Electrical Characterizations Through a Nanoprobing System Installed in a Field Emission Scanning Electron Microscope

Speakers:
Mattia Silvestre
Antonio D'Orecchia

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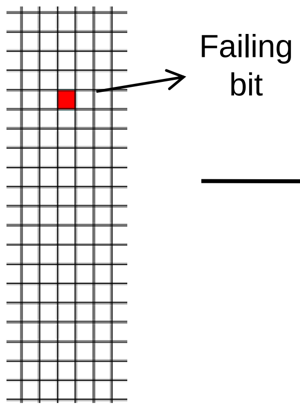
Objectives

- Importance of I-V Nanoprobing in Failure Analysis (FA) Sector
- Description of the Nanoprobing System in CNIS
- Microprobe Station vs SEM-Based Nanoprobing Comparative Measurements
- Evaluation of Electrical Tests at Nanoscale

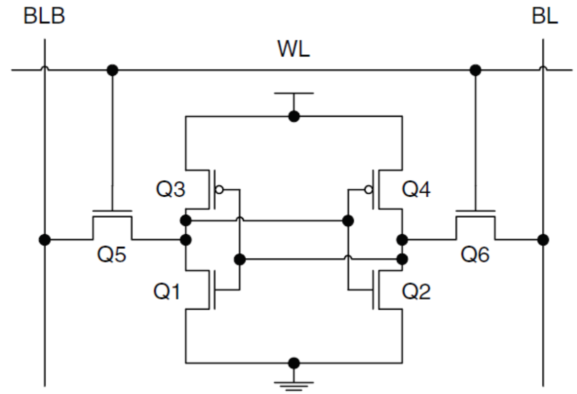
Nanoprobing Technique in FA – Importance of Nanoprobing

Semiconductor technology nodes continue to get smaller (even below 100 nm), and traditional Failure Analysis methods (e.g. microprobing) are not capable of isolating the fault location.

SRAM array



SRAM failing cell



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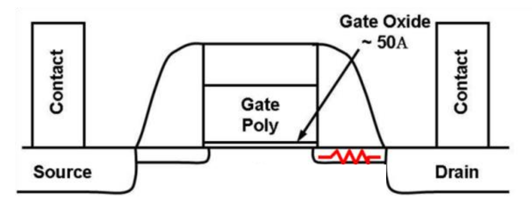
Failing transistor



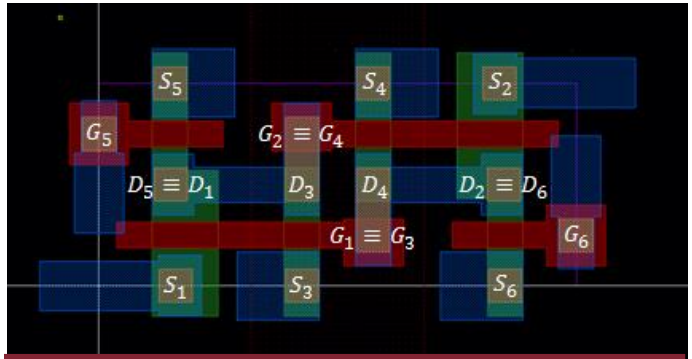
Transistors are decreasing in size, therefore the defects that cause failure are also decreasing in size. The smaller defects are extremely difficult to visualize with FIB-SEM inspection or TEM analysis unless the exact location of the defect in the transistor.

Nanoprobing is a powerful tool to improve the resolution of the electrical analysis of failing ICs. It allows to test IC's sub-features up to the nanometer range and helps to narrow down the suspected failing area

Nanoprobing Technique in FA – I-V Characterization

In this work, a nanoprobing system is installed in a field emission scanning electron microscope

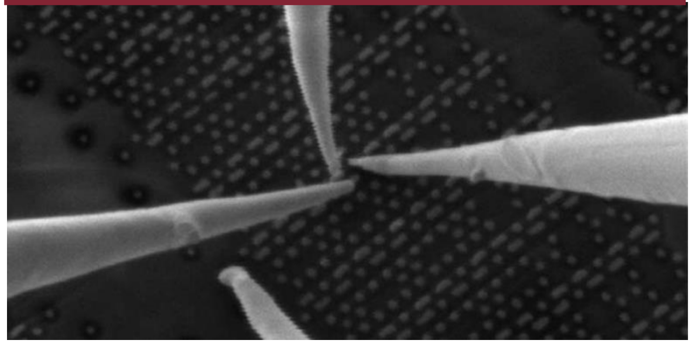
The aim is studying the possibility to combine nanoprobing I-V characterization capabilities to important FIB/SEM functionalities

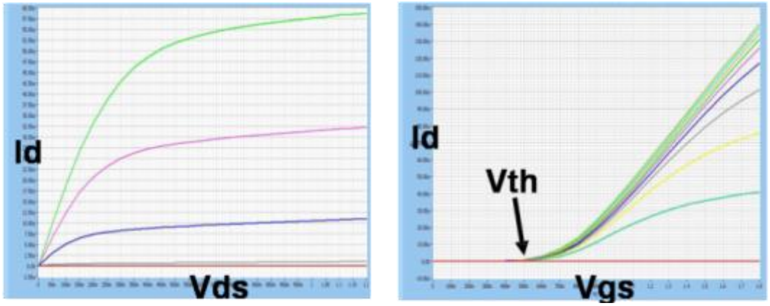


SRAM Cell Layout

SEM-based nanoprobing consists in placing piezo-controlled nano-tips on transistor contacts to perform I-V characterizations of the device

Nanoprobing



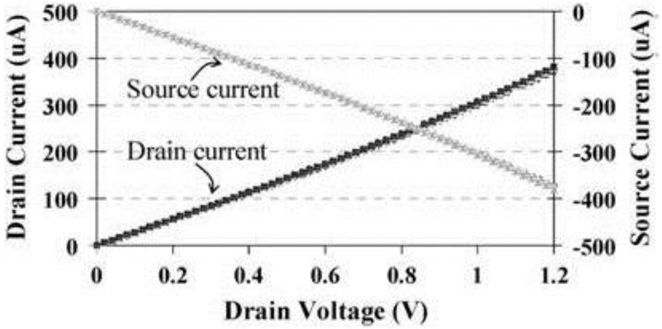


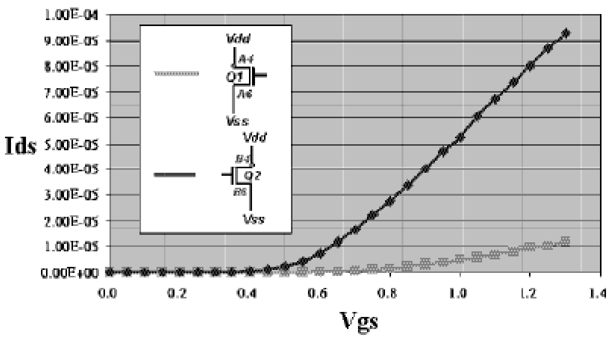
The main measurement is the classical 4-probe measurement to achieve the I_D vs V_{DS} and the I_D vs V_{GS} characteristics

Nanoprobing Technique in FA – Case Studies

✓ Ohmic short between source and drain

Toh et al., "In-Depth Electrical Analysis to Reveal the Failure Mechanisms With Nanoprobing", IEEE Transactions on Device and Materials Reliability, Vol. 8, No. 2, pp. 387-393, 2008



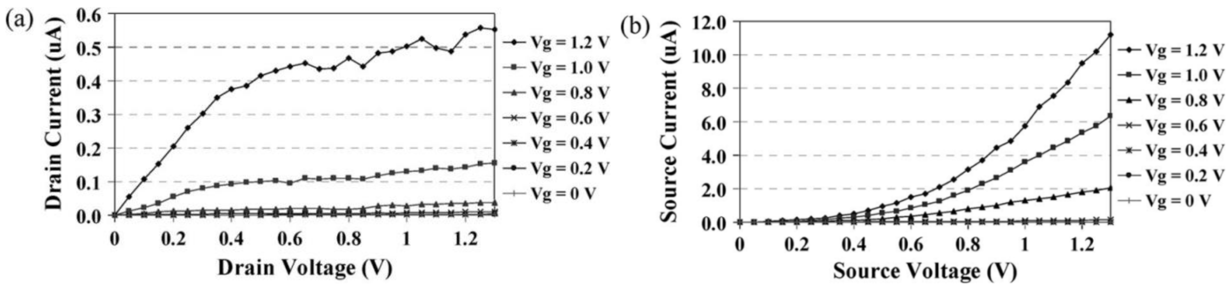


✓ Threshold voltage mismatch

Lin et al., "A Study of Asymmetrical Behaviour in Advanced Nano SRAM Devices", IEEE Proceedings of the 13th International Symposium on the Physical and Failure Analysis of Integrated Circuits, Singapore, pp. 63-66, 2006

✓ Asimmetry in the S/D curves

Toh et al., "In-Depth Electrical Analysis to Reveal the Failure Mechanisms With Nanoprobing", IEEE Transactions on Device and Materials Reliability, Vol. 8, No. 2, pp. 387-393, 2008



Measurement Setups – Nanoprobing Instrumentation

Zeiss Scanning Electron Microscope AURIGA
+
Physics d'Orsay Focused Ion Beam COBRA

- Modular workstation
  - SEM Imaging
  - FIB Milling
  - FIB Gas Assisted Deposition (through GIS)

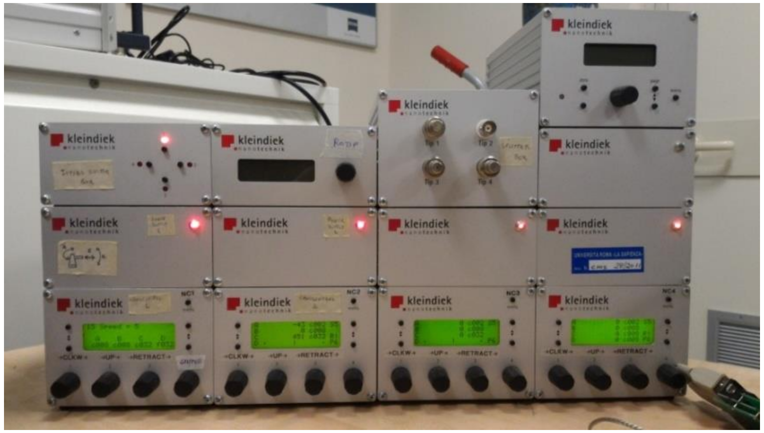
Keithley SourceMeters 2400/6430

- Precise and highly stable DC power supply
- Low noise and high-impedance multimeter
- Remote connection:
  - Computer
  - GPIB (General Purpose Interface Bus) cables
  - Driver software (National Instrument)
  - LabTracer 2.0 Software

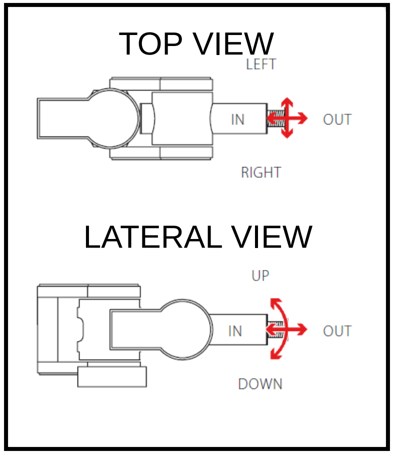
Measurement Setups – Nanoprobing Instrumentation

Kleindiek MM3A Manipulator

Kleindiek Nanomanipulation System

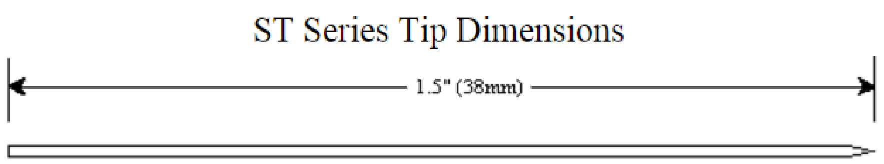


- Material: Stainless steel, aluminium
- Piezoelectric motor
- Three degrees of freedom:
  - Right/Left (A), resolution: 5 nm, range: 240°
  - Up/Down (B), resolution: 5 nm, range 240°
  - In/Out (C), resolution: < 0.5 nm, range 12 mm
- Probing current range/max. probing voltage: 10 nA -100 mA/100 V
- Motion modalities: Fine mode, Coarse mode

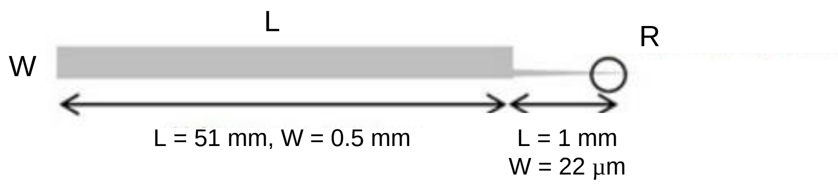


Measurement Setups – Nanoprobing Instrumentation

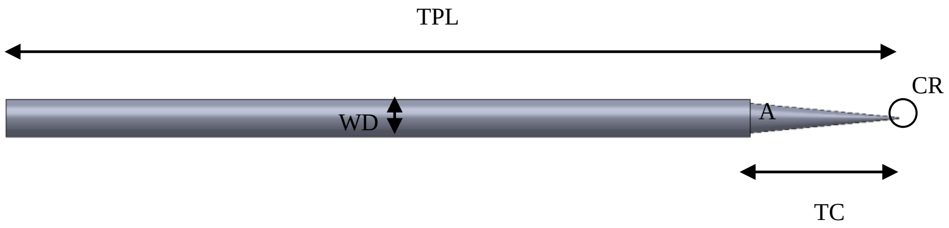
Probe Tips



ST Series Solid Tungsten Probe Tips		
Part Number	Solid Tungsten Shaft Diameter	Point Radius (µm)
ST-20-1.0	0.020" (0.51 mm)	< 1.0
ST-20-5.0	0.020" (0.51 mm)	< 5.0



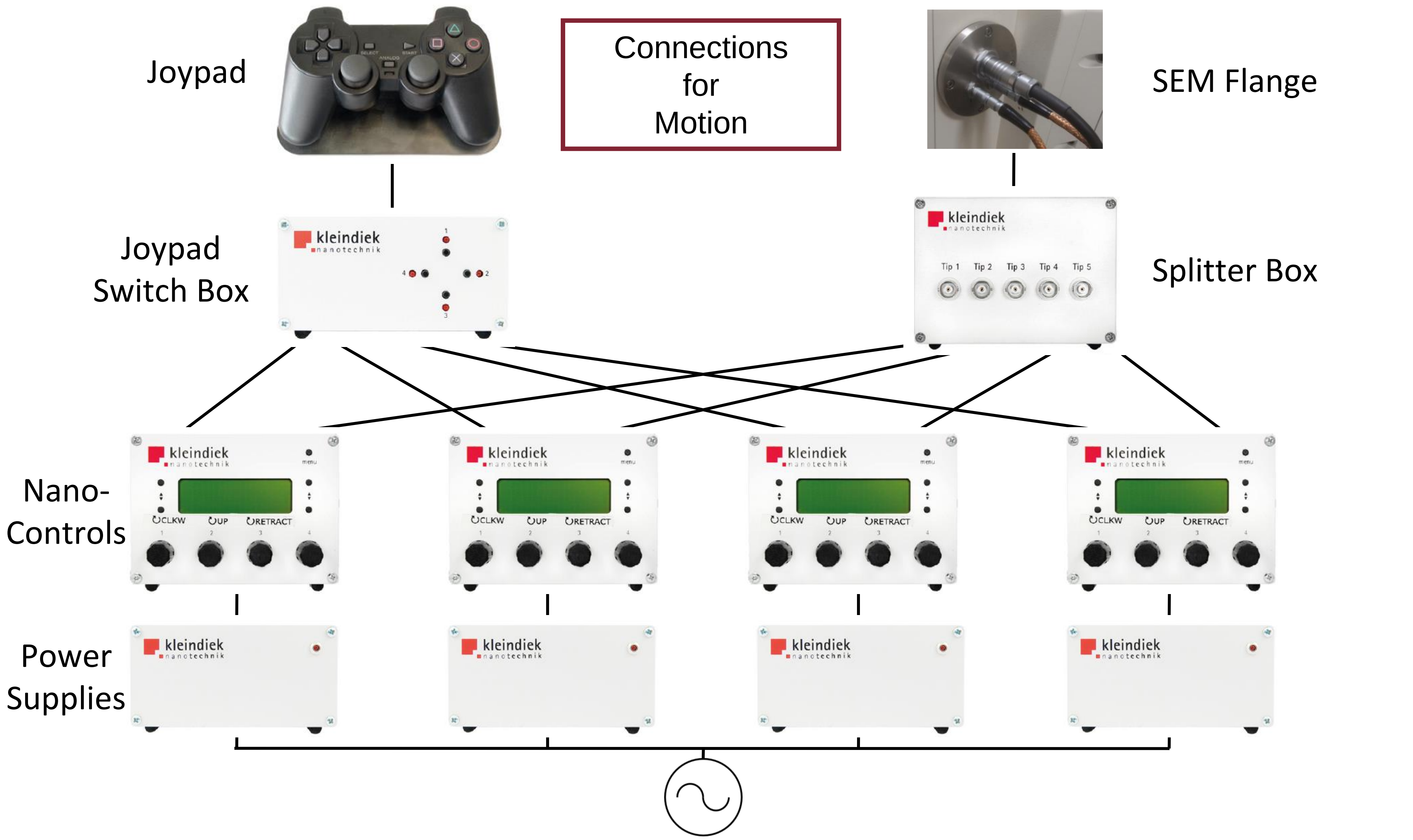
PT Series Probe Tips			
Part Number	Length	Copper Shaft Diameter	Tungsten Curvature R
PT-14-6705-B	52 mm	0.5 mm	100 nm



MSCT – SA 025 TPL013 TC025 A2 – CR35

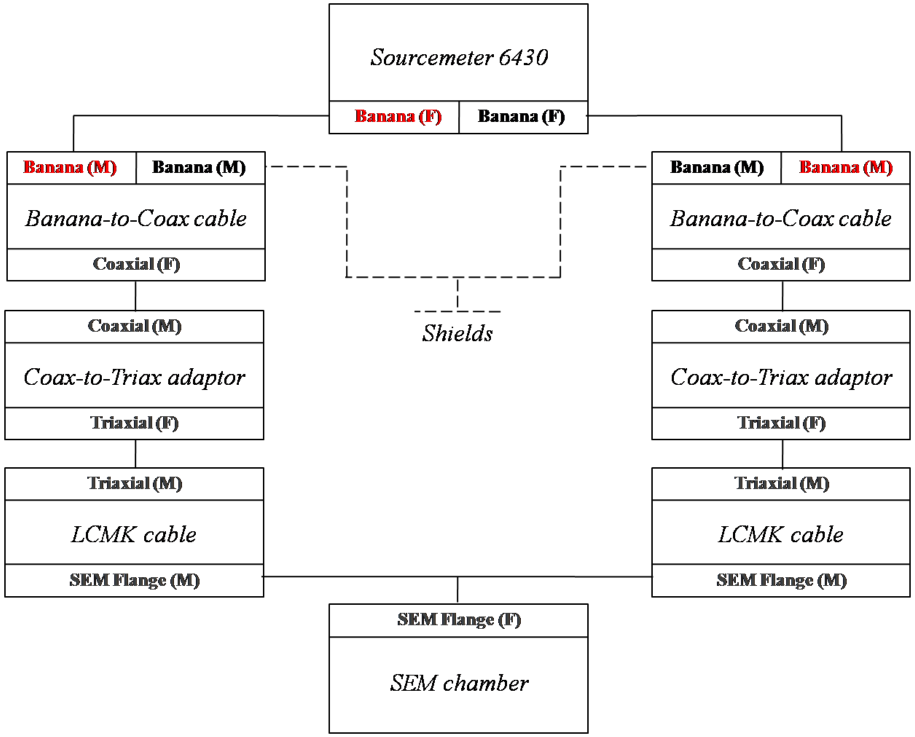
- SA = SEM based electrical nanoprobing probe application type
- 025 = 0.25 mm Probe Wire Diameter (WD)
- TPL013 = 13 mm Total Probe Length
- TC025 = 2.5 mm Tape Cone Lenght
- A2 = Cone Angle Type (A1 is the smallest, A3 is the biggest)
- CR35 = 35 nm Curvature Radius (on tip apex)

Measurement Setups – Nanoprobing System Setup

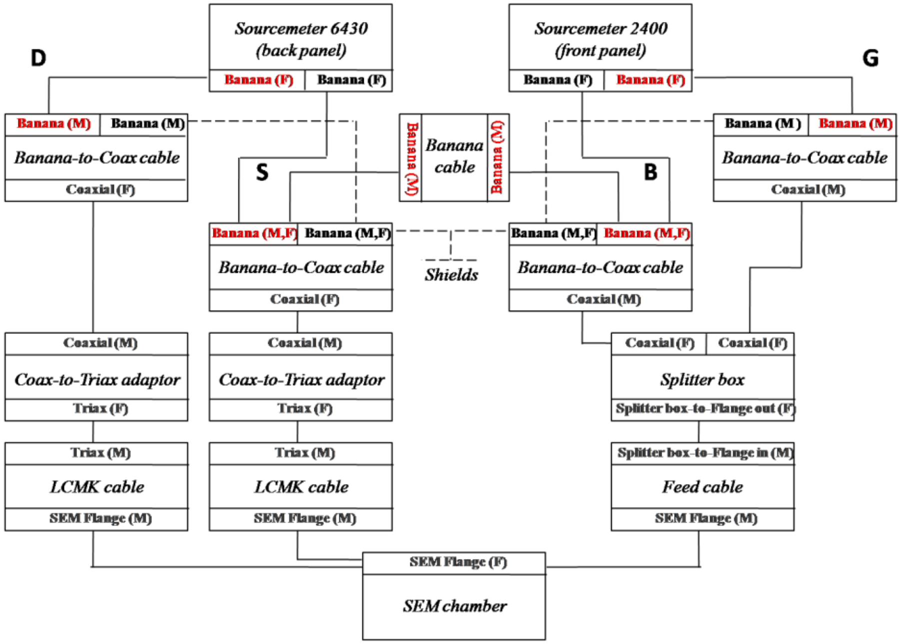


Measurement Setups – Nanoprobing System Setup

Two-tips measurement connection

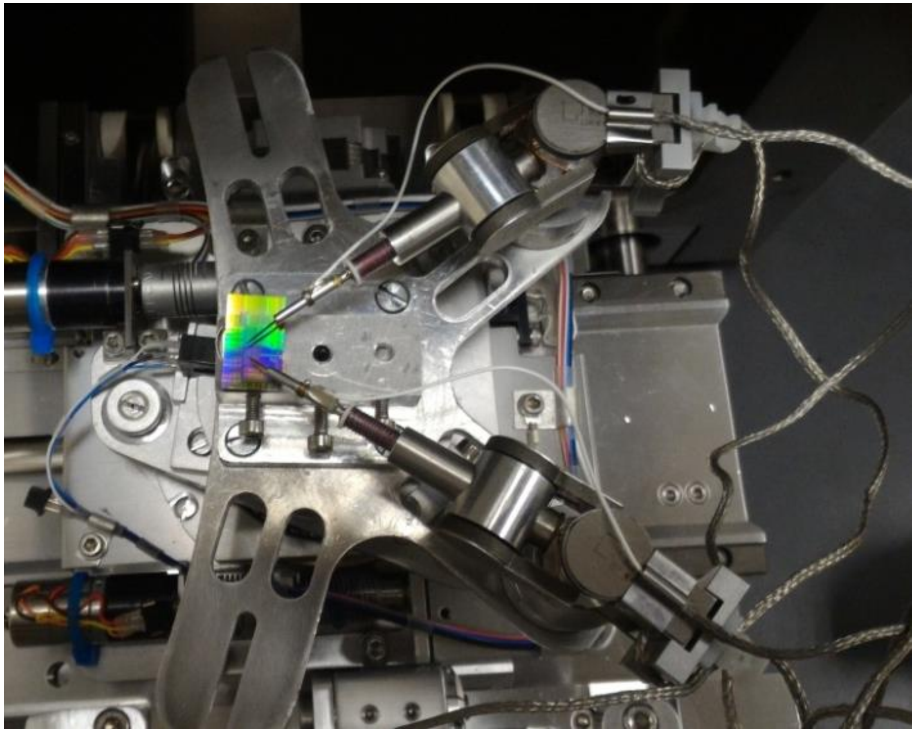


Four-tips measurement connection

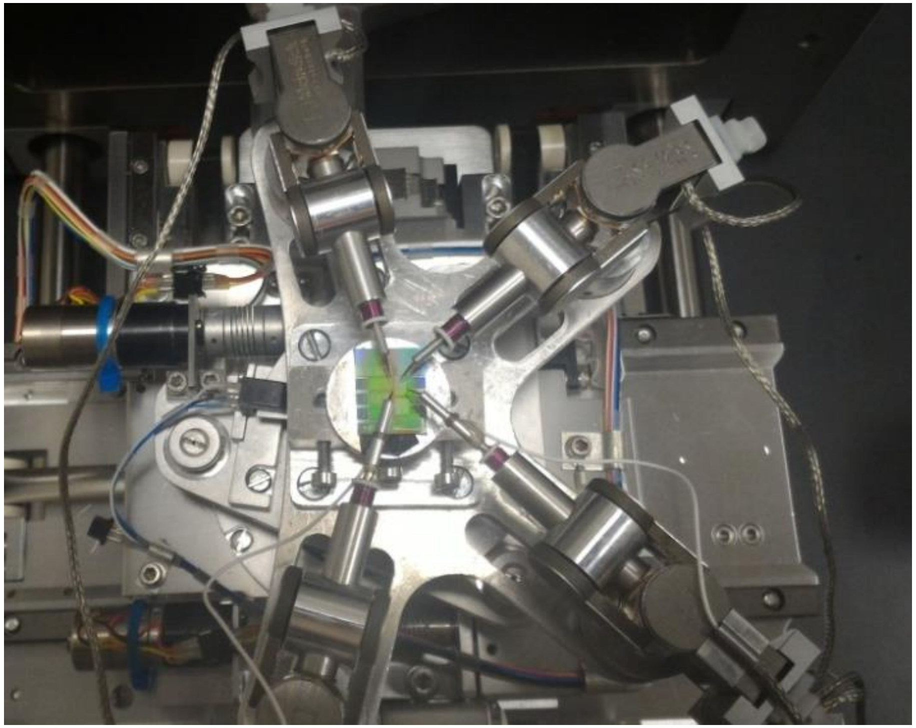


Measurement Setups – Nanoprobing System Setup

Two-tips setup



Four-tips setup

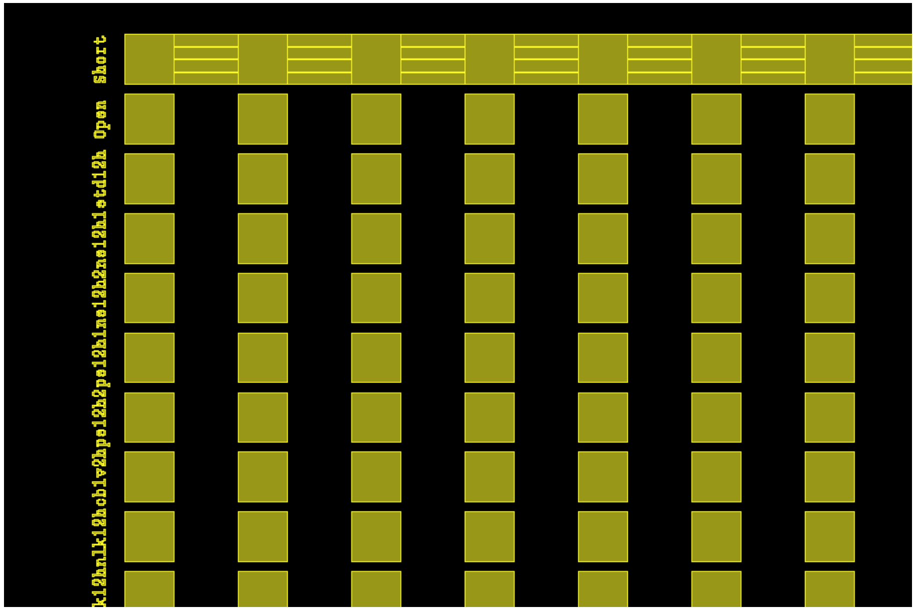


Device Characterizations – Tested Specimens

Parametric structures

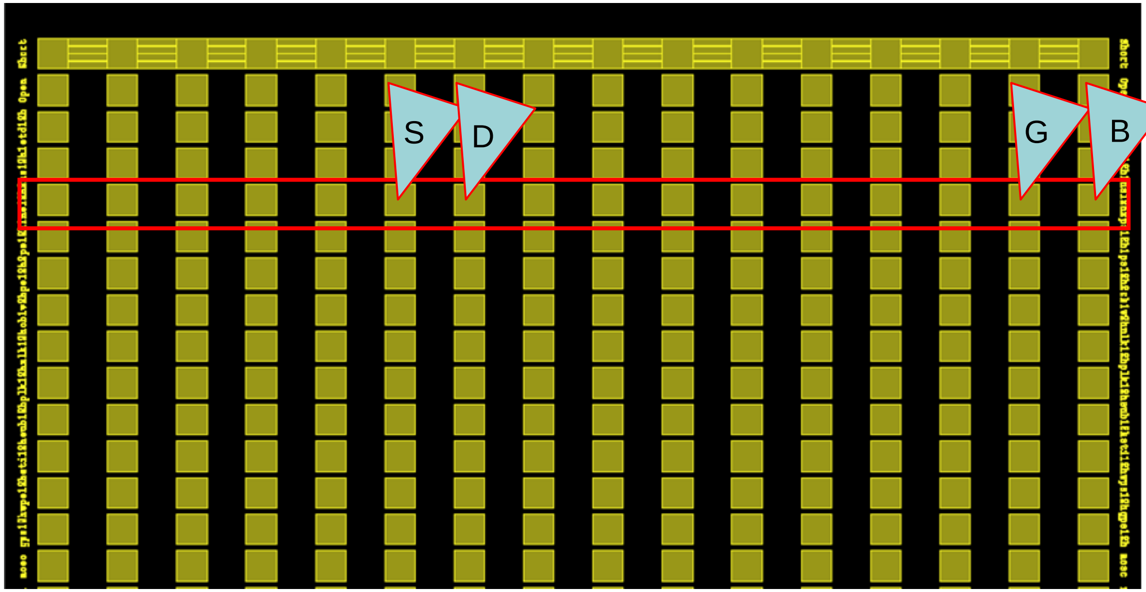
A parametric structure is a block designed for testing and measure various flavours of IC's components (resistors, transistors, etc.) that will be integrated in functional modules (SRAM, Flash memories etc.).
These data are extremely important to study:

- Process setup/margin/optimization
- Design problems/enhancements
- Electrical performances



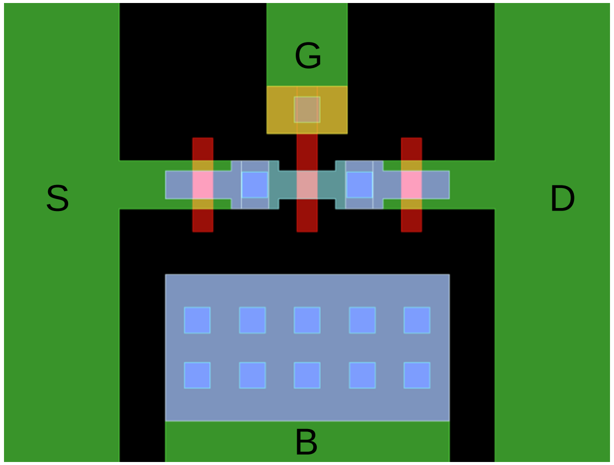
Device Characterizations – Tested Specimens

Transistor Parametric Structure



• Pad dimensions: 50 µm x 50 µm

• Material: Aluminium

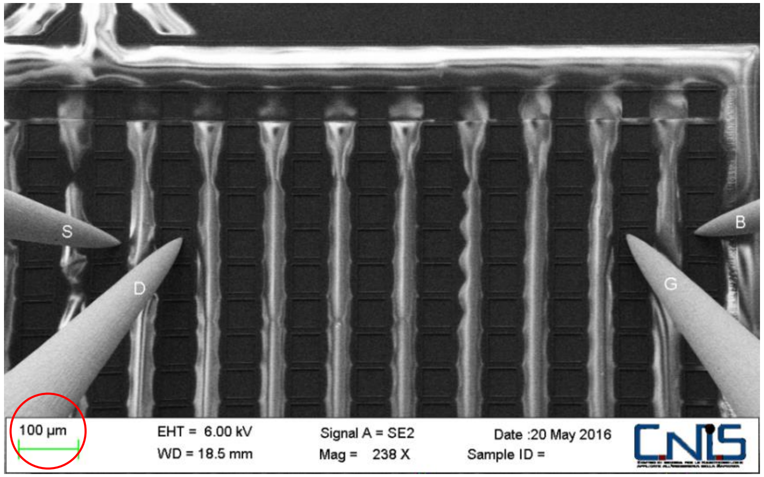


• Channel L = 110 nm

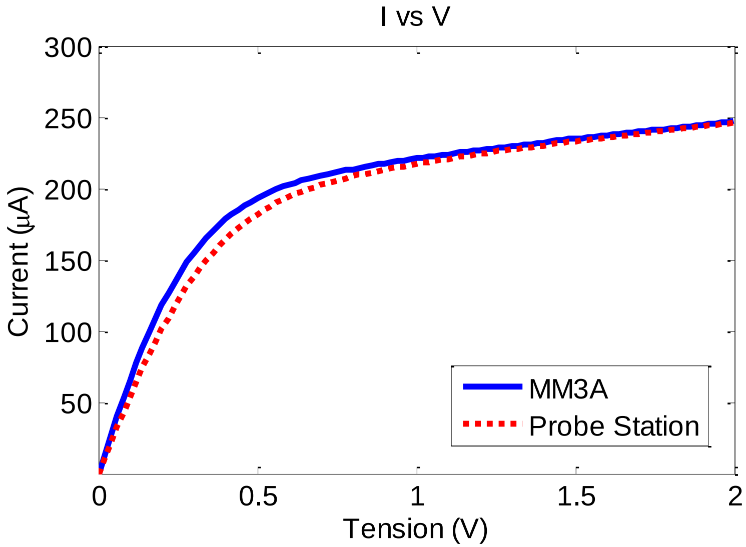
• Channel W = 300/150 nm

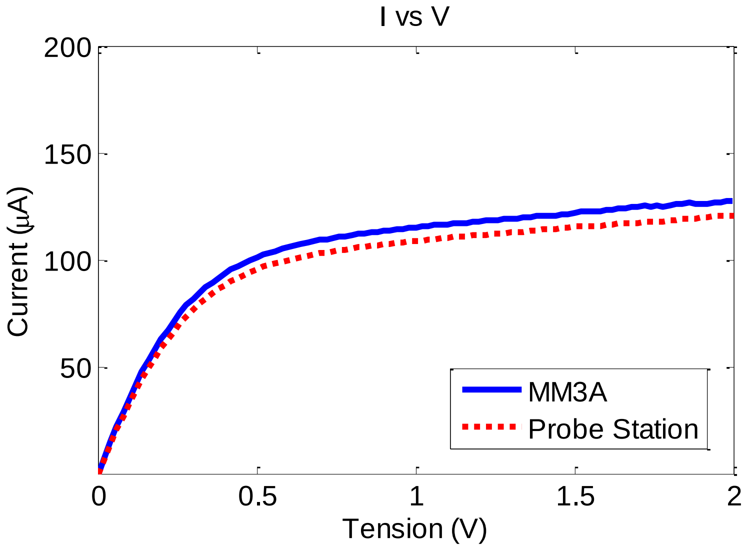
Device Characterizations – Comparative Electrical Tests

Results



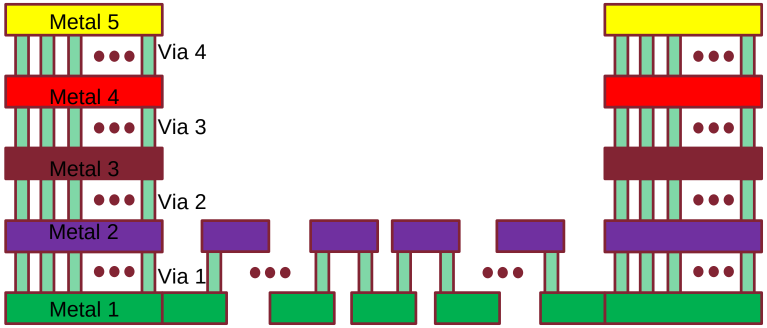
SourceMeter 6430	
Channel Function	Sweep Voltage
Range	0/2 [V]
Number of points	101
Sweep type	Linear
Compliance	10 [mA]
SourceMeter 2400	
Channel Function	Bias Voltage
Range	0-1.2 [V]
Number of points	5

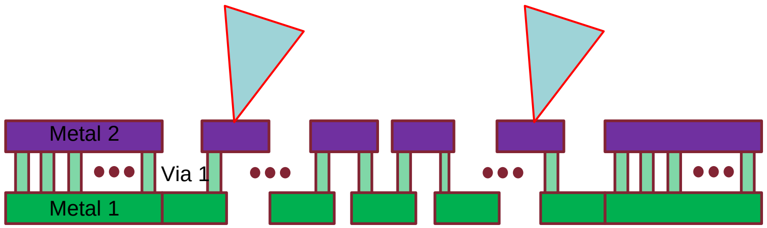




Device Characterizations – Tested Specimens

De-processing





Plasma Etching (RIE)
[Gas: mixture (CHF_3, CF_4, He)]

→

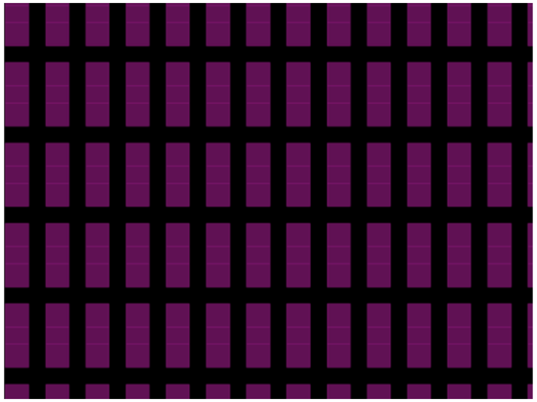
Mechanical Planarization
[Abrasive slurry: Aluminium oxide-based, 0.3 µm diameter (AlO2)]

→

Polishing:
Deionized water +
N_2 spray gun

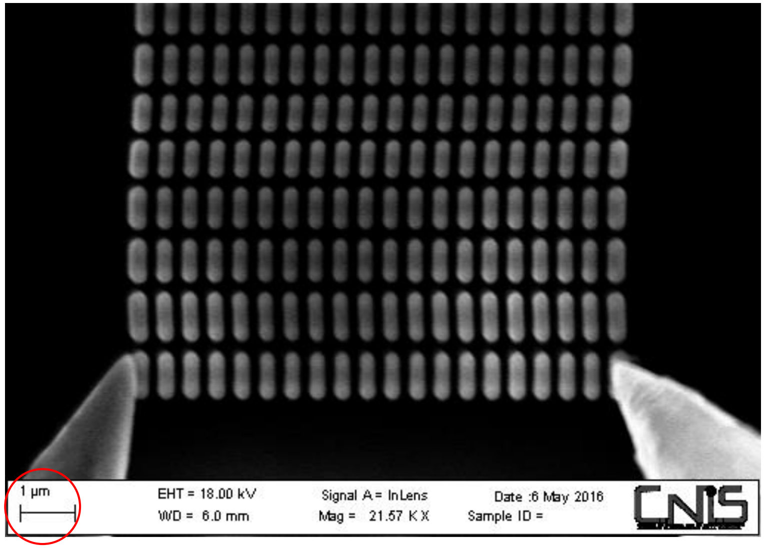
Via chain

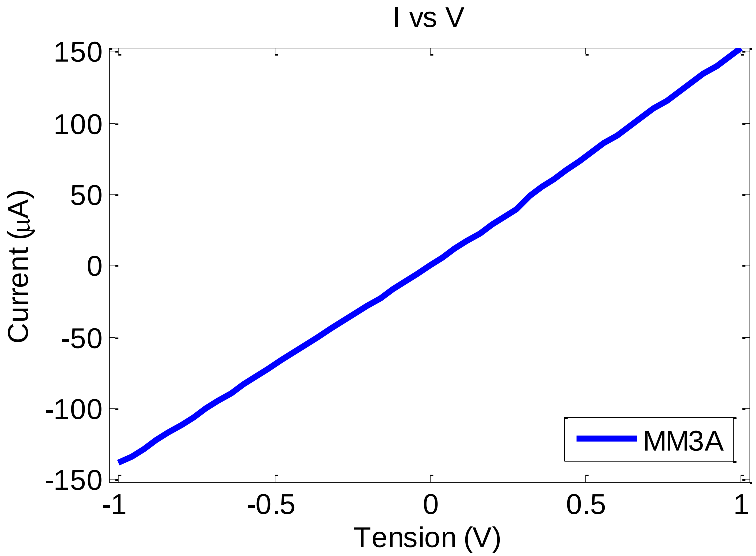
- Pad dimensions: 270 nm x 740 nm
- Material: Aluminium



Device Characterizations – Measurements at Nanoscale

Results



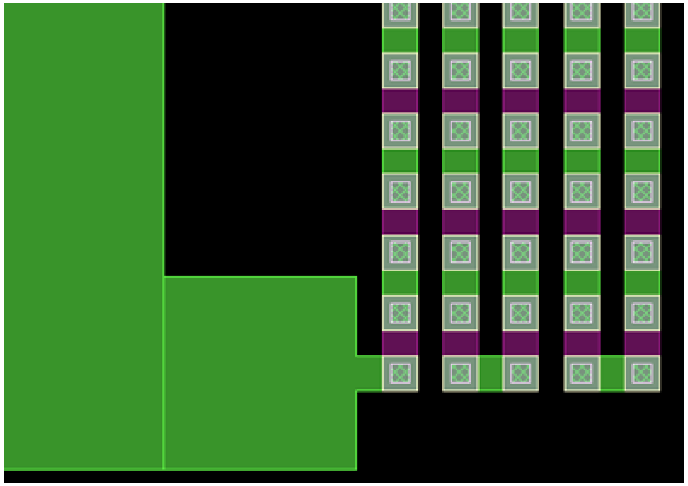


SourceMeter 6430	
Channel Function	Sweep Voltage
Range	-1/1 [V]
Number of points	51
Sweep type	Linear
Compliance	10 [mA]

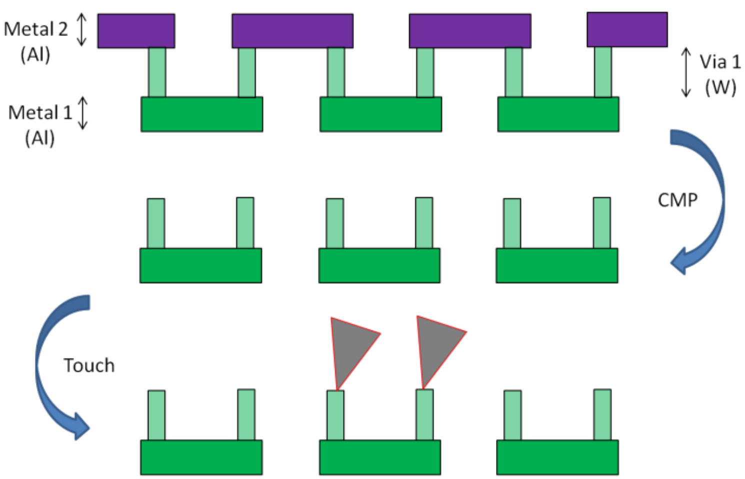
Pad 3 – Pad 4	
Parameters	**Values**
Nominal value	5 [kΩ]
Nanoprobing System measurement	6.94 [kΩ]

Device Characterizations – Measurements at Nanoscale

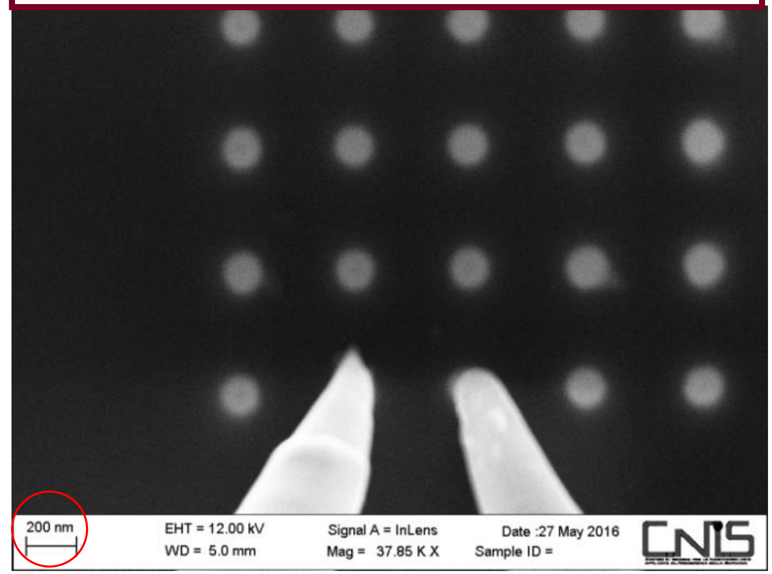
Via Contacts



De-processing



Touch



- Contact diameter: 150 nm
- Material: Tungsten

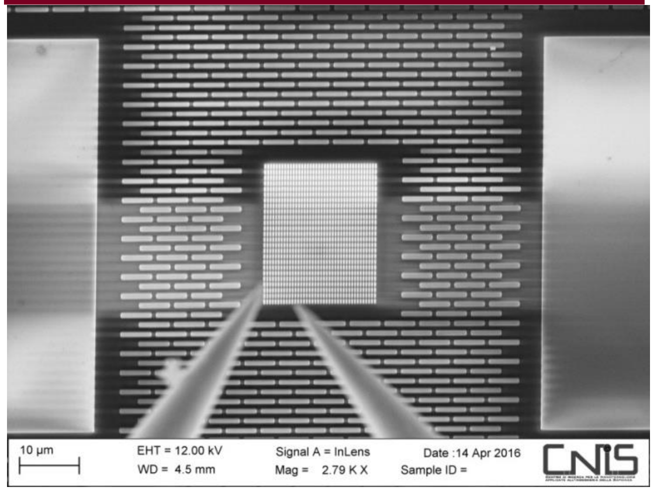
Device Characterizations – Measurement Issues

Charging

IC oxidation

↓

Reactive Ion Etching



System Instability

Manipulator Control

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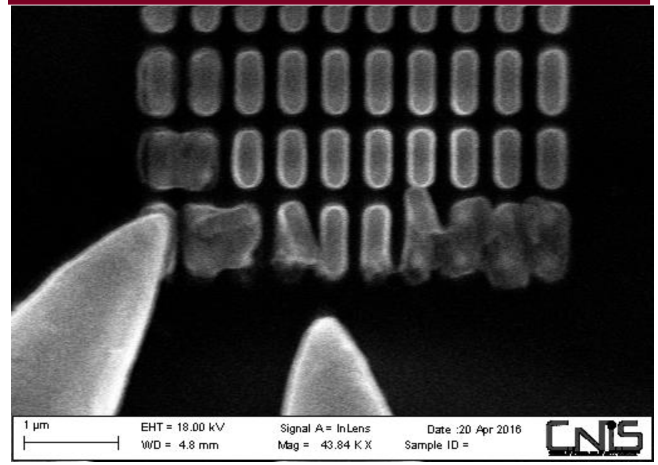
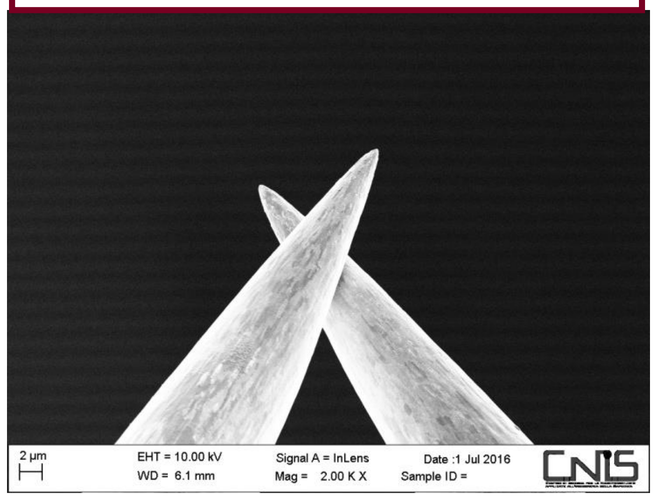
Voltage regulation



Tips ohmic contact



R ≈ MΩ, GΩ

↓

FIB polishing

Conclusion and Future Advancements

1. The nanoprobing instrumentation setup has been optimized in terms of motion and electrical tests;

2. The comparison between microprobe station measurements and SEM-based nanoprobing results has been successfully realized;

3. In attempting to scale down the measurement process at nanoscale, stability and tips contact issues have been faced and resolved.

Some of the most interesting continuation topics can be:

- Improvement of the W tip-to-W contact touch at nanoscale;
- Establishment of I-V nanoprobing measurements on more complex devices, like SRAMs;
- Beginning and conclusion of a complete FA process flow through nanoprobing;
- Designing an automated system for landing and touchdown process.