IEEE SW Test Workshop

Semiconductor Wafer Test Workshop

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Contact formation in wafer test probing

Fritting, breakdown, pad damage and conduction

SWTW

June 12 to15, 2011

San Diego, CA   USA

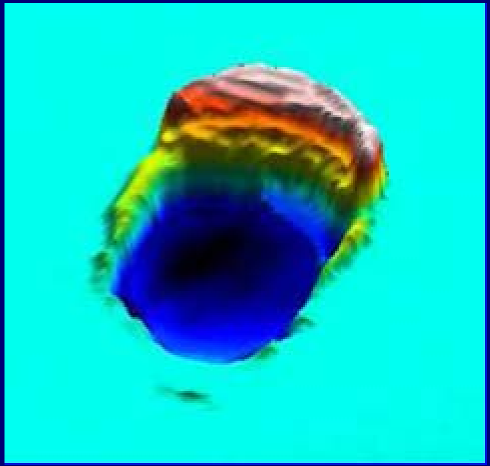
Our motivation for these experiments:

Todays probing is rather aggressive: 200-800nm probe mark depth is common practice.

POAA requires very careful probing to avoid damaging the delicate structures under the pad.

- We want to probe less aggressively!

- We need to understand the contact interface!



scrub mark on Al

Content

- System description: Test machines, methods and material.

- Results for probing copper, aluminum and gold.

- Influence of fritting.

- Properties of a very soft contact.

- Simulation as a tool to optimized soft contacts.

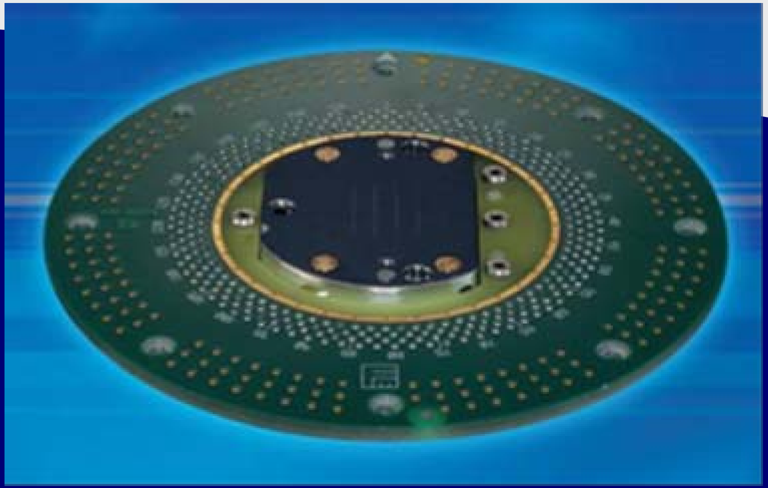
System Description

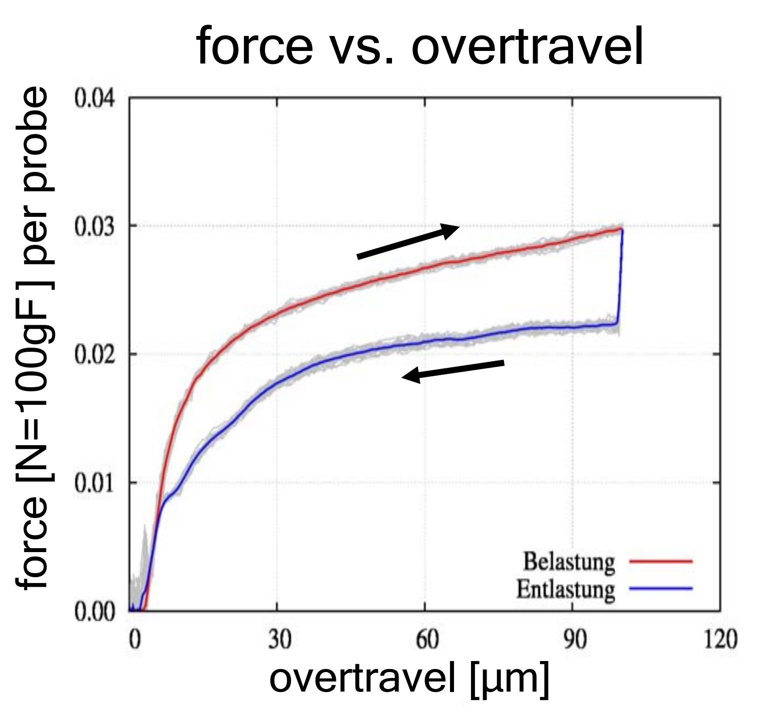
- ViProbe® S-Type
  59µm pitch for up to 180°C
  self scrub vertical probe technology

- Trivar®-HC probe for high current

- 45 probes test image
  (more than 2000 probes possible)

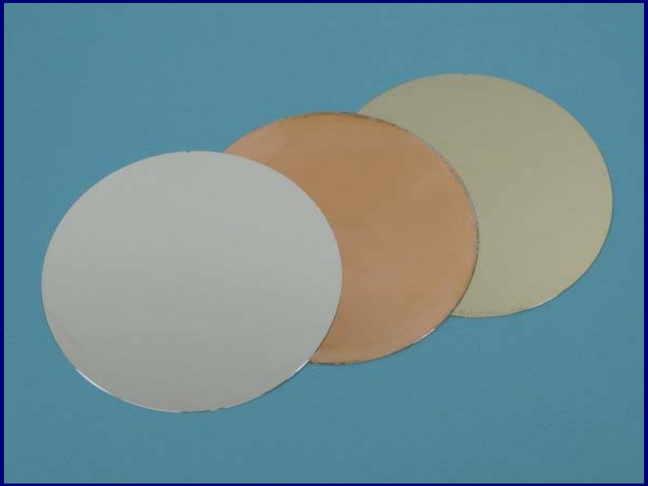
➔ all tests done using this type of probe head





System Description

- Prober: UF-3000
- Tester: Keithley 2601A
  with 500-channel multiplexer
- Class 10.000 clean room
- Wafer: → blank $AlCu_{0.5\%}$, 1200nm
  → blank plated Cu, 7100nm
  → blank plated Au, 2000nm



We know we can

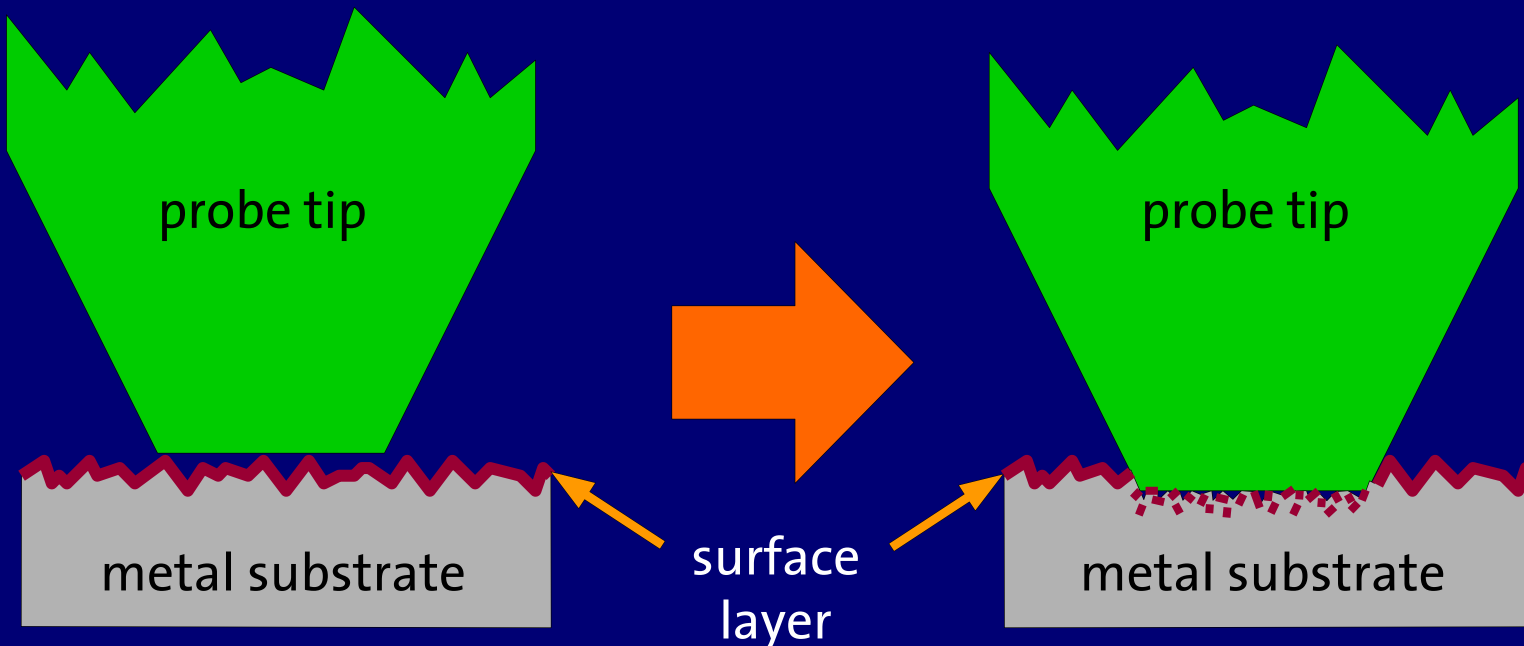
probe perfectly

…. but to learn we need to

provoke failure!

- NO online cleaning
- reduced overtravel for some tests
- mixing pad materials

Classical Concept of an Electrical Contact

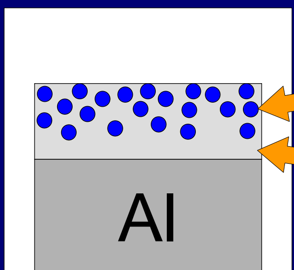


a non conductive surface film inhibits current to flow

metal has partly contact to tip fritting* widens the contact areas

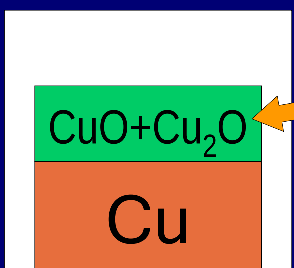
* see SWTW, MARTENS 2006 and 2009 and DEGEN 2006

Aluminum, Copper, Gold - Surfaces

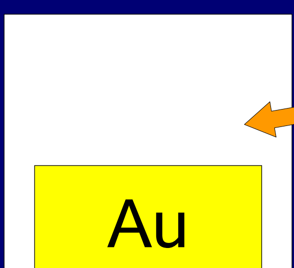


>17nm Al_2O_3+H_2O

>3 nm Al_2O_3



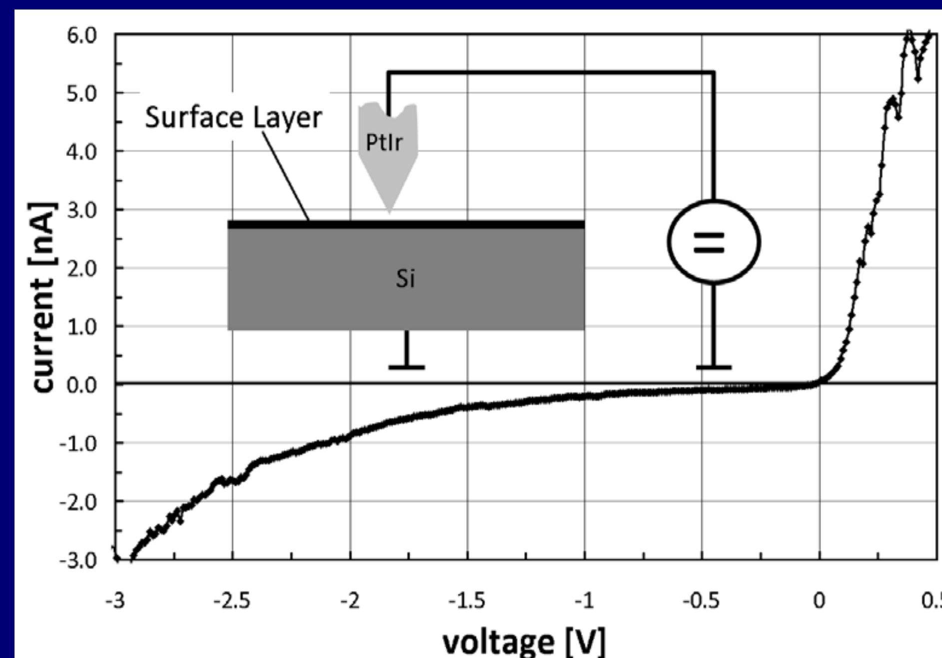
>20nm Cu_xO_y



no film

dimensions
are examples

Non-metal surface layers have
non linear I / U properties
(probed by STS measurement)

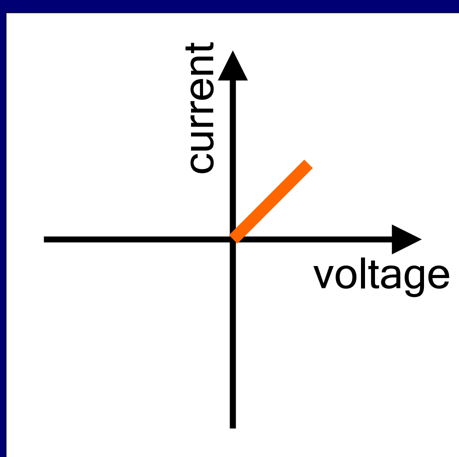


If the film is closed
we should see an energy gap.

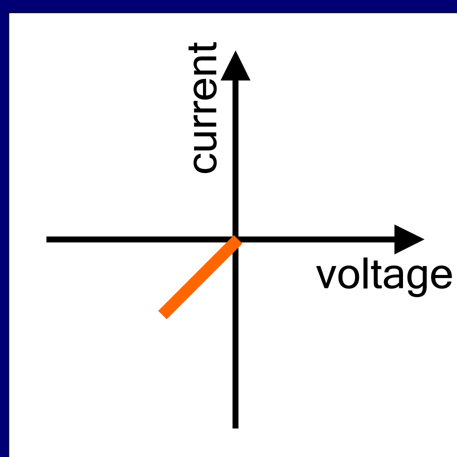
Experiment setup

- Common probing (+28°C; +180°C, 80µm overtravel) with common resistance testing @ 2V, 20mA limits

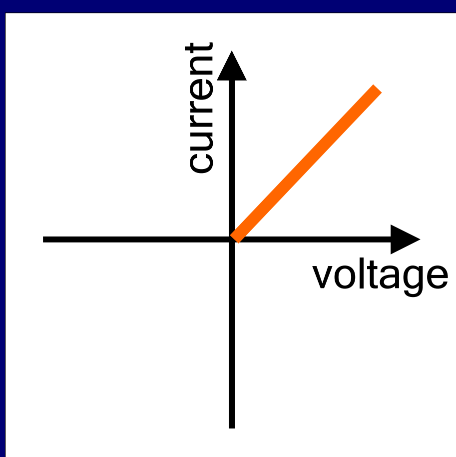
- for selected touchdowns alternatively "I / U -measurements", 6x current slopes with limited voltages: 10µA to 100mA (6steps/dec.) @ +10mV; -10mV; +100mV; -100mV; +1.0V; -1.0V



1st: +10mV



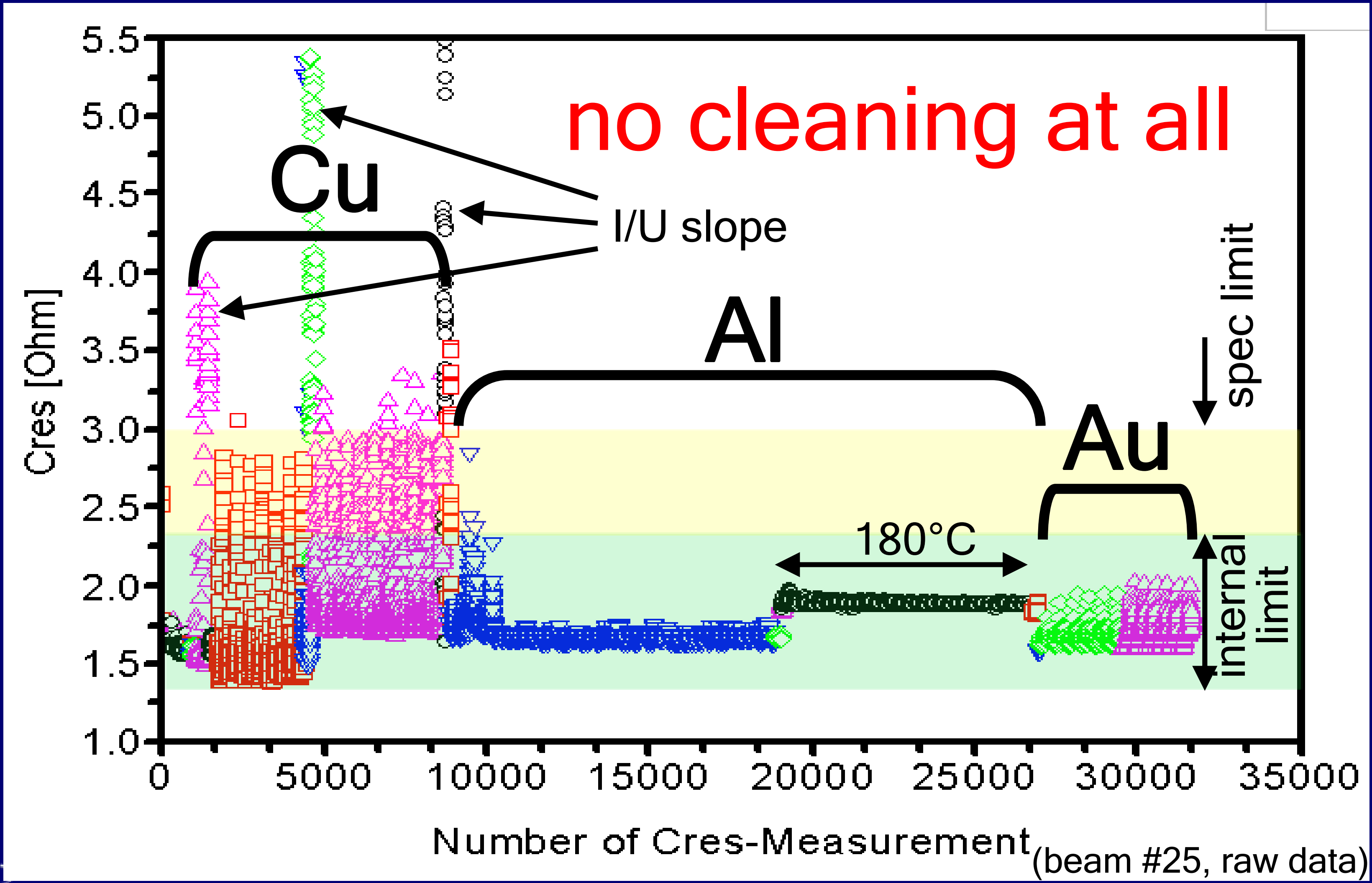
2nd: -10mV



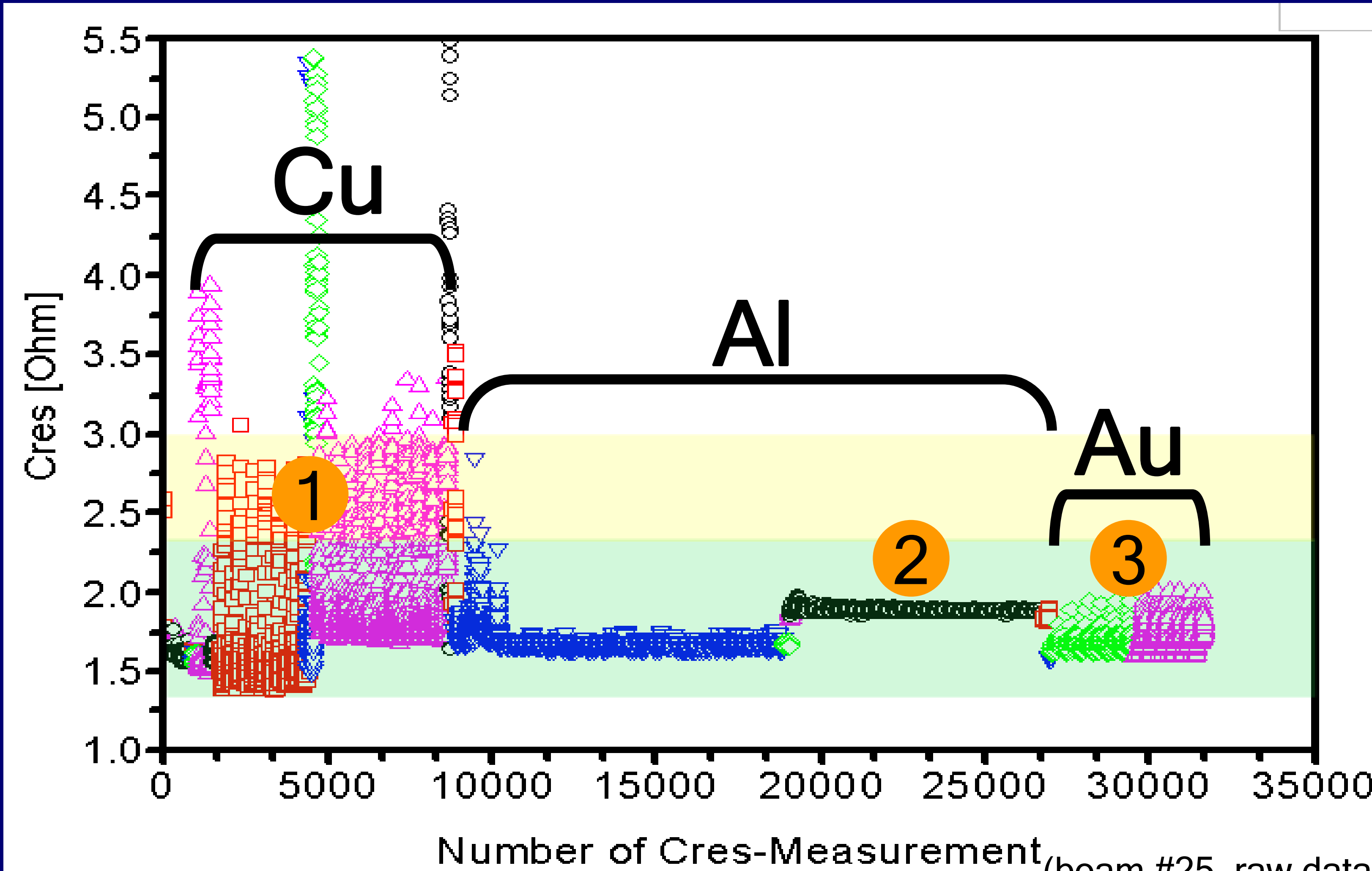
3rd: +100mV

....

Experiment Overview: 26 single steps

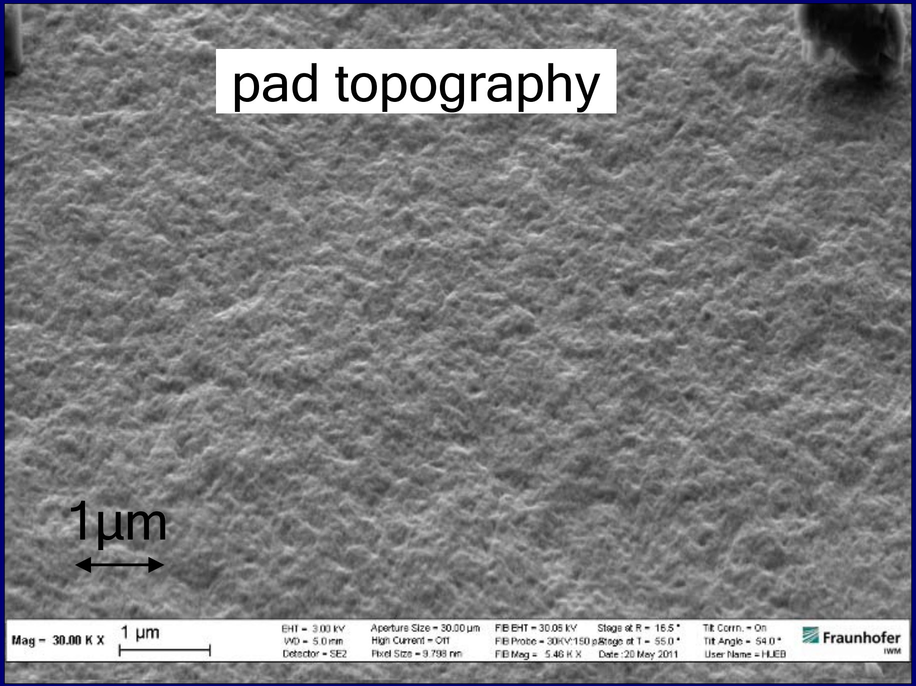


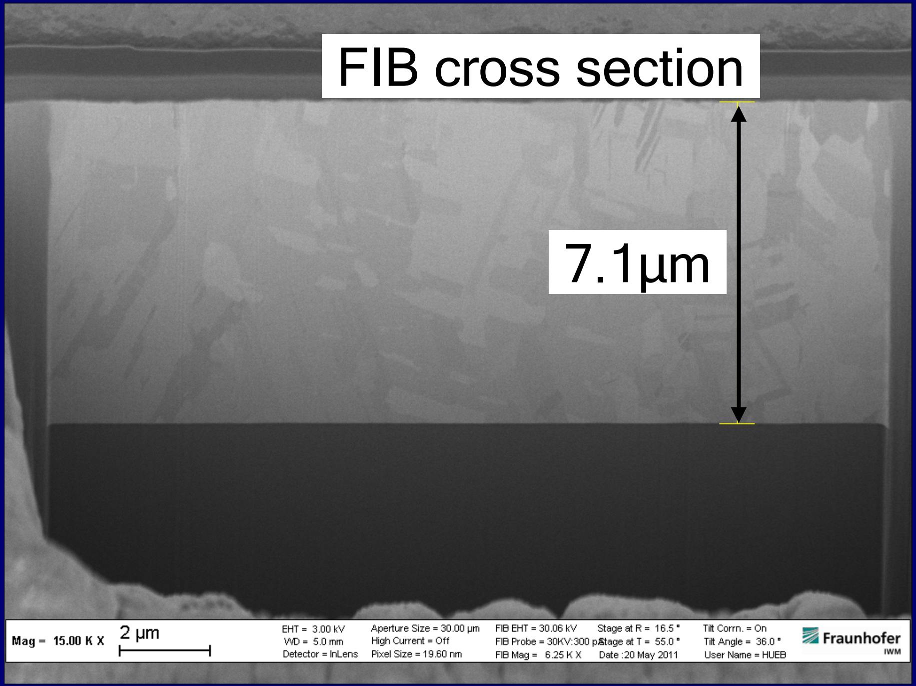
Experiment Overview: reference



(beam #25, raw data)

1 Cu Probing: Material

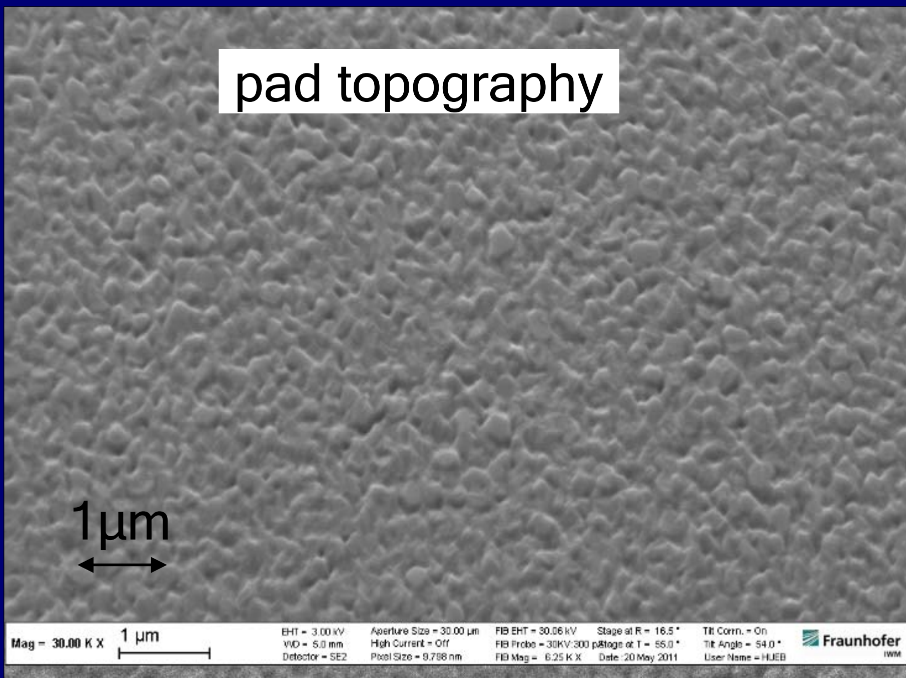




Modulus[1)]: 120 GPa
Hardness[1)]: 1.42 GPa
Resistance: 1.93 10^{-8} Ohm*m

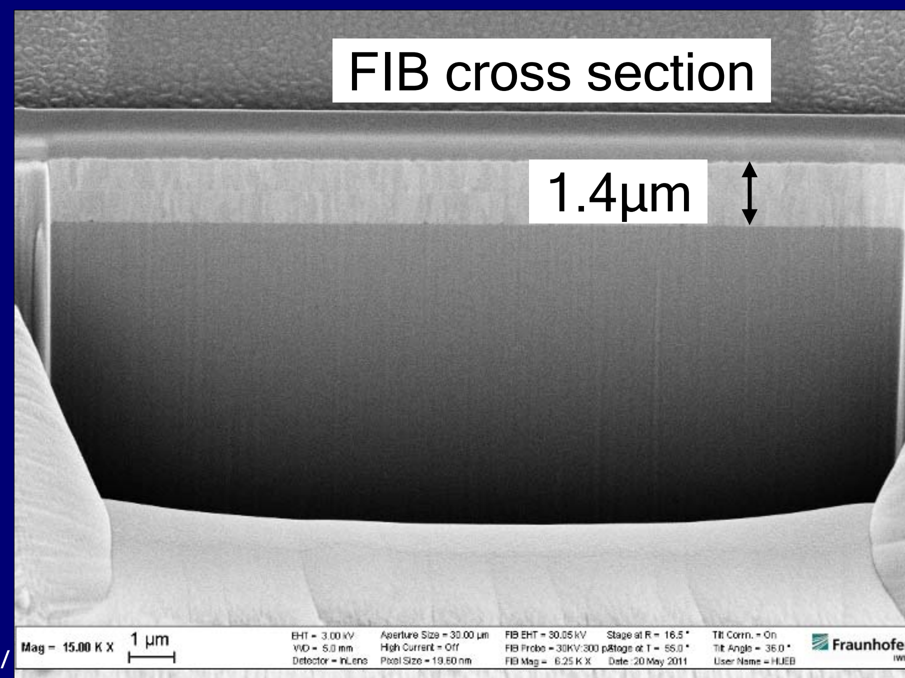
[1)]by nano-indentation

2 Al-Probing: Material

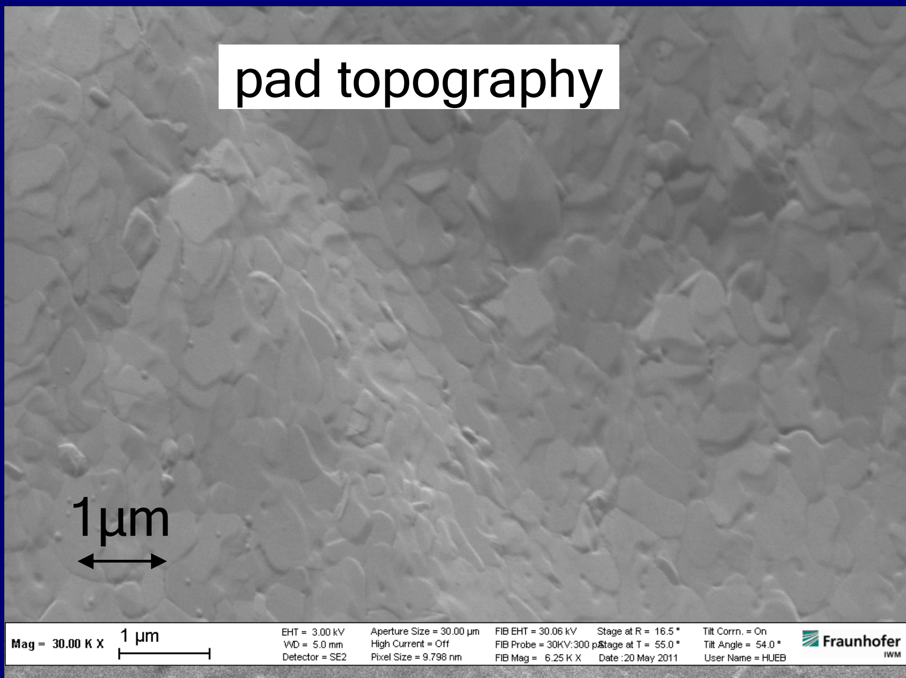


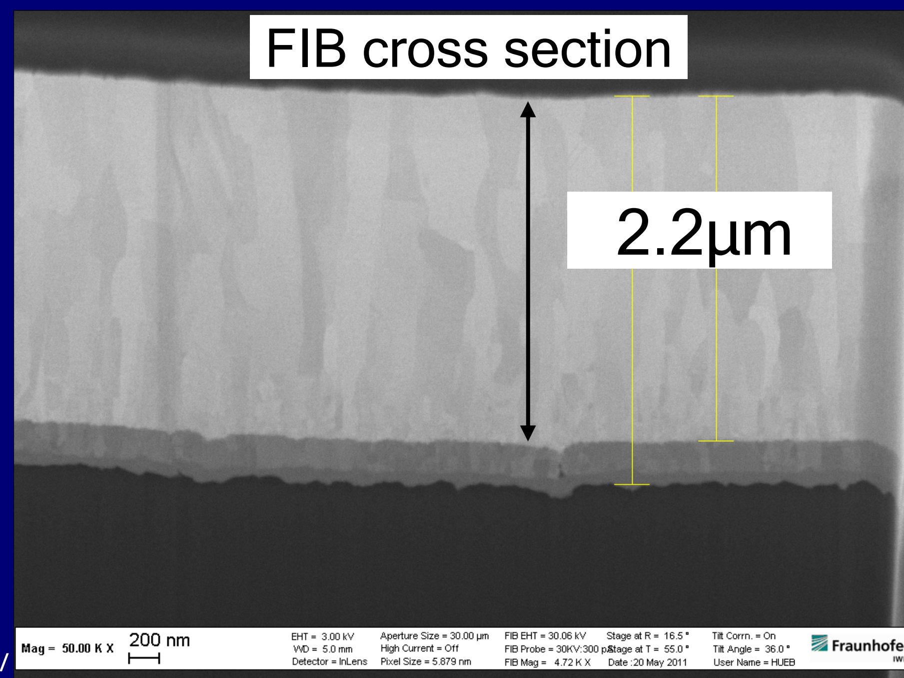
Modulus[1)]: 75 GPa
Hardness[1)]: 1.75 GPa
Resistance: 3.51 10^{-8} Ohm*m

[1)]by nano-indentation



3 Au-Probing: Material



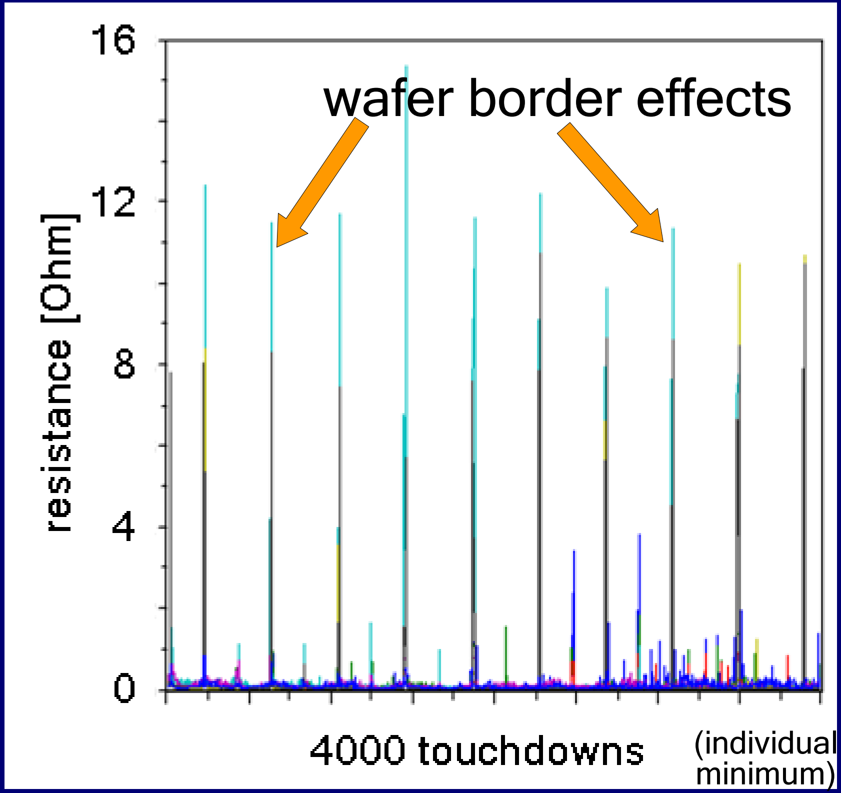


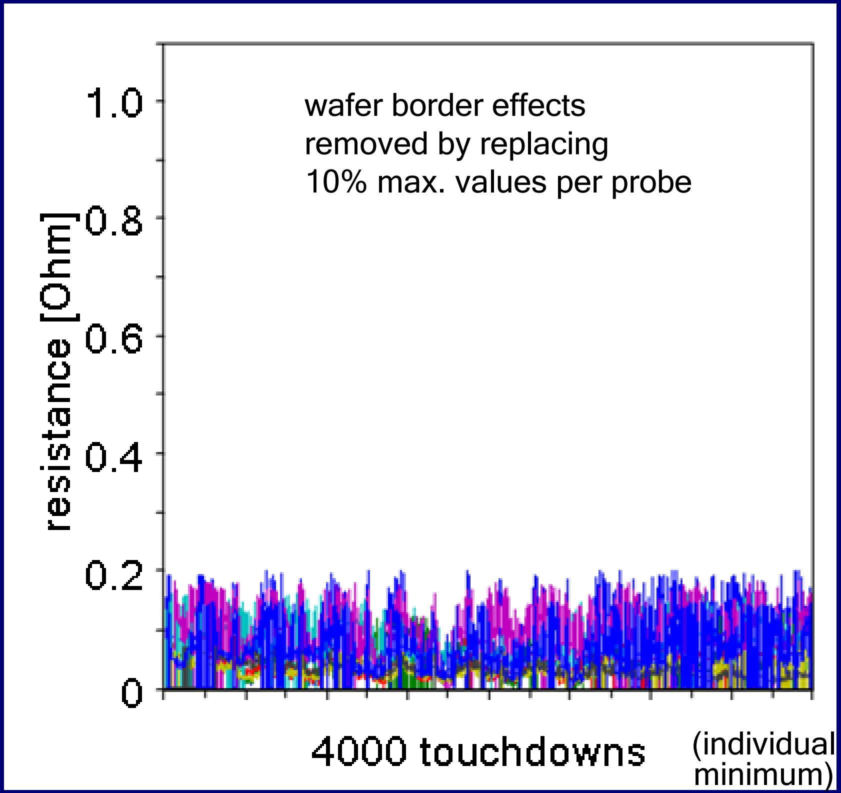
Modulus[1)]: 83 GPa
Hardness[1)]: 0.99 GPa
Resistance: 2.98 10^{-8} Ohm*m

[1)]by nano-indentation

1 Copper Probing: Cres

Best performing probes only (8 out of 45)

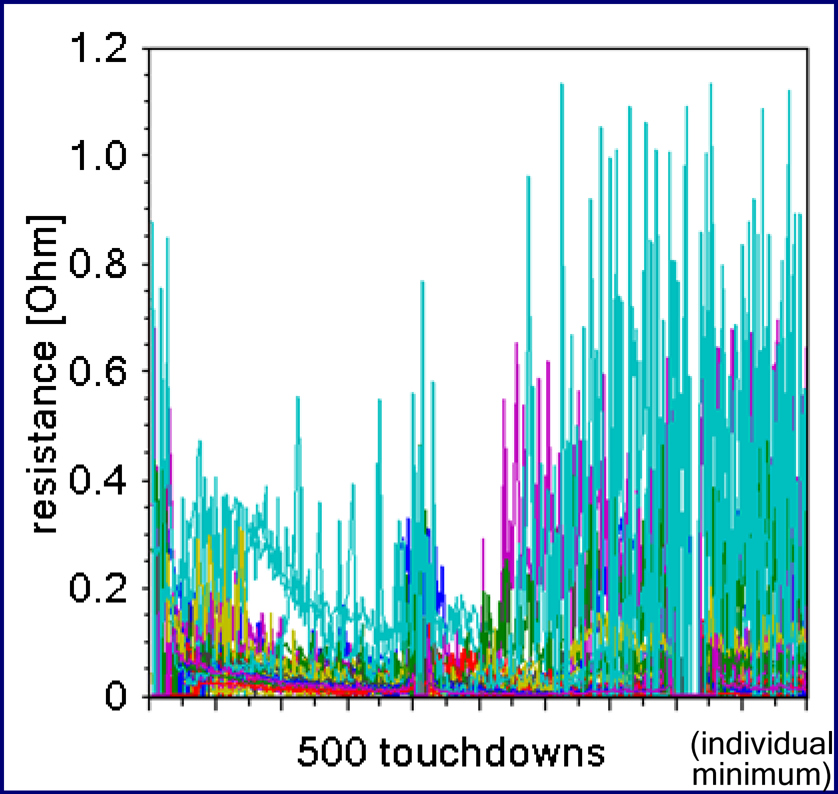


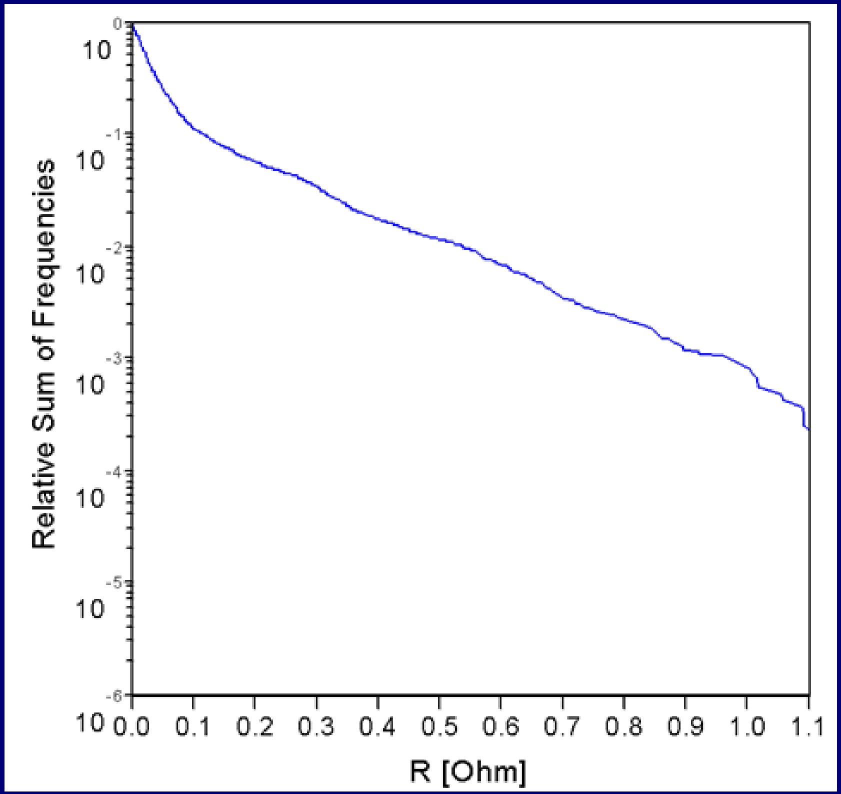


→ the system reacts sensitive to disturbances

1 Copper Probing: Cres

Best performing probes only (33 out of 45, wafer border effects removed)

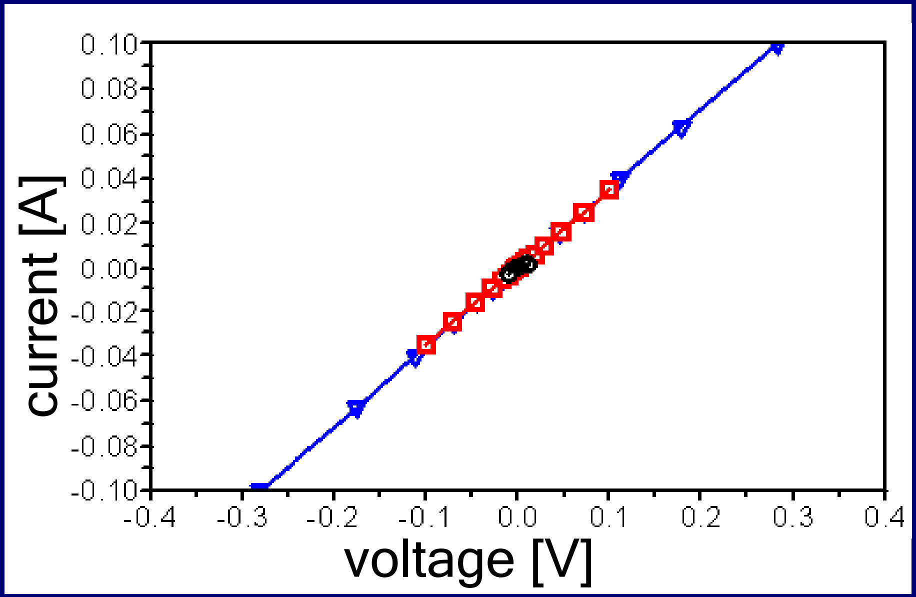




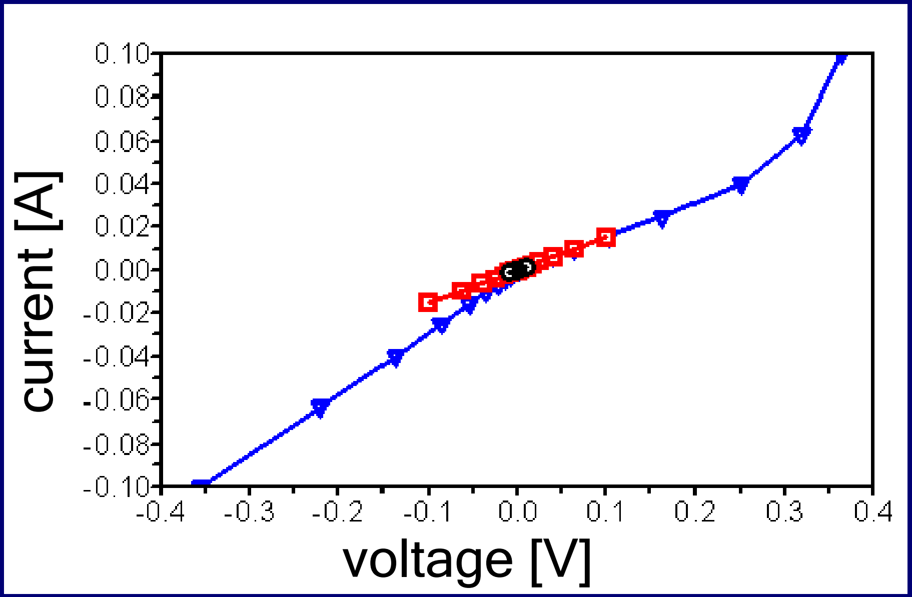
➔ 2/3 are in spec initially

1 Copper Probing: fritting

selected probes



Example for bad contact on copper: 2.8 Ohm

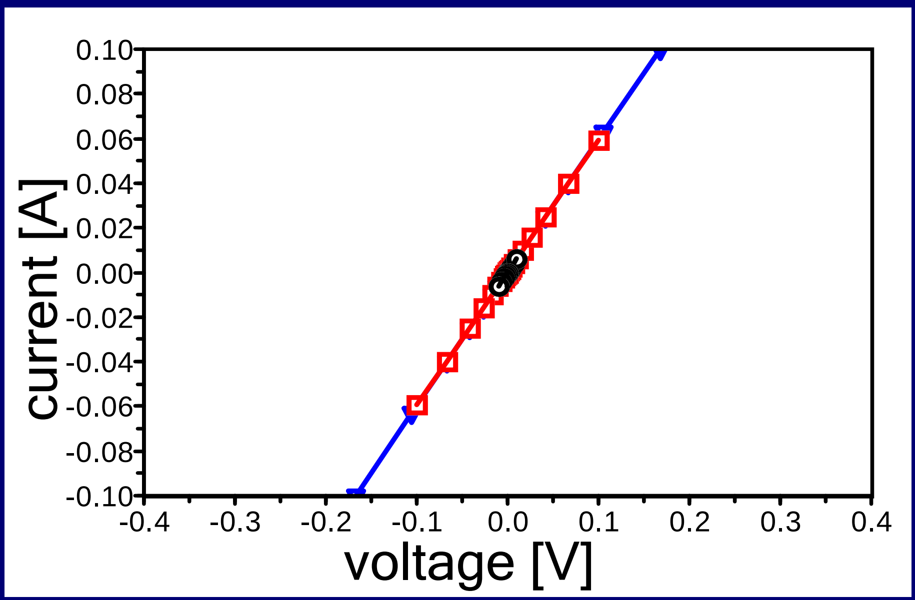


Same probe, next touchdown.
Starting with even worse resistance of 6.3Ohm, fritting at 0.35V, then 3.5 Ohm resistance.

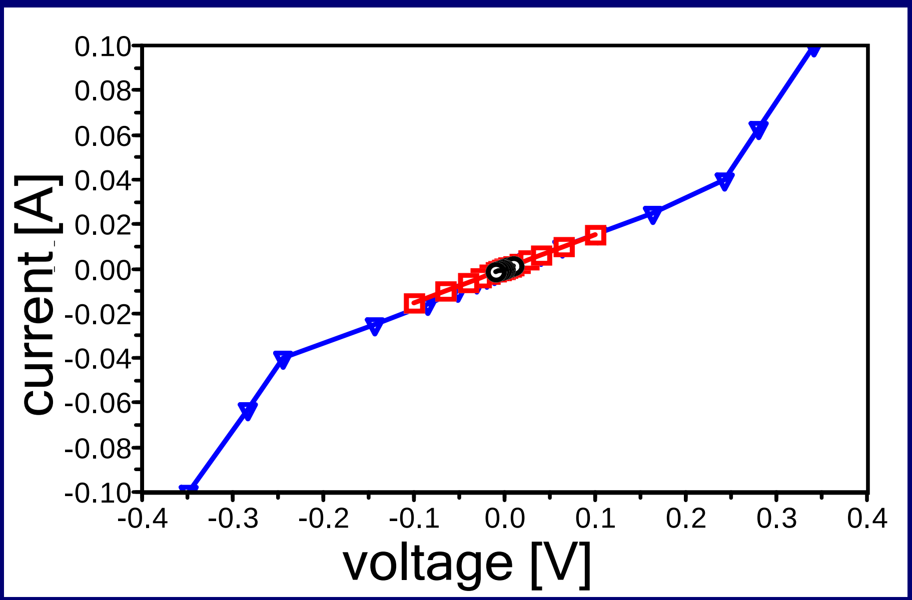
➔ fritting makes it better, but not perfect

1 Copper Probing: I / U measurements

selected probes



Example for a good contact on copper: 1.7 Ohm



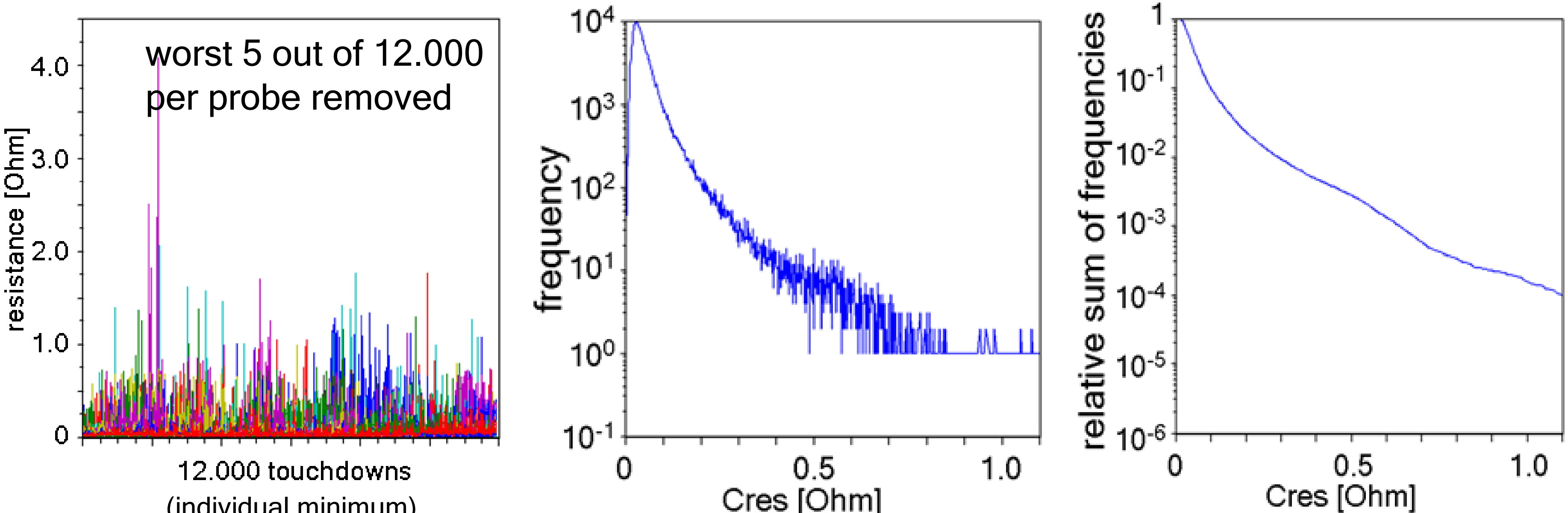
Example for a contact that shows an energy barrier around +/- 0.25V

➔ surface layer effects are visible

1 Copper Probing: summary

Copper probing is different from Al-probing:
- copper types are different
- same type can show a broad range of surface conditions

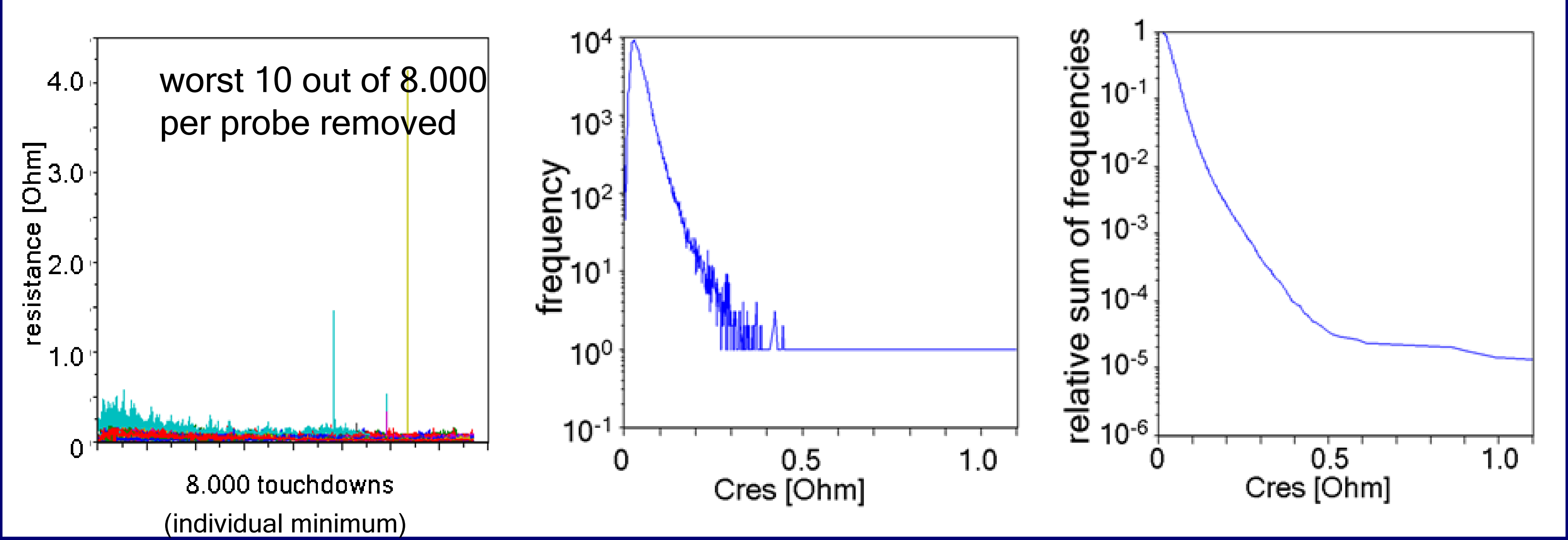
2.5mil probe on copper studs after application specific cleaning application



➔ copper probing requires an application specific online cleaning for optimized Cres, lifetime and stability

2 Aluminum Probing: Cres

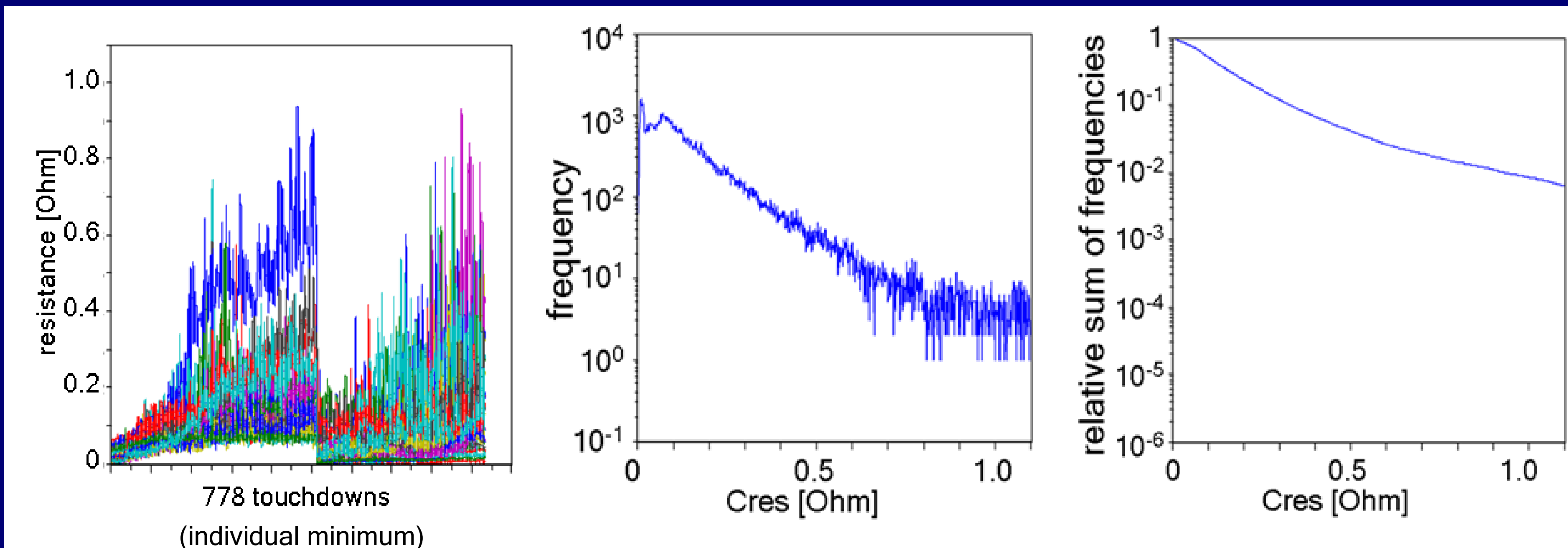
- 180°C probing
- still no cleaning at all



➔ Very low Cres, even though the probes have been contaminated with copper

Gold Probing:
3 Cres after Contamination with Cu_xO_y and Al_2O_3

- I/U – measurements only
- best 36 probes out of 45

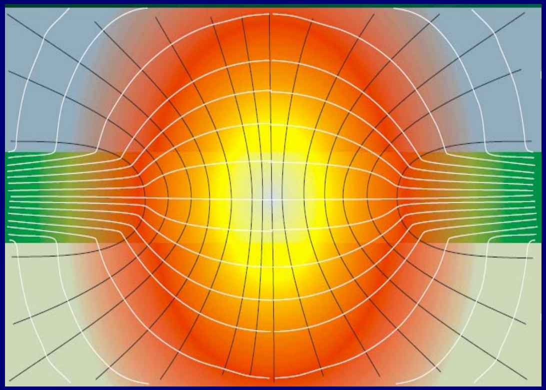


→ tip contamination leads to instable contacts, even on Gold

Our Results

- Aluminum probing has been very stable, even under bad conditions
- Copper probing often requires application specific online cleaning
- Gold probing needs fresh tips

Fritting Investigation



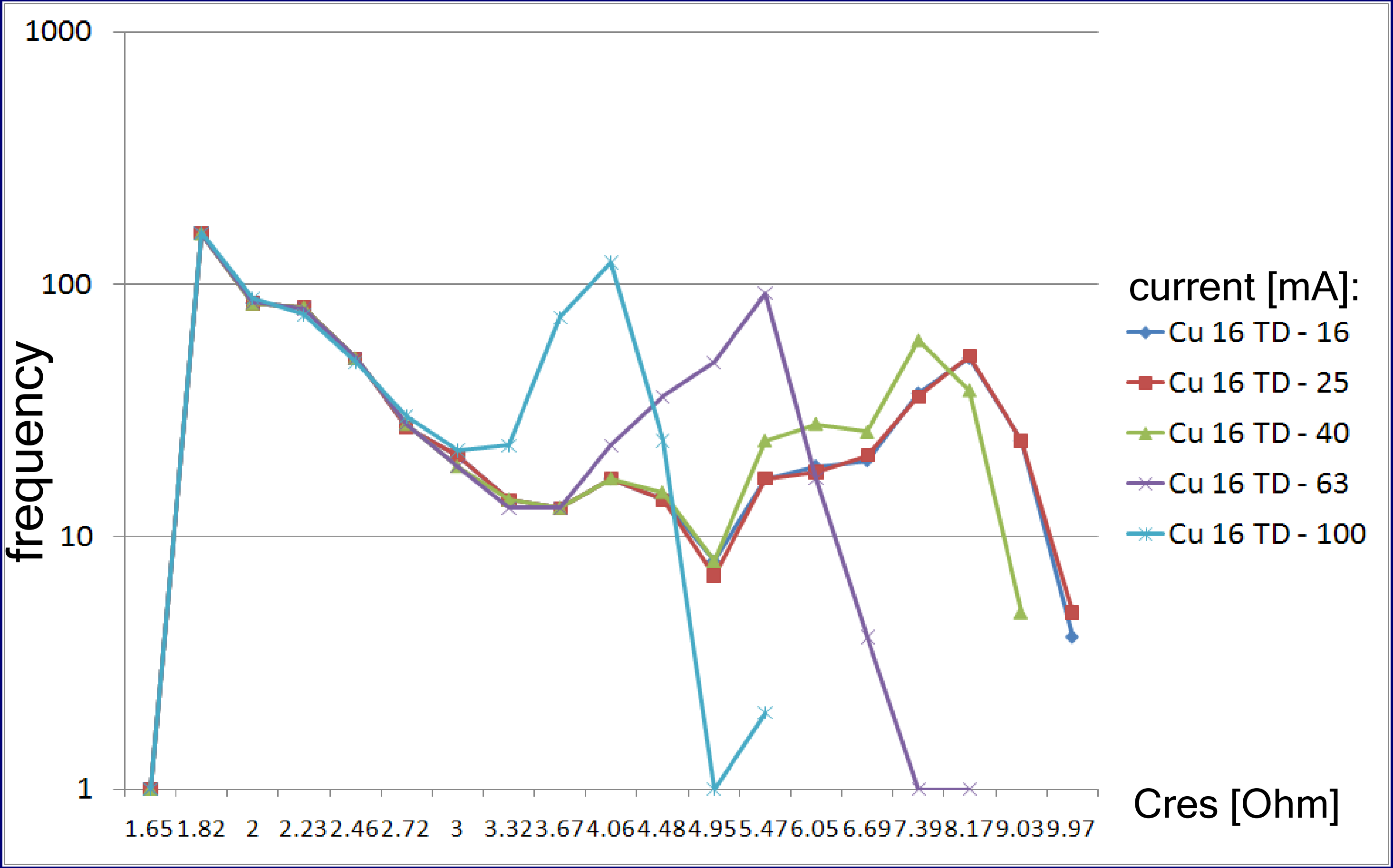
- Selected data from the I/U-measurements
- Fritting definition:
  $R_{100mA} - R_{63mA} > 30mOhm$ Cres change
- **Available data sets so far:**

	percentage fritting contacts
– 50 TD on aluminum / 80µm OT	0.22%
– 16 TD on copper / 80 µm OT	36.16%
– 13 TD on aluminum / 80µm OT	1.37%
– 1 TD on copper / 13 sets of OT (20-80µm)	1.20%
– 1 TD on aluminum / 13 sets of OT (20-80µm)	1.71%
– 350 TD on gold / 80µm OT	3.54%

test order

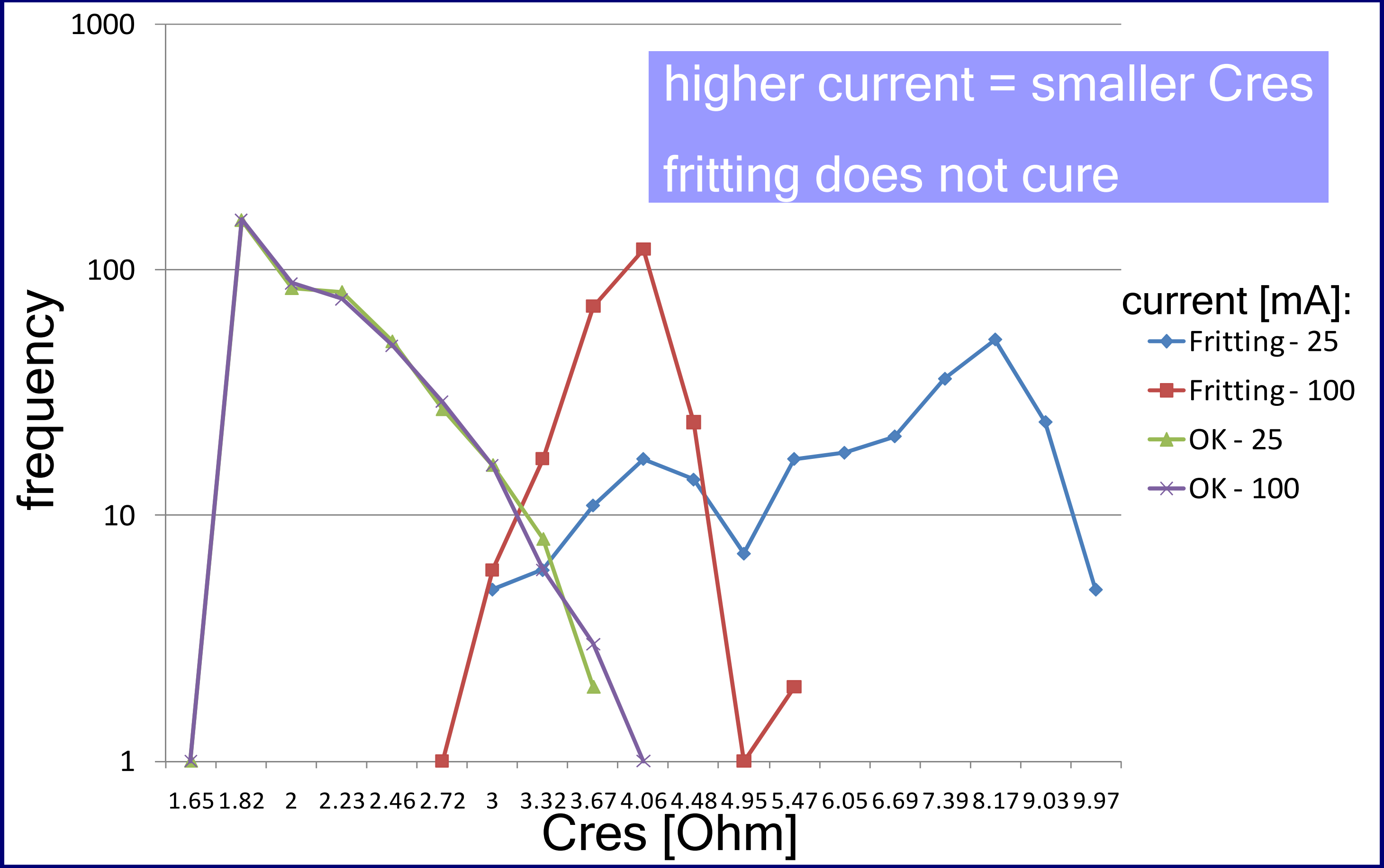
Fritting on Copper

16 TD CRES distribution



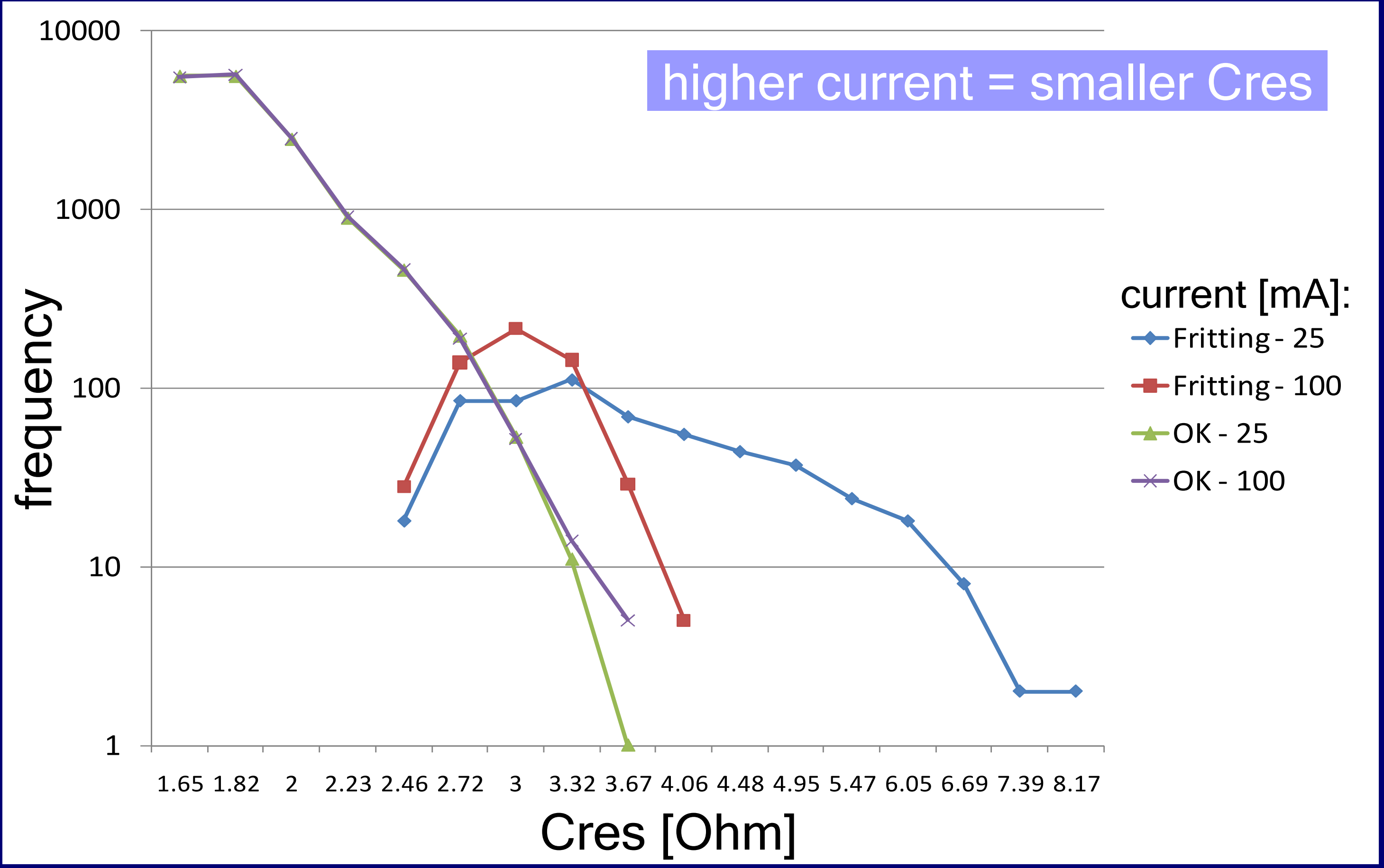
Fritting on Copper

16 TD CRES distribution



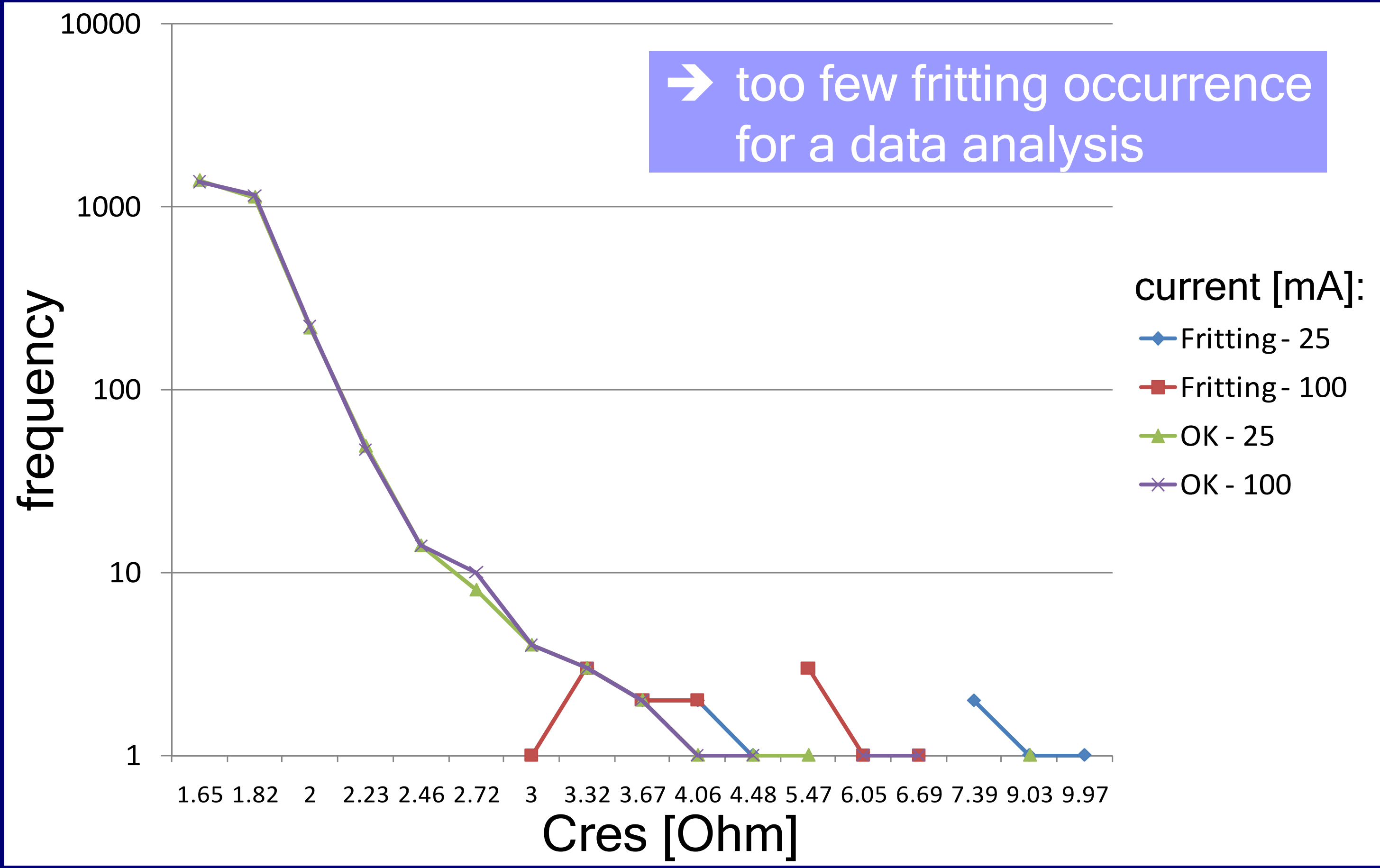
Fritting on Gold after Contamination with Cu_xO_y and Al_2O_3

350 TD CRES distribution

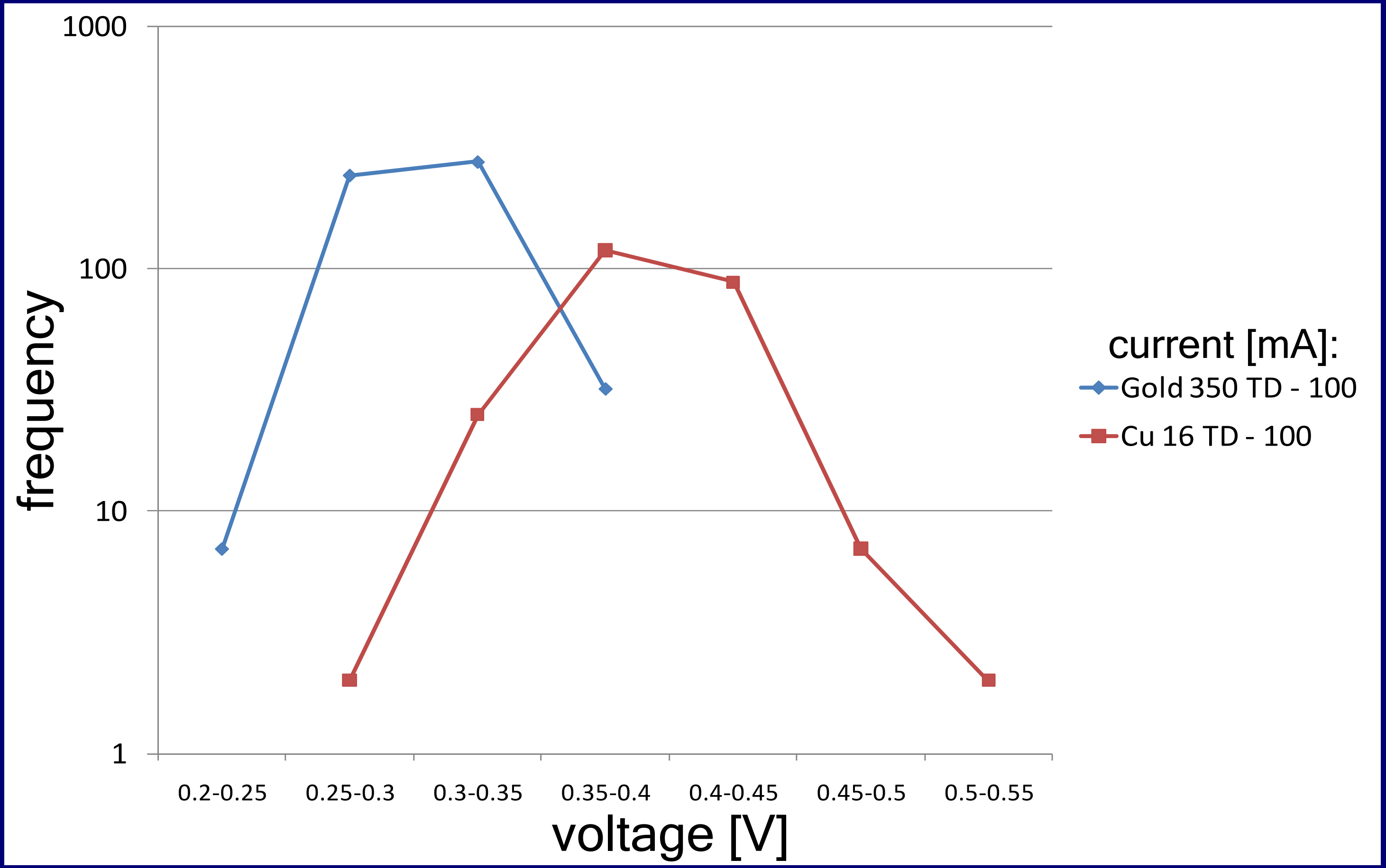


Fritting on Aluminum

50+13 TD CRES distribution



Fritting Voltage Distribution @ 100mA



→ indication towards material dependence of fritting voltage

Our Results

- Fritting requires a specific minimum current and voltage.*

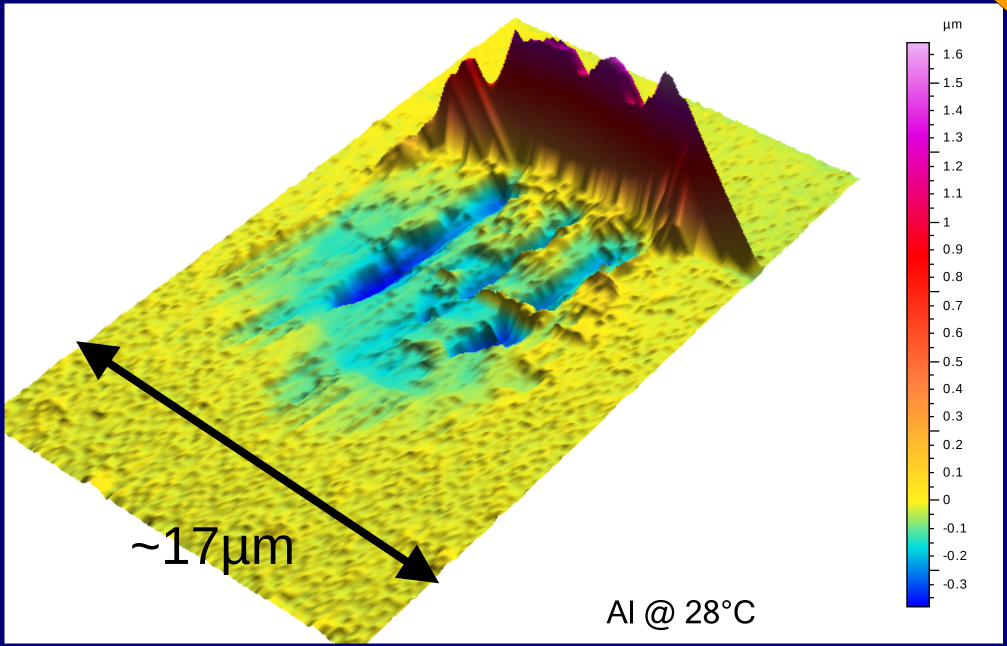
- Higher current yields lower resistance.
  Fritting does not “heal” the contact.*

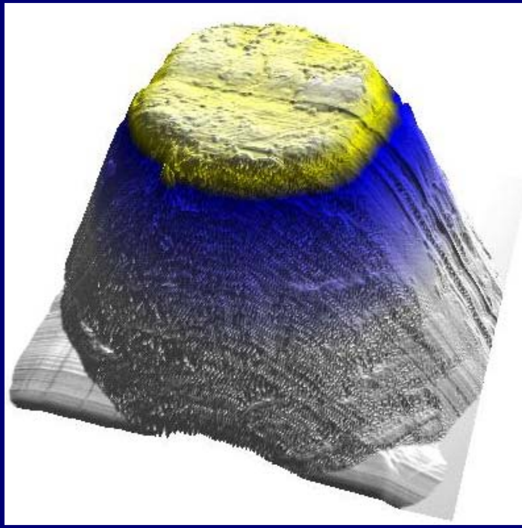
- Fritting voltages may depend on pad materials.
  We found values from 0.2V to 0.5V.

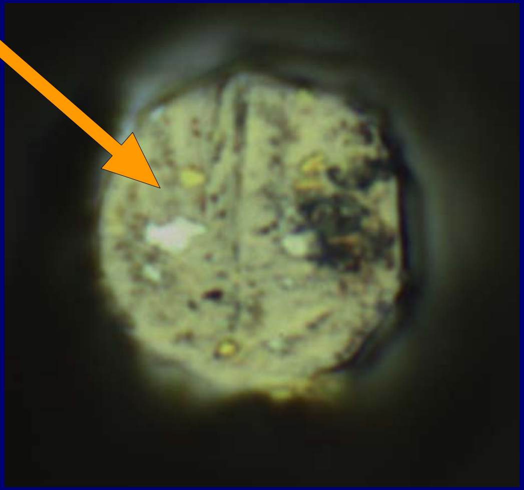
* see SWTW, MARTENS 2006 and 2009 and DEGEN 2006

AFM Measurements on Probe #25
Probe Tip and Scrub Mark Topography

Beam after 26439 touchdowns
Diameter: 14 µm
Traces of all pad materials on surface

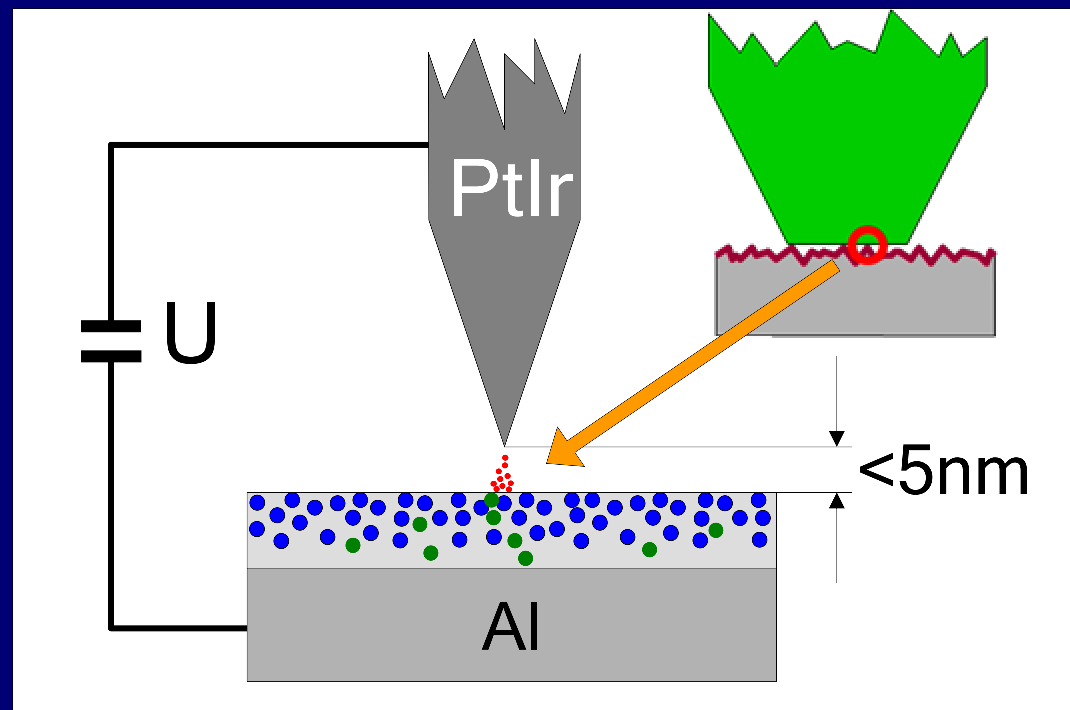






Scanning Tunnel Spectroscopy

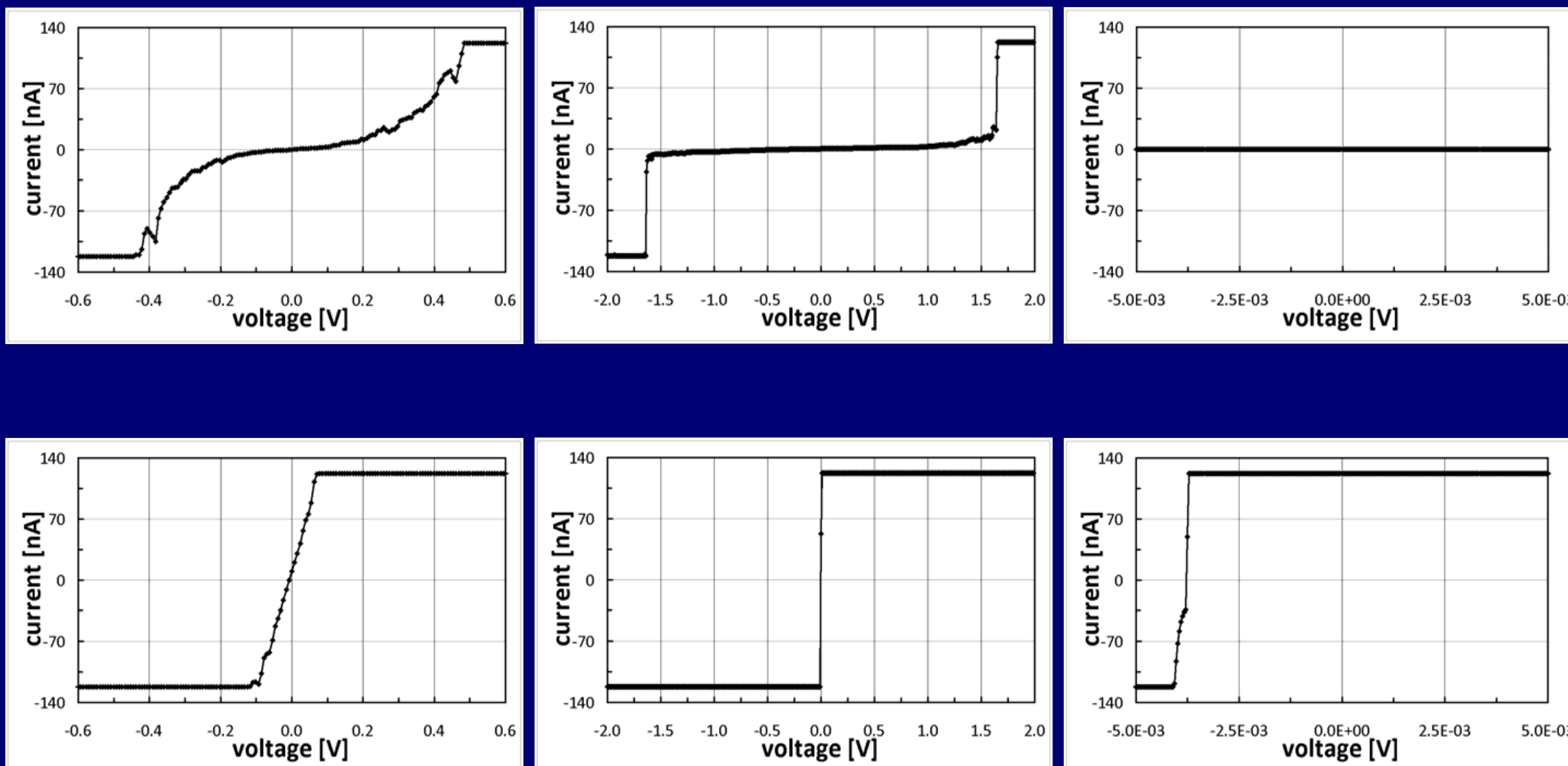
- Measuring the conductivity of a surface
- NO contact to the surface, but distance in the tunneling range
- extremly tight distance control



Scanning Tunnel Spectroscopy

voltage dependent resistance

constant resistance

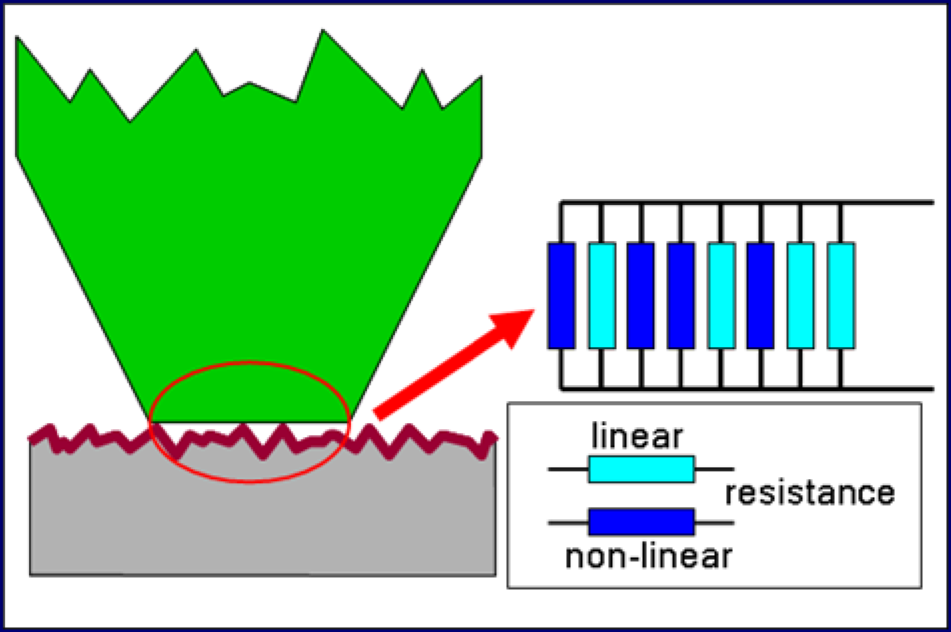


copper aluminum gold

Soft contacts for POAA

"No damage" contacts for POAA will rise the following challenges:

- more complex contact physics:
  - acceptable for logic I/O
  - critical for power/GND
  - difficult for analog signals
- non-linear contact characteristics

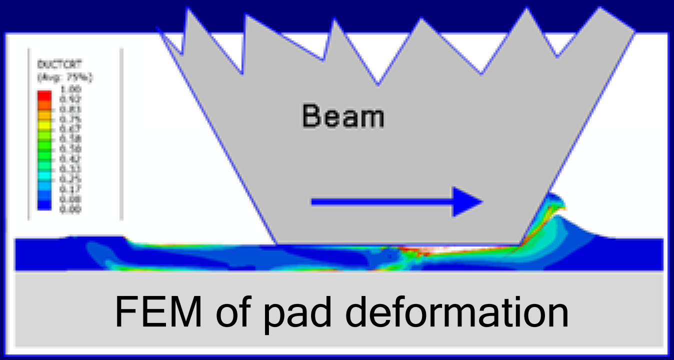


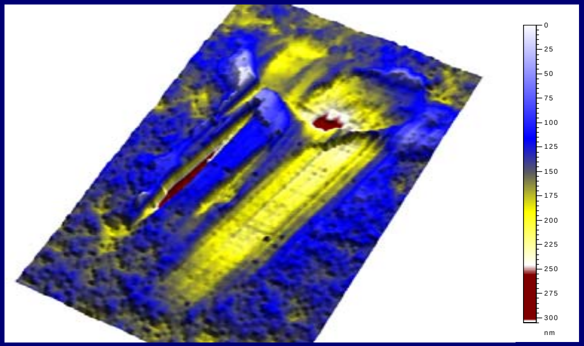
→ no real limit for measurements, but a challange for power supply

Advanced Contact Requirements are Covered by Simulations

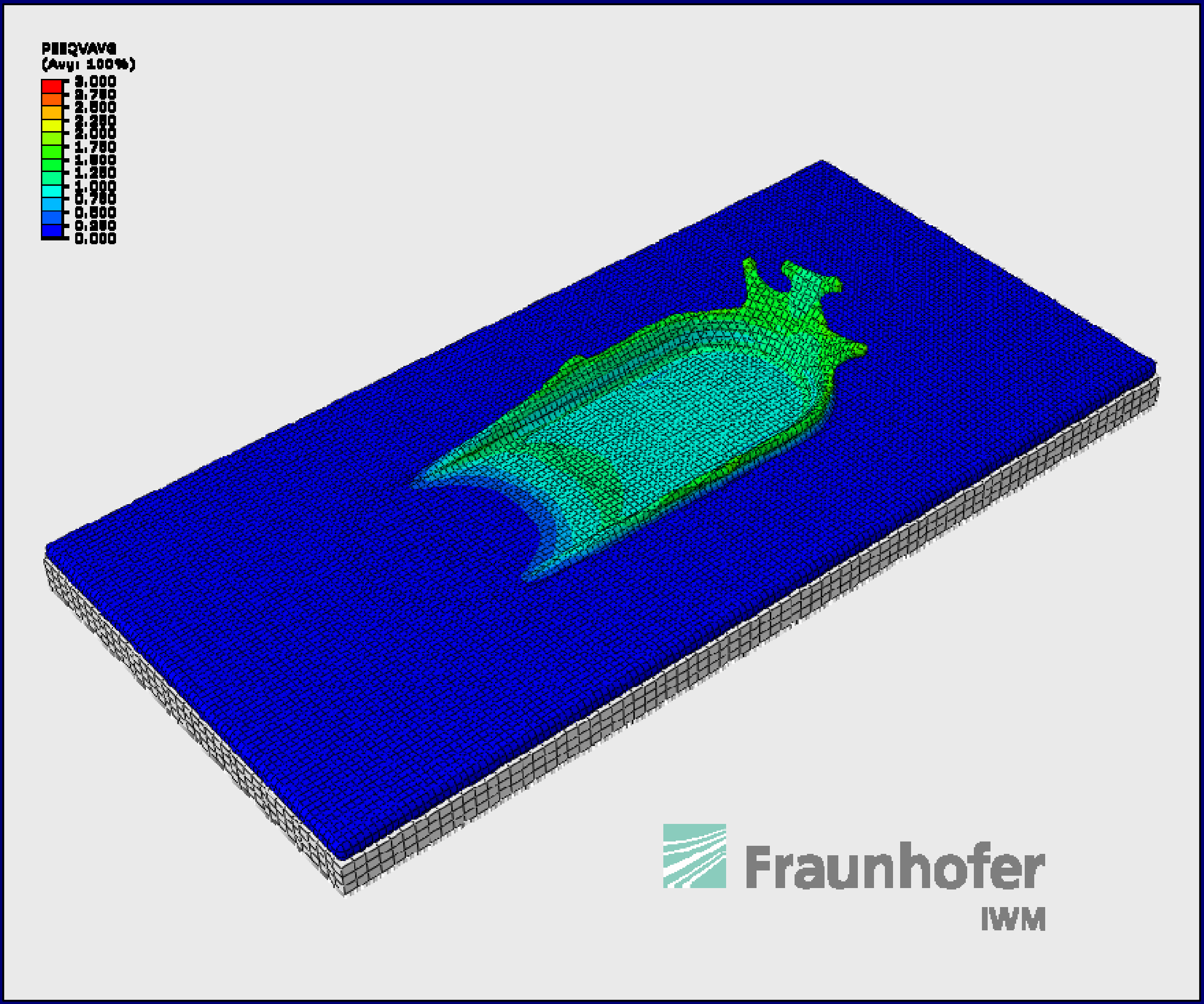
To optimize a system the following components are required:

- Accurate measurements of scrub mark dimension and depth using AFM
- Measurements of the tip using AFM or SEM and microscope
- FEM simulation to correlate the theory to the experiment





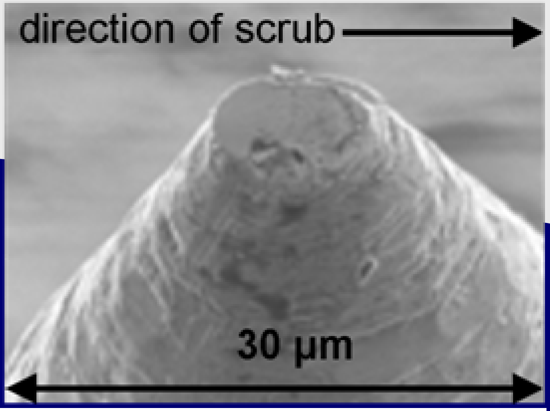
FEM simulation of probing Al with 1.6mil probe

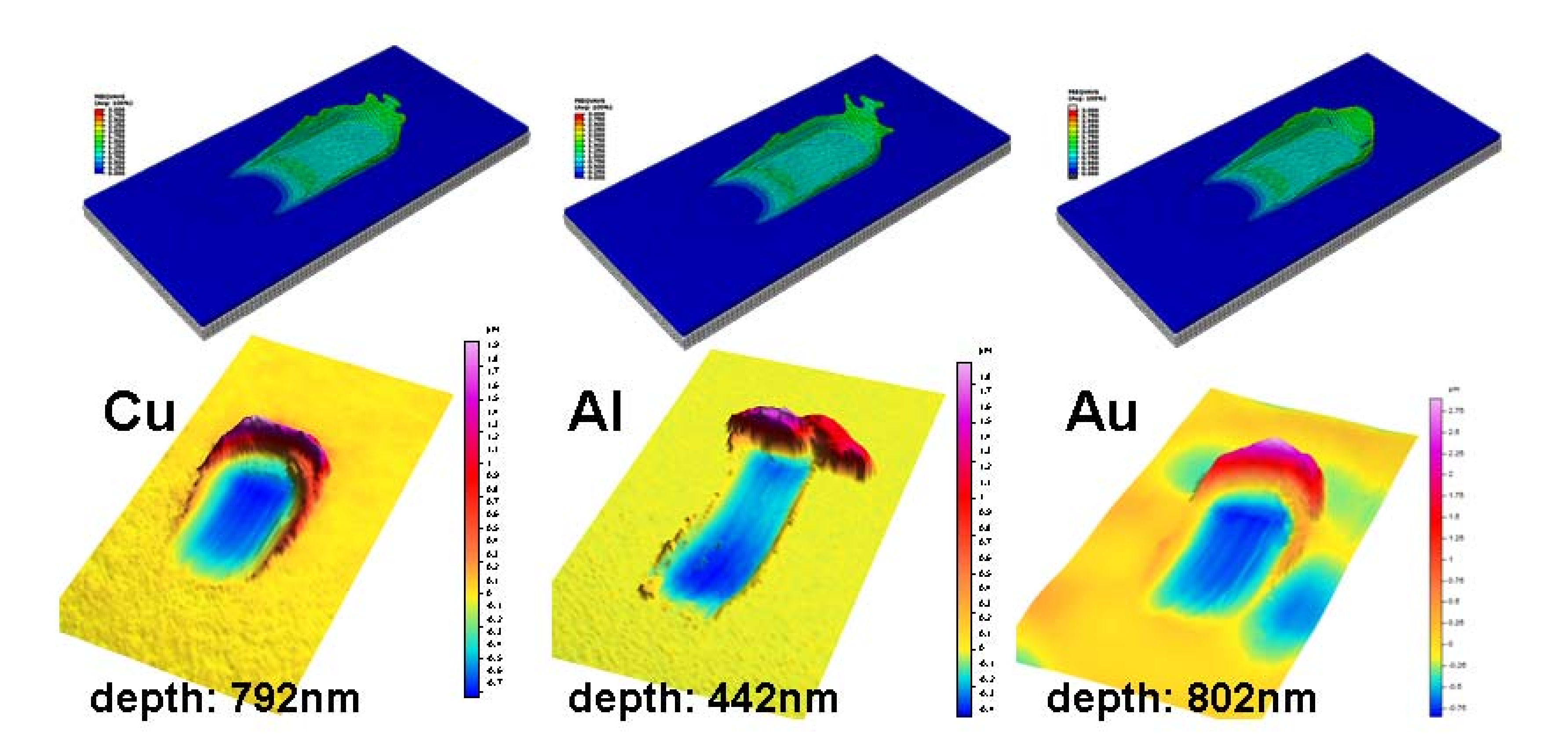


path controlled

calculation

Comparison of FEM and AFM Measurements





the probe above has been used for these scrubs

Summary

- Common probing relys on surface deformation but leads to a contact with constant, small resistance

- "No damage" probing requires a more detailled test algorithm to take the contact interface into account.

- An optimized system allows for stable soft contacts.
  Optimization will include detailled surface analysis combined with extended simulation.

- Fritting can be predicted by initial resistance measurement.

Outlook

- Extending the experiments towards service life.
- Including very high current applications.
- Constantly enhance analytics for probes and pads.
- Develop simulations towards CAE/CAM for next generation probes.

Acknowledgements

Tino Stephan (Fraunhofer-IWM)	-	AFM measurements, film thickness
Georg Lorenz (Fraunhofer-IWM)	-	FEM simulations
Martin Bogner (Uni-Stuttgart)	-	STS measurements
Juergen Bauersfeld (FEINMETALL)	-	prober tests, prober software
Michael Holocher (FEINMETALL)	-	testhead preparation
Georg Steidle (FEINMETALL)	-	AFM measurements
Christoph Gers (FEINMETALL)	-	contact technology

Thank You.

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