IEEE SW Test Workshop
Semiconductor Wafer Test Workshop

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Investigating Copper Metallurgy Effects for Sort Process and Cleaning Performance Metrics

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- Joint Venture Overview
  - FM: ViProbe®
  - ITS: Lab Capabilities
  - NXP: Engineering Environment
- Contact Resistance and Fritting Theory
- Experimental Data
- Production Data
- Results & Future Work

Motivation

Joint Venture Overview

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Motivation

- “Public” knowledge of bare copper probing is limited and industry “rumors” suggest difficult process control.
- Sort floors are often resource limited for performing fundamental characterization studies.
- Testing with “full-build” probe cards is expensive and often not feasible, particularly with large array probe cards.
- Assessing combinations of key performance parameters performed quickly under known and controlled conditions.

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Feinmetall ViProbe®
Contacting on Copper

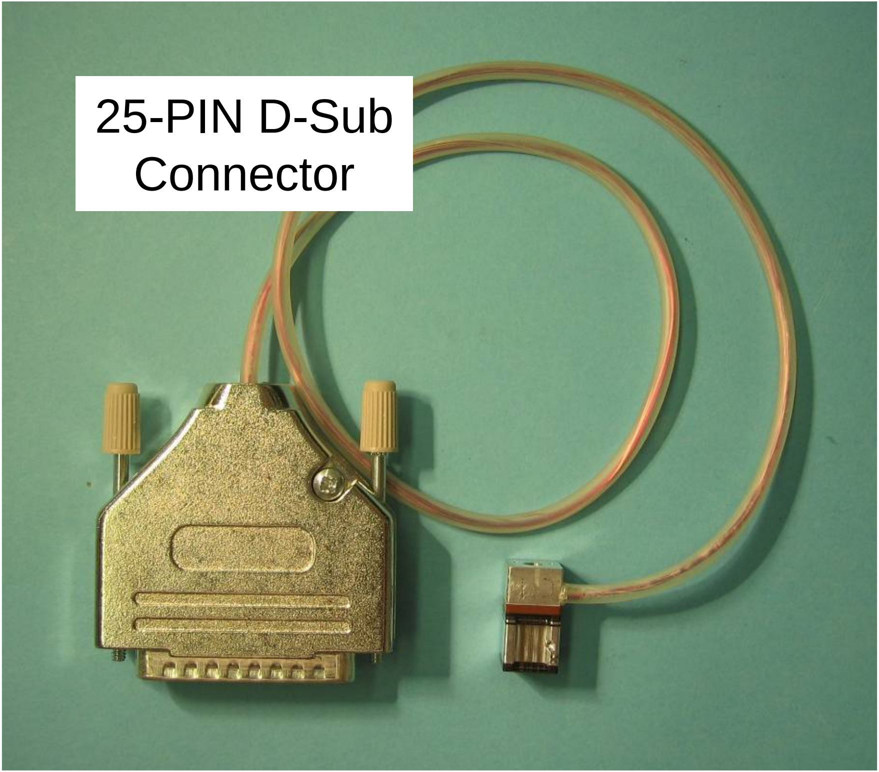
- Contacting on bare copper is becoming more important for the semiconductor industry.
- Feinmetall is faced with different costumers and different types copper based technologies.
- Aluminium vs. copper seems to be two different worlds for wafer test.

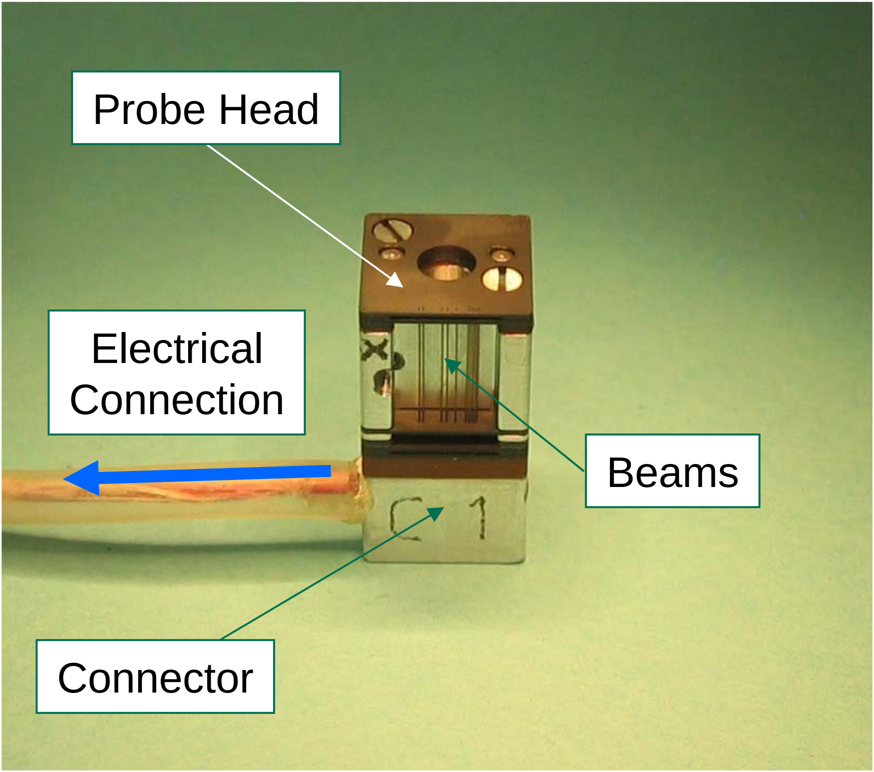
Feinmetall ViProbe® Trivar® HC

- SWTW2008 – Tests on aluminium with 3 mil beams
  - 800 mA maximum current.
- SWTW2009 – Tests on copper with 2 mil beams
  - 300 mA current
  - minimum beam pitch: 75 µm
- To decrease the pitch and make the next technology step Feinmetall has introduced a new fine pitch beam:
  - 1.6 mil diameter
  - 200 mA max. current
  - 59 µm minimum needle pitch

ViProbe® Testvehicle

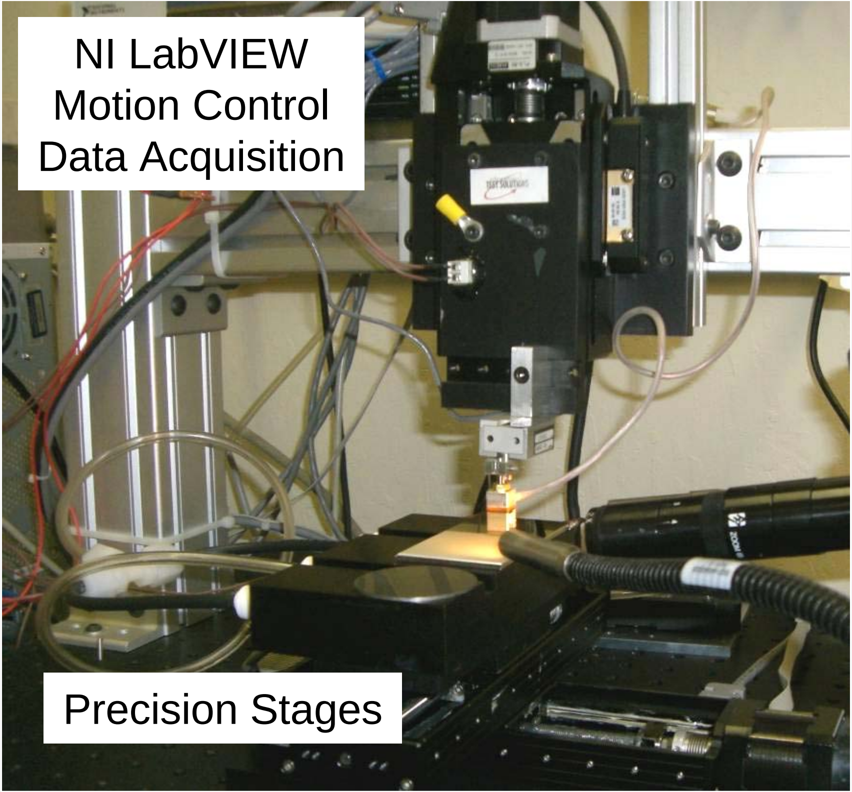
- Smallest ViProbe® test head ever designed and built
  - 1.6 mil, 2 mil, 2.5 mil and 3 mil ViProbe® compatibility





Controlled Test Conditions

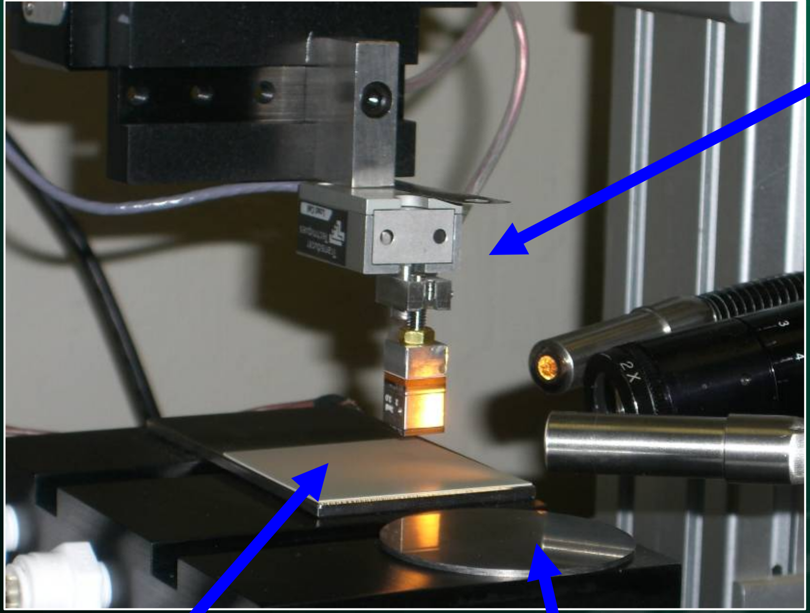
- Bench-top instrument for material characterization and probe performance testing.



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.**

Bench Top Testing

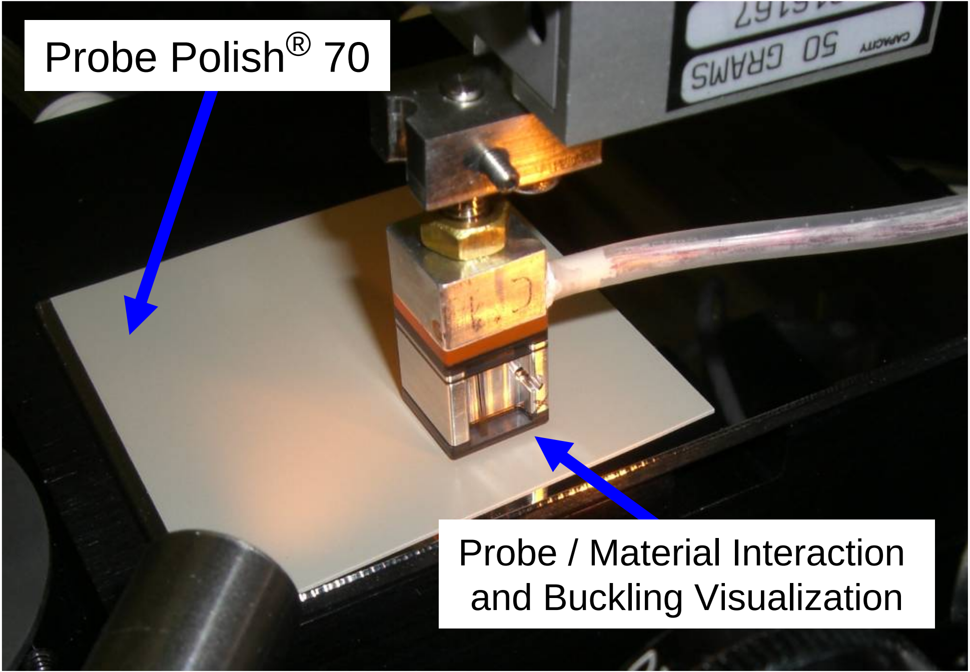


ViProbe® with
50 gram load cell

Cleaning Zone

Electrical Test Zone

Synchronized DAQ
Load vs. overtravel vs. CRES



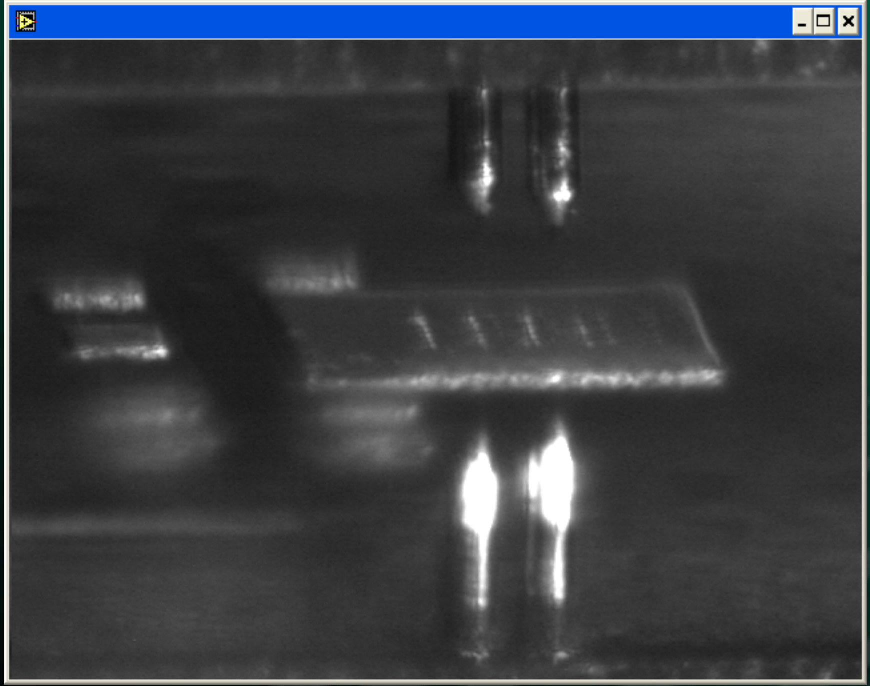
Probe Polish® 70

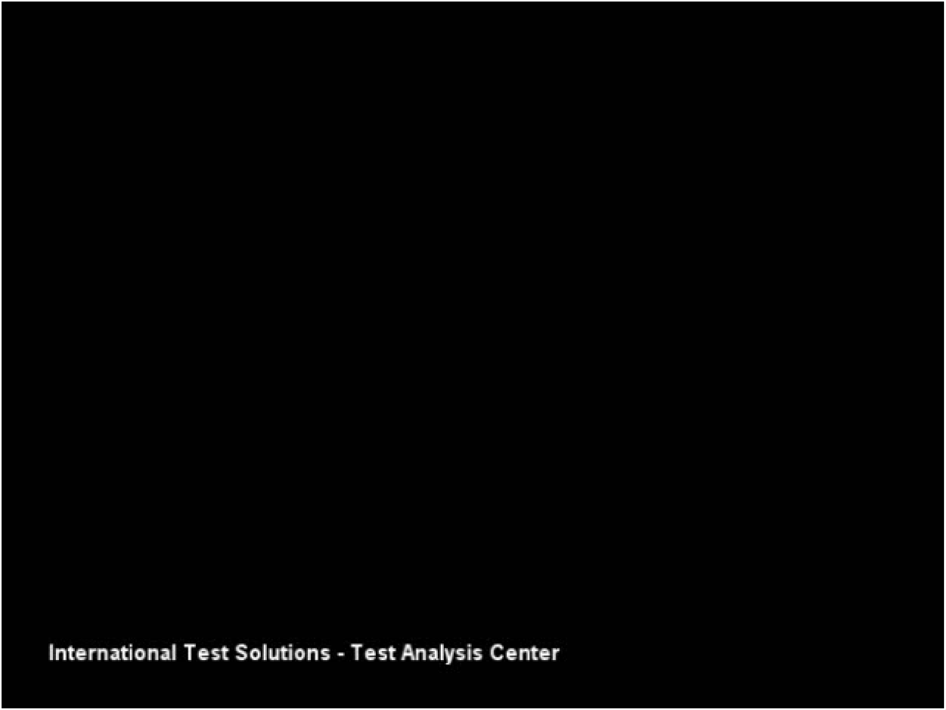
Probe / Material Interaction
and Buckling Visualization

NXP Testcenter Hamburg Engineering Environment

- Engineering site for automotive and identification business, digital, and mixed signal products.
- Applications with high multisite factors and small pad pitch.
- Capability to collect contact resistance data within production like environment

Multi Probing Within Pads to Maximize Touchdowns





Pin to Pin CRES
4-wire Measurement

Motivation

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Contact Resistance and Fritting Theory

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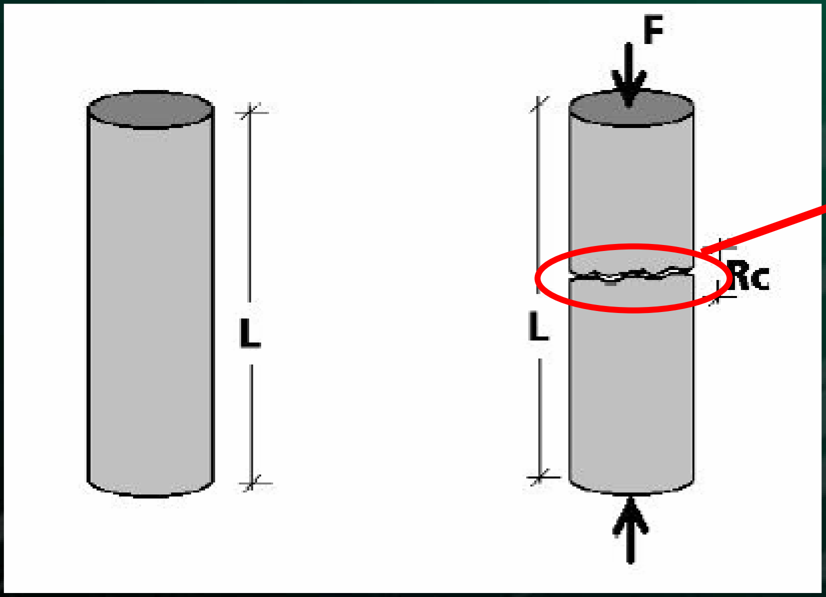
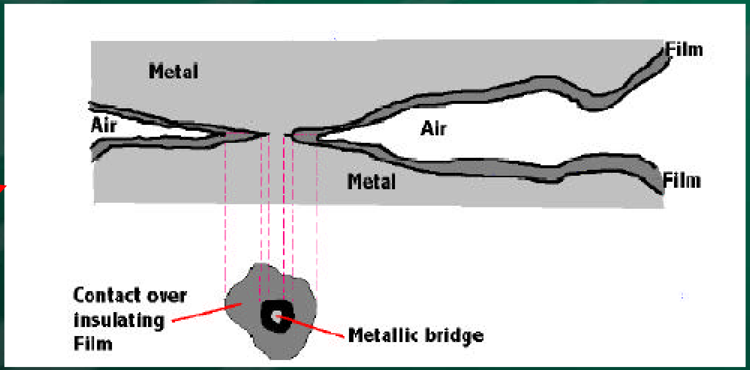
Contact Resistance (CRES)

- CRES is considered the most <u>CRITICAL</u> parameters in wafer sort
- CRES Fundamentals …
  - CRES occurs between two bodies in contact
  - Creates losses in electrical and thermal systems





- Current flow is constricted to the inter-metallic contacts
- Localized joule heating

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 eventually dominates the magnitude and stability of the CRES.

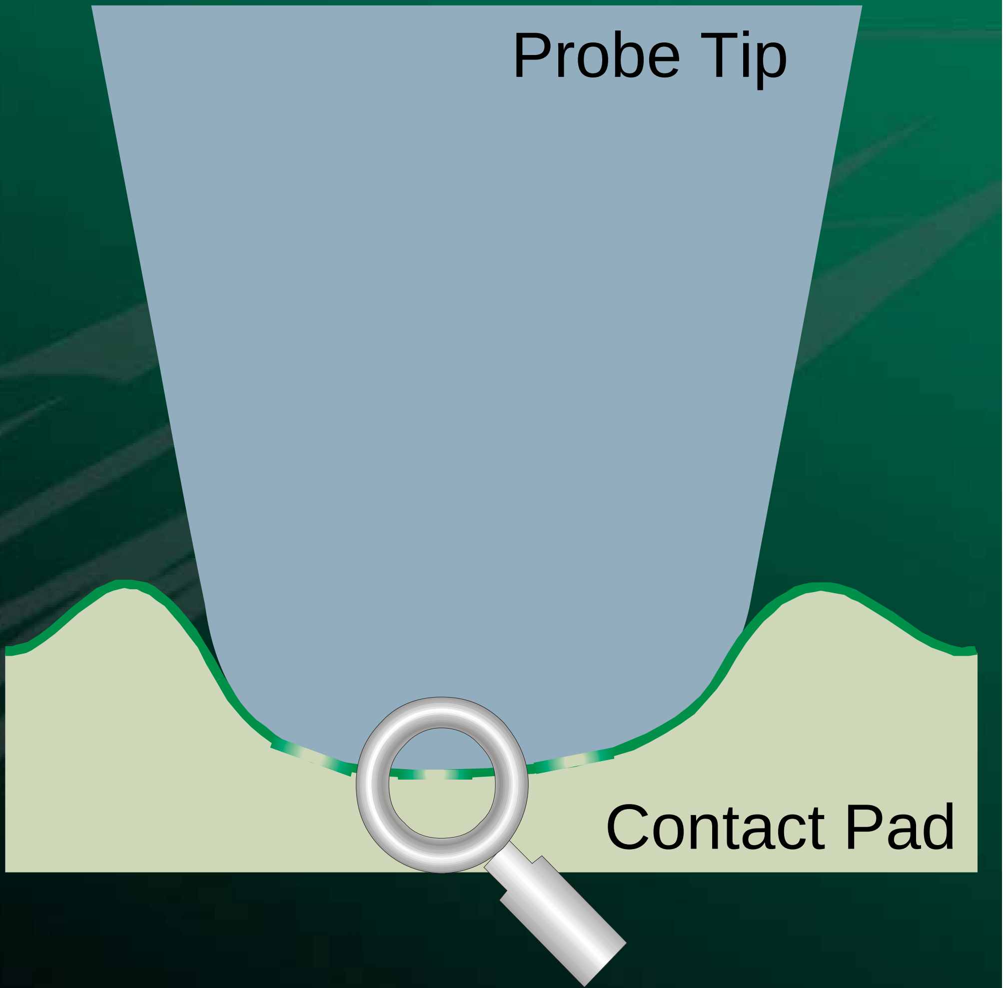
- Probe shape and needle contact mechanics play an important role
  - Displacing the contaminants from the true contact area
  - Surface characteristics affect the “a-Spot” density
    - R. Martens, et. al, *IEEE SW Test Workshop (2004)*
    - C. Manion, et. al, *IEEE SW Test Workshop (2000)*

- Pad hardness contributes to pad penetration and acummulation
  - Softer Pads ➔ Better oxide break through but more debris
  - Harder Pads ➔ Less debris but worse oxide break through
    - Ehrler, et. al, *IEEE SW Test Workshop (2007)*

- Amplitude and directionality of the voltage or current applied.
  - Voltage or current must be sufficient to breakdown the oxide
    - J. Martens, et. al, *IEEE SW Test Workshop (2008)*
    - J. Martens, , et. al, *IEEE SW Test Workshop (2006)*

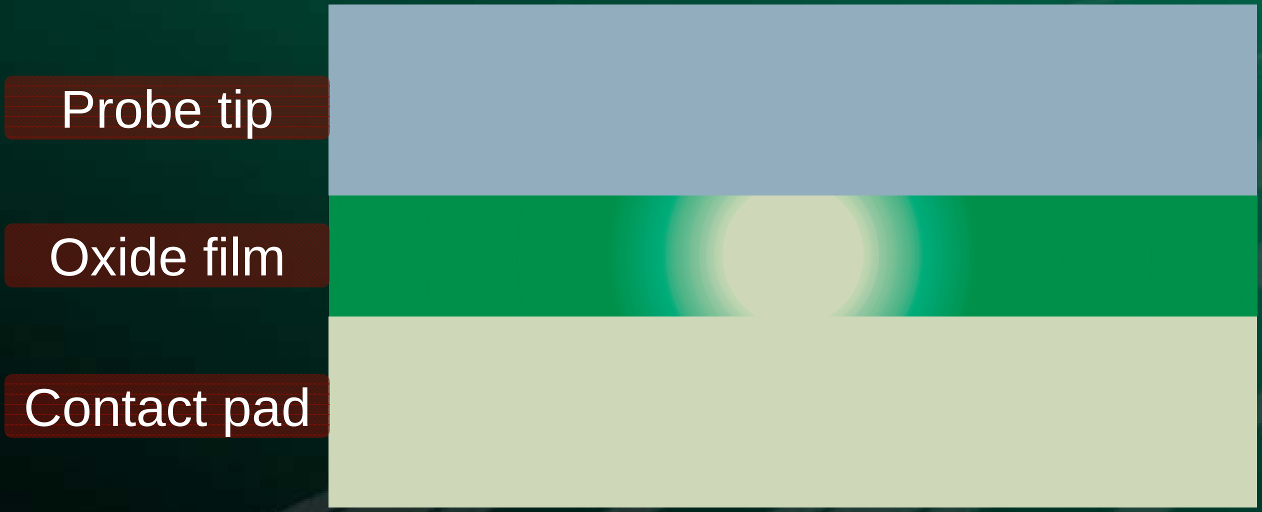
Fritting – Theory

- 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?



Probe tip

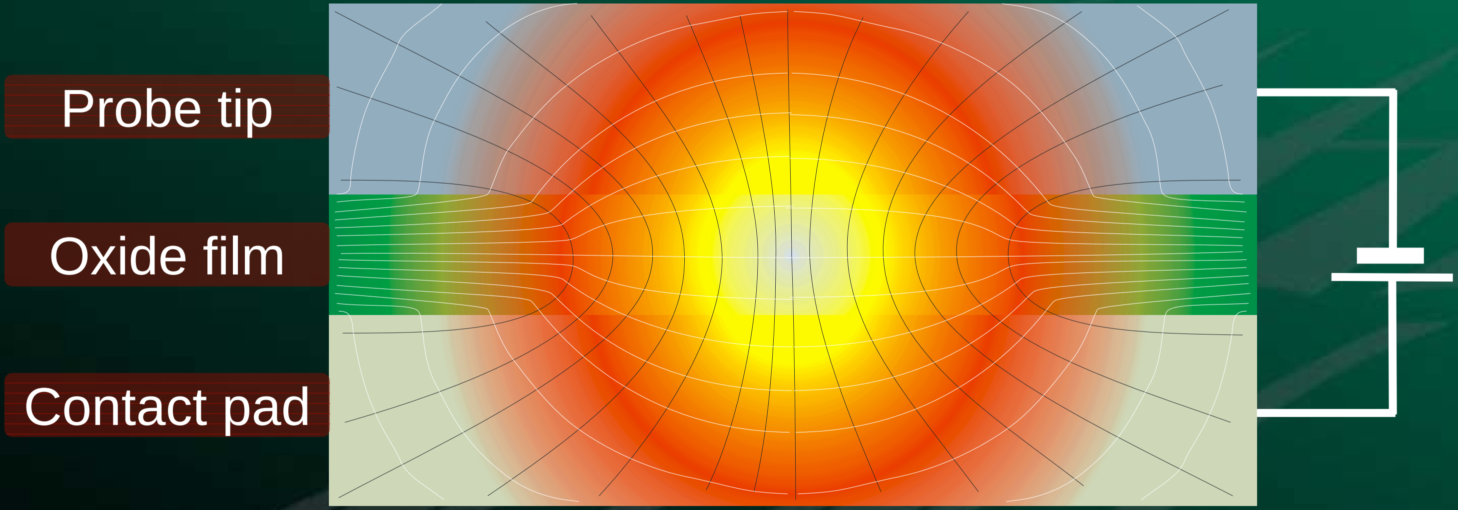
Oxide film

Contact pad

Small bridge through oxide film.
Before high current flow.

Fritting – Theory

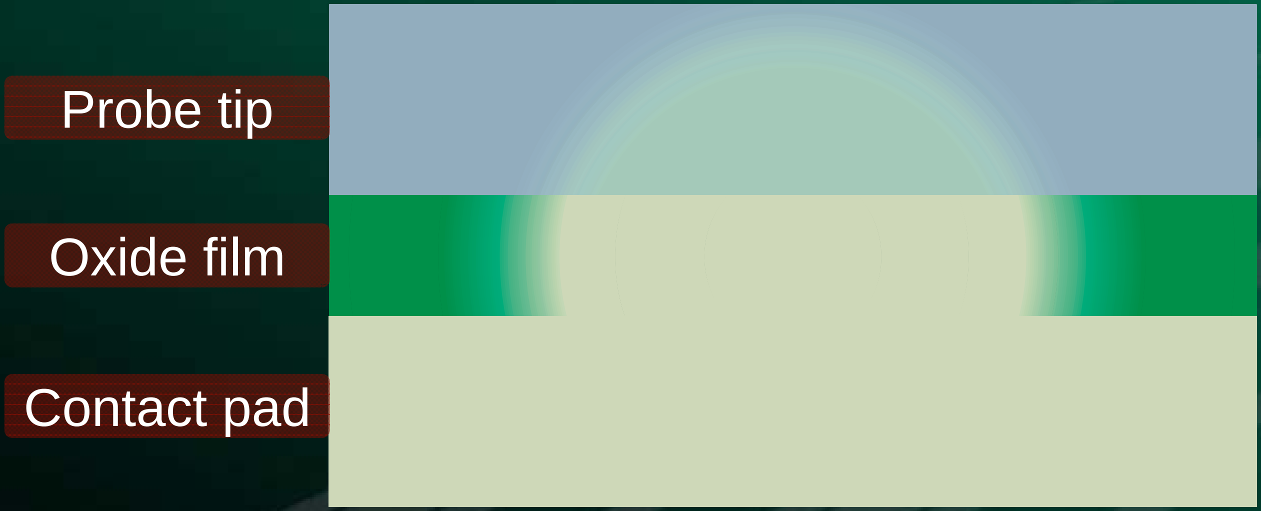
- Current must flow through small bridge.
- Bridge and neighborhood are heated up
- Contact Pad material migrates to the bridge.



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

Fritting – Theory

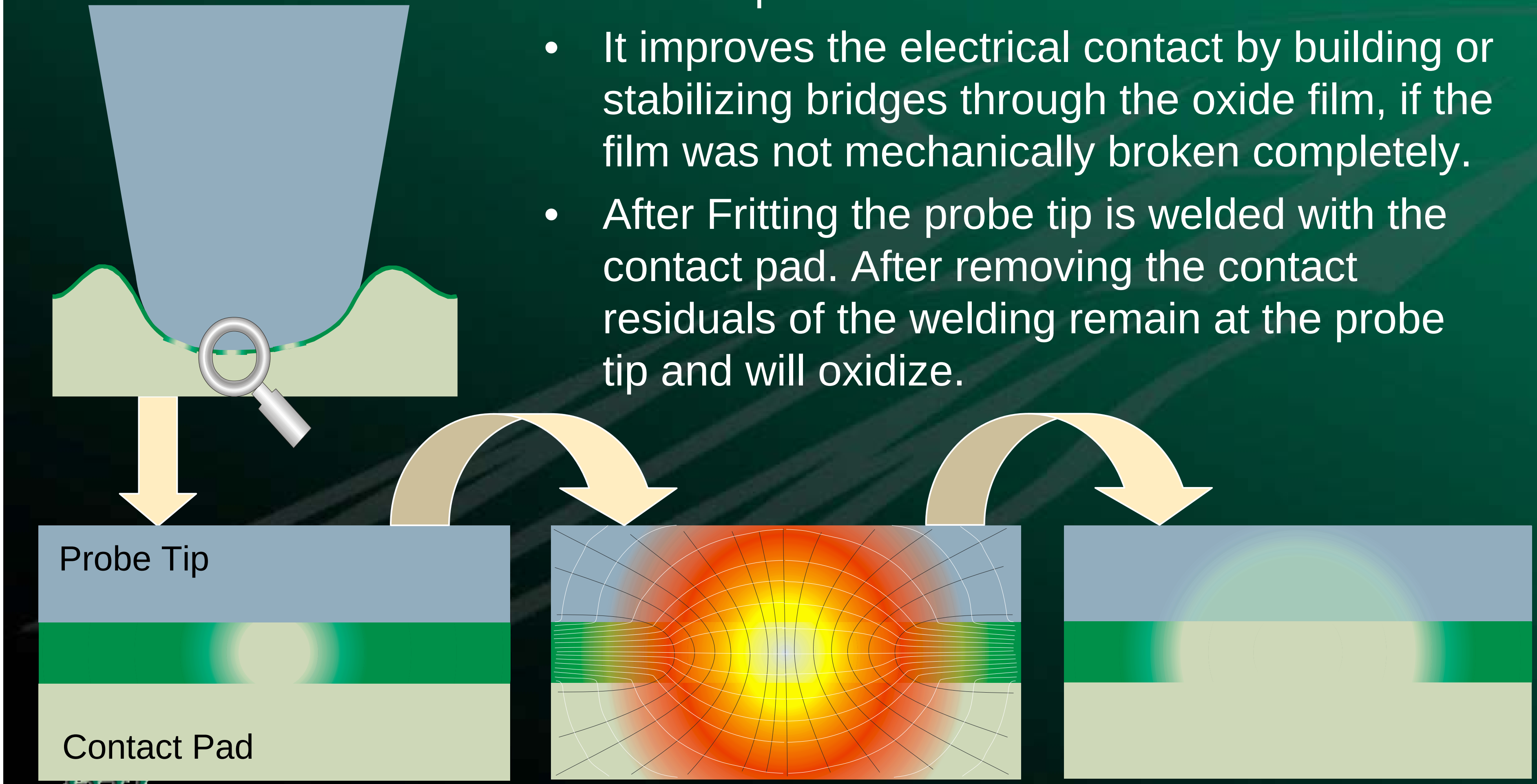
- Bridge is widened → C_{RES} decreased
- Contact pad material migrated to the bridge and tip surface



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.



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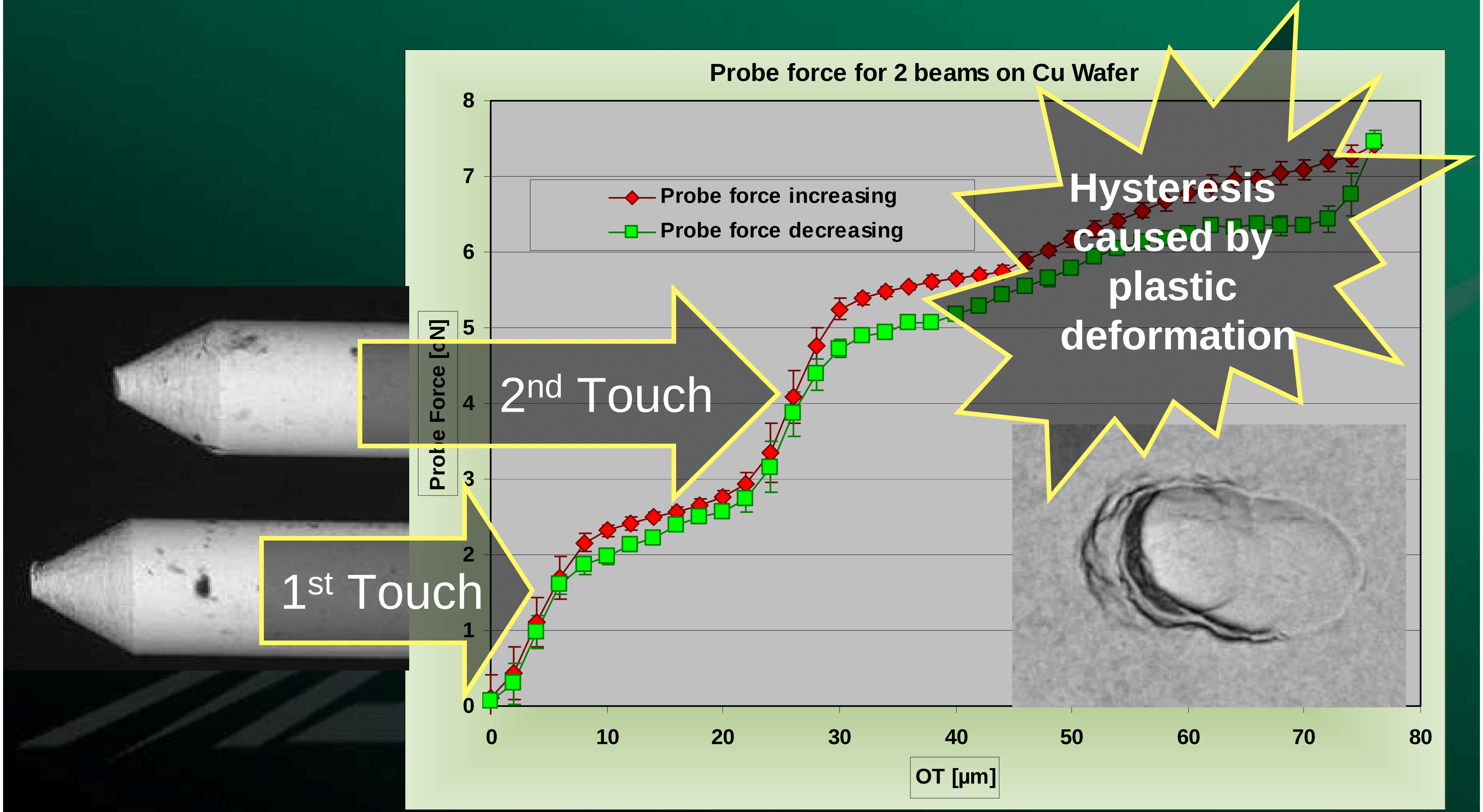
Description DOE 1

- CRES vs. Overtravel (OT) characteristic on several pad materials
  - Rhodium plate (reference) → Rh plate
  - Blanket aluminum wafer ('08 data) → Al Wafer
  - Blanket galvanic copper wafer (10µm) → Cu Wafer
  - NXP internally processed product → NXP source A
- Current @ 1mA pin to pin
- 6TDs each material up to 75µm OT
- Measuring CRES and Probe force

Probe Force Result DOE1

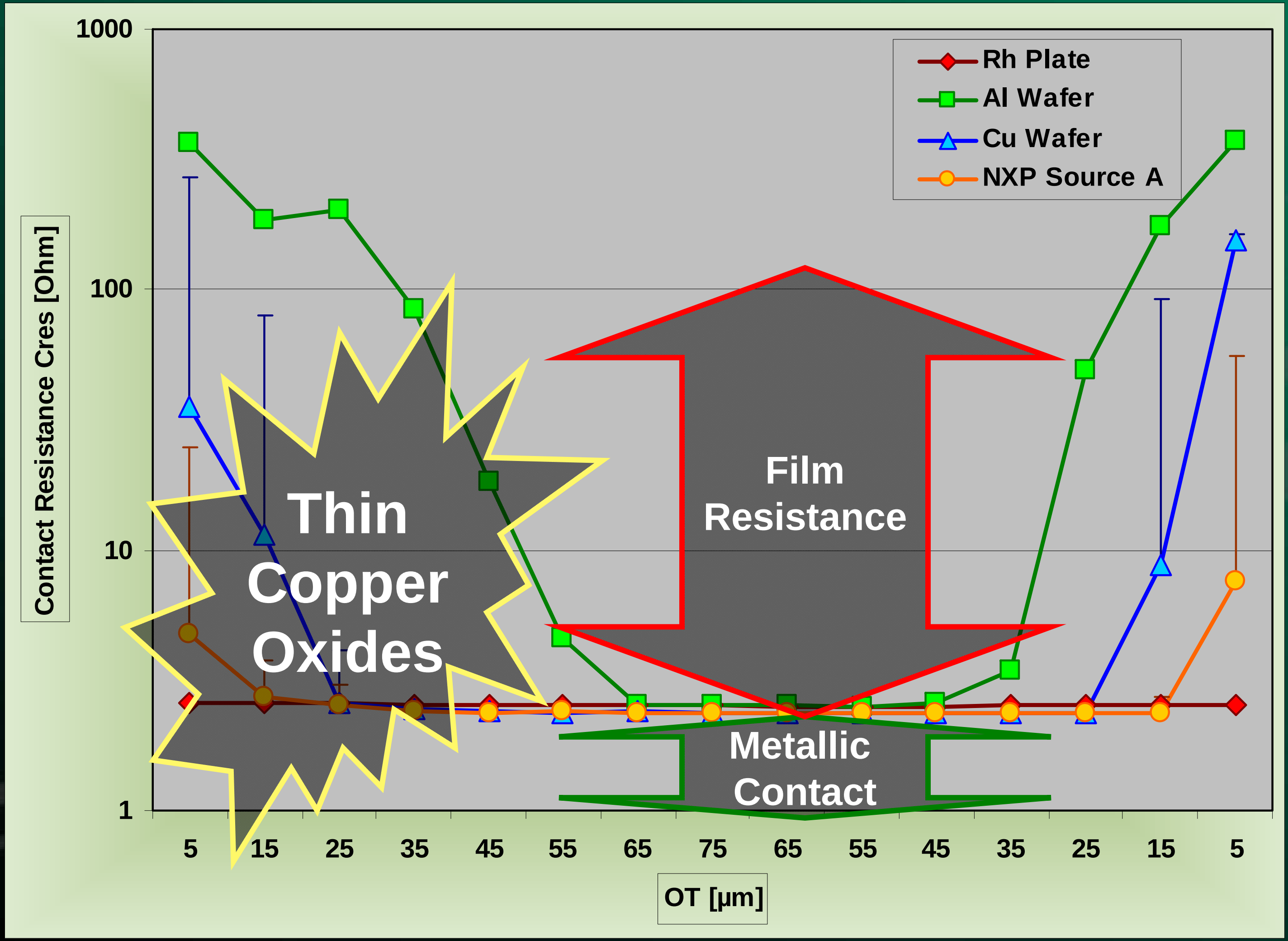


2nd Touch

1st Touch

Hysteresis caused by plastic deformation

CRES Results DOE1



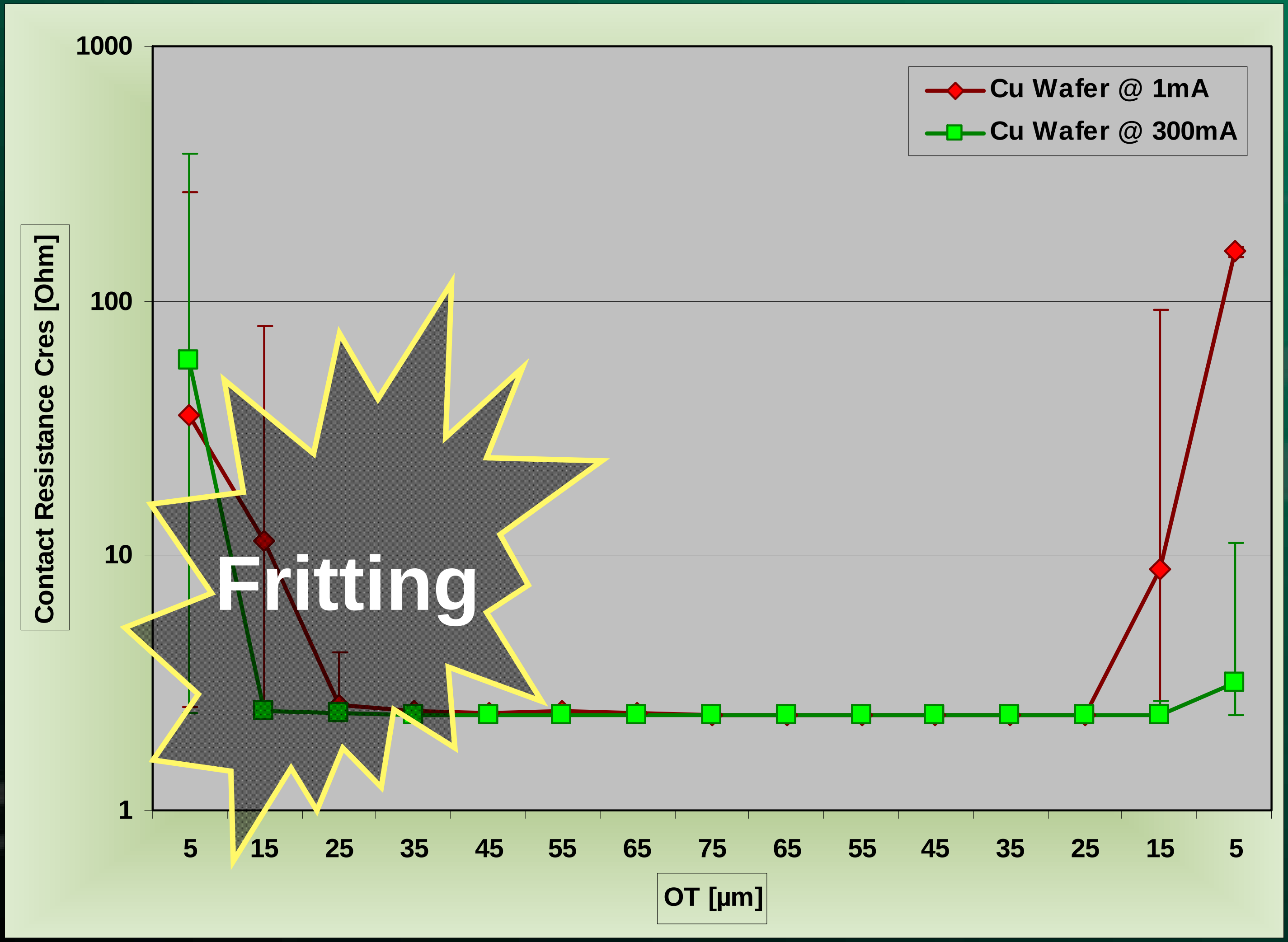
Description DOE 2

- CRES vs. Overtravel (OT) characteristic on several pad materials

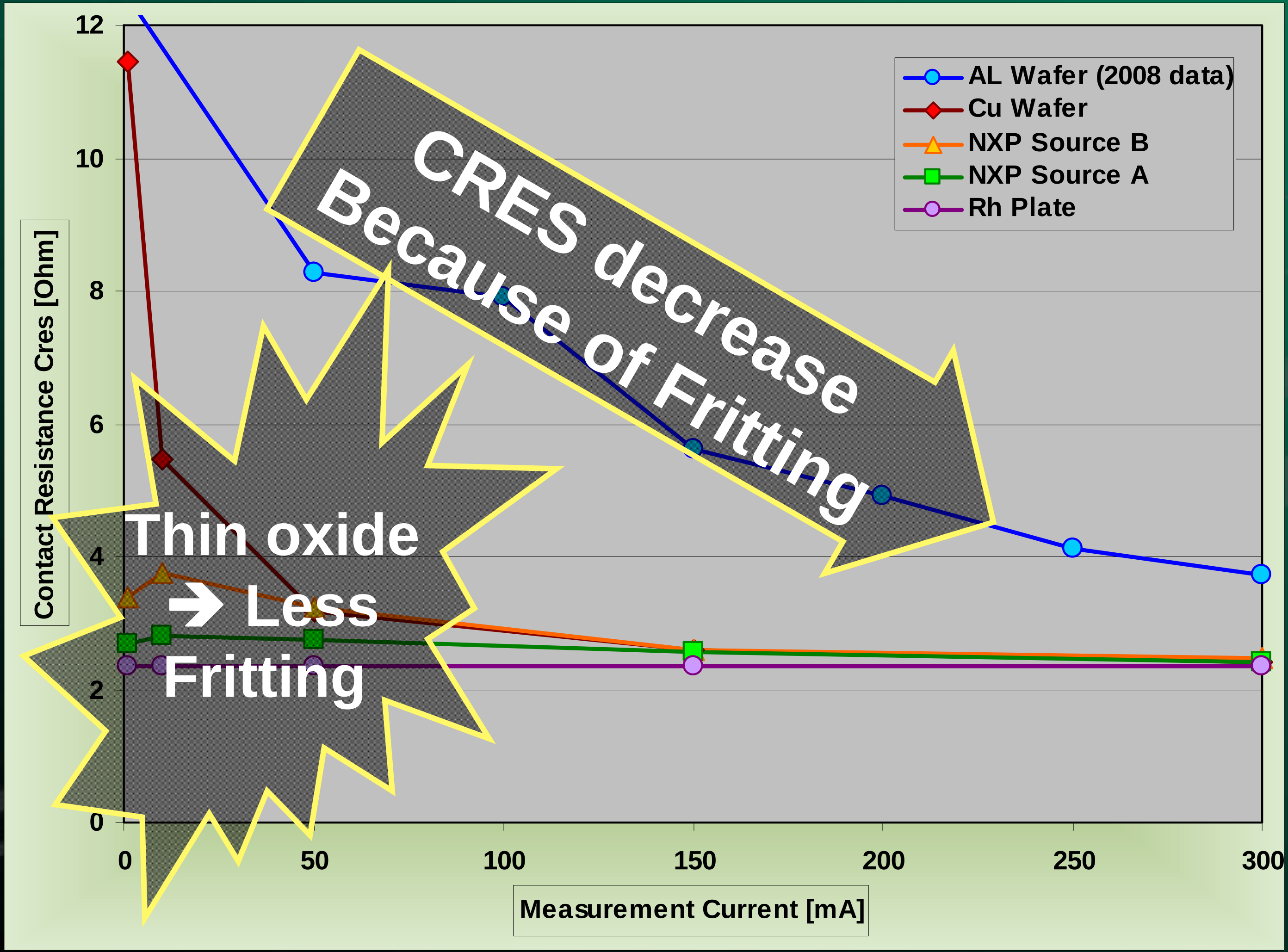
– Rhodium plate (reference)	→ Rh plate
– Blanket aluminum wafer (‘08 data)	→ Al Wafer
– Blanket galvanic copper wafer (10µm)	→ Cu Wafer
– NXP internally processed products	→ NXP source A and B

- Current from 1mA to 300mA
- 6TDs each material up to 75µm OT
- Data taken from 20µm OT (forcing fritting by “bad” mechanical scrub through oxide)

CRES Results DOE2



CRES Results DOE2



CRES decrease Because of Fritting

Thin oxide
➔ Less Fritting

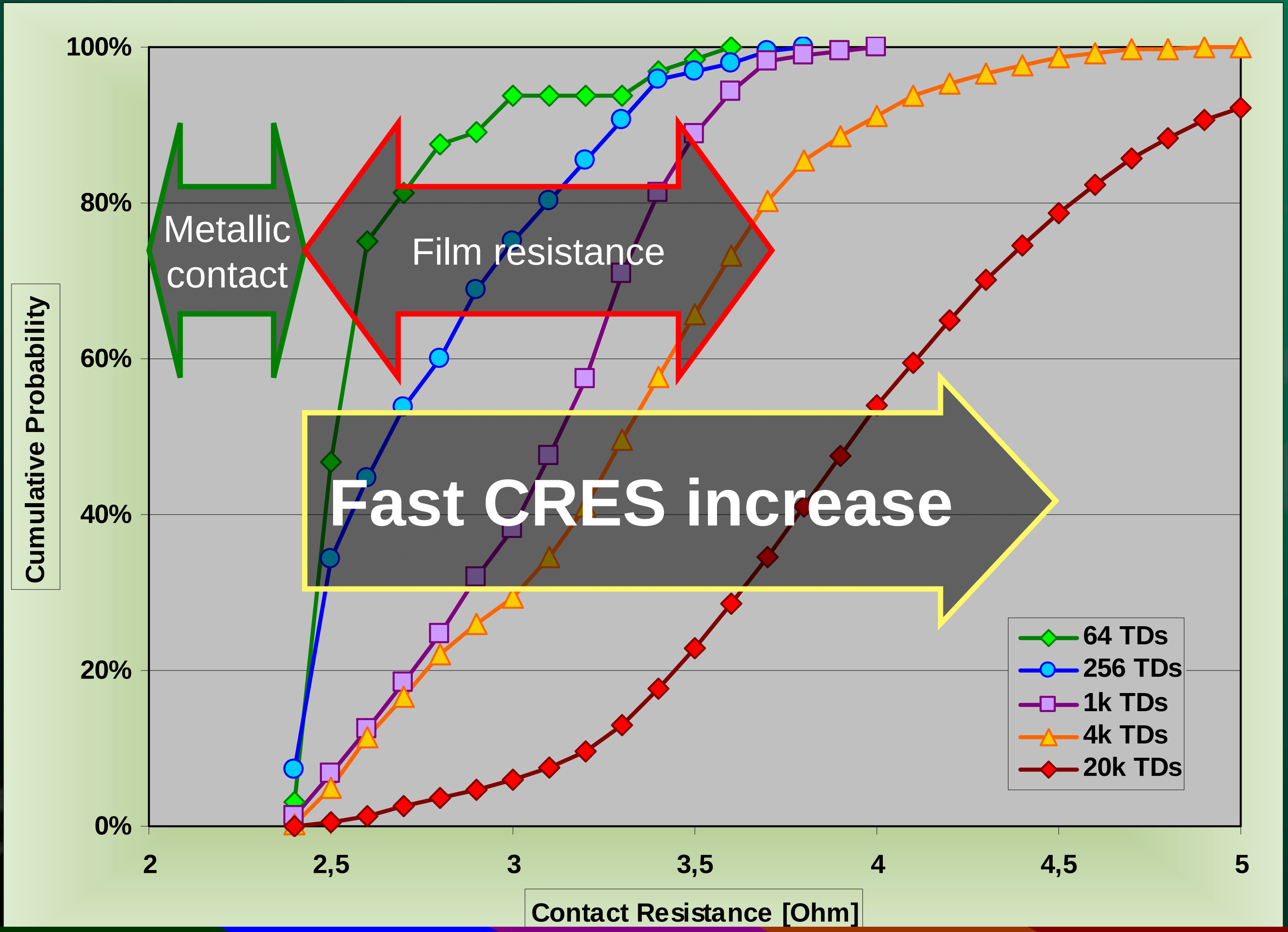
Description DOE 3

- Long term test (LTT) with up to 20k TDs
  - Blanket aluminium wafer (‘08 data) ➔ Al Wafer
  - Blanket galvanic copper wafer (10µm) ➔ Cu Wafer
  - NXP internally processed products ➔ NXP source A and B

- Pin to Pin Current 150mA on Cu
- OT at 20µm (forcing fritting by bad mechanical scrub through oxide)

- Different cleaning settings
  - No cleaning to establish baseline CRES trending
  - “Frequent” cleaning
    - Cleaning interval 128 TDs with 32 cleaning TDs at 75µm OT
    - ITS Probe Polish® 70
  - Infrequent cleaning
    - Cleaning interval 1k TDs with 128 cleaning TDs at 75µm OT
    - ITS Probe Polish® 70

Cu Wafer LTT without cleaning



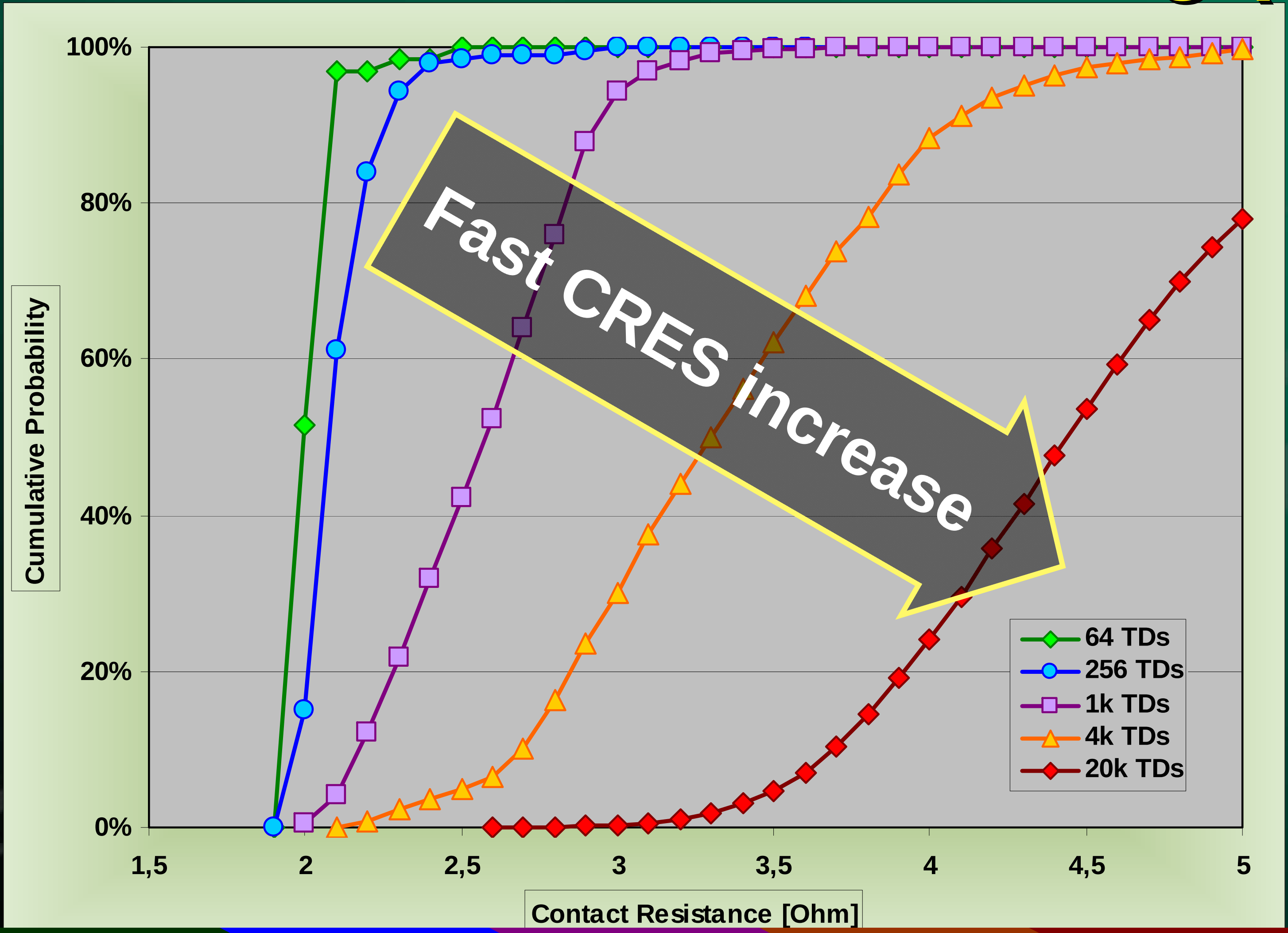
Metallic contact

Film resistance

Fast CRES increase

64 TDs → 256 TDs → 1k TDs → 4k TDs → 20k TDs

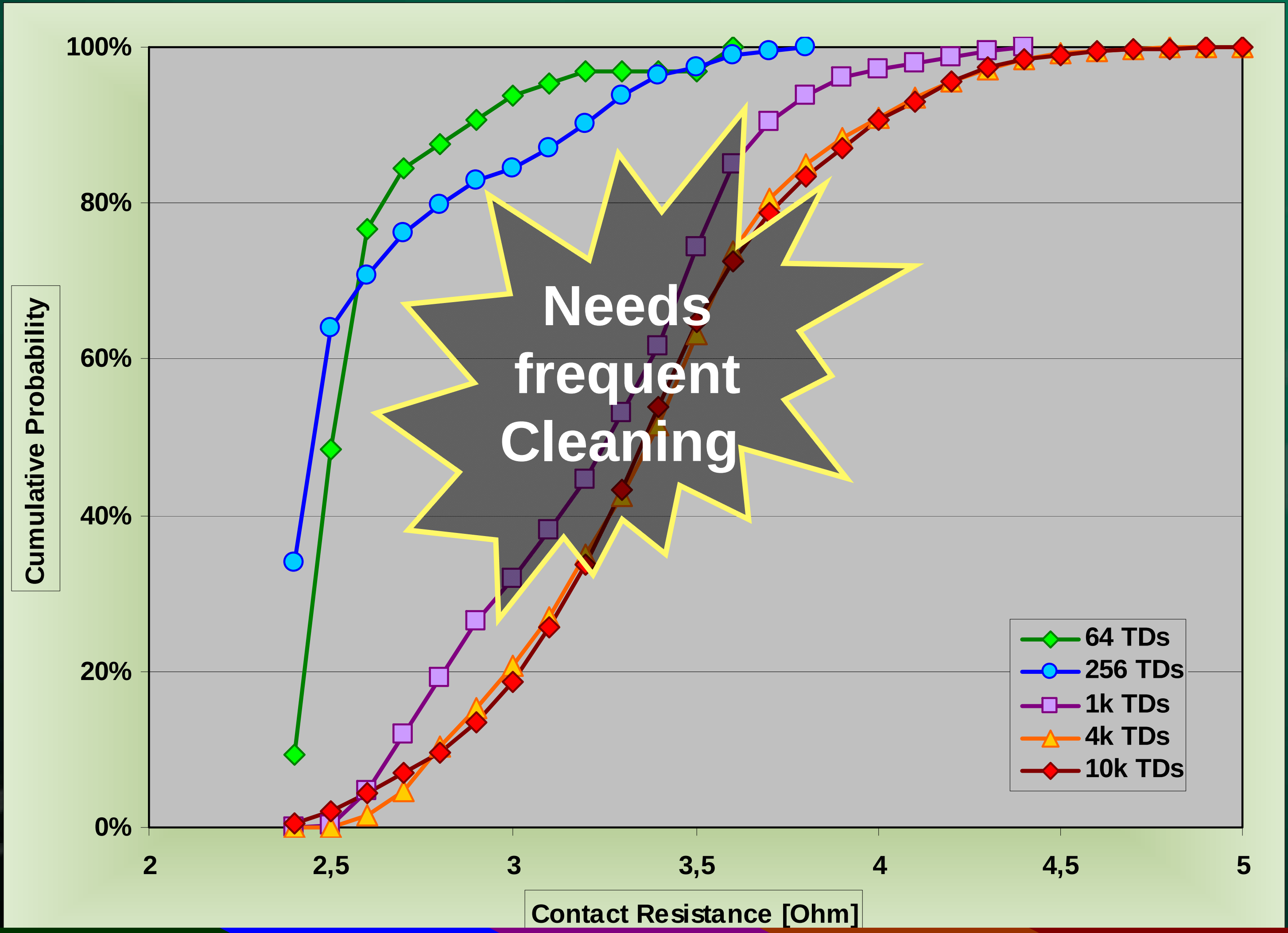
Al Wafer LTT without cleaning ('08)



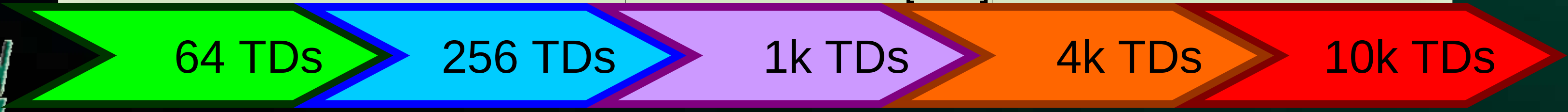
Fast CRES increase

64 TDs → 256 TDs → 1k TDs → 4k TDs → 20k TDs

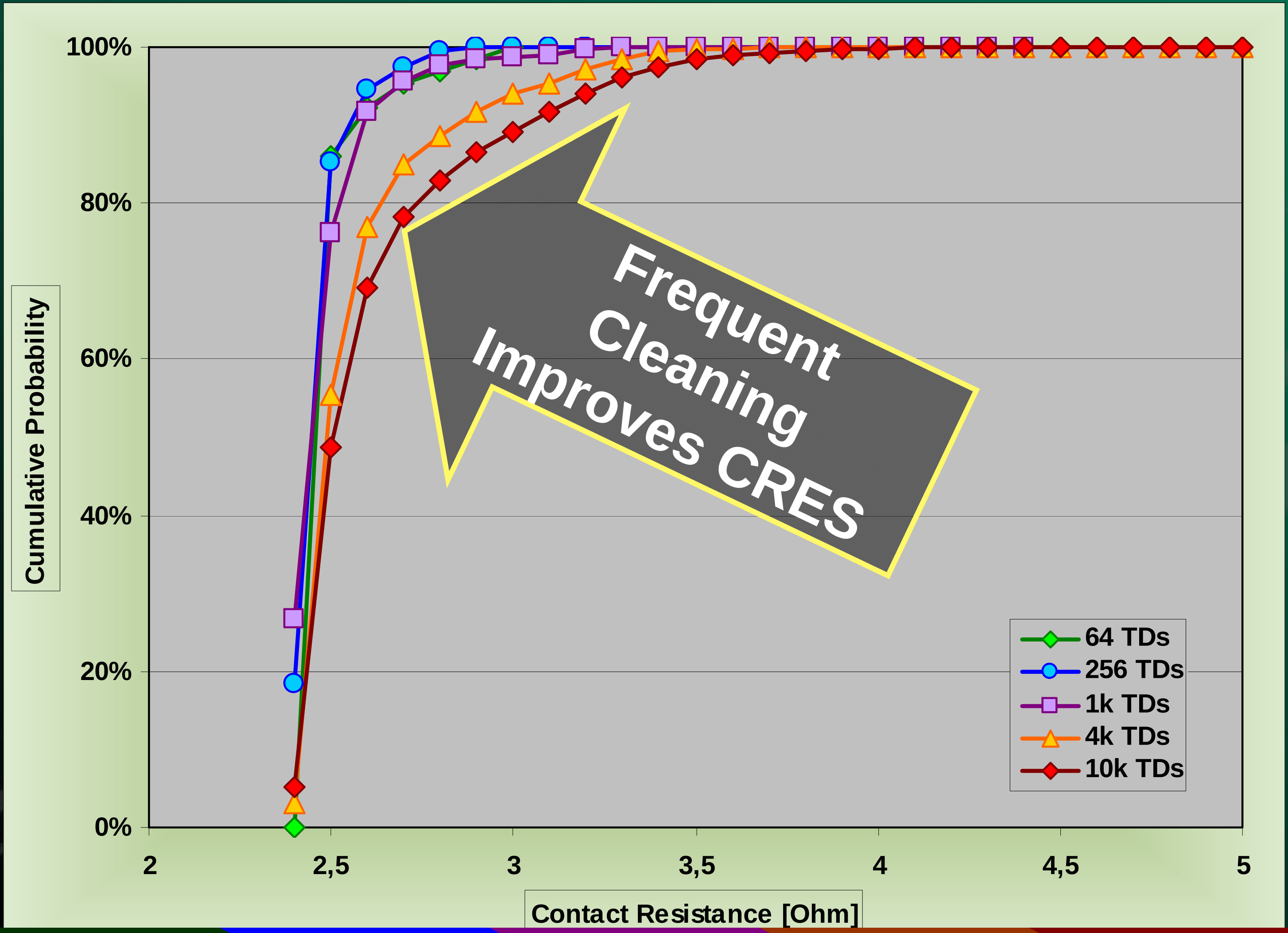
NXP Source B LTT without cleaning



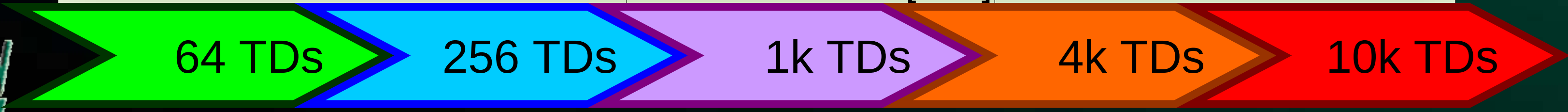
Needs frequent Cleaning



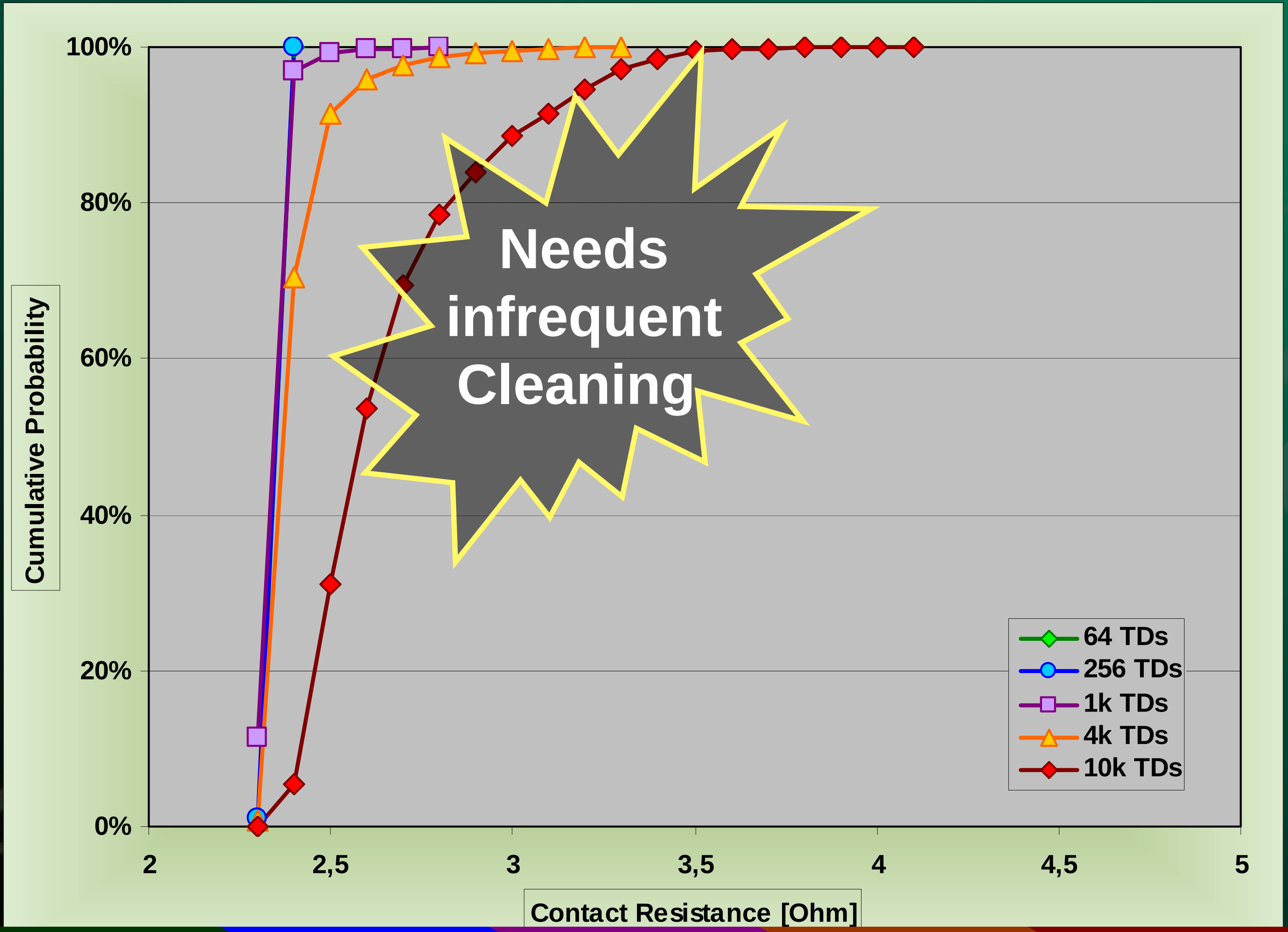
NXP Source B LTT with frequent cleaning



Frequent Cleaning Improves CRES



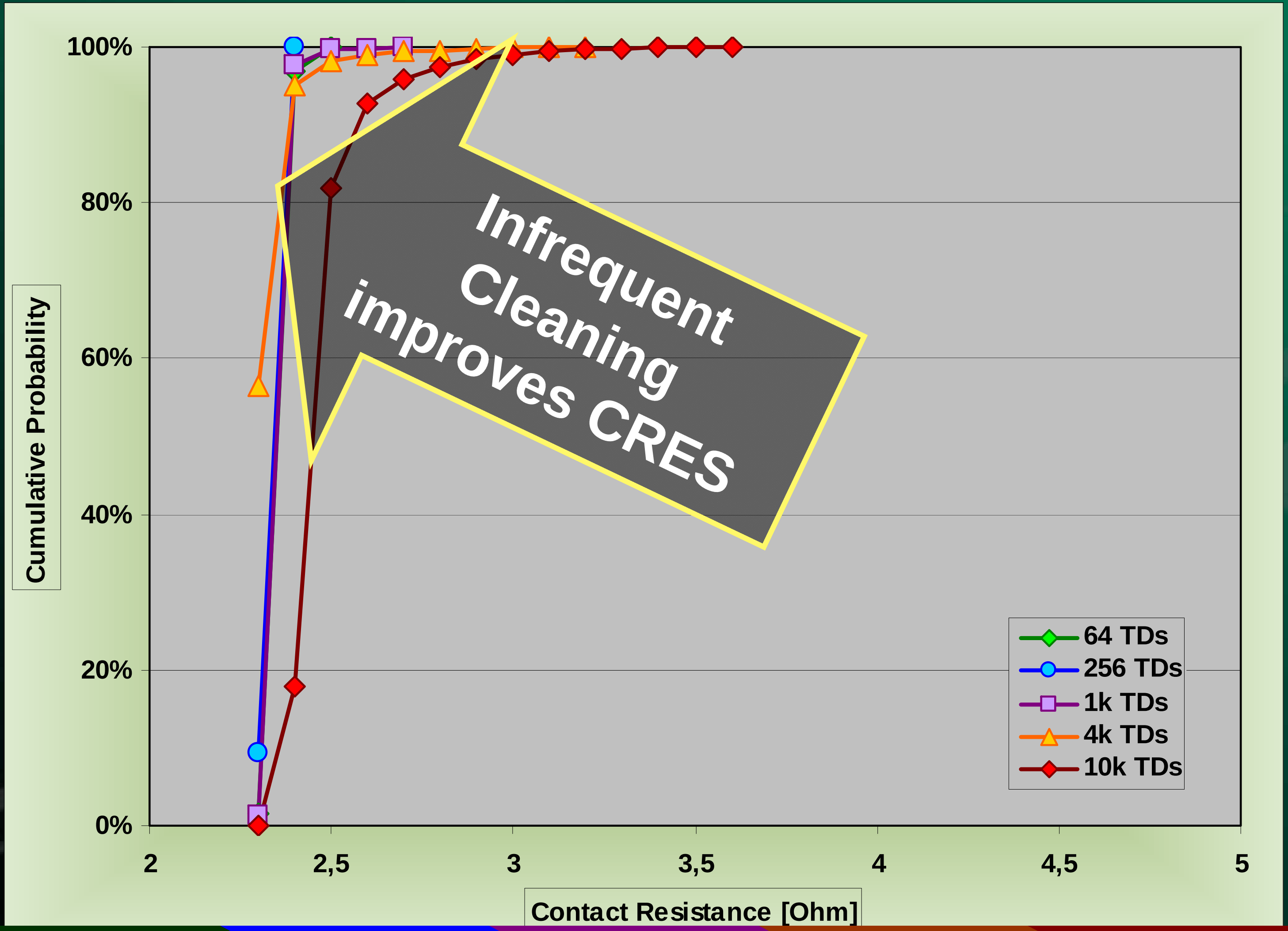
NXP Source A LTT without cleaning



Needs infrequent Cleaning

64 TDs → 256 TDs → 1k TDs → 4k TDs → 10k TDs

NXP Source A LTT with infrequent cleaning

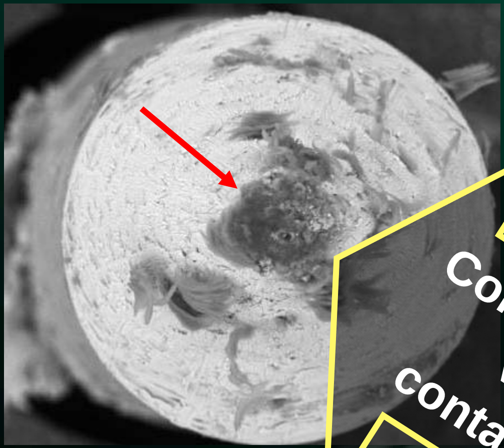


Infrequent Cleaning improves CRES

64 TDs → 256 TDs → 1k TDs → 4k TDs → 10k TDs

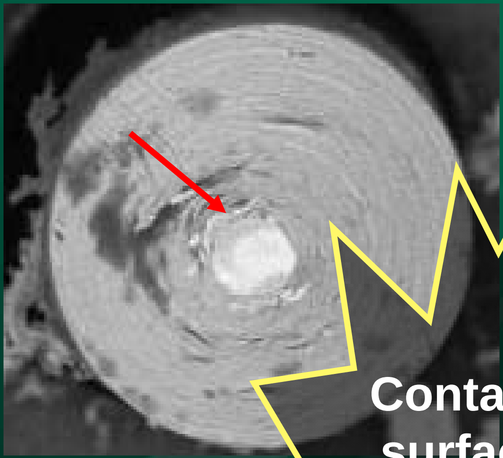
SEM pictures after 20k LTT without any cleaning

Al Wafer



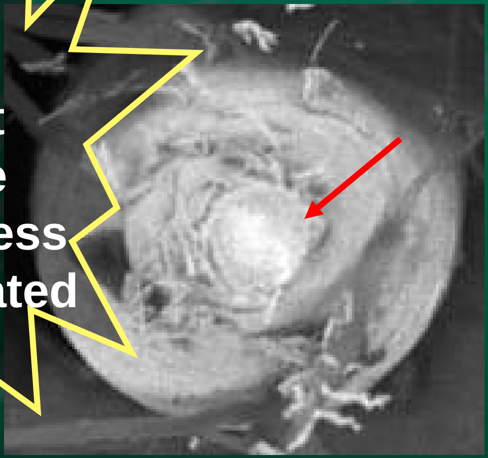
Contact surface visibly contaminated

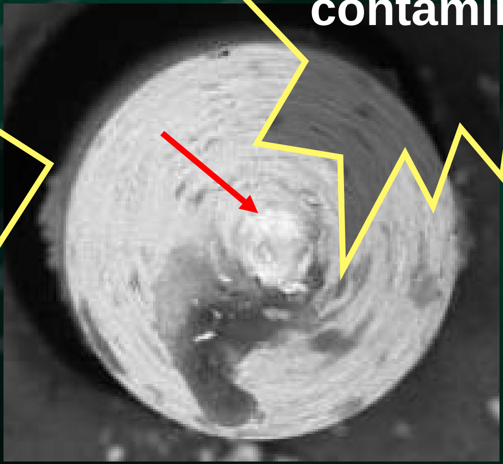
NXP Source A



Contact surface appears less contaminated

Blanket Cu Wafer





NXP Source B

Motivation

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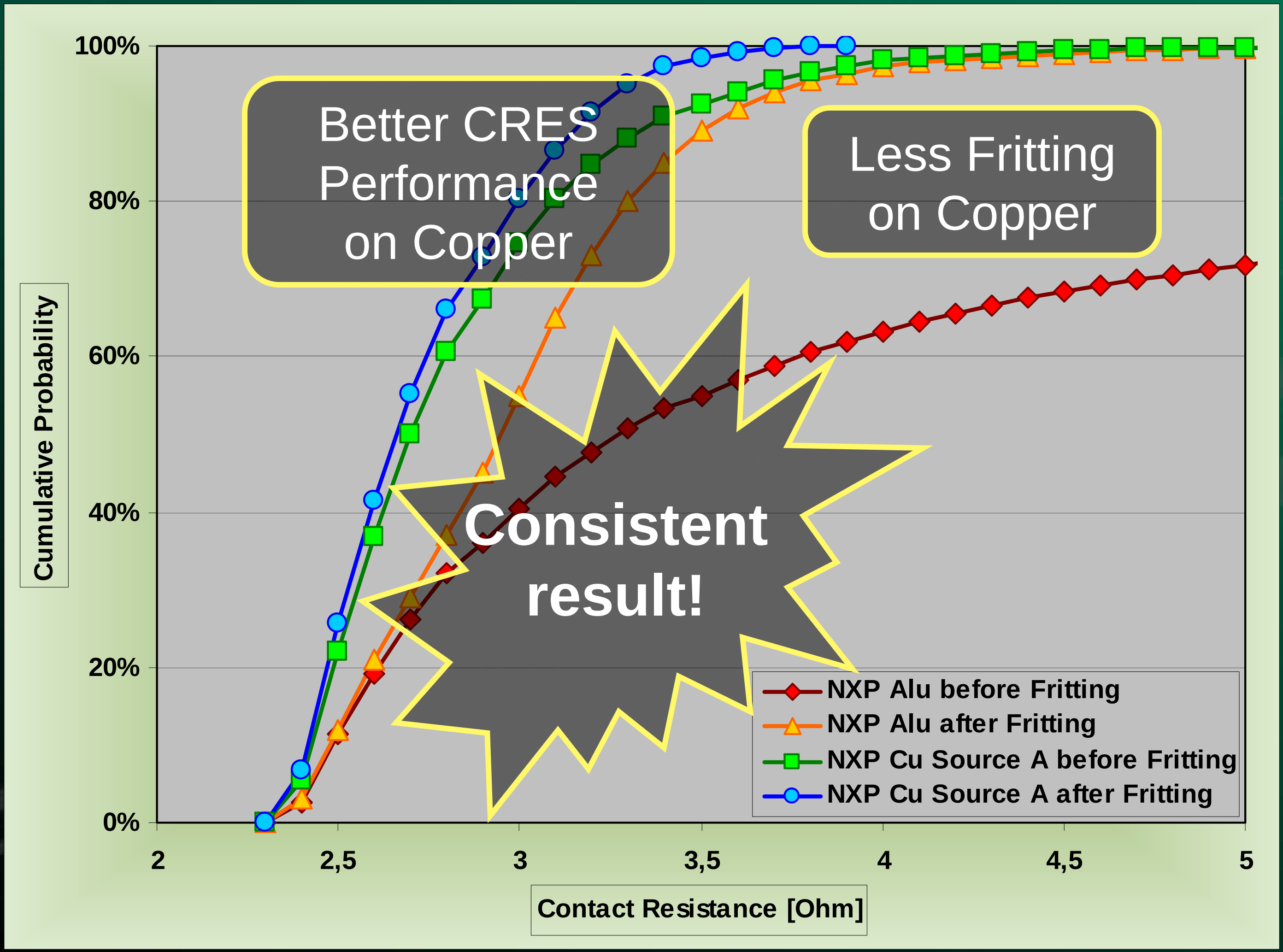
Production CRES Measurement

- Evaluation of NXP Source A and aluminium reference.
- Probecard with 16 Kelvin contacts (3mil beams).
- Rebuild for pin to pin and 4-wire CRES measurement
- 3.5k test runs to identify contact performance.
- Fritting study with 300mA current between CRES measurements of 3mA.
- No cleaning to differentiate the CRES performance.

Production CRES Comparison

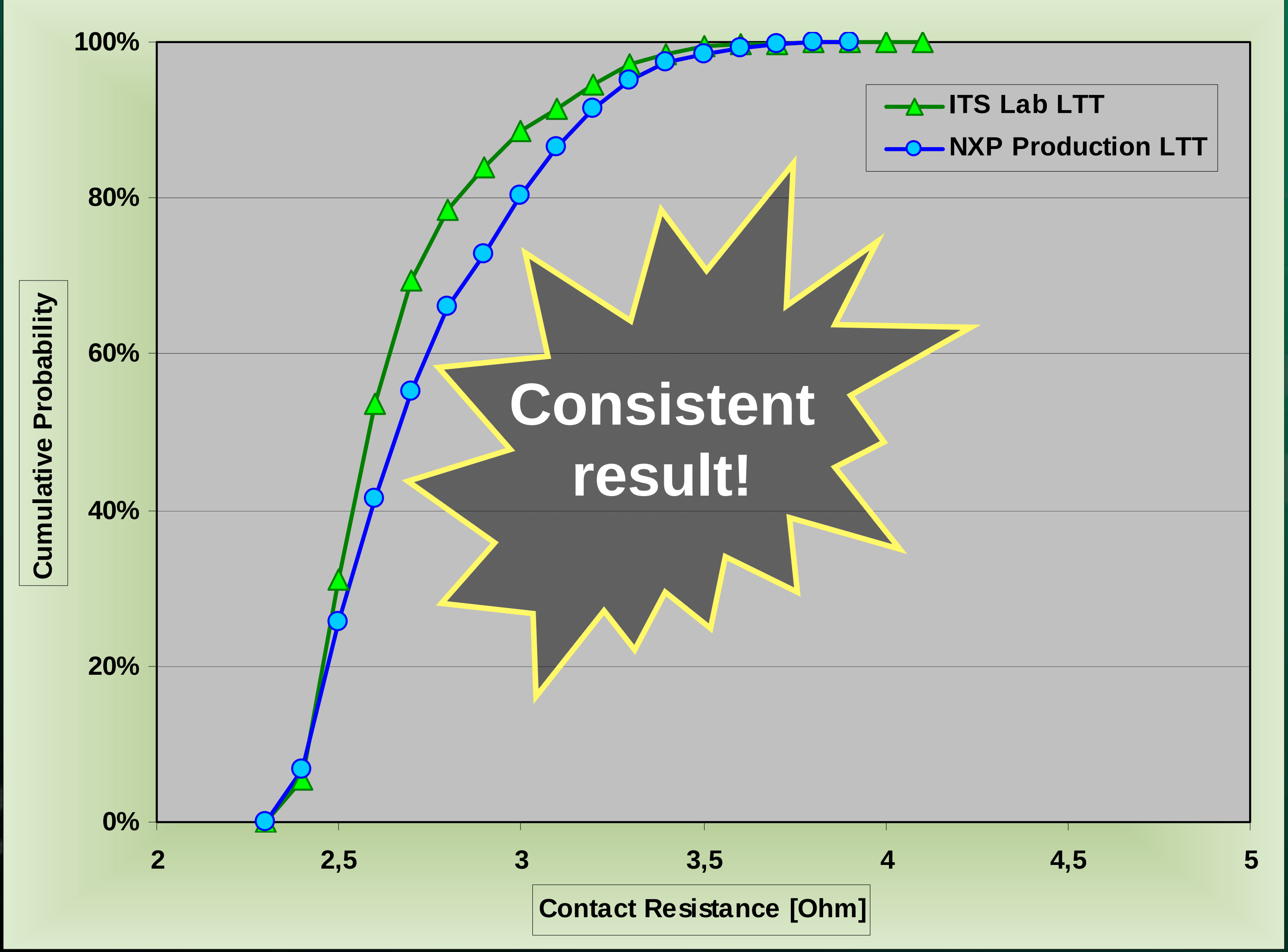


Better CRES Performance on Copper

Less Fritting on Copper

Consistent result!

Production CRES Comparison



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Results / Discussion

- Several copper source analysed and fritting was observed on all sources detected.
- NXP sources perform better than reference blanket copper wafer.
- Thinner oxides on copper compared to aluminum reduce the effect of Fritting because of better oxide penetration.
- Copper debris on contact surfaces are barely detectable by optical inspection.

Results / Discussion

- FM ViProbe® with 2 mil beams show consistent probe force and CRES performance.
- Production and lab data fit consistently for proof of this analysis strategy.
- NXP copper sources qualified and ranked and cost effective cleaning recipes optimized.

Future Work

(many interesting studies !)

- Copper at different temperatures (high AND low).
- FM ViProbe® 1.6 mil beam performance.
- Extended long long term tests (> 20K TDs).
- Analyse background of copper performance differences.
- Investigating the effects and repercussions of the fritting mechanisms
  - Temperature
  - Frequency
  - Fab materials

Acknowledgements

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  - Andrea Haag (Engineering Technician)

Men At Work


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AUGU
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Thank you!
Questions?