Impact of piezoelectric nano-positioner displacement accuracy on On-wafer S parameters repeatabilities

EMPIR Project 14IND02 PlanarCal

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HF On-Wafer (or On-Device) Characterizations in Nano-electronics

The next-generation nanodevices will all depend on our ability to accurately and reproducibly measure properties and performance characteristics at the nanoscale over a wide frequency range.

• Providing robust modeling for circuit/system designs.

• Providing feedbacks for technological developments.

• Increasing knowledge of new material/device properties into complex technologies.
Outline

Context of the Study

Measurement set-up

Methodology

Results

Conclusion
Microwave & mm-Waves Measurements: Why?

Microwave to sub-mm wave length characterizations provide an important quantity of information on the electrical, physics and technological behaviors of devices.
HF On-Wafer Measurements: Why?

Calibrated/De-embedded S, Y, Z-Significant Parameters for physics / technology/modeling
Context of this study

On-Wafer Measurements Repeatability: Many causals

- Drift over measurement time

- Random effects
  - Instrument/external noise sources (HF, LF …)
  - Probe/Pad contacts degradation
  - Probe positioning
  - Others

This study aims to study the influence of probe positioning accuracy on $S_{ii}$ repeatability up to 50 GHz

(*action only on Z-axis*)
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**XYZ Positioners: several types**

**Mechanical:**
X, Y, Z reticule ~2.5 µm

**Piezoelectric:**
X, Y, Z accuracy ~ 25 nm
Displacement range ~ 1 cm
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**Industrial on-wafer station**
X, Y Accuracy ~ 1µm
Z Accuracy ~ 0.5 µm
Description of the Measurement Set-up

➢ EXPERIMENTAL SET-UP

➢ EXPERIMENTAL CONDITIONS

- 0.05-50 GHz
- 100 MHz (Frequency step)
- 491 (# frequency points)
- 100 Hz (IF bandwidth)
- 0dBm (RF signal power)
Outline

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Methodology 1/2

- 1-Port uncalibrated measurements of Short, Open-air and Load
  - dependent contact measurement
    - Short, Load
  - Independent contact measurement
    - Open-air

- Number of measurements (for each device): 15

- Measurement duration: almost One day (half day: mechanical; half day: piezoelectric)
Methodology 2/2

Initial positioning:

- ISS Theta alignment;
- Initial manual Z-axis positioning to ensure $S_{11}$ stable frequency response;
- $X_i$ and $Y_i$ positions recorded for $i=$ short, open and load (Piezoelect. in remote control).

Z-axis up and down displacements:

- Mechanical displacements (to the same cursor position for all measurements): estimated set-point accuracy +/-2.5µm
- Piezoelectric displacements (the Z-axis displacement was controlled in close loop operation): set-point accuracy +/-25nm
Measurement environmental conditions

All measurements are carried out in a controlled environment (IEMN Nano-characterization Center) with:

• Temperature variations less than +/- 1°,
• Anti-vibration building and experimental tables
• Stable ambient hygrometry close to 50 %.
Outline

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Measurements Analysis

From uncalibrated reflection coefficient $S_{11}$...

Example: $S_{11\_Short}$

We calculate the standard deviation of the complex reflection coefficient defined by:

$$\sigma = \left( \frac{1}{n-1} \sum_{i=1}^{n} |S_{11i} - \bar{S}_{11}|^2 \right)^{\frac{1}{2}}$$
Results and Discussion 1/3

- The Standard Deviation of « Short » is reduced by a factor of 4 in case of the Nano-positioner.

- For frequencies above 15-20 GHz, other sources of random deviations are predominant.

- The Standard Deviation is also reduced by 2 for “Load.”

RF wafer probing with improved contact repeatability using nanometer positioning
DAFFE K., DAMBRINE G., VON KLEIST-RETZOW F., HADDADI K.
Results and Discussion 2/3

- The Open standard is not a contacted device
- The Standard Deviation is not influenced by this experimental comparison
Results and Discussion 3/3

- Mean value of the relative errors over the frequency range
  - Significant improvement for Nano-positioner are shown below 20 GHz.

<table>
<thead>
<tr>
<th></th>
<th>0.05 – 20 GHz</th>
<th>20 – 50 GHz</th>
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</thead>
<tbody>
<tr>
<td><strong>Manual</strong></td>
<td><strong>Piezoelect.</strong></td>
<td><strong>Manuel</strong></td>
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<tr>
<td><strong>Short</strong></td>
<td>0.23 %</td>
<td>0.06 %</td>
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<tr>
<td><strong>Load 50Ω</strong></td>
<td>0.35 %</td>
<td>0.1 %</td>
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Conclusion

HF on-wafer based characterization remains challenging and needs to develop new instruments.

Probe/Pad positioning inaccuracy is one causal of random error,

Nano-robotic based positioners (with nm resolution) are a solution to reduce it significantly up to 15-20 GHz,

Nano-robotic based on-wafer station is a reality for on-line test of microelectronic.

https://www.uni-oldenburg.de/en/computingscience/amir/research/research-group-microwave-nanoscopy-and-nanorobotics/

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Acknowledgements:
- [http://www.planarcal.ptb.de/planarcal/14ind02-home.html](http://www.planarcal.ptb.de/planarcal/14ind02-home.html)
- This work was supported by the EQUIPEX ‘ExCELSiOR’ project (www.excelsior-ncc.eu) and partly supported by the French RENATECH network.