IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

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Methodologies for Assessing On-line Probe Process Parameters

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  - FM: Probe Materials
  - ITS: Lab Capabilities
  - NXP: Production Environment
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Motivation

Joint Venture Overview

FM: Probe Materials

ITS: Lab Capabilities

NXP: Production Environment

Contact Resistance and Fritting Theory

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Production Data

Results & Future Work

Motivation

- Production sort floors are often manpower, materials, and financially limited for fundamental characterization studies which could lead to process understanding and improvement.
- Testing with “full-build” probe cards is expensive and often not feasible, particularly with large array probe cards.
- Assessing combinations of key parameters, such as current amplitude and directionality, probe needle materials, and FAB processing effects on bond pads, requires substantial resource allocation.
- Bench-top testing with a single probe or reduced probe count test vehicles can be performed quickly under known and controlled conditions.

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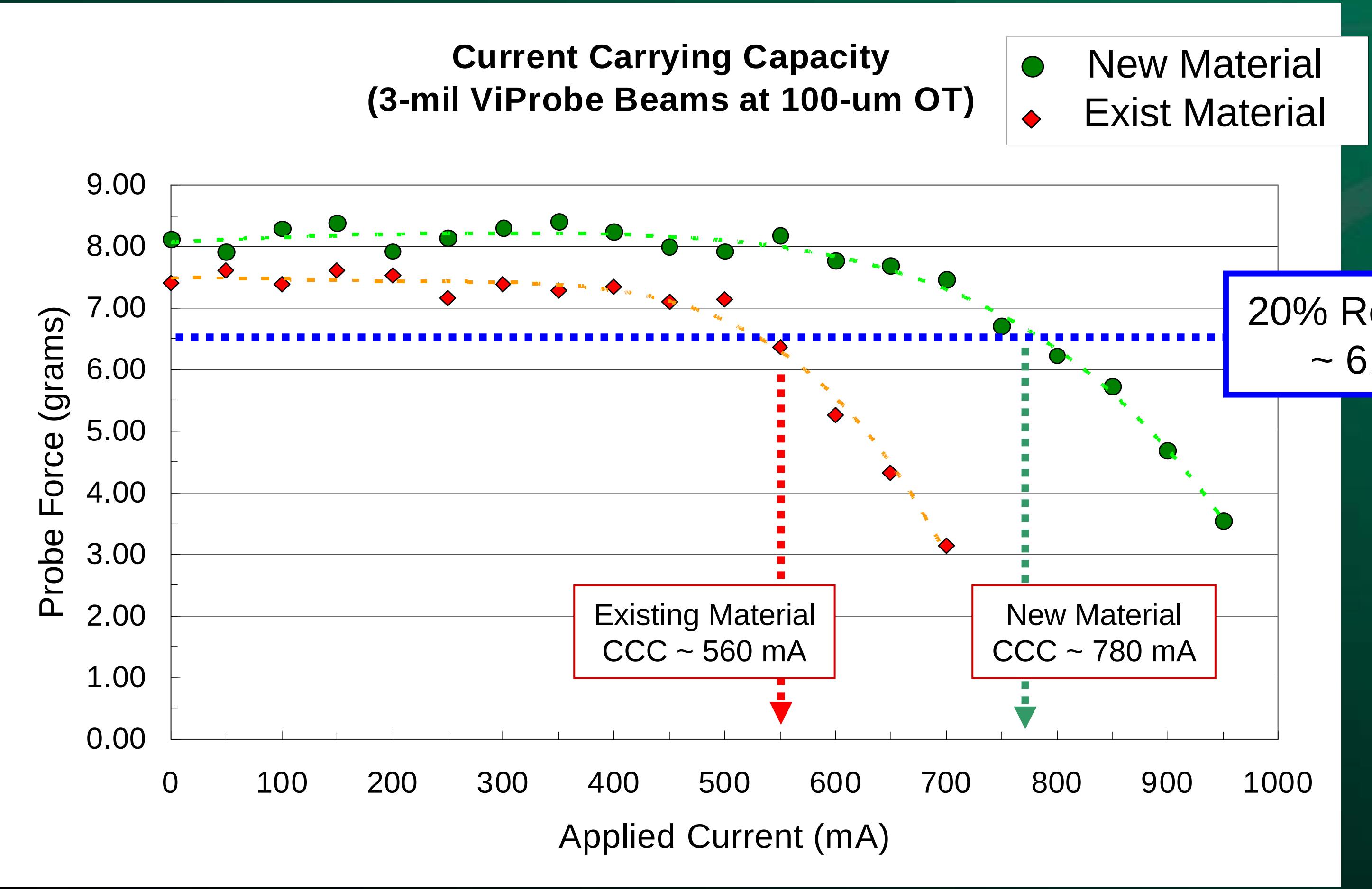
Feinmetall ViProbe®
New Beam Material

- Beam material with improved performance:
  - high amperage (current carrying capacity, up to 800 mA)
  - low voltage/current applications
  - electrical resistivity: 0.12 $\Omega \cdot mm^2/m$
- Both materials (existing and new one) are palladium - silver alloys
- Mechanical behaviour of the new beams similar to the existing beams with 2.0 mil, 2.5 mil and 3.0 mil diameter

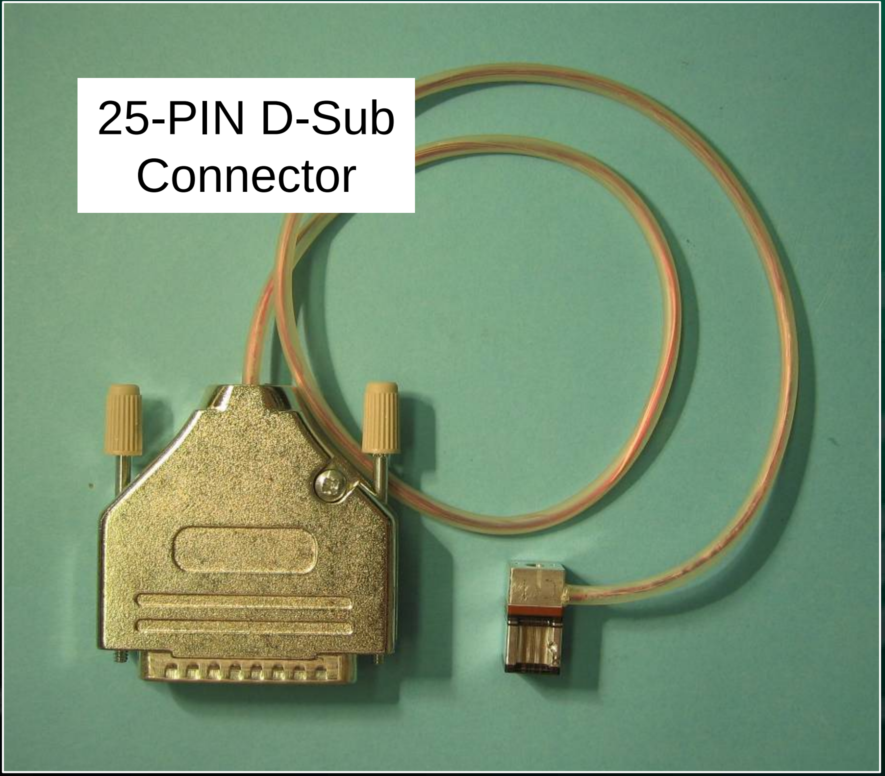
Feinmetall ViProbe®
New Beam Material

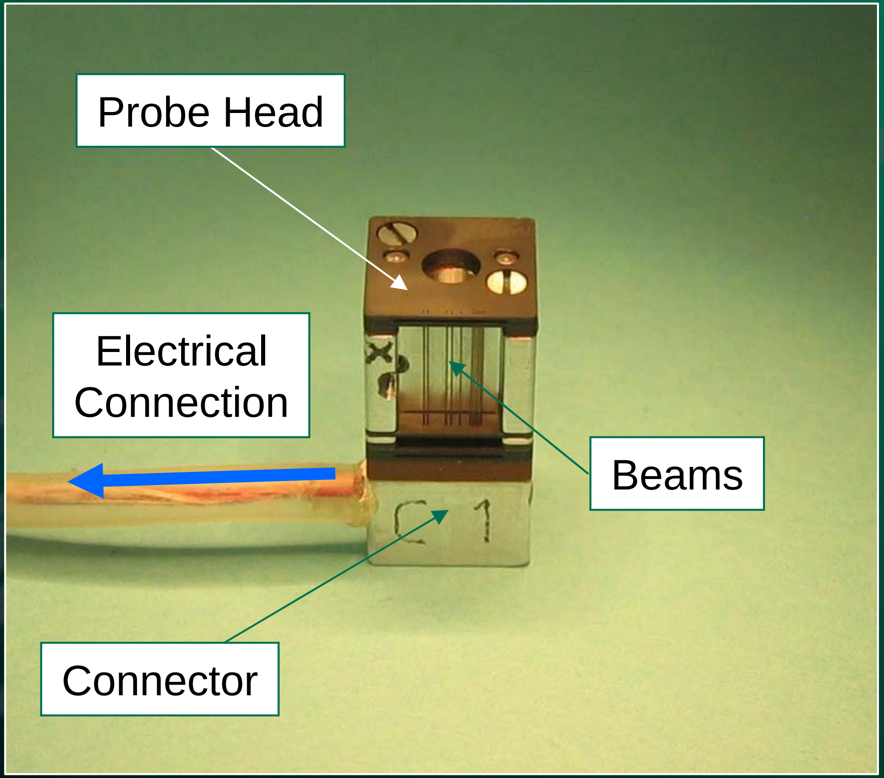
- Probe Force vs. Applied Current



ViProbe® Testvehicle

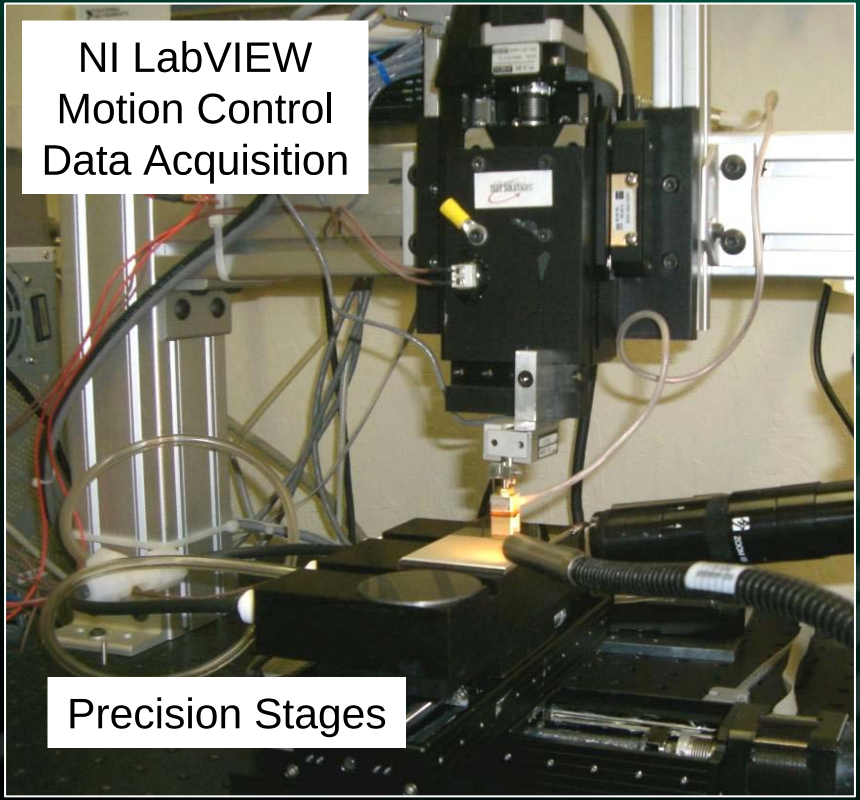
- Smallest ViProbe® test head ever designed and built
  - 2mil, 2.5mil and 3mil ViProbe compatibility





Controlled Test Conditions

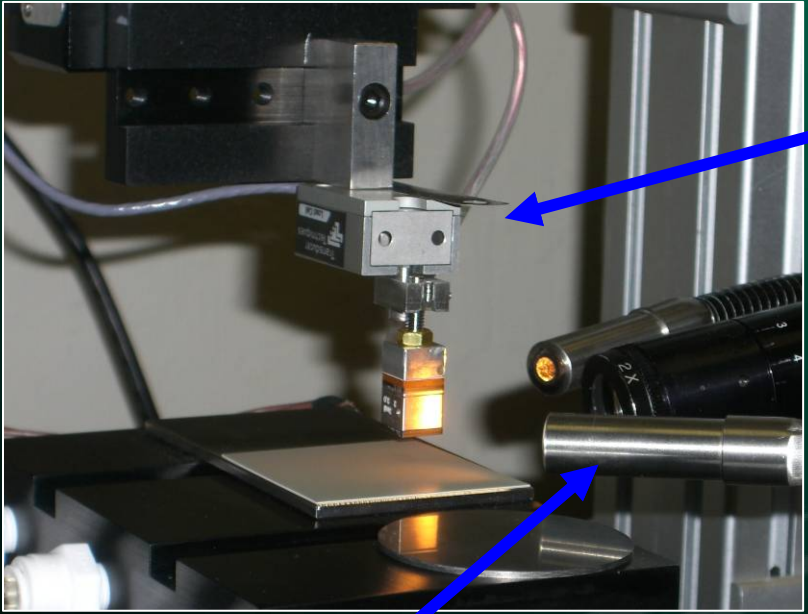
- Bench-top instrument for material characterization and probe performance testing.



ITS LTU Probe-Gen System

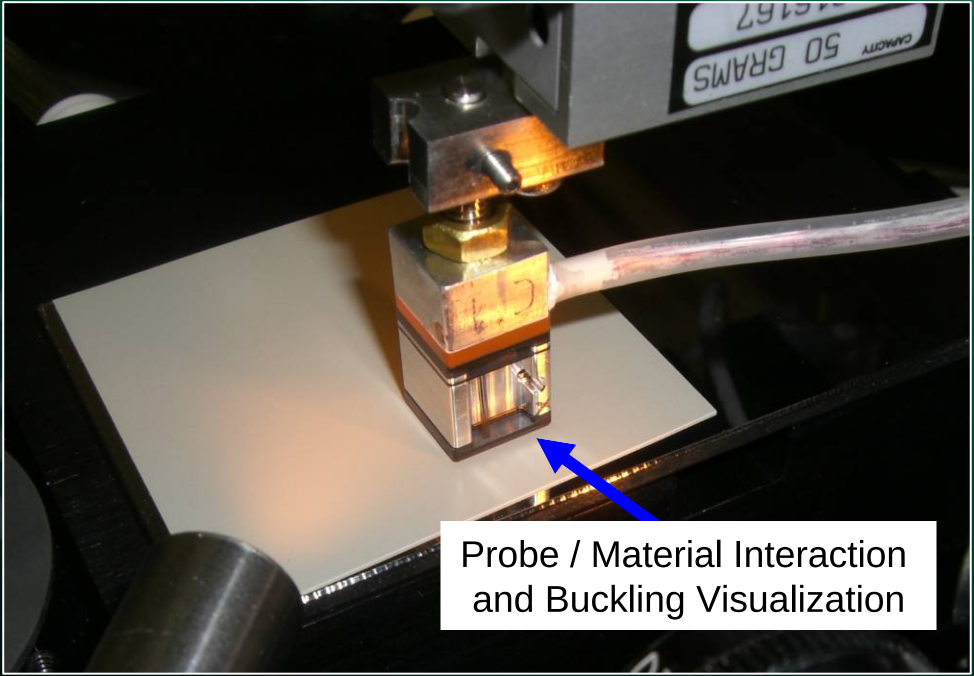
- **Testing System Details**
  - **Variable z-speed and z-acceleration.**
  - **Low gram load cell measurements.**
  - **Synchronized load vs. overtravel vs. CRES data acquisition.**
  - **High resolution video imaging and still image capture.**
  - **Current forcing and measurement with Keithley 2400 source-meter.**
  - **Micro-stepping capable to maximize number of touchdowns.**
  - **Multi-zone cleaning functionalities.**

Test Vehicle



ViProbe Test vehicle installed onto 50 gram load cell

High resolution imaging system for video acquisition



Probe / Material Interaction and Buckling Visualization

NXP Testcenter Hamburg Production Environment

- Mass production and engineering site for Automotive and Identification business, digital and mixed signal
- Applications with high multisite factors and small pad pitch
- Capability to collect contact resistance data within production environment

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Contact Resistance (CRES)

- Contact Resistance is a combination two main parameters
  - Localized physical mechanisms … metallic contact
  - Non-conductive contribution … film resistance

- Model for CRES has two main factors

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

METALLIC CONTACT

FILM RESISTANCE

  - ρ_{pad}, ρ_{probe}, σ_{film} = resistivity values
  - H = hardness of softer material
  - P = contact pressure
  - Contact pressure (P) applied force normalized by true contact area

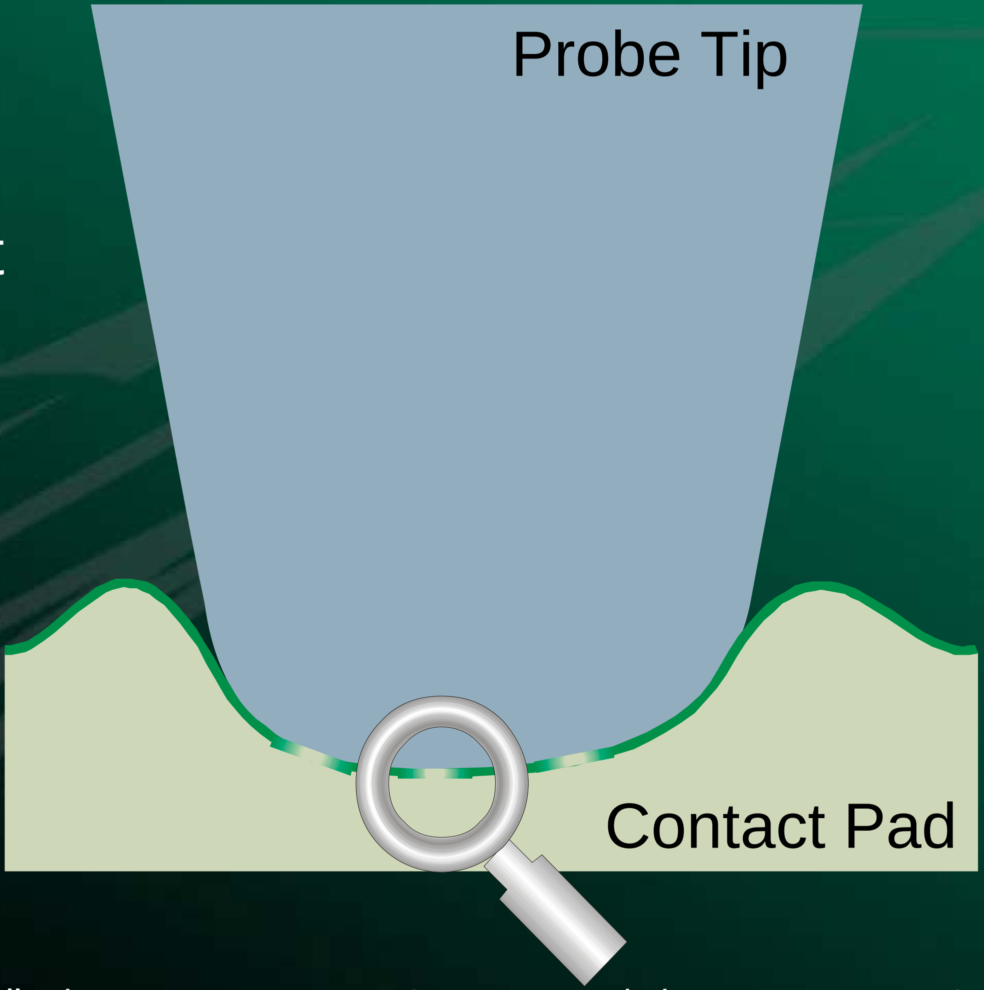
- Unstable CRES is dominated by the film contribution term due to the accumulation of non-conductive materials

Key Factors that affect CRES

- Presence of contamination, e.g. debris, oxides, residues, etc.
  - Film resistance eventually dominates the magnitude and stability of the CRES
- Probe tip shape plays an important role in displacing the contaminants from the true contact area
  - *True* Contact Area = $\mathcal{F}$ (Tip Shape, Applied Force, Surface Finish)
    - *True* contact are is "large" ➔ applied pressure and *a-Spot* density are "low"
    - *True* contact area is "small" ➔ applied pressure and *a-Spot* density are "large"
- Probe tip surface characteristics affect the "a-Spot" density
  - Asperity density depends on the microscopic surface roughness
    - Smooth surfaces have a high asperity density
    - The increase in asperity density decreases the electrical CRES
    - A "rough" finish facilitates material accumulation on contact surface
- Amplitude and directionality of the voltage or current applied.
  - Voltage or current must be sufficient to breakdown the oxide.

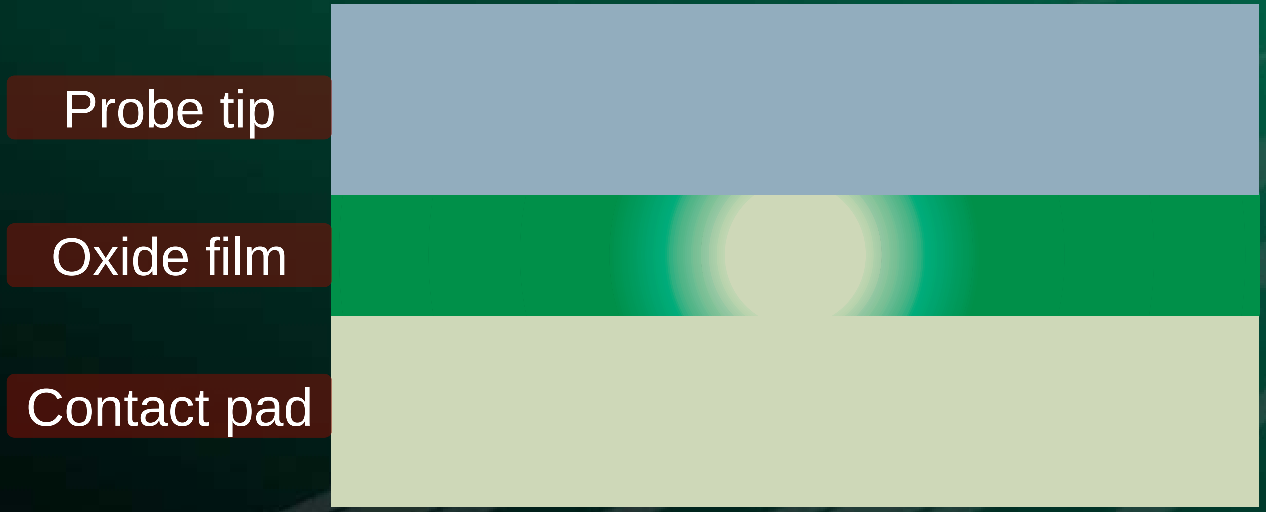
Fritting – Theory

- The vertical Probe tip touches the contact pad.
- Depending on the contact pressure the oxide film is broken partly and electrical bridges arise.
- The number and size of the bridges is equivalent to the C_{RES} quality



Fritting – Theory

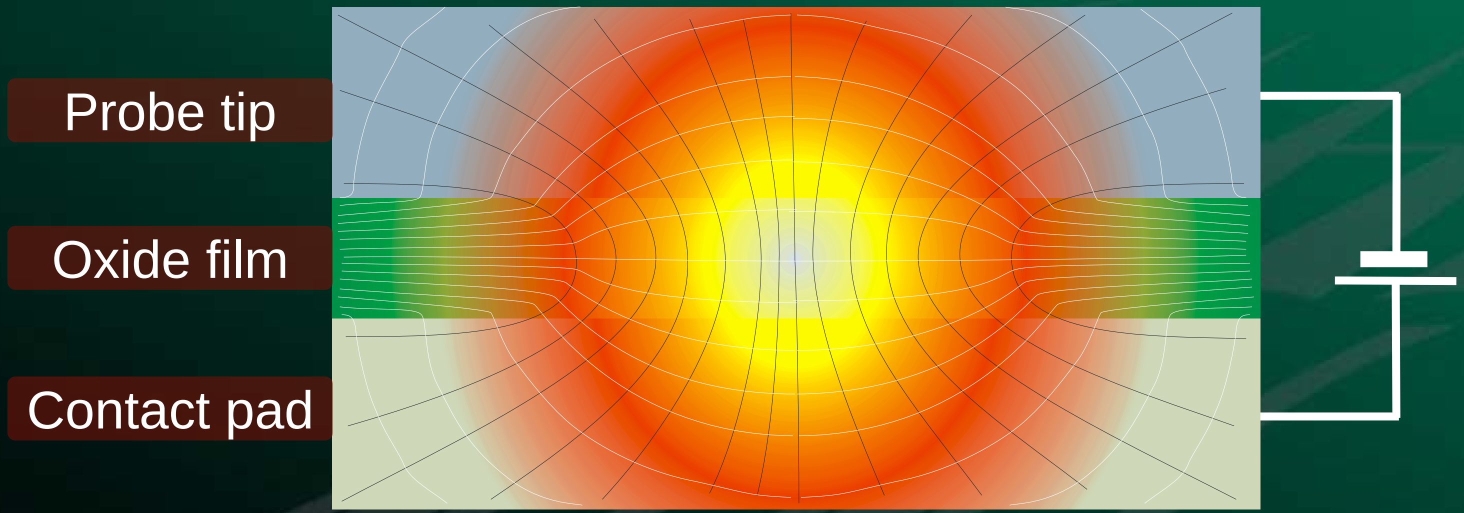
- What happens, if bridges are only few and small?



Small bridge through oxide film.
Before high current flow.

Fritting – Theory

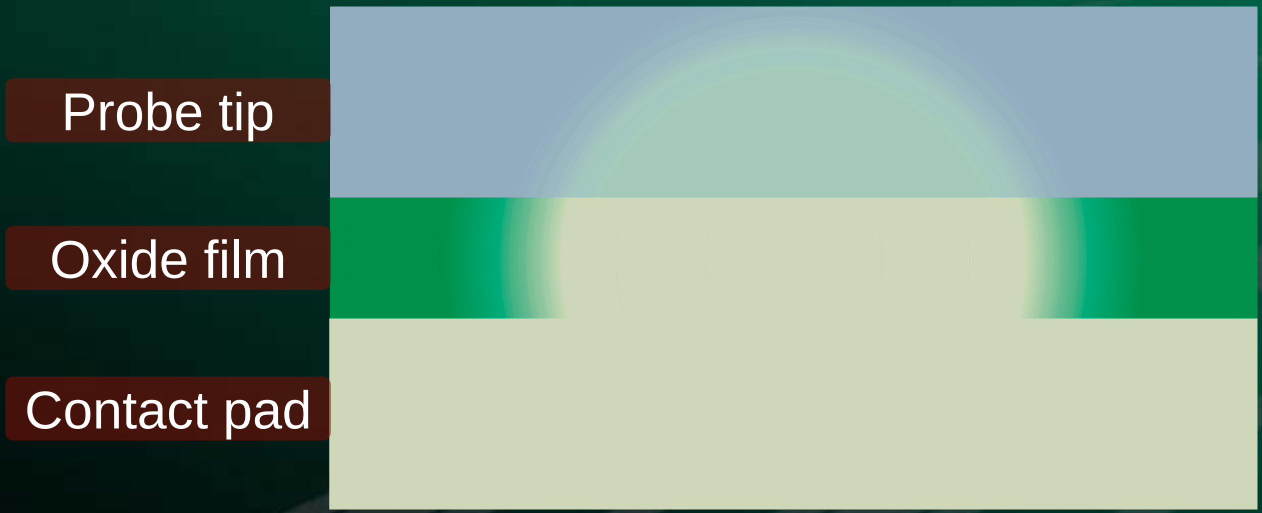
- Current must flow through small bridge.
- Bridge and neighbourhood are heated up
- Contact Pad material migrates to the bridge.



High current flow situation:
Black → Lines of current flow.
White → Lines of equipotential surface.

Fritting – Theory

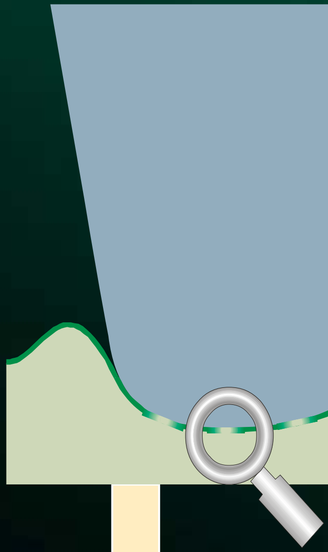
- Bridge is widened → C_{RES} decreased
- Contact pad material migrated to the bridge and tip surface

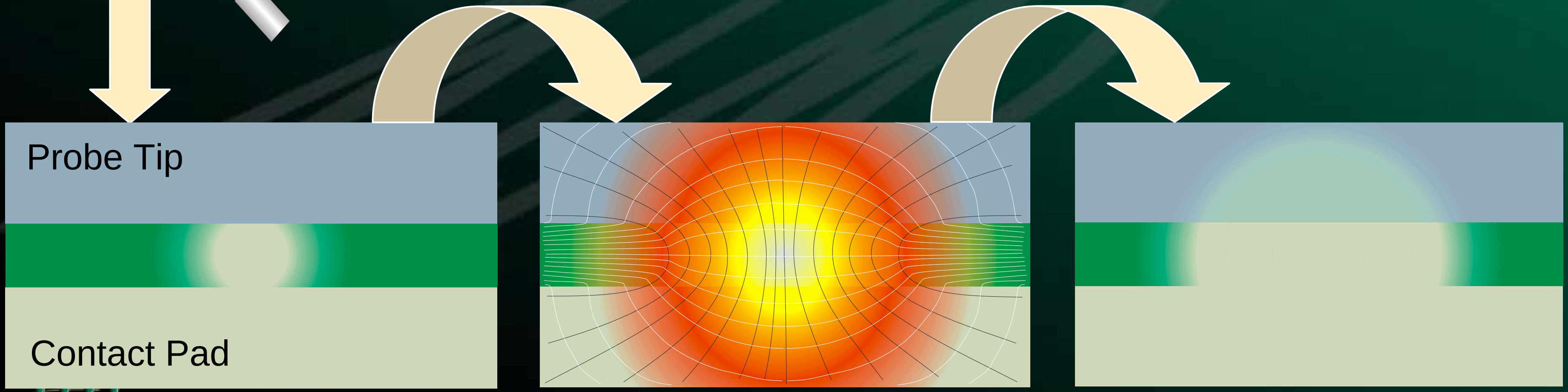


Wide bridge through oxide film.
After high current flow.
Tip surface is contaminated.

Fritting – What‘s that?

- Fritting is a kind of electrical breakdown at the contact surface between the probe tip and the contact pad of the IC.
- It improves the electrical contact by building or stabilizing bridges through the oxide film, if the film was not mechanically broken completely.
- After Fritting the probe tip is welded with the contact pad. After removing the contact residuals of the welding remain at the probe tip and will oxidize.





Motivation

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Experimental Data

Production Data

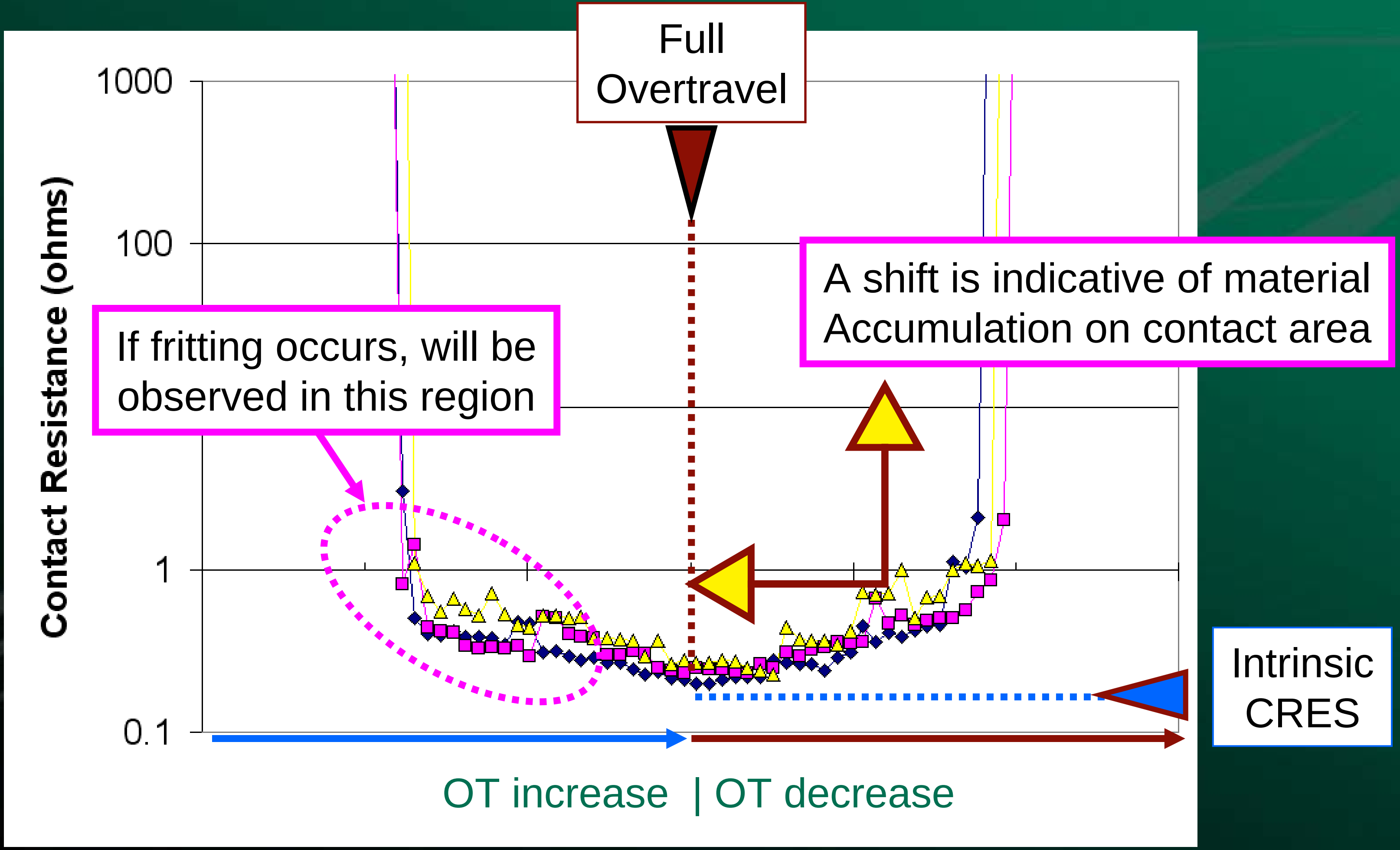
Results & Future Work

Experimental Data / Parameters

- Input Parameters:
  - Overtravel (OT, µm)
  - Probe Material
  - Contact Material (Rhodium, Rh, Aluminum 600nm, Al)
  - Electrical Conditions (Current and direction, mA)
  - Number of Touchdowns (TDs)
- Output Measures:
  - Contact Resistance (Cres, Ohm)
  - Contact Force (CF, cN)
  - Visual Inspection (Video Camera System)
  - Scanning Electron Microscope (SEM)

What is a "Bathtub" Curve ?

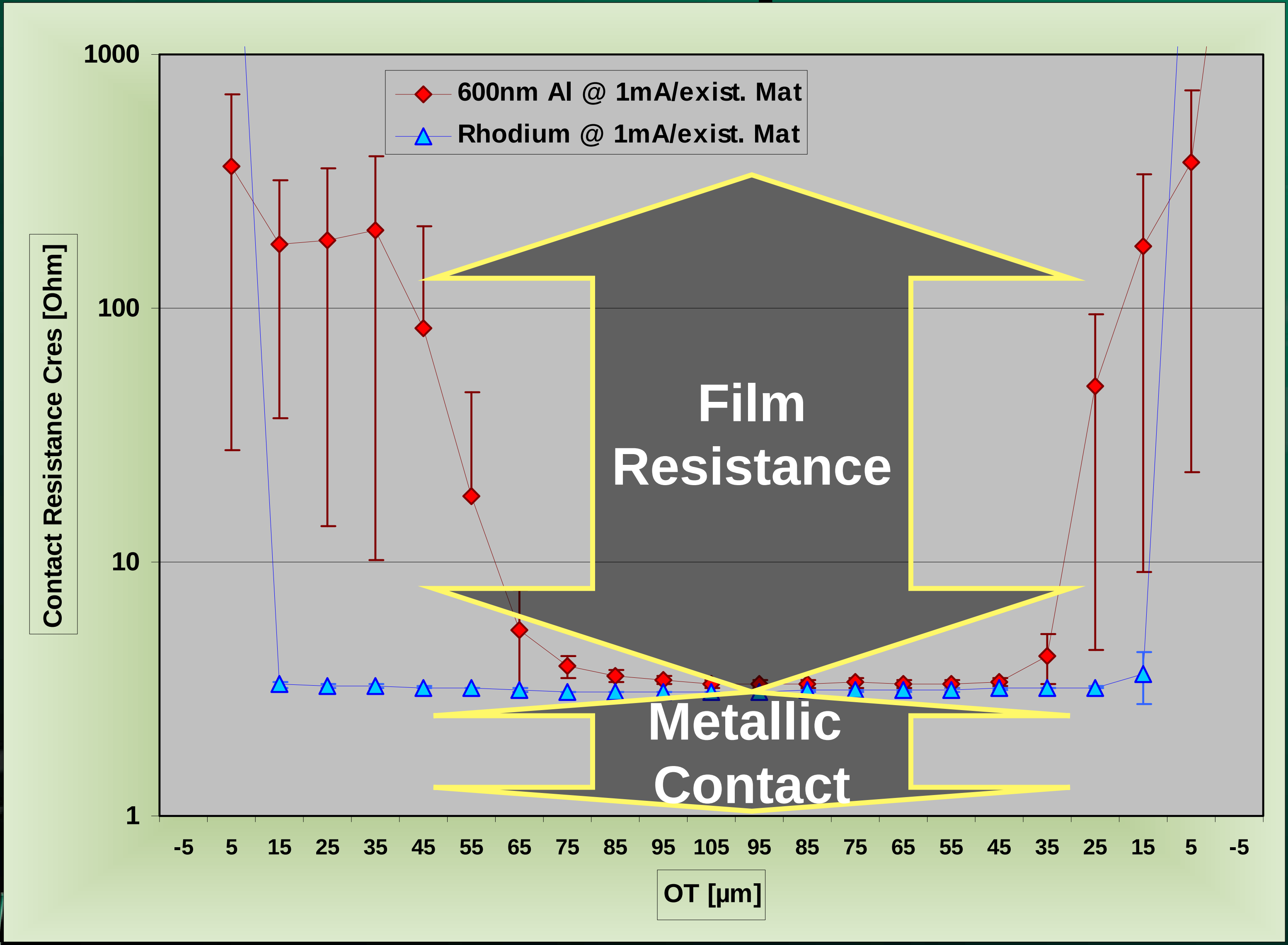
- A symmetric "bathtub" curve at full overtravel is preferable.



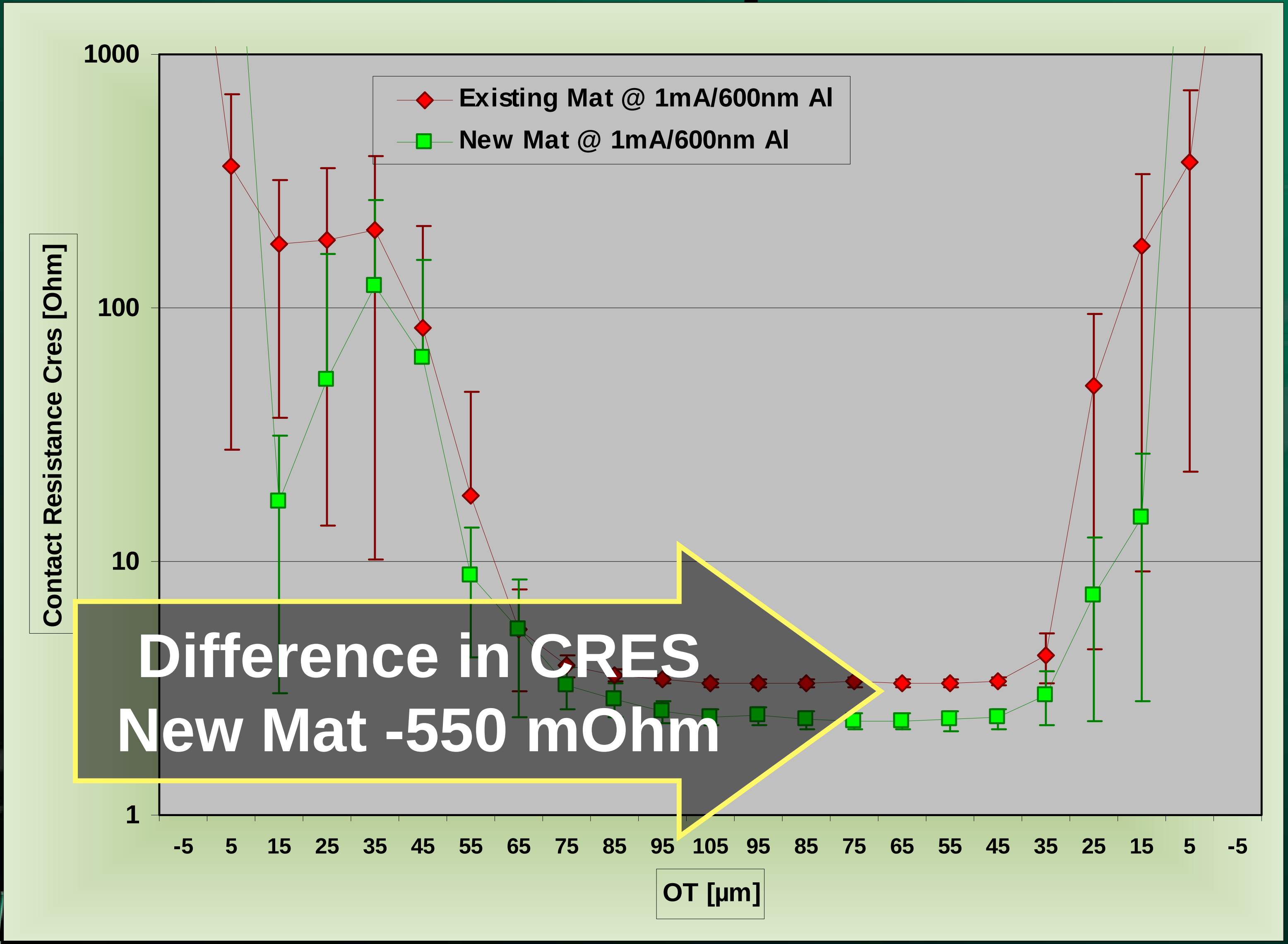
Bathtub Experiments

- Test Sequence
  - CRES vs Overtravel performance tests up to 100µm overtravel (OT)
  - CRES measurement Pin-to-Pin with 3mil diameter
- Test Execution for total 30 TDs each
  - Performed on Rh-Plate and Al-Wafer
  - Performed with existing and new beam material
  - Performed at 1mA and 100mA

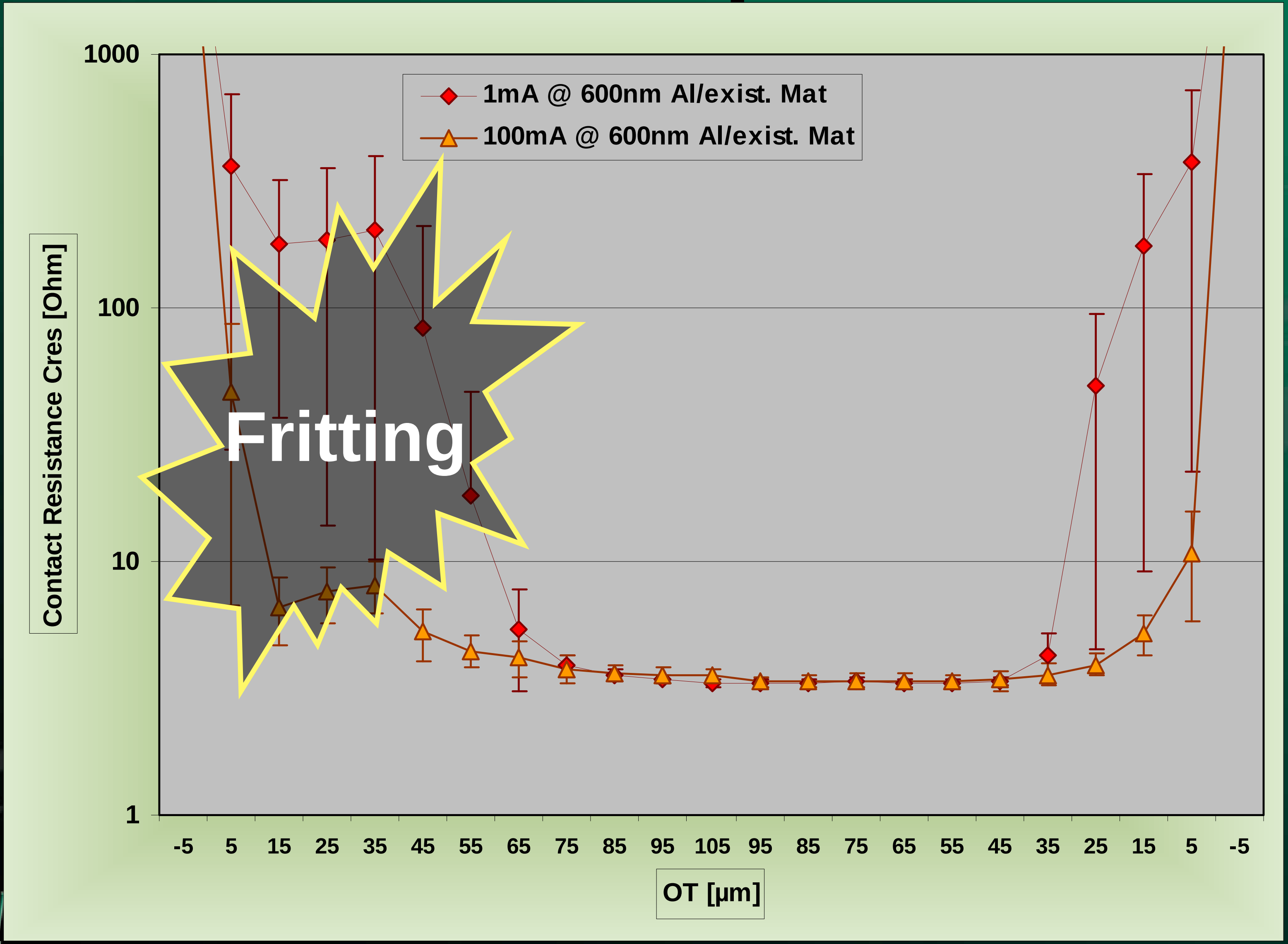
Bathtub Comparison I



Bathtub Comparison II



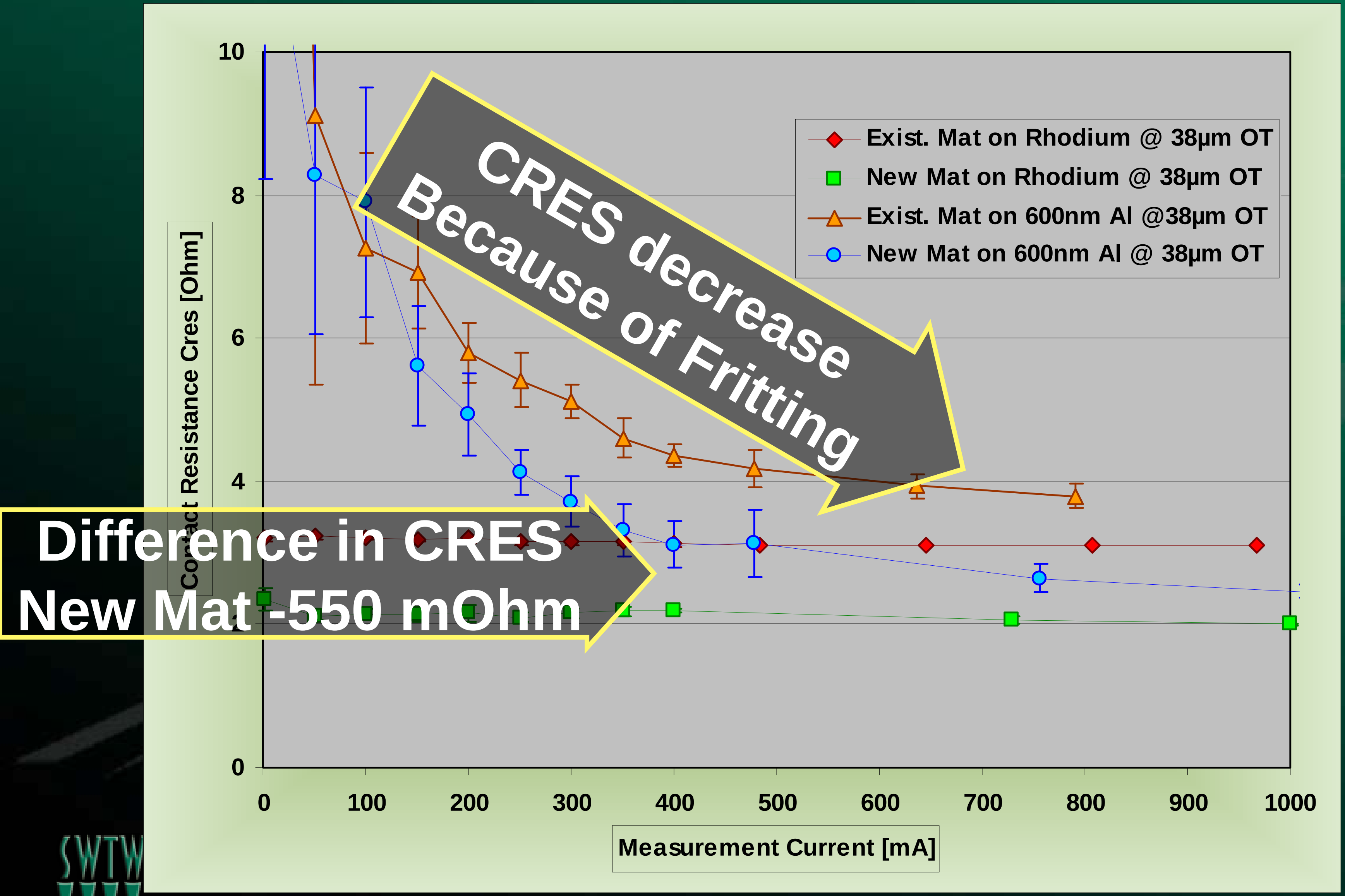
Bathtub Comparison III



CRES vs. Current

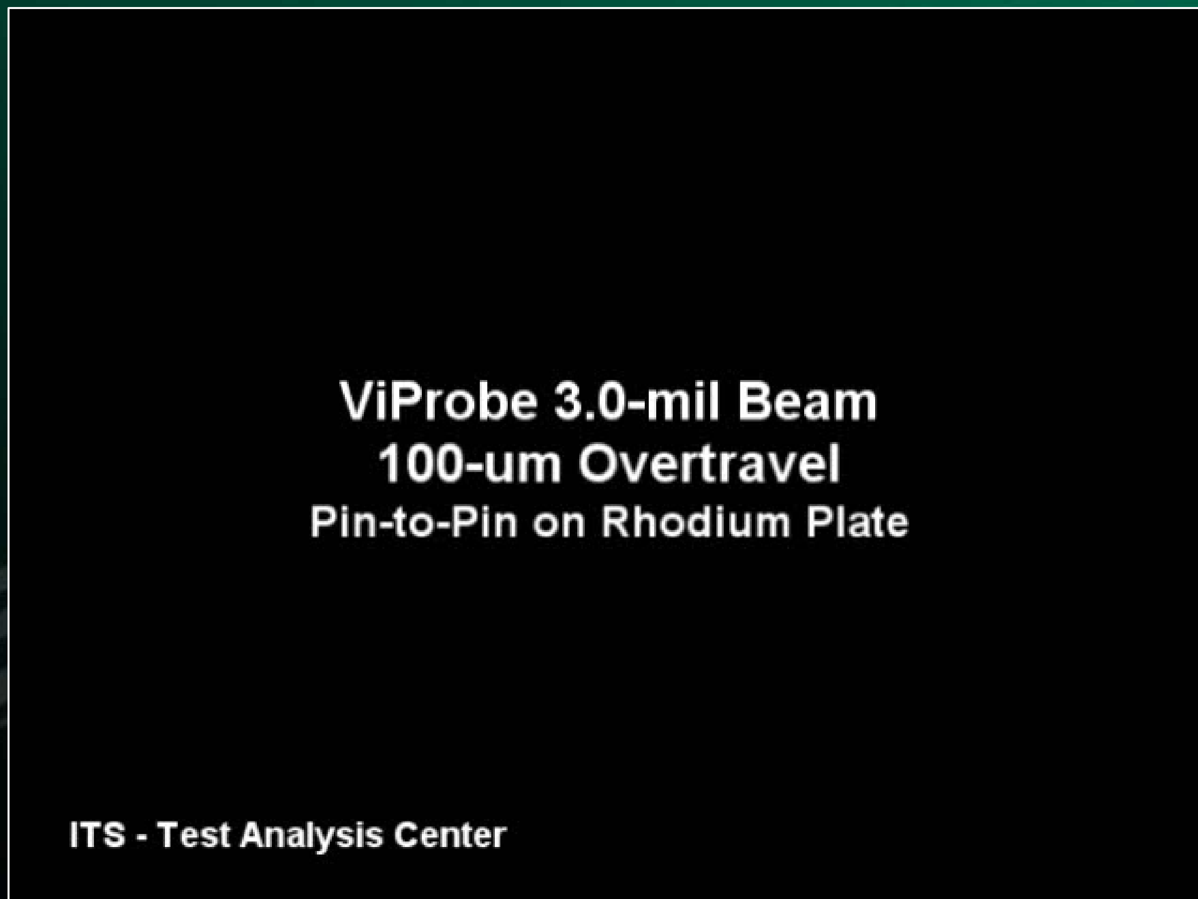
- Test Sequence
  - 30 TDs at 38µm Overtravel (no intermetallic contact on Al-Wafer)
  - CRES measurement Pin-to-Pin with 3mil beam diameter
- Test Execution for total 30 TDs each
  - Performed for a set of currents (1mA-1A)
  - Performed on Rh-Plate and on Al-Wafer
  - Performed with existing and new beam material

CRES vs. Current



Visualization of Test

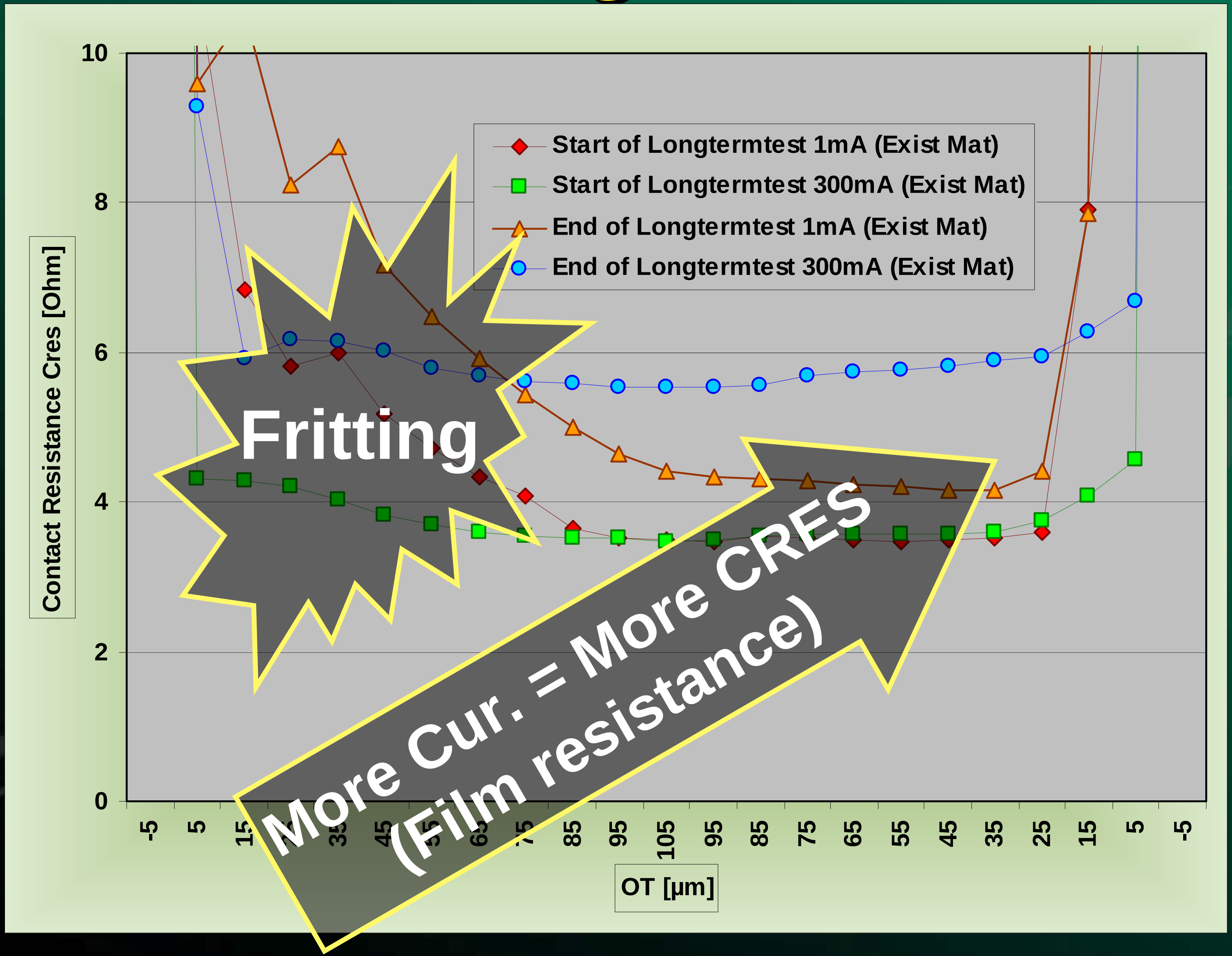
- Pin-to-Pin CRES across substrates
  - **NO FRITTING** observed on Rhodium plate
  - **FRITTING** observed 600nm Aluminum wafer



CRES Longterm tests

- Test Sequence
  - 200 TDs on a 600nm Aluminum Wafer at 38µm Overtravel
  - CRES vs Overtravel performance tests up to 100µm overtravel on a Rh-Plate
- Test Execution for total of 20K TDs on wafer
  - Al-wafer with 1mA and Rh-Plate at 1mA
  - Al-wafer with 300mA and Rh-Plate at 300mA
  - Performed with existing and new beam material
  - Performed Pin-To-Pin
  - No Cleaning at all

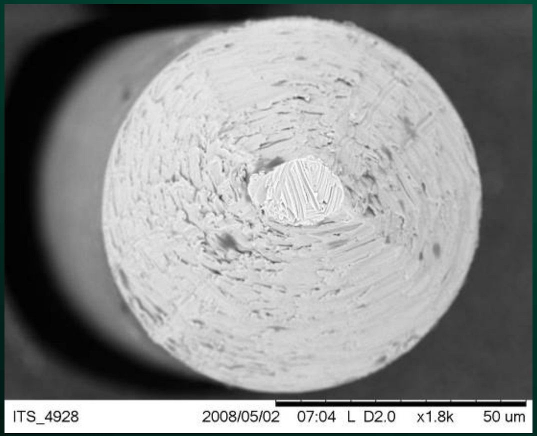
CRES Longterm Tests



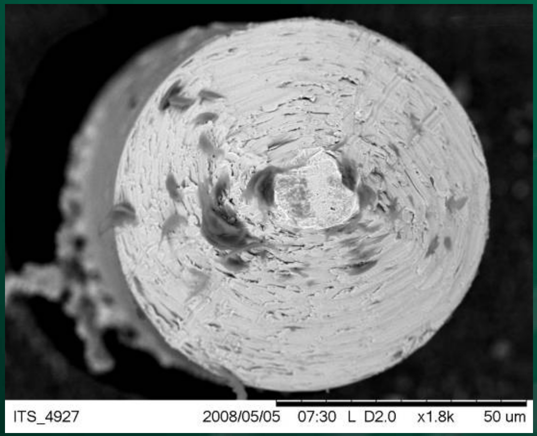
CRES Longterm Tests

SEM Images after 20K TD Longterm Test @ 1 and 300mA without any Cleaning

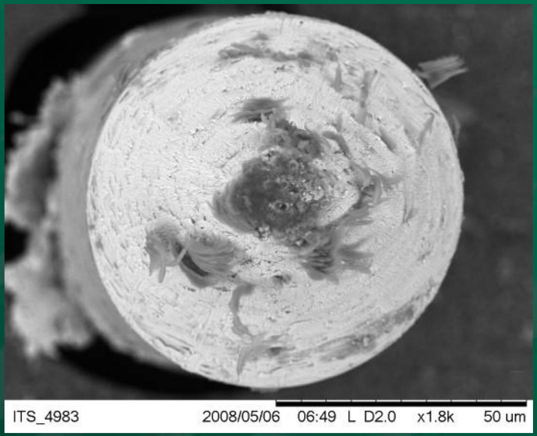
Existing Material - Initial



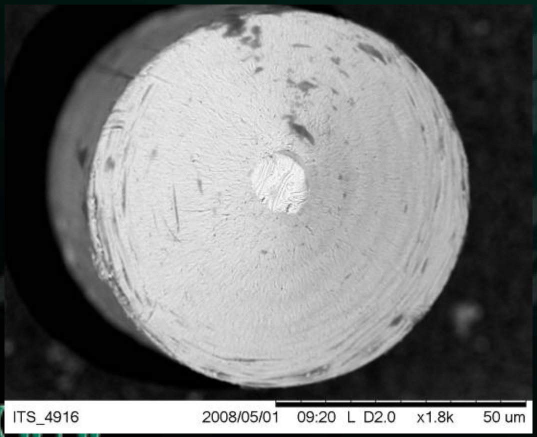
20K 1mA Al + 1mA Rh



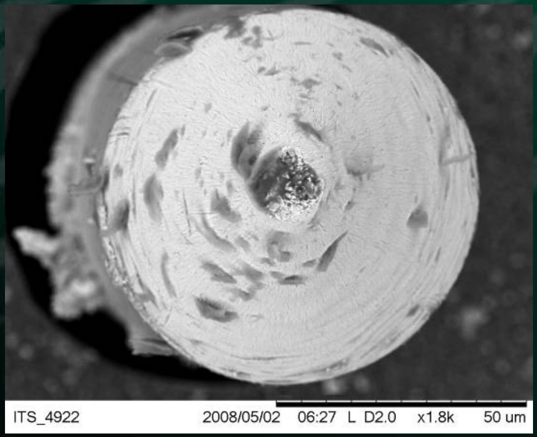
20K 300mA Al + 300mA Rh



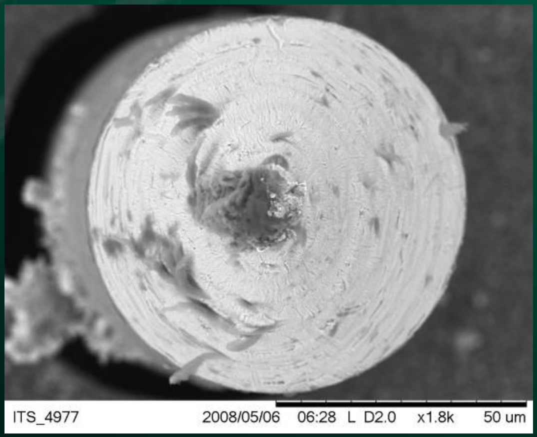
New Material - Initial



20K 1mA Al + 1mA Rh



20K 300mA Al + 300mA Rh

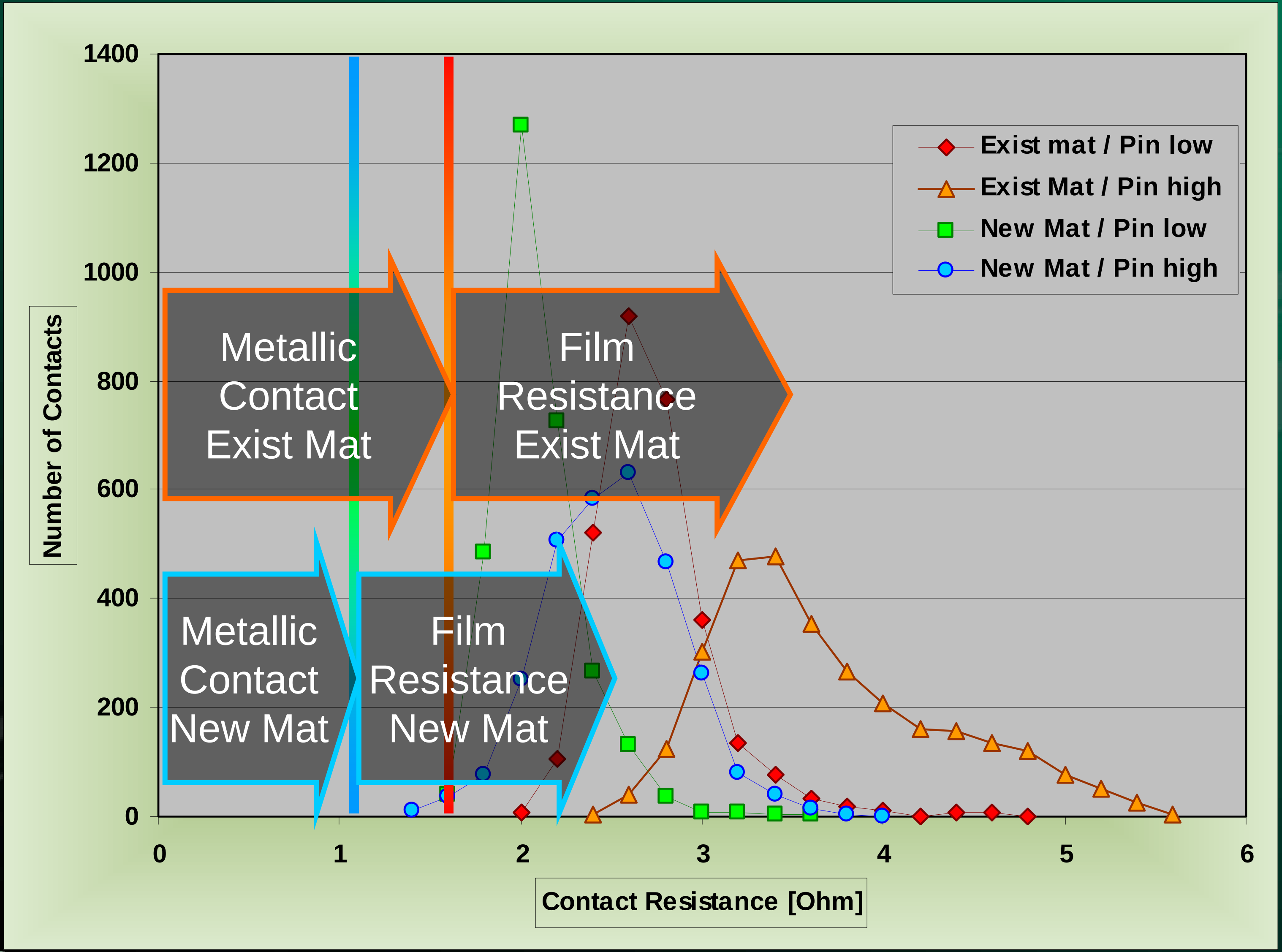


CRES Longterm Tests
Pin High / Low

- Test Sequence
  - 200 TDs on a 600nm Aluminum Wafer at 25µm Overtravel
  - CRES vs Overtravel performance tests up to 100µm overtravel on a Rh-Plate
- Test Execution for total of 20K TDs on wafer
  - Pin with 300mA (High) and Rh-Plate (Low)
  - Pin with 300mA (Low) and Rh-Plate (High)
  - Performed with existing and new probe material
  - Performed without cleaning

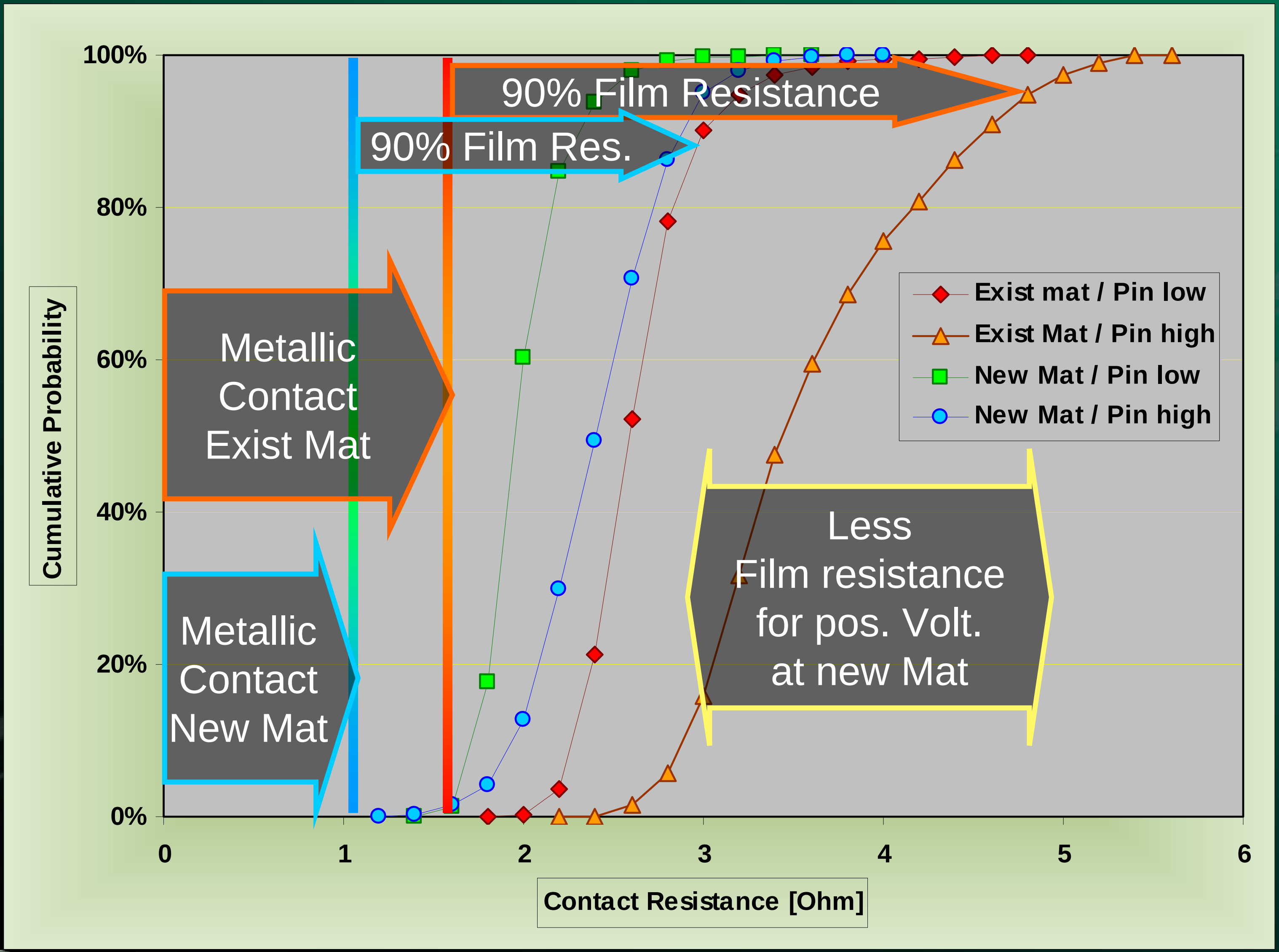
CRES Longterm Tests

CRES Histogram after 15K TDs @ 300mA without Cleaning



CRES Longterm tests

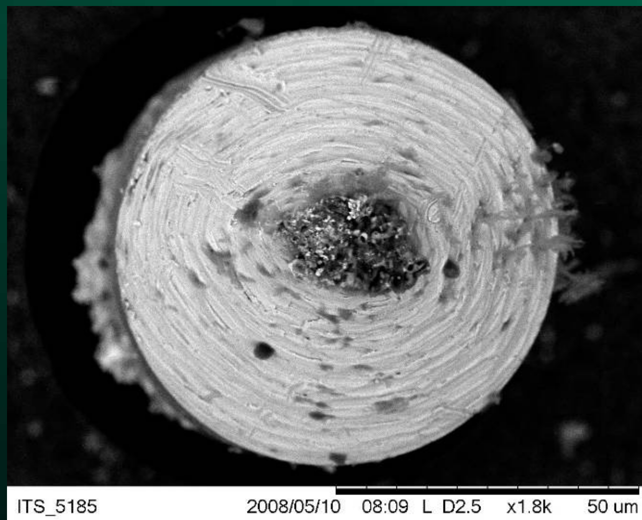
CRES Cum. Probability after 15K TDs @ 300mA without Cleaning

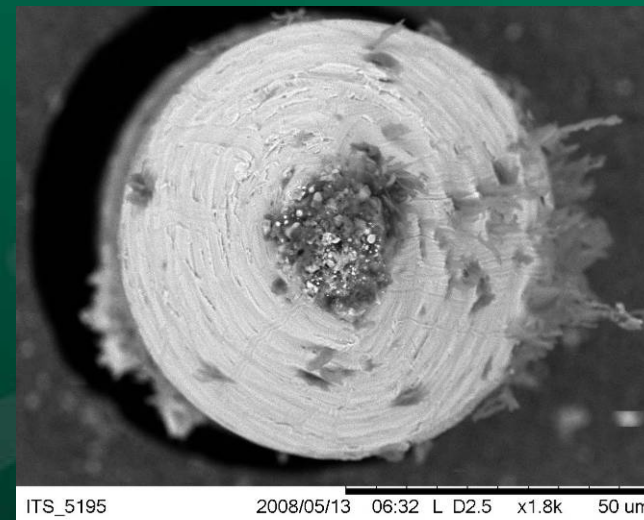


SEM Images after 20K TD Longterm Test @ 300mA without any Cleaning

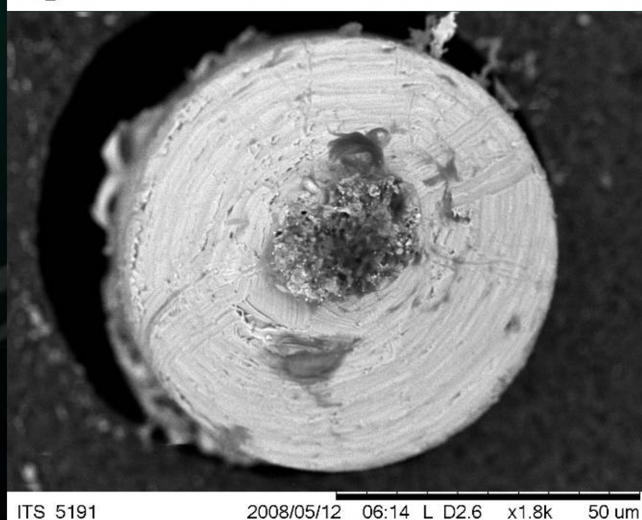
Pin low | Pin High

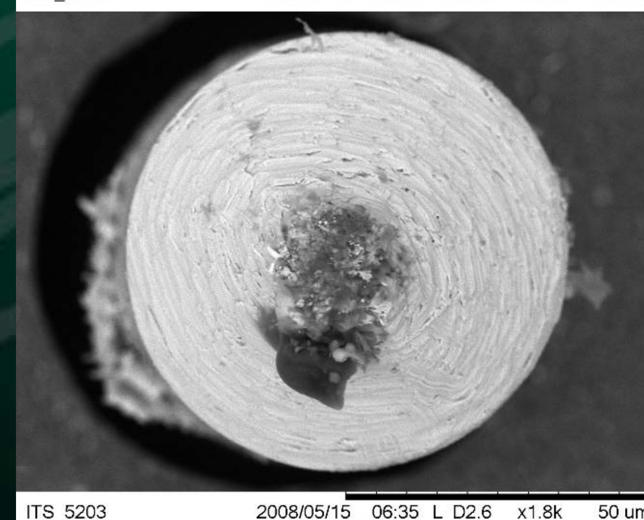
Exist Mat





New Mat





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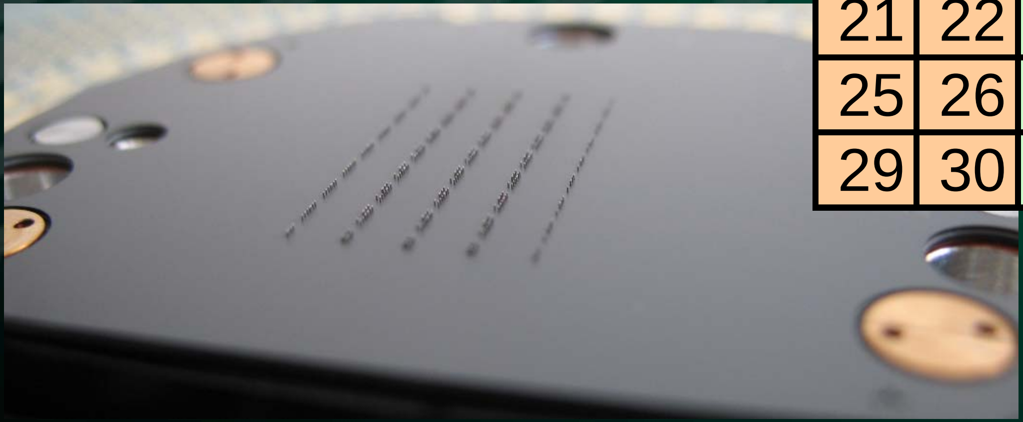
Results & Future Work

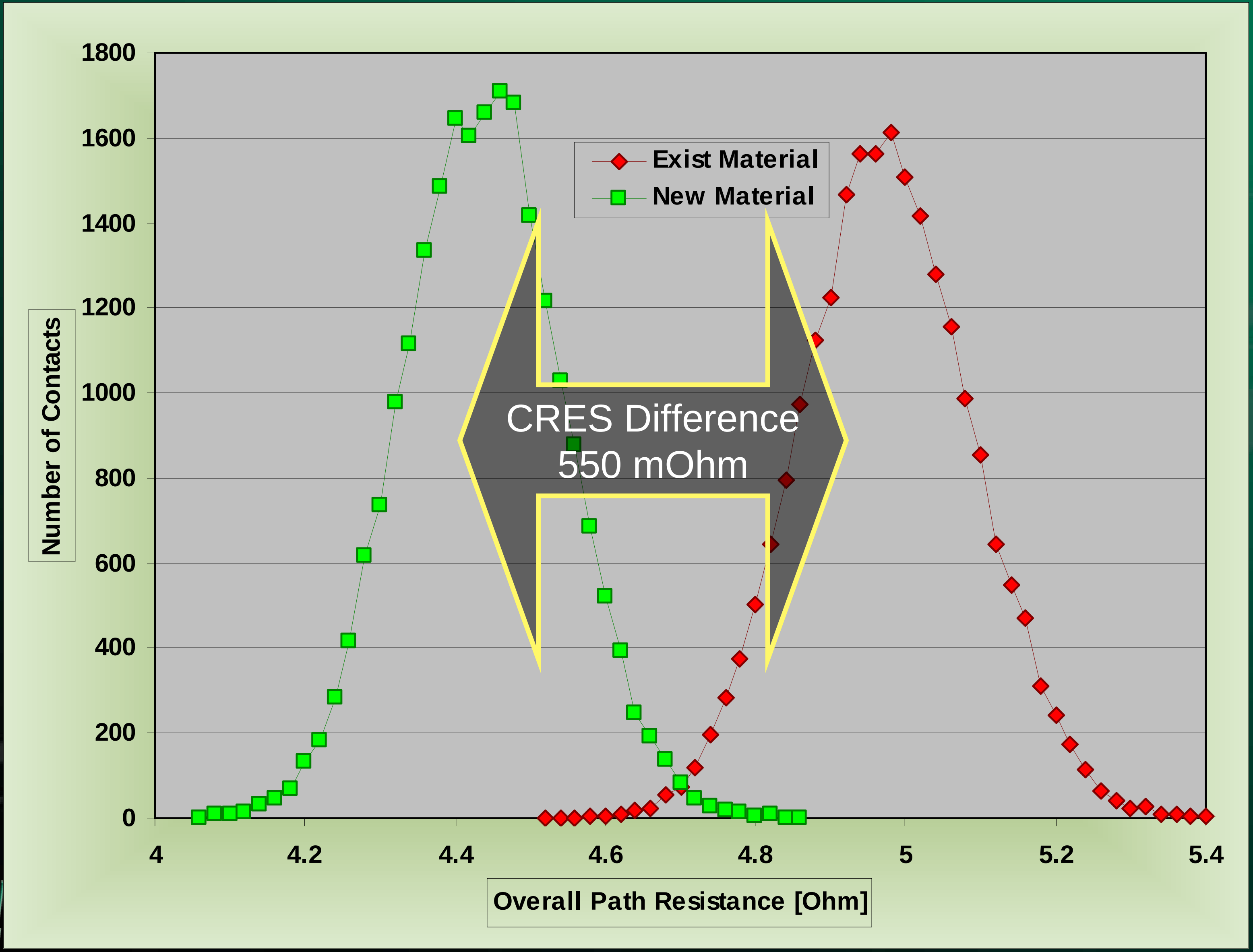
Production CRES Measurement

- Smartcard application 32x parallel
- One Probecard with
  16 sites existing Material (red)
  16 sites new Material (green)
  with symmetric pattern
- CRES Monitor on digital channel put into std. Production Test Program

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32



Production Data



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Results & Future Work I

- New beam material was evaluated in lab and production environments
  - Decrease of resistivity proven: -550 mOhm compared to existing material
  - New Beam material shows better film contact resistance and fritting performance

- Amplitude and directionality of applied current/voltage highly influenced the accumulation of debris as well as the increase of film resistance
  - Higher currents lead to higher CRES
  - Positive voltages higher affected than negative voltages

- Off-line testing under controlled conditions with "standardized" methods can provide key insights for understanding CRES behavior that can help a probe engineer develop wafer sort processes and define cleaning practices.

Results & Future Work II (many interestesting studies !)

- Evaluate fab processed materials
  - Shorted wafers and test die
- Define an "Online Cleaning Rules Set"
- Investigating the effects and repercussions of the Fritting mechanisms
- Temperature influence on film resistance
  - Range similar to production

Acknowledgements

- Feinmetall Engineering Development and Design Teams

- ITS Applications Engineering Team
  - Andrea Haag (Engineering Technician)

Men At Work

Thank you!
Questions?