3D nanoscale metrology in advance semiconductor process control

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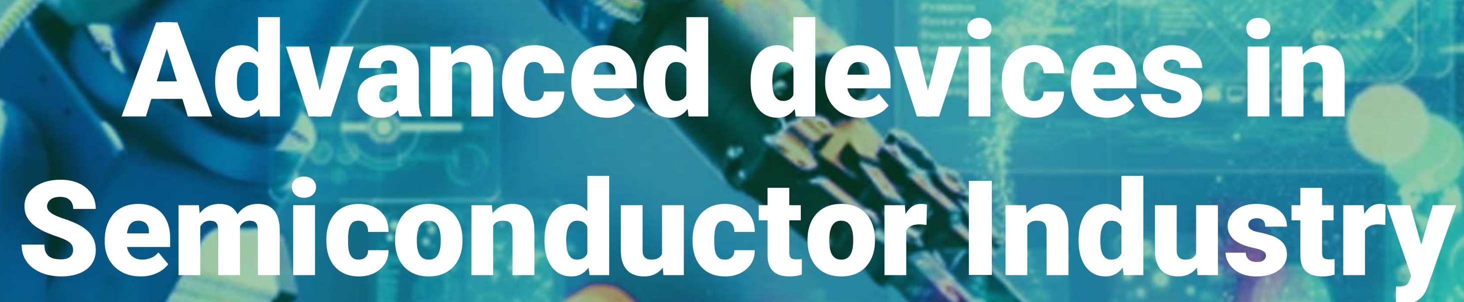

Advanced devices in
Semiconductor Industry

Industrial and societal challenges push innovation and growth in semiconductor device manufacturing (new nodes and 3D)

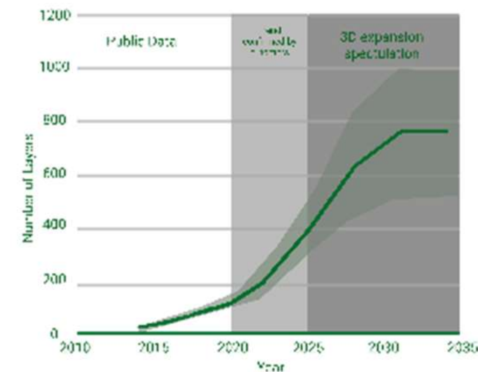
Market Trends

Key Industries

Large market opportunity benefitting from the industry push towards smaller and 3D structures

Key Enabler: Leading-edge Process Technology nodes

	N7 vs. 16FF+	N7 vs. N10	N7P vs. N7	N7+ vs. N7	N5 vs. N7	N5P vs. N5	N3 vs. N5	<1nm
Power	-60%	-40%	-10%	-15%	-30%	-10%	-25-30%	"Promising 2D materials identified.. Maintains high (mobility) at channel thickness below 1 nm.. Carbon Nano Tubes..integrate d with Si CMOS.."
Performance	+30%		+7%	+10%	+15%	+5%	+10-15%	
Logic area					0.55		0.58	
Reduction (%)	-70%	>37%		-17%	-45%		-42%	
Density					1.8x		1.7x	
High Volume				Q219	Q220		H222	



Moore's Law is brighter than ever

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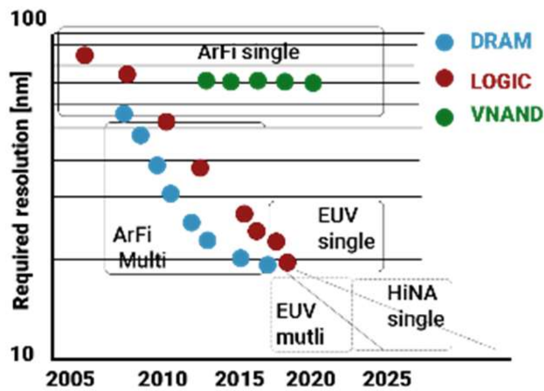
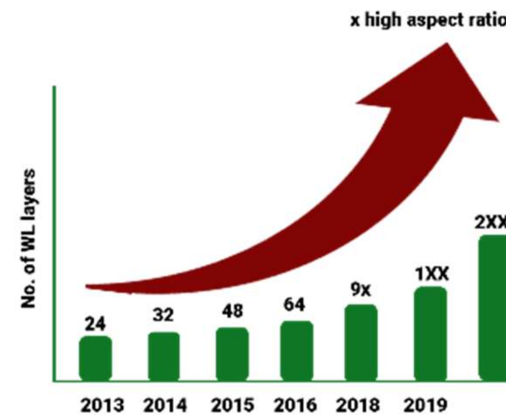
Advanced devices, advanced process control challenges

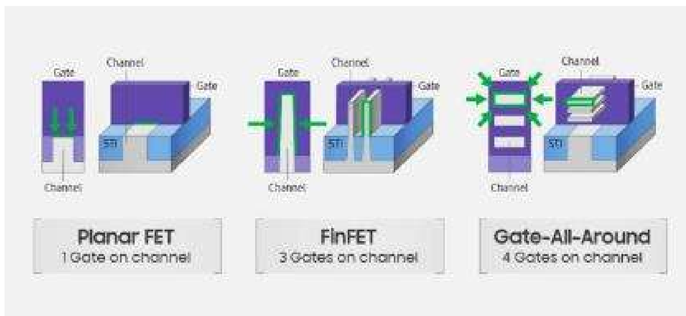
Aggressive scaling

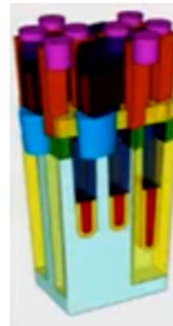


Aggressive HAR



3D structure complexity





New Material

- High-K
- Low-K
- Low resistance

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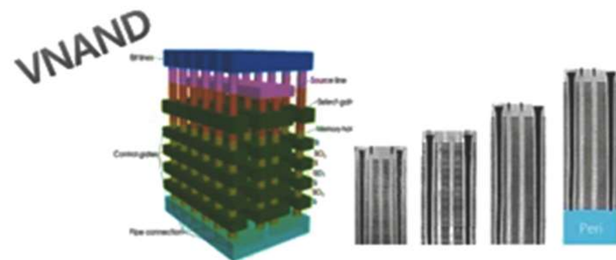
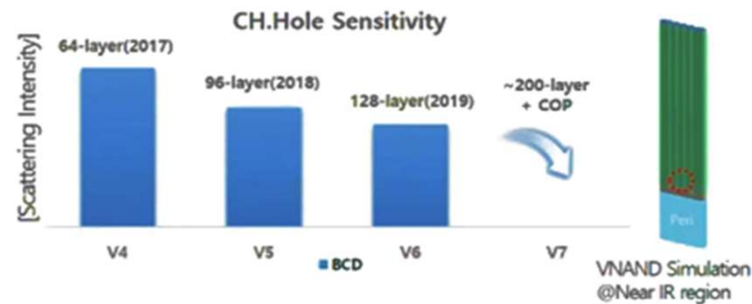
Optical Technology Limitation

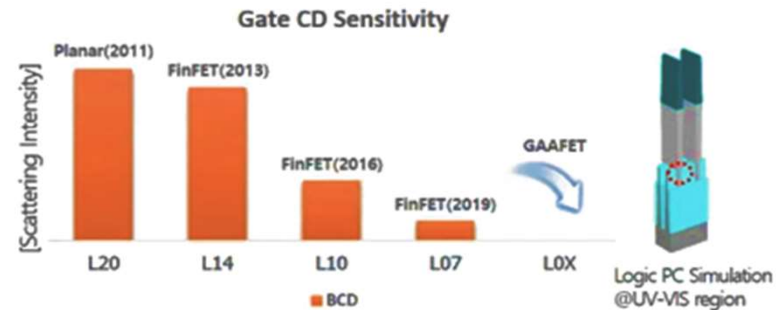
- Sensitivity limitation due to the increased complexity



- Stacking layer increase ⇒ Bottom Sensitivity ↓
  + Cell on Peri. Structure



- Structure Complexity ↑ ⇒ OCD Variables ↑
- Pattern Shrinkage ⇒ Sensitivity ↓



Courtesy of

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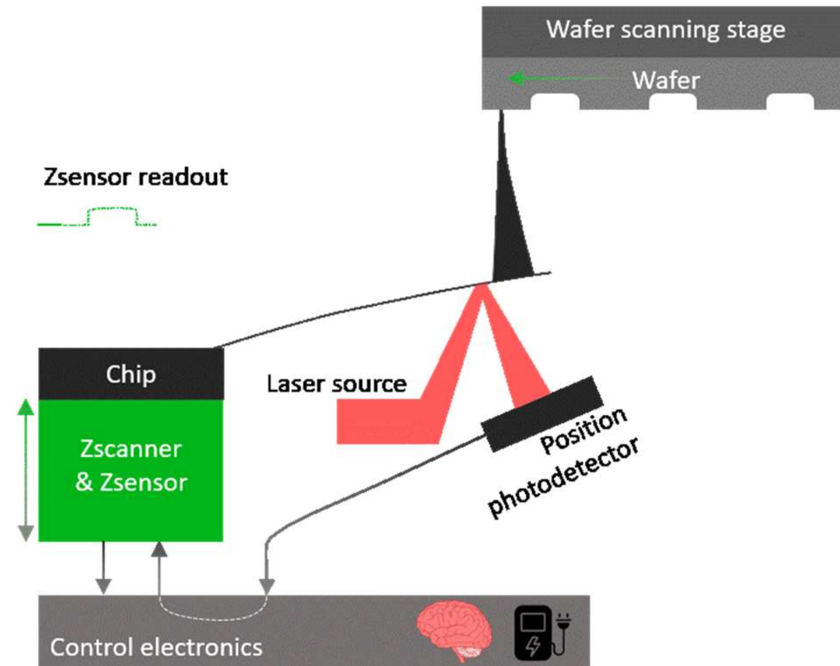
SPM/AFM

- Fundamental benefits:
  - 3D local probe (atomic scale)
  - Not subject to optical or e-beam aberrations (n&k, charging)
  - Well suited for combination with other techniques (pump-probe)



- Limitations:
  - No access to deep trenches
  - Extremely slow, not suitable for HVM

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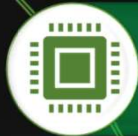
Nearfield Instruments at Glance

Nearfield Instruments at a Glance



Delivering semiconductor metrology equipment

Application focus: aggressive shrink, aggressive 3D

The Netherlands: Rotterdam and Eindhoven
South Korea: Nearfield Korea Ltd., Hwaseong

Top talent High Tech team of 130 employees

Broad & strong IP Portfolio

1. QUADRA ‘Surface Metrology’: CD, Profile, Roughness, Defects
2. SONARA ‘Subsurface Metrology’: Opaque Mask Overlay, Defects

Nearfield Instruments offers two products:

QUADRA

HT-SPM (Surface Metrology)*

SONARA

SSPM: Subsurface Metrology**

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QUADRA

QUADRA: High Throughput 3D Nanometrology

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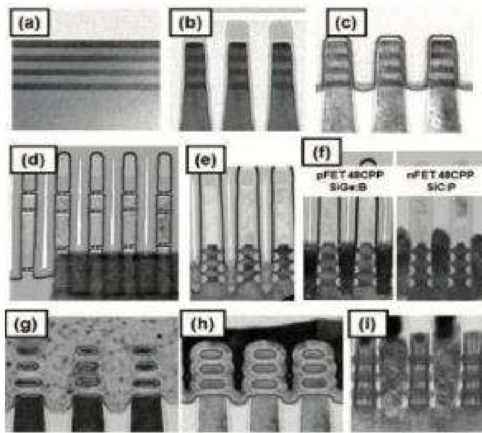
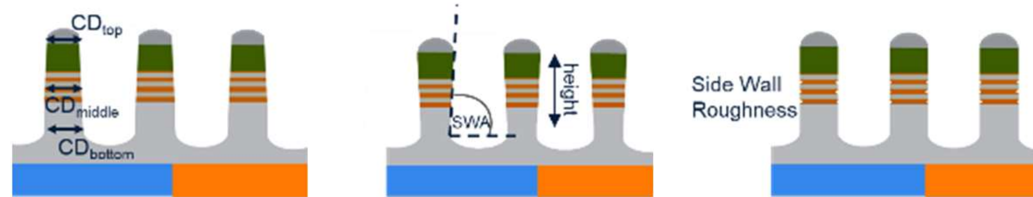
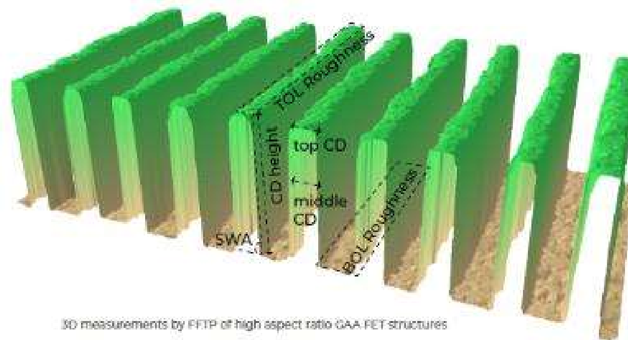
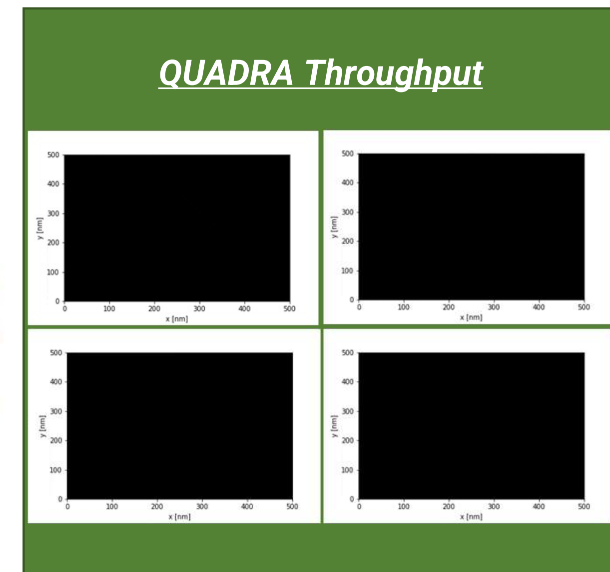
3D nanometrology of high aspect ratio devices



Gate all Around (GAA) FE







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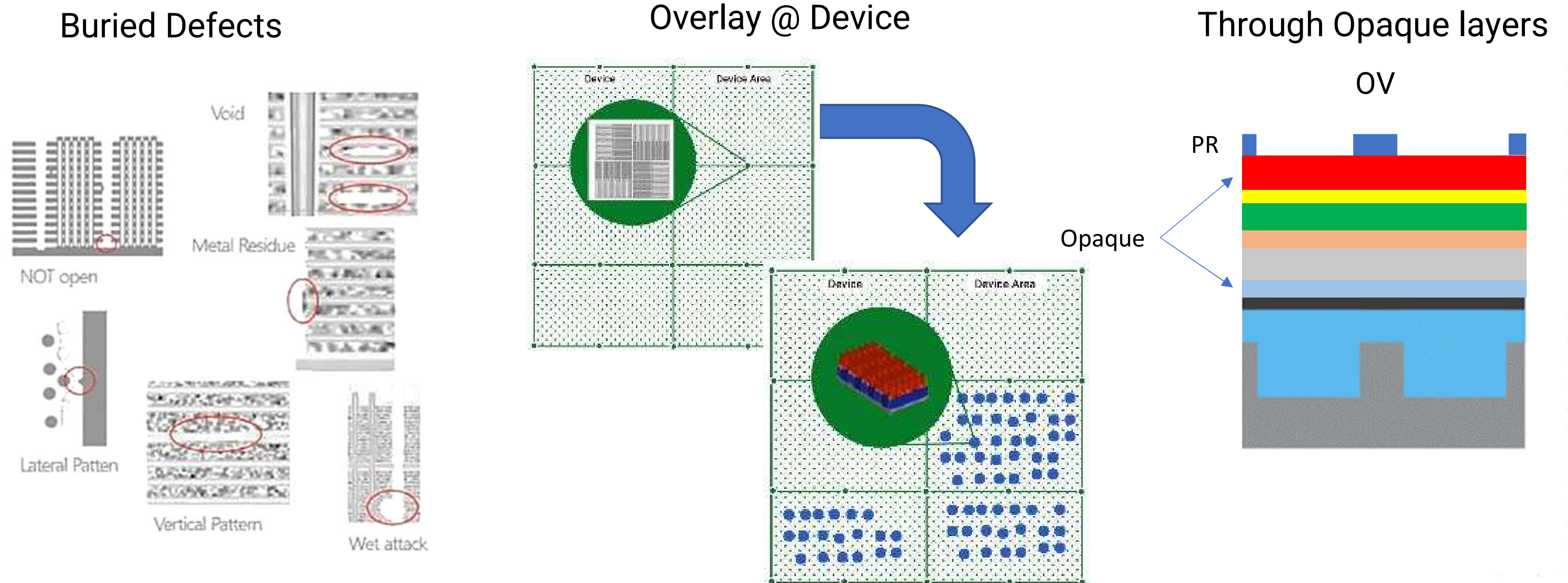
Subsurface metrology and beyond

Nondestructive subsurface metrology

‘Seeing’ with Sound, ‘Listening’ with Probe



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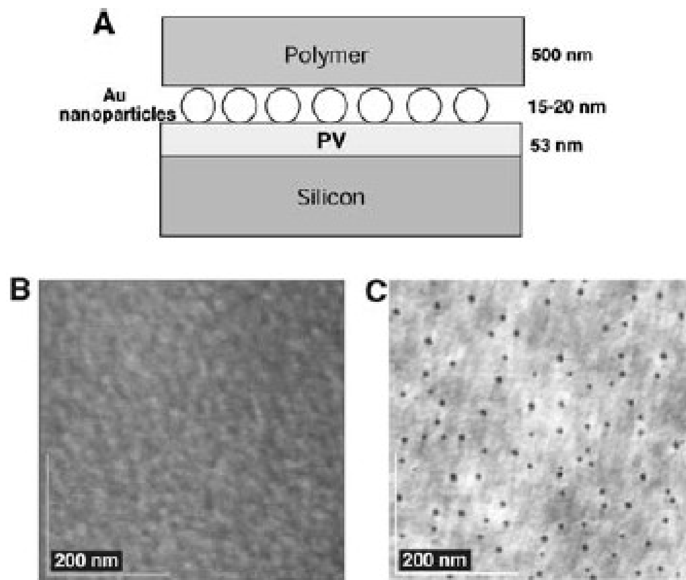
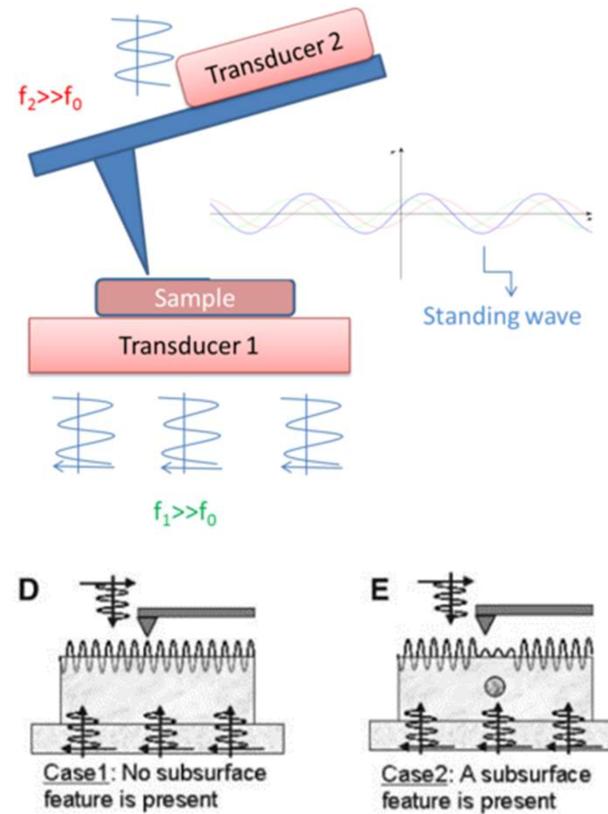
Subsurface SPM in literature





Detection of 20 nm particle buried under 500 nm layer.

Science , Vol. 310, Issue 5745, pp. 89-92, 2005

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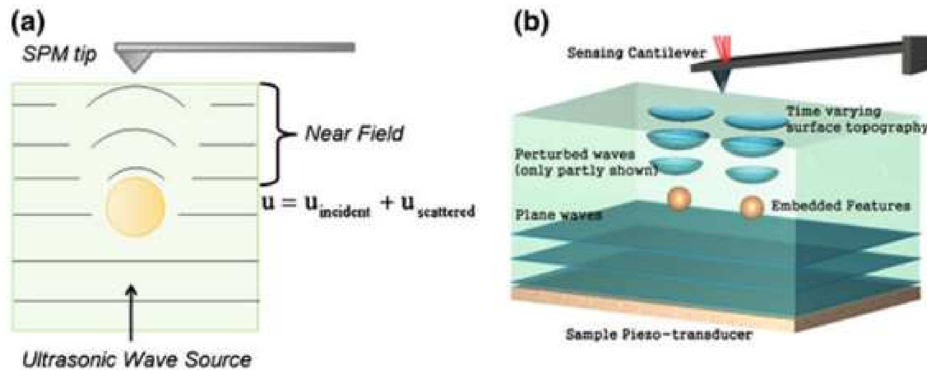
Subsurface SPM in literature (3/3)



- Ultrasound frequency: 2.1 MHz
- Particle size is 15-20 nm

7 OCTOBER 2005 VOL 310 SCIENCE

- Claimed:
- Acoustic waves propagating through bulk of a vibrated sample get perturbed by subsurface features.
- The perturbations in acoustic waves travel to top of the sample surface.
- Perturbation of waves is detected by SPM as a high resolution antenna.

Our understanding:
Contrast cannot be wave scattering @ 2 MHz, for particle sizes of 50 nm.

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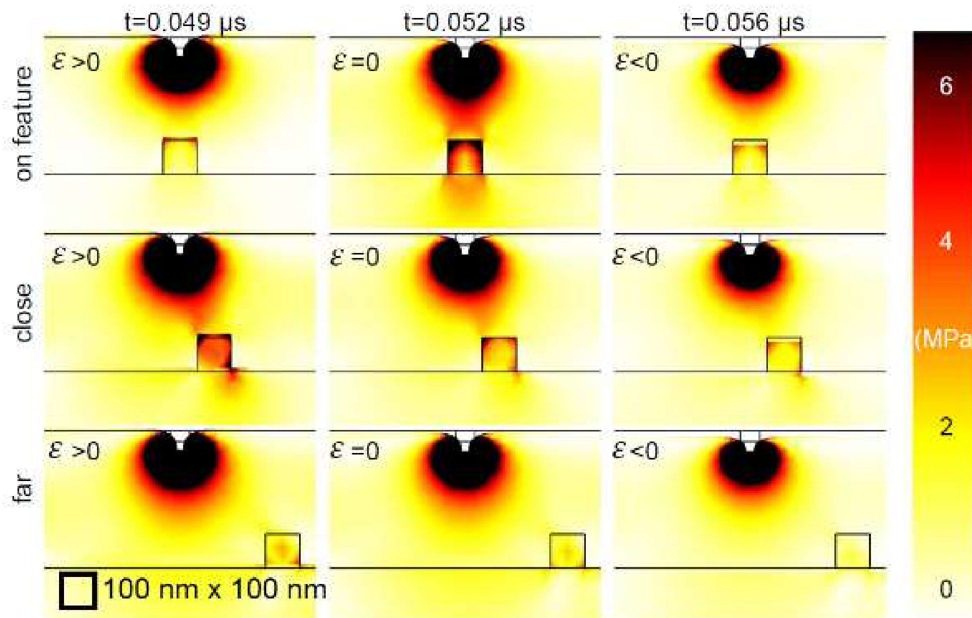
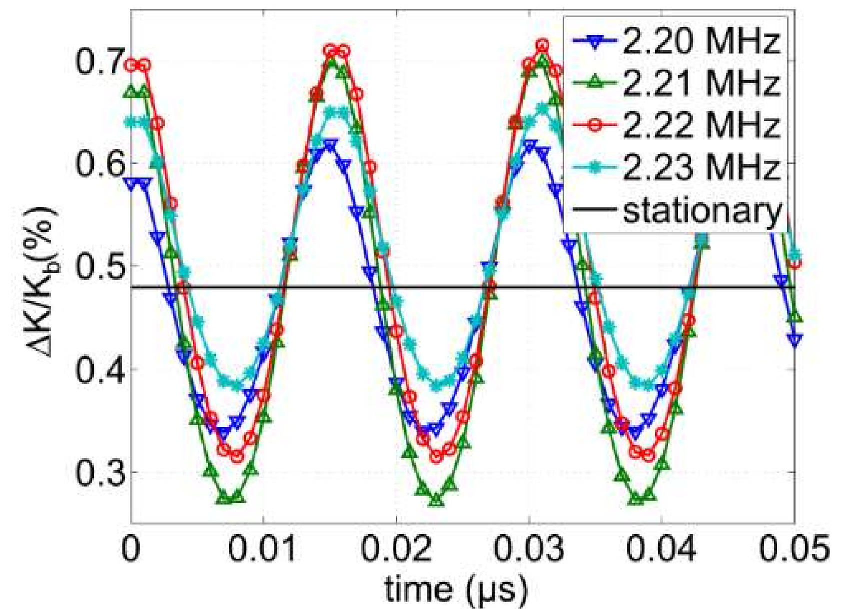
Effect of modulation frequency



Stress field for different time steps (horizontally) and different positions of the feature



Contact stiffness variation for different modulation frequencies

D. Piras et al., Journal of Physics D: Appl. Phys. 50 (2017) 235601

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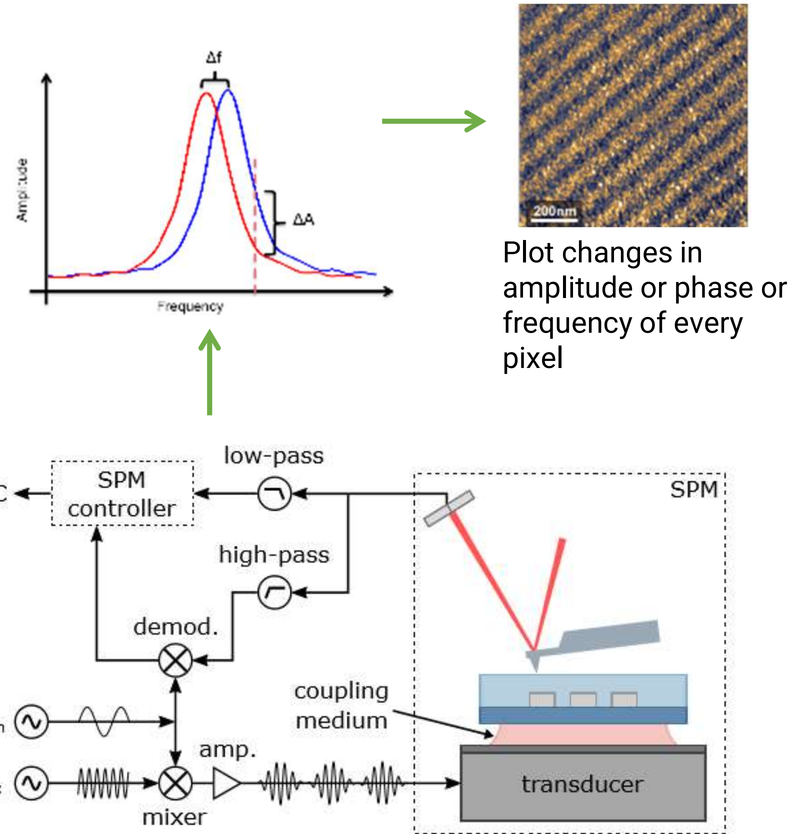
Subsurface Ultrasonic Resonance Force Microscopy

- Sample or tip is vibrated at 10s of MHz:
  - To interrogate the elasticity below the surface, by making the cantilever virtually stiffer
- Then measure the changes in resonance frequency (amplitude phase, frequency)
  - To increase the SNR
  - To increase the sensitivity to minute stiffness changes

M. Van Es *et al.*, Ultramicroscopy, 2017.



Plot changes in amplitude or phase or frequency of every pixel

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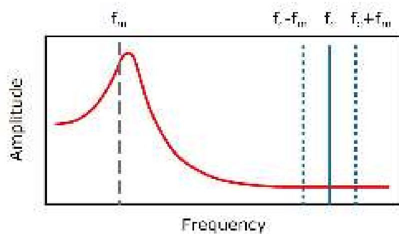
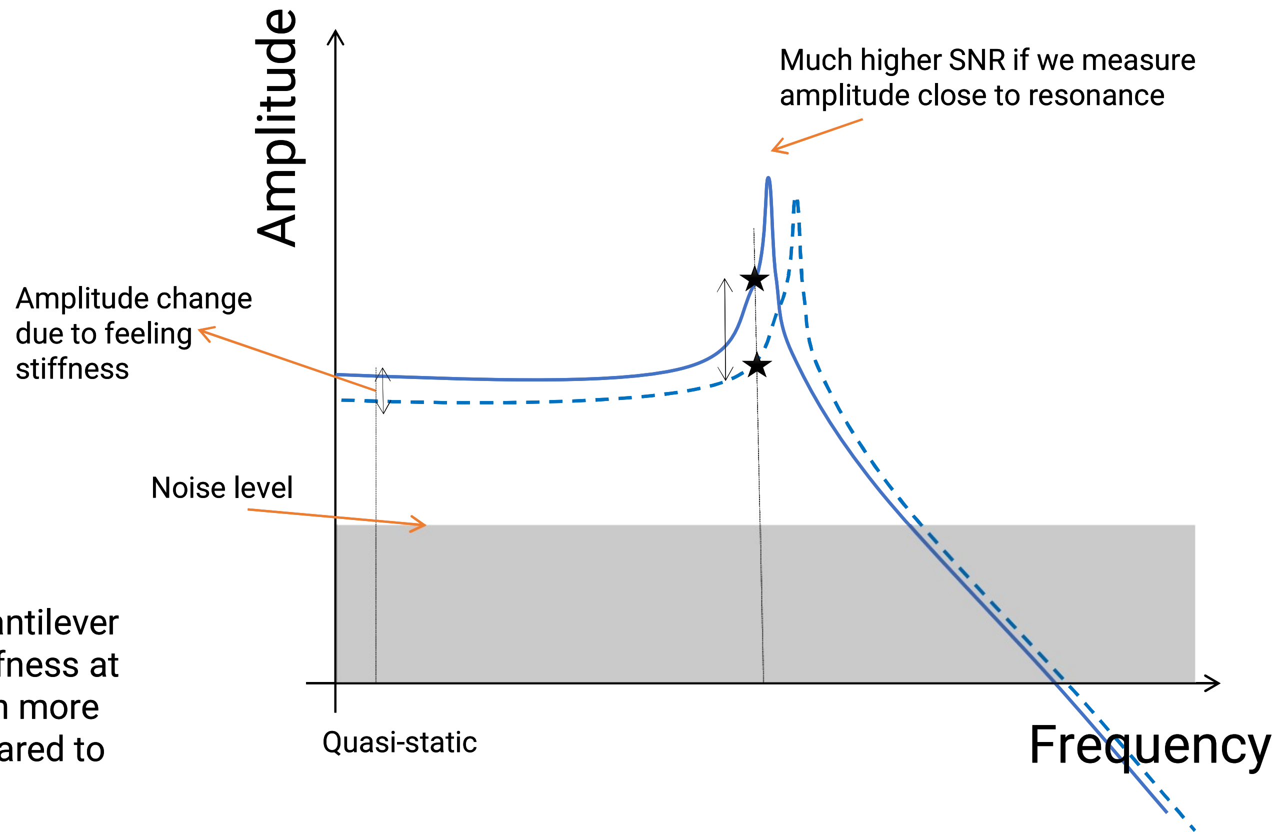
Why very high ultrasound frequency?





Conclusion:
Measuring the response of cantilever due to minute changes in stiffness at or close to resonance is much more sensitive and high SNR compared to low frequency deflection.

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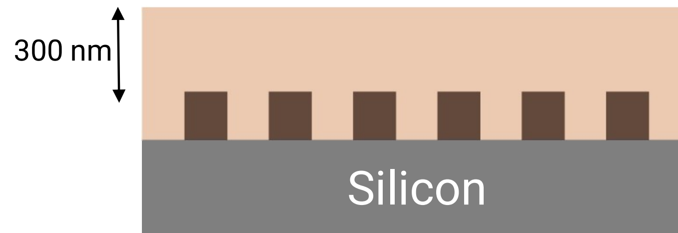
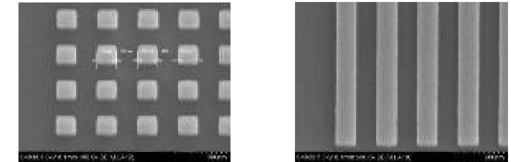
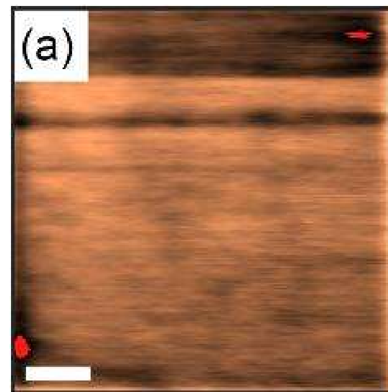
Through Layers Imaging

- Rigid structures in soft matrix
- Multilayers
- Rigid structures in rigid matrix
- Depth of imaging

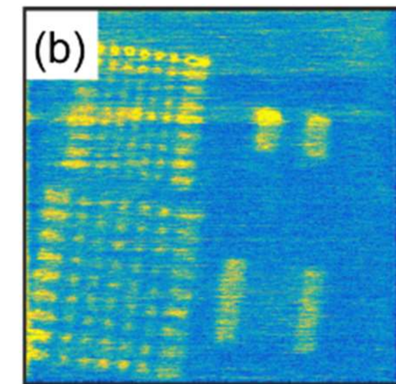
- CD, LER, LWR
- Invisible defects
- Location/pitch







Surface imaging



Through layers imaging

Piras et al., Journal of Physics D: Applied Physics 50 (23), 235601

TNO innovation for life

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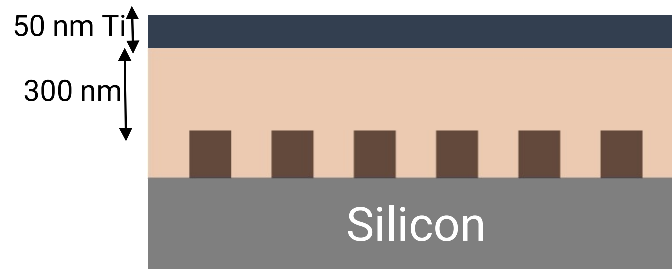
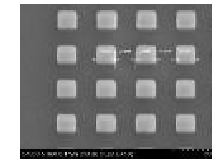
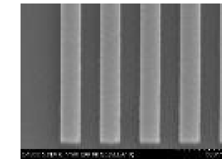
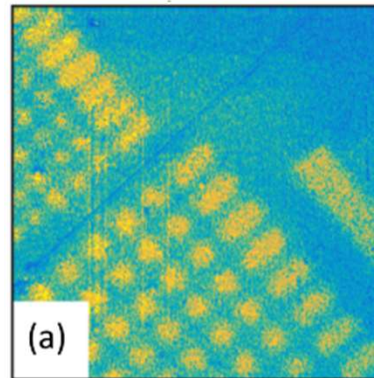
Through Layers Imaging

- Rigid structures in soft matrix
- Multilayers
- Rigid structures in rigid matrix
- Depth of imaging

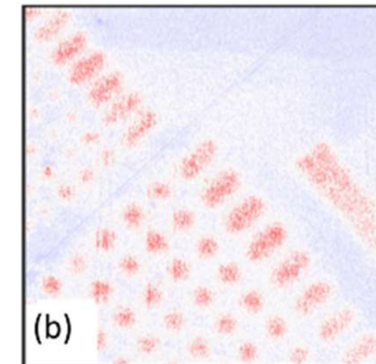








Amplitude



Phase

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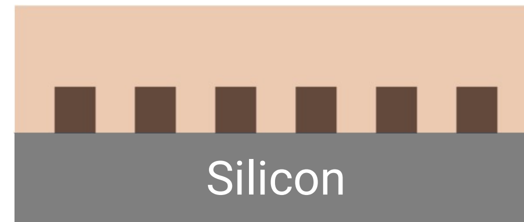
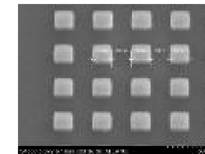
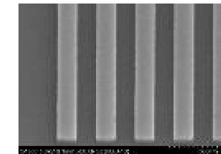
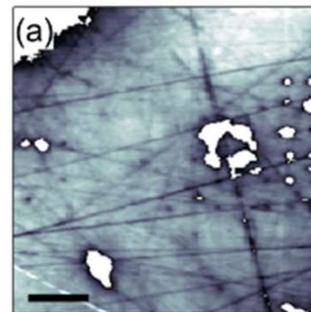
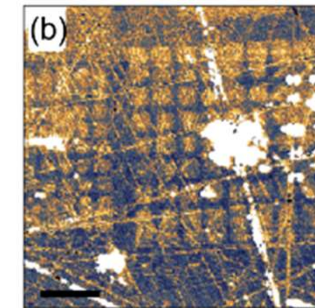








Surface imaging



Through layers imaging

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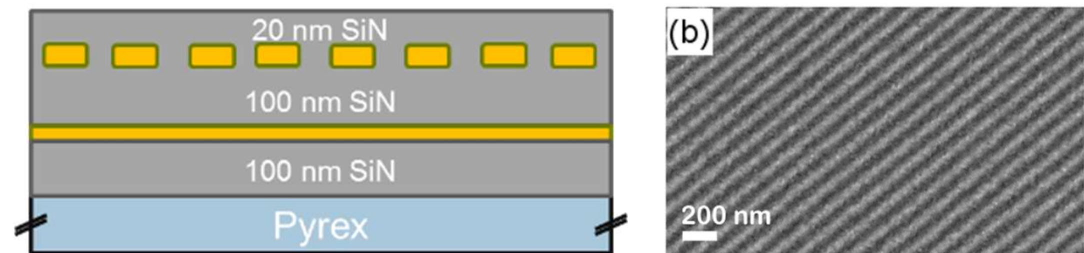
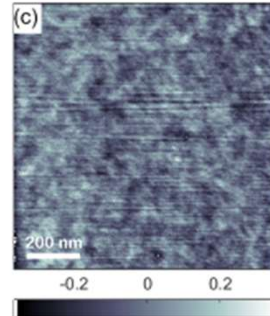
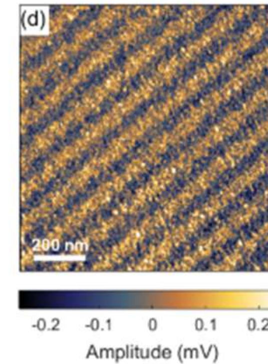
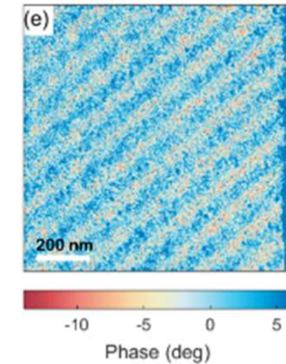




Surface topography





Device fabrication:
courtesy of A. Storm, H. van der Berg, R. Schmits

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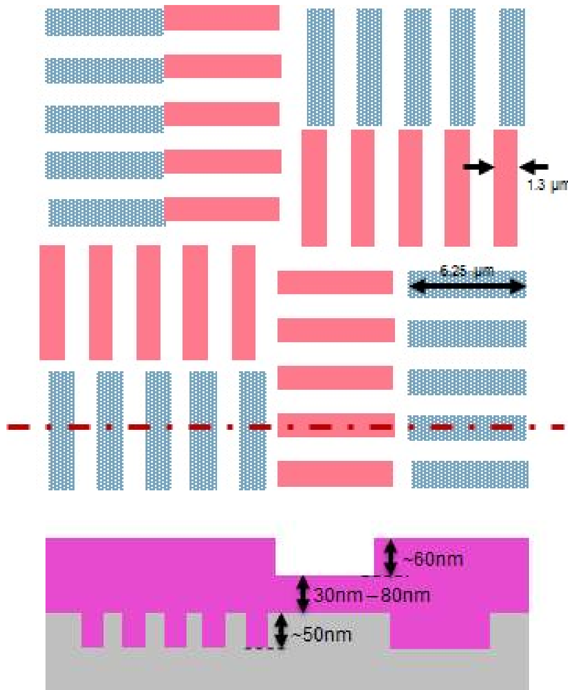
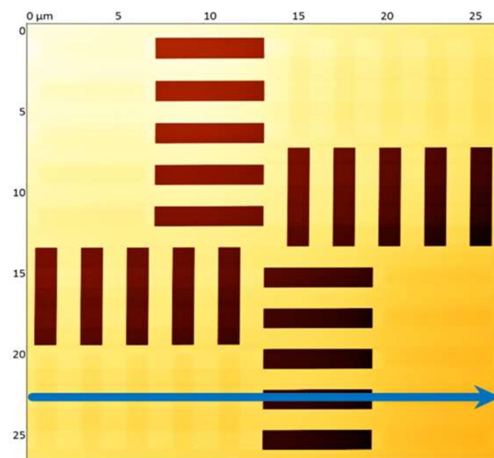
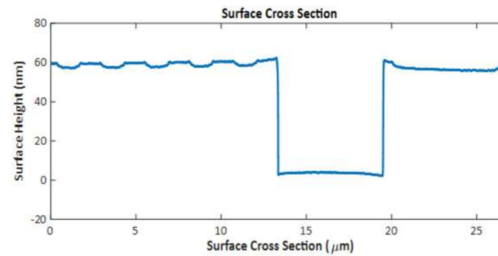
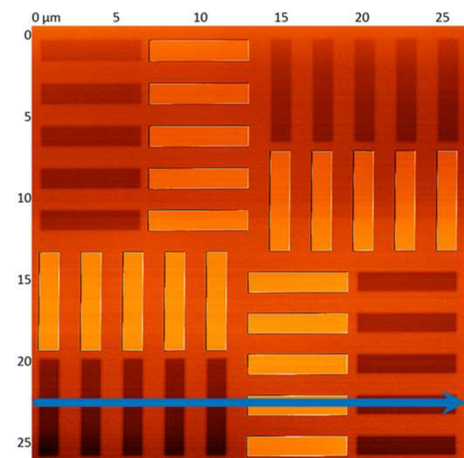
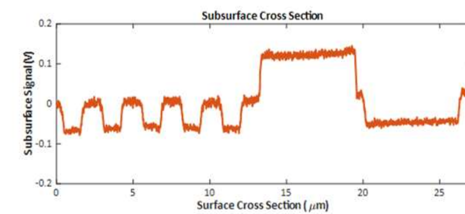
Overlay metrology (AIM target comparison)



Subsurface Ultrasonic Resonance Force Microscopy

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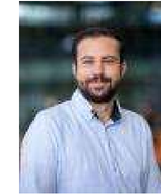
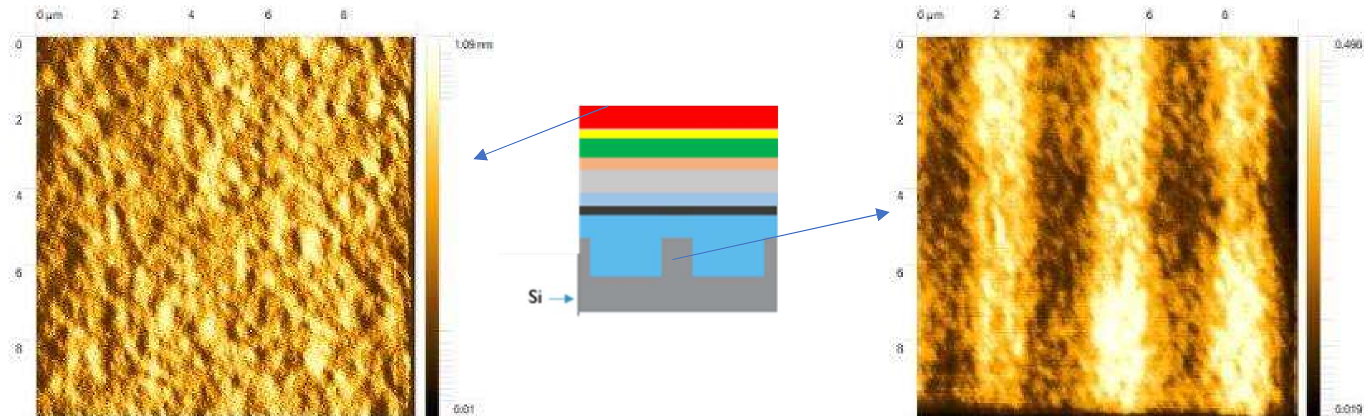
Deep Subsurface nanoimaging



Higher frequency excitations, frequency shift detection for deep subsurface nanoimaging



Surface topography **Subsurface patterns**

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Acknowledgment:
TNO
TU/e
Madein4 EU consortium

Thank you

From the Nearfield Team

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