# QUANTITATIVE TOMOGRAPHY WITH SUBSURFACE SCANNING ULTRASOUND RESONANCE FORCE MICROSCOP

**Maarten van Es, Laurent Fillinger, and Hamed Sadeghian**
**NOMI, TNO, Delft, The Netherlands**

TNO innovation for life

# VISION & MISSION

NOMI ecosystem is setup based on the following vision of the future:

We see a future where humanity will solve many of future's challenges in data, energy and life sciences by a continuous miniaturization in device fabrication down to an atomic scale

The NOMI-ecosystem develops the technologies that enable exploration and exploitation of the atom-scale world level leading to the real-world applications

The NOMI-ecosystem research to create the **instruments to image, measure and fabricate devices at the level of individual atoms** at an humanly acceptable and economically attractive level

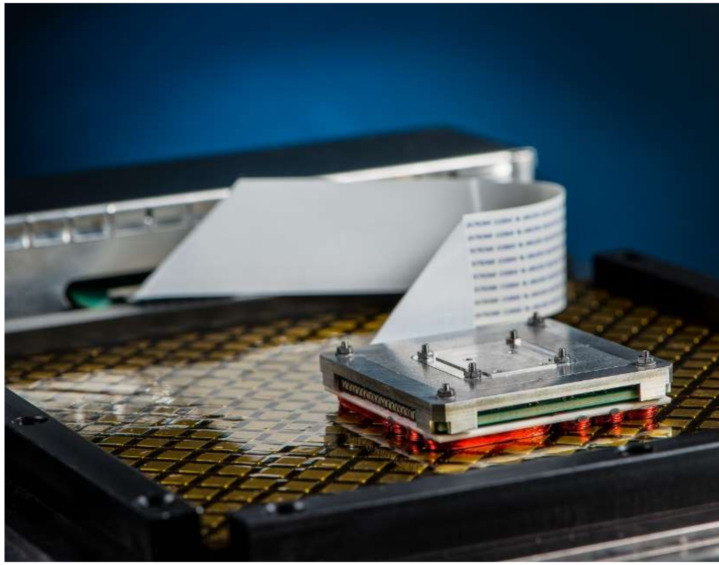
- About NOMI
  - SPM platforms
  - SPM modalities for metrology

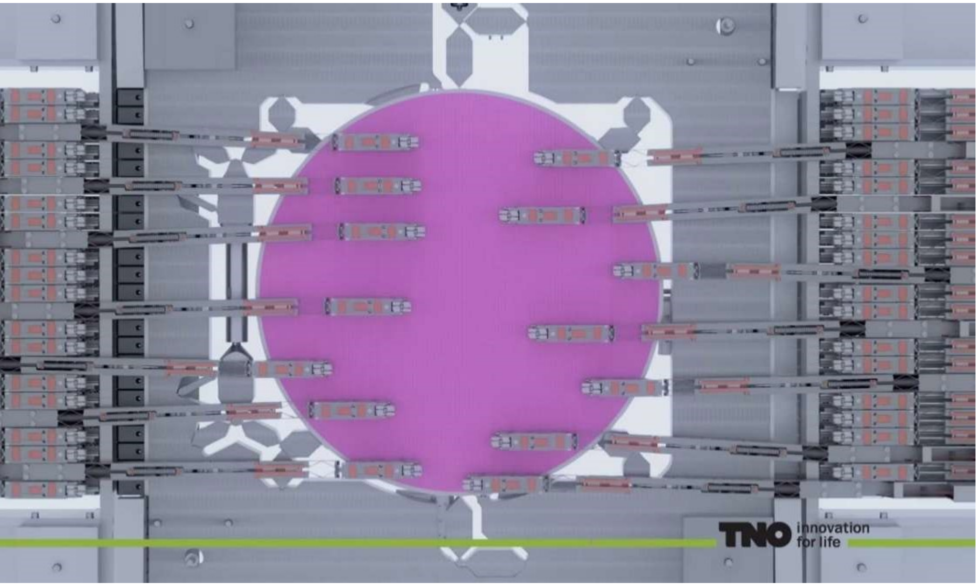
- Scanning Subsurface Probe Microscopy
  - Technical background
  - Application possibilities
  - Quantifying SSPM: hurdles and solutions (see also next talk!)
  - Results

- NOMI SPM Platforms:
  - High Throughput SPM
  - Large Dynamic Range SPM

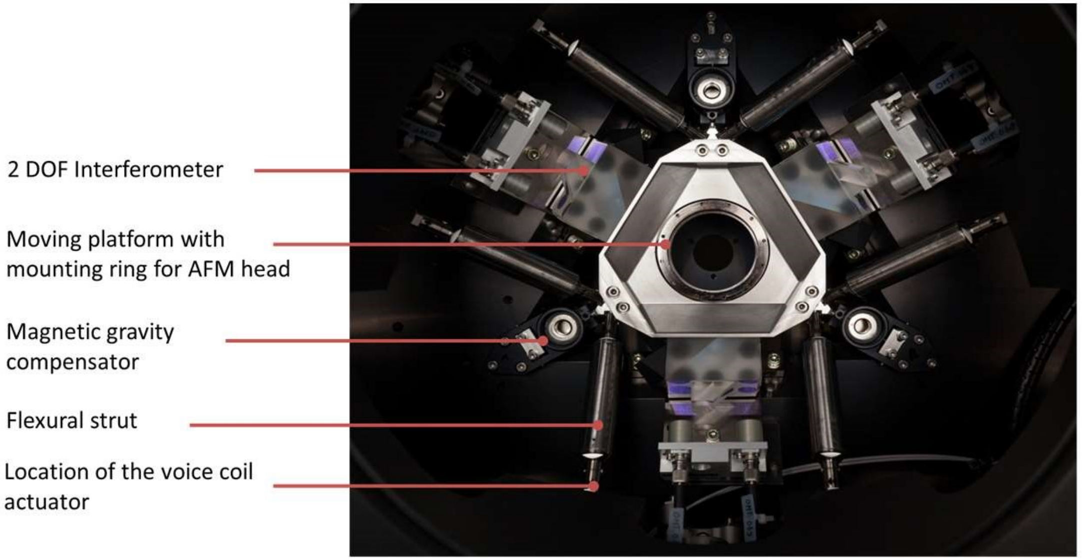
- NOMI SPM modalities
  - High Aspect Ratio
  - SubSurface SPM
  - Nanolithography
  - NEW: Chemical Characterization (hydrophobicity)

- NOMI SPM Platforms:
  - **High Throughput SPM**
    - **fully automated**
    - **in- or near-line inspection**
  - Large Dynamic Range SPM






- NOMI SPM Platforms:
  - High Throughput SPM
  - **Large Dynamic Range SPM**
    - **sub-nm precision over mm distances**
    - **overlay – distance between product features and markers**
    - **characterizing abberations across a full die**

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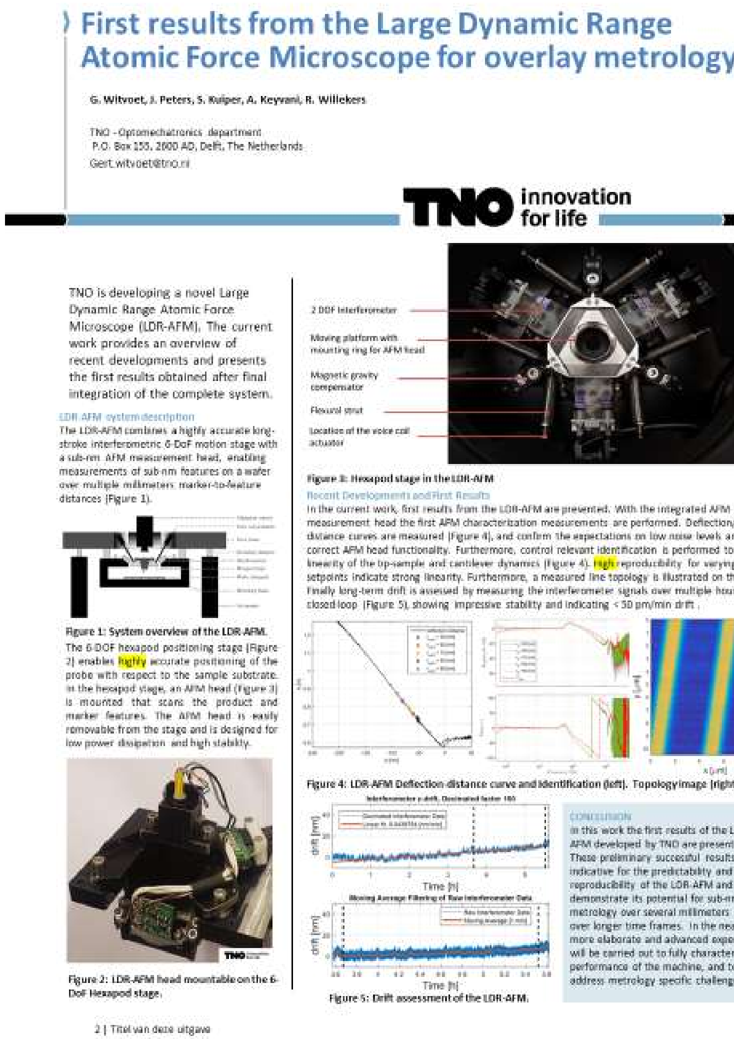
First results from the Large Dynamic Range Atomic Force Microscope for overlay metrology

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TNO is developing a novel Large Dynamic Range Atomic Force Microscope (LDR-AFM). The current work provides an overview of recent developments and presents the first results obtained after final integration of the complete system.

LDR AFM system description

The LDR-AFM combines a highly accurate long-stroke interferometric 6-DoF motion stage with a sub-nm AFM measurement head, enabling measurements of sub-nm features on a wafer over multiple millimeters marker-to-feature distances (Figure 1).

Figure 1: System overview of the LDR-AFM.

Figure 3: Hexapod stage in the LDR-AFM

Recent Developments and First Results

Figure 2: LDR-AFM head mountable on the 6-DoF Hexapod stage.

Figure 5: Drift assessment of the LDR-AFM.

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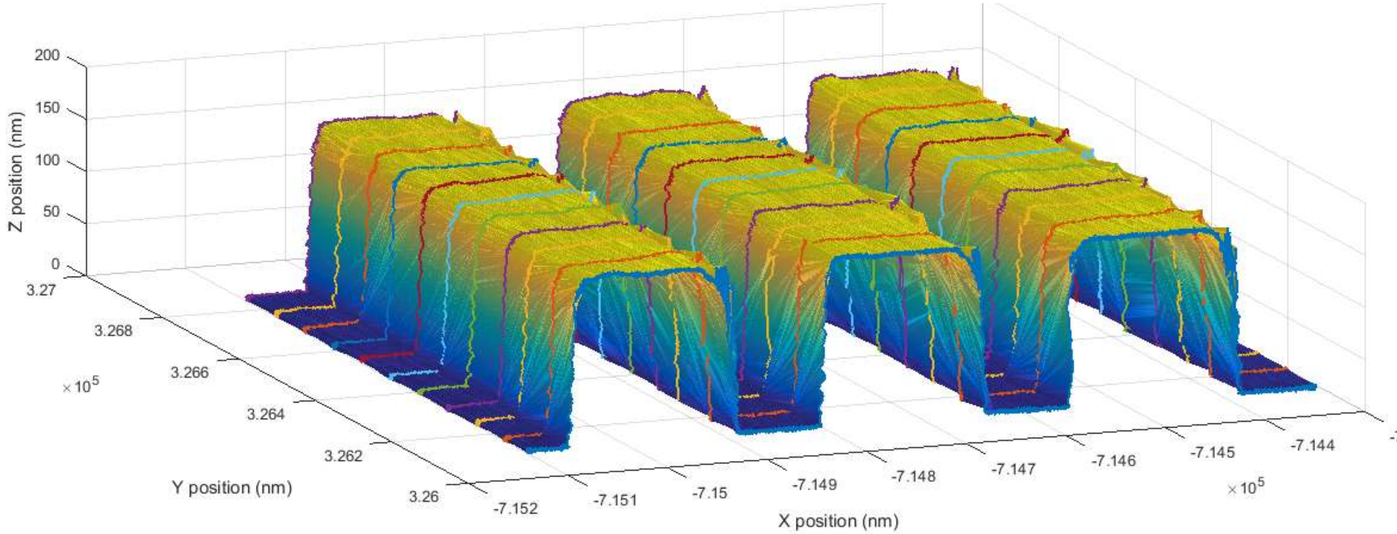
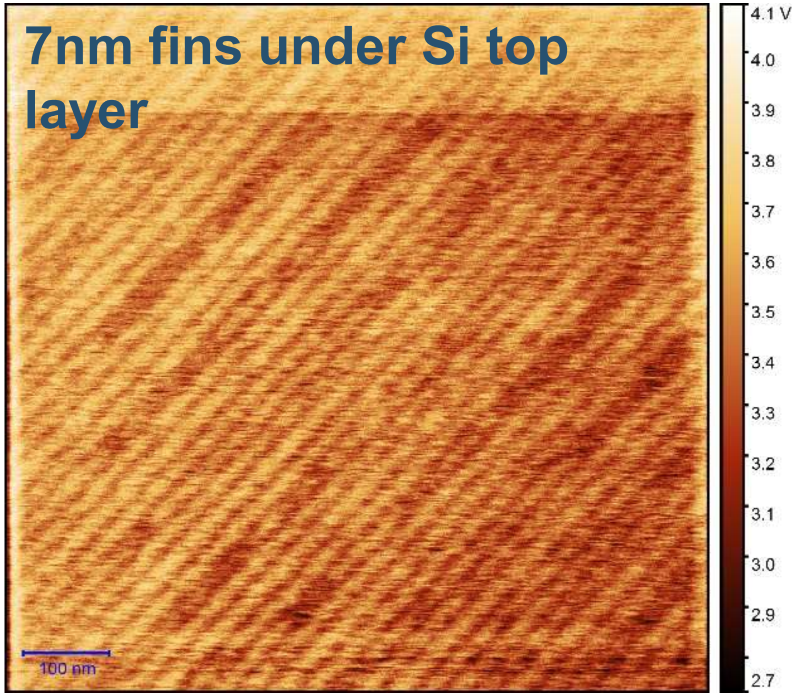



87 degrees sidewall angle!
150 nm feature height

- NOMI SPM Platforms:
  - High Throughput SPM
  - Large Dynamic Range AFM
- NOMI SPM modalities
  - High Aspect Ratio
  - **SubSurface SPM**
    - **CD**
    - **alignment**
    - **overlay**
    - **defect review**
  - Nanolithography
  - NEW: Chemical Characterization (hydrophobicity)

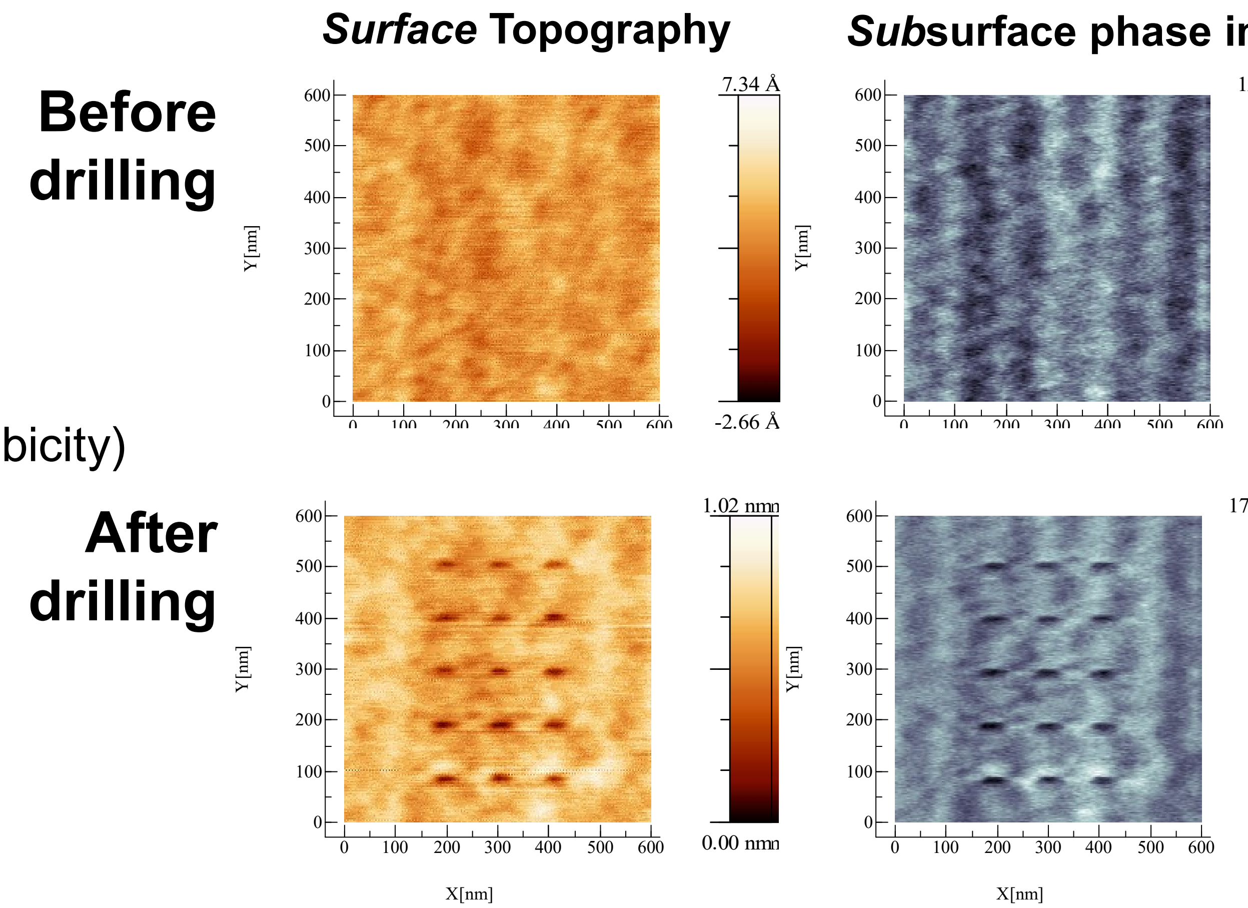


NOMI SPM Platforms:

- High Throughput SPM
- Large Dynamic Range AFM

NOMI SPM modalities

- High Aspect Ratio
- SubSurface SPM
- **Nanolithography**
  - **contact holes**
- NEW: Chemical Characterization (hydrophobicity)

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- NOMI SPM Platforms:
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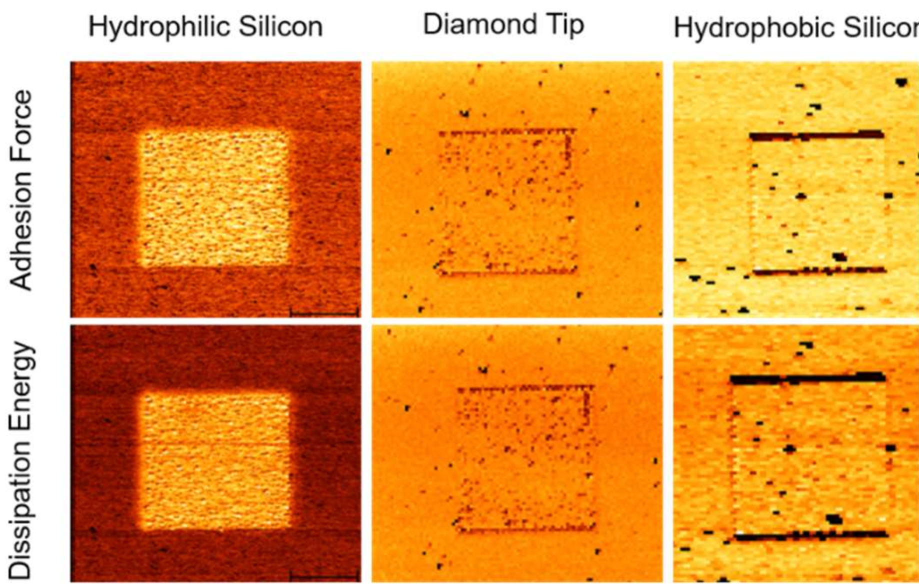
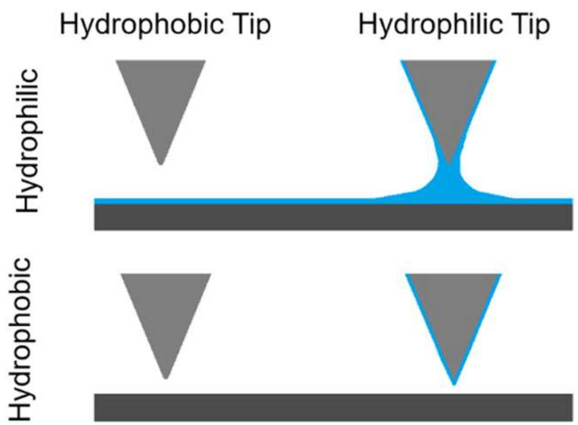
- NOMI SPM modalities
  - High Aspect Ratio
  - SubSurface SPM
  - Nanolithography
  - **NEW: Chemical Characterization**
    - **low k materials (hydrophobicity)**
    - **characterization of contaminations**
    - **...?**



# QUANTITATIVE SUBSURFACE SCANNING PROBE MICROSCOPY

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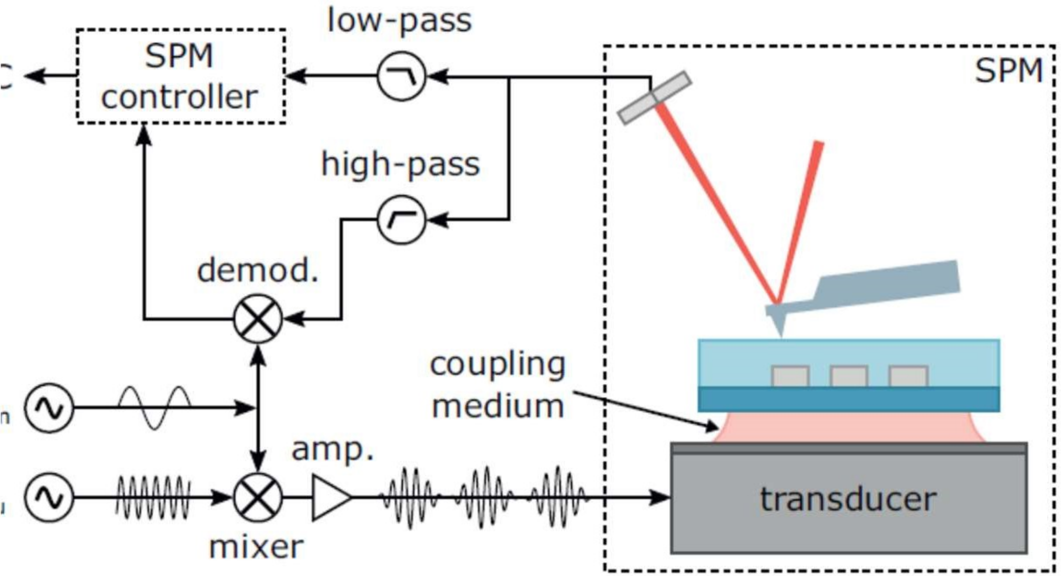
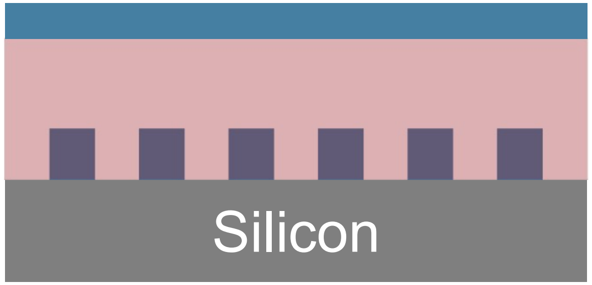
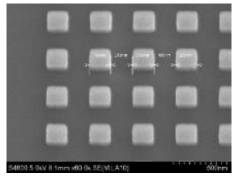
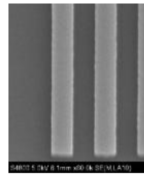
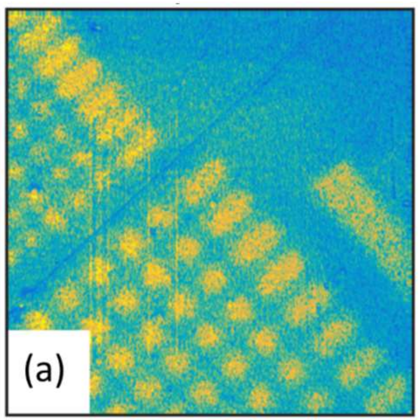


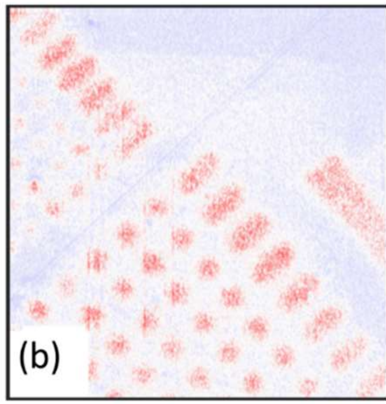








Amplitude




Phase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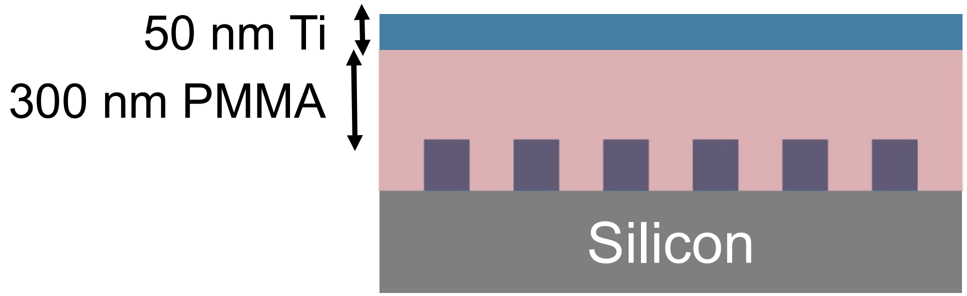
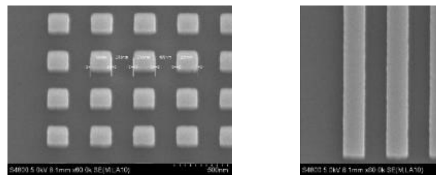
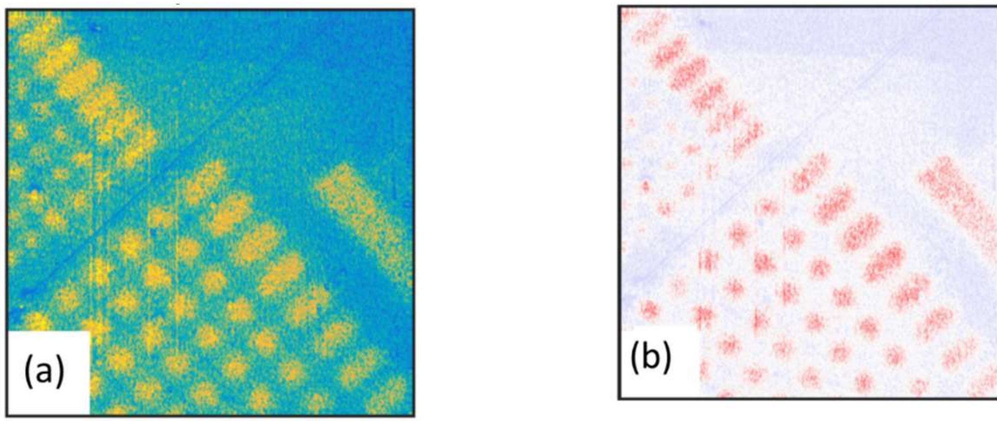
# SUBSURFACE SCANNING PROBE MICROSCOPY

- SSPM Achievements
  - **Imaging of deep structures**
  - Imaging of small structures
  - Imaging of defects



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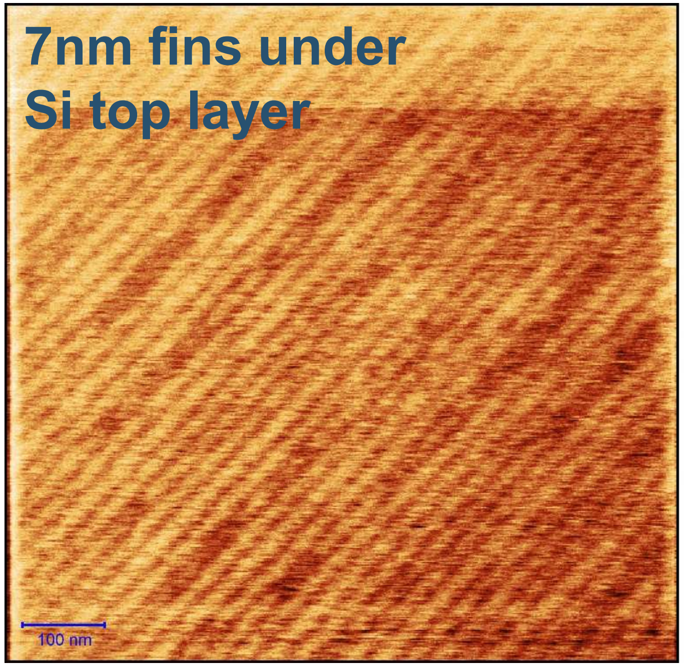

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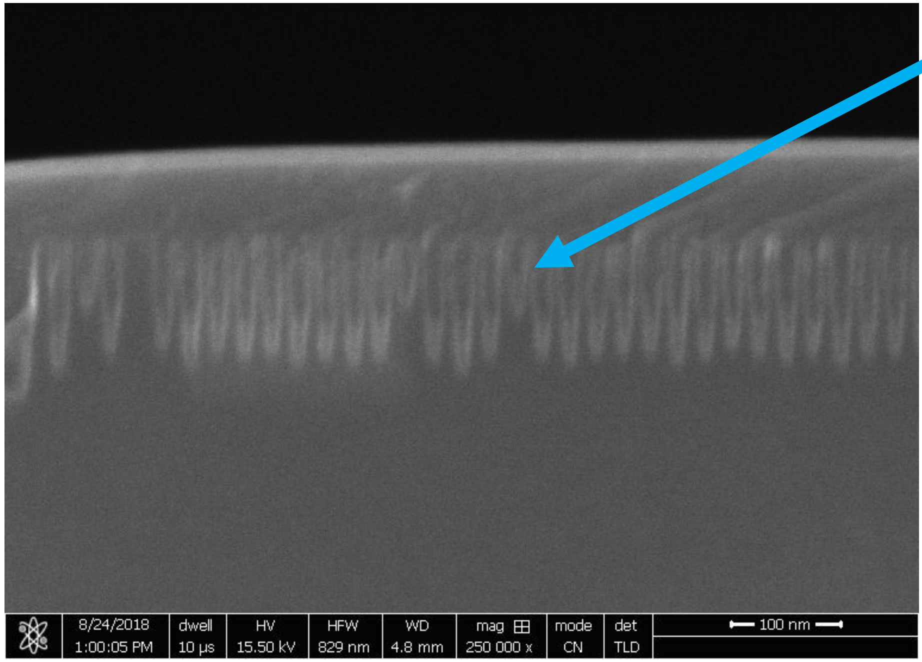
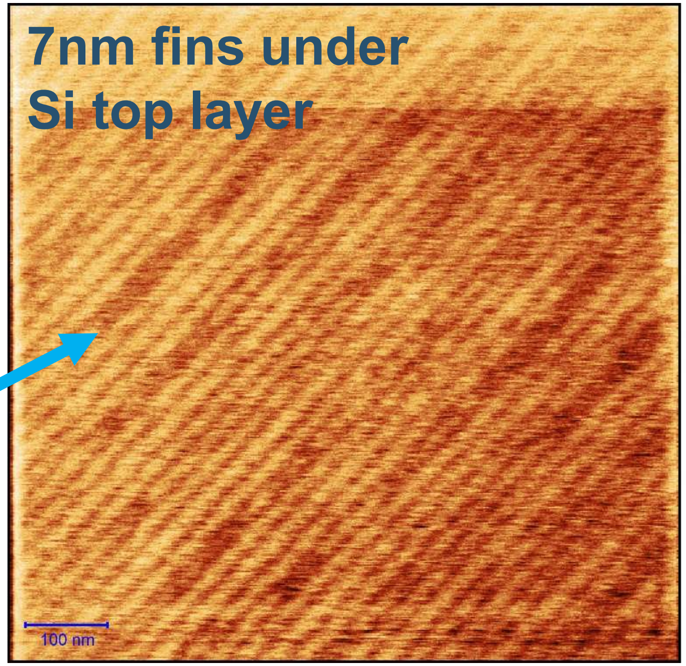
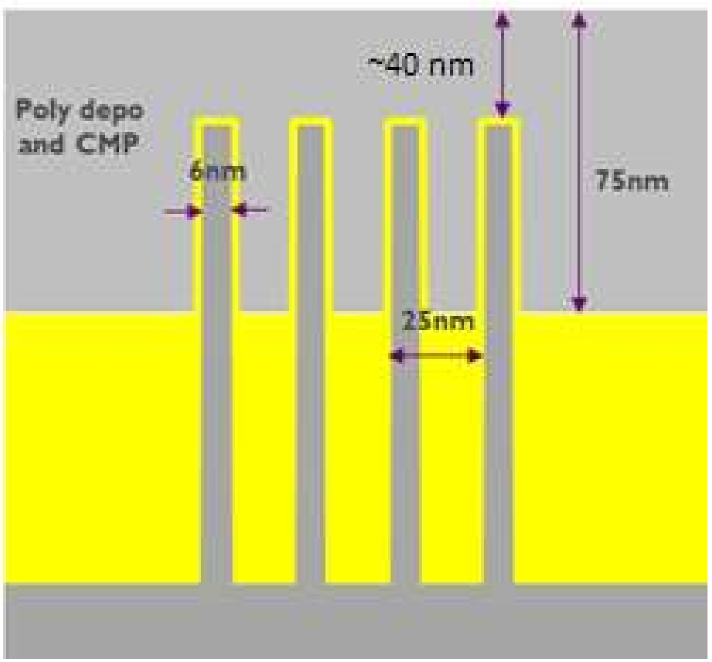


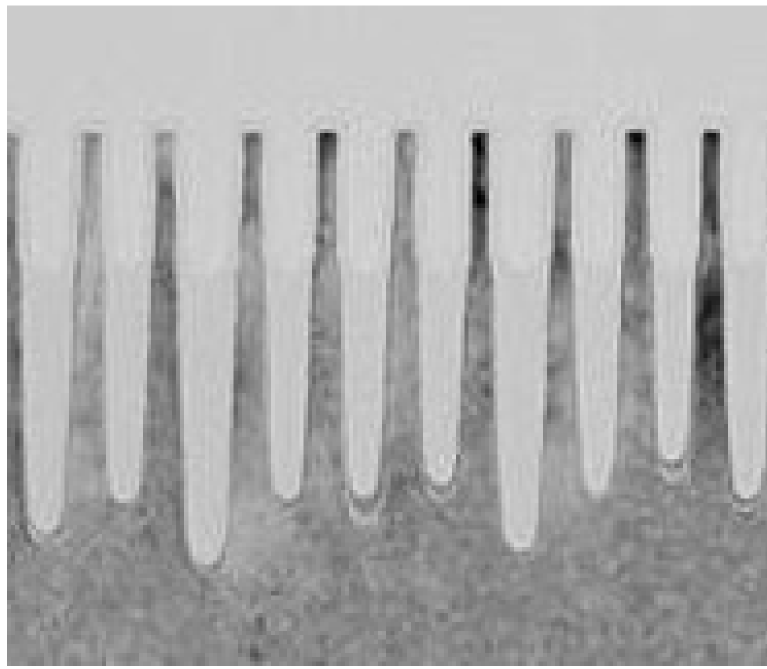



# QUANTIFYING SSPM

How to obtain Critical Dimensions from SSPM data?

- Combine Finite Element Modeling with quantifiable measurements



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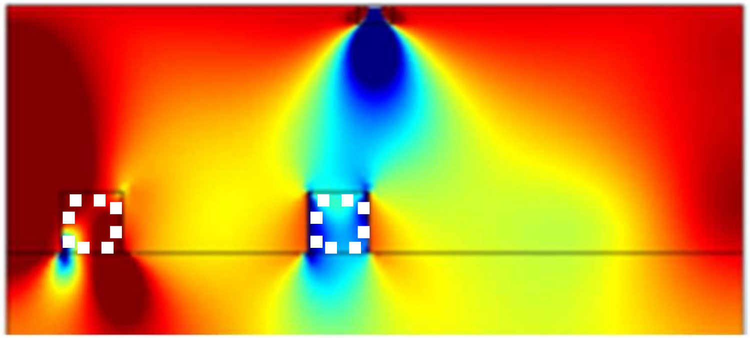

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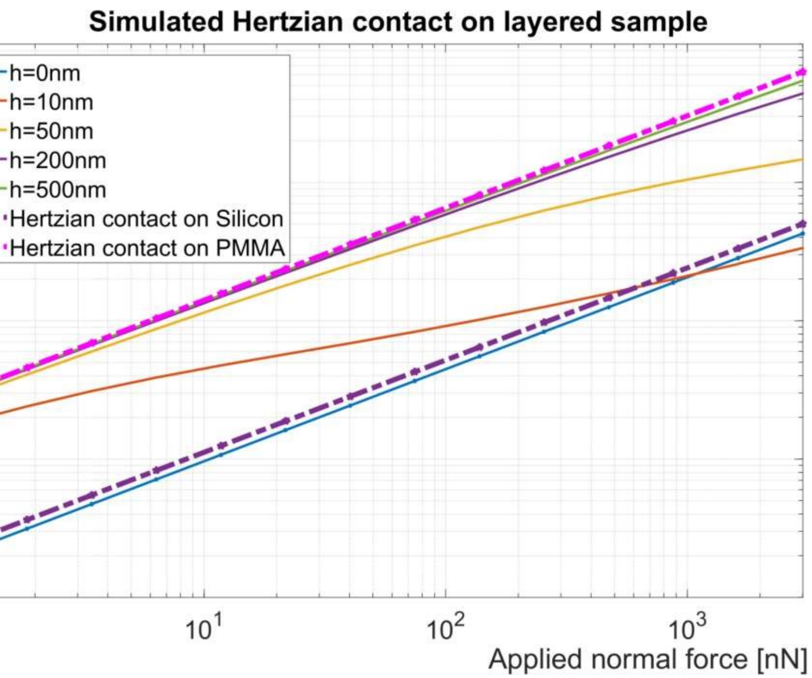


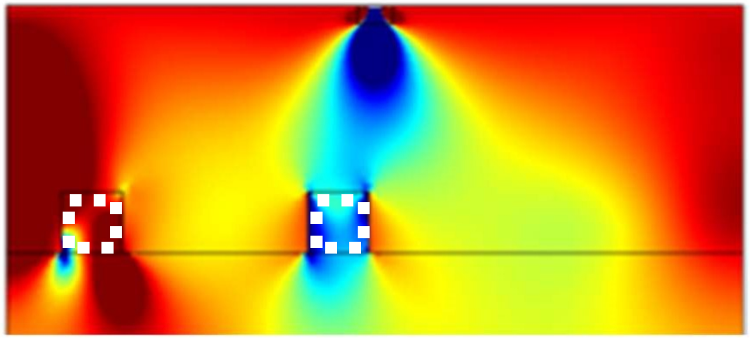

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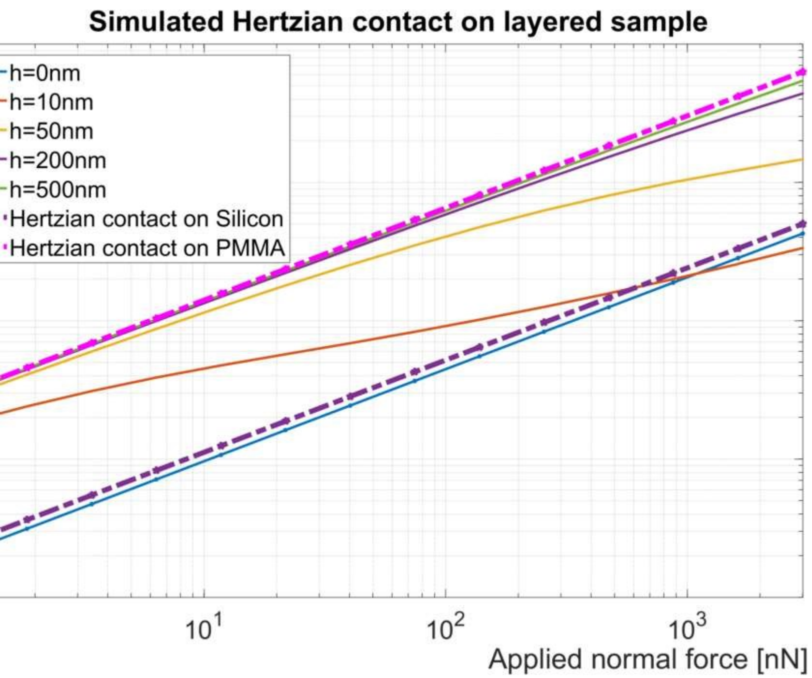


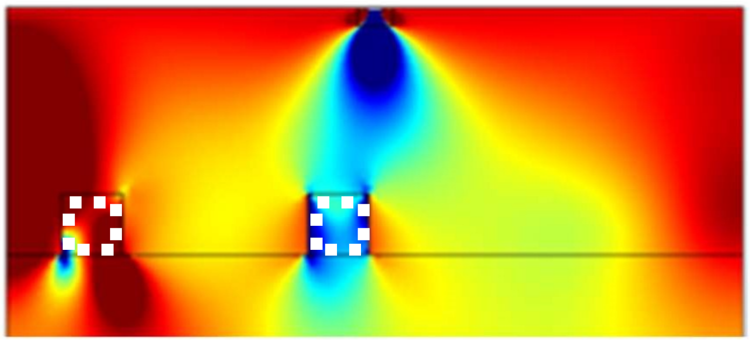

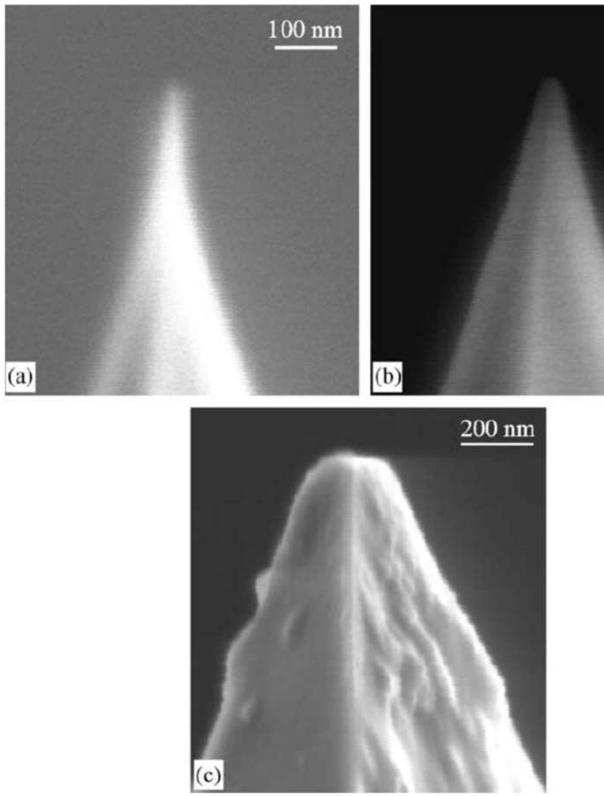


Fig. 2. SEM images of brand new tips revealing the wide d
possible new-tip geometry. The scale is the same for all thre
Sharp tip with radius of curvature $R<10$ nm.(b) Tip with
Very blunt tip with possible surface contamination not seen i

*M. Kopycinska-Müller et al. / Ultramicroscopy 106 (2006)*

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How to obtain Critical Dimensions from SSPM data?

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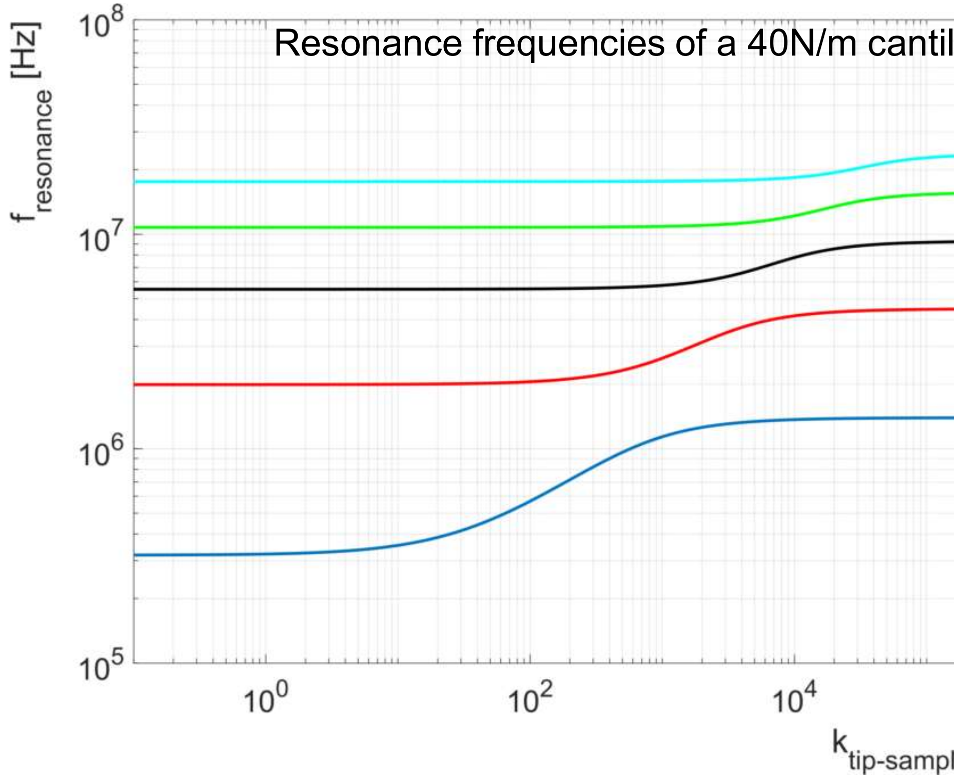
Euler Bernoulli beam equation:

$$\frac{\partial^2}{\partial x^2}\left(EI\frac{\partial^2 w}{\partial x^2}\right) = -\mu\frac{\partial^2 w}{\partial t^2} + q(x)$$



| Boundary | $w'''$ | $w''$ | $w'$ | $w$ |
|---|---|---|---|---|
| Clamp | | | $\Delta w' = 0*$ | $\Delta w = 0 *$ |
| Simple support | | $\Delta w'' = 0$ | $\Delta w' = 0$ | $\Delta w = 0 *$ |
| Point force | $\Delta w''' = \lambda$ | $\Delta w'' = 0$ | $\Delta w' = 0$ | $\Delta w = 0$ |
| Point torque | $\Delta w''' = 0$ | $\Delta w'' = \tau$ | $\Delta w' = 0$ | $\Delta w = 0$ |
| Free end | $w''' = 0$ | $w'' = 0$ | | |
| Clamp at end | | | $w'$ fixed | $w$ fixed |
| Simply supported end | | $w'' = 0$ | | $w$ fixed |
| Point force at end | $w''' = \pm\lambda$ | $w'' = 0$ | | |
| Point torque at end | $w''' = 0$ | $w'' = \pm\tau$ | | |

# QUANTIFYING SSPM

How to obtain Critical Dimensions from SSPM data?

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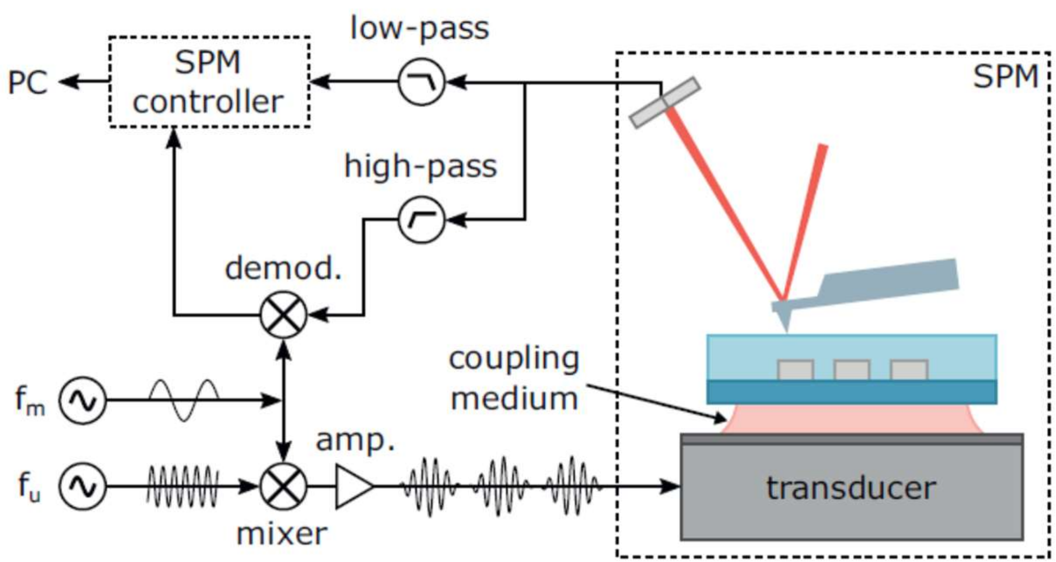
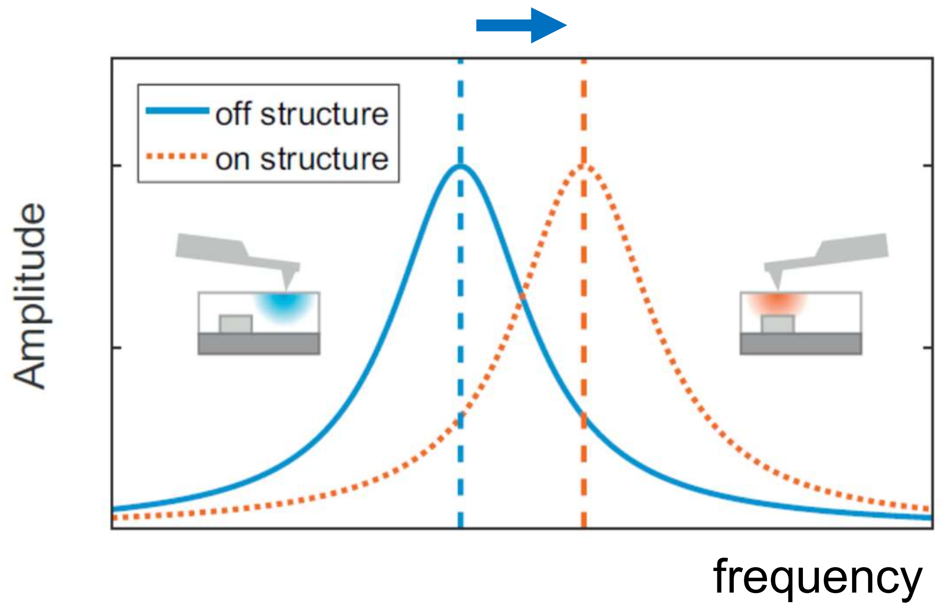
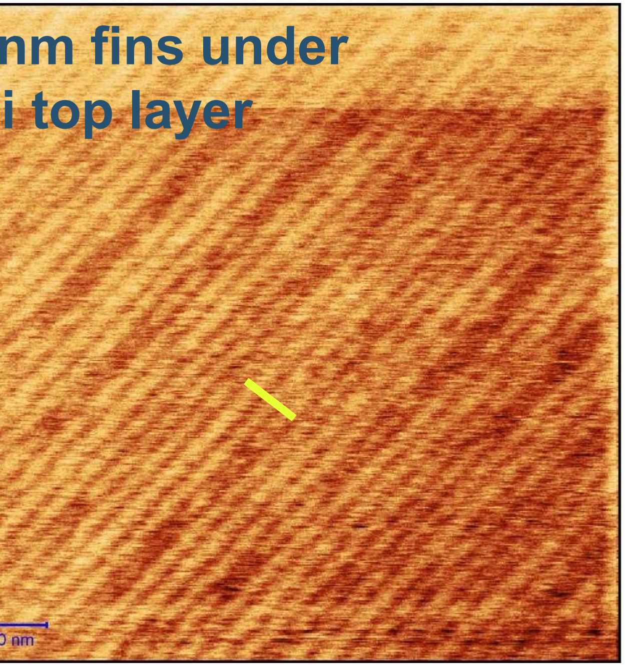
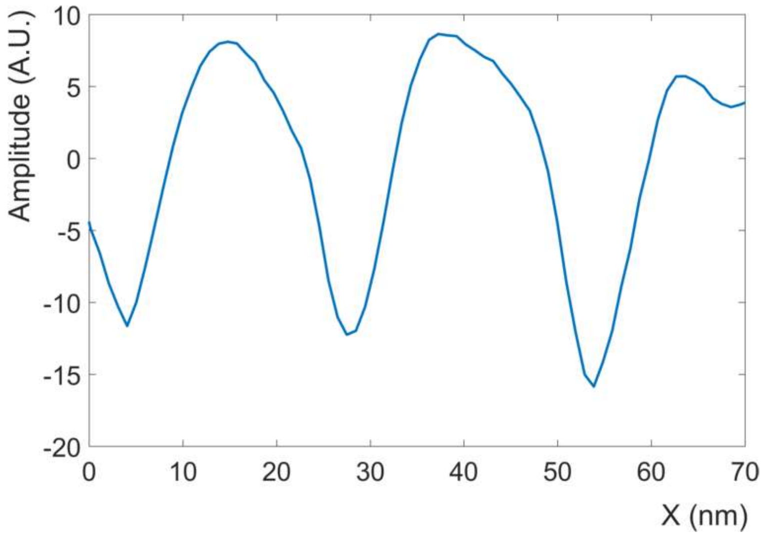
Next talk: How to measure $\Delta f_{res}$
and how not to have a transduc
below the wafer

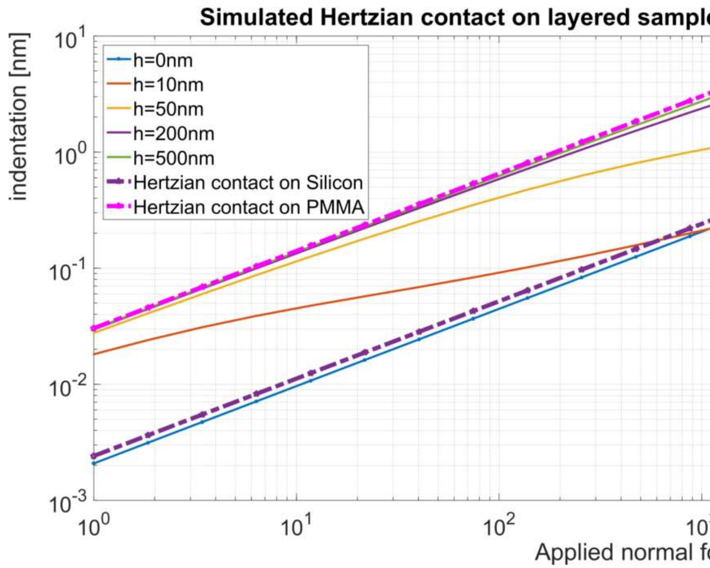


# PRELIMINARY RESULTS



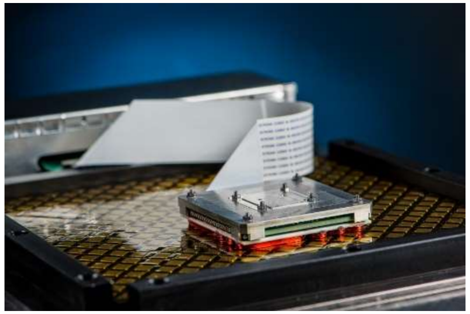
# CONCLUSIONS

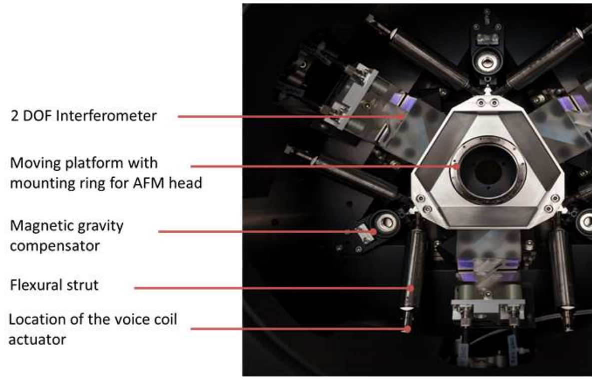
NOMI brings a range of platforms and modalities for SPM to solve manufacturing challenges in semiconductor applications

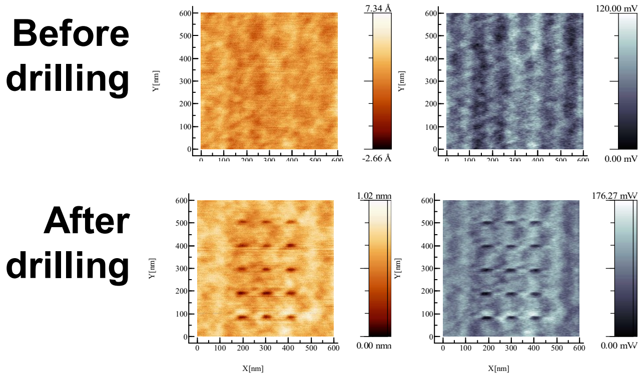
SubSurface Probe Microscopy visualizes structures under layers of arbitrary materials with high resolution

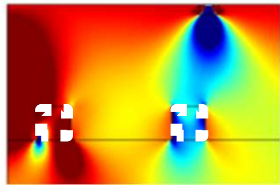
Suitable for alignment, overlay and defect characterization applications

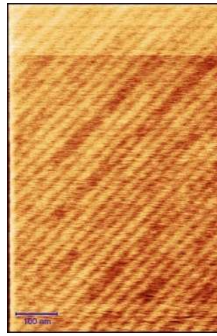
SubSurface Probe Microscopy can also extract structural parameters such as CD height or width

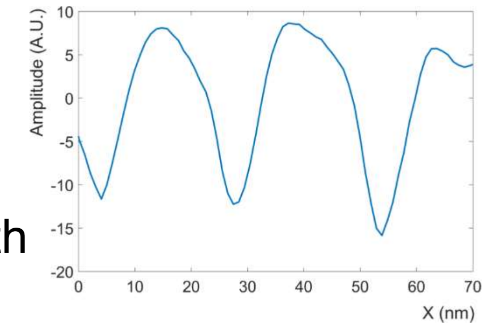


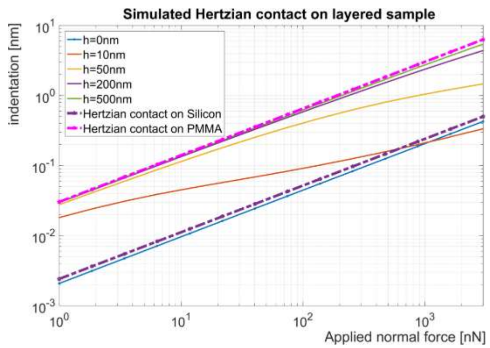






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# THANK YOU FOR YOUR ATTENTION