Novel Methodologies for Assessing On-line Probe Process Parameters

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Overview

- Introduction
- Approach / Objectives
- Methodology
- Implementation / Characterization
- Summary

Introduction – What we already know !

- Intimate and reliable contact between the probe and the device under test is critical for proper test routine execution.
- High and unstable contact resistance (CRES) is one of the biggest factors in reduced wafer sort yields.
- CRES instability is caused by debris accumulation and a build-up of contamination on the contacting surface.
- CRES is entirely attributable to the interfacial phenomena across the contact area and with any adherent contaminant.

Introduction – What we already know !

- Simply, probes generate debris and accumulate materials.

- One of many models proposed (Babu, et. al 2001) …

$$C_{RES} = \frac{\left(\rho_{probe} + \rho_{wafer}\right)}{4}\sqrt{\frac{\pi H}{P}} + \frac{\sigma_{film} H}{P}$$

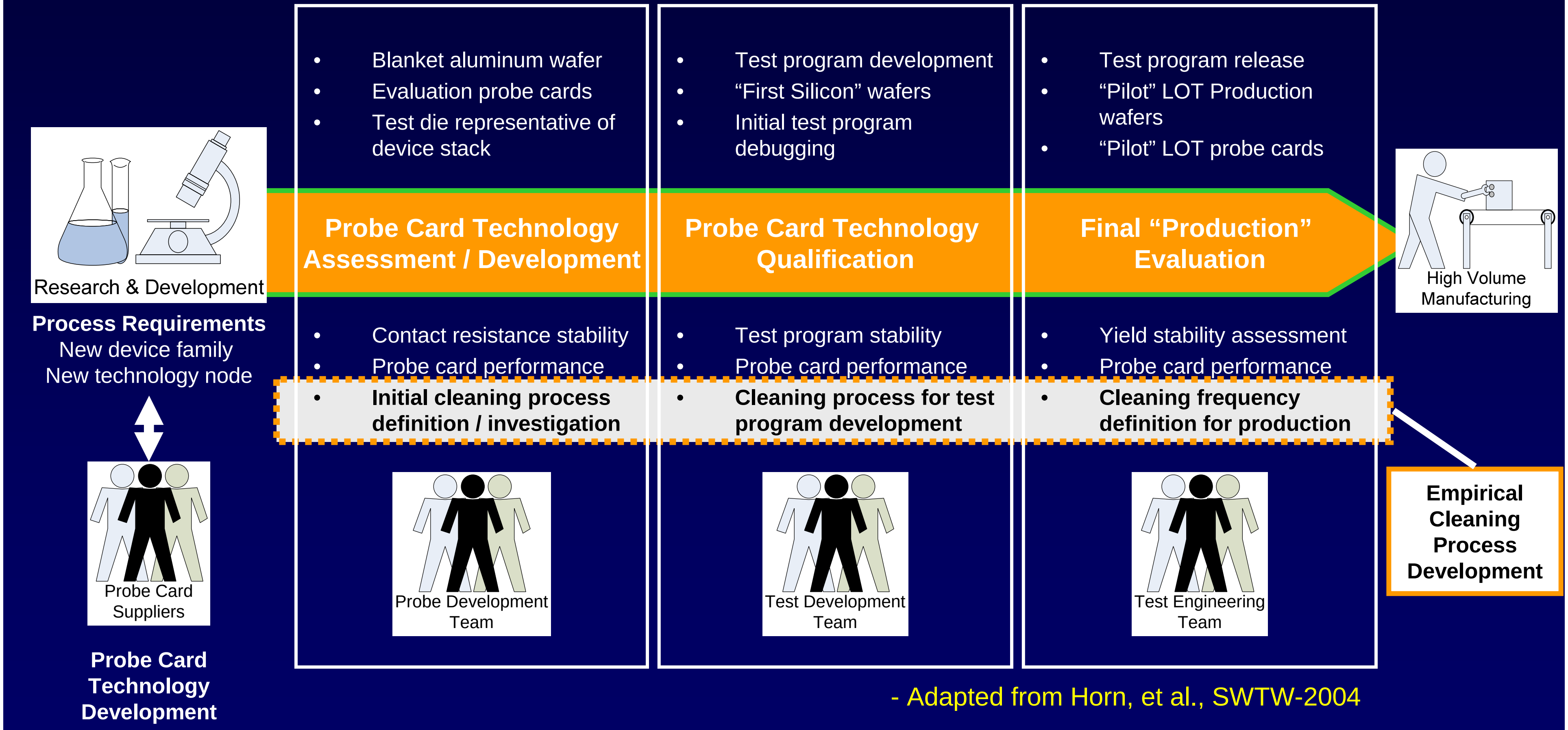
  - ρ_{pad}, ρ_{probe}, ρ_{film} = resistivity values
  - σ_{YS} = material yield strength
  - P = contact pressure
  - a = average radius of contacting asperities, or *a-Spot* size
  - η = number density of *a-Spots* that are in real contact

  – Contact pressure (P) applied force normalized by true contact area
  – η, a depend on the surface roughness of the contacting solids

- Probe cleaning <u>IS</u> needed in wafer sort for CRES control and maintaining Equipment Operating Efficiency (OEE).

General Probe Evaluation Process

- Although probe cleaning has a measurable impact on all aspects of OEE, key parameters (e.g., frequency, etc.) are empirically determined.



Process Requirements
New device family
New technology node

Probe Card Technology Development

Probe Card Technology Assessment / Development
- Blanket aluminum wafer
- Evaluation probe cards
- Test die representative of device stack
- Contact resistance stability
- Probe card performance
- **Initial cleaning process definition / investigation**

Probe Card Technology Qualification
- Test program development
- "First Silicon" wafers
- Initial test program debugging
- Test program stability
- Probe card performance
- **Cleaning process for test program development**

Final "Production" Evaluation
- Test program release
- "Pilot" LOT Production wafers
- "Pilot" LOT probe cards
- Yield stability assessment
- Probe card performance
- **Cleaning frequency definition for production**

Empirical Cleaning Process Development

- Adapted from Horn, et al., SWTW-2004

Approach / Objectives

- From a probe cleaning standpoint, several key shortcomings of the general evaluation process can be identified …
  - Blanket materials are not truly representative of the device metal.
  - Resources to assess material(s) performance are unavailable.
  - Limited “first silicon” and short product development cycles prohibit a high number of touchdowns as well as iterative characterizations.
  - Development of “optimized” cleaning processes for the high volume manufacturing (HVM) environment often occurs “on the fly”.

Approach / Objectives

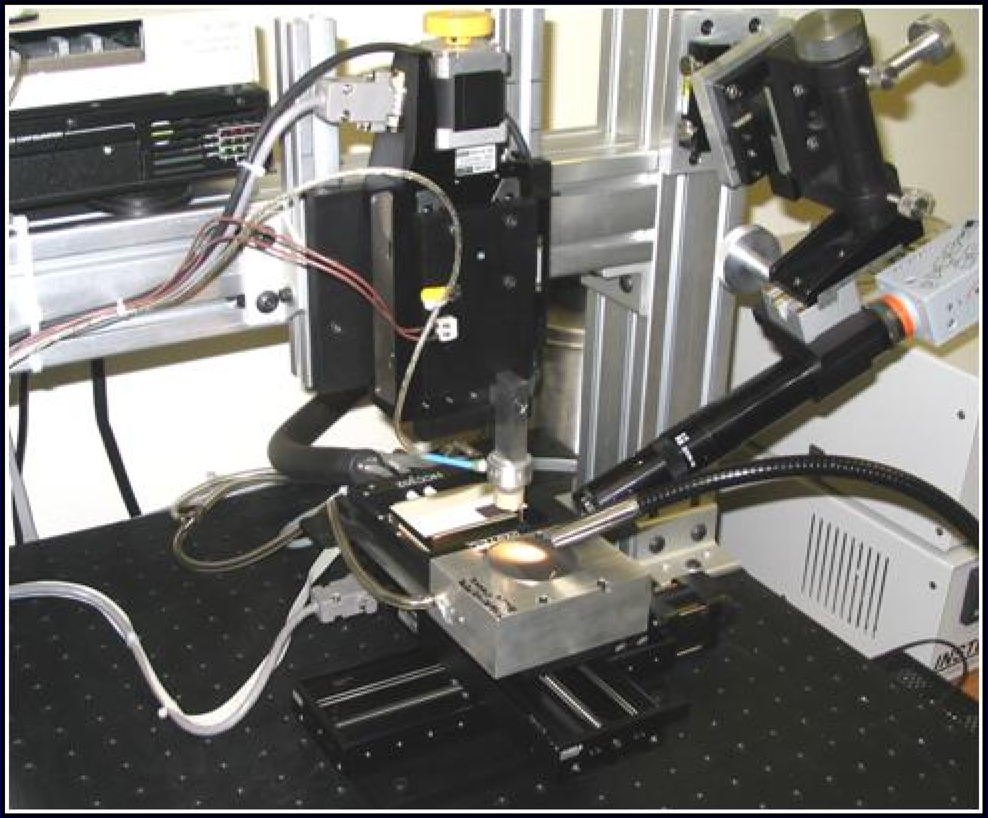
- Cleaning process development should be possible using blanket wafers, test-die, scrapped die, etc., as well as various probe technologies.
  - Process development should not be limited to blanket materials.
  - High number of touchdowns utilizing very “little real estate”
  - z-Overtravel consistency and low-load measurement capabilities to facilitate investigation of pad materials (thickness, hardness, etc.)

Approach / Objectives

- GOAL - Develop tools and methodologies to effectively …
  - Characterize / quantify key cleaning material performance metrics.
  - Visualize probe technology and cleaning material interactions.
  - Develop “standardized” methodologies for cleaning process optimization using materials representative of the FAB process (e.g., scrapped devices).

- Characterization tool requirements …
  - Basic material testing capabilities
    - Probe force vs. z-Overtravel to assess performance consistency
    - Repeated insertions to quantify probe-tip wear
    - Probe force vs. z-Overtravel vs. CRES for basic contact studies
    - Stable thermal performance across a wide temperature range
  - Precise motion control along all axes

Laboratory Test Unit (LTU)



LTU with precision XY Stages (± 1 um)
and high precision Z-Stage (± 0.2 um)

NI - LabVIEW for Motion Control,
DAQ, and Video Capture

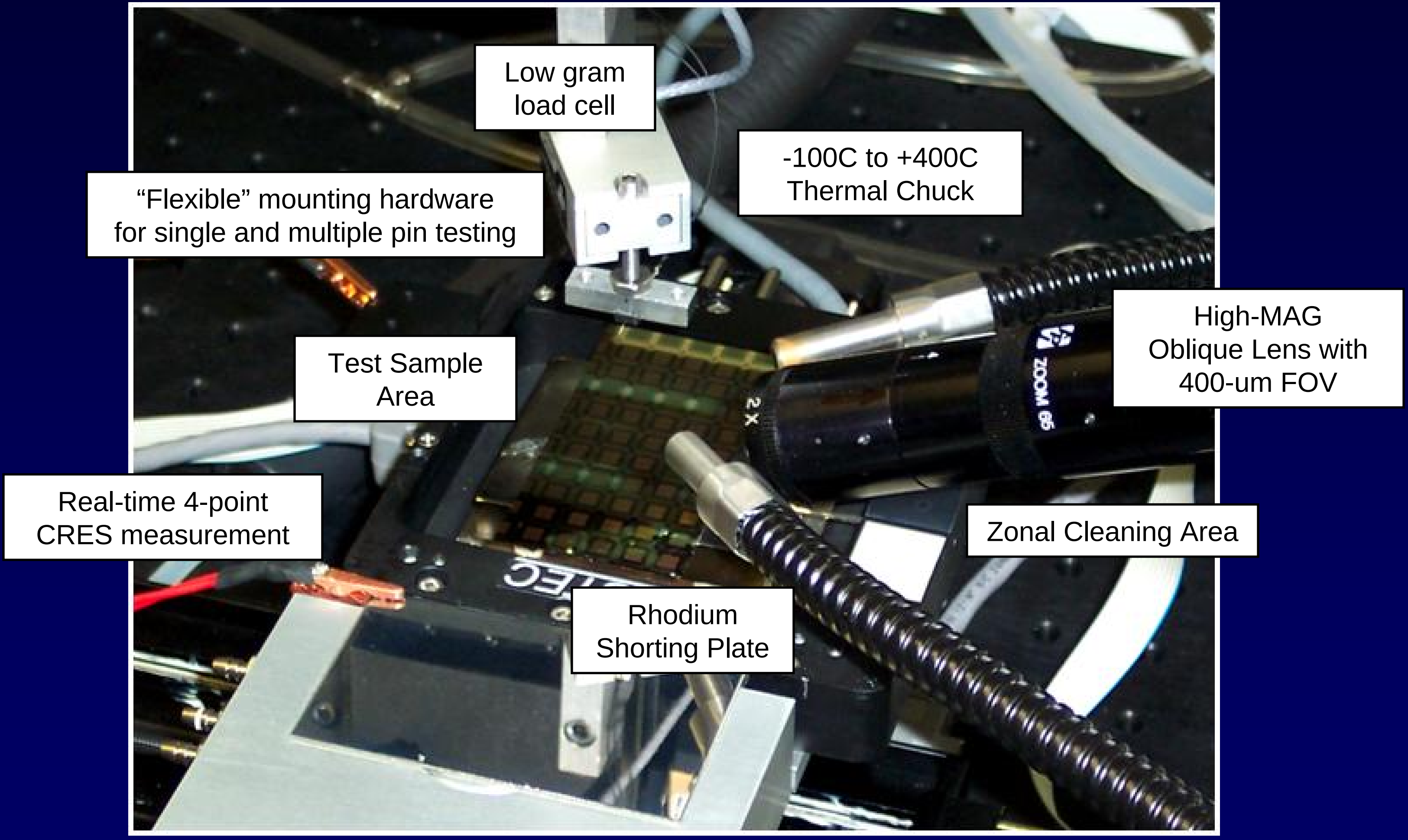
Bench-top Testing System …

- Cleaning material performance tests.
- Synchronized load vs. overtravel vs. CRES data acquisition.
- High resolution video imaging and still image capture.

Test Cell Overview …

- Cleaning execution frequency, z-only, and special moves.
- CRES measurement on metallized wafer or rhodium shorting block.
- Micro-stepping capable to maximize number of touchdowns.
- Proprietary signal collection and load stabilization routines.
- Automated surface feature profiling of all testing areas.
- Thermally controlled vacuum chuck.

Test Cell Details



Low gram load cell

-100C to +400C Thermal Chuck

“Flexible” mounting hardware for single and multiple pin testing

High-MAG Oblique Lens with 400-um FOV

Test Sample Area

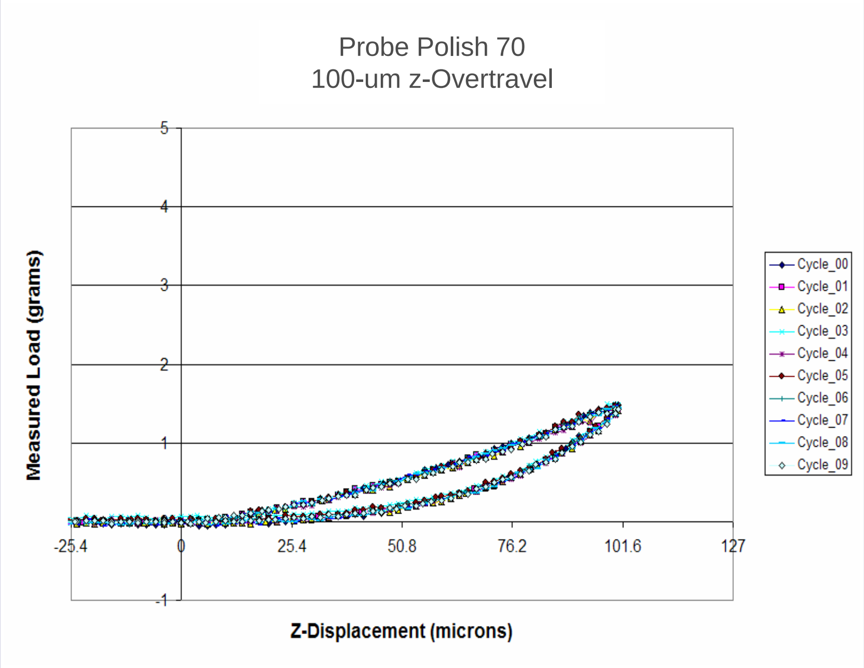
Real-time 4-point CRES measurement

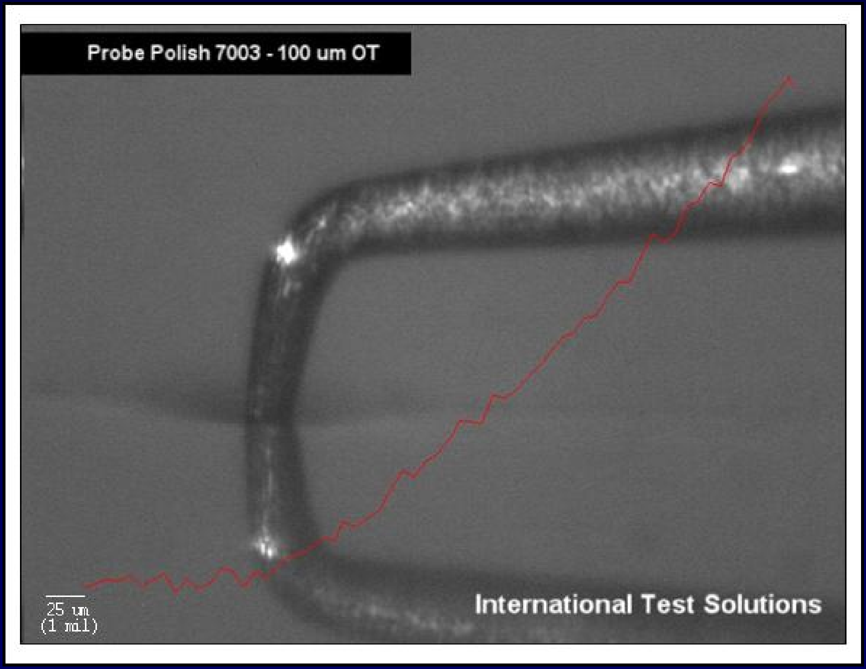
Zonal Cleaning Area

Rhodium Shorting Plate

Mechanical Behavior of Materials

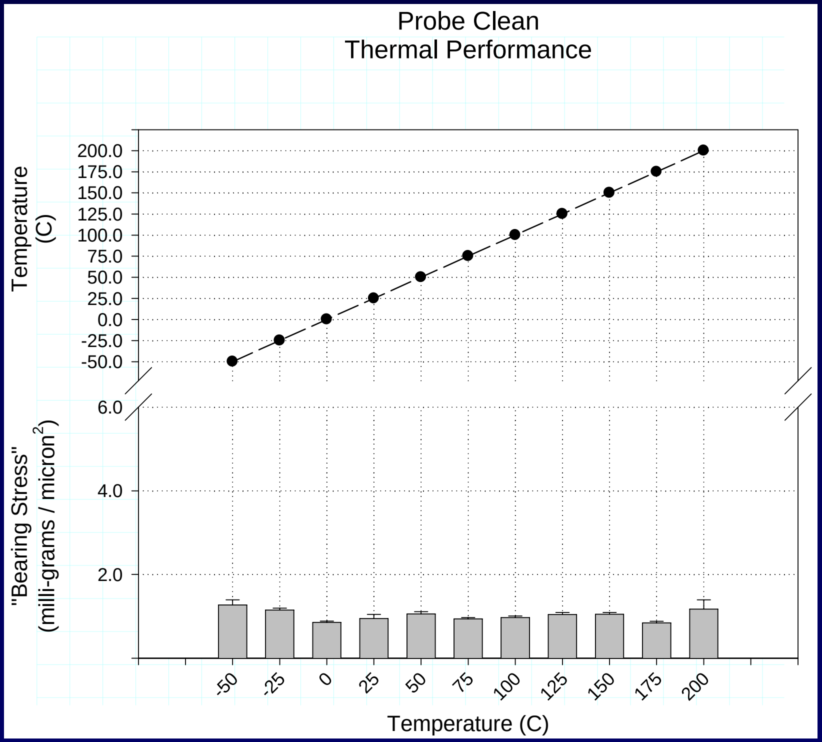
- Characteristic curve assessment of cleaning materials
  - Probe force vs. z-Overtravel curves are indicative of consistency.
  - Performed under quasi-static conditions facilitate visualization.

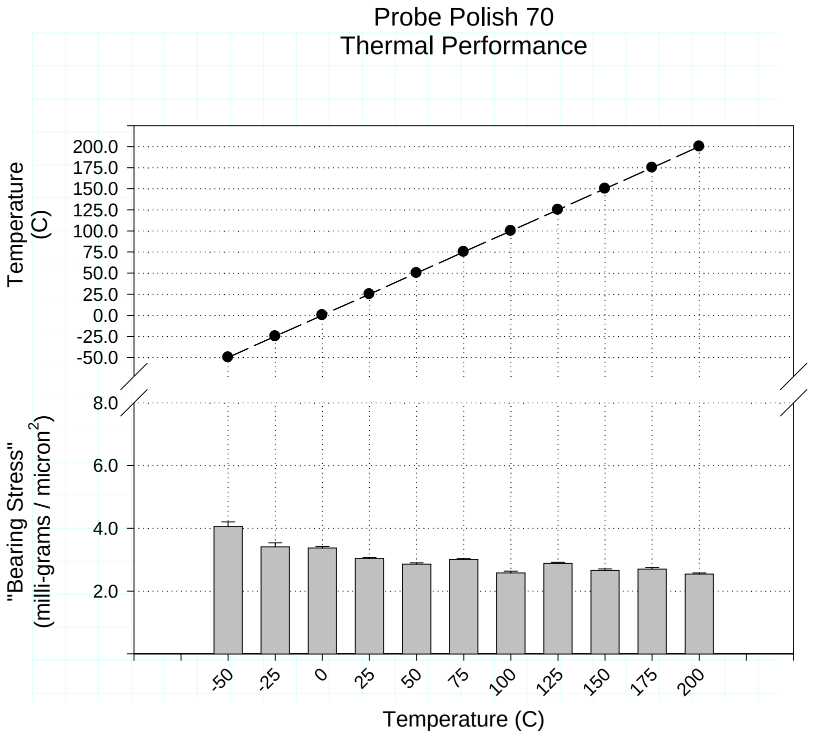




Thermal Performance Testing

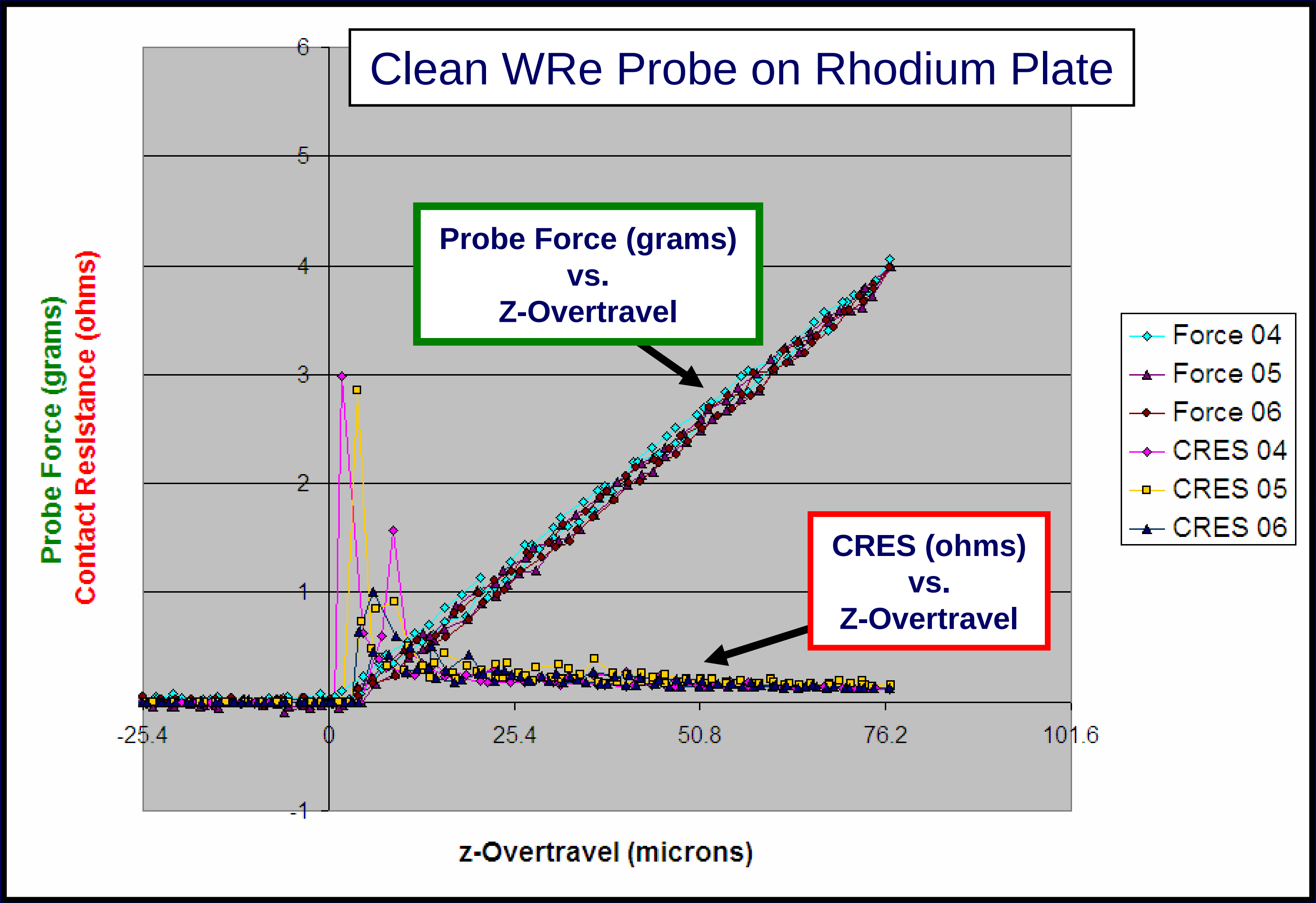
- Insertion hardness is one of several critical cleaning material properties
  - Material hardness varied by +20% at –50C (i.e., the material was harder) to –15% at +200C (i.e., the material was softer).
  - Such property variations are small across the wide temperature range.





Basic Contact Mechanics and CRES

- Characteristic performance curve on contact materials
  - Probe Force vs. Z-overtravel vs. CRES for contact modeling



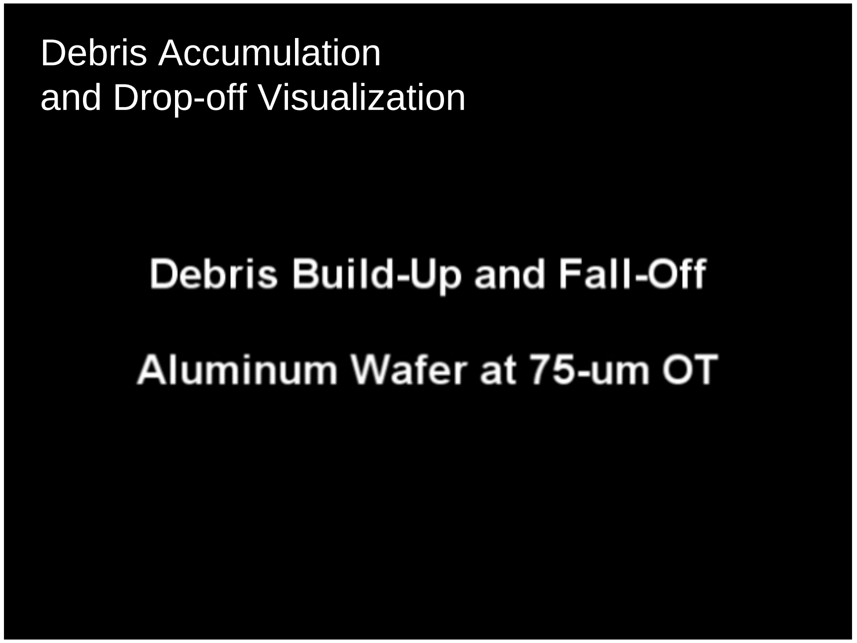
Clean WRe Probe on Rhodium Plate

Probe Force (grams)
vs.
Z-Overtravel

CRES (ohms)
vs.
Z-Overtravel

Debris Build-Up / Tip Maintenance

- Time Lapse image collected for visualization
  - Debris accumulation (and “drop off”) DURING repeated touchdowns
  - Radius tip shape maintenance / forming visualization



Debris Accumulation
and Drop-off Visualization

Debris Build-Up and Fall-Off

Aluminum Wafer at 75-um OT

Radius Probe
Tip Maintenance

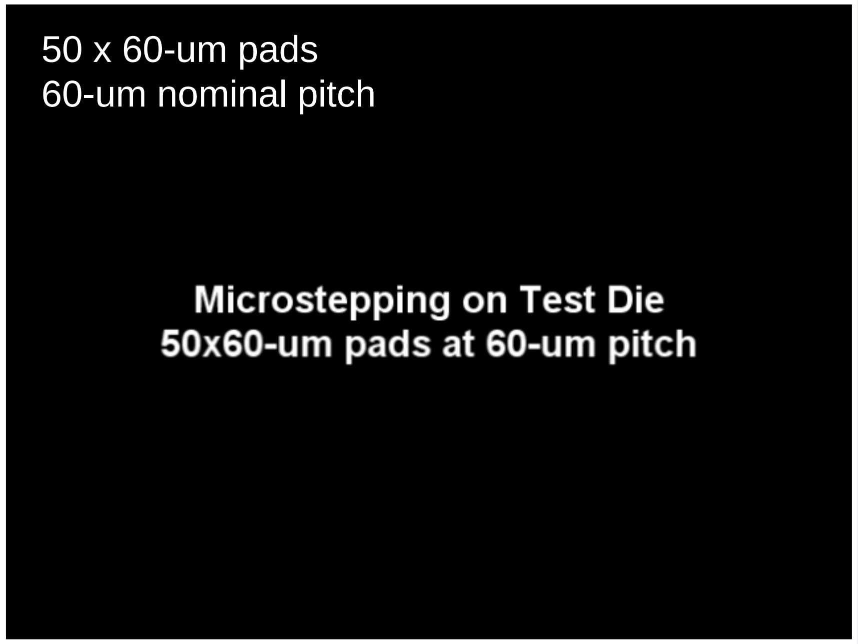
Micro-stepping on Wafers

- Real-time videos of Probe to Pad Interactions
  - – Metal debris accumulation and probe cleaning execution
    - Blanket aluminum wafer for maximal probe touchdowns
  - – Customer test device probed with micro-stepping routine

Spiral stepping at 50-um pitch
Cleaning after 100 TDs

Spiral Stepping on Al-Wafer

Probe Polish 70 Cleaning



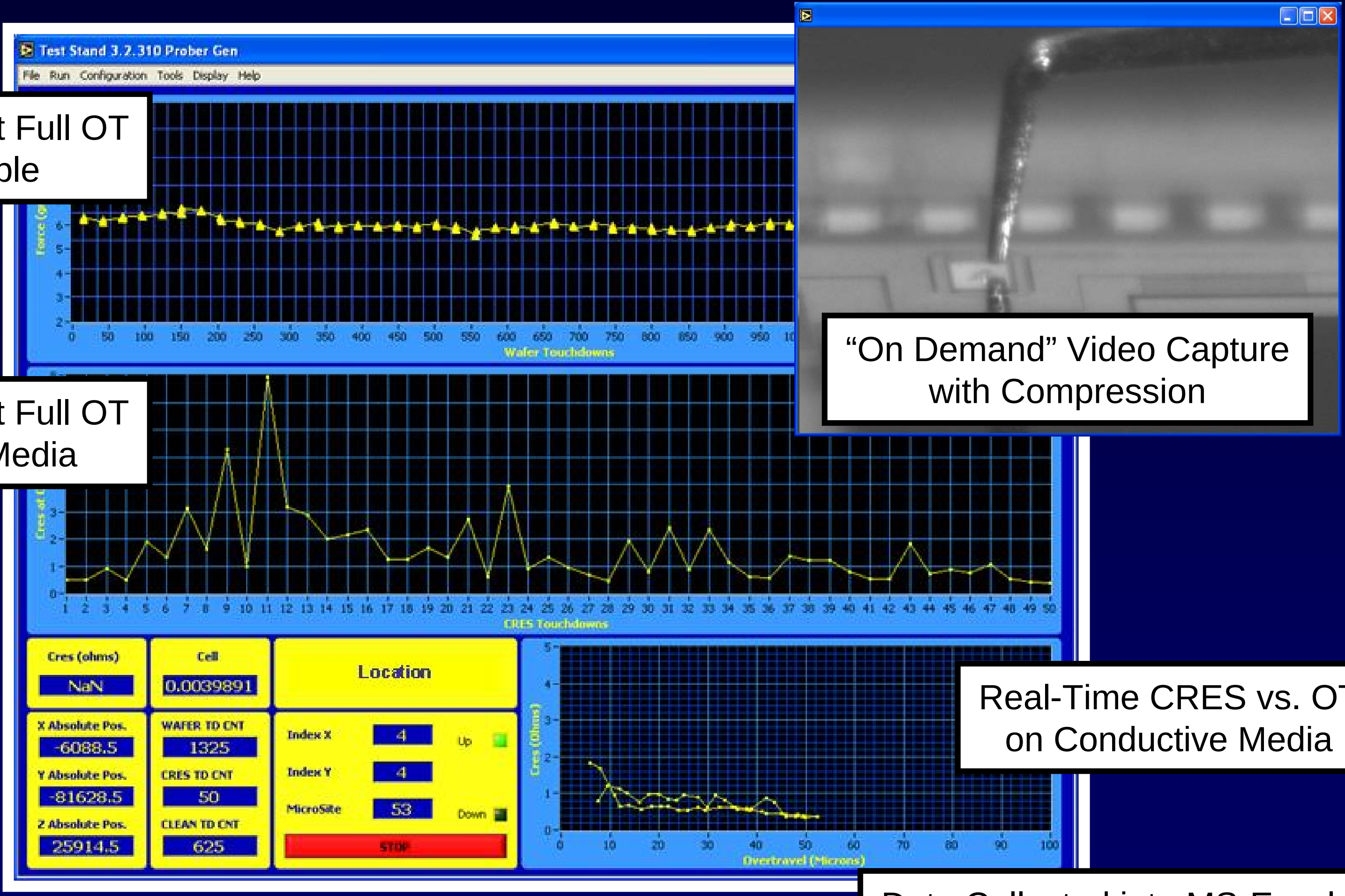
50 x 60-um pads
60-um nominal pitch

Microstepping on Test Die
50x60-um pads at 60-um pitch

“Prober Gen” Multi-Functional Overview

- Custom 3D surface profiling functions
  - Test device, cleaning zone, and shorting area for z-Overtravel consistency
- Within device micro-stepping and between device indexing
  - Micro-site stepping to maximize utilization device pads and scribe-line test structures
- Synchronized data collection of Force vs. OT vs. CRES
  - Load at full overtravel on test device, cleaning zone, and shorting area
  - Custom load stabilization and signal processing functions for high data quality
  - “On Demand” video capture
- Flexible cleaning execution functionality
  - Variable frequency, insertion count, and motion (z-Only and special move)
- Force vs. OT vs. CRES curves in shorting area
  - Before and/or after cleaning execution

Representative Screenshot



Cres (ohms): NaN

Cell: 0.0039891

X Absolute Pos.: -6088.5

Y Absolute Pos.: -81628.5

Z Absolute Pos.: 25914.5

WAFER TD CNT: 1325

CRES TD CNT: 50

CLEAN TD CNT: 625

Index X: 4

Index Y: 4

MicroSite: 53

Real-Time Force at Full OT on Test Sample

Real-Time CRES at Full OT on Conductive Media

"On Demand" Video Capture with Compression

Real-Time CRES vs. OT on Conductive Media

Electrical and Positional

Data Collected into MS-Excel Compatible Files

Test Program Execution Status

Micro-step / Die Index Tracking

“Prober Gen” Application

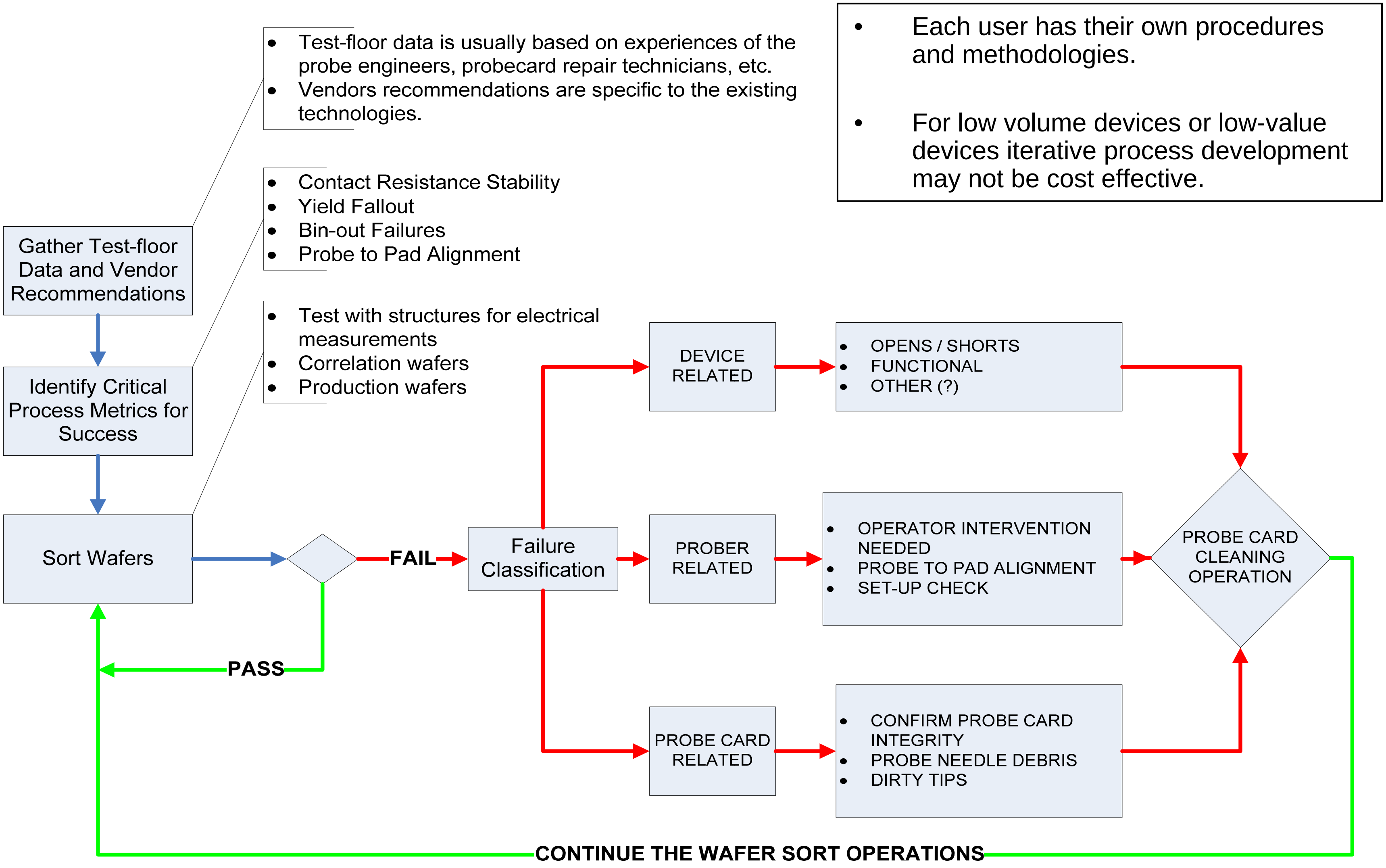
A Case Study

General Cleaning Process Development

- For low volume devices, iterative cleaning process developments are not economical.
  - For high volume devices, cleaning processes are usually tailored and optimized to the specific environment.
- Determining cleaning requirement with “full-build” probe cards may not be feasible.
  - Multiple probe-card technologies are expensive
  - Demanding electrical requirements may require several different cleaning procedures.
- Often a sound “best guess” from past experience is implemented.
  - Resources are limited for developing individual cleaning protocols for each probe-card technology and device.

General Cleaning Process Development

- Each user has their own procedures and methodologies.
- For low volume devices or low-value devices iterative process development may not be cost effective.



Gather Test-floor Data and Vendor Recommendations

- Test-floor data is usually based on experiences of the probe engineers, probecard repair technicians, etc.
- Vendors recommendations are specific to the existing technologies.

Identify Critical Process Metrics for Success

- Contact Resistance Stability
- Yield Fallout
- Bin-out Failures
- Probe to Pad Alignment

Sort Wafers

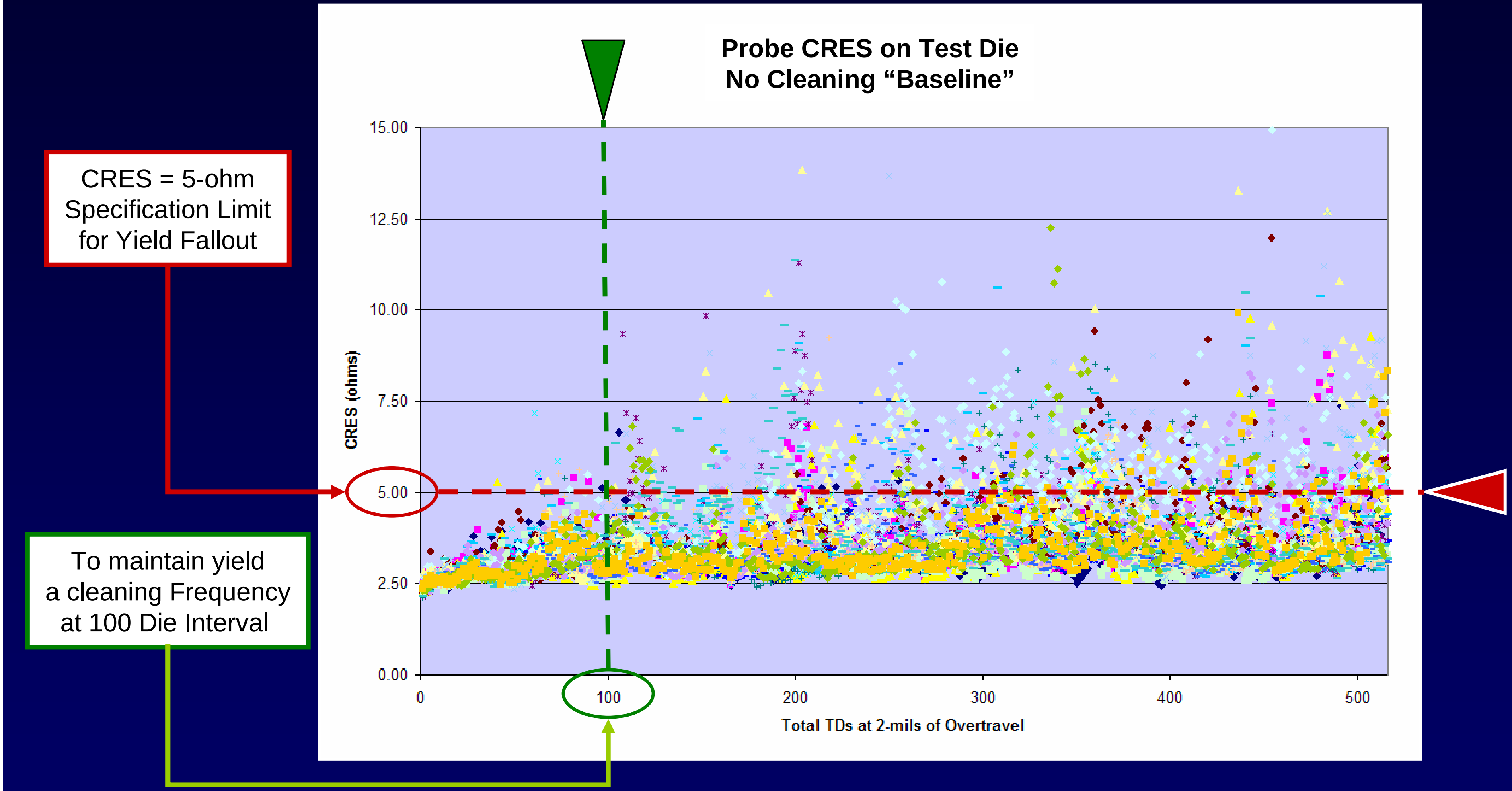
- Test with structures for electrical measurements
- Correlation wafers
- Production wafers

DEVICE RELATED:
- OPENS / SHORTS
- FUNCTIONAL
- OTHER (?)

PROBER RELATED:
- OPERATOR INTERVENTION NEEDED
- PROBE TO PAD ALIGNMENT
- SET-UP CHECK

PROBE CARD RELATED:
- CONFIRM PROBE CARD INTEGRITY
- PROBE NEEDLE DEBRIS
- DIRTY TIPS

Process Development with a Test Die

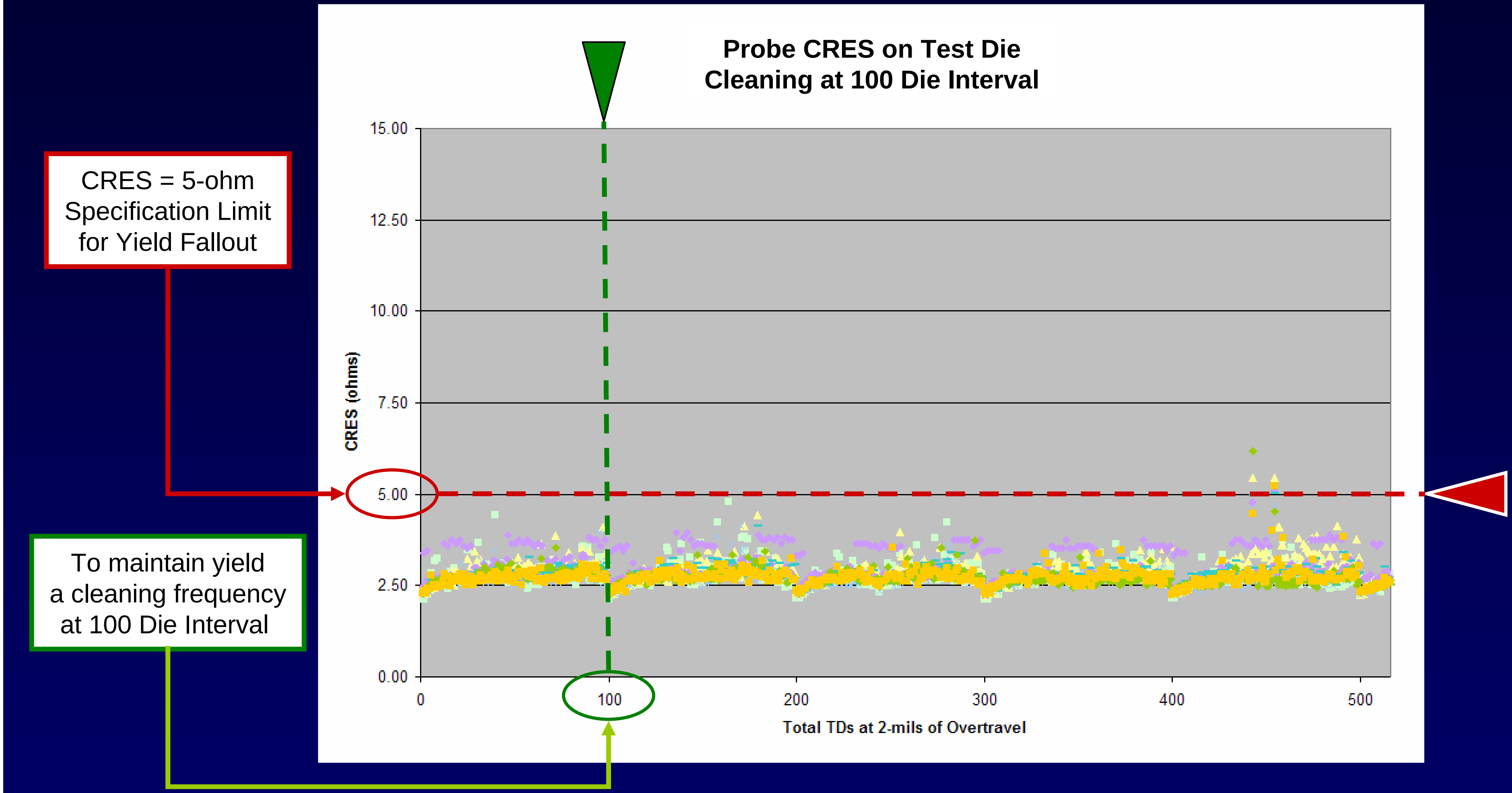


CRES = 5-ohm Specification Limit for Yield Fallout

To maintain yield a cleaning Frequency at 100 Die Interval

"Test Die" was representative of the FAB processed devices.

Process Development with a Test Die



CRES = 5-ohm Specification Limit for Yield Fallout

To maintain yield a cleaning frequency at 100 Die Interval

“Test Die” wafers may not be available to all sort-floors.

A Need for Off-line Capabilities

- Without test-die, production wafers must be used to define the cleaning process.
  - Devices with “active” bond pads present many challenges for cleaning process development.
- Micro-stepping on actual (and individual) device pads allows for a large number of touchdowns to be performed.
  - The number of contributing process variables are reduced.
  - Material stack contribution / effects can be studied.
- “Prober Gen” testing procedures under controlled conditions with the LTU can provide …
  - A “snap-shot” of the current process performance.
  - A reasonable “starting point” for cleaning process optimization.
  - A means of exploring alternative technologies (probe-related and/or cleaning materials) without significant resource utilization.

Overview – Process Assessment

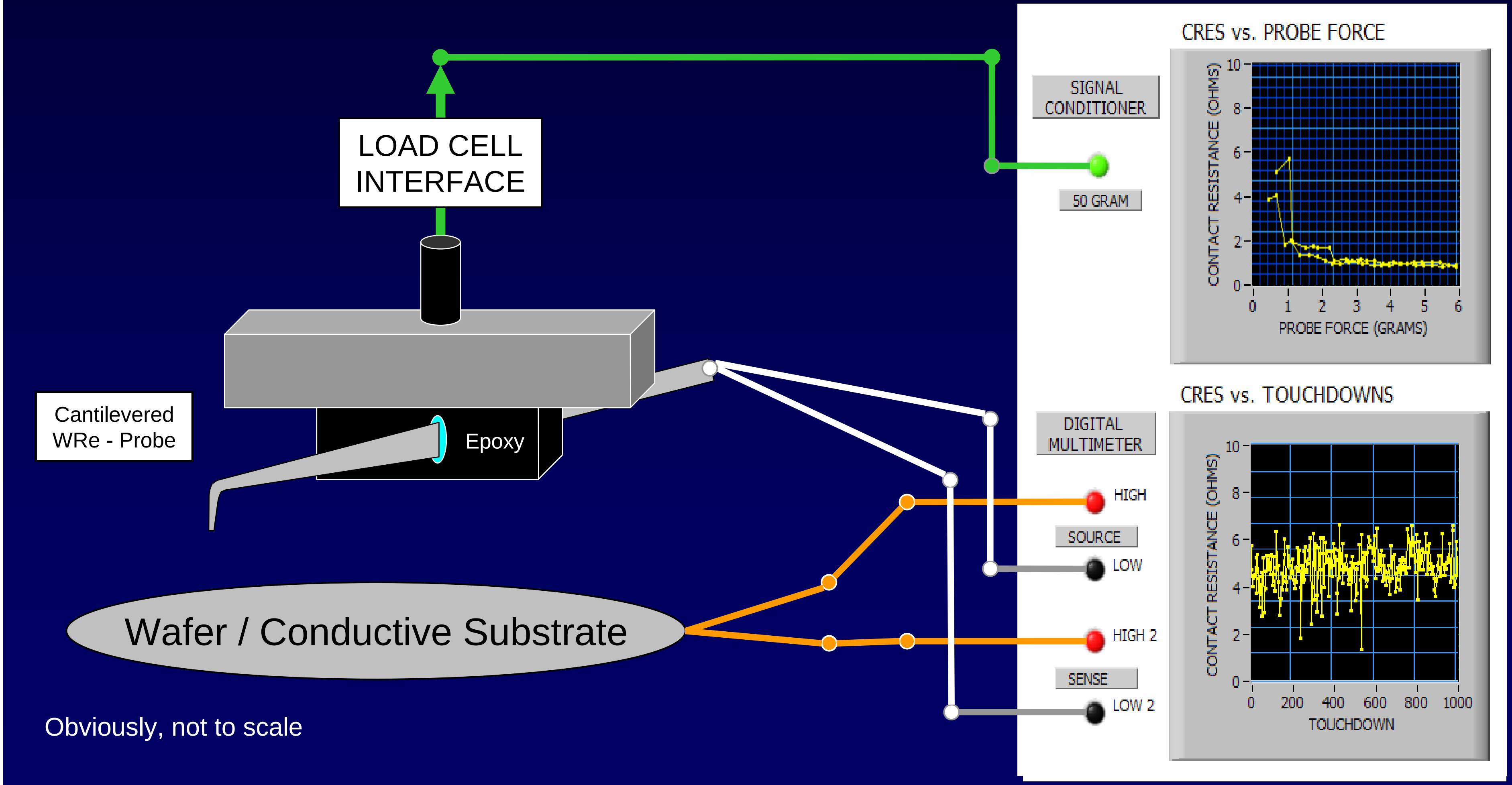
- Imaging device was provided by Micron for evaluation
  - Device with at least 50 aluminum bond pads.
  - Scrapped wafers were cleaved for testing procedures.

- Test Parameters for process assessment
  - Sort-floor operations performed with multi-site probe cards that are cleaned using Probe Polish (filled polymer) materials.
  - “One probe test vehicles” were built by JEM-America according to Micron probe card specifications.

- “Prober Gen” Test sequence overview …
  - “Conditioning” performed for Time = 0 clean probe CRES measurement
  - Touchdowns on aluminum pads at 50-um OT
  - CRES measurement on rhodium check-plate at 50-um OT
  - Cleaning insertions performed on cleaning unit
  - CRES measurement on rhodium check-plate at 50-um OT
  - Repeat sequence until every pad on each die was probed

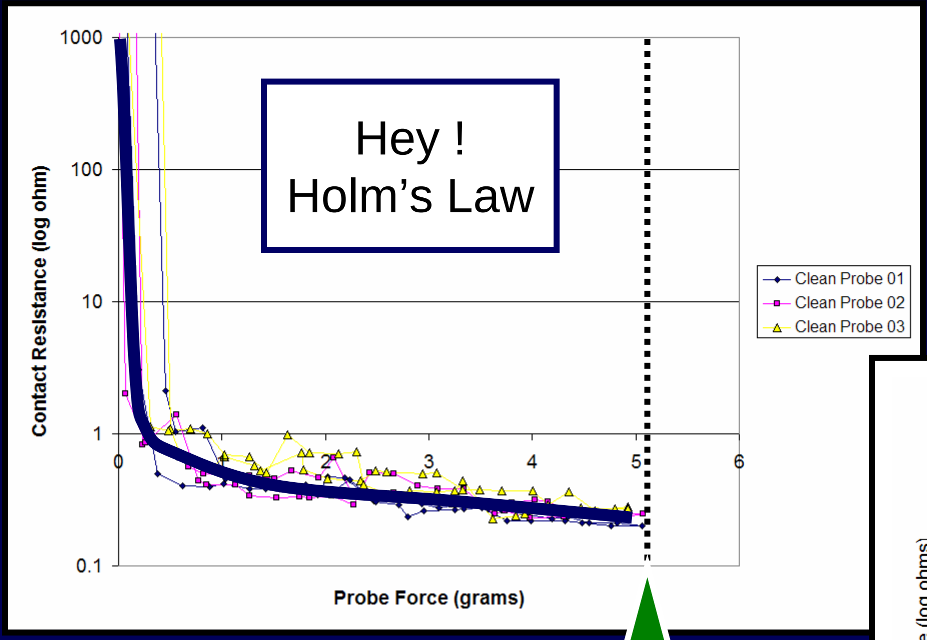
Basic Fixtures for Test Execution

- Single probe with electrical connection for 4-wire CRES measurements
- Micro-stepping to visualize aluminum accumulation on tips.



Obviously, not to scale

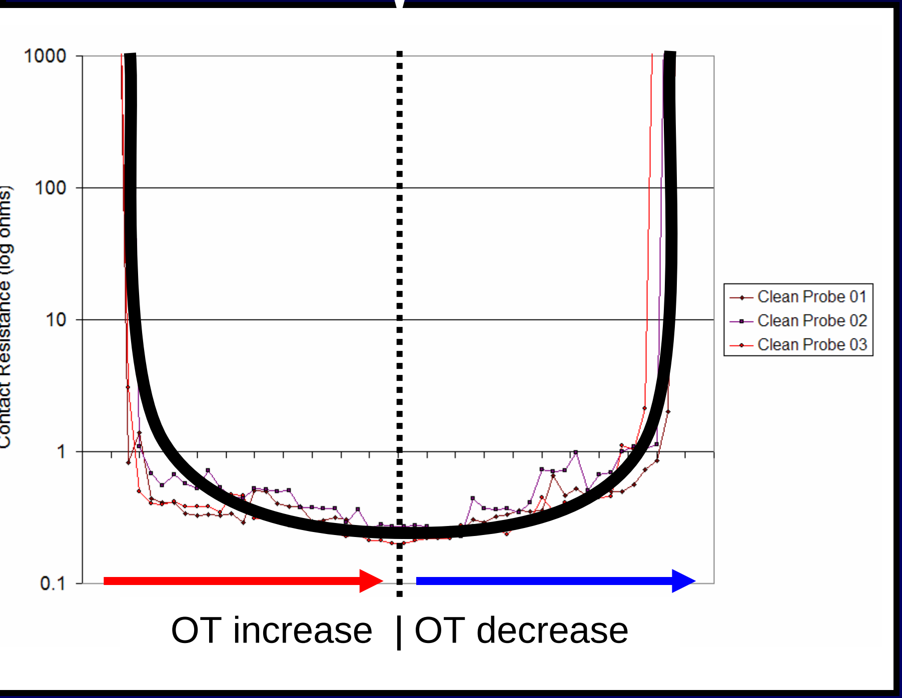
“Bathtub” Curve – Rhodium Plate



Full Overtravel

- A symmetric “bathtub” curve at full overtravel is preferable.

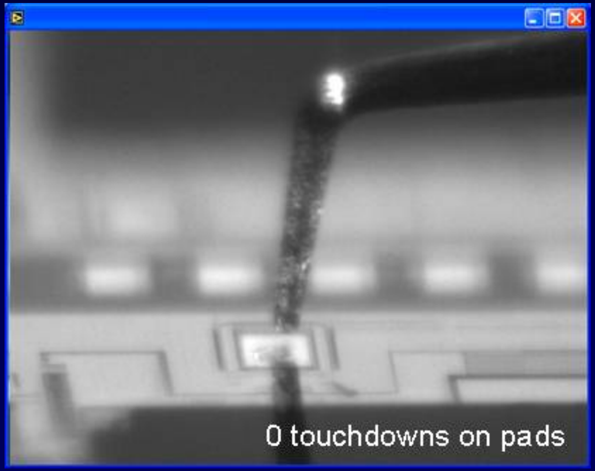
Full Overtravel

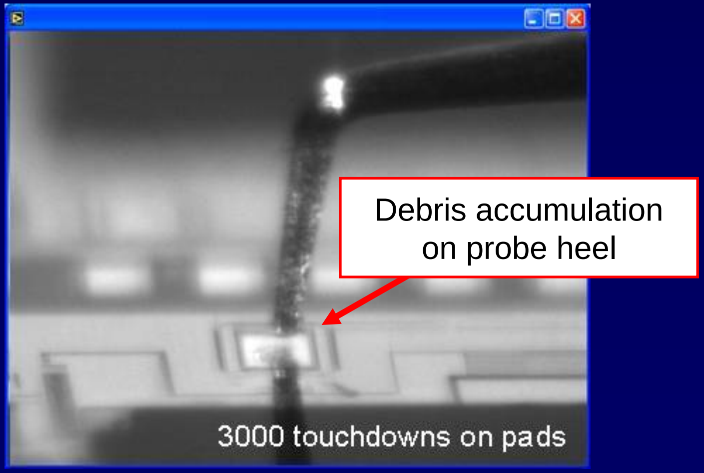


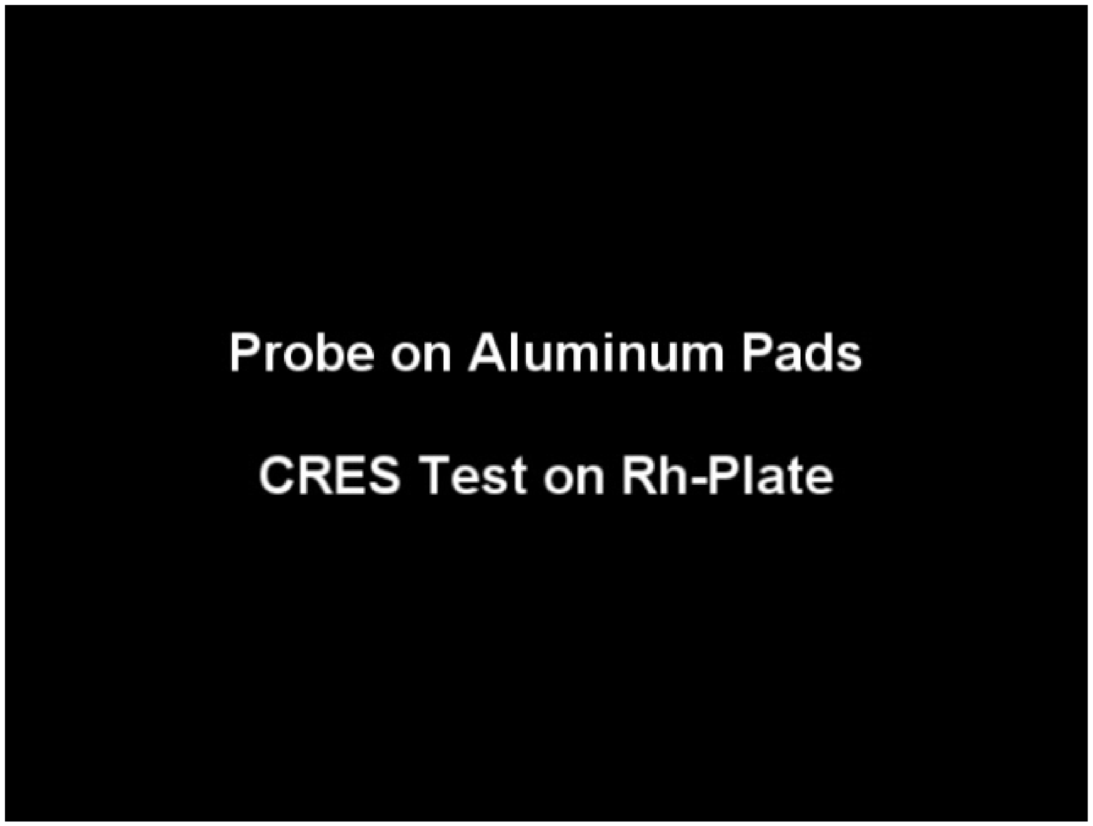
- Probe was conditioned using a combination of abrasive insertions and debris removal.

Test Execution – No Cleaning

- No cleaning execution to “baseline” process.
- CRES on rhodium plate at ~50 TD intervals.



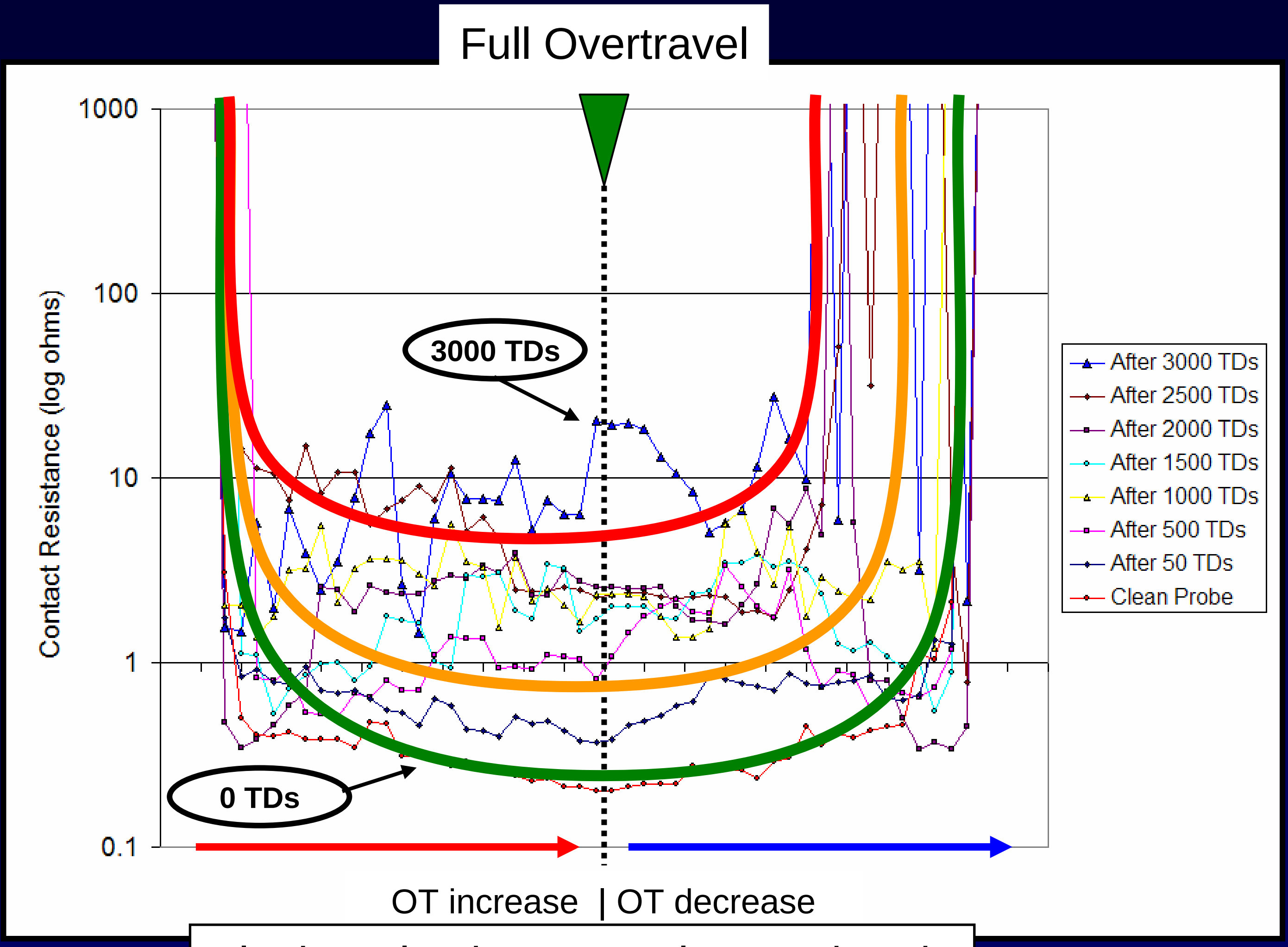



Probe on Aluminum Pads

CRES Test on Rh-Plate

"Bathtub" Curve – Rhodium Plate

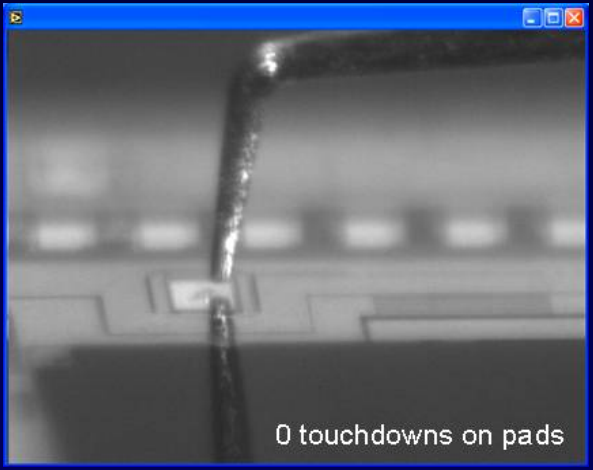
Increasing CRES Instability

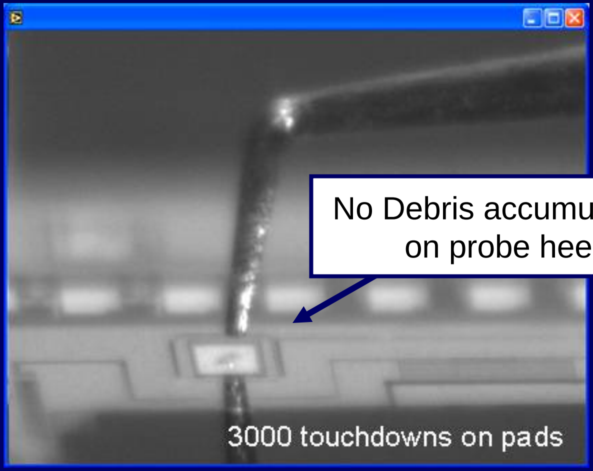


Blanket Aluminum Metal on Probe Tip

Test Execution – Standard Cleaning

- Cleaning with Probe Polish was performed at ~50-TDs.
- CRES on rhodium plate before and after cleaning.



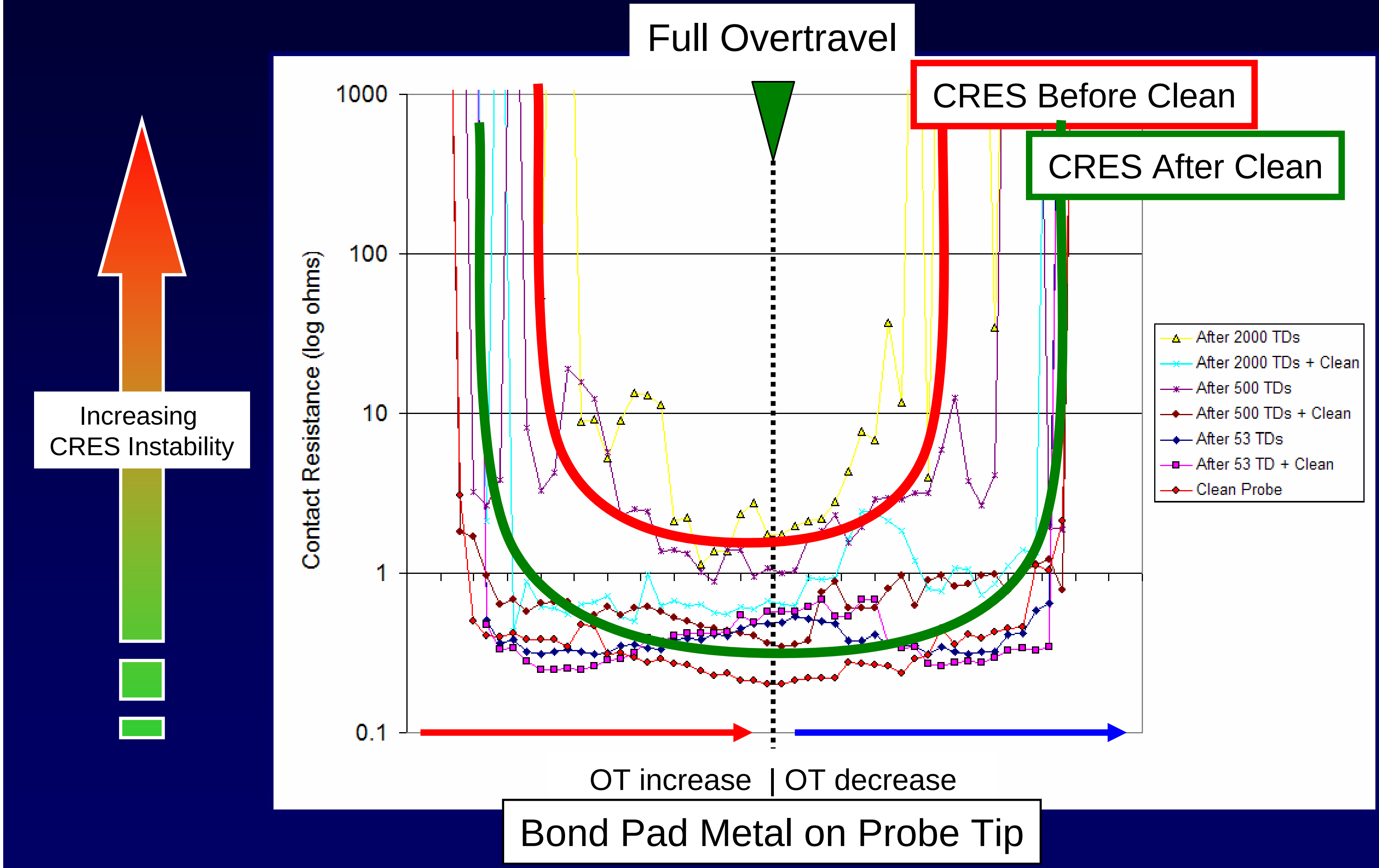


No Debris accumulation on probe heel

Probe on Aluminum Pads

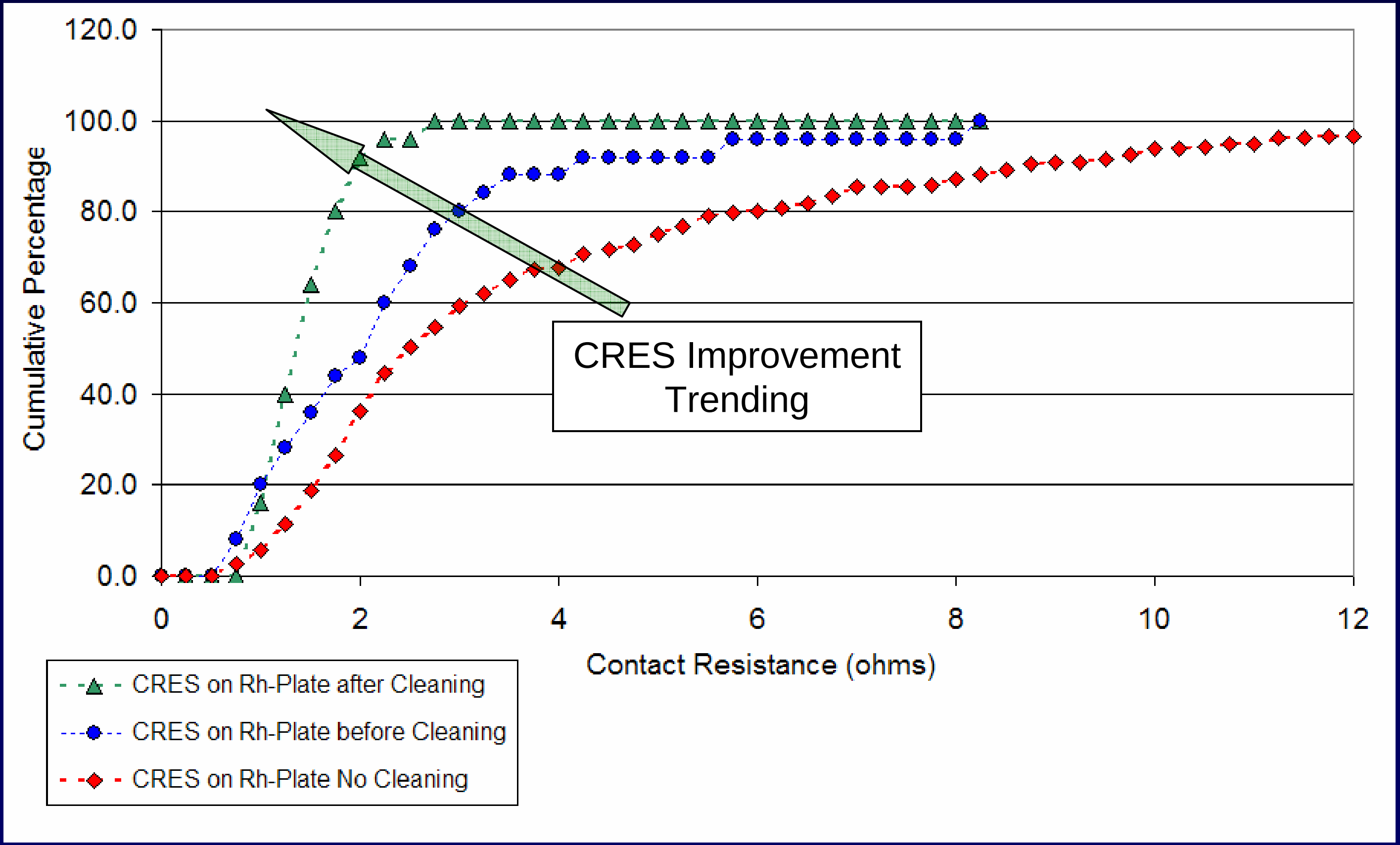
Cleaning with Probe Polish 70

"Bathtub" Curve – Rhodium Plate



Cumulative Frequency Distribution

- Ogive shape reflects the “level” of CRES instability
  - Easy way to compare different large data sets.
  - Incremental changes in CRES behavior can be identified.



Results – Process Assessment

- A sectioned wafer was sufficient to execute at least 3500 touchdowns on actual bond pads.
  - CRES instability was demonstrated via a rhodium plate.
  - A similar number of touchdowns on the sort-floor using a multisite production probe card would require substantially more time and resource allocation.

- Probe cleaning was executed at an interval of ~50 pad touchdowns
  - CRES recovery was demonstrated via a rhodium plate.
  - Additional work is on-going to further evaluate the cleaning requirements

- Implementing an off-line approach and working with sort-floor engineers can significantly reduce the amount of resources required to develop on-line cleaning processes.

- It is foreseeable that the initial cleaning processes could be developed and implemented as each new technology nodes is developed.

Summary / Conclusions

- A bench-top system and novel methodologies to assess cleaning material performance were presented.
  - Visualization of cleaning material and probe interaction
  - Wear testing and probe tip shape visualization
  - Long-Term CRES performance / CRES recovery
  - Off-line cleaning process development

- The industry is looking for optimal on-line cleaning processes as a critical element of wafer level test.
  - Probe technology + optimal cleaning solution

- Developing individual cleaning procedures for specific probe-cards and new devices requires additional resources.
  - Many sort floors do not have enough man-power.
  - Non-optimized cleaning processes reduce probe card life, affect throughput, and reduce prober up-time.
  - Cleaning process optimization could delay technology fan-out.

Future Work

- Thermal (hot and cold) characterization
- Probe technology visualization and evaluation
- High forcing current applications

Acknowledgements

- Micron Probe Engineering Group
- JEM-America Applications Group

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Thank you for your attention

Questions ???