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

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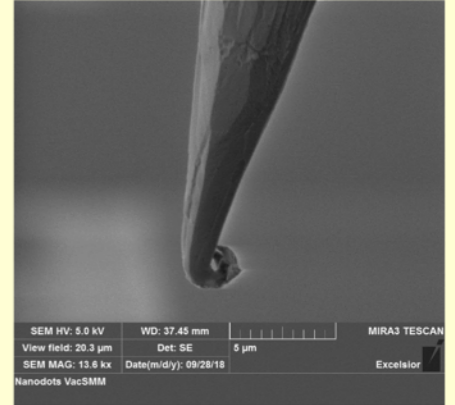
## Multimodal Atomic Force Microscopy, Microwaves, and Scanning Electron Microscopy

### 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.

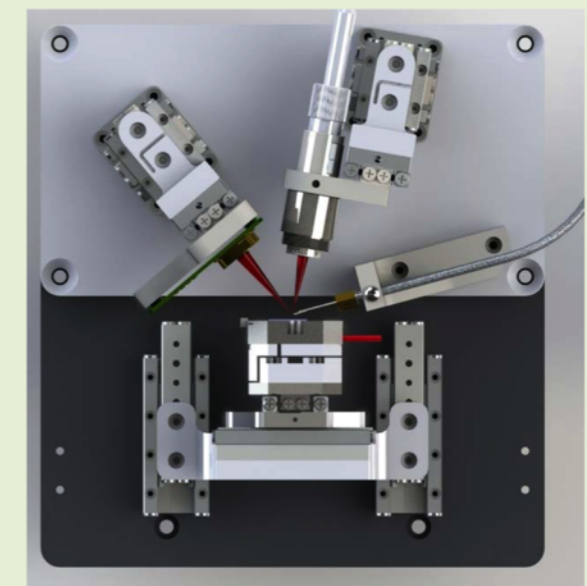
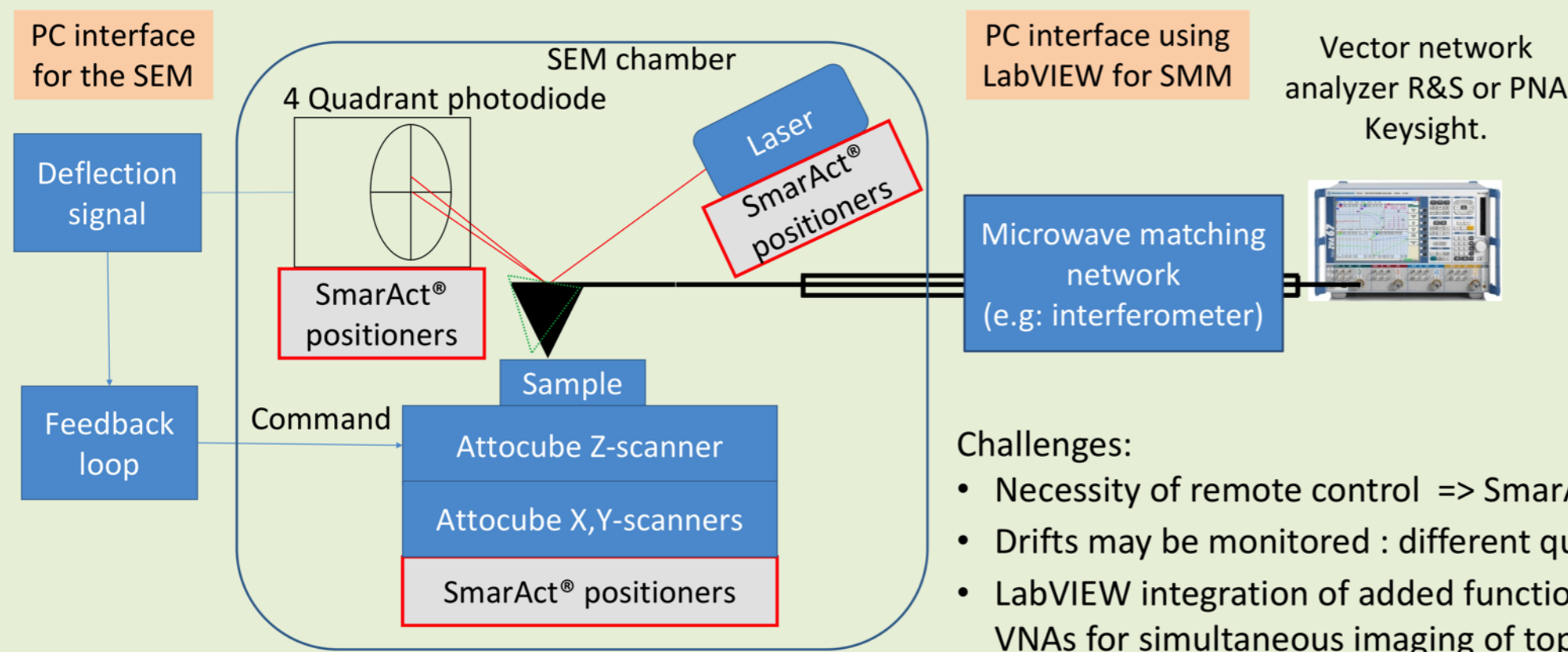
Complementary objective: development of Scanning Microwave Microscopy (SMM) technology towards high performance : spatial electrical resolution, increased frequency range (up to 110 GHz), and different sizes of microwave probes.



## SMM in SEM instrumentation

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

SEMM platform implementation (SolidWorks®)

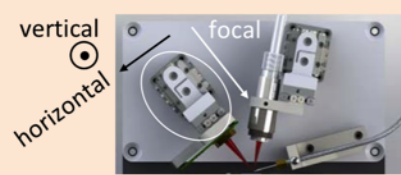
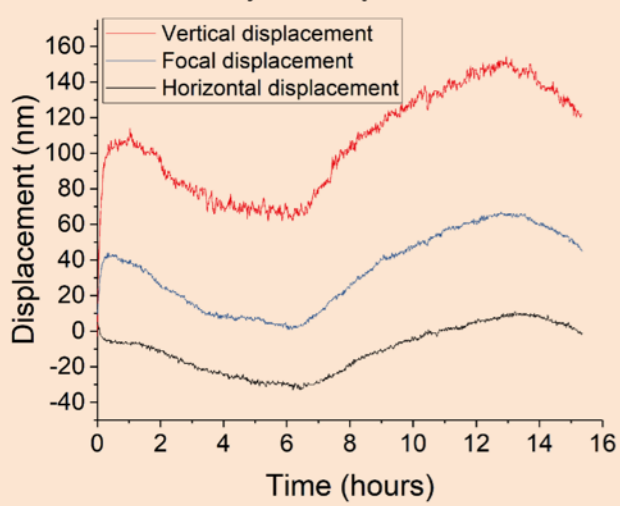


### Challenges:

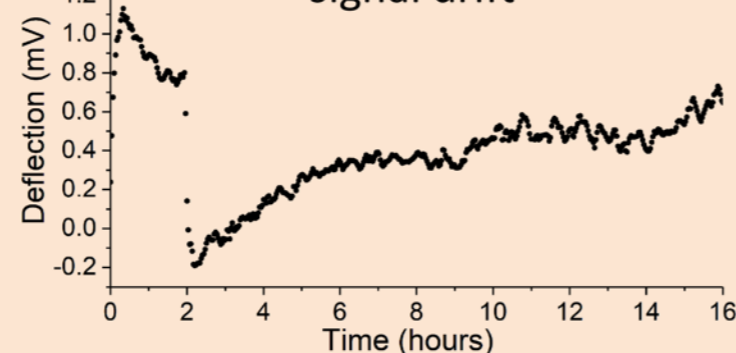
- Necessity of remote control => SmarAct® piezoelectric nano-positioners are included.
- Drifts may be monitored : different quantities are measured and analyzed.
- LabVIEW integration of added functionalities using Keysight® and Rohde&Schwarz® (R&S) VNAs for simultaneous imaging of topography (Nanonis®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

## Instrument qualification

### Drift of SmarAct® positioners detected by an optical sensor

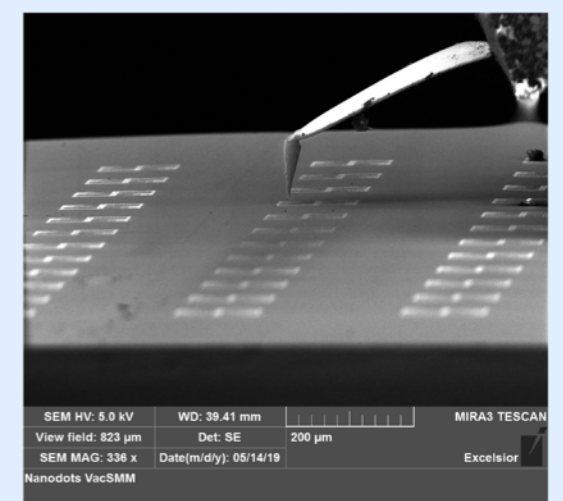
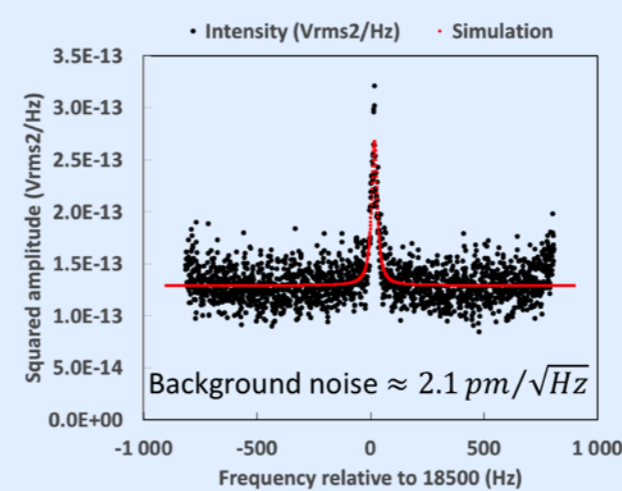


### 4Q photodiode deflection signal drift

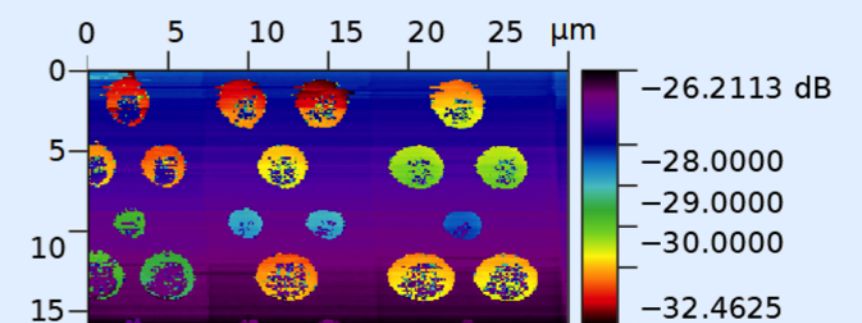
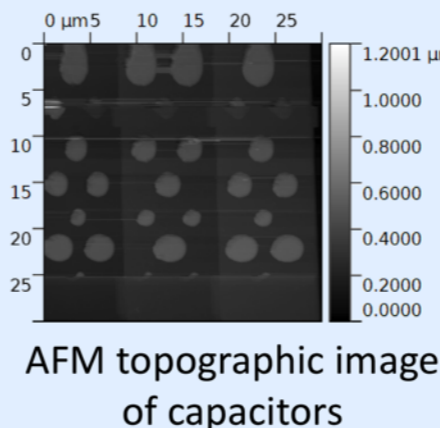


- 4 quadrant diode position stable within a 100 nm range over 16 hours => much lower than the spot size (~ a few µm) and position on the cantilever (10s of nm).
- Deflection signal stability of 1 mV <=> 10 nm fluctuation.

## SMM and SEM results



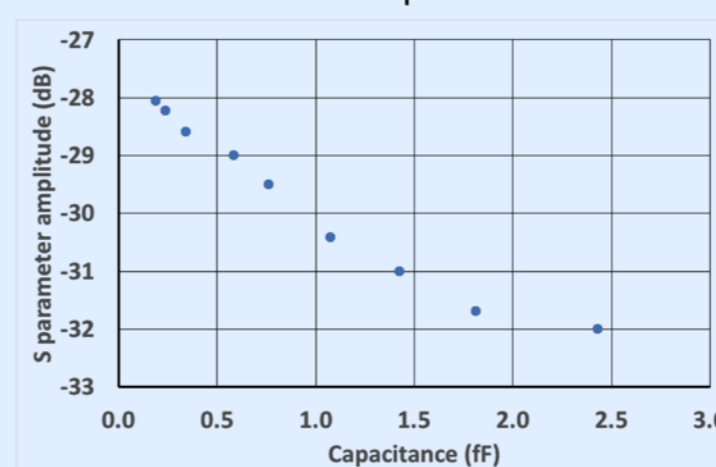
- Thermomechanical noise detection of the cantilever (25Pt300D RMN®).
- SEM observation of a capacitance calibration sample and AFM probe.



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

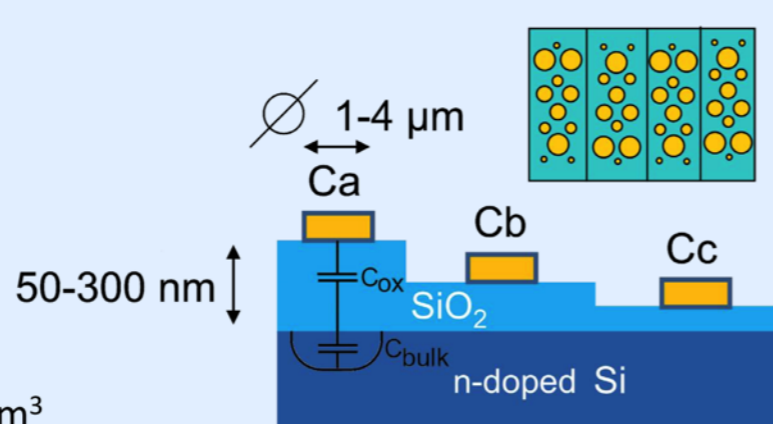


$$C_{ox} = A \frac{\epsilon_0 \epsilon_r \text{SiO}_2}{d_{ox}}$$

$$C_{depl} = A \frac{\epsilon_0 \epsilon_r \text{Si}}{d_{depl}}$$

$$d_{depl} = \sqrt{2 \epsilon_0 \epsilon_r \text{Si} \psi / q N_A}$$

$$\psi = 200 \text{ mV} \quad N_A = 8 \times 10^{15} / \text{cm}^3$$



### Calibration sample :

- Si wafer with SiO<sub>2</sub> staircase and Au disks as top electrodes (1 to 4 µm ø).
- Capacitance modeling : oxide and depletion capacitances in series

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