CAPRES
Technology Roadmap 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 multi-point-probing technology for R&D and production
- Supplier to semiconductor-, memory- and disk drive industries
- Installed base of approximately 80 tools worldwide
- A long range of patents and patent applications
- HQ in Copenhagen Denmark and local offices in USA and Asia
CAPRES' worldwide organization and representation
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
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)
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’ 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 $10 \text{m}\Omega/\text{sq} - 3\text{M}\Omega/\text{sq}$
- Measure mobility within a range of $<10 - 10,000 \text{cmsq/Vs}$ covering all materials used in the semiconductor industry
- Can measure Rs directly on ultrathin ($\sim 10\text{A}$) to thick conducting material (CU tested up to 1100nm (1.1um))

Measure with a high spatial resolution (Spot size $<24\text{um}$ on blanket and patterned wafers)
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**
The MicroRSP is the first tool that enables accurate, direct Rs measurements on patterned wafers.
Inline Process Control applications using microRSP-A300 or MicroHALL-A300

- **Inline monitor**
  - Rs, Mobility & Active Carrier Density
  - Rs, Mobility & Active Carrier Density
  - Rs, Mobility & Active Carrier Density
  - Rs

- **Application step**
  - LDD IMPLANT & ANNEALING
  - SiGe and SiP
  - EPI PROCESS
  - S/D IMPLANT & ANNEALING
  - NiSi or TiSi FORMATION
  - Gate material (Al or W), Cu interconnection

1. Process control for LDD & Halo implantation
2. U% optimization annealing process (RTP, Laser, Flash)

1. Rs, Mobility and Carrier Density monitor
2. Strain relaxation monitor

1. Process control for Source& Drain implantation
2. U% optimization for annealing process (RTP, Laser, Flash)

1. Thickness and annealing control

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 enabling a faster and closer control of the RTP-annealer across wafer uniformity”!

• "Enables closer RTP proces control and better RTP Tool-to-Tool matching”!

• "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)

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.

Rs data from both blanket and patterned wafers
CAPRES microRSP-A300
Rs measurements directly on blanket and patterned wafers
Optimization of:
RTP systems for spike and soak annealing.

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.
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
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
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.
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

![Graphs showing Rs variation, Mobility variation, and Active Carrier Density variation](image-url)
With the microHALL module for microRSP-A300 CAPRES has set a whole new standard for direct mobility and active carrier density measurement.

“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”

- 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
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 inhomogeneities
- 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.
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

- **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

- **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)

**microRSP-A300**: Direct sheet resistance measurements on product and blanket wafers
Micro and Nanoscale Electrical Probing
CAPRES 2016

Metal Module

User benefits:

Extended Rs measurement range and improved 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 translates to an improved repeatability for the measured Rs on thick metal films.
**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.

<table>
<thead>
<tr>
<th>Tool configuration</th>
<th>Sample</th>
<th>Av. RS (Ω□)</th>
<th>Rel. Std. dev. RS (Ω□)</th>
</tr>
</thead>
<tbody>
<tr>
<td>microRSP-A300</td>
<td>Ta (2 nm)</td>
<td>2174</td>
<td>0.3%</td>
</tr>
<tr>
<td>Metal Module</td>
<td>Ta (2 nm)</td>
<td>2321</td>
<td>0.06%</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Tool configuration</th>
<th>Sample</th>
<th>Av. RS (Ω□)</th>
<th>Rel. Std. dev. RS (Ω□)</th>
</tr>
</thead>
<tbody>
<tr>
<td>microRSP-A300</td>
<td>Cu (1100 nm)</td>
<td>0.0167</td>
<td>0.23%</td>
</tr>
<tr>
<td>Metal Module</td>
<td>Cu (1100 nm)</td>
<td>0.0165</td>
<td>0.20%</td>
</tr>
</tbody>
</table>
Thin conductive film

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

\[
L_{m}(Cu) = 39 \text{ nm}
\]

\[
t \gg L_m
\]

\[
\rho = R_s \cdot t
\]

\[
\rho = 1.72 \cdot 10^{-8} \, \Omega \text{m}
\]

**Fuchs-Sondheimer model:** In the regime where the thickness is smaller than \( L_m \) the resistivity will be a function of thickness.

\[
L_{m} = 39 \, \text{nm}
\]

\[
t < L_{m}(Cu)
\]

\[
\rho = f(t)
\]

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

<table>
<thead>
<tr>
<th>Thin Film</th>
<th>Measured by microRSP-A300</th>
<th>Measured with Metal Module</th>
<th>Improvement in ability to measure thinner film</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiN</td>
<td>&gt; 20 Å</td>
<td>15 Å</td>
<td>&gt; 25 %</td>
</tr>
<tr>
<td>TaN</td>
<td>&gt; 40 Å</td>
<td>40 Å</td>
<td>-</td>
</tr>
<tr>
<td>W</td>
<td>&gt; 30 Å</td>
<td>10 Å</td>
<td>&gt; 67 %</td>
</tr>
<tr>
<td>Ru</td>
<td>&gt; 10 Å</td>
<td>5 Å</td>
<td>&gt; 50 %</td>
</tr>
<tr>
<td>Ta</td>
<td>20 Å</td>
<td>10 Å</td>
<td>&gt; 50 %</td>
</tr>
<tr>
<td>Wsi</td>
<td>&gt; 30 Å</td>
<td>10 Å</td>
<td>&gt; 67 %</td>
</tr>
<tr>
<td>Al</td>
<td>75 Å</td>
<td>50 Å</td>
<td>&gt; 33 %</td>
</tr>
<tr>
<td>Ti</td>
<td>&gt; 30 Å</td>
<td>20 Å</td>
<td>33 %</td>
</tr>
<tr>
<td>Pt</td>
<td></td>
<td>10 Å</td>
<td></td>
</tr>
<tr>
<td>WN</td>
<td></td>
<td>15 Å</td>
<td></td>
</tr>
<tr>
<td>Ta</td>
<td></td>
<td>20 Å</td>
<td></td>
</tr>
</tbody>
</table>
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.

$R_S = 161.95 \pm 52.22 \, \text{k}\Omega/\text{sq.}$
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:

\[ t = \frac{\rho_{Cu}}{R_s} \quad \rho_{Cu} = 1.71 \cdot 10^{-8} \ \Omega \text{m} \]

<table>
<thead>
<tr>
<th>Wafer type</th>
<th>Thickness (nm)</th>
<th>Av. $R_s$ (Ω/sq)</th>
<th>Std. dev. $R_s$ (Ω/sq)</th>
<th>Relative std. dev.</th>
<th>Thickness calculated from $R_s$: $t$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>1100</td>
<td>0.0164</td>
<td>0.0002</td>
<td>1.2%</td>
<td>1041</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>Wafer type</th>
<th>Thickness (nm)</th>
<th>Average $R_s$ (Ω/sq)</th>
<th>Standard dev. $R_s$ (Ω/sq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>1100</td>
<td>0.0192</td>
<td>0.0213</td>
</tr>
</tbody>
</table>
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
Micro and Nanoscale Electrical Probing
CAPRES 2016

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

FEOL
- Channel, Source & Drain formation
- EPI Processes SiGe (B)
- Source, Drain & Gate interconnect
- Silicides, Nitrides, Tungsten Plugs

BEOL
- Metal and Interconnect
- M1 to M11
- Functional test of dies
- Sorting of dies

CAPRES microETEST

Traditional E-Test
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
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)
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 inhomogeneity

- In use for optimization of key process and process tools at MTJ formation
- Ready for direct measurements on MTJs on 300mm patterned wafers
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 measurements 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
CAPRES multipoint probes at the forefront of the technological development

“From micro-scale to nano-scale - as the world’s 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

M12PP_005 (WIDE) - 177 μm
M12PP_007 (STANDARD) - 55.5 μm Mean Probe Pitch: [1.5 μm; 18.5 μm]
M12PP_004 (NARROW) - 24.7 μm Mean Probe Pitch: [1.5 μm; 8.3 μm]
N12PP_750 (NANO) - 17.6 μm Mean Probe Pitch: [0.75 μm; 5.9 μm]
Your provider of cutting edge micro- and nano-scale electrical probing solutions!

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