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Improving Signal Integrity through Advanced Probe Card Design and Advanced Probe Card Metrology

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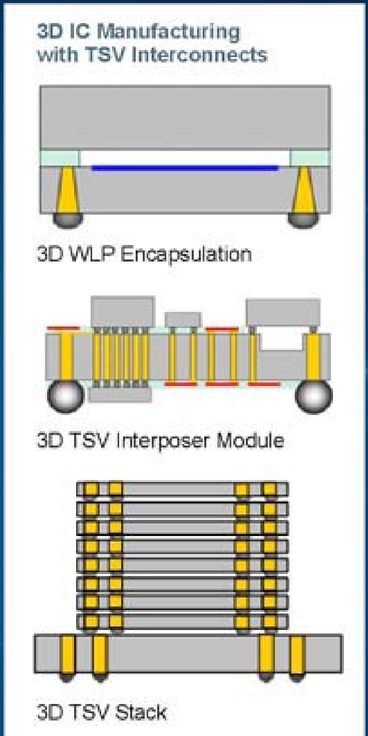
Introduction

- **Trends**
  - Advanced packages
  - Shrinking technology nodes
  - More RF
- **Details of Cascade Microtech probe cards**
  - Pyramid Probe
  - RBI
- **Need for Metrology**
- **Metrology Challenges**
- **Metrology methods for Cascade Microtech probe cards**
  - Pyramid Probe
  - RBI

Trends – Advanced Package

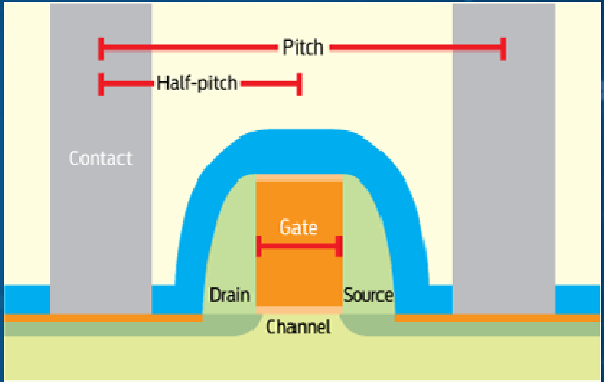
- **Trend – Advanced packages**
  - 3D-TSV for 3D die stacks
    - Wide I/O memory interface
  - 2.5D packages
- **Challenges**
  - 40 and 50 µm pitch arrays
  - Large arrays
- **Pyramid Probe® response**
  - Photolithographically defined probe tips in a membrane space transformer
  - Rocking Beam Interposer demonstrated at imec



Courtesy Yole Development

Trends – Smaller Technology Nodes

- **Trend – Shrinking technology nodes**
  - More content per unit area of the die
- **Challenges**
  - More I/O
  - Finer pitch
- **Pyramid Probe® response**
  - Membrane space transformer
    - Fine pitch array routing capabilities

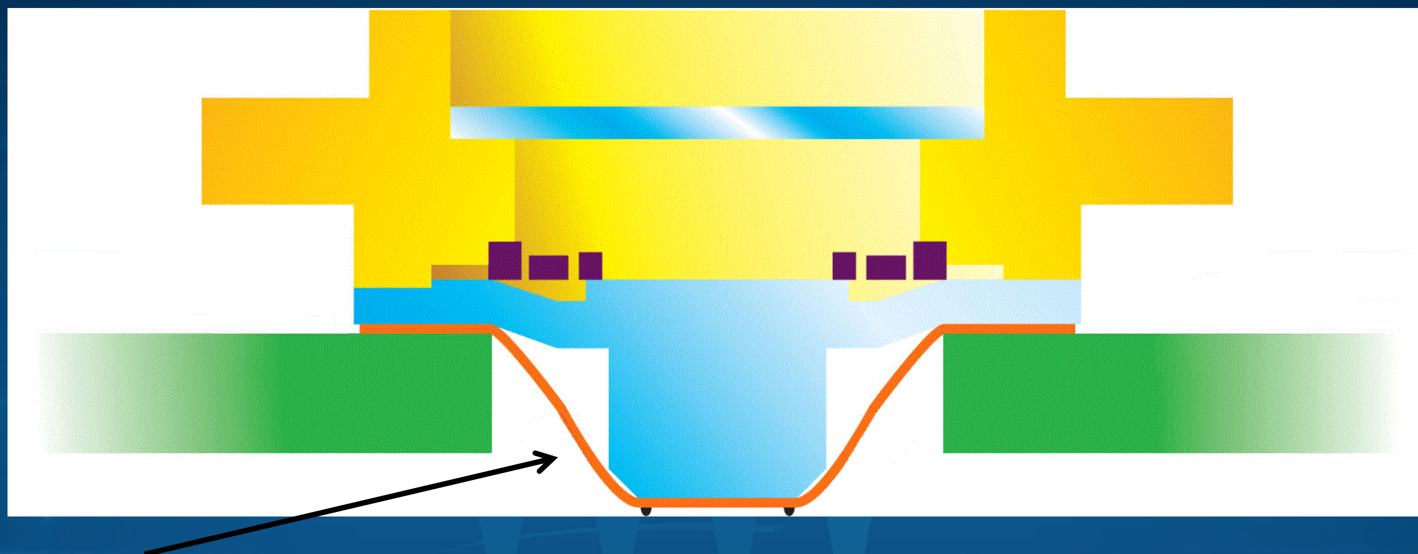


Source: IEEE Spectrum

Trends – More RF

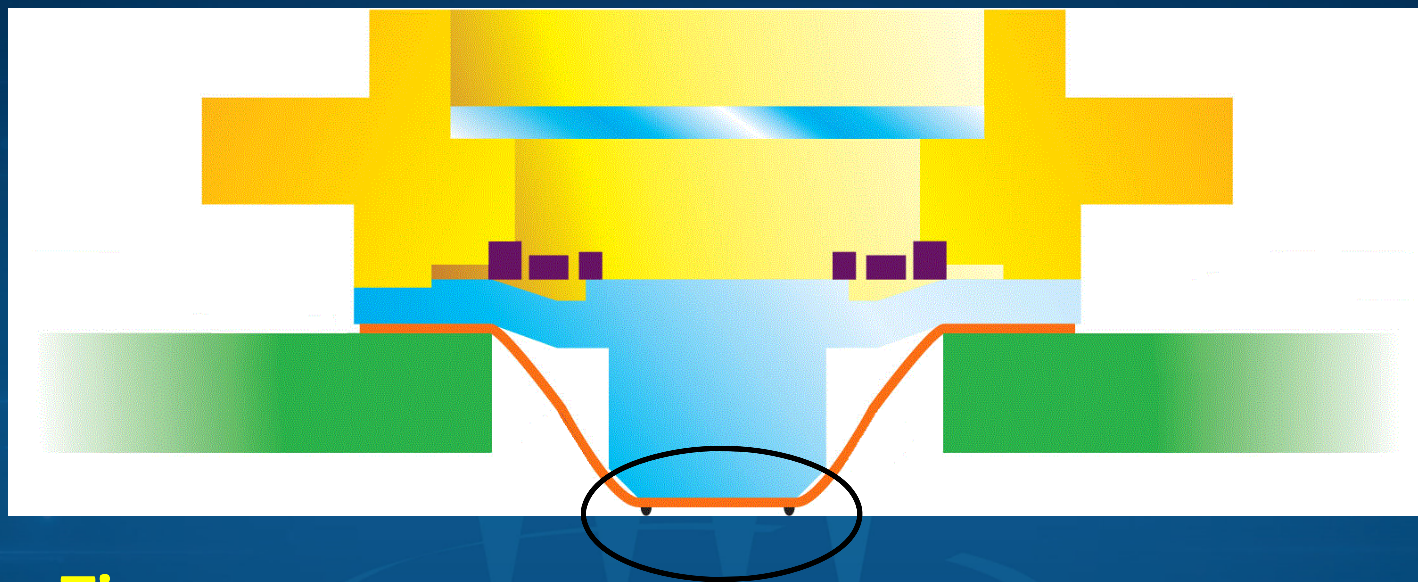
- **Trend – More RF**
  - More integration results in more RF ports per DUT
  - Higher frequency bands being used
    - 5 GHz 802.11ac
    - 60 GHz 802.11ad and backhaul
    - 80 GHz Automotive radar
- **Challenges**
  - Impedance control on supplies and transmission lines
  - Probe inductance
- **Pyramid Probe® response**
  - Membrane space transformer
  - Short probe tips

Pyramid Probe



- **Membrane space transformer**
  - Two layers for impedance control and low inductance power and ground
    - 0.04 nH probe tip
  - Finer pitch routing than ceramics or packages

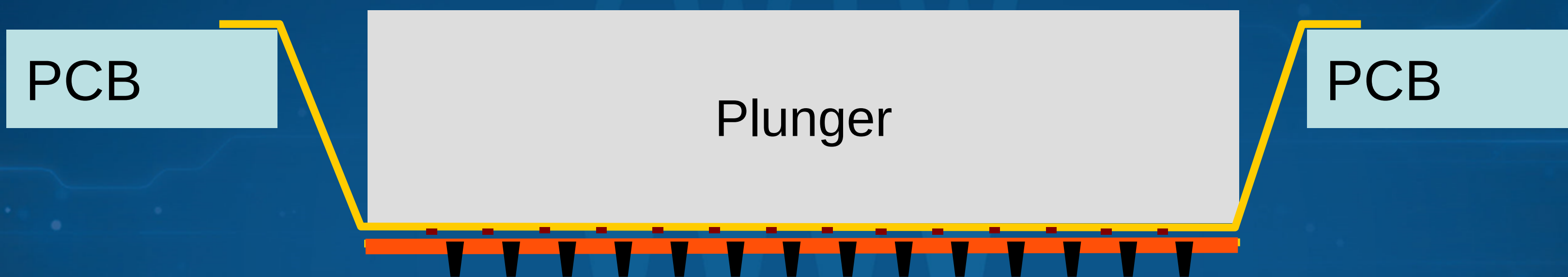
Pyramid Probe



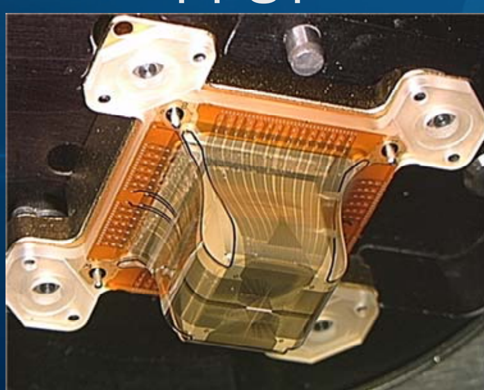
- **Probe Tips**
  - Positioned photolithographically to access smaller pads and finer pitches
    - 35 µm pads and 50 µm pitch with <5 µm scrub
    - 15 µm µbump on 40 x 50 µm array demonstrated for RBI
  - Short for low inductance and smaller scrub marks
    - 0.04 nH probe tip inductance

Rocking Beam Interposer (RBI)

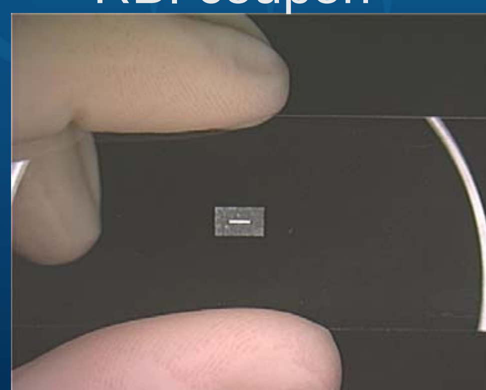
- A demonstrated technology in development for an emerging industry



PPST



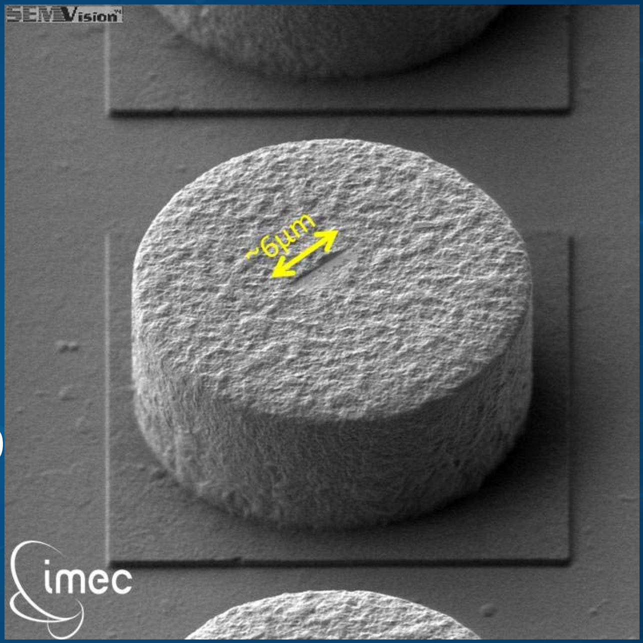
RBI coupon



Single RBI

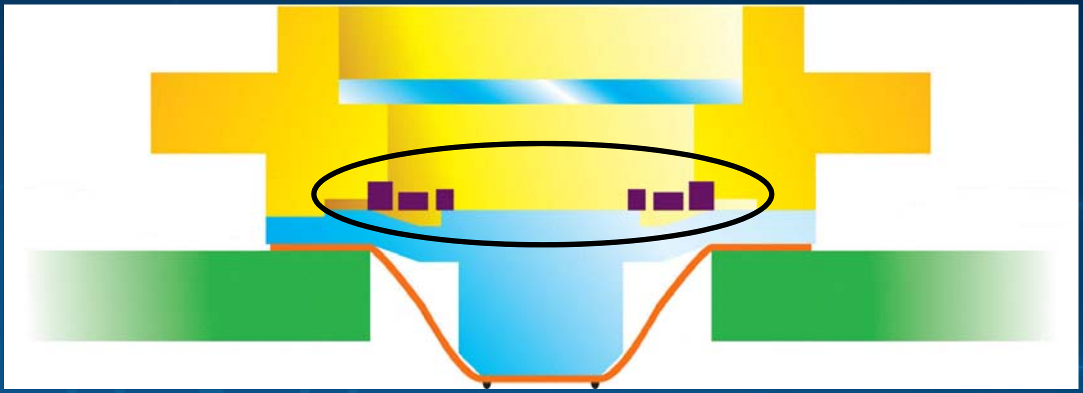
Rocking Beam Interposer

- **Addressing the Challenges of Testing Wide IO Microbumps**
  - Softer springs
    - Contact without damage
    - 1 gram at overtravel
  - Smaller probe tips
    - Higher density routing like the Wide I/O memory interface
  - Membrane space transformer
    - Clean power delivery
    - Power and GND with wider traces
    - Bypass caps on the membrane



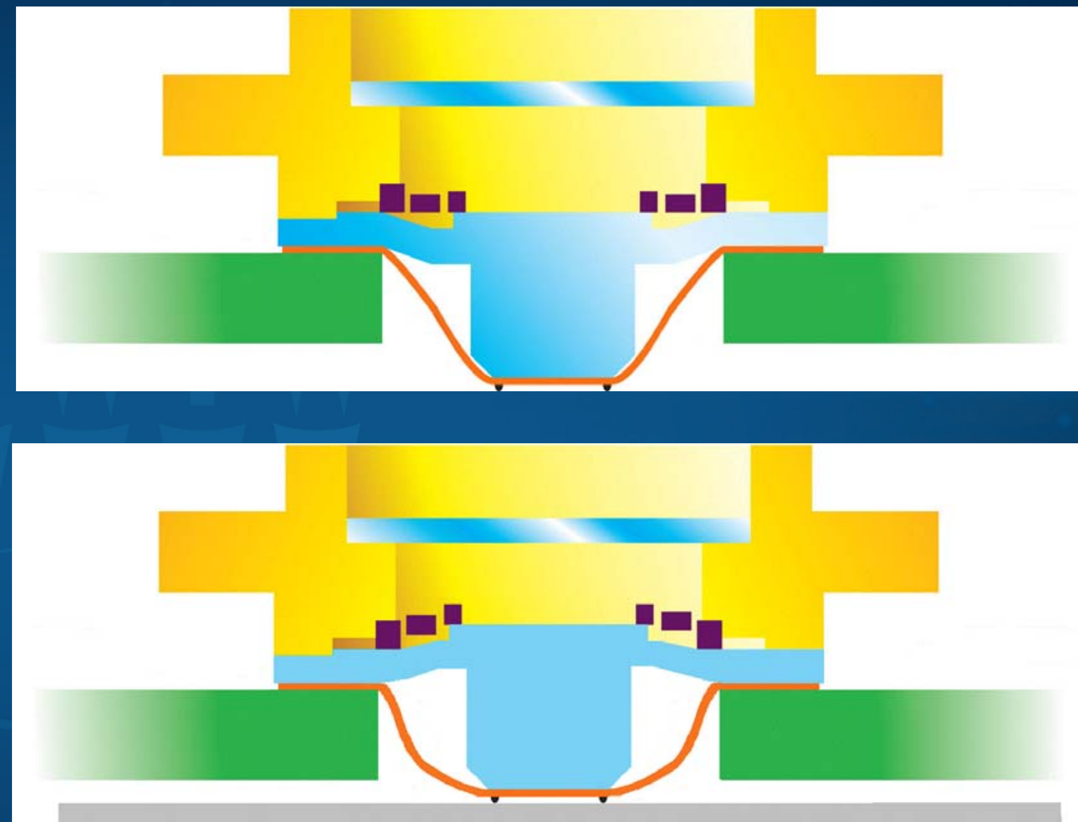
Pyramid Probe Coupled System

- **Probe Card Compliance**
  - Membrane connected to PCB by a spring
  - 10 g per tip at 150 µm overdrive
    - 0.067 g/µm per tip
    - 1.7 g/mil per tip



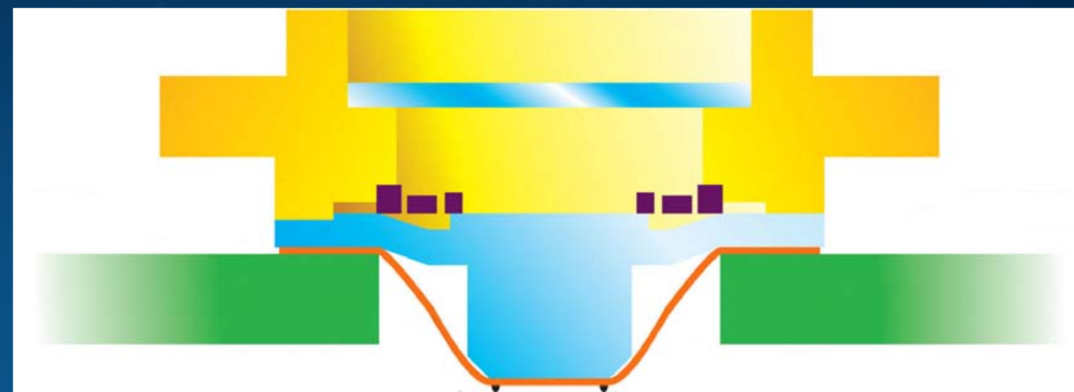
Pyramid Probe Coupled System

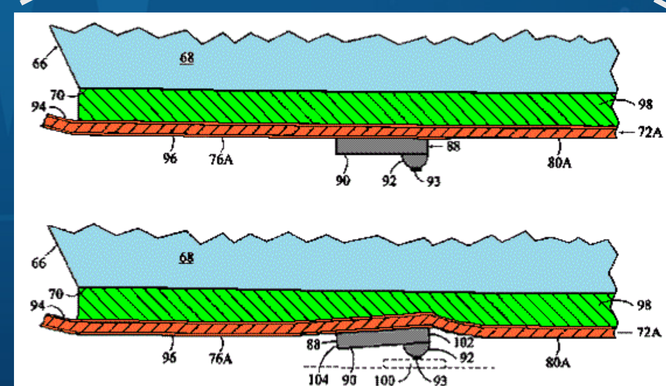
- **Probe card compliance**
  - Membrane connected to PCB by a spring
  - 10 g per tip at 150 µm overdrive
    - 0.067 g/µm per tip
    - 1.7 g/mil per tip
- **Plunger spring**
  - Force between tip and DUT
  - One spring shared by all the tips



Pyramid Probe Coupled System

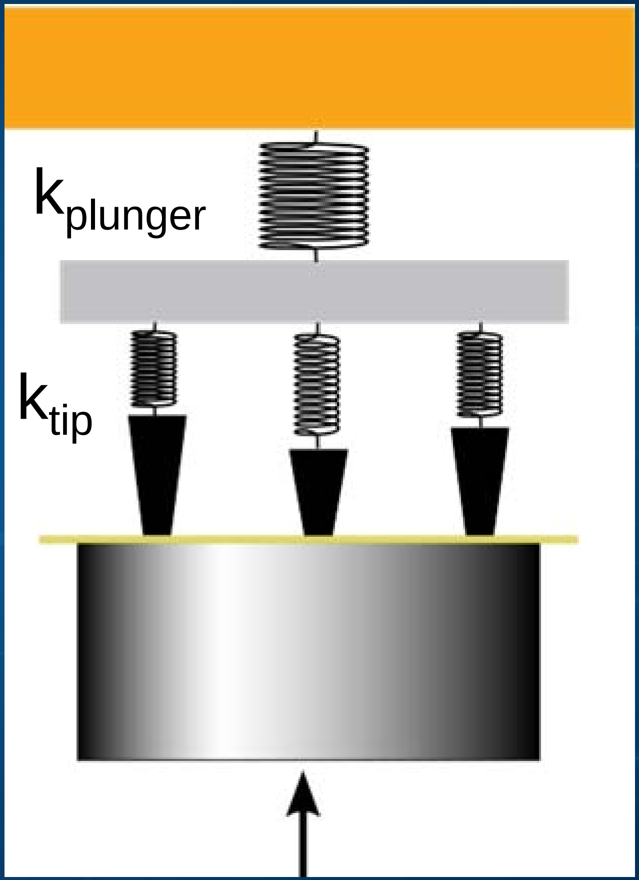
- **Probe tip compliance**
  - Membrane attached to plunger with compliant adhesive layer
  - About 2 g/µm per tip
    - 50 g/mil per tip
- **Tip spring**
  - MicroScrub®
  - Local compliance





Pyramid Probe Coupled System

- Model with series and parallel springs
- For a single tip, just series springs

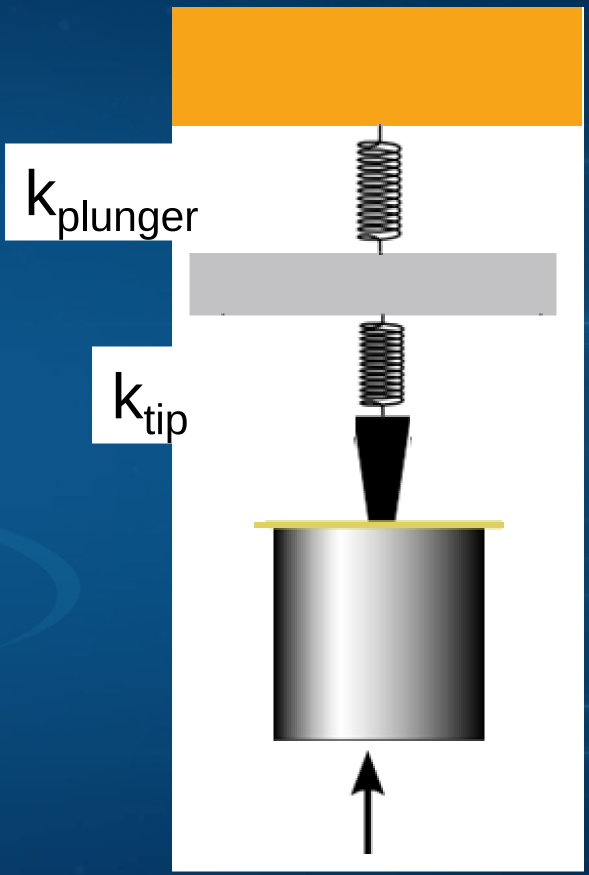


Pyramid Probe Coupled System

- Model with series and parallel springs
- For a single tip, just series springs

$$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$$

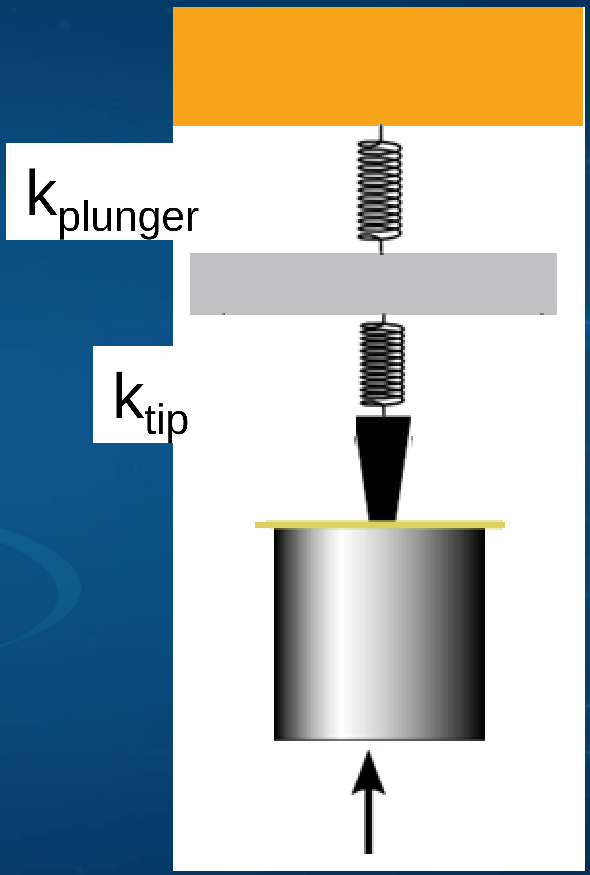
Source: Wikipedia



Pyramid Probe Coupled System

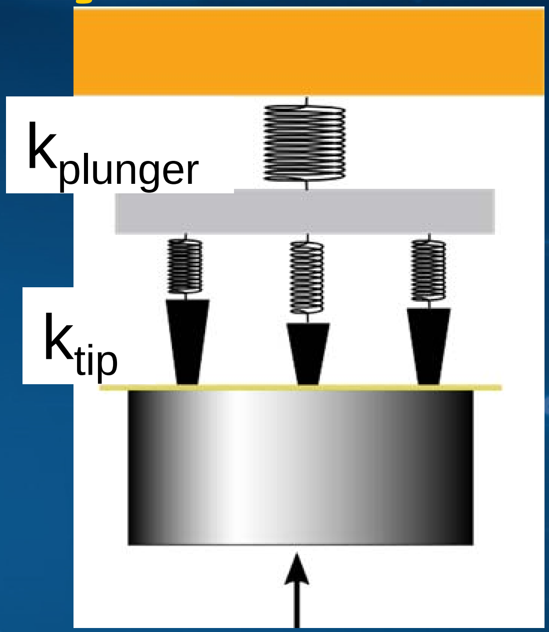
- **Series springs**
  - $k_{plunger}$ = 0.067 g/µm per tip
  - k_{tip} = 1.9 g/µm per tip
- **Programmed OT = 150 µm**
  - Plunger 145 µm
  - Tip 5 µm

$$F_{total} = k_{total} * x$$
$$F_{total} = F_{plunger} = F_{tip}$$
$$F_{total} = k_{tip} * x_{tip}$$
$$x_{tip} = F_{total} / k_{tip}$$

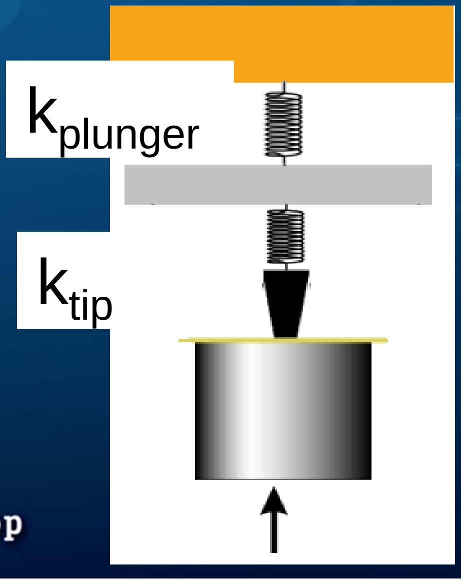


Measuring a Coupled System

- **Planarity at Plate**
  - Measure the coupled system that correlates to the wafer probe environment



- **Planarity at Post**
  - Measure manufacturing tolerances that lead to tip height variation

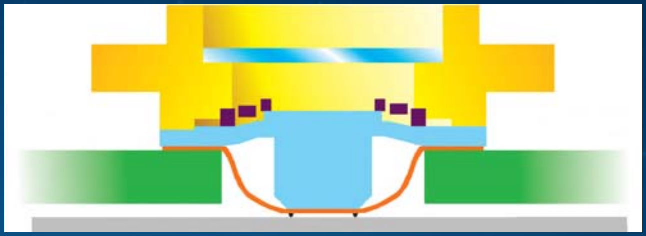


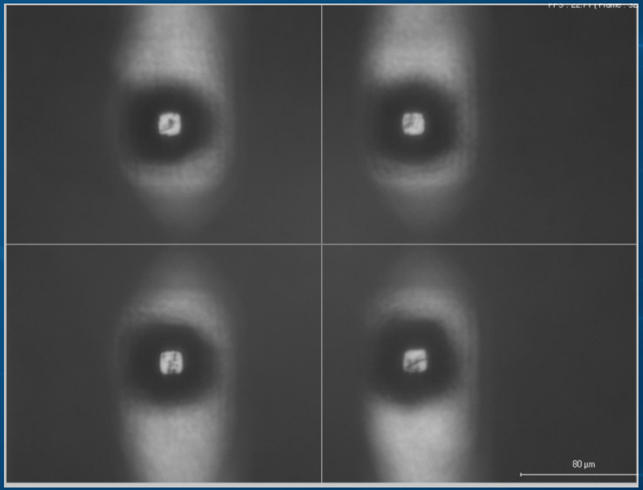
Need for Metrology

- **Internal**
  - Manufacturing/Quality
    - X,Y
    - Planarity
    - Contact resistance
    - Leakage
  - Engineering
    - Don’t try this at home
- **Customer**
  - IQC
  - Troubleshooting
    - X,Y
    - Planarity
    - Contact resistance
    - Leakage

Metrology Challenges

- **Membrane space transformer**
  - Coupled system – tip to tip
    - Requirement for full contact or small deflection
  - Coupled system – spring stack
    - Unconventional spring rates
  - Over travel control
  - Force control
- **Short probe tips**
  - Short
    - Vision system
    - Over travel control
    - Force control
- **Mechanical vs. Electrical Trade-offs**
  - Easy to measure bulk behavior with a plate
  - Challenges when measuring with a post

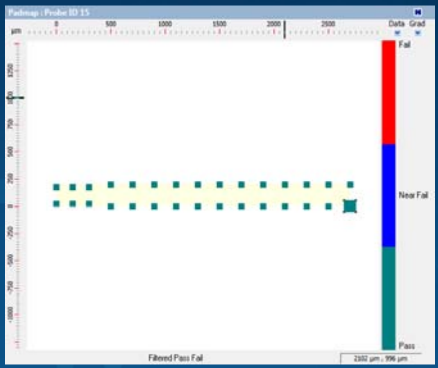


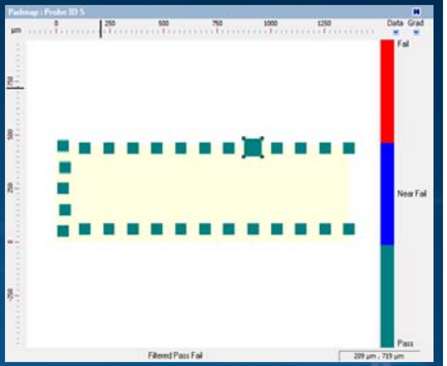


Metrology Challenges Summary

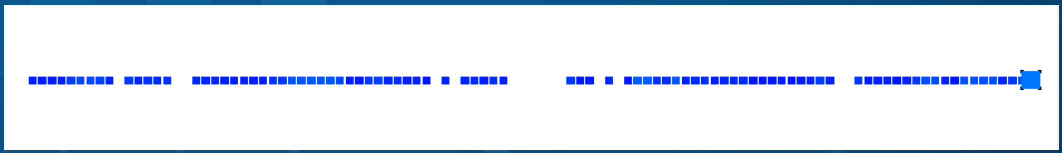
- **Pyramid Probe Cards**
  - Very strong probe tip spring (1-4 grams/micron)
  - Individual probe tip overtravel (OT) must be limited to 20 microns
  - Coupled system of probe tip springs and plunger spring
  - No overhanging probes during overtravel
- **RBI Probe Cards**
  - Individual probe tip overtravel (OT) must be limited to 5 microns
  - Coupled system of probe tip springs and plunger spring
  - No overhanging probes during overtravel
  - Small probe tips surrounded by visible structure (grainy beams, posts, traces, pads)
  - Short probe tips so surrounding structure is close to probe tip focus plane

Test Setup



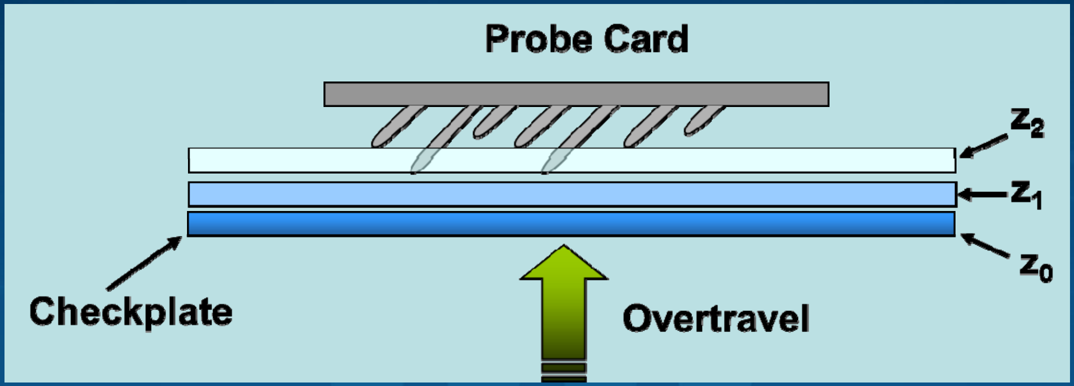


- **Pyramid Probe Cards**
  - Parametric probe cards
  - 30 probes
  - 100-150 micron minimum pitch
  - Spring rates ~= 1.3gm/um, 1.9gm/um
- **RBI Probe Card**



  - Microbump probe card
  - ~100 probes, limited electrical connections
  - 40 micron minimum pitch
  - Spring rate ~= 0.3 gm/um
- **VX4**
  - Configured with 35 micron diameter posts

Planarity @ Plate Measurement (non-bussed probes)



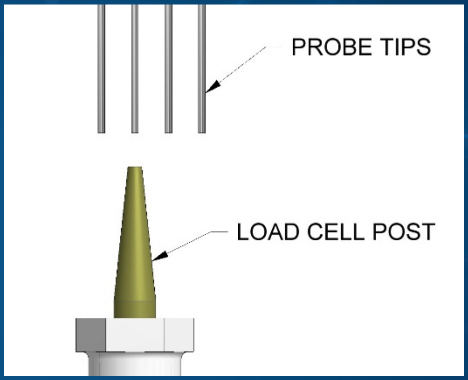
Pyramid and RBI Probe Cards

- Easy!
- Coupled system of springs
  - May need large Max OT in order for high probes to contact checkplate

Planarity @Post Measurement (all probes)

Pyramid and RBI Probe Cards

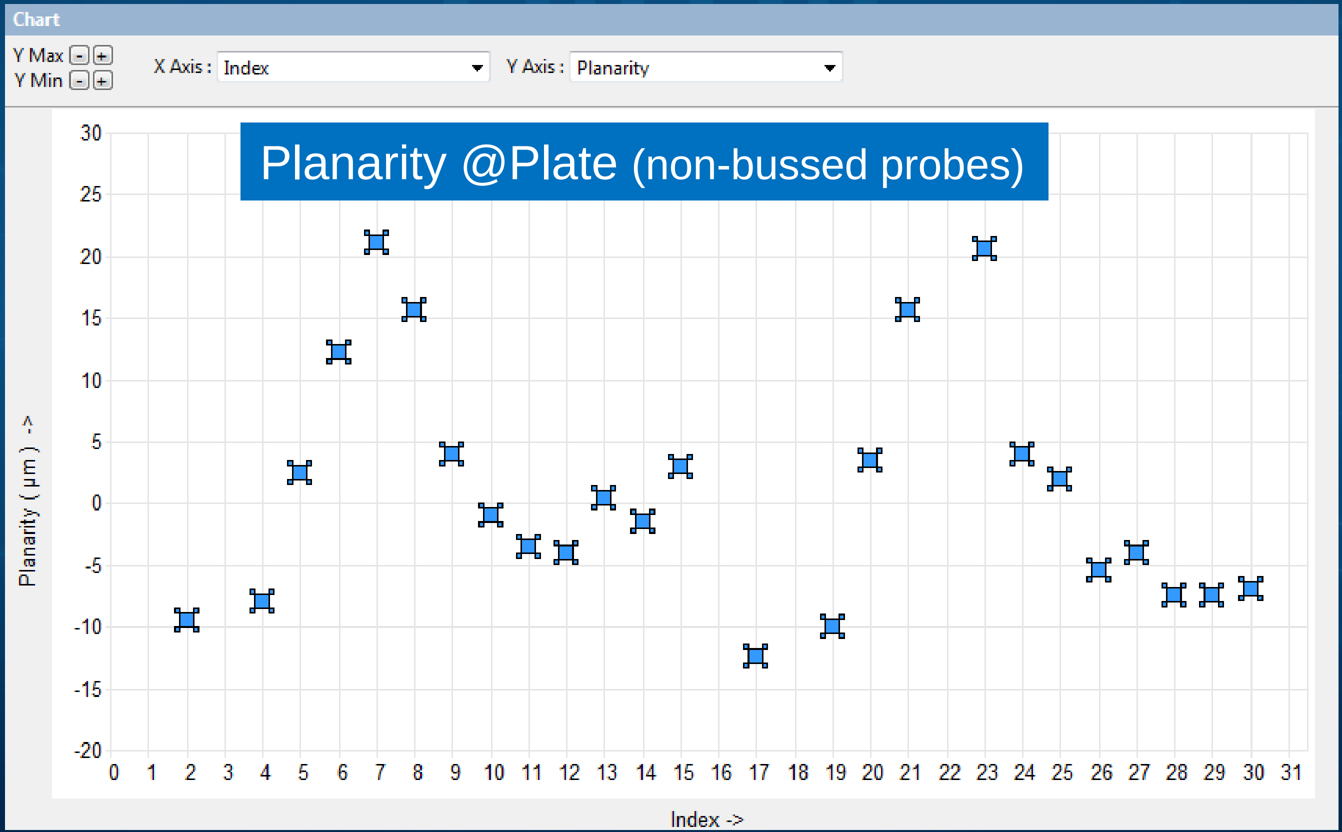
- **Pyramid Probe individual probe tip MaxOT = 20 microns**
- **RBI individual probe tip MaxOT = 5 microns**
  - Utilize post attached to load cell for measurement
  - Provides two layers of safety for Z-motion:
    - Stop on electrical contact
    - Stop on load
  - Planarity is measured by either electrical contact or force
  - Requires ultra-precise overshoot control to maintain throughput



– **RBI Fine Pitch (40 microns)**
  - Small diameter post required
  - Accurate post position calibration, accurate stage positioning and accurate measurement of probe tip positions

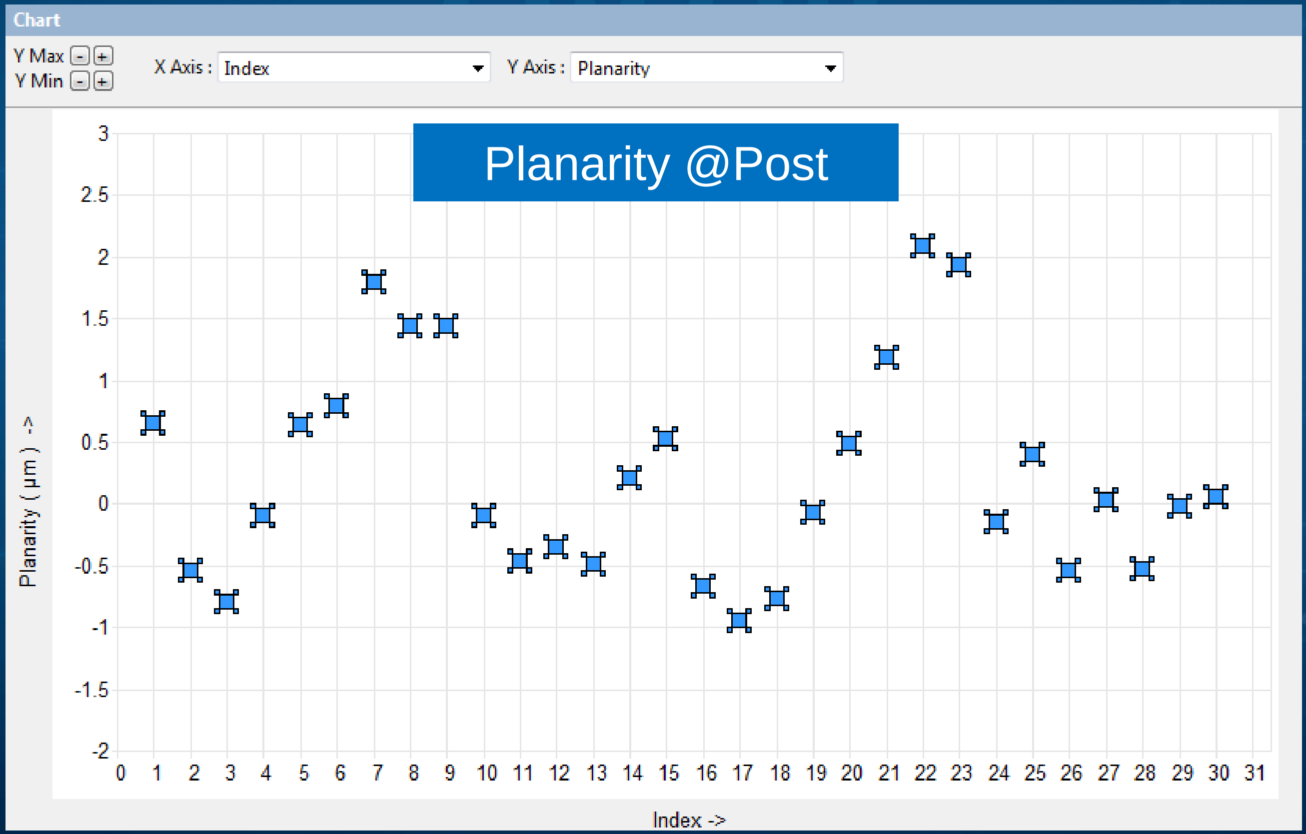
Planarity@ Plate Results – Pyramid Probe Card

- Correlates to when probes will contact wafer
- Planarity range ~= 40 microns



Planarity @Post Results – Pyramid Probe Card

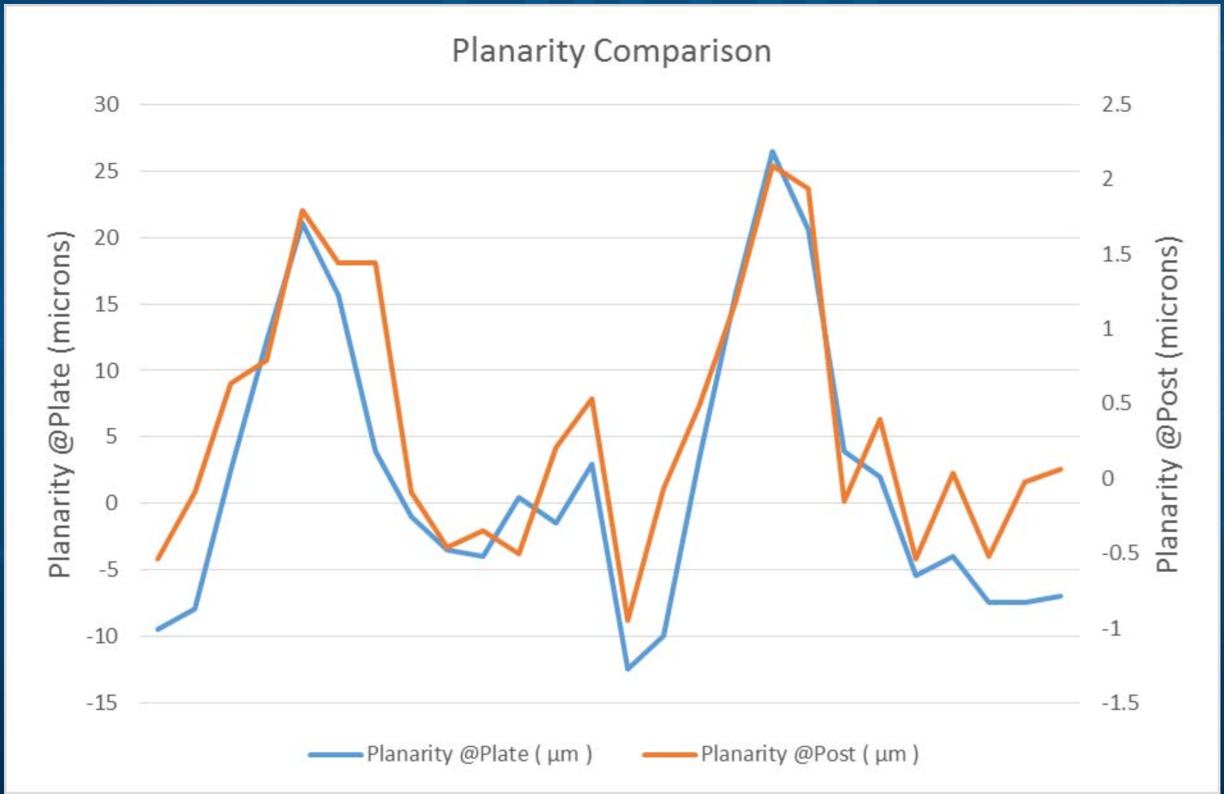
- Corresponds to tip height variation
- Planarity range ~= 3 microns



Planarity Comparison – Pyramid Probe Card

- Compare Planarity @Plate to Planarity @Post
- Same shape, different ranges due to effects of coupled system

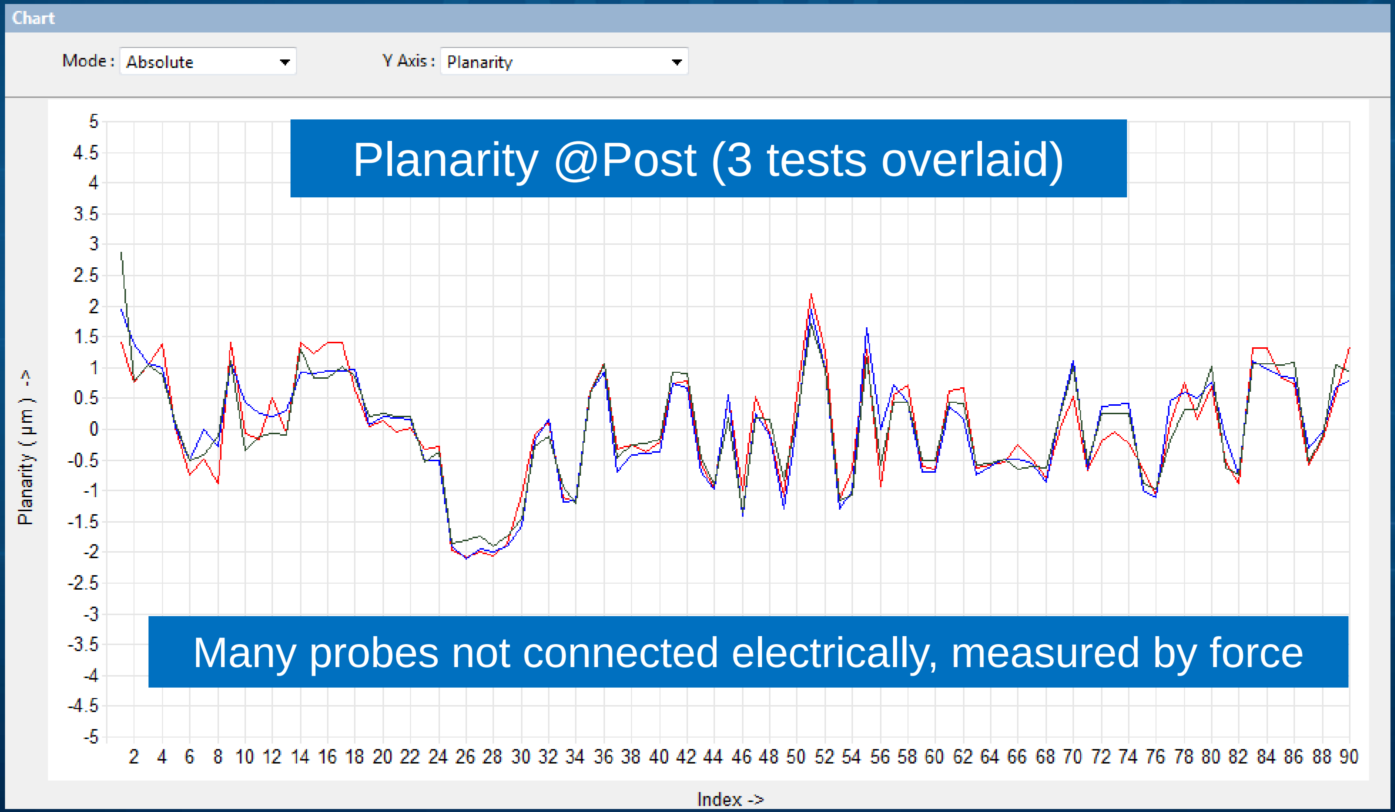
Plate



Post

Planarity @Post Results – RBI Probe Card

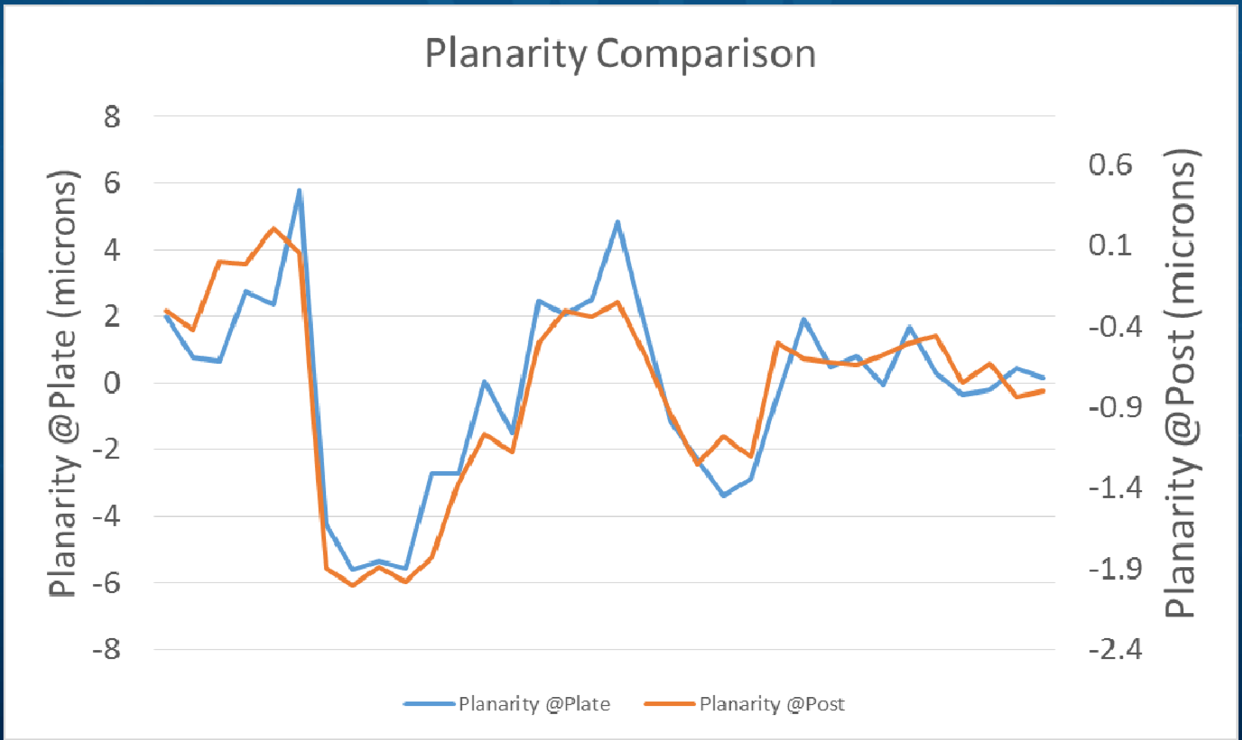
- **Corresponds to tip height variation**
- **Planarity range ~= 4 microns**



Planarity Comparison – RBI Probe Card

- Only have a sub-set of Planarity @Plate data for comparison (due to lack of electrical connections)
- Same shape, different ranges due to effects of coupled system

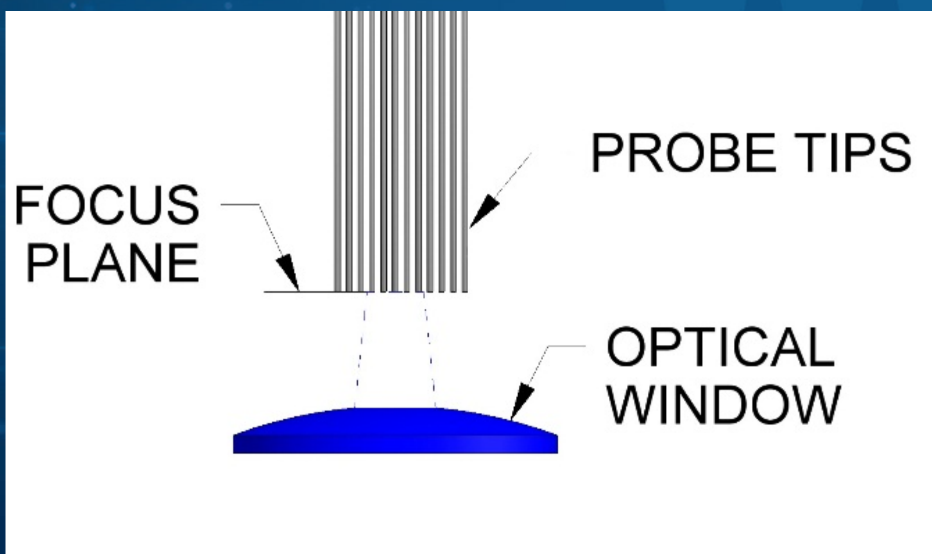
Plate

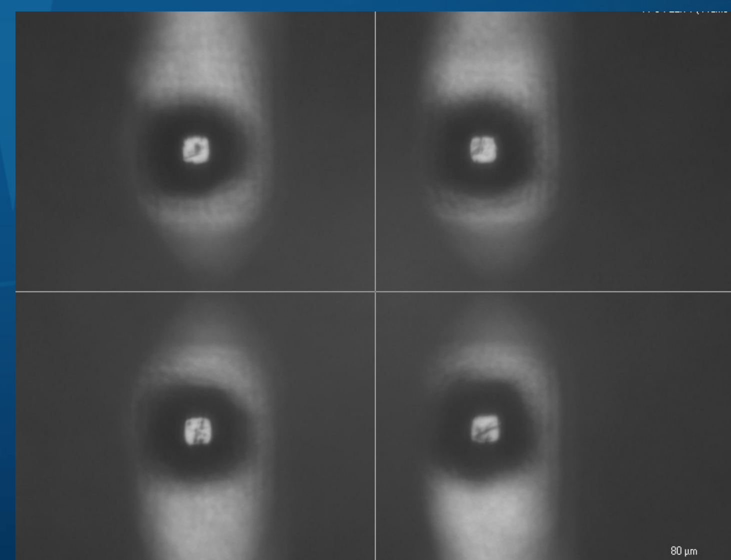


Post

Alignment Measurement: Pyramid Probe Cards

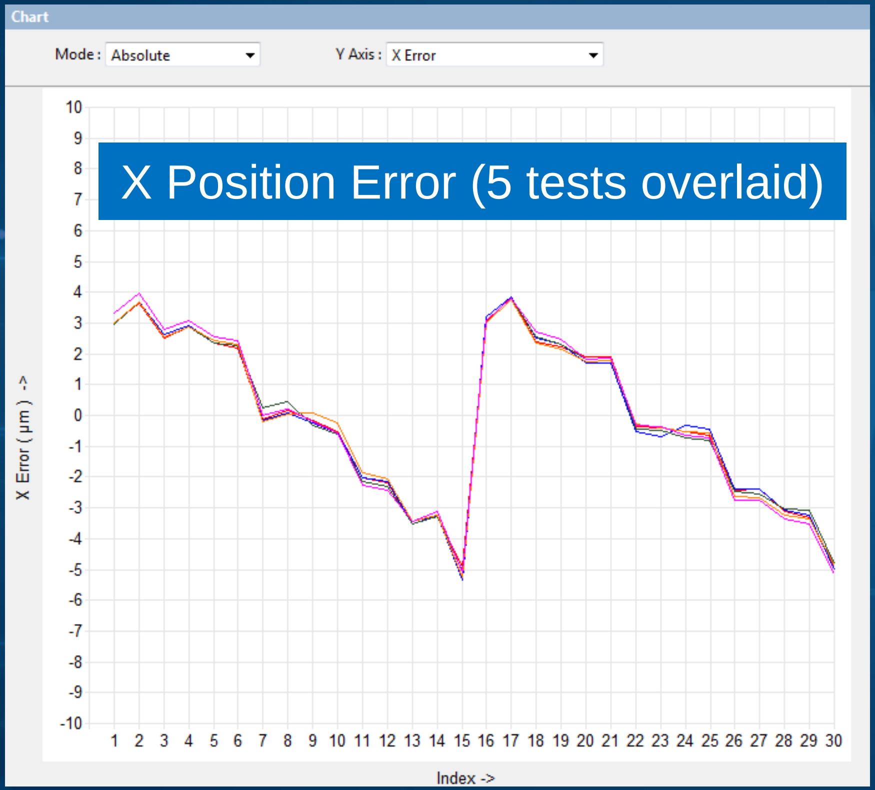
- **Probe array must be fully supported**
- **Probe tips have minimal scrub at OT**
  - Measure X, Y probe position without contacting probe tips with focus position well above window surface (No-Touch Alignment)

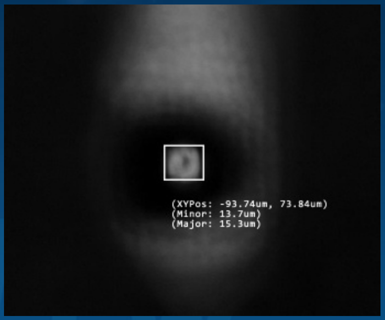


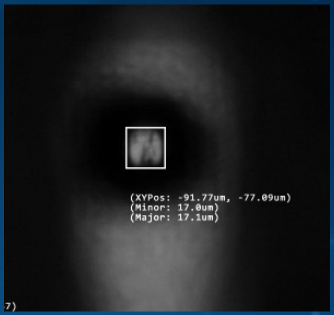


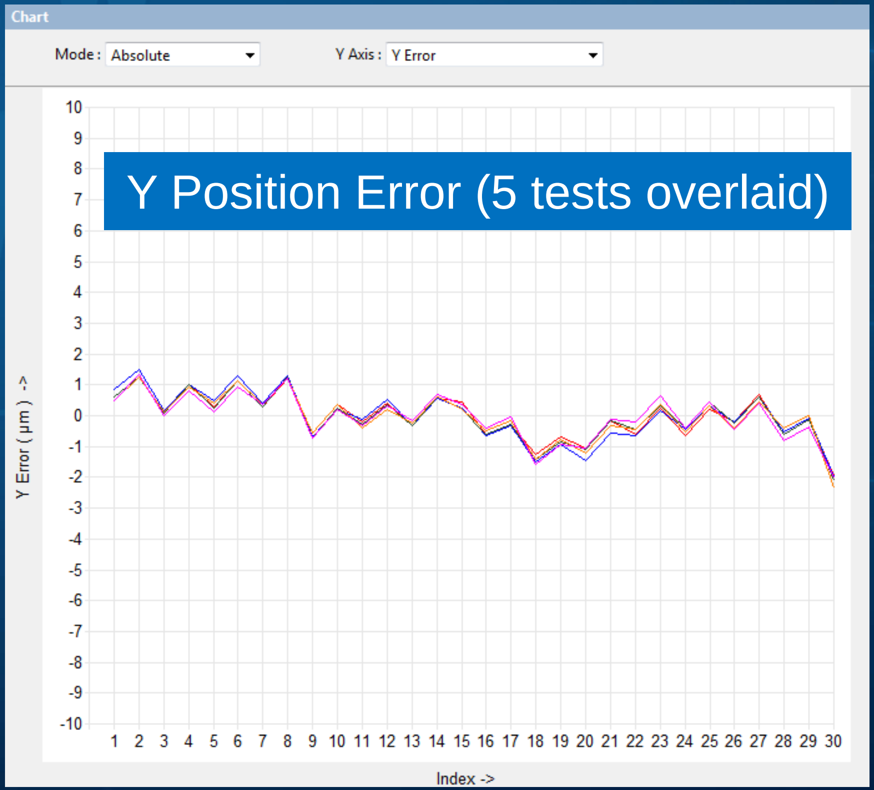
Alignment Results – Pyramid Probe Card

Pyramid Probe Card





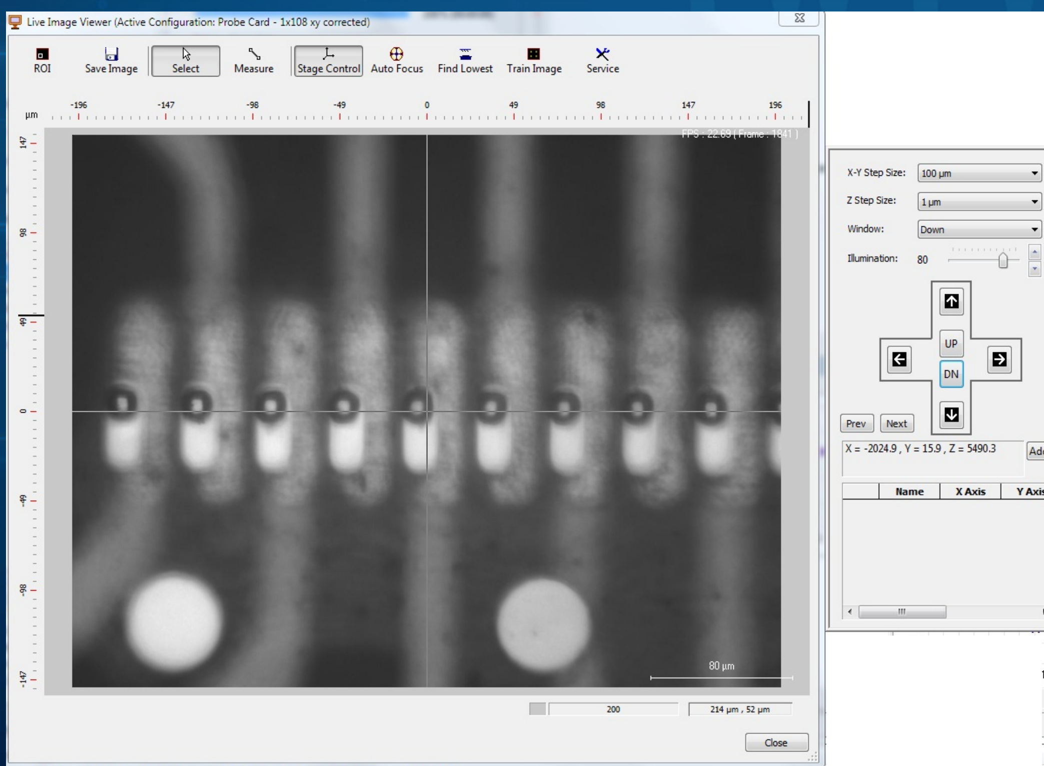


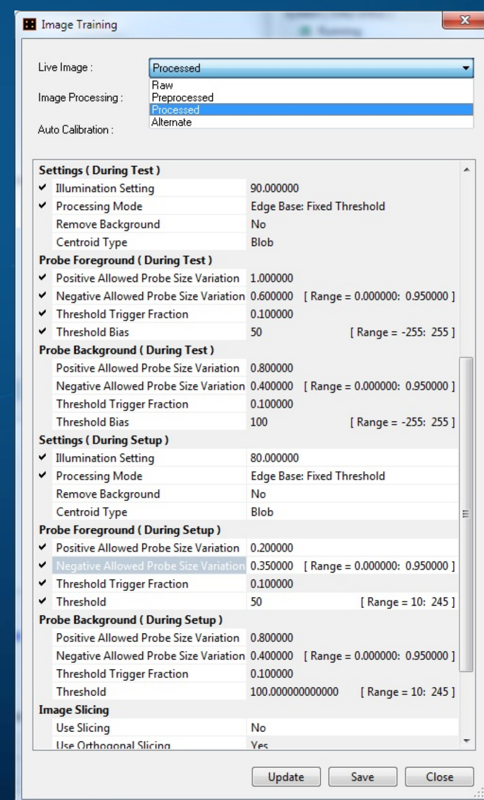


- Very repeatable Alignment results (sub-micron)

Alignment Measurement : RBI Probe Cards

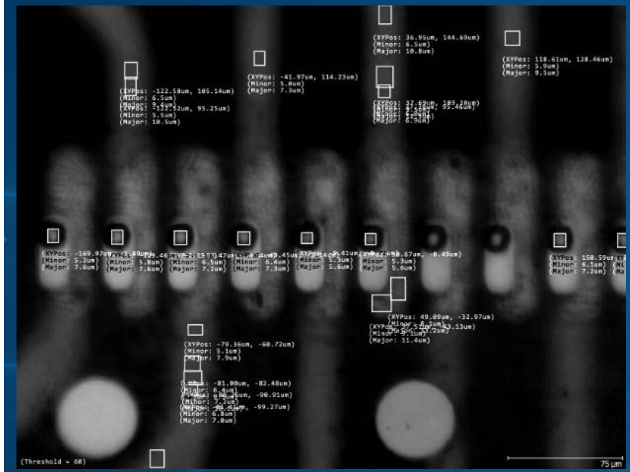
- **RBI has small probe tips and lots of in focus visible structure surrounding probe tips (grainy beams, posts, traces, pads)**
  - Live Image Viewer provides in real-time tunable image processing to discriminate probe tips from background

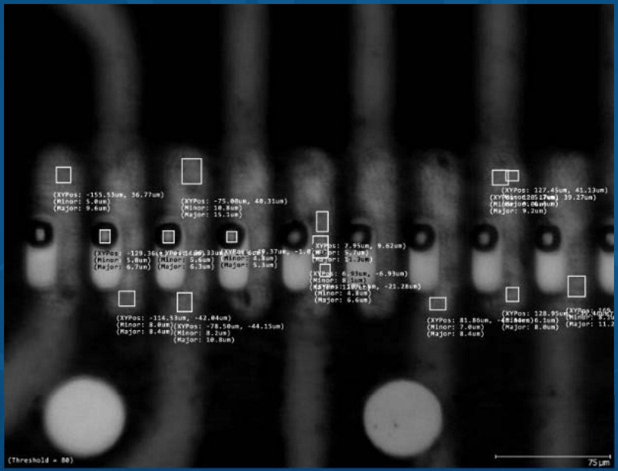


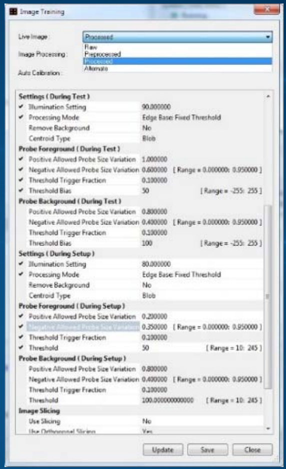


Alignment Measurement : RBI Probe Cards

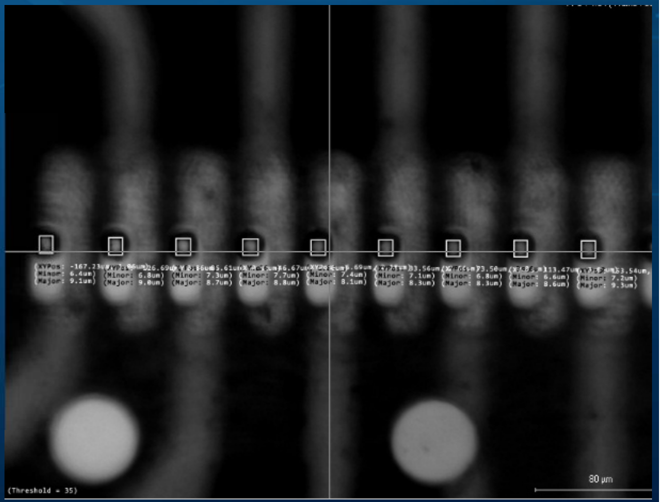
- Using Live Image Viewer to tune image processing parameters in real-time





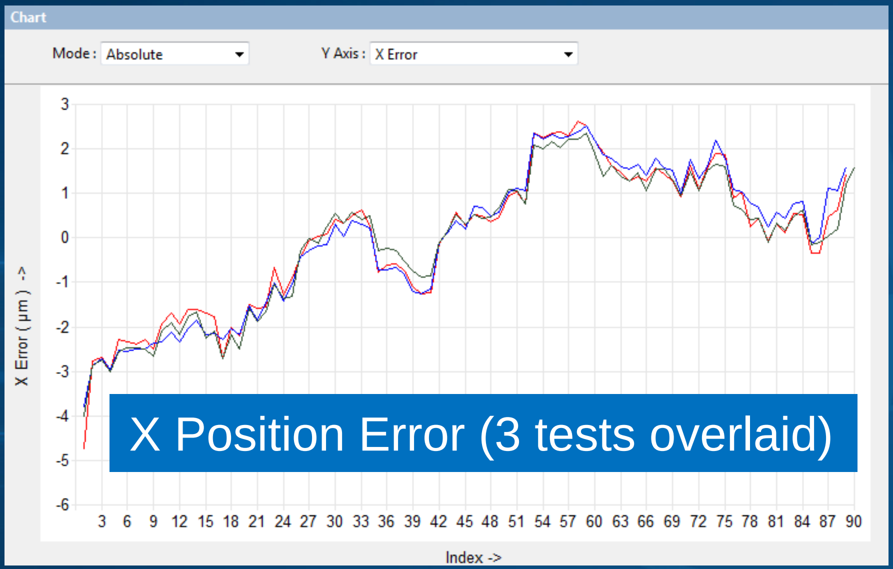


Tuning image processing parameters

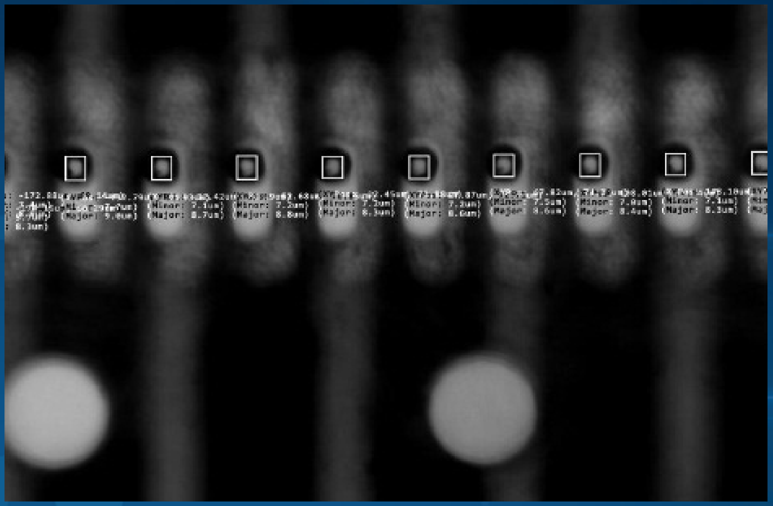


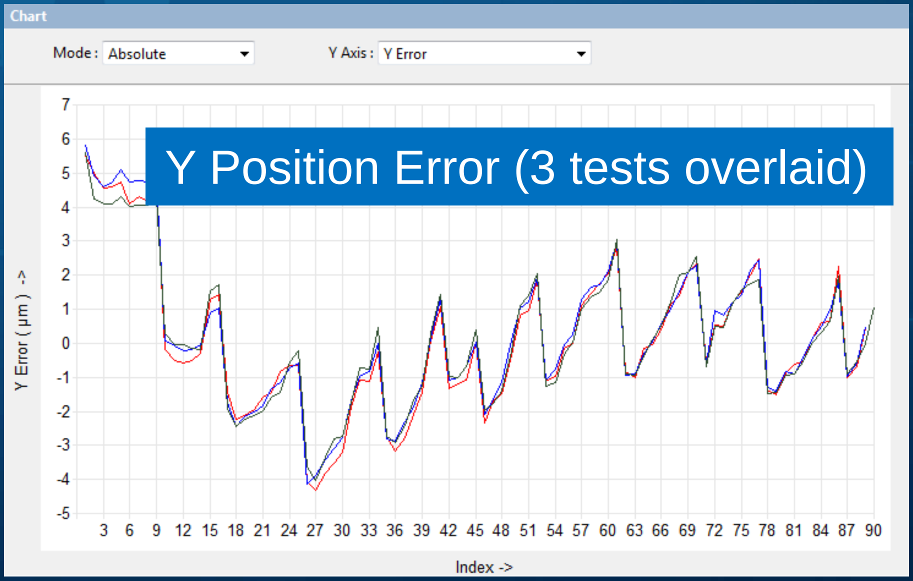
Alignment Results – RBI Probe Card

RBI Probe Card



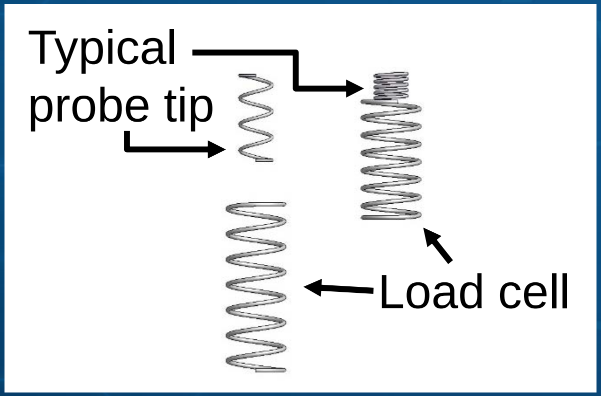
- Very repeatable Alignment results (sub-micron)

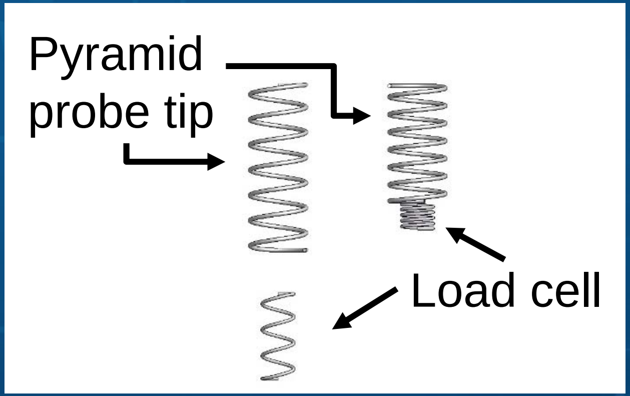




Probe Force Measurement: Pyramid Probe Cards

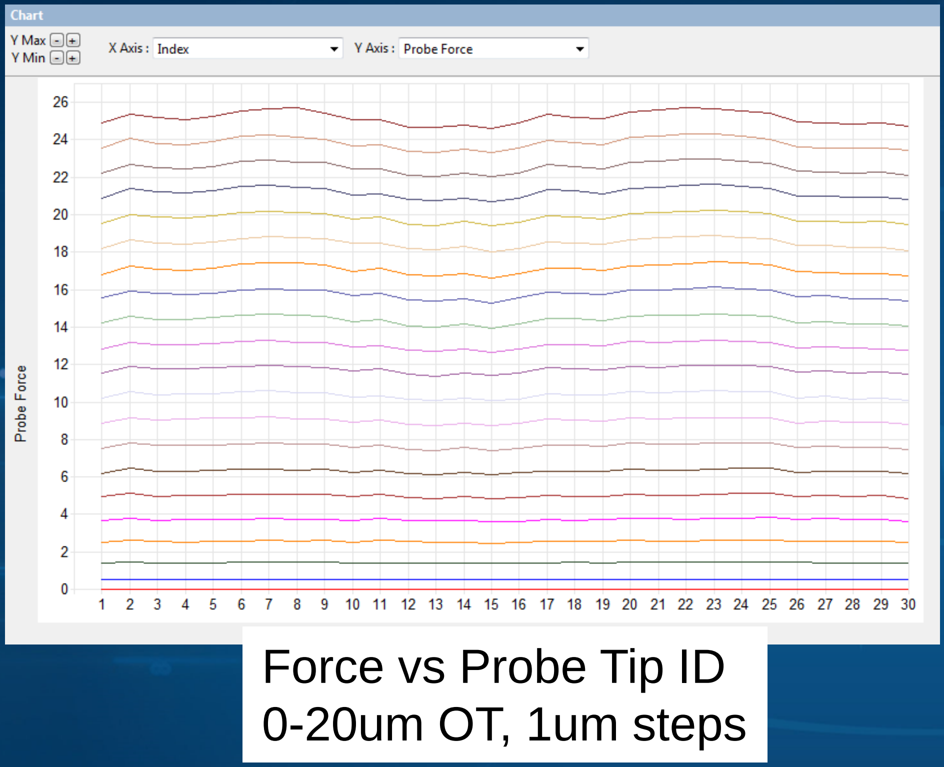
- **Large probe tip spring rate (1–4 gm/um)**
  - Probe force measurement uses a compliant load cell
    - Need to compensate for load cell deflection (AOT ≠ POT) to get accurate probe force measurements
    - Load cell spring is typically > 5X stiffer than probe tip

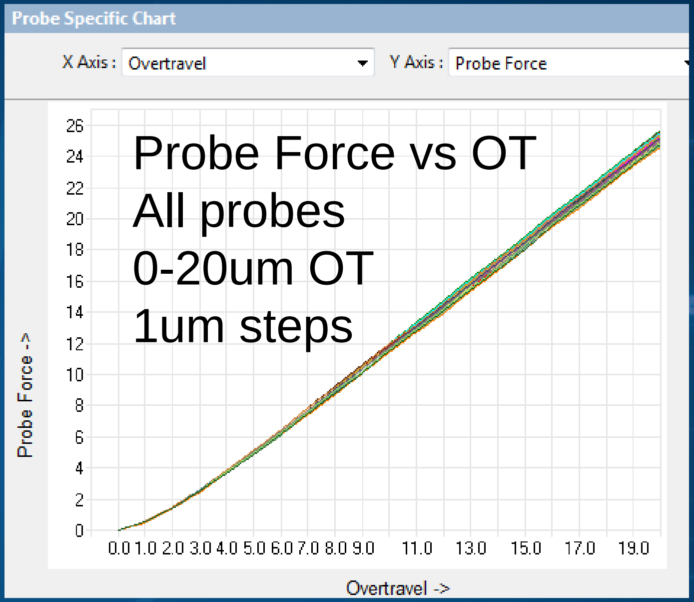




- **Pyramid probe tip spring can be 5X stiffer than load cell spring**
  - Without compensation Pyramid Probe tip AOT << POT during PF testing
  - Accurate deflection compensation is **<u>critical</u>** for Pyramid Probes

Probe Force Results – Pyramid Probe Card





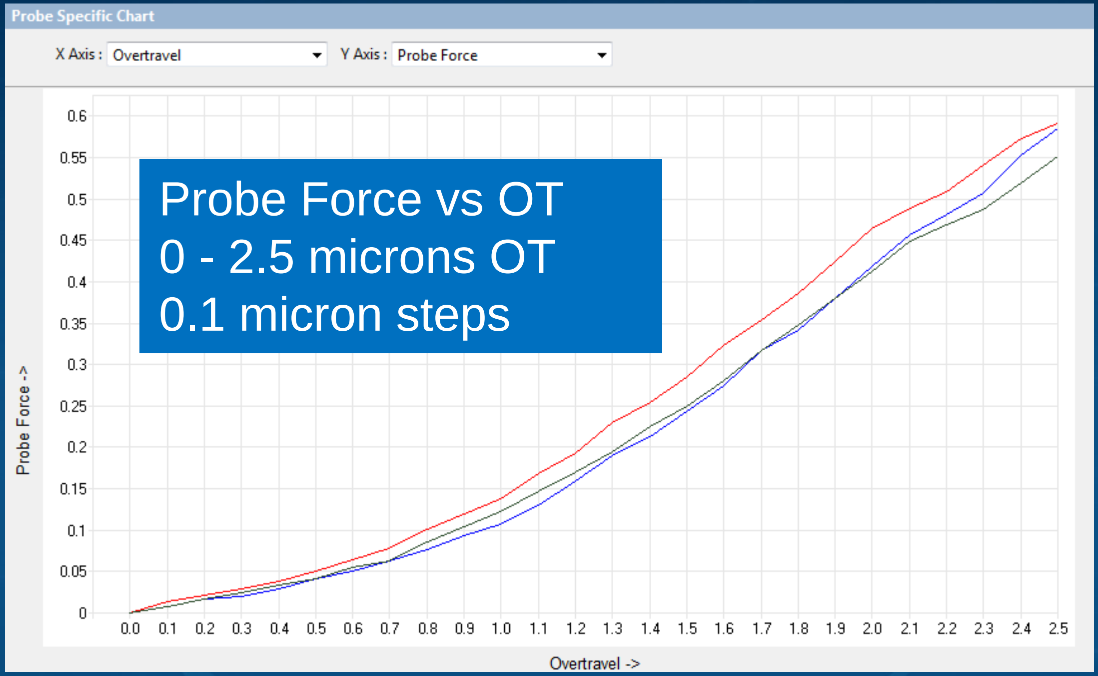
- Probe force is very uniform across the array
- Probe tip spring is very linear
- Load cell compensation working effectively

Probe Force Measurement: RBI Probe Cards

- **RBI individual probe tip MaxOT = 5 microns**
  - Two layers of safety for Z-motion:
    - Stop on electrical contact and stop on load
  - Requires ultra-precise overshoot control to maintain throughput
  - Requires high resolution z-motion to collect data over small range of allowed overtravel
  - Requires high precision force measurement to measure small changes in force over small range of allowed overtravel

– **RBI Fine Pitch (40 microns)**
  - Requires small diameter post (35 micron)
  - Accurate post position calibration, accurate stage positioning and accurate measurement of probe tip positions

Probe Force Results – RBI Probe Card



- **Results demonstrates precision force measurement to resolve the small changes in force (0.5 grams over 2.5 microns OT)**
- **Results demonstrate high resolution z-motion (100nm steps) needed to characterize force over this small range of OT**

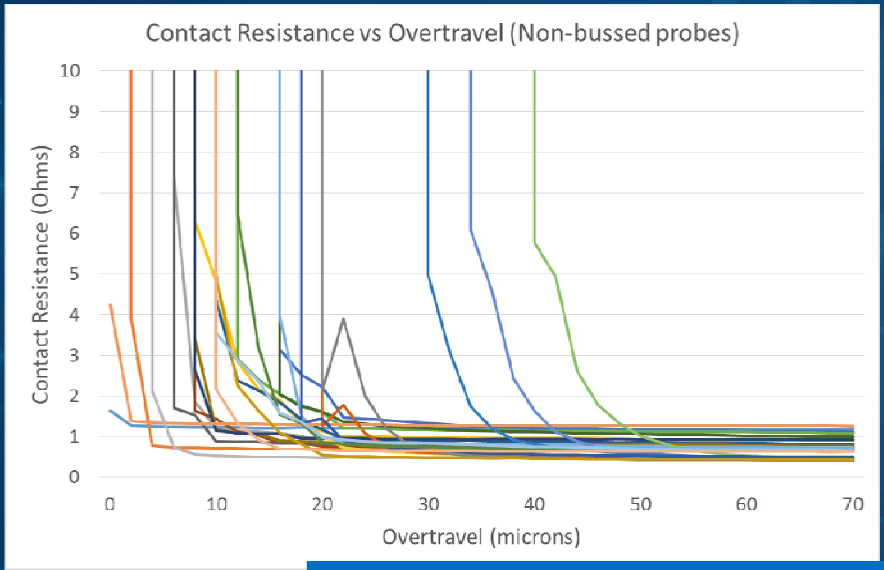
Contact Resistance Measurement

Pyramid and RBI Probe Cards

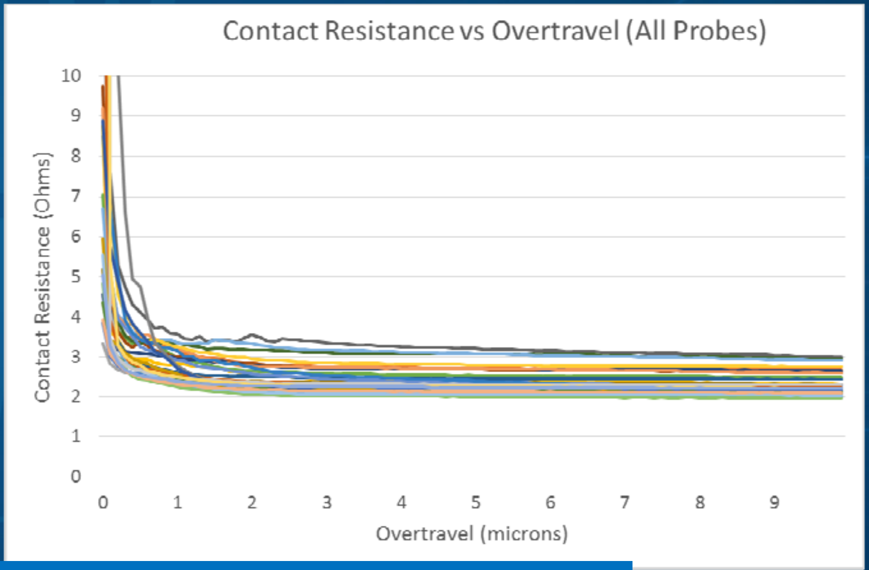
- **CRES @Plate (Non-bussed probes)**
  - Easy!
  - Need to provide sufficient overtravel to ensure all probes make good contact
- **CRES @Post (All probes)**
  - Need to provide additional overtravel so AOT = POT for Pyramid probes
  - Need to provide ultra-precise OT and overshoot control for RBI probes

CRES Results– Pyramid Probe Card

CRES with Rh Plate: 0-70um
Step size = 2 microns



CRES with W-C Post: 0-10um
Step size = 0.1 microns



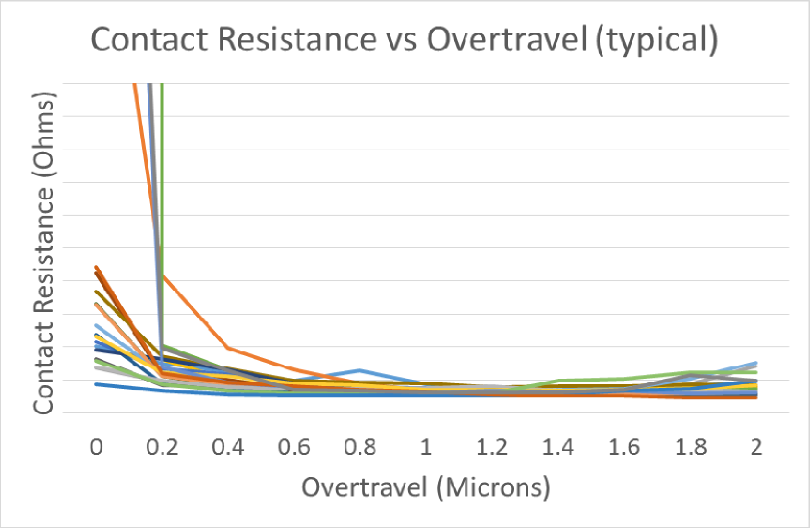
Values includes path resistance of both probe card and probe card analyzer

- Excellent contact performance
  - CRES values stabilize almost immediately after initial contact

CRES Results– RBI Probe Card

CRES with Tungsten-Carbide Post

0-2 microns OT, Step size = 0.2 microns



- **CRES values stabilize almost immediately after initial contact**
- **Extremely high resolution Z-motion needed to characterize tip resistance over this range of OT**

Summary

- **Pyramid Probe and RBI are well poised to meet industry trends**
  - Advanced packages
  - Shrinking technology nodes
  - More RF
- **Pyramid Probe and RBI provide unique metrology challenges**
- **VX4 able to meet metrology challenges of Pyramid Probe and RBI and successfully measure:**
  - Planarity at Plate (Non-bussed probes)
  - Planarity at Post (all probes)
  - Alignment
  - Contact Resistance at Plate (Non-bussed probes)
  - Contact Resistance at Post (all probes)
  - Probe force

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References

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