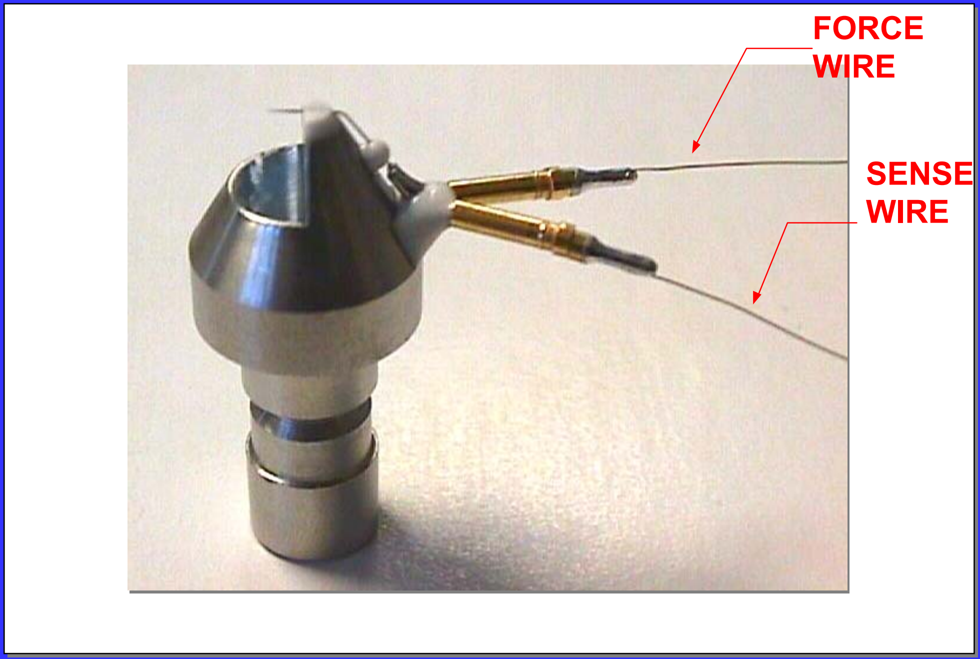
Prober/Tester/Probe Card system has tolerance stack error which can invalidate results -or- result in REPEAT experiments. Sources of variation include:

Chuck Planarity	Wafer Planarity
Bond Pad Corrosion	Probe card
Die Performance	Electrical Contact Force

The MHT system can **eliminate months** by reducing the evaluation to days helping expedite product to market!

As few as **a dozen “non functional” die,** not wafer, can be used to complete most analysis.

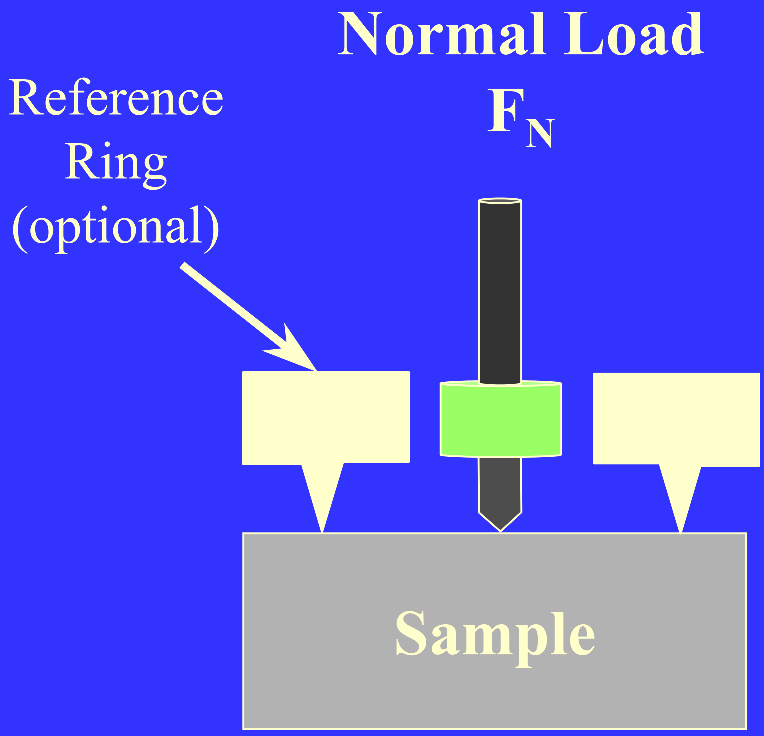
Indentation Tips



- **Static and dynamic loading, as well as cyclical loading applied accurately since no electrical contact required (introducing error).**
- Residual contact area determined by measuring the residual imprint diagonal with an optical microscope (can also image during probing)
- Various probe needles can be used including vertical tips.
- **Cheaper and more accurate for the initial development work.**
- Calibration is fast and easy.

Open Platform Configuration

MHT senses the surface nondestructively with less than 1mN (~.1 grams). With a displacement resolution of less than 1nm, the load can be varied to simulate probe speeds or slower for a detailed analysis of the load curve.



Low-K

Low K Materials

Include:

Organic - bubbles and trapped air

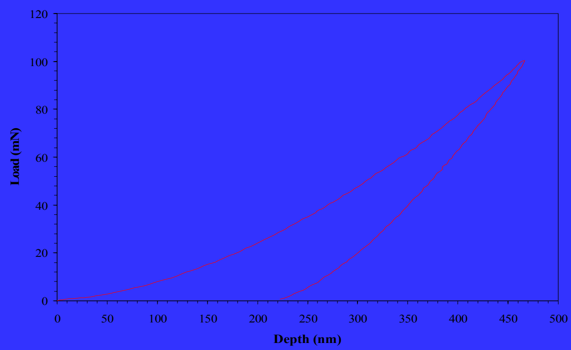
Inorganic - brittle

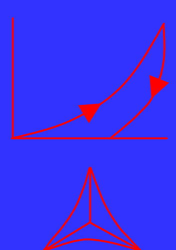
An understanding of brittle materials under static and dynamic load is a key:

- **Normal load**
- **Versus Angle**
- **Versus Movement**
- **Versus Contact Geometry**

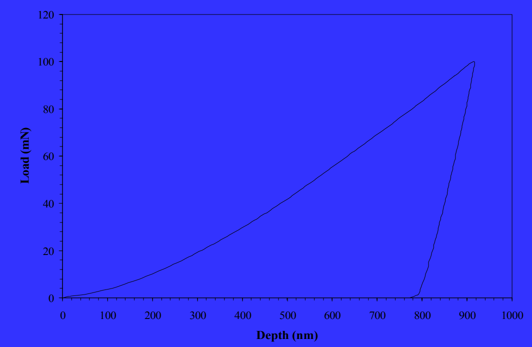
Typical Indentation Load-Displacement Output

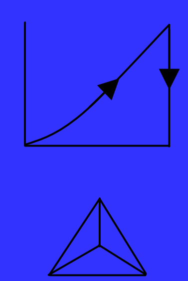
Comparison of elastic, perfectly plastic, and elastic-plastic contact characteristics





Titanium Carbide

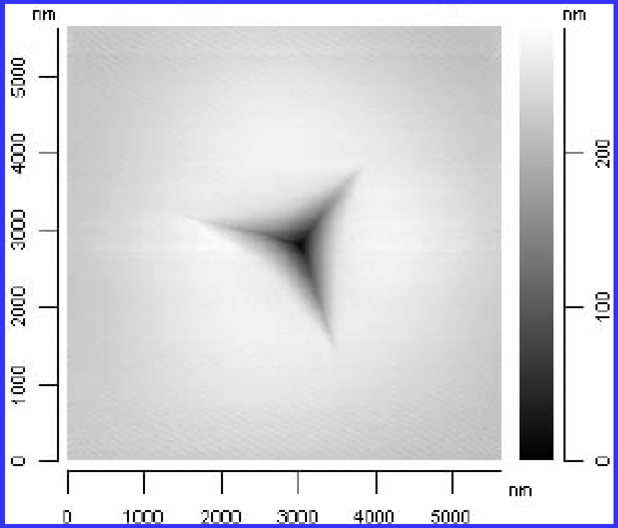


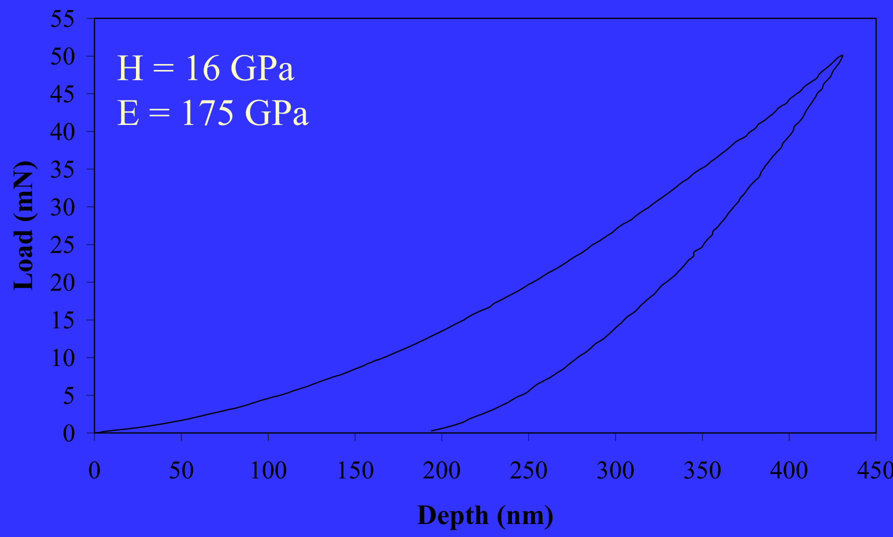


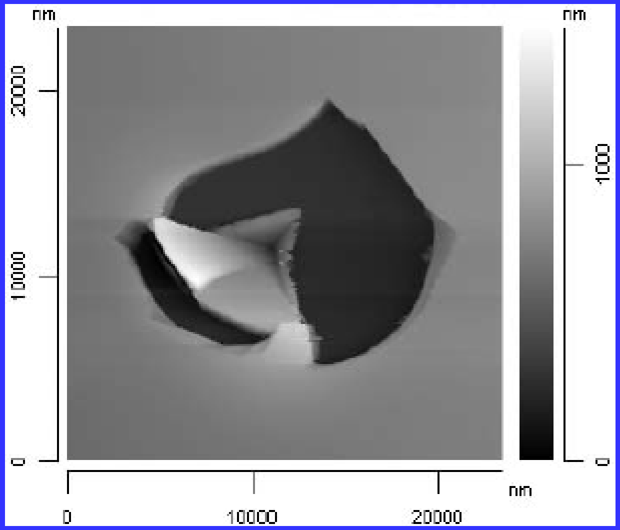
Rhodium

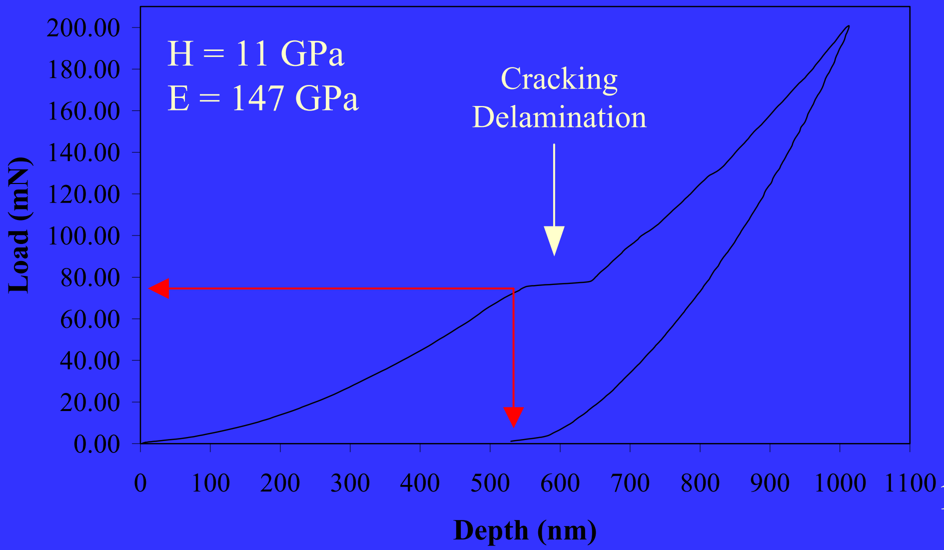
Micro-Hardness Test

Mechanical properties of Cr_2O_3 thin films



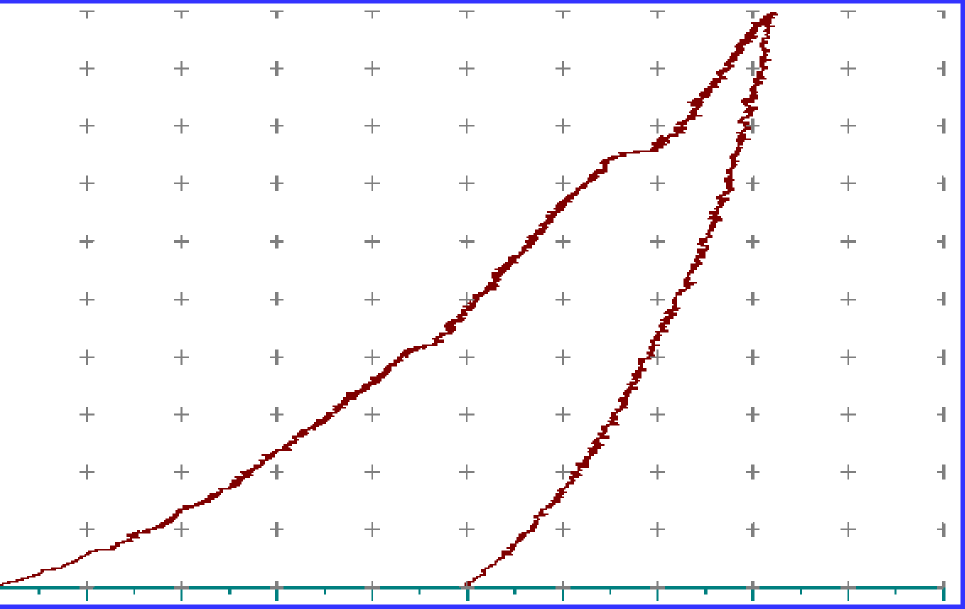


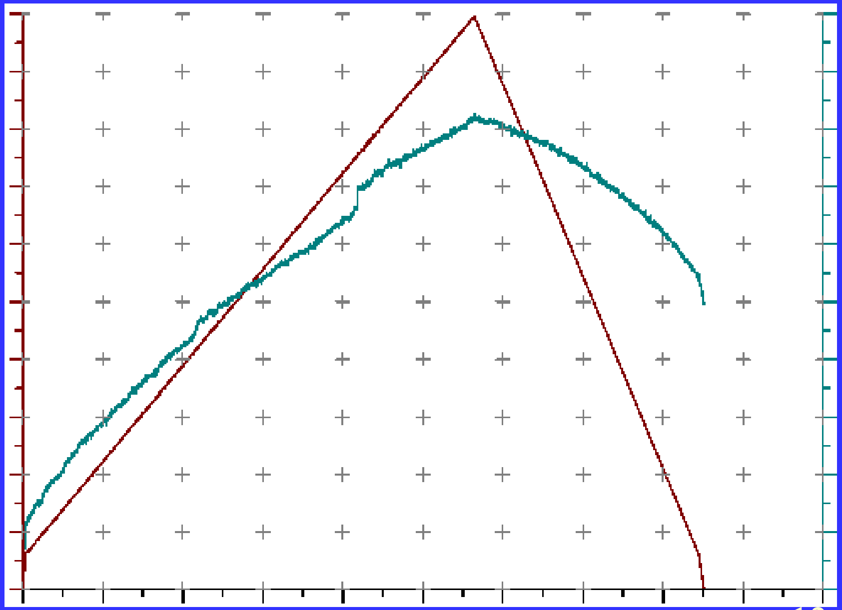




Sample Run Profile on a Target Pad

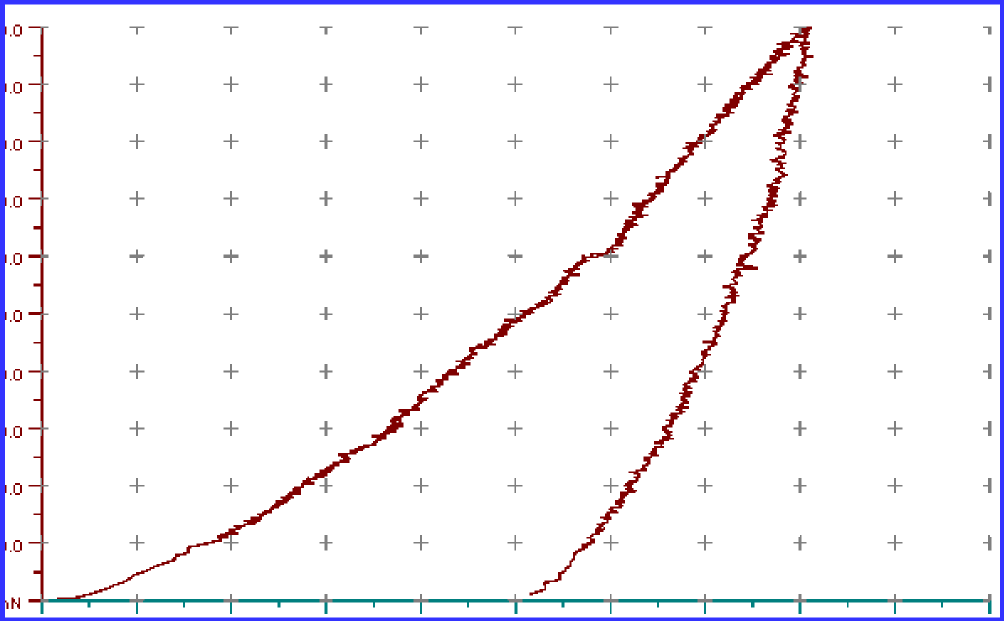
Using only a few bond pads, results are obtained in hours or days at a fraction of the cost. Results are accurate and repeatable. Multi cycle loading can also be performed as well as probing target areas of the pad.

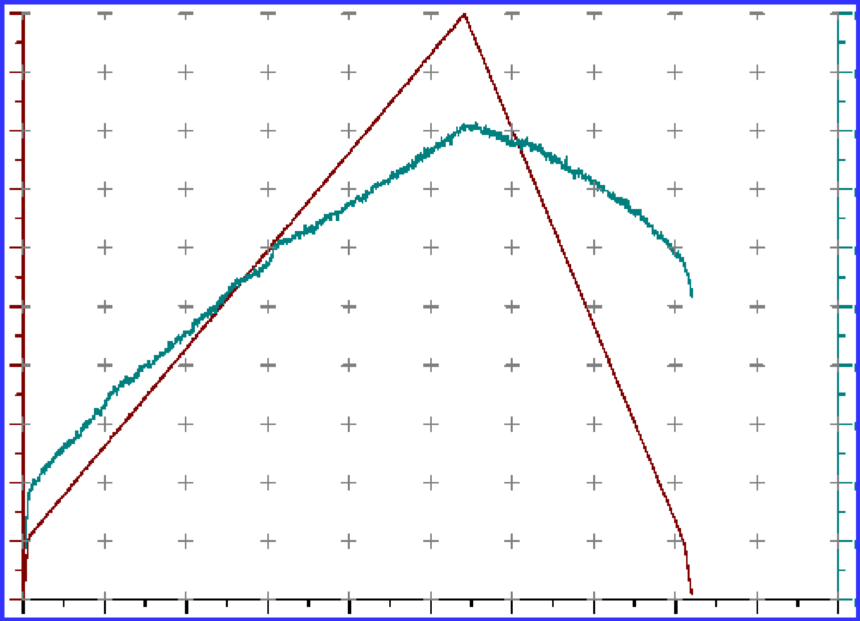




Second set at lower loading. Only one inflection is captured.

Higher load values can be run to show silicon and other structural damage.





In-Process Quality Assurance

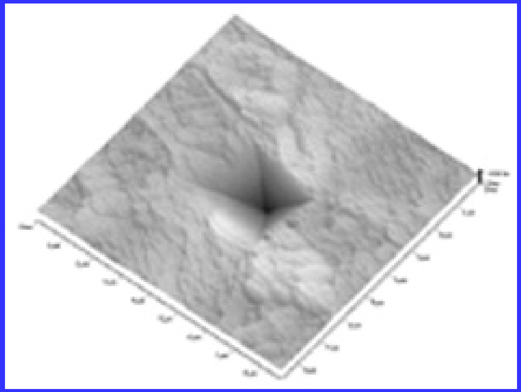
(Pad Morphology)

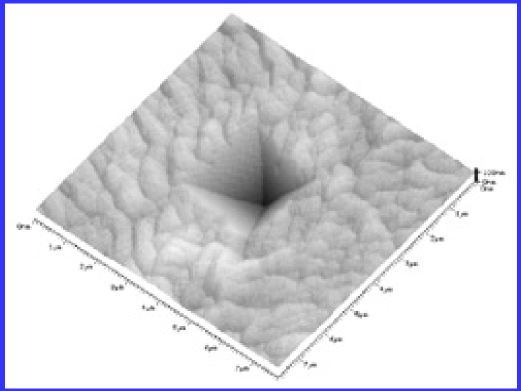
Typical Pad Limitations

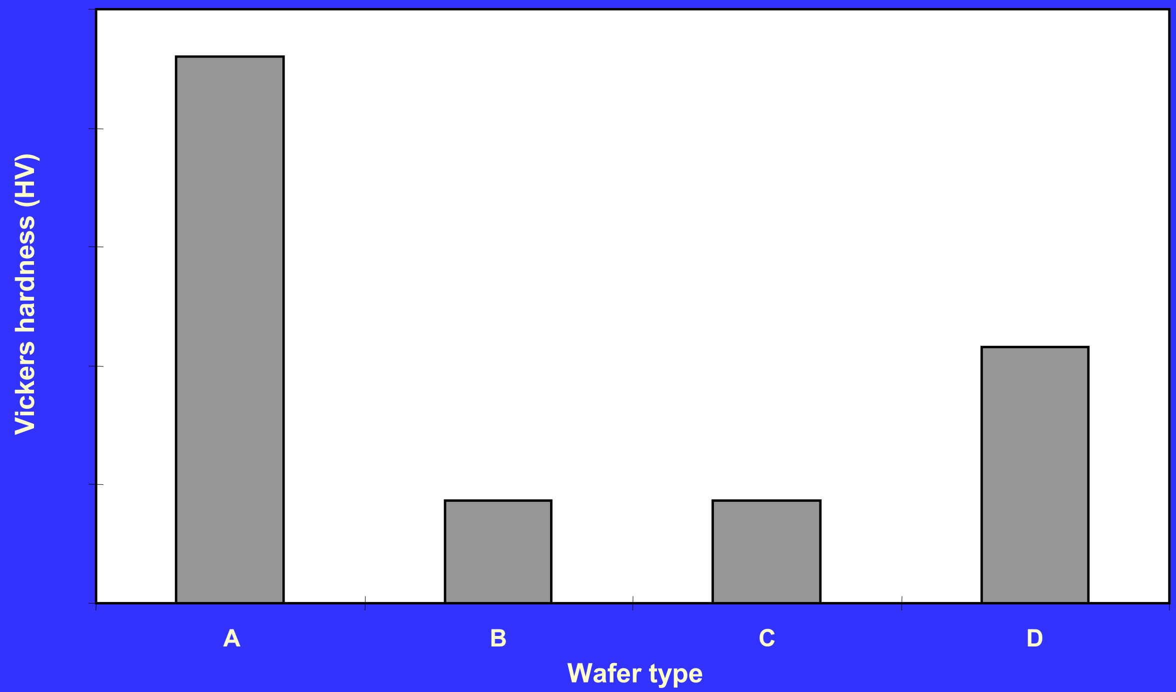
- Localized Sample Variability
- Surface Roughness
- Sample Grain Size
- Sample Preparation
- Surface Contamination

Hardness Test

Integrated Circuit (IC) Bonding Pads





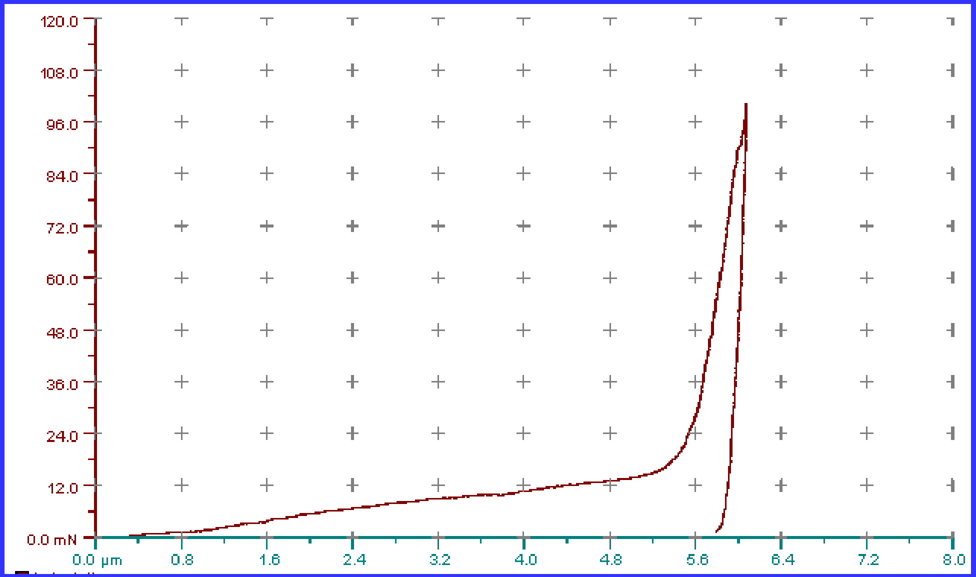


One of these ran much better than the others

<u>Regardless of the initial conditions, analysis can lead to root cause understanding whereby equivalent performance can be achieved.</u>

Pad to pad variability, surface roughness, grain size and contamination are critical parameters at probing and wire bond (**needle to pad contact force - friction**).

Without the ability to **quickly -and- non destructively verify the conditions of the bond pad, the test floor must run material as received.**



A real time, non-destructuve wafer analysis reveals conditions that could contribute to poor probing or wire bond Either probing an active pad or another target area will highlight potential process control issues.

This example shows the impact of landing on a "nodule".

What is Time Zero Contact Resistance (TZ-CRES)

With the proper setup, the time zero CRES can be accurately determined for a given probe wire to bond pad interface **(did that nodule really impact CRES).**

The tester impedance and impedance of the hardware can be minimized without setting up a complicate 4-point probe.

Optical measurements can be made simultaneously to correlate the probe tip action on the bond pad.

The process window for load required to make electrical contact can now be documented to optimize the min and max values of overtravel required for electrical contact.

As a QA check or during development, the true amount of electrical force required to make contact is demonstrated from lot to lot or pad to pad.

CRES, Cleaning and Friction

- The ability to quickly verify electrical contact provides an opportunity to look at contact resistance, cleaning and the interaction of probe tips on the bond pad and cleaning media.
- Probes of various needle geometry **can be quickly interchanged to analyze bond pads (or other structures)** to measure contact resistance or to evaluate the impact on low-K structures.
- The capability to **optimum cleaning material and hardware settings** to time zero impedance values are now quickly and easily obtained with no material scrap.

As demonstrated on the next few pages, cleaning has a significant impact on probe needle life. **The most economical solution for cleaning is not necessarily the best for the card life and performance.**

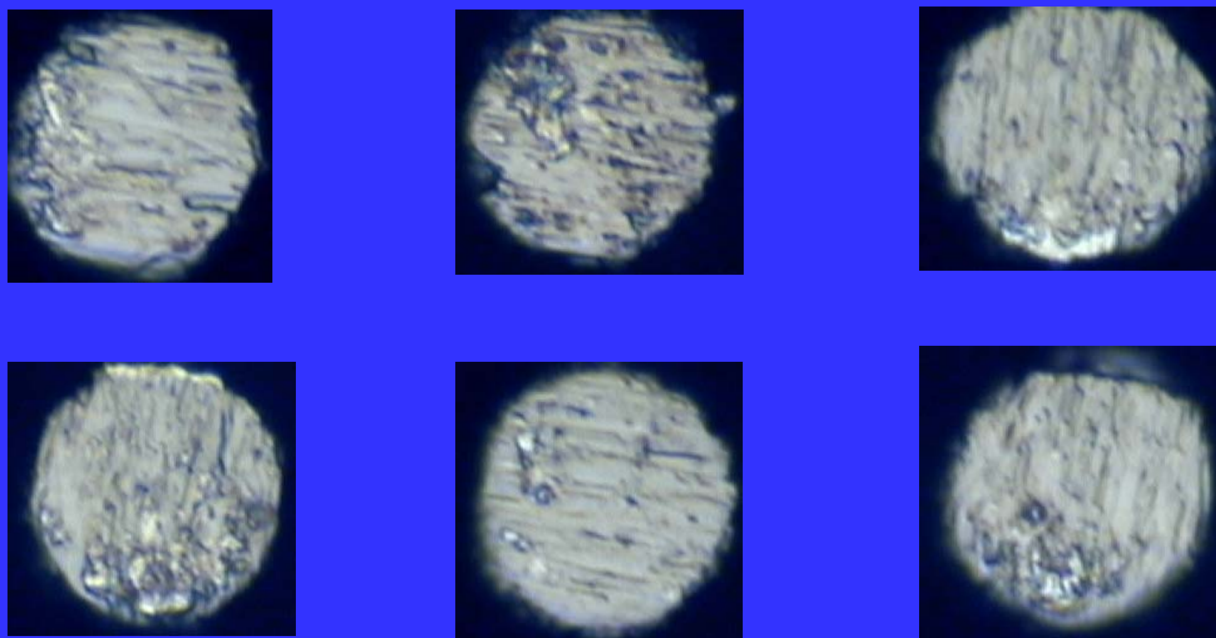
Cleaning Solutions

- Pads - various micron grit in a binder - cheap
- WC - harder and more stable than pads - more expensive than pads.
- Wafers - off line and can take longer cleaning cycles - more expensive process

To effectively probe or clean, one must know the contaminants that form on the wafer/bump and probe needle.

In most instances, the “kitchen soup” of material on the bond pad has little alumina (Al_2O_3)!

Probe Tip Images

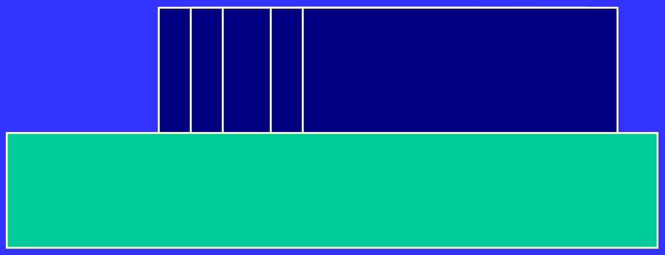


<u>Yield is improved by cleaning the hardware:</u>

- Reduces contact resistance to time zero values but
- Each cleaning cycle reduces the hardware life and
- Increases cycle time resulting in throughput loss as well as
- Additional yield loss at subsequent processing steps.

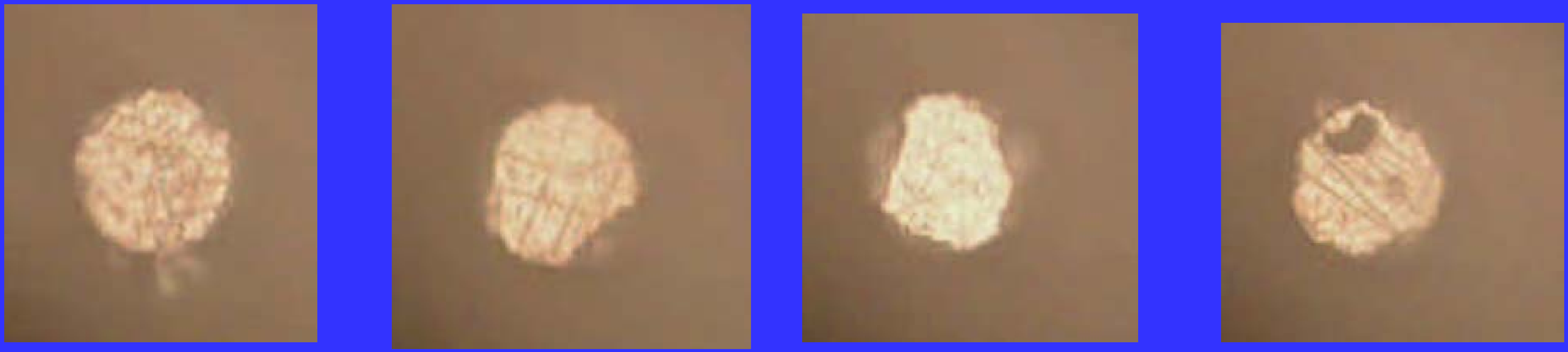
Friction……..

A force tangential to the common boundary of two objects in contact that resist the motion or tendency of motion of one relative to another.



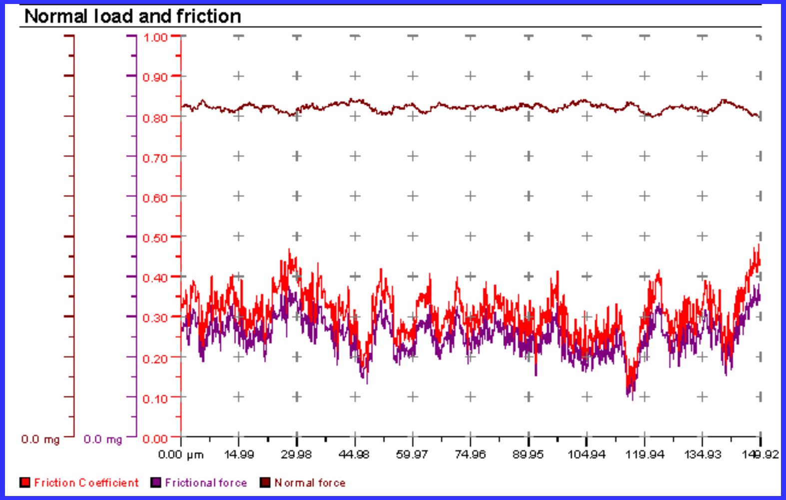
A rougher surface or the presence of a lubricant changes frictional force (more force is required to move the objects). Thus friction on a bond pad, cleaning surface or polished crystal will differ.

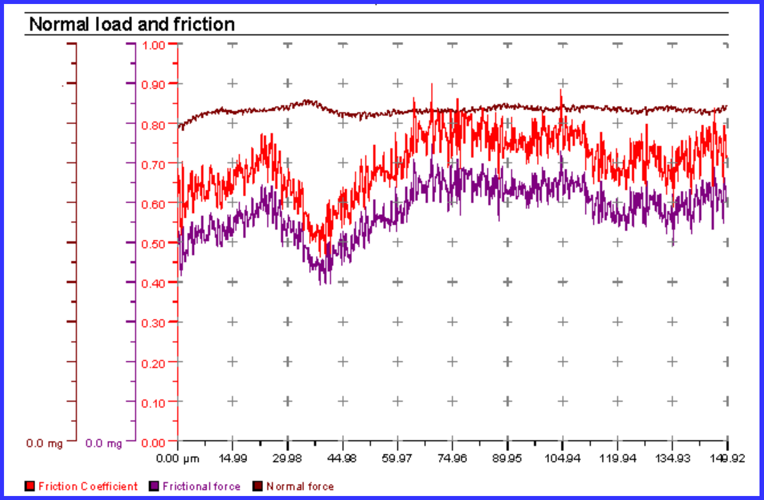
Post Cleaning Needles

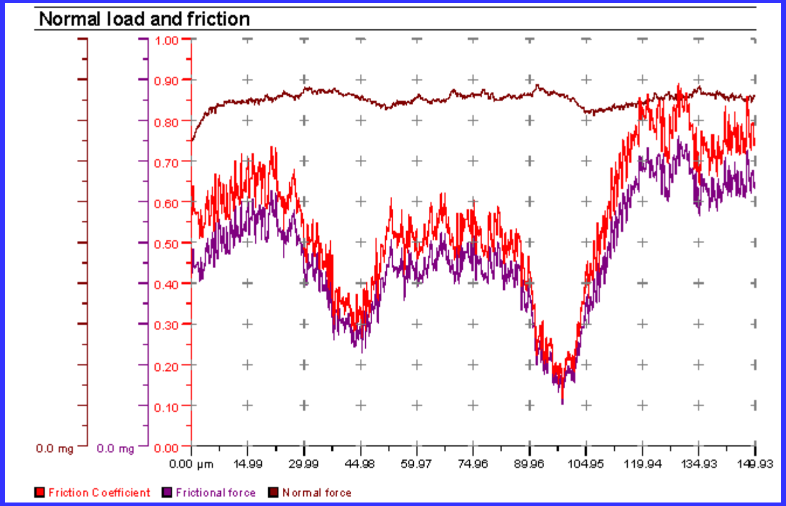


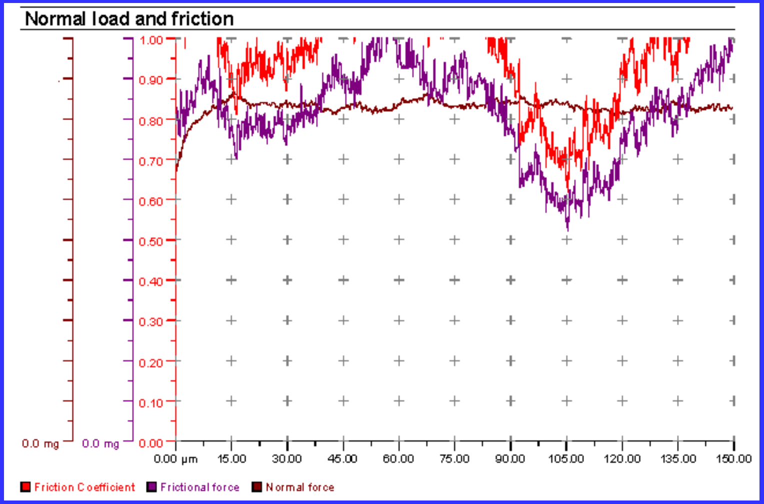
Cleaning friction profiles can be the death of a probe card. The tips show that various cleaning solutions, **<u>after only a few cleans, have minor to major impact on needles</u>**.

Common Cleaning Materials



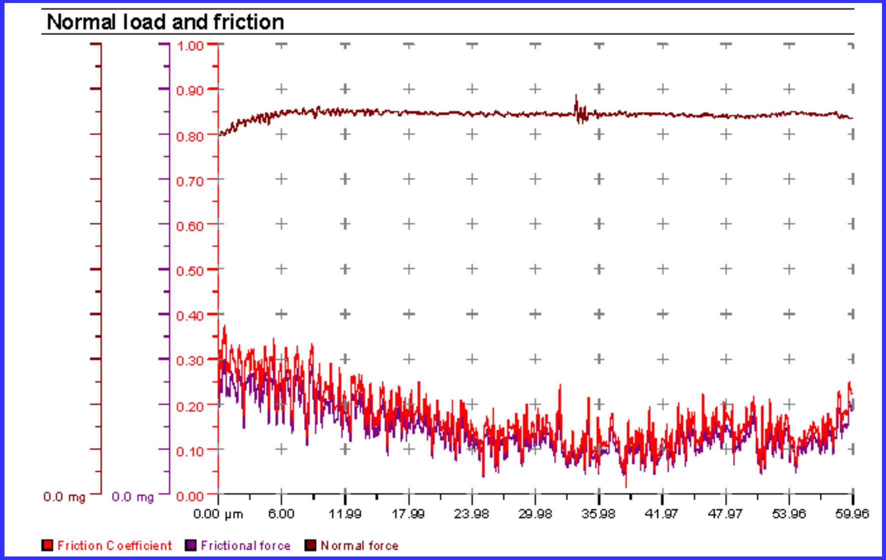


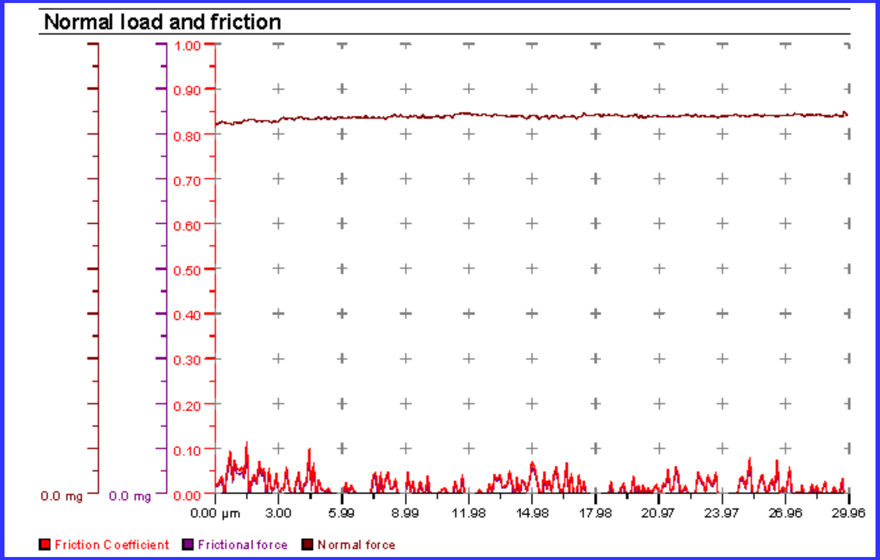




Which do you want in your process!

Comparing Friction: Pad Versus a Polished Crystalline Surface





Various factors impact friction:

The results here demonstrate that the **friction on a pad is dramatically different than on a polished crystalline** surface. The materials vary enough not allow apples to apples comparisons.

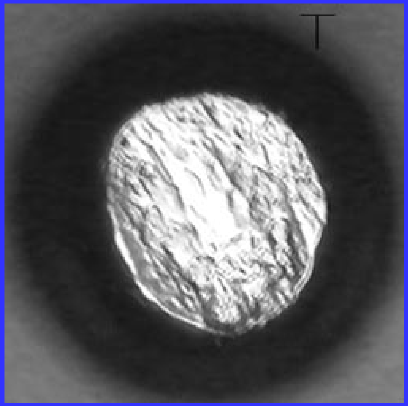
Flip Chip
(PbSn and Pb-free)

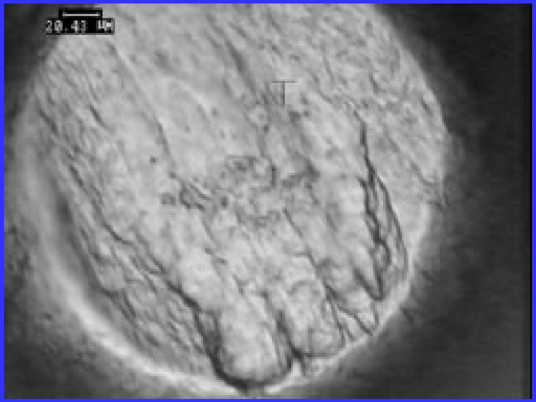
Industry has over 50 years of experience with PbSn alloys. To date, there is not one standard Pb-free alloy.

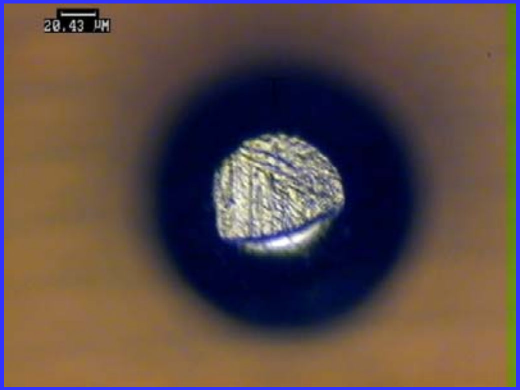
To select the best alloy for the process requires an understanding of feature geometry, electro-mechanical properties, materials and the interactions between the three.

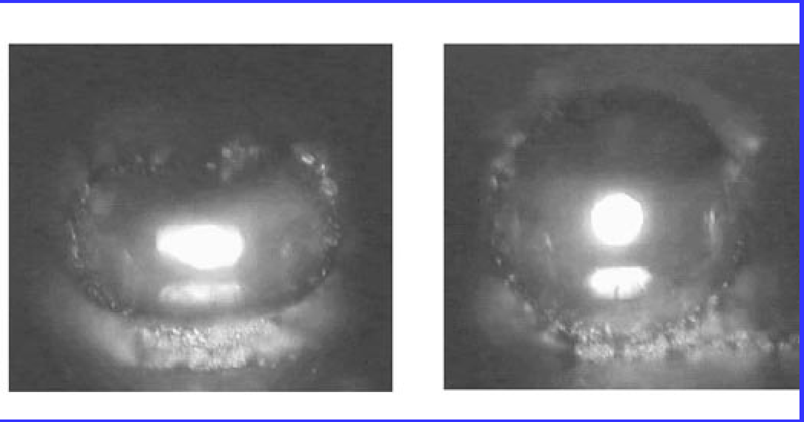
The question the process manager should continuously ask is "How do I optimize my current PbSn probe process while integrating a Pb-free solution?"

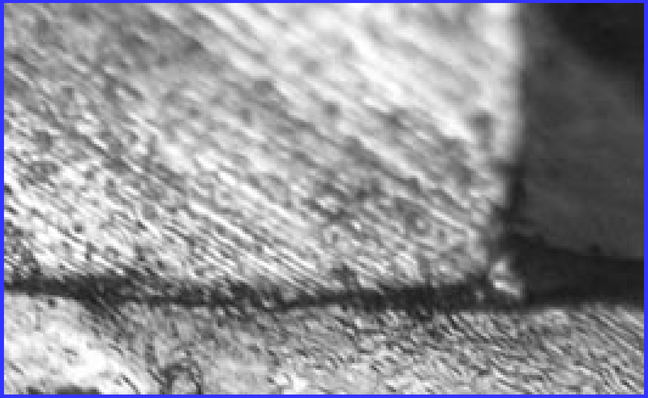
Various anomalies due to Improper Setup



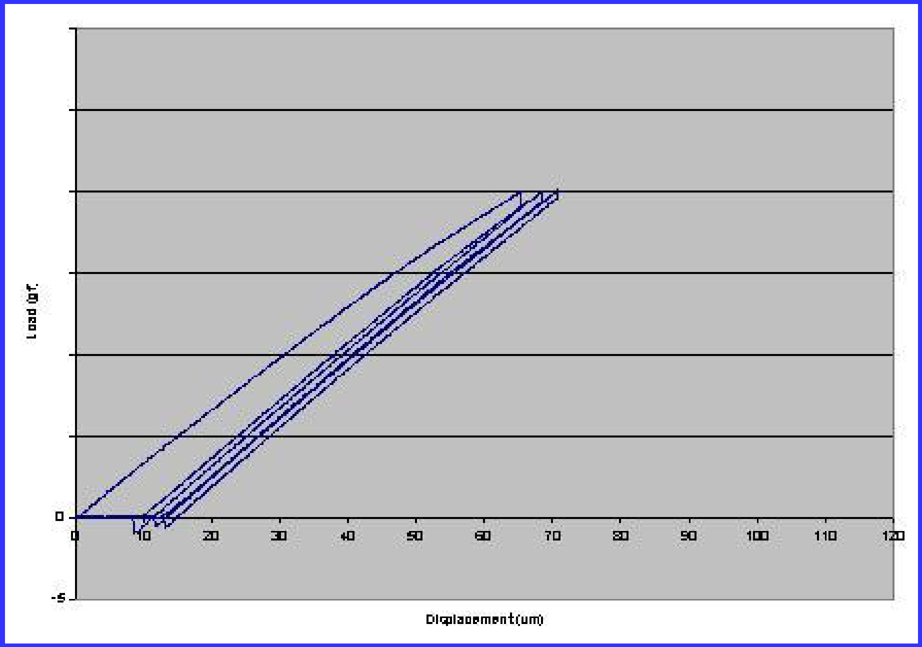


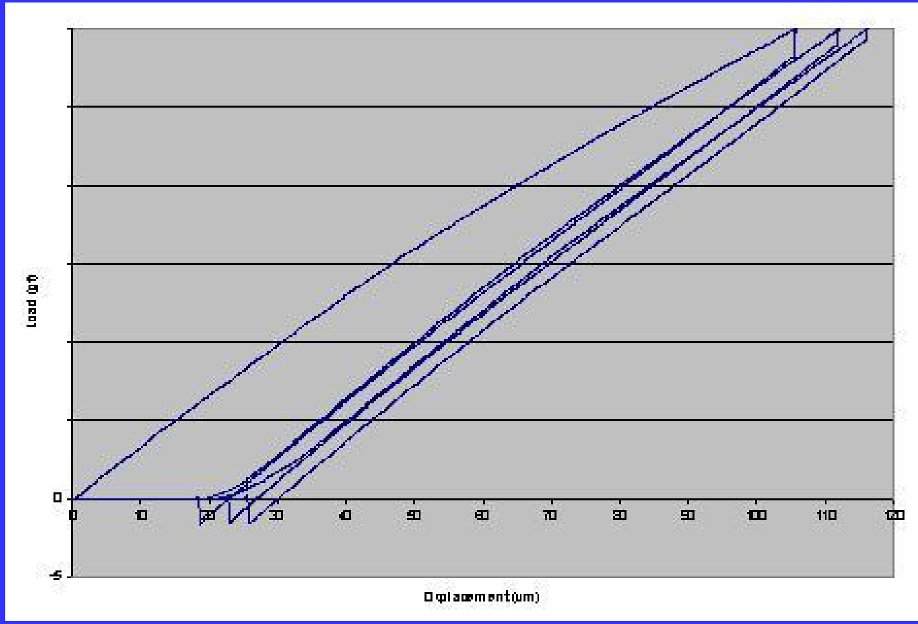






Probe Endurance

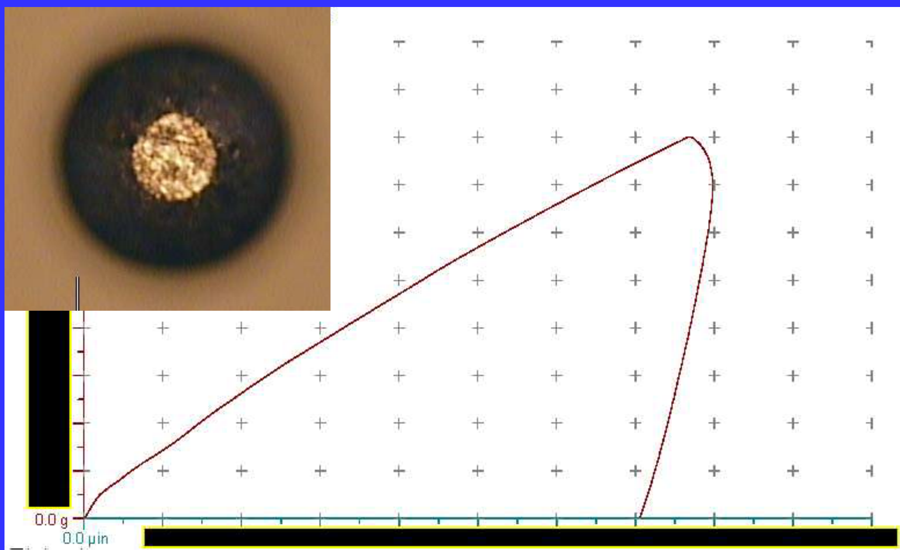


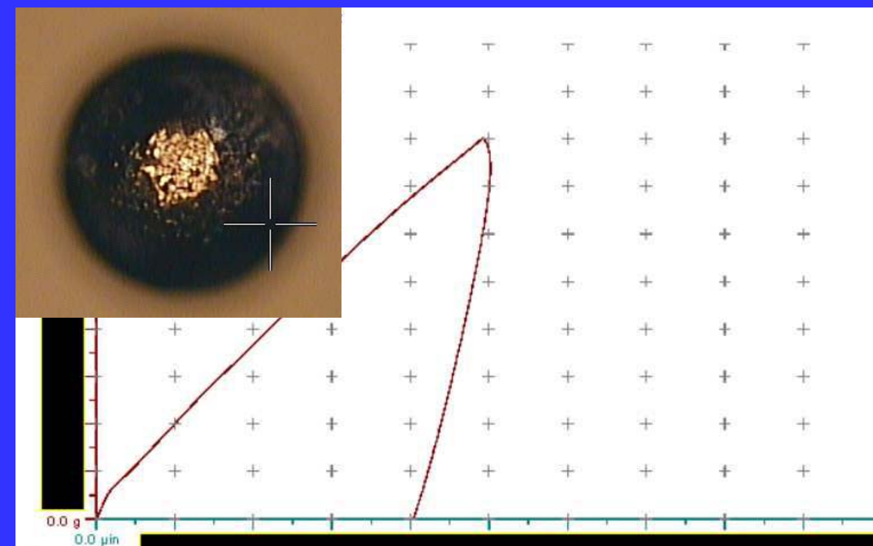


One can quickly determine how much force a bump can endure.(scales are the same)

The **settings where the transition from “deformation” to “damage”** are obtained by evaluating two solder bumps instead of hundreds!

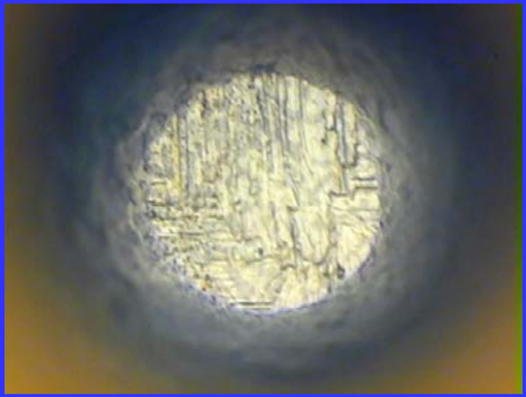
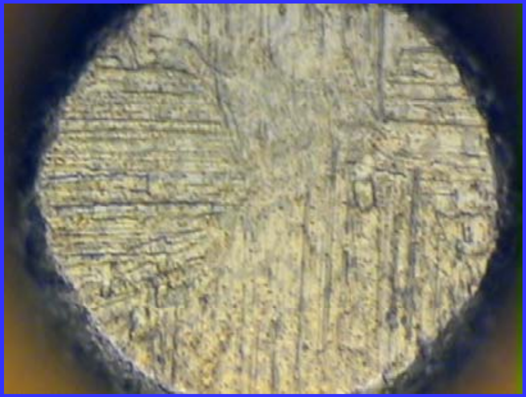
Pb-F Solder Bump Evaluations





Impact of Pb-free conversion on the force required to successfully probe the FCP or an equivalent CSP. Also note the slope of the line changes on load and unload cycles demonstrating divergence in mechanical properties.

Which Mark Represents Your Process


The amount of deformation, or damage, has a significant impact on yield:

Planarity
Additional process steps
Final device reliability

Contamination
Poor solder joints

Why Use the MHT Instead of Others

ISSUE	Other systems	MHT
Calibration	Almost impossible to calibrate applied load and displacement accurately due to inherent hysteresis and non-linearity of piezo scanner	Highly accurate and reproducible Load and Depth calibration to ASTM standard references
Positioning Accuracy	Positioning to nearest 0.01 µm	**Positioning to nearest 0.1 µm** (NHT accuracy is 0.01um)
Contact Conditions	Extremely sharp tip: for mechanical properties testing, this produces a very high contact pressure which is far greater than standard probe test pressures…	MHT **uses loads and indenter geometries which correspond exactly to probe testing conditions**. Actual probe tips can be mounted on the MHT for accurate simulation testing.
Data Analysis	Cannot provide accurate material properties	Instrumented indentation data can provide Hardness, Elastic Modulus, Stress-Strain, Fracture Toughness, etc….
Ease of Use	Non-automated	**Completely automated in Open Platform configuration. Accepts wafers.**

Conclusions

- Non-destructive fast, accurate and repeatable results can be obtained dramatically shortening the time to market and development costs.
- Complete Pb-Free analytical capability.
- Process improvements are obtained using a real time setup to QA received material (true CRES and electrical first contact).
- Scrub marks are evaluated using the friction setup to review bond pads and evaluate cleaning solutions.
- Probe cards R&D becomes simpler and efficient since an individual needle can be economically mounted to a tip.

Special Thanks

Special Thanks to:

Texas Instruments

et. al.

For supplying wafers and cleaning media for evaluation.