CAPRES

Technology Roadmap 2016

CAPRES
Technology Road Map 2016

Take the straight road towards next generation technology nodes using the Capres technology

AND

Bridge the gaps in development, ramp-up and production using the Capres technology

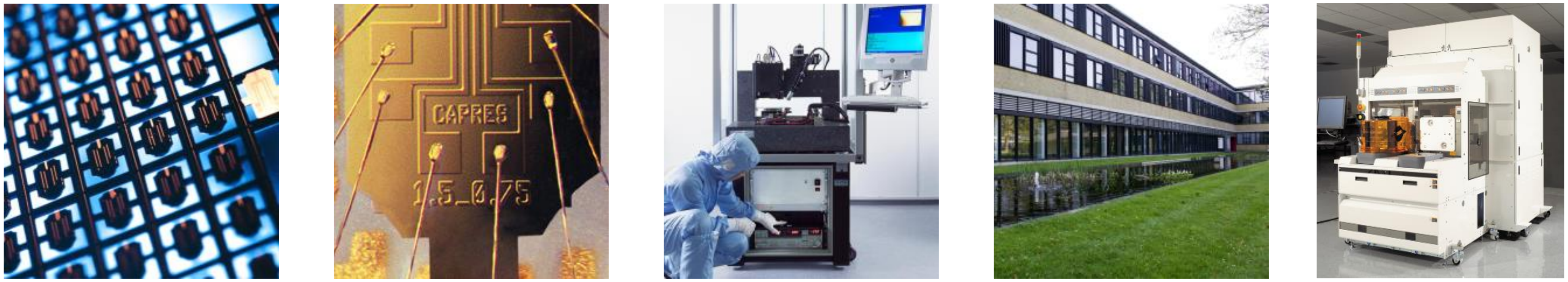
Technology Road Map 2016

Agenda

- CAPRES Introduction
- Technology Road Map 2016
- Fully Automated Tool Platform & Upgrades
- Consumables

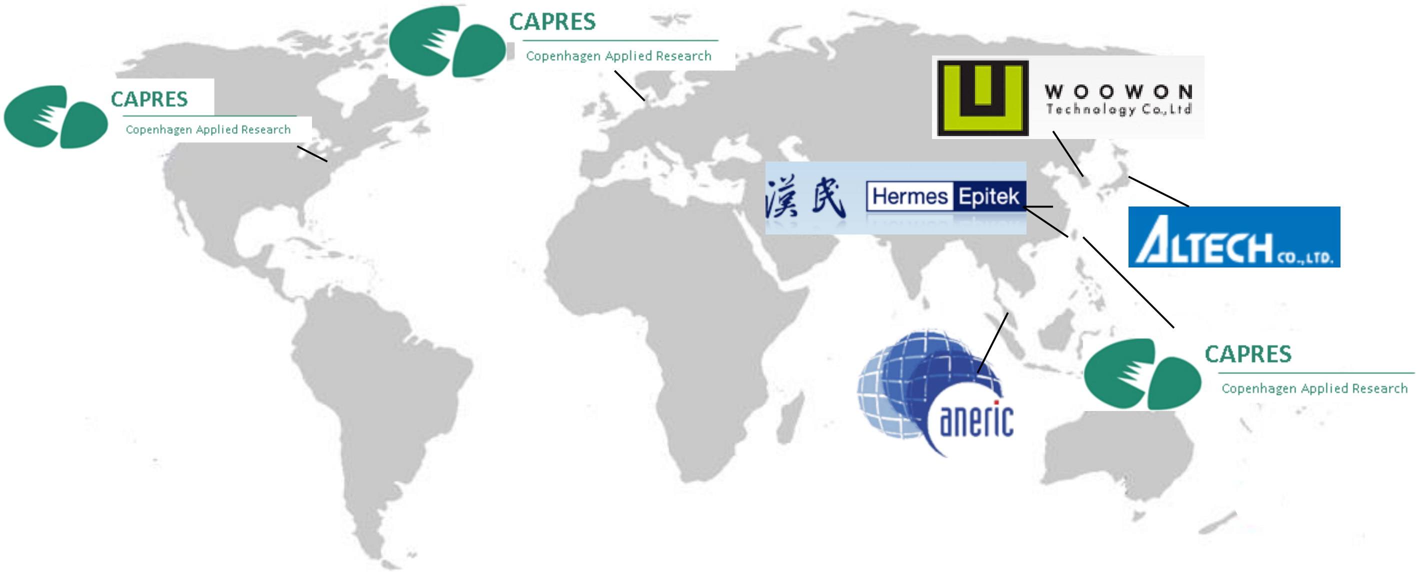
CAPRES introduction

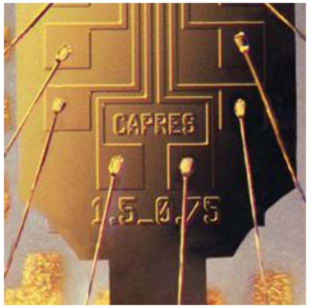
- Founded in 1999 at Technical University of Denmark
- Leader in advanced muti-point-probing technology for R&D and production
- Supplier to semiconductor-, memory- and disk drive industries
- Installed base of approximately 80 tools world wide
- A long range of patents and patent applications
- HQ in Copenhagen Denmark and local offices in USA and Asia



CAPRES introduction

CAPRES' worldwide organization and representation





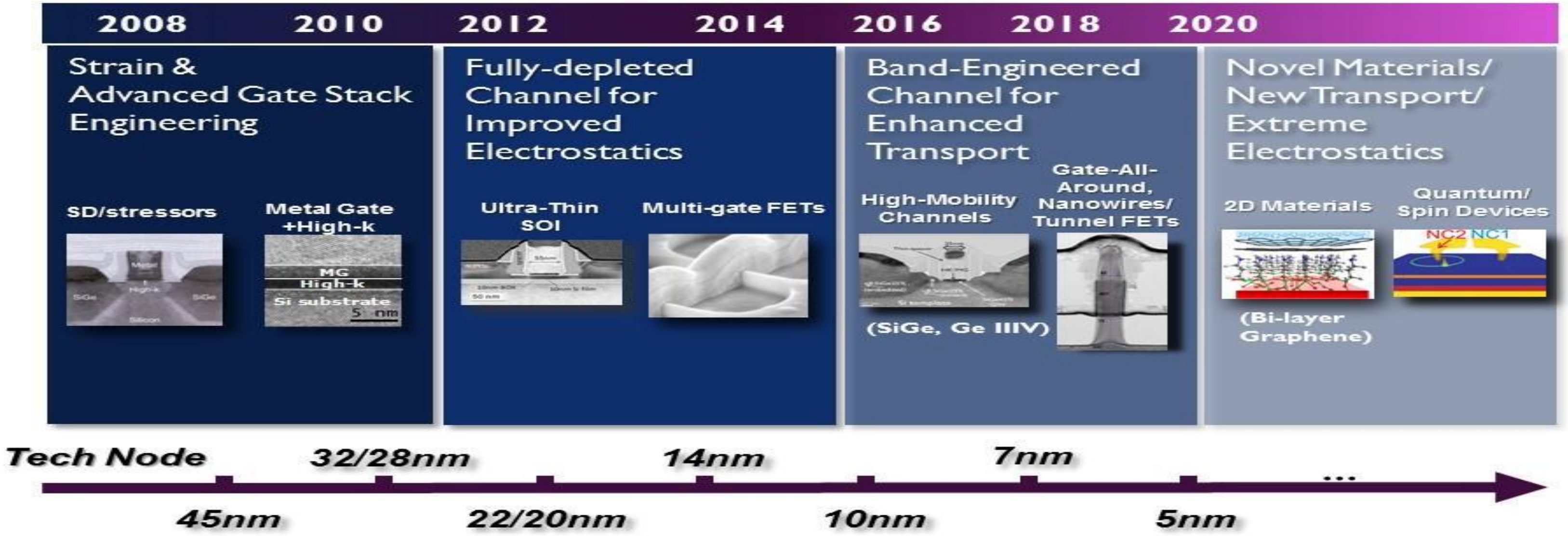
CAPRES introduction

Some of CAPRES' customers

- Anelva
- Applied Materials
- Crocus
- Dainippon Screen
- DSI/Micron
- Everspin
- Fujitsu
- Global Foundries
- Grandis
- Headway
- Hitachi Global Storage
- IBM
- IMEC
- Intel
- LAM
- Leti
- Maxim
- NEC
- Renesas
- Samsung
- Seagate
- Singulus
- TDK
- Toshiba
- TSMC
- Ultratech
- WDC

Technology Road Map 2016

Capres tools are in use at 28nm; 22nm; 16/14nm; 10nm; 7nm and 5nm technology nodes



CAPRES' fully automated tool platform

microRSP-A300
Rs measurements on blanket and patterned wafers

microRSP-A300
Metal Module
(Thick and ultra thin conductive films)

MicroETEST-A300
Direct electrical measurements on 2D and 3D structures

microHALL-A300
Direct Rs, Mobility and Active Carrier Density measurements

CIPTECH-A300
Direct characterization of MRAM (Magnetic Random Access Memory)

CAPRES Confidential

Technology Road Map 2016

Capres external and internal R & D projects 2015 – 2018

EU-projects with IMEC and partners:

Metro4-3D:

”Metrology for the future 3D-technologies”……………………………………........2016 - 2018

3DAM:

”3D Advanced Metrology and materials for advanced devices”………………..2016 - 2018

Industrial Ph.D and Post Doc projects:

Ph.D project: (Concluded):

”Advanced Metrology for Characterization of Magnetic Tunnel Junctions”...2012 – 2015

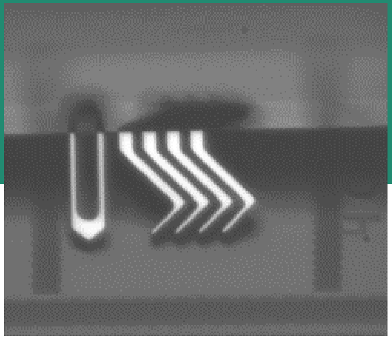
Post Doc project #1:

” Metrology for Improvements of Interconnect Materials”……………………....2014 – 2016

Post Doc project #2:

”Vibration Tolerant micro-electrodes for In-line
charaterization of magnetic tunnel junctions”…………………………................. 2015 – 2017

CAPRES introduction



Capres' Tools and Technology enables:

- Measure with a high spatial resolution (Spot size less than 24um using the 8um 4PP) on blanket and patterned wafers

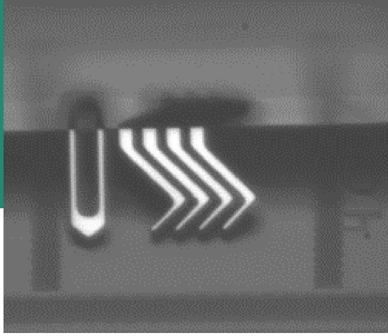
- Can measure with <100nm step size between points all the way to the bevel of the wafer (Zero edge exclusion)

- Can be upgraded to Ciptech (MTJ) and microETEST measurements

- If Resistivity is a known factor the thickness can be extracted from the Rs measurements

- If the Thickness is a known factor the resistivity can be extracted from the Rs measurements

Capres' Tools and Technology enables



- Direct electrical measurements (Based on the well-known
- 4pp technique…..Ohms law)

- Measure Rs, Mobility, Active Carrier Density directly.

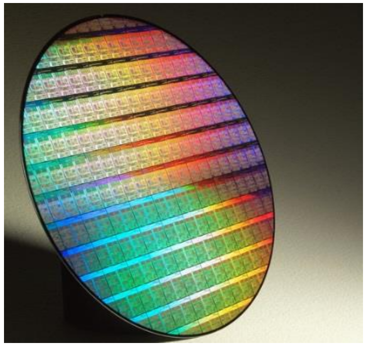
- Can measure Rs, Mobility and Active carrier density on activated Semiconductor samples plus all (most) other conducting materials (metals, Nitrides, Silicides etc.) within **10mΩ/sq – 3MΩ/sq**

- Measure mobility within a range of <10 – 10.000 cmsq/Vs covering all materials used in the semiconductor industry

- Can measure Rs directly on ultrathin (~10A) to thick conducting material (CU tested up to 1100nm (1.1um)

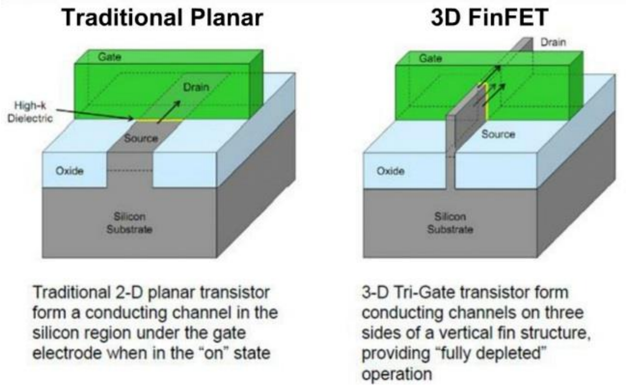
Measure with a high spatial resolution (Spot size <24um on blanket and patterned wafers

CAPRES introduction



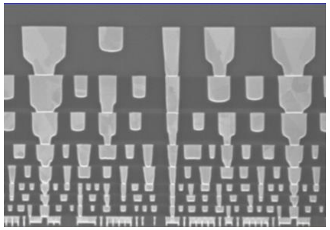
Capres' tools and probing technology for:

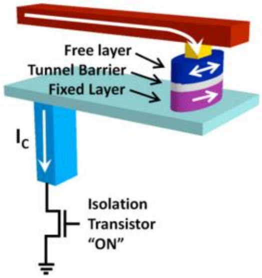
- Direct electrical measurement in FEOL
- Optimization of 2D and 3D transistor formation process and process tools
- Optimization of Barrier- and Interconnect material deposition process and process tools
- Early direct electrical test on small specific 2D and 3D MicroETEST structures
- Direct characterization of Magnetic Tunnel Junctions used in Magnetic Random Access Memory, MRAM



Traditional 2-D planar transistor form a conducting channel in the silicon region under the gate electrode when in the "on" state

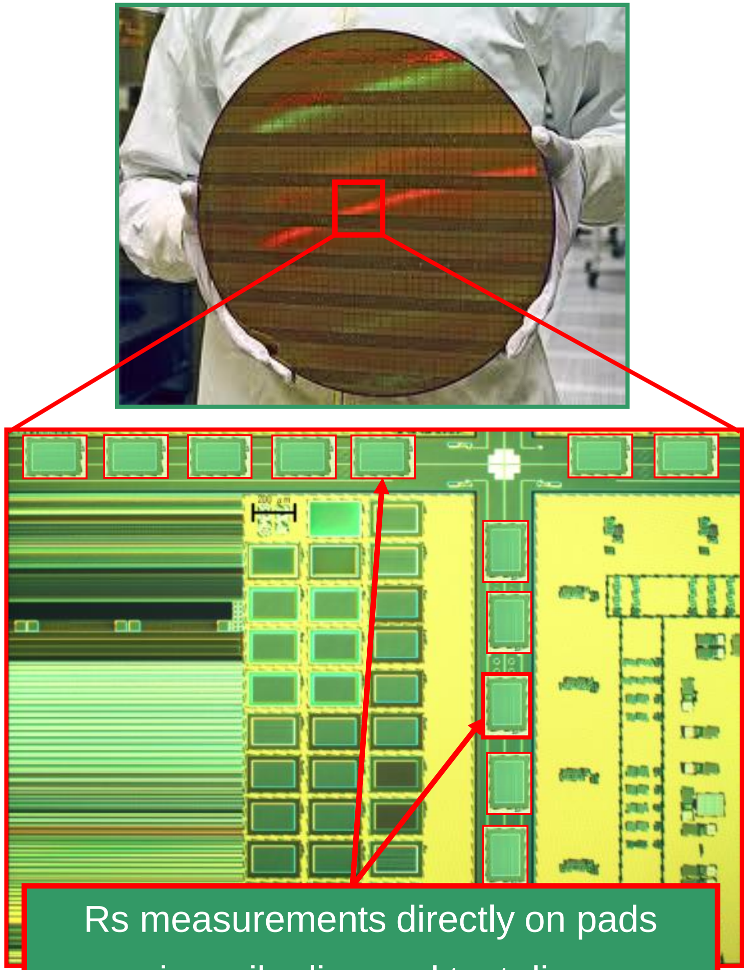
3-D Tri-Gate transistor form conducting channels on three sides of a vertical fin structure, providing "fully depleted" operation



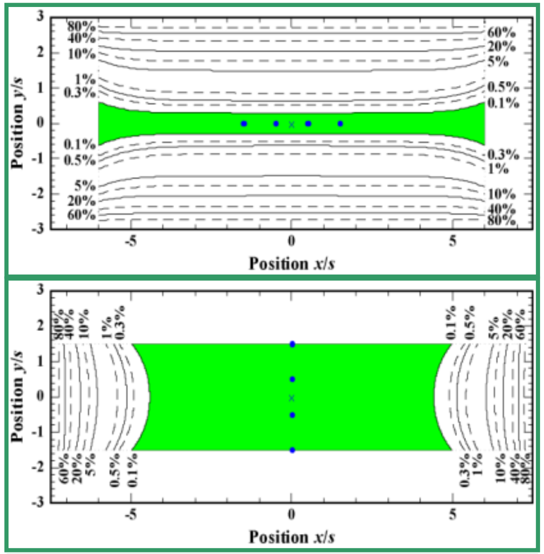


2009 – Measurement on Patterned Wafers

The MicroRSP is the first tool that enables accurate, direct Rs measurements on patterned wafers

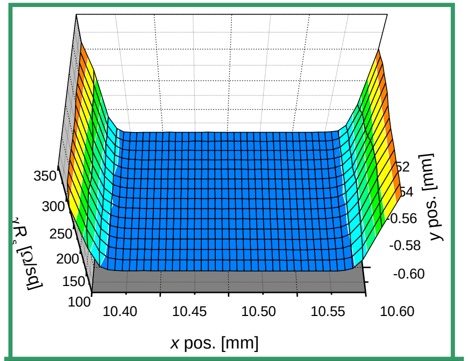


Rs measurements directly on pads
in scribe line and test die area



Effect of probe orientation

Rs measurement on 70 x 70um test pad



Full Rs area scan on test pad

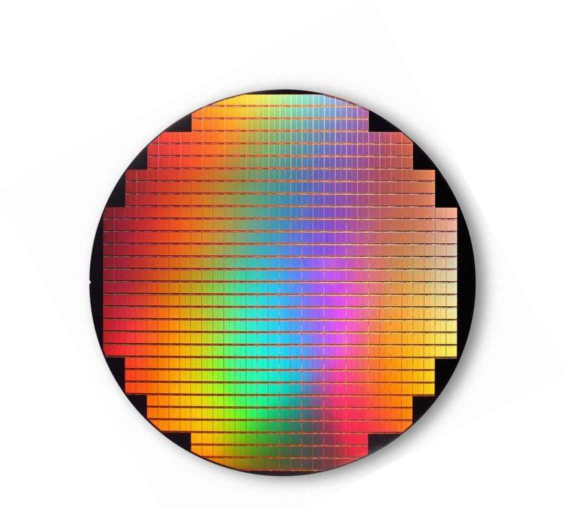
Inline Process Control applications using microRSP-A300 or MicroHALL-A300

•Inline monitor	•Application step	
Rs, Mobility & Active Carrier Density	•LDD IMPLANT & ANNEALING	1. Process control for LDD & Halo implantation 2. U% optimization annealing process (RTP, Laser, Flash)
Rs, Mobility & Active Carrier Density	•SiGe and SiP EPI PROCESS	1. Rs, Mobility and Carrier Density monitor 2. Strain relaxation monitor
Rs, Mobility & Active Carrier Density	•S/D IMPLANT & ANNEALING	1. Process control for Source& Drain implantation 2. U% optimization for annealing process (RTP, Laser, Flash)
Rs	•NiSi or TiSi FORMATION	1. Thickness and annealing control
Rs	•Gate material (Al or W), Cu interconnetion	1. Polish time definition 2. U% check across wafer

Optimization of:
RTP systems for spike and soak annealing.

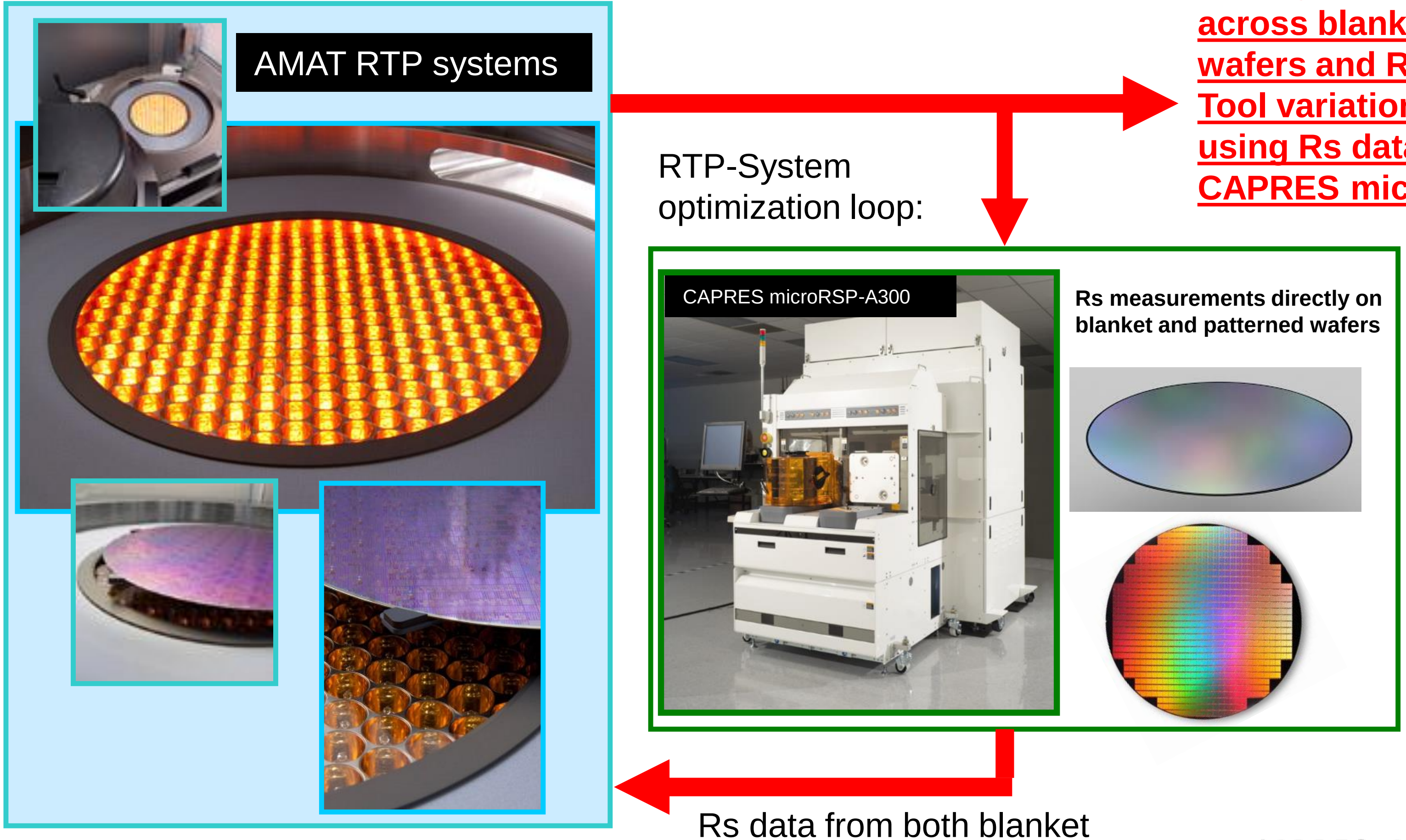
CAPRES Tier 1 customer:

- ”Using Rs measurement on patterned wafers (product wafers) as feedback, enables a >35% improvement of the RTP-annealer across wafer uniformity”!
- ”The CAPRES microRSP-A300 can be used for direct Rs measurements on product wafers enabeling a faster and closer control of the RTP-annealer across wafer uniformity”!
- ”Enabels closer RTP proces control and better RTP Tool-to-Tool matchning”!
- ”microRSP-A300 NOW used in RTP APC (Advanced Process Control) loop”
- ”Yield up 2-3%”



Optimization of:
The Applied Vantage Vulcan RTP, Vantage RadiancePlus and other RTP systems for spike and soak annealing.

APC (Advanced Process Control)



AMAT RTP systems

RTP-System optimization loop:

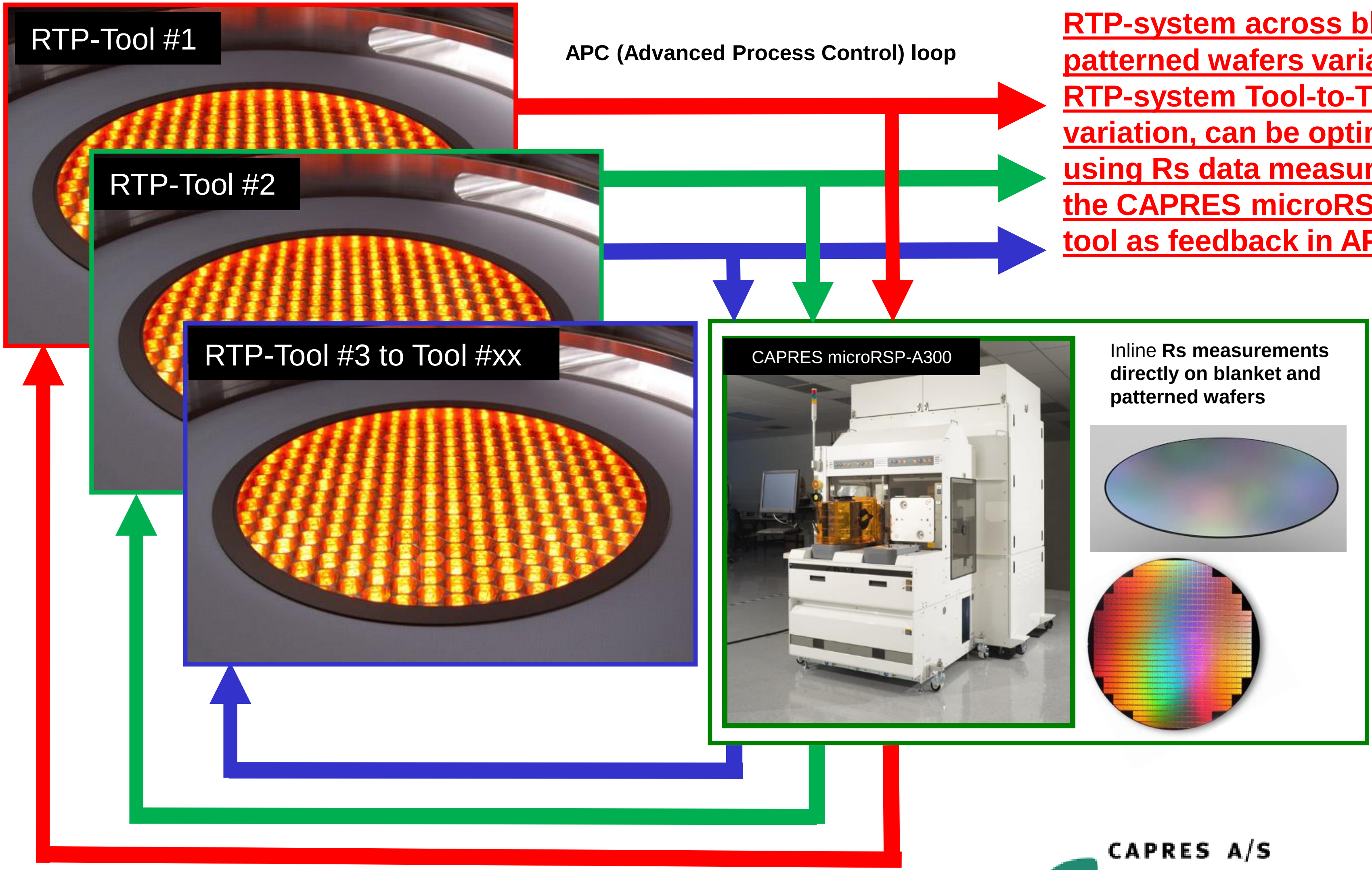
CAPRES microRSP-A300

Rs measurements directly on blanket and patterned wafers

Rs data from both blanket and patterned wafers

RTP-system Temperature Profile across blanket- and patterned wafers and RTP-system Tool-to-Tool variation, can be optimized using Rs data measured by the CAPRES microRSP-A300 tool.

Optimization of:
RTP systems for spike and soak annealing.



RTP-Tool #1

RTP-Tool #2

RTP-Tool #3 to Tool #xx

APC (Advanced Process Control) loop

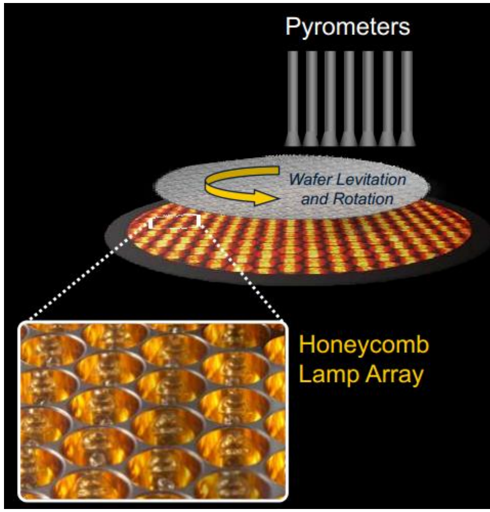
CAPRES microRSP-A300

Inline **Rs measurements directly on blanket and patterned wafers**

<u>RTP-system across blanket- and patterned wafers variation and RTP-system Tool-to-Tool variation, can be optimized using Rs data measured using the CAPRES microRSP-A300 tool as feedback in APC loop</u>

CAPRES A/S
COPENHAGEN APPLIED RESEARCH

Optimization of:
RTP systems for spike and soak annealing.



- RTP system key characteristics
  - 392 lamps in honeycomb array with 18 zones
  - 7 pyrometers & 1 emissions meter
  - Wafer rotation, 240 RPM (AMAT BKM)
- Tuning offset table of 7 pyrometers for U% control
  - Offline 121 pts Rs monitor on blanket wafer per 48 hours
  - Use “Opitune” APP to calculate offset value
- Breakthrough by microRSP-A300 tool
  - Thermal U% is different between pattern and blanket wafer
  - Thermal U% is different between products
  - Inline monitor on small pad is necessary to optimize the thermal process corresponding to every specified product

Can be optimized using the microRSP-A300 tool

Laser Annealing Tool optimization

For sub-45 node technology the conventional rapid thermal processing is not adequate due to dopant diffusion and limited electrical activation. Flash annealing and laser annealing are two prime candidates for possible replacement of classical annealing methods, e.g., spike annealing.

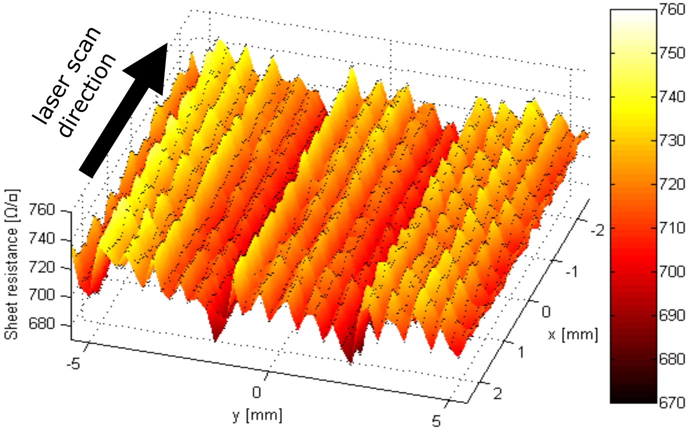
Laser annealing is a metastable process lasting few msec to nanosec in which dopants can be frozen in the lattice sites well above the solid solubility.

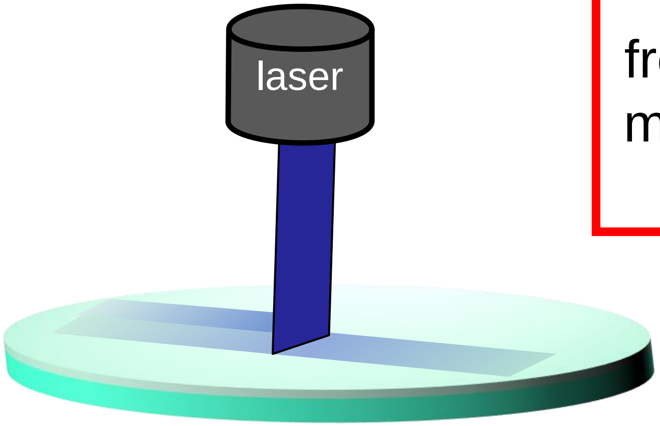
For volume manufacturing process, uniformity and repeatability are the key concerns.

For laser beam processing, one will face macro- and micro-scale Rs uniformity issues and substantial Rs variation close to wafer edge due to:

1. **Over time drift in laser tool setup**
2. **Overlapping or “stitching” of the laser beam during laser scans**
3. **Laser beam density and laser power fluctuation**
4. **Rs variation close to wafer edge due to thermal gradient**

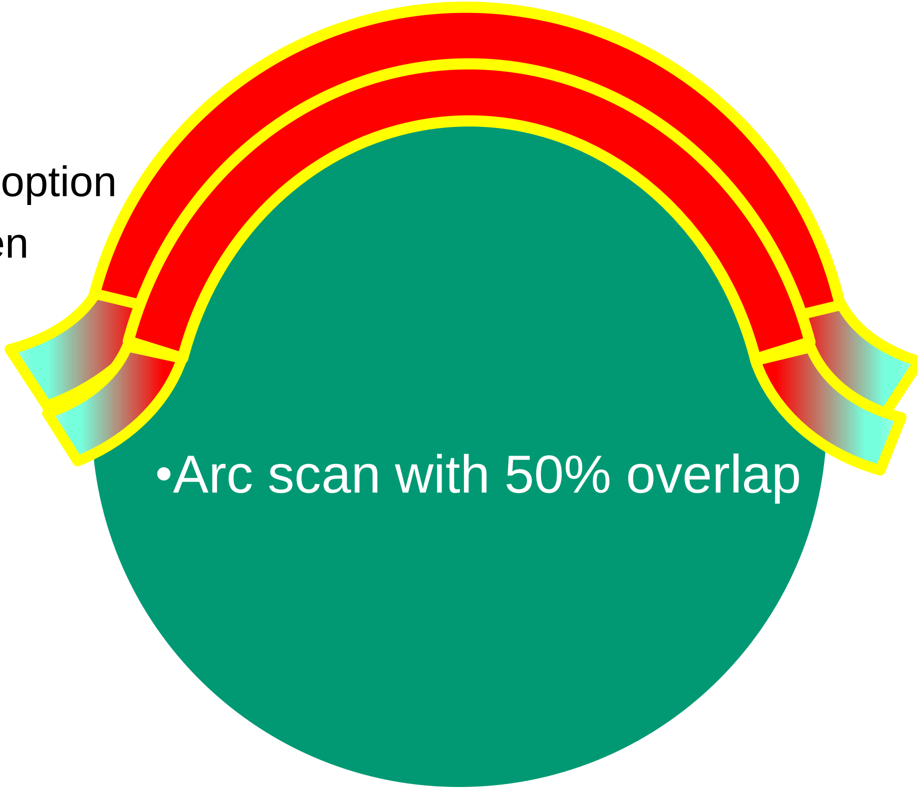
Can be controlled and optimized using Rs feedback from the Capres microRSP-A300 tool





Optimization of annealing tool – CO2 Laser

- CO2 laser system key characteristics
  - ~7mm beam length
  - Linear scan or Arc scan mode by customer option
  - 50% entrance power to prevent wafer broken
  - 0% or 50% overlap by customer option
  - Detect temperature by 3 color sensor in 10000 Hz sampling rate
- Tuning thermal U% is not trivial
  - Off-line 121 pts Rs monitor by blanket wafers
  - Beam shape tuning by optical method
  - Skirt position optimization
- Breakthrough by microRSP-A300 tool with high spatial resolution capability
  - Stitching effect optimization
  - Beam shape tuning by Rs measurement
  - Wafer placement centering



Can be optimized using the microRSP-A300 tool

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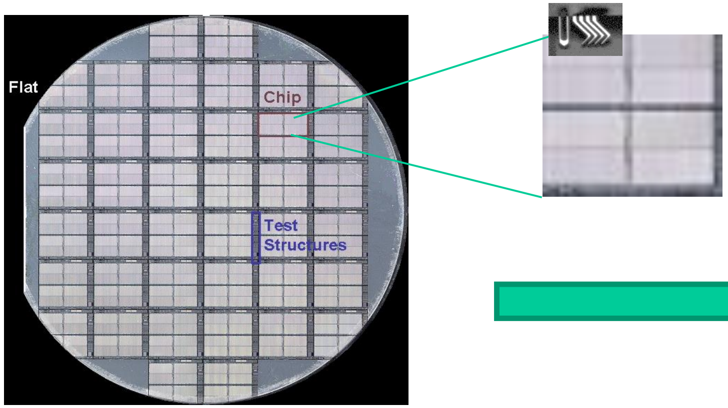
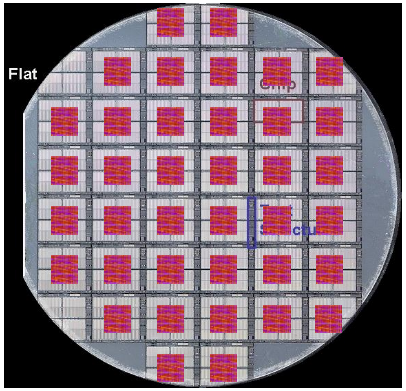
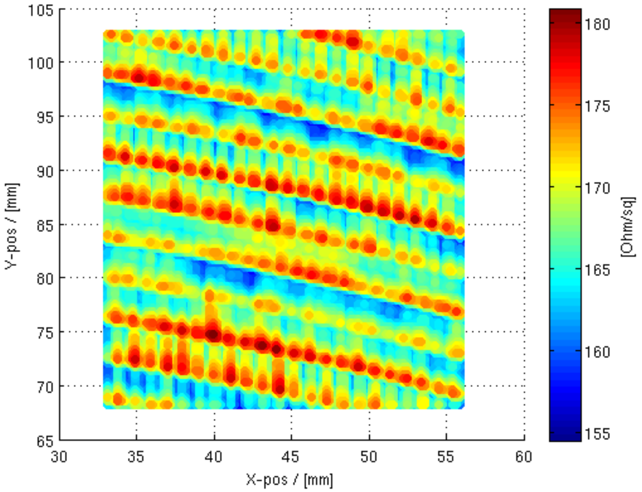
Optimization of annealing tool – CO2 Laser

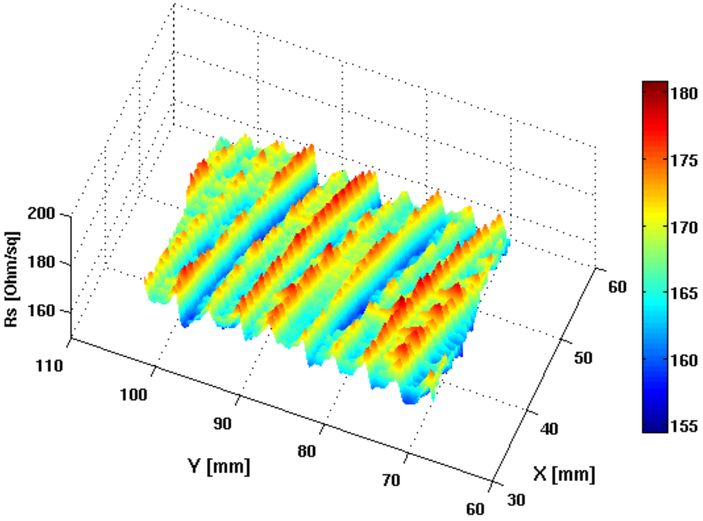


Dense Rs scan in Die-area. Used for LSA tool optimization





Rs variation in Die-area. Variation due to LSA tool stitching and/or LSA tool drift



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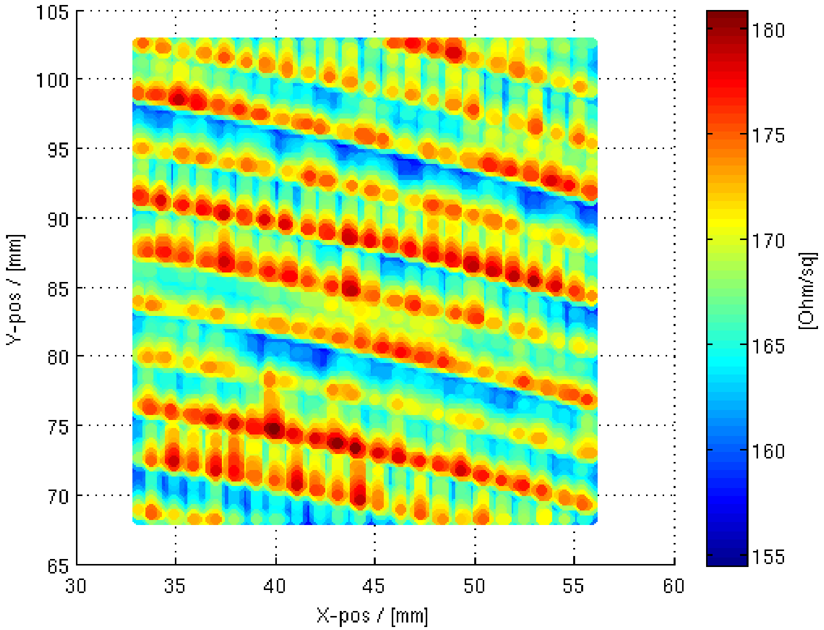
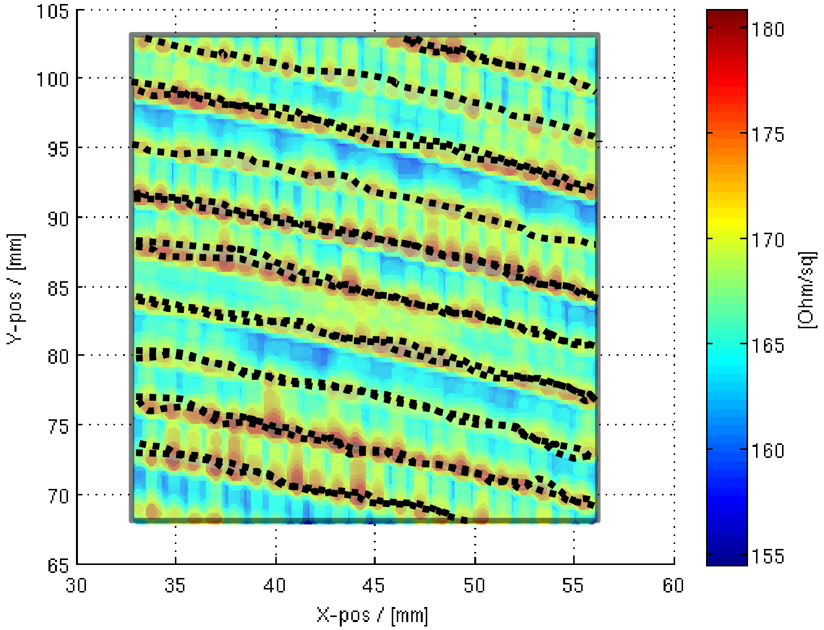
Optimization of annealing tool – CO2 Laser



Rs variation in Die-area due to LSA tool stitching and/or LSA tool drift

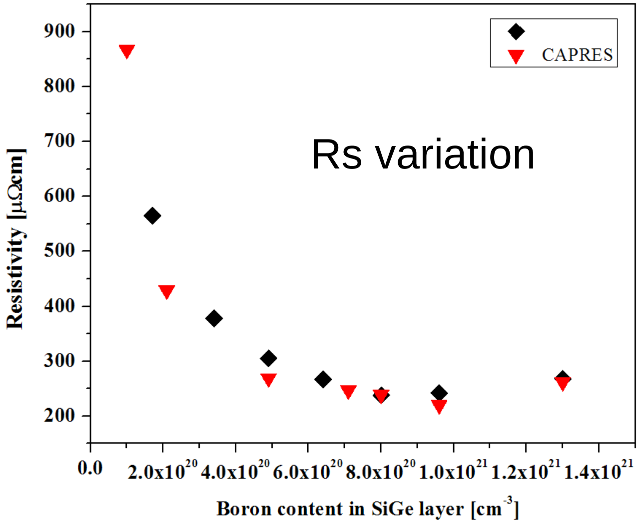


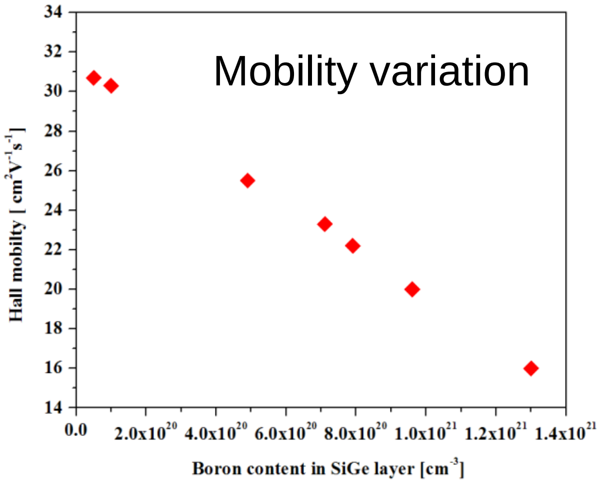
1:1 correlation between Bit-error and local Rs-variation in actual device!

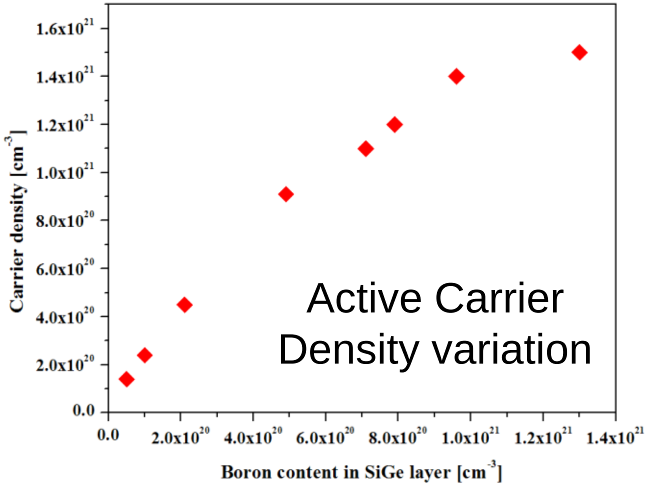
Can be optimized using the Capres microRSP-A300 in LSA-tool process control loop

EPI system optimization using feedback from Capres microHALL-A300

Direct measurement of Sheet Resistance, Mobility and Active Carrier Density on Boron and Carbon Co-doped SiGe





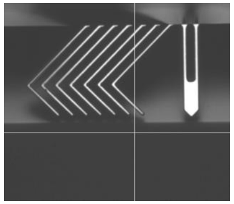


- Enables fast and accurate EPI process feedback
- Enables fast and accurate EPI process optimization

microHALL Module

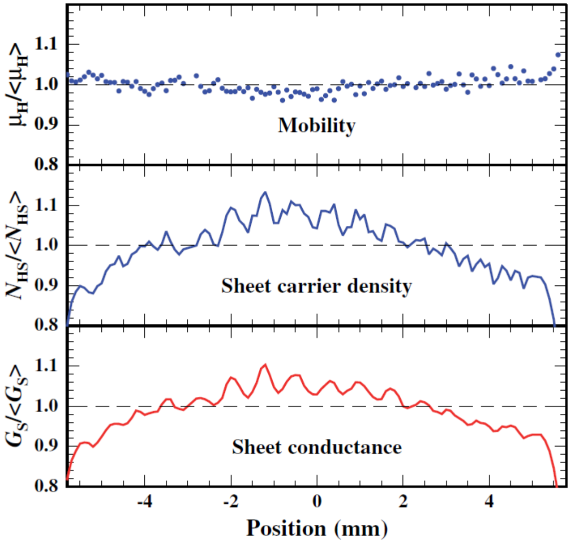
With the microHALL module for microRSP-A300 CAPRES has set a whole new standard for direct mobility and active carrier density menasurement.

“The module is capable of performing fully automated and direct electrical measurement of Hall mobility and active carrier density on product wafers and cleaved blanket wafers by single touchdown using the microscopic 7-point-probe”



m7PP for single
touchdown measurement

- Rs, Mobility and Active Carrier Density measurements
- In use at Junction formation process and process optimization
- In use at EPI process and process tool optimization
- In use for III/V process and process optimization
- In use at R&D in new interconnect materials



Line scan along the width of a laser beam

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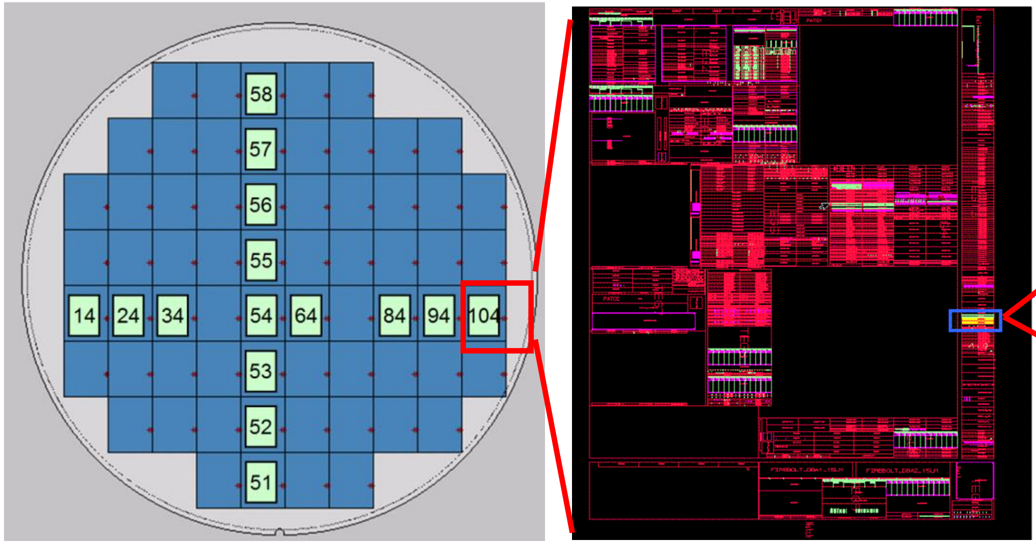
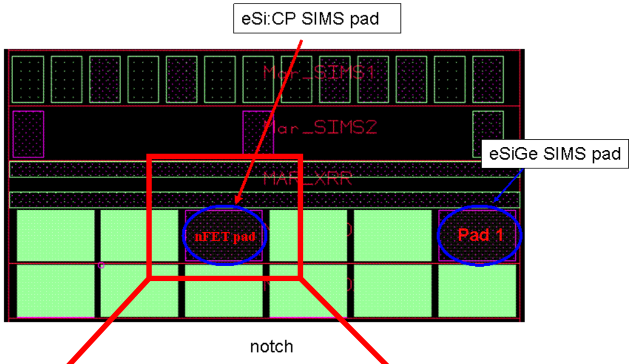
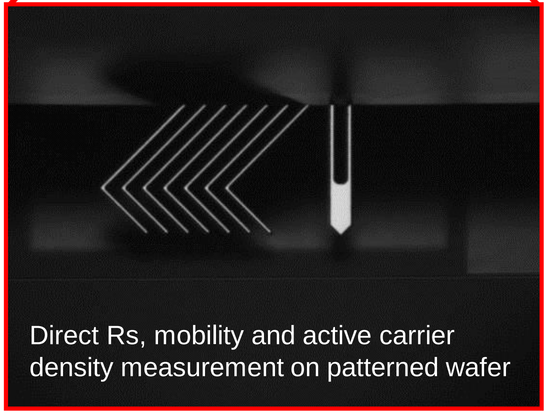
Applied Centura EPI system optimization using feedback from Capres microHALL-A300



SIMS pads



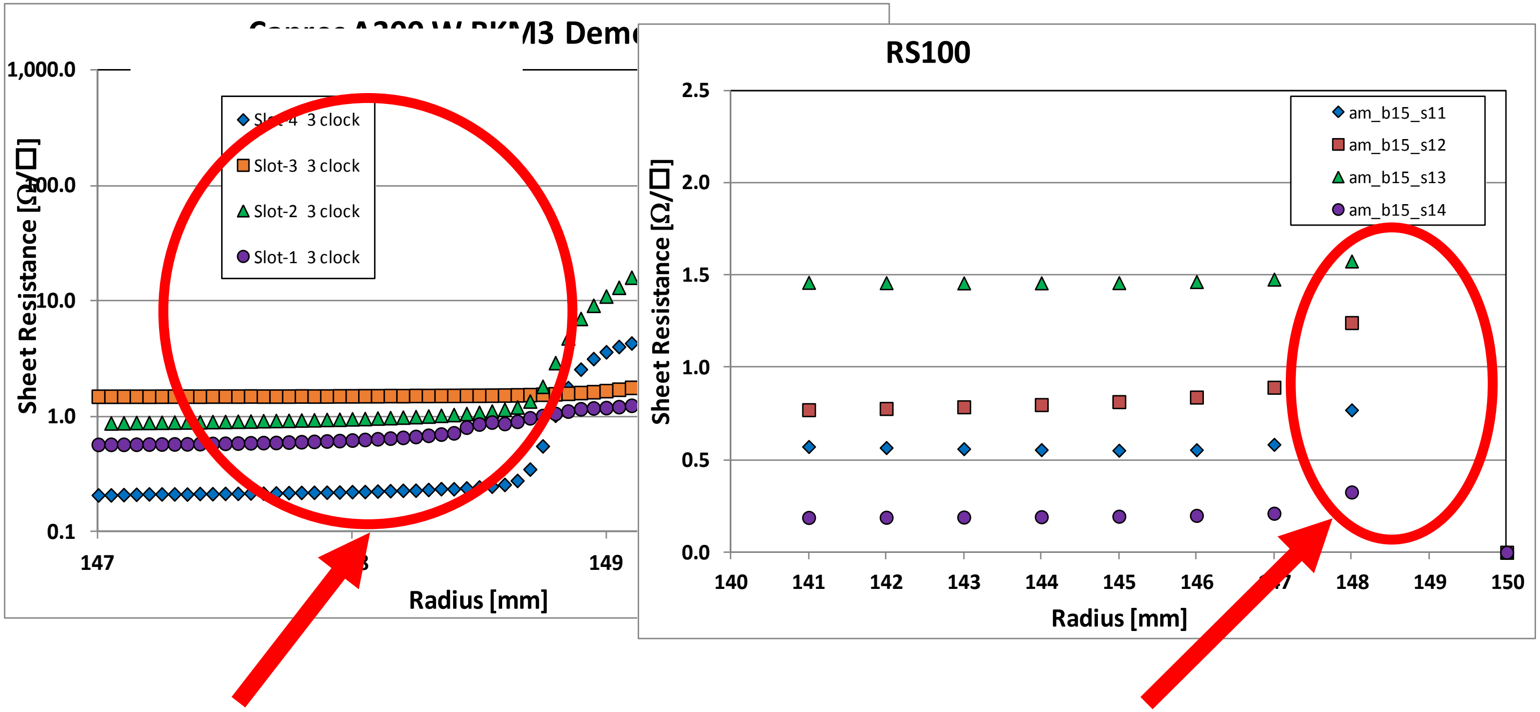


Direct Rs, mobility and active carrier density measurement on patterned wafer

Direct Rs, Mobility and Active Carrier Density measurements on patterned wafers

- Enables direct extraction of the across wafer Rs, Mobility and Active Carrier Density variation and in-pad inhomogenities
- Enables fast and accurate feedback for across-wafer process control, product optimization and production ramping

CVD, ALD & ECD
Thin film deposition, control and optimization



Detailed Rs information near edge exclusion zone using Capres microRSP-A300

No Rs information using standard 4PP.
RS100/200 lacks information near edge exclusion.

Fully Automated Tool Platform & Upgrades

Innovative and cost-effective metrology solutions by advanced modular design

CAPRES microHALL and CIPTech modules can be delivered as upgrades to microRSP-M300 tools or as stand alone tools including microRSP-M300 functionality.

microRSP-M300
Direct sheet resistance measurements on product and blanket wafers

Base tool model: microRSP-M300

←

microHALL Module
Hall mobility and active carrier density of scribe line pads

←

CIPTech Module
Electrical characterization of MTJs (MRAM/STT-RAM)

Upgrade modules for microRSP-M300

CIPTech-M200 is also available for CIPTech measurement of MRAM/STT-RAM (for 200mm wafers and smaller wafers or coupons)

Fully Automated Tool Platform & Upgrades

Base tool model:
microRSP-A300

Current upgrade modules for
microRSP-A300

microRSP-A300
Direct sheet resistance measurements on product and blanket wafers

Metal Module
Sheet resistance of thick and ultra thin conductive films

microHALL Module
Hall mobility and Hall sheet carrier density of scribe line pads

microETEST Module
Resistance, Hall mobility and –carrier density of submicron 2D/3D structures

CIPTech Module
Electrical characterization of MTJs (MRAM/STT-RAM)

Metal Module

User benefits:

<u>Extended</u> Rs measurement range and <u>improved</u> Rs measurement capability on ultra thin and thick conductive films

NEW: Rs measurement range 10mΩ/sq – 3MΩ/sq (previous 20mΩ/sq – 0.5MΩ/sq)

Metal Module solution description

- **Thin conductive films:** The metal module includes an electronic module with improved control of the current used for measurement on thin metal films, thus preventing damage to the film that would otherwise have made the sample unmeasurable.

- **Thick conductive films:** The Metal Module includes measurement electronics with an extended range for the measurement current, thus providing a larger pickup signal when measuring on samples with a very low Rs. This translate to an improved repeatability for the measured Rs on thick metal films.

Metal Module

Enhanced Measurement Range:
The Metal Module enhances the measurement range of the fully automated tool platform in both the lower and the higher resistance range

Enhanced Measurement Range	
microRSP-A300	20 mΩ□ to 0.5 MΩ□
with Metal Module	10 mΩ□ to 3 MΩ□

Thin conductive films: The Metal Module allows CAPRES tools to measure very thin conductive films without mechanically or electrically damaging the film.

microRSP-A300 vs microRSP-A300 with Metal Module			
Tool configuration	Sample	Av. RS (Ω□)	Rel. Std. dev. RS (Ω□)
microRSP-A300	Ta (2 nm)	2174	0.3%
Metal Module	Ta (2 nm)	2321	0.06%

Thick conductive films:
The Metal Module allows CAPERS tools to measure thick conductive films with a higher measurement current and improved standard deviation.

microRSP-A300 vs microRSP-A300 with Metal Module			
Tool configuration	Sample	Av. RS (Ω□)	Rel. Std. dev. RS (Ω□)
microRSP-A300	Cu (1100 nm)	0.0167	0.23%
Metal Module	Cu (1100 nm)	0.0165	0.20%

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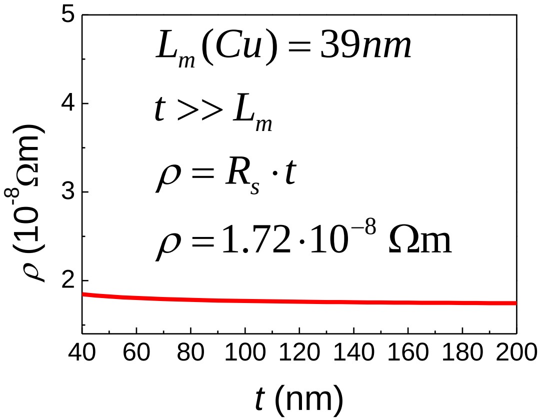
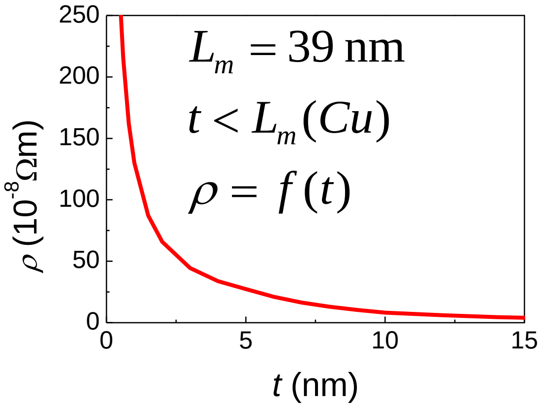
Metal Module

Thin conductive film

Conventional resistivity theory: In the regime where the thickness is much larger than the electron mean free path (Lm) the resistivity will be constant

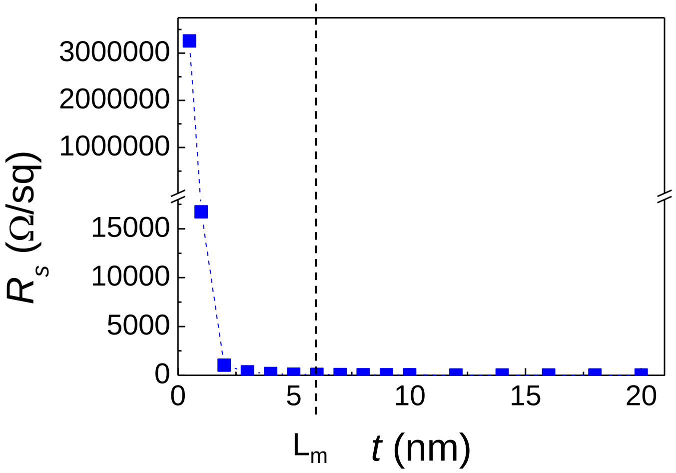


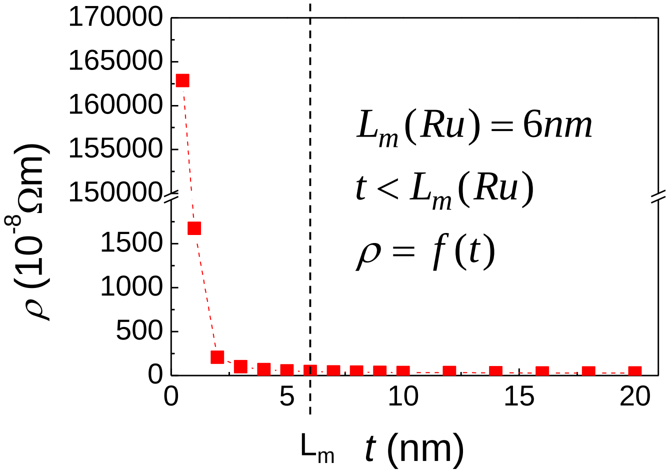
Fuchs-Sondheimer model: In the regime where the thickness is smaller than Lm the resistivity will be function of thickness.



Experimental data (Ru): Ru samples with varying thickness measured by microRSP-A300 with Metal Module.

The experimental data is consistent with Fuchs-Sondheimer's model.





CAPRES A/S
COPENHAGEN APPLIED RESEARCH

Metal Module

Thin conductive films: The Metal Module allows CAPRES tools to measure very thin conductive films without mechanically or electrically damaging the film.

Thin Film	Measured by microRSP-A300	Measured with Metal Module	Improvement in ability to measure thinner film
TiN	> 20 Å	15 Å	> 25 %
TaN	> 40 Å	40 Å	-
W	> 30 Å	10 Å	> 67 %
Ru	> 10 Å	5 Å	> 50 %
Ta	20 Å	10 Å	> 50 %
Wsi	> 30 Å	10 Å	> 67 %
Al	75 Å	50 Å	> 33 %
Ti	> 30 Å	20 Å	33 %
Pt		10 Å	
WN		15 Å	
Ta		20 Å	

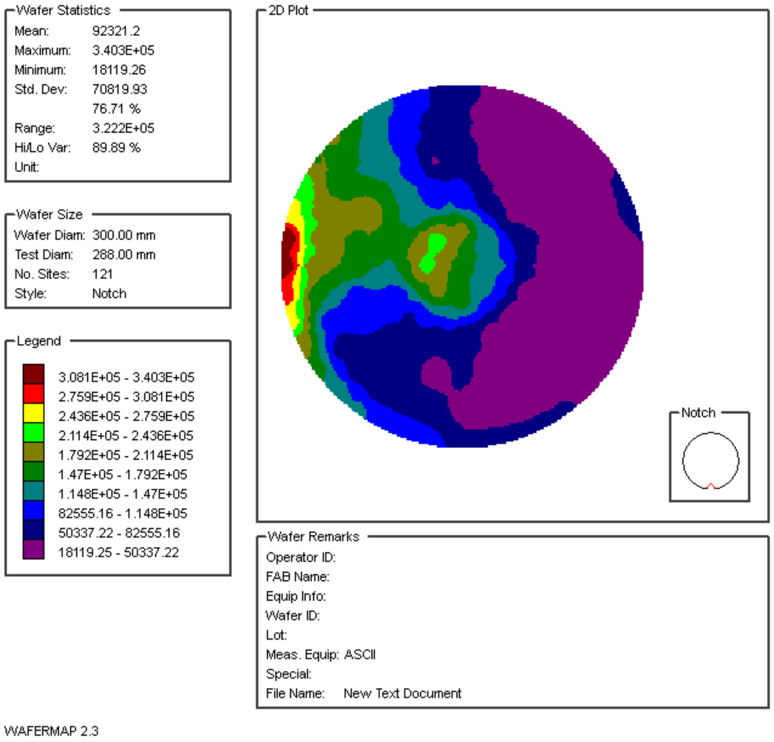
Metal Module

Thin conductive film

Experimental Data: TiN 15Å (ALD)

For the TiN 15Å sample wafer below map and line scan show a large variation on R_S value. This indicates a large in homogeneity in the film thickness.

121 point wafer map



Wafer Statistics
Mean: 92321.2
Maximum: 3.403E+05
Minimum: 18119.26
Std. Dev: 70819.93
76.71 %
Range: 3.222E+05
Hi/Lo Var: 89.89 %
Unit:

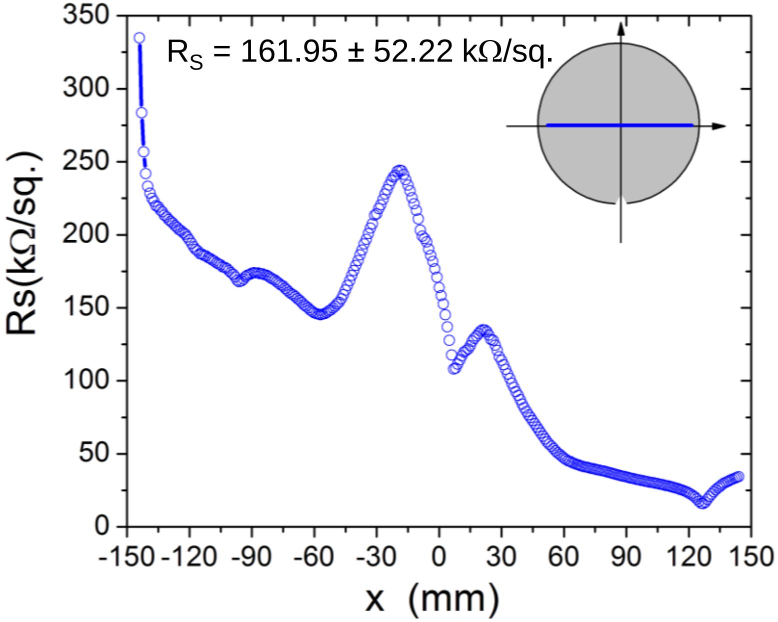
Wafer Size
Wafer Diam: 300.00 mm
Test Diam: 288.00 mm
No. Sites: 121
Style: Notch

Legend
🟫 3.081E+05 - 3.403E+05
🟥 2.759E+05 - 3.081E+05
🟨 2.436E+05 - 2.759E+05
🟩 2.114E+05 - 2.436E+05
🟫 1.792E+05 - 2.114E+05
🟩 1.47E+05 - 1.792E+05
🟦 1.148E+05 - 1.47E+05
🟦 82555.16 - 1.148E+05
🟦 50337.22 - 82555.16
🟪 18119.25 - 50337.22

Wafer Remarks
Operator ID:
FAB Name:
Equip Info:
Wafer ID:
Lot:
Meas. Equip: ASCII
Special:
File Name: New Text Document

WAFERMAP 2.3

R_S line scan along x direction with 1mm steps



R_S = 161.95 ± 52.22 kΩ/sq.

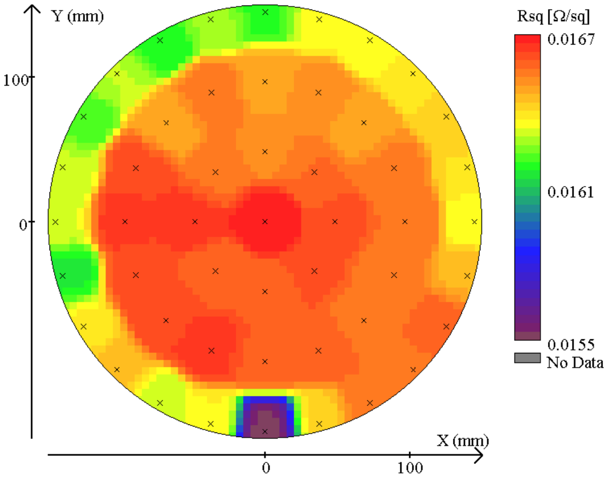
Metal Module

Thick conductive film

49 Point Polar Wafer Map:

R_s measurements performed as a 49 point polar wafer map of the 1100nm Thick Cu wafer. The thickness, *t*, is calculated as follows: $t = \frac{\rho_{Cu}}{R_s}$ $\rho_{Cu} = 1.71\cdot10^{-8}\ \Omega\text{m}$

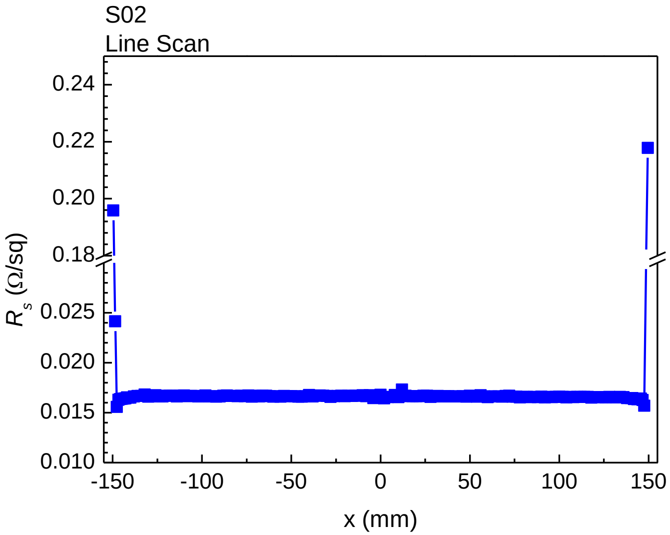
Wafer type	Thickness (nm)	Av. R_S (Ω/sq)	Std. dev. R_S (Ω/sq)	Relative std. dev.	Thickness calculated from R_S: t (nm)
Cu	1100	0.0164	0.0002	1.2%	1041



161 Point Line Scan:

R_s measurements performed in a 161 point line scan. The step size is 2 mm in the central area of the wafer and 0.96 mm until 10 mm from the edge:

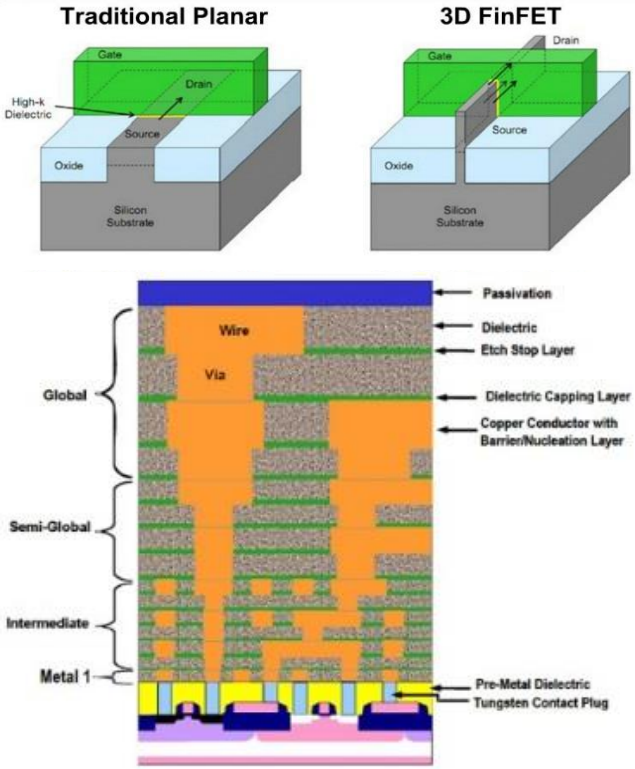
Wafer type	Thickness (nm)	Average R_S (Ω/sq)	Standard dev. R_S (Ω/sq)
Cu	1100	0.0192	0.0213



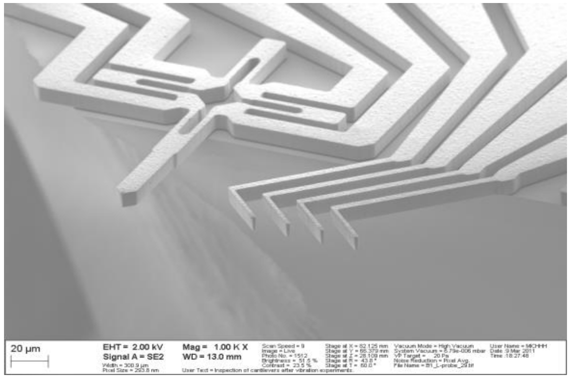
microETEST Module

Fully automatic microETEST-A300 tool for direct electrical measurements on small process control test structures early in FEOL

- Inline measurement of planar and 3D structures
- Measure E-test parameters in FEOL before metal
- Reduce size of Test-key/Test-macro
- In use at tier 1 semiconductor fab
- CV and Parametric measurements possible



Direct Planar, 3D FinFet and interconnect process monitoring

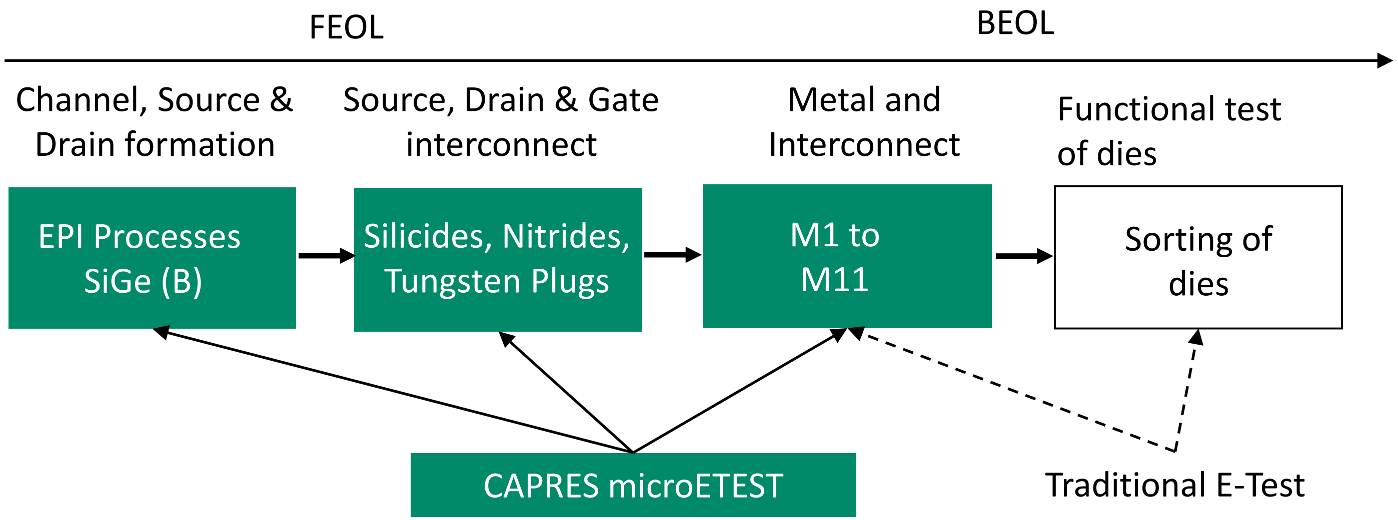


CAPRES A/S
COPENHAGEN APPLIED RESEARCH

microETEST Module

Advantages

- Early electrical test of critical process parameter
- Reduce test area and/or increase number of test structures
- Measure in-line on product wafers



Comparing microETEST and traditional E-Test

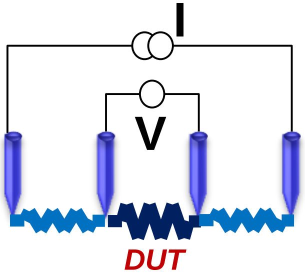
microETEST Module

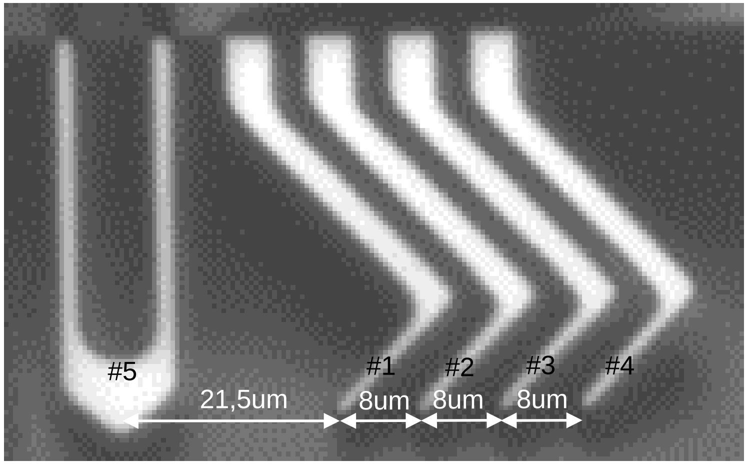
The microETEST module requires a Test-Macro designed for Capres microprobe

Using the 4 pin probe for resistance measurement

Current (I) is applied between the outer pins and the voltage drop (V) is measured between the inner pins – in between which the DUT is located

$$R_{DUT} = \frac{V}{I}$$





Test-Macro designed for Capres microprobe

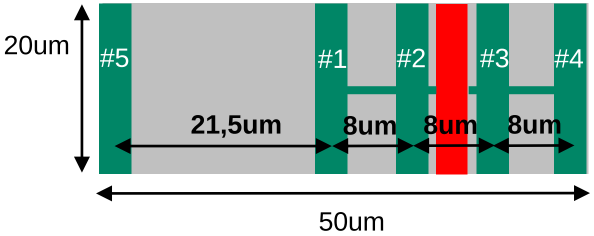
The test macro consists of five contacts, one for each probe pin, and a device under test

Contact #1 is electrically connected to contact #2

Contact #3 is electrically connected to contact #4.

Contact #5 if for surface detection.

The device under test (DUT) is placed in between contact #2 and #3 and is electrically connected to contact #2 and #3



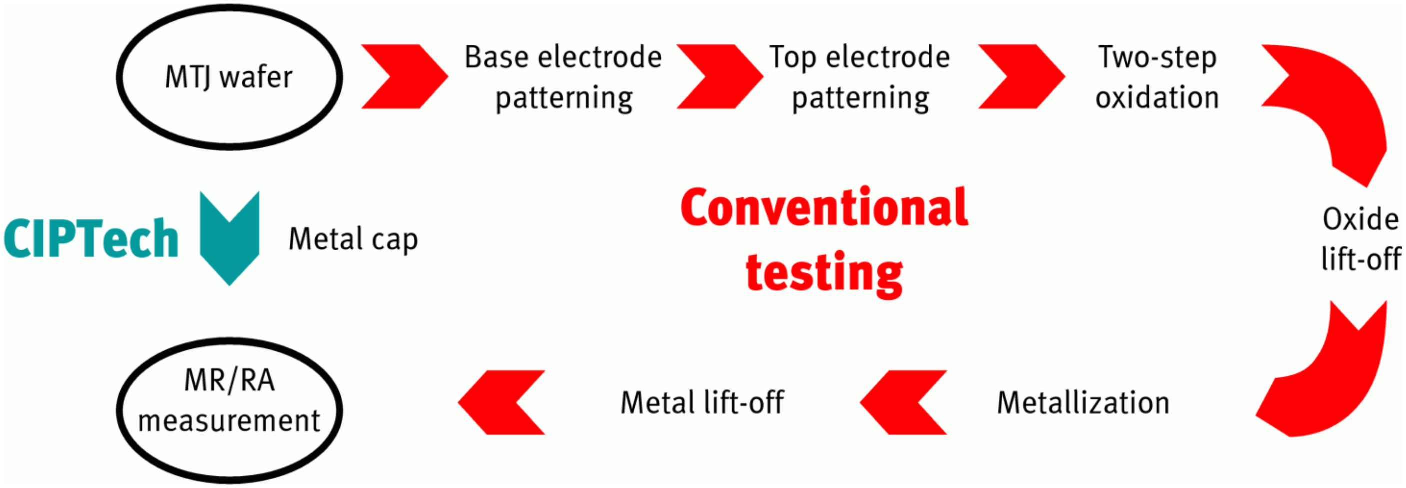
Contact for probe pin: 🟩

Device under test (DUT): 🟥

CIPTech Module

The CIPTech-A300 from CAPRES is the industry’s fast track to fully automated characterization of MTJs in STT-RAM/MRAM

- Accurate characterization of magnetic tunnel junctions (MTJs)
- Substantial reduction in process confirmation cycle (from days to minutes)



MTJ wafer

Base electrode patterning

Top electrode patterning

Two-step oxidation

Oxide lift-off

Metallization

Metal lift-off

MR/RA measurement

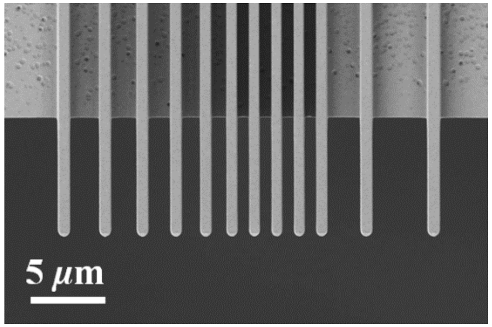
Metal cap

CIPTech

Conventional testing

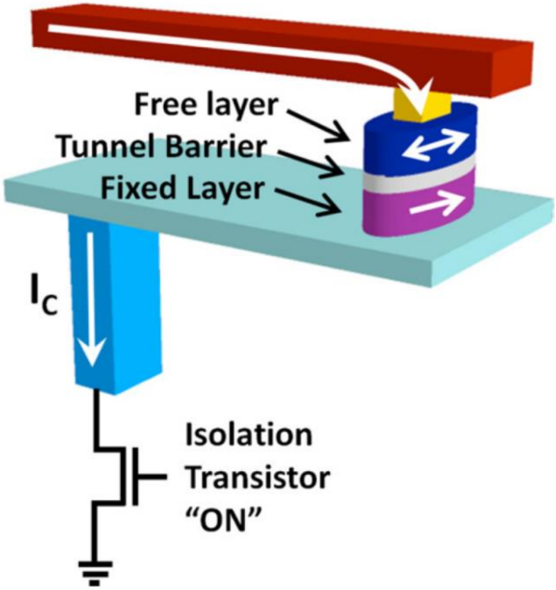
CIPTech Module

Available as a dedicated fully automated tool (CIPTech-A300) or as a CIPTech upgrade to an existing microRSP-A300 tool



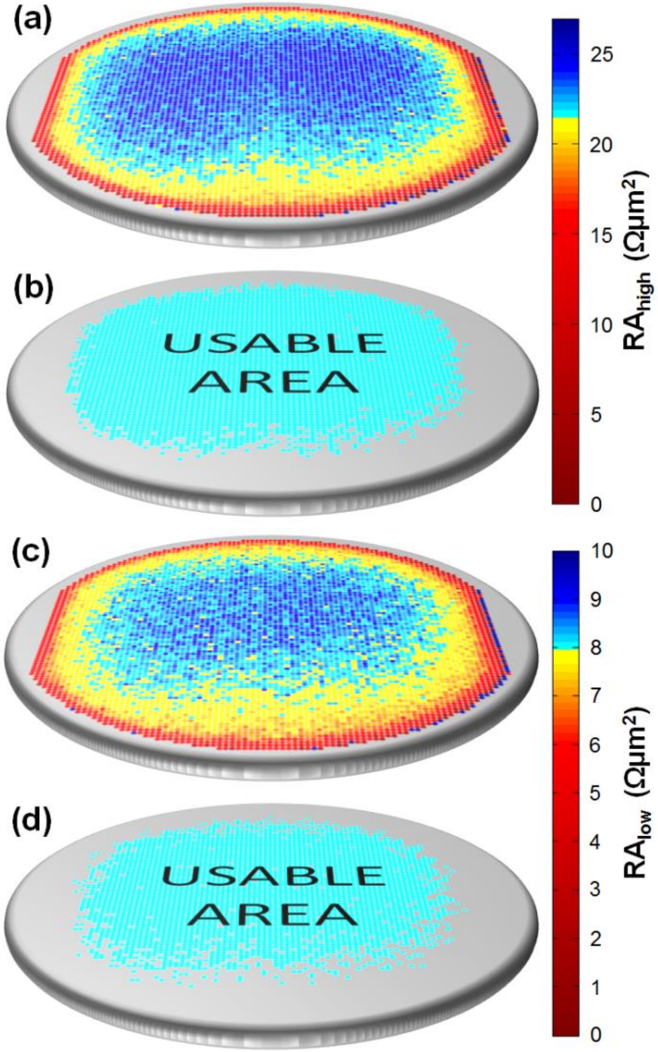
Advantages:

- Direct extraction of Ra and MR on MTJ wafers
- Measurements on 300mm blanket and patterned wafers
- Improved data fitting model
- Automatic probe exchange and build in pattern recognition

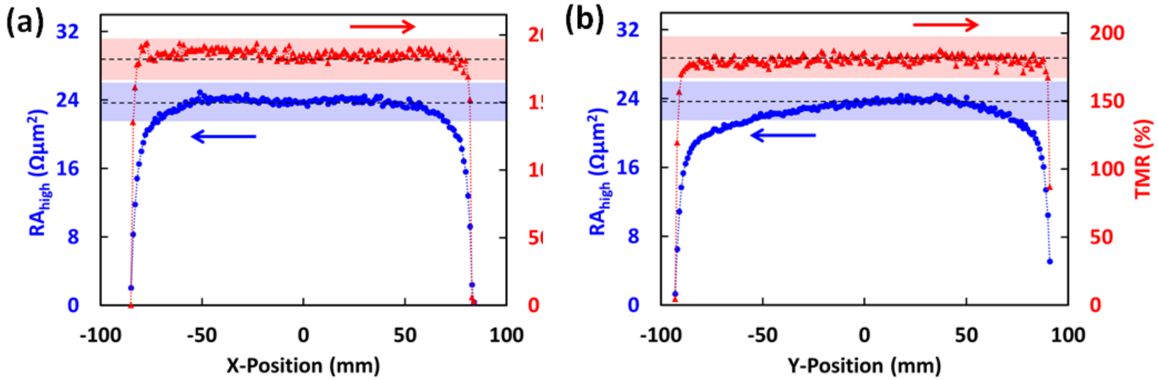


Spin transfer torque (STT) MRAM

CIPTech Module



Direct measurements of RA and MR as line scans and/or wafer maps reveal across wafer inhomogenity



- In use for optimization of key process and process tools at MTJ formation
- Ready for direct measurements on MTJs on 300mm patterned wafers

Consumables for automated tool platform

Capres' fully automated tool platform include an automated probe exchange system.

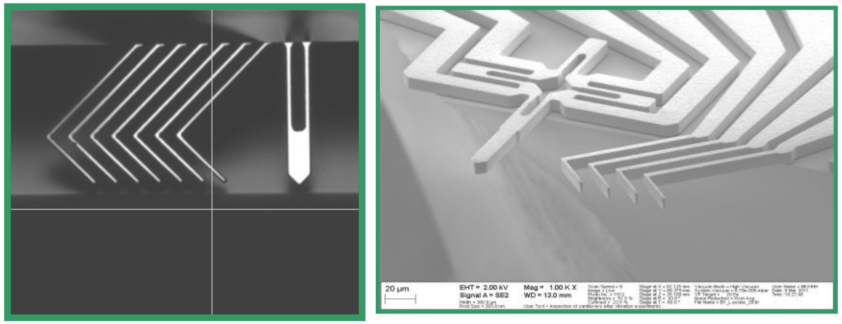
Probes are loaded in 4 probe magazines. Each probe magazine contains 25 probes with a guaranteed total number of mesaurements depending on measurement type:

- 25,000 Sheet resistance measurements
- 25,000 Resistance measurements (microETEST)
- 12,500 Rs, Hall mobility and -sheet carrier density measurement
- 12,500 CIPTech measurements (RA, MR, Rt, Rb)

Magazine loading port for 4 probe magazines

25 micro-probes in each cassette

10um pitch M7PP and 8um pitch M4PP

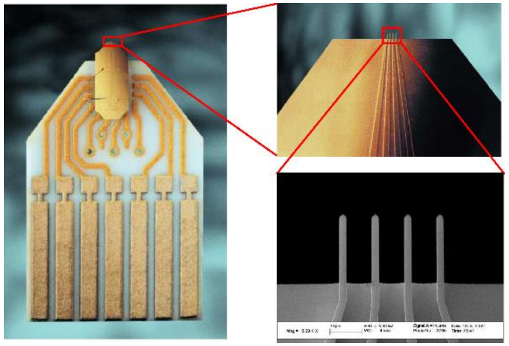


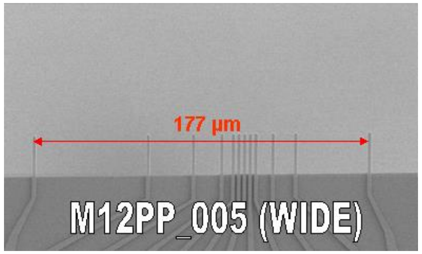
Consumables for semi-automated tool platform

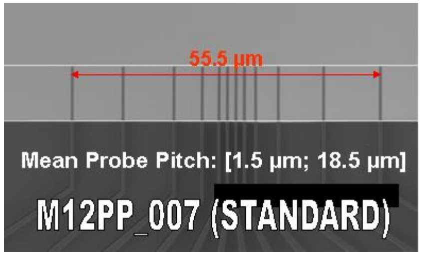
CAPRES multipoint probes at the forefront of the technological development

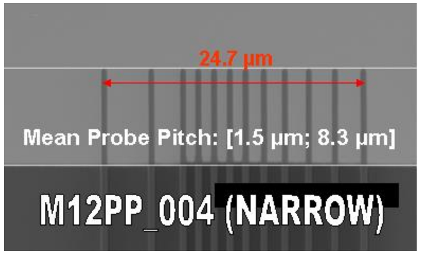
“From micro-scale to nano-scale - as the worlds only supplier CAPRES offers probes for present as well as future technology nodes”

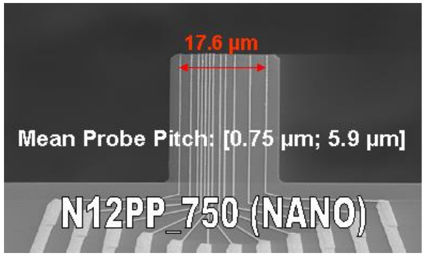
- Advanced high-precision MEMS process
- Production at foundry
- Scalable, reproducible, uniform and reliable (no need for calibration between probe changes)
- R&D at local facility at Technical University of Denmark











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