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A near-field scanning microwave microscope in a scanning electron microscope: design and challenges.

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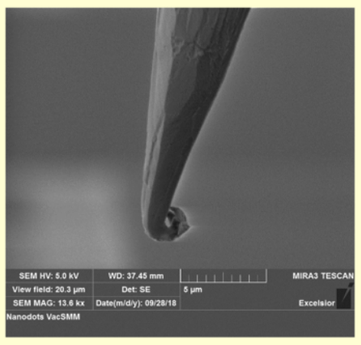
Multimodal Atomic Force Microscopy, Microwaves, and Scanning Electron Microscopy

Context and objectives

- SMM combines an AFM with microwaves. It allows the nanoscale electrical characterization of material properties.
- However the AFM probe tip can not be monitored during the experiment => possible shape evolution that impacts the effective electric contact area.
- Water forms a meniscus at the tip - sample interface => uncontrolled parasitic capacitance.

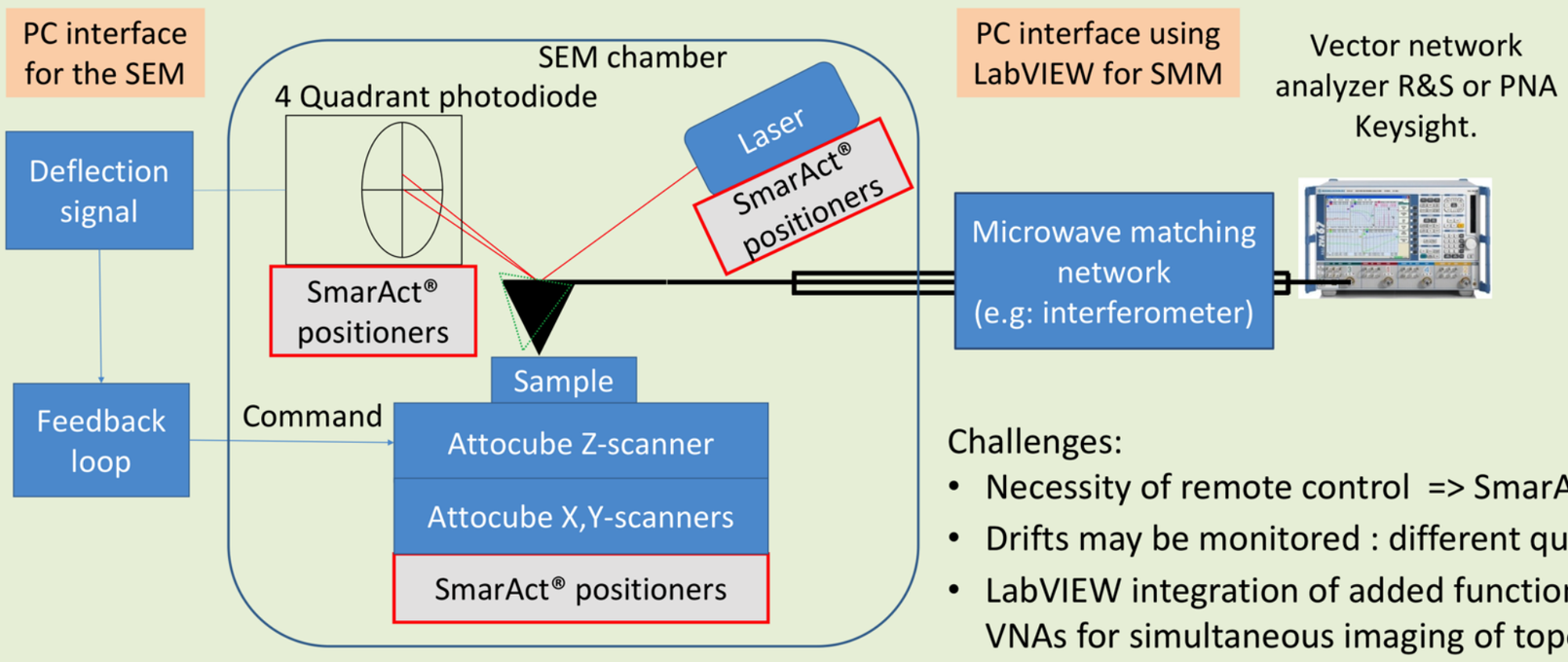
⇒ Proposed solution: combining SMM with SEM for monitoring humidity and tip degradation.

Complementary objective: development of Scanning Microwave Microscopy (SMM) technology towards high performance : spatial electrical resolution, increased frequency range (up to 110 GHz), and different sizes of microwave probes.

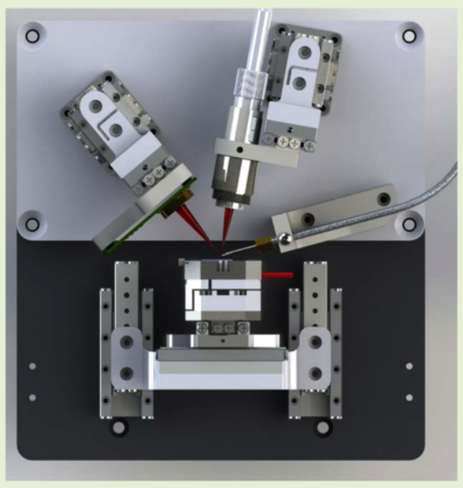


SMM in SEM instrumentation

Design of the mm-wave SMM compatible with the SEM chamber size and environment



SEMM platform implementation (SolidWorks®)

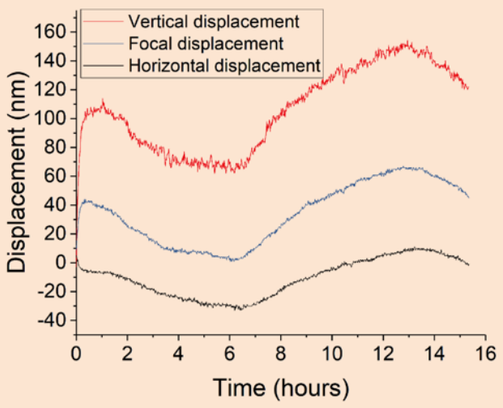


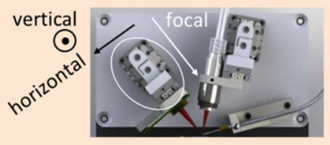
Challenges:

- Necessity of remote control => SmarAct® piezoelectric nano-positioners are included.
- Drifts may be monitored : different quantities are measured and analyzed.
- LabVIEW integration of added functionalities using Keysight® and Rohde&Schwarz® (R&S) VNAs for simultaneous imaging of topography (Nanonis® software) and microwave signals.

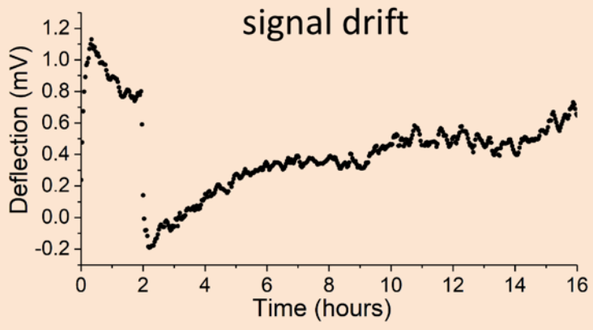
Instrument qualification

Drift of SmarAct® positioners detected by an optical sensor





4Q photodiode deflection signal drift



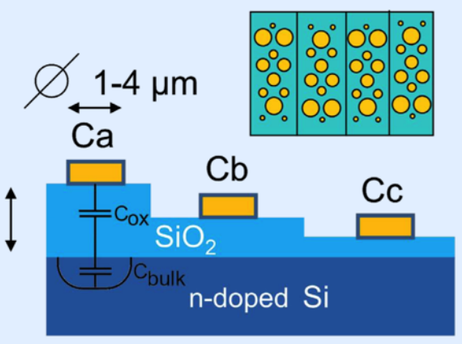
- 4 quadrant diode position stable within a 100 nm range over 16 hours => much lower than the spot size (~ a few µm) and position on the cantilever (10s of nm).
- Deflection signal stability of 1 mV <=> 10 nm fluctuation.

$$C_{ox} = A\frac{\varepsilon_0 \varepsilon_{rSiO_2}}{d_{ox}}$$

$$C_{depl} = A\frac{\varepsilon_0 \varepsilon_{rSi}}{d_{depl}}$$

$$d_{depl} = \sqrt{2\varepsilon_0 \varepsilon_{rSi}\psi / qN_A}$$

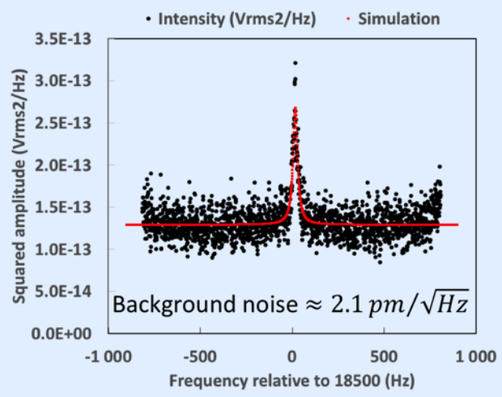
ψ =200 mV $N_A = 8\times10^{15}$ /cm³

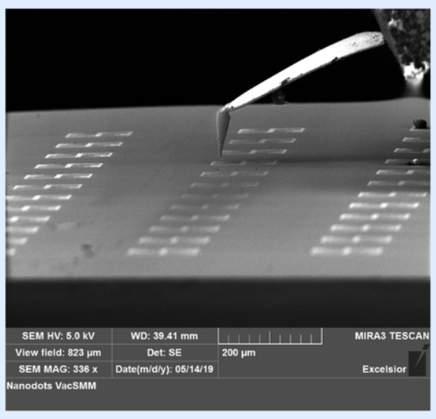


Calibration sample :

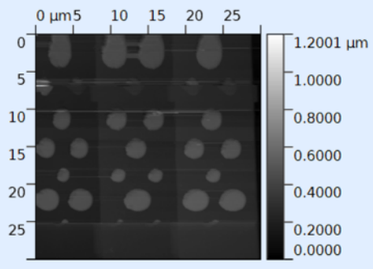
- Si wafer with SiO_2 staircase and Au disks as top electrodes (1 to 4 µm ø).
- Capacitance modeling : oxide and depletion capacitances in series

SMM and SEM results

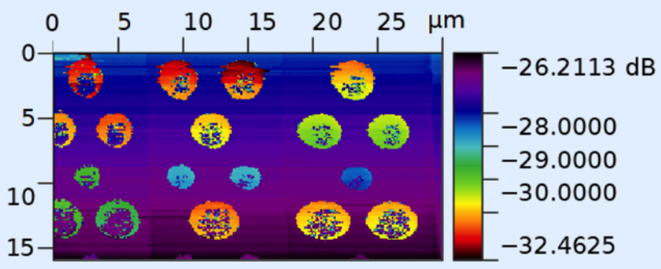




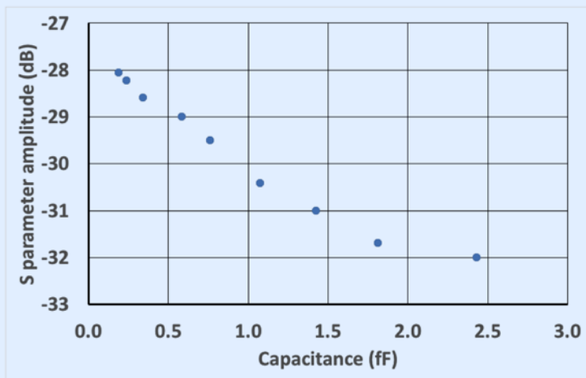
- Thermomechanical noise detection of the cantilever (25Pt300D RMN®).
- SEM observation of a capacitance calibration sample and AFM probe.



AFM topographic image of capacitors



Amplitude of the microwave reflection coefficient (S parameter)



Dependence of the S parameter with the capacitance value => possible calibration of the microwave signal for further impedance measurement.

- Frequency = 7.59 GHz
- Microwave signal power = -5 dBm
- Demodulation IF Bandwidth = 100 Hz

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