



QUANTITATIVE TOMOGRAPHY WITH SUBSURFACE SCANNING ULTRASOUND RESONANCE FORCE MICROSCOP

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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

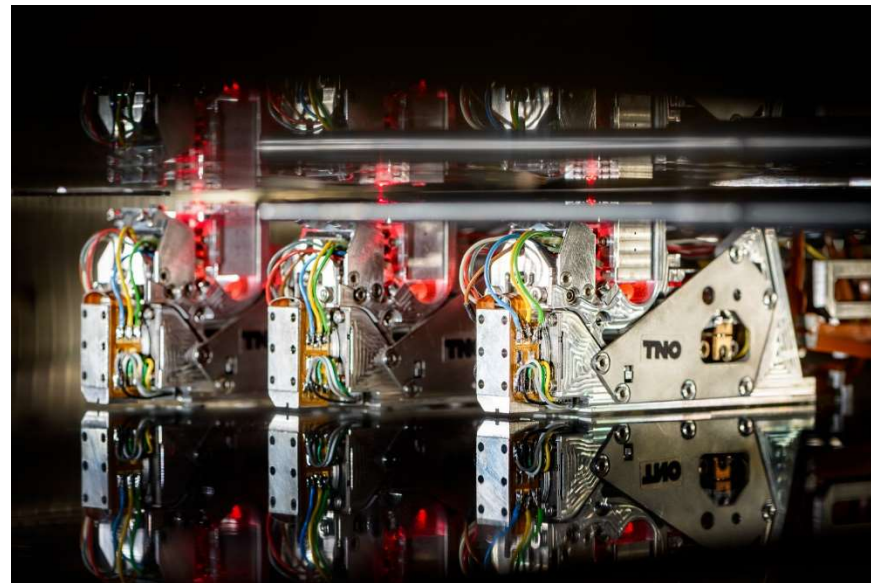
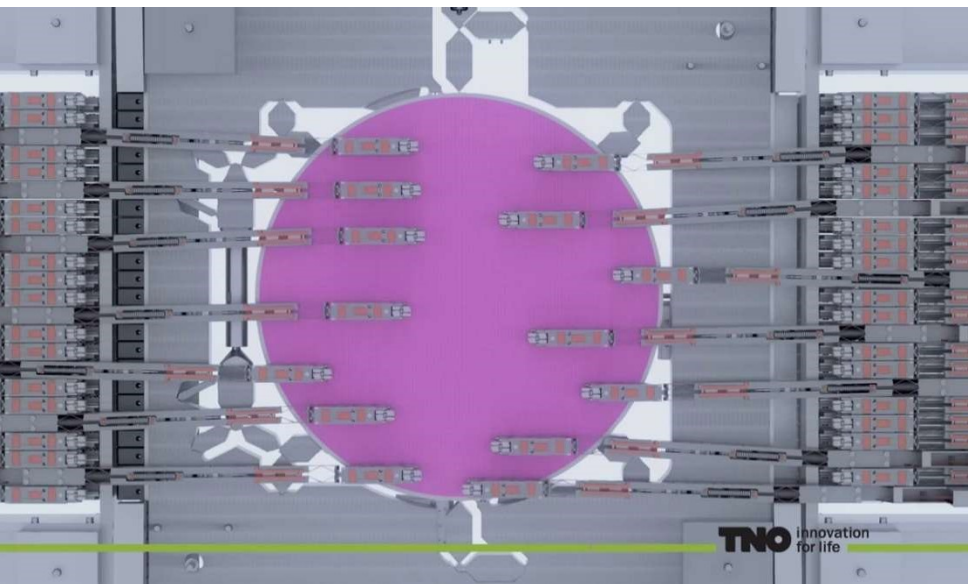
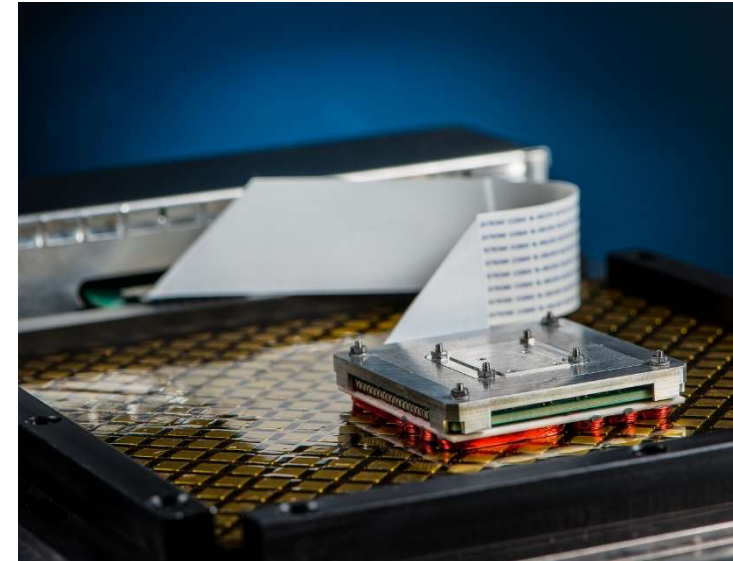
- › About NOMI
 - › SPM platforms
 - › SPM modalities for metrology

- › 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)

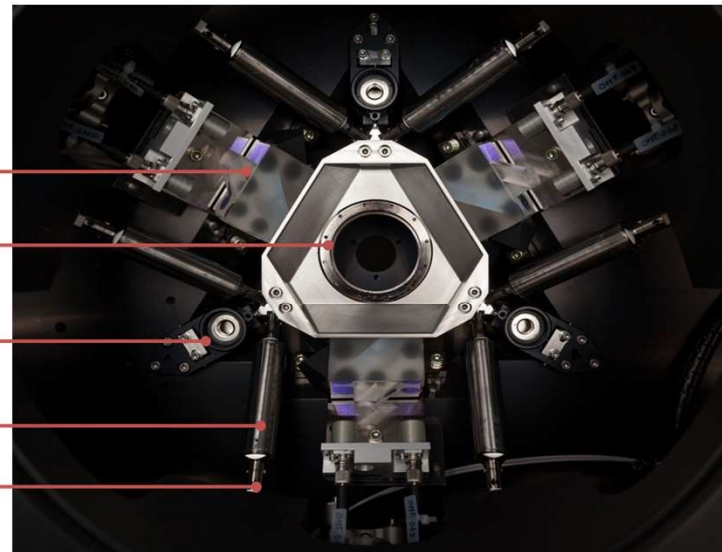
▶ NOMI SPM Platforms:

- ▶ **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 aberrations across a full die

- 2 DOF Interferometer
- Moving platform with mounting ring for AFM head
- Magnetic gravity compensator
- Flexural strut
- Location of the voice coil actuator



Poster: 10959-85

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. The 6-DOF hexapod positioning stage (Figure 2) enables highly accurate positioning of the probe with respect to the sample substrate. In the hexapod stage, an AFM head (Figure 3) is mounted that scans the product and marker features. The AFM head is easily removable from the stage and is designed for low power dissipation and high stability.



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

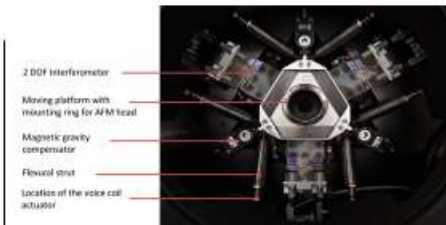


Figure 3: Hexapod stage in the LDR-AFM

Recent Developments and First Results
In the current work, first results from the LDR-AFM are presented. With the integrated AFM measurement head the first AFM characterization measurements are performed. Deflection distance curves are measured (Figure 4), and confirm the expectations on low noise levels and correct AFM head functionality. Furthermore, control relevant identification is performed to know the tip-sample and cantilever dynamics (Figure 4). High reproducibility for varying setpoints indicate strong linearity. Furthermore, a measured line topology is illustrated on the finally long-term drift is assessed by measuring the interferometer signals over multiple hours closed loop (Figure 5), showing impressive stability and indicating < 50 pm/min drift.

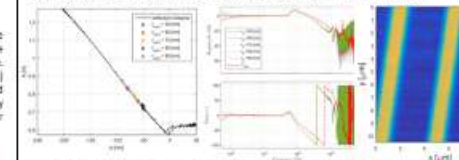


Figure 4: LDR-AFM Deflection distance curve and identification (left). Topology image (right).

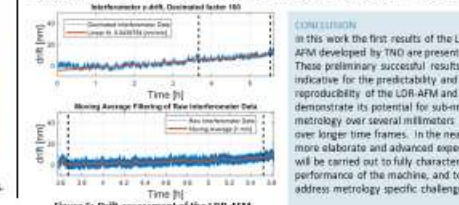


Figure 5: Drift assessment of the LDR-AFM.

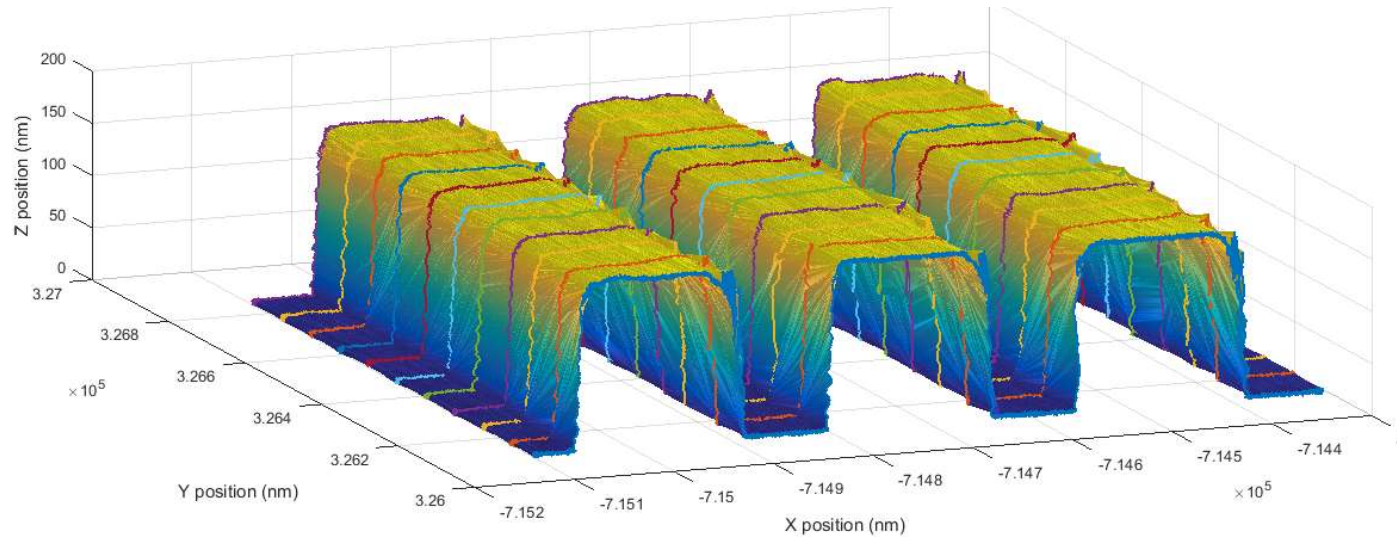
CONCLUSION
In this work the first results of the LDR-AFM developed by TNO are presented. These preliminary successful results indicate for the predictability and reproducibility of the LDR-AFM and demonstrate its potential for sub-metrology over several millimeters over longer time frames. In the near future more elaborate and advanced experiments will be carried out to fully characterize the performance of the machine, and to address metrology specific challenges.

▶ NOMI SPM Platforms:

- ▶ High Throughput SPM
- ▶ Large Dynamic Range AFM

▶ NOMI SPM modalities

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



87 degrees sidewall angle!
150 nm feature height

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



▶ NOMI SPM Platforms:

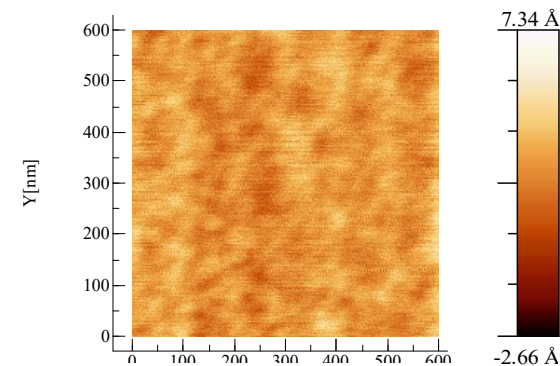
- ▶ High Throughput SPM
- ▶ Large Dynamic Range AFM

▶ NOMI SPM modalities

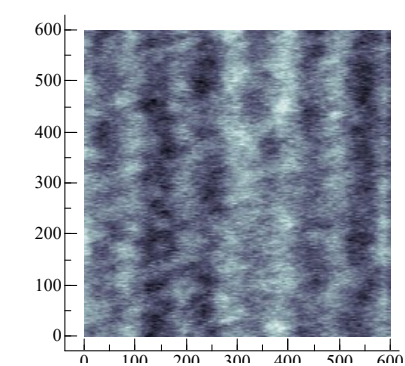
- ▶ High Aspect Ratio
- ▶ SubSurface SPM
- ▶ **Nanolithography**
- ▶ **contact holes**
- ▶ NEW: Chemical Characterization (hydrophobicity)

**Before
drilling**

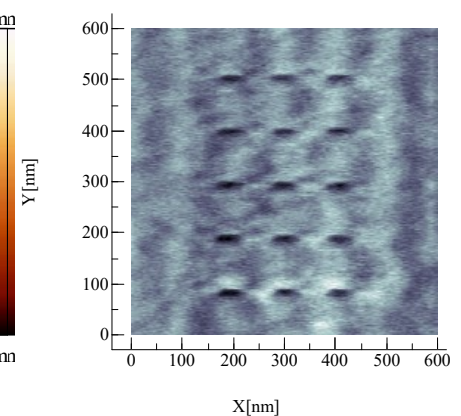
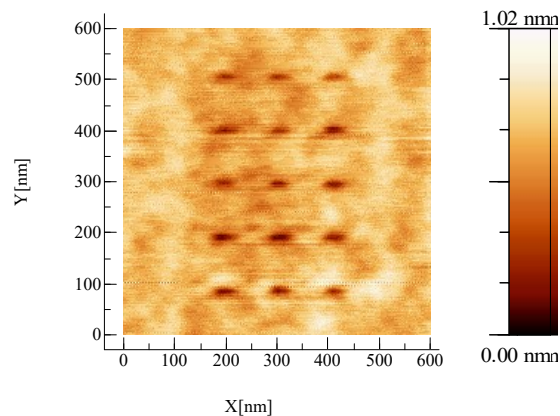
Surface Topography



Subsurface phase im



**After
drilling**

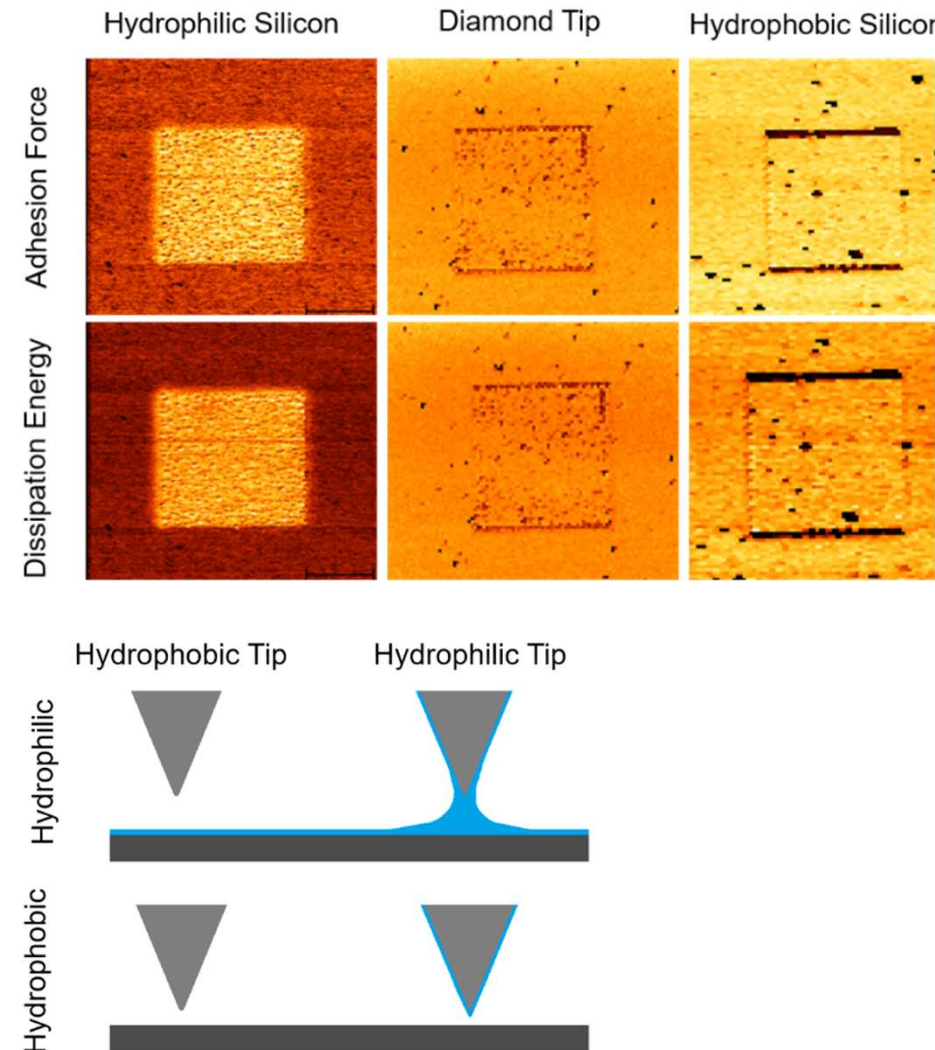


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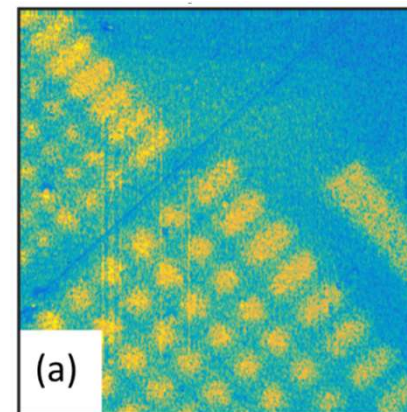
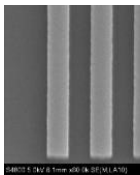
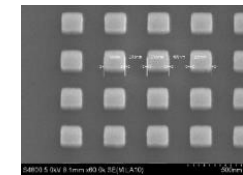
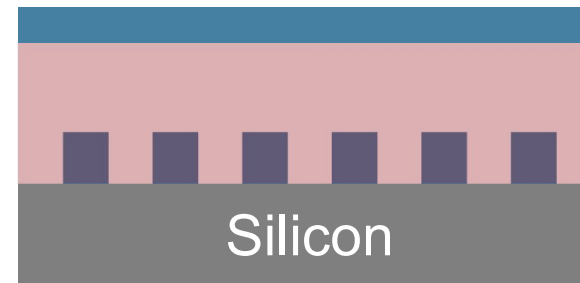
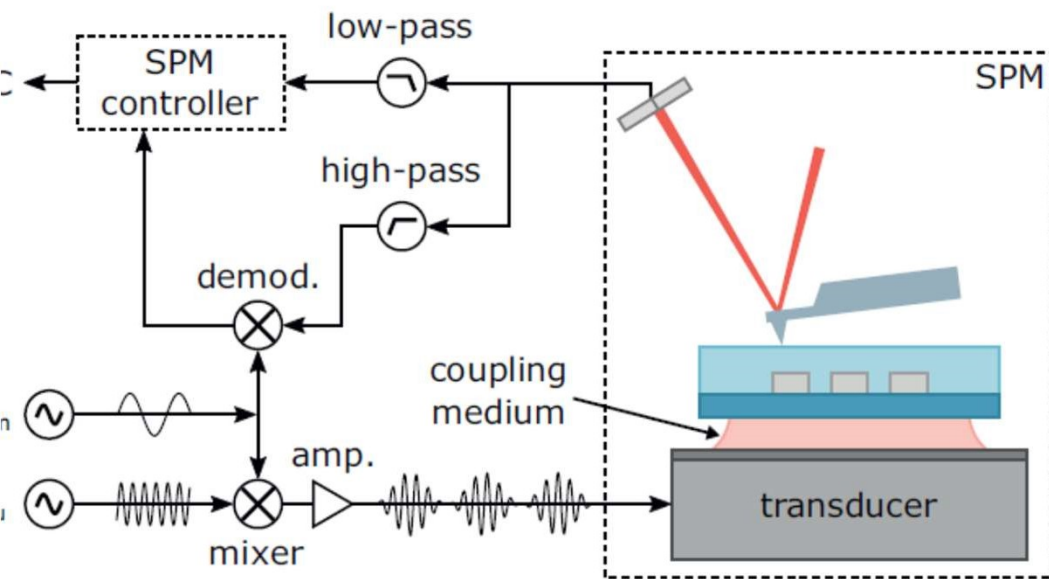
- › High Aspect Ratio
- › SubSurface SPM
- › Nanolithography
- › **NEW: Chemical Characterization**
 - › **low k materials (hydrophobicity)**
 - › **characterization of contaminations**
 - › ...?



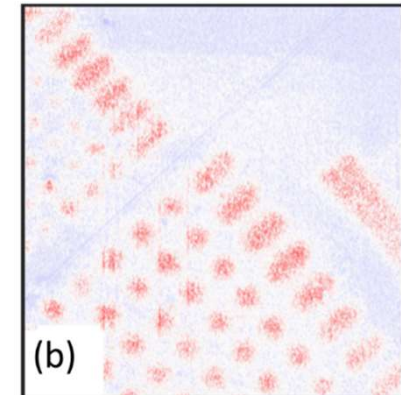
QUANTITATIVE SUBSURFACE SCANNING PROBE MICROSCOPY

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SUBSURFACE SCANNING PROBE MICROSCOPY



Amplitude

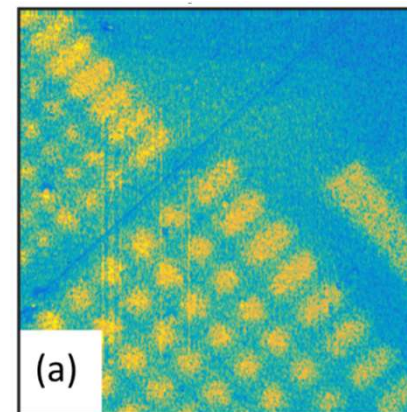
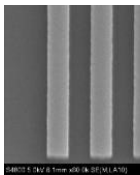
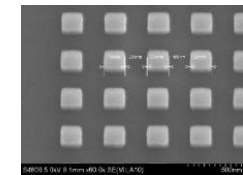
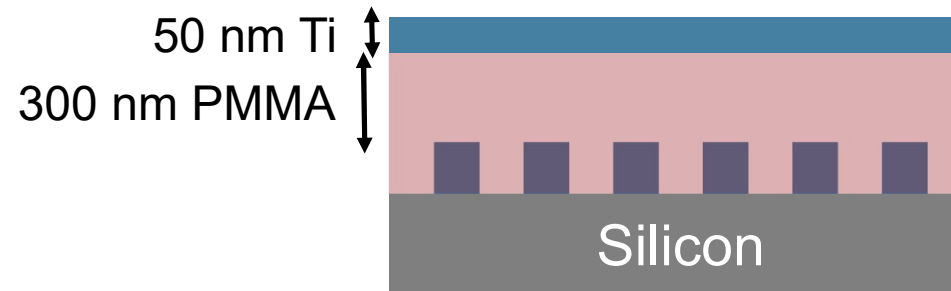


Phase

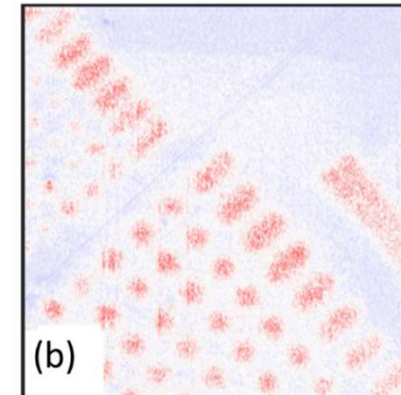
SUBSURFACE SCANNING PROBE MICROSCOPY

› SSPM Achievements

- › **Imaging of deep structures**
- › Imaging of small structures
- › Imaging of defects



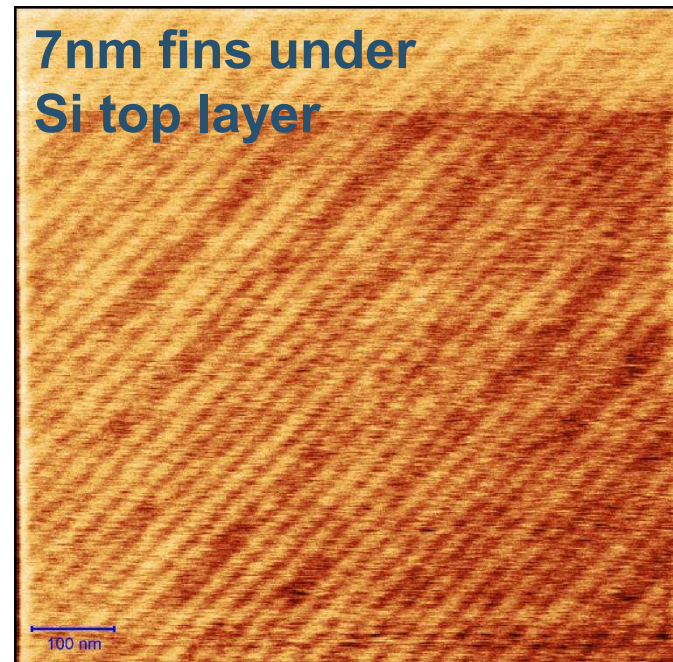
Amplitude



Phase

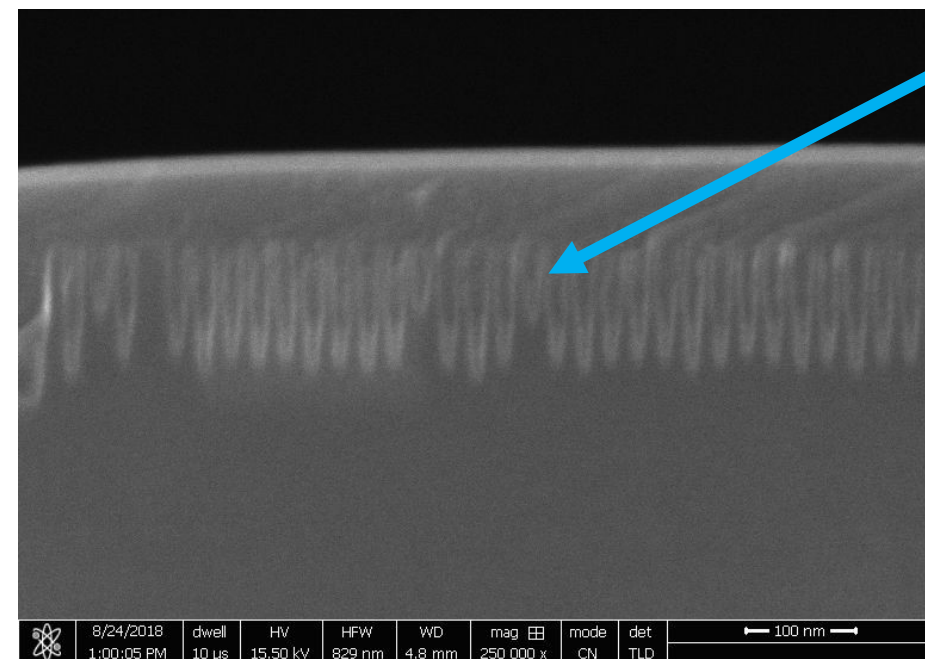
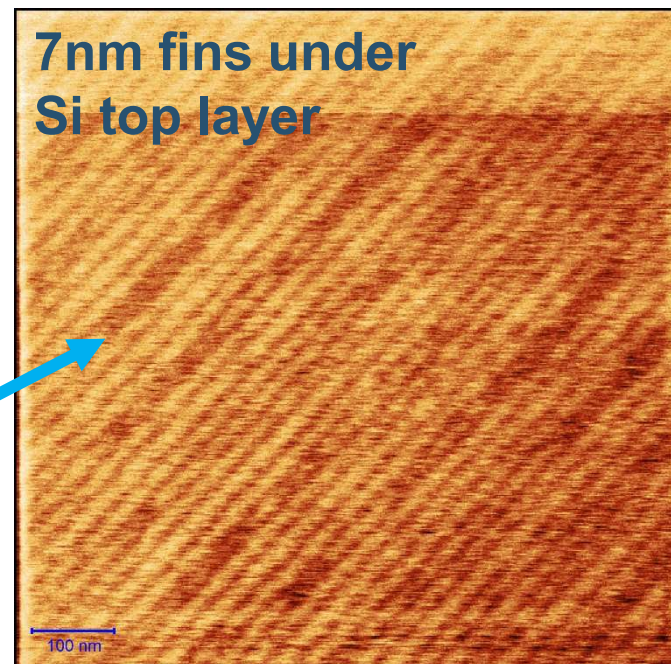
SUBSURFACE SCANNING PROBE MICROSCOPY

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



SUBSURFACE SCANNING PROBE MICROSCOPY

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



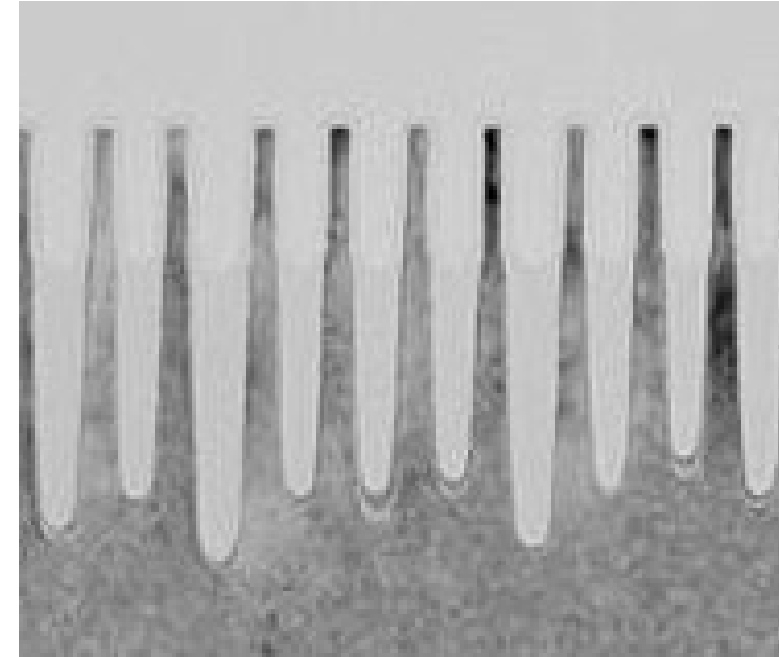
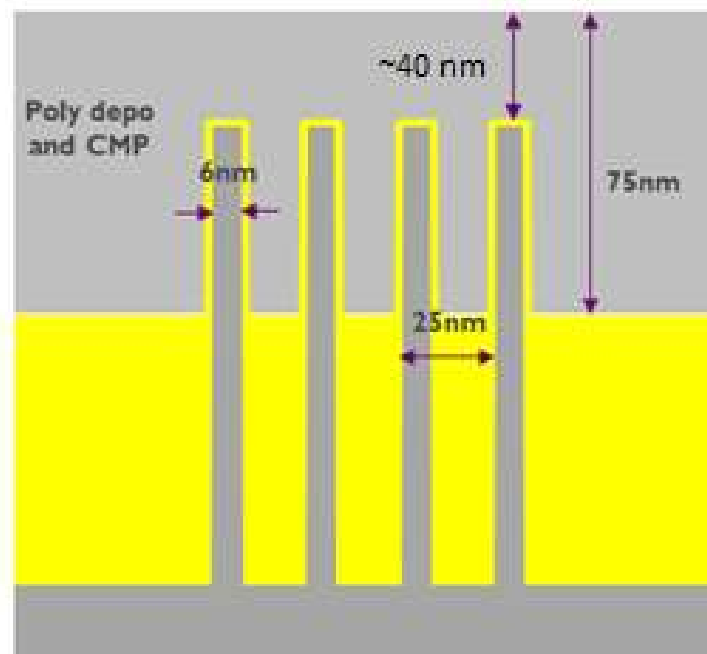
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1:00:05 PM	10 μ s	15.50 kV	829 nm	4.8 mm	250 000 x	CN	TLD

100 nm

QUANTIFYING SSPM

How to obtain Critical Dimensions from SSPM data?

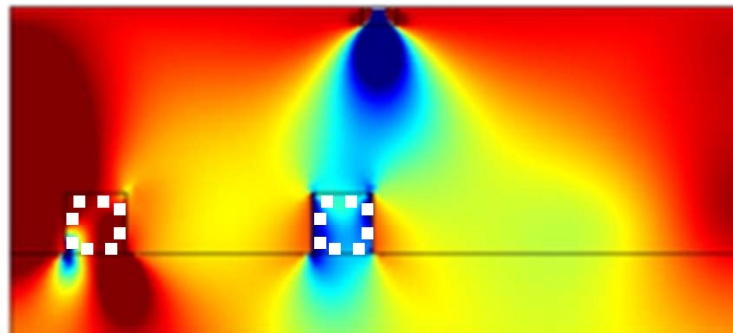
- › Combine Finite Element Modeling with quantifiable measurements



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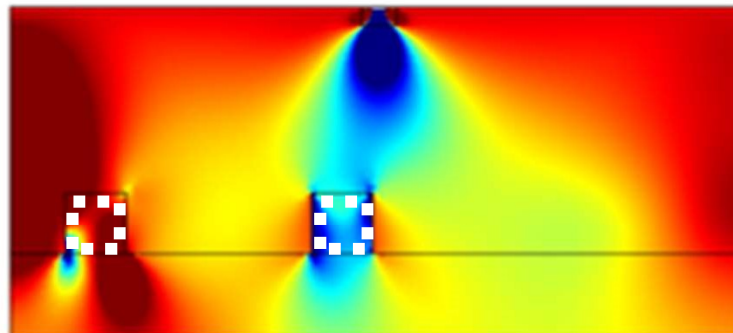
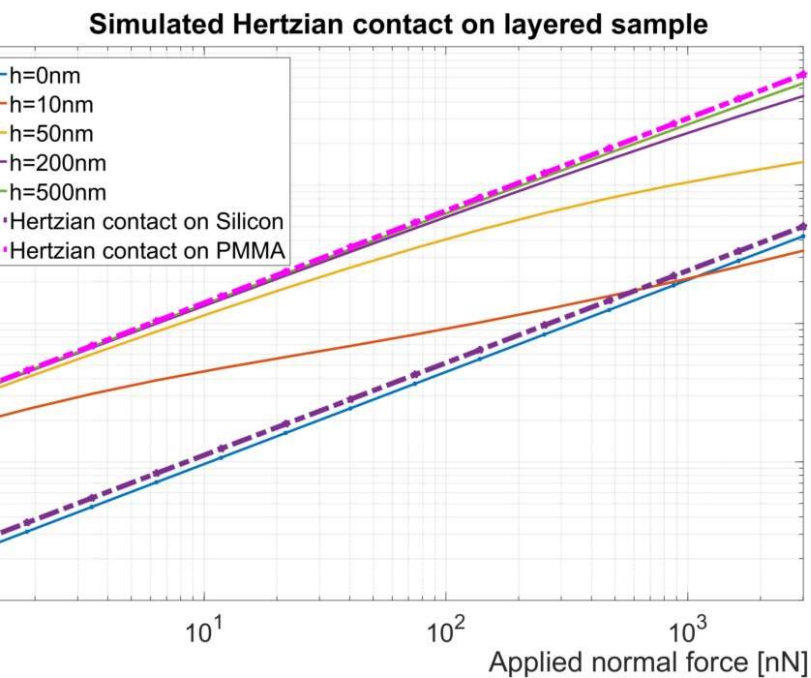
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QUANTIFYING SSPM

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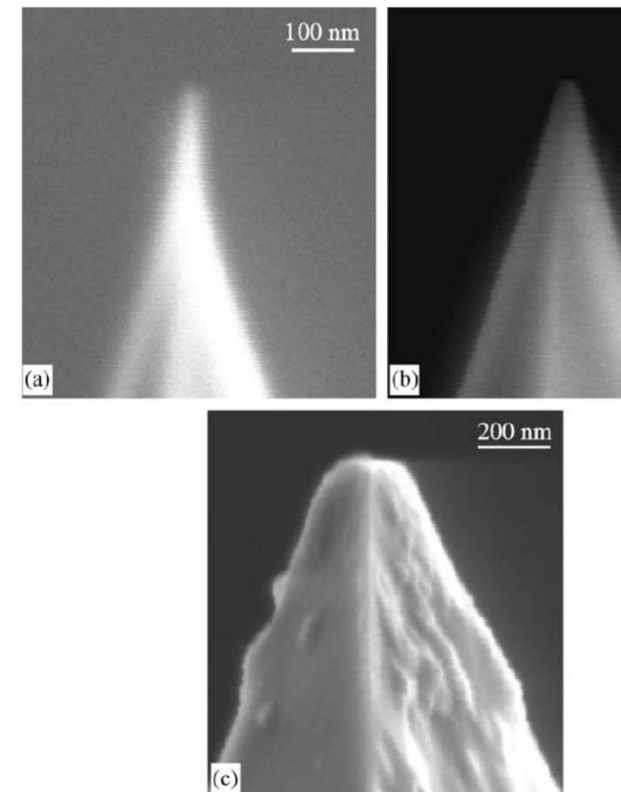
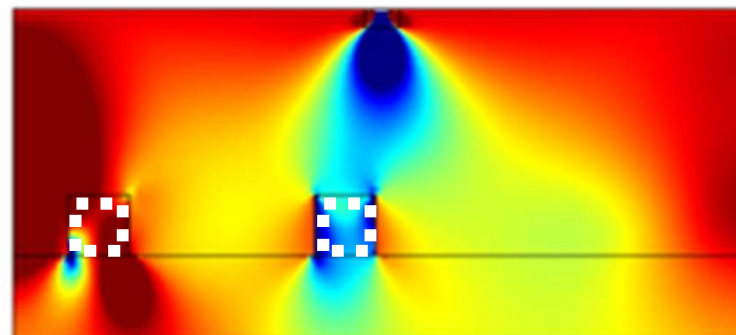
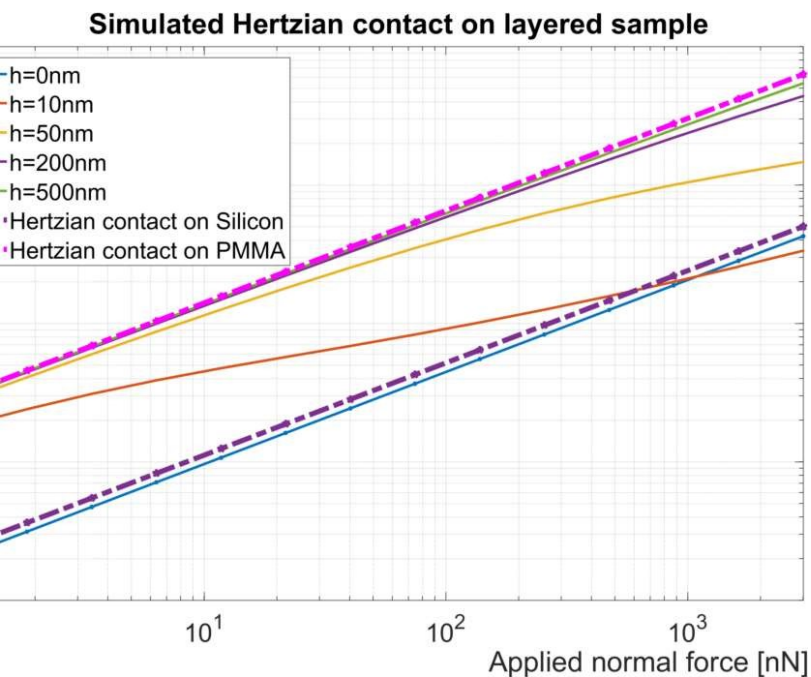


Fig. 2. SEM images of brand new tips revealing the wide d possible new-tip geometry. The scale is the same for all three. Sharp tip with radius of curvature $R < 10\text{ nm}$. (b) Tip with R Very blunt tip with possible surface contamination not seen i

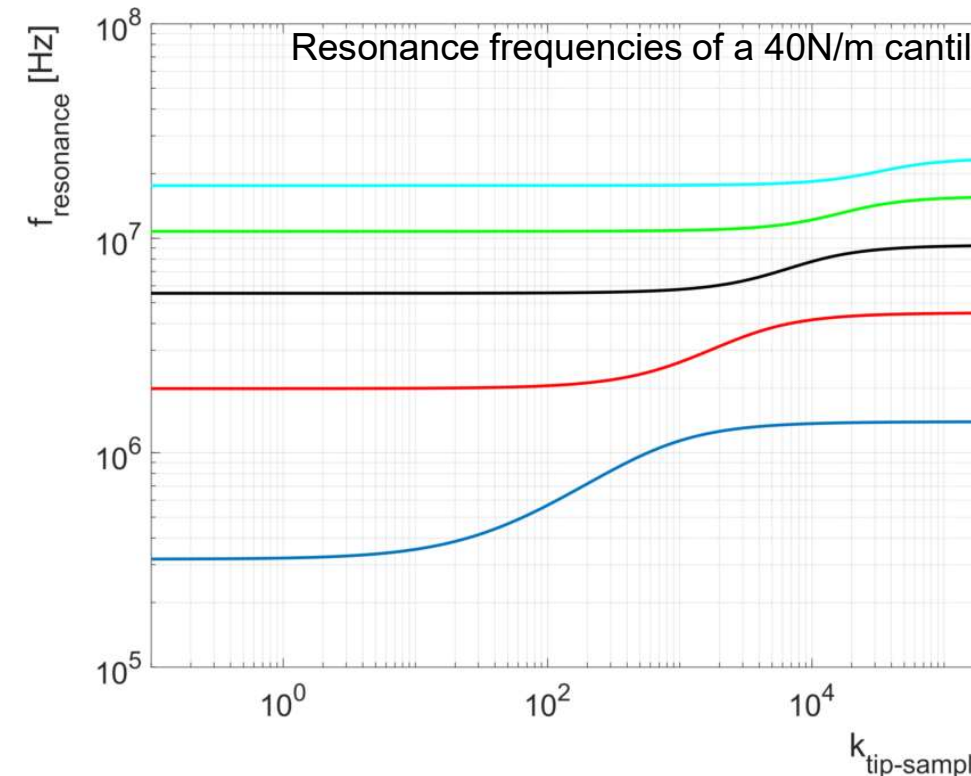
QUANTIFYING SSPM

How to obtain Critical Dimensions from SSPM data?

- Combine Finite Element Modeling with quantifiable measurements

Euler Bernoulli beam equation:

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

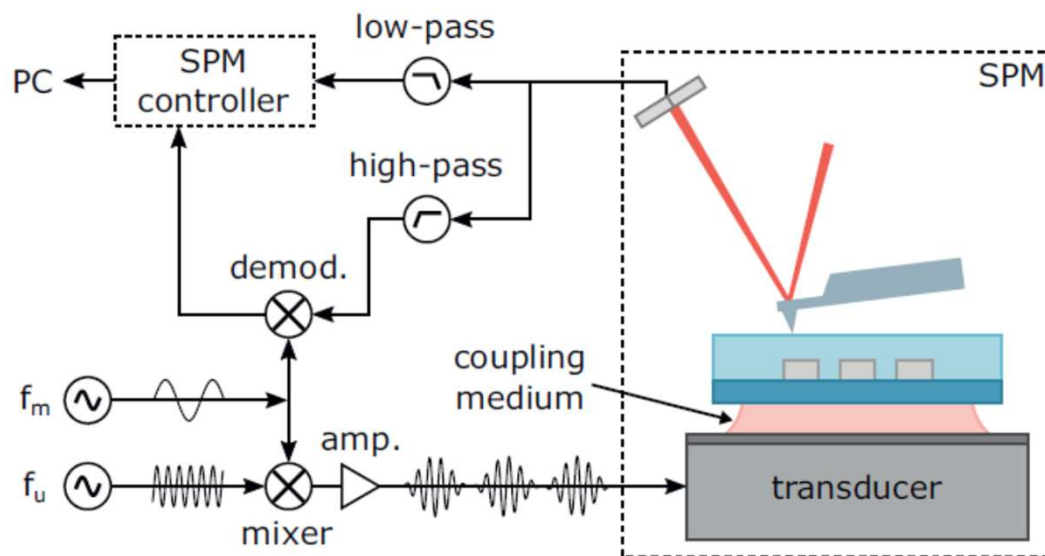


Boundary	w'''	w''	w'	w
Clamp			$\Delta w' = 0^*$	$\Delta w = 0^*$
Simple support		$\Delta w'' = 0$	$\Delta w' = 0$	$\Delta w = 0^*$
Point force	$\Delta w''' = \lambda$	$\Delta w'' = 0$	$\Delta w' = 0$	$\Delta w = 0$
Point torque	$\Delta w''' = 0$	$\Delta w'' = \tau$	$\Delta w' = 0$	$\Delta w = 0$
Free 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	$w''' = 0$	$w'' = \pm \tau$		

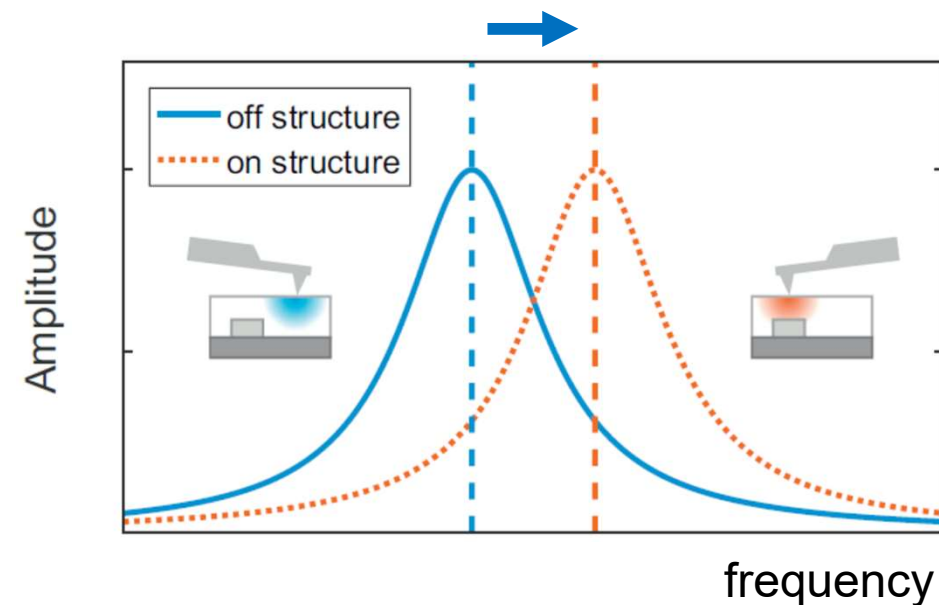
QUANTIFYING SSPM

How to obtain Critical Dimensions from SSPM data?

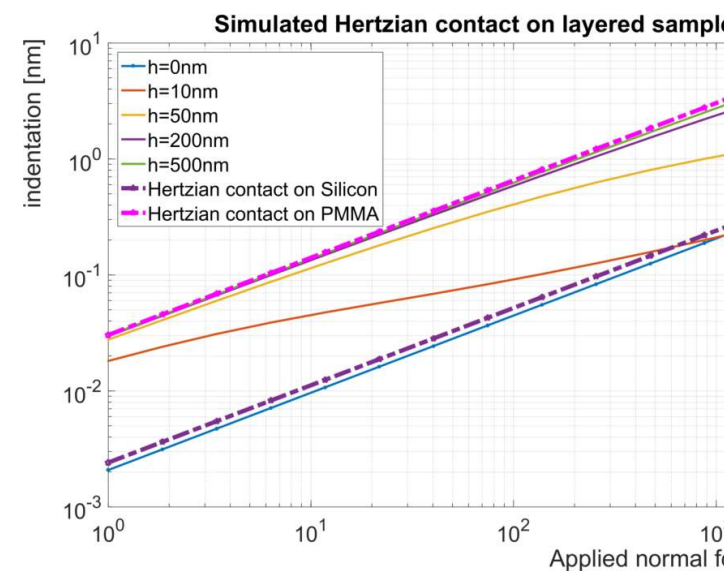
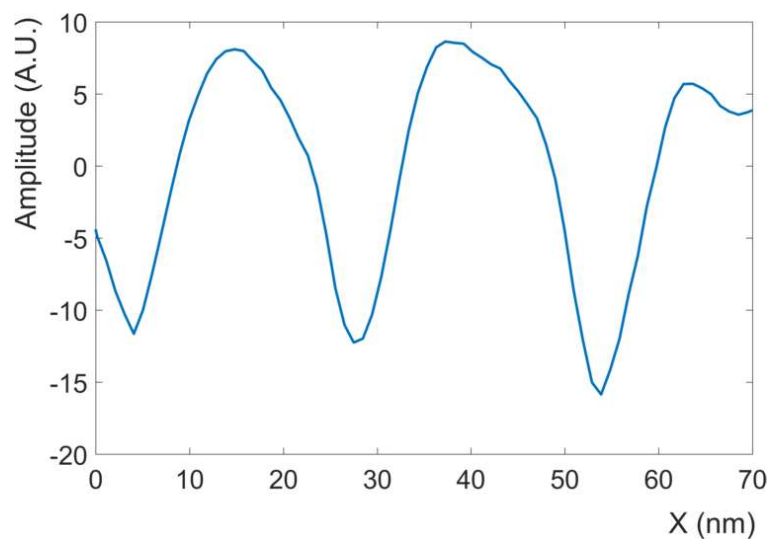
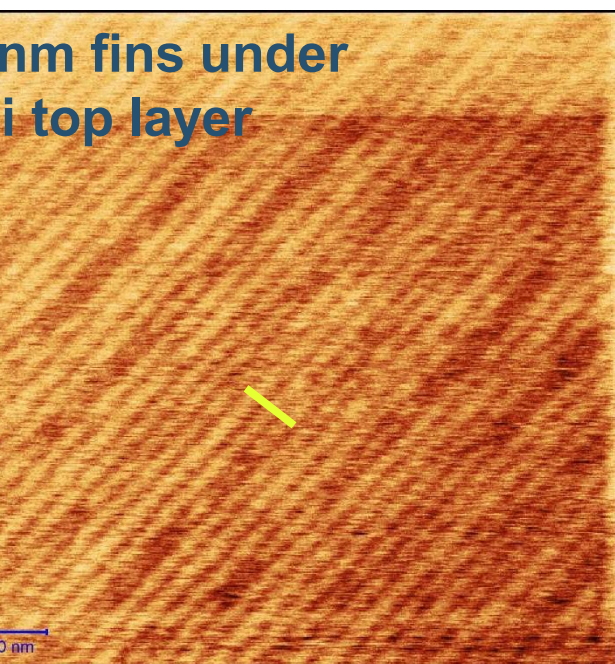
- Combine Finite Element Modeling with quantifiable measurements



Next talk: How to measure Δf_{res}
and how not to have a transducer
below the wafer



PRELIMINARY RESULTS



CONCLUSIONS

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

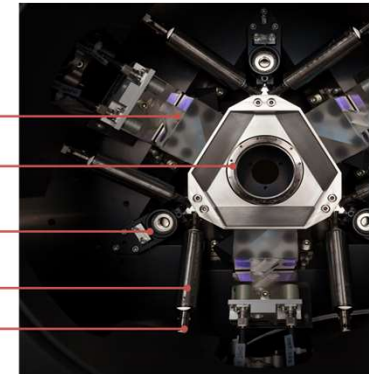
SubSurface Probe Microscopy visualizes structures under layers of arbitrary materials with high resolution

Suitable for alignment, overlay and defect characterization applications

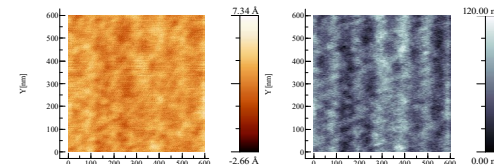
SubSurface Probe Microscopy can also extract structural parameters such as CD height or width



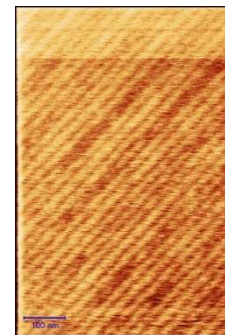
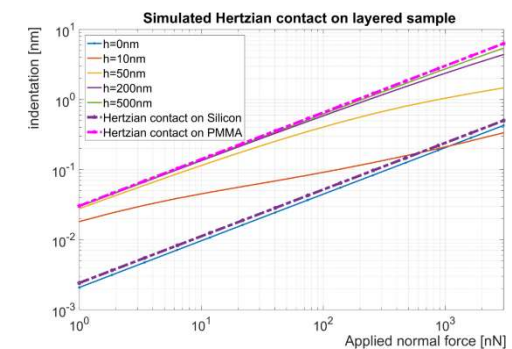
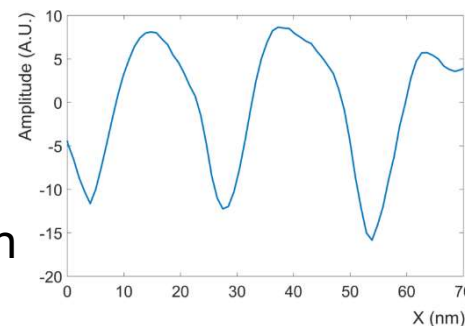
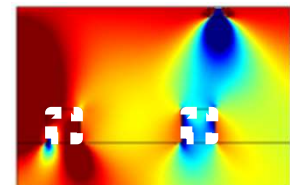
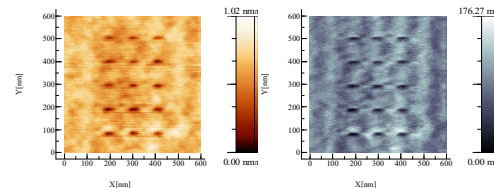
2 DOF Interferometer
Moving platform with mounting ring for AFM head
Magnetic gravity compensator
Flexural strut
Location of the voice coil actuator



Before drilling



After drilling



ACKNOWLEDGEMENT



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› **THANK YOU FOR YOUR ATTENTION**

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