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Marie Skłodowska-Curie Actions COFUND

ASML

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Pushing the Limits of Nanopatterning via Extreme Ultraviolet Lithography

EMPA Postdocs II and PSI- FELLOW II- 3i Retreat 2018, EMPA, Dübendorf
September 21st, 2018

Outline

- Part 1: Pushing the Limits of Nanopatterning by EUV-Interference Lithography
  - Overview on EUV Interference Lithography
  - Our Global EUV Resist Screening Program with ASML
  - Highlights of the Resist Screening Tests in Q1-Q3 2018 ASML

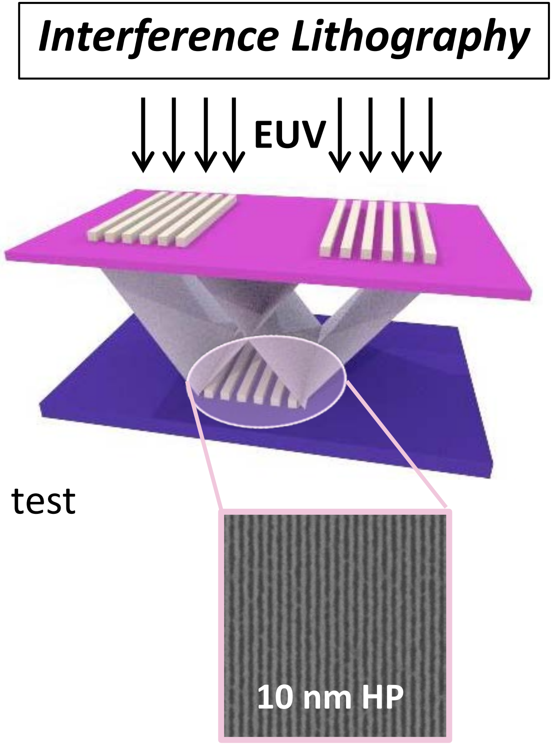
- Part 2: Pushing the Limits of Nanofabrication by E-Beam Lithography Marie Skłodowska-Curie Actions COFUND
  - Semiconductor Nanowires for Sensor Applications
  - Results

- Conclusions and Outlook

EUV Resist Testing at PSI

- XIL-II beamline at Swiss Light Source (SLS): a **powerful** tool for the development of EUV resists
- Advantages of using EUV-IL for resist testing:
  - Periodic patterns with high resolution
    - theoretically: 3.5 nm
    - experimentally : down to 7 nm HP
  - No dose, outgassing and contamination limitations
  - Thus, low cost technique, allows easy access for resist vendors to test their novel resists

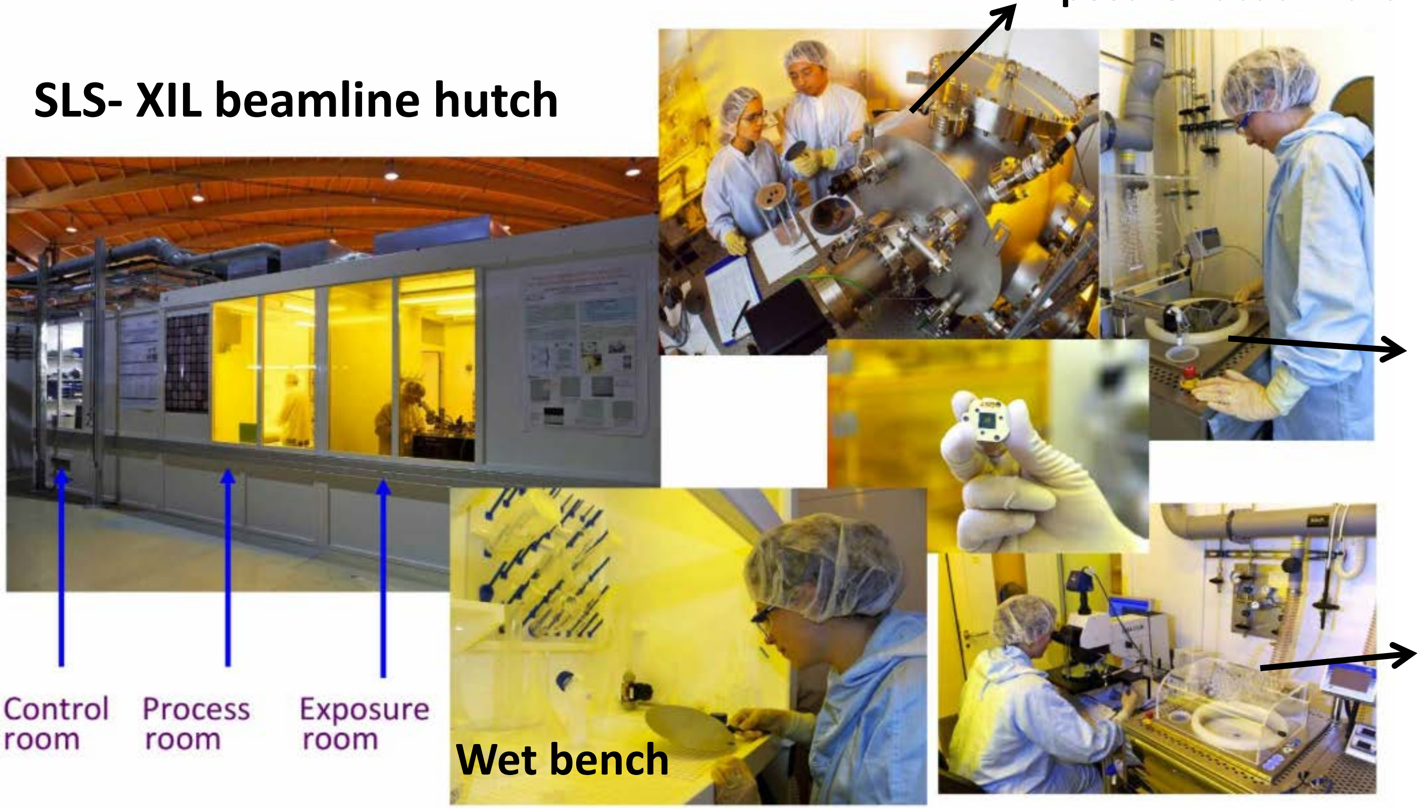
The **resolution** that we can achieve is still **limited** by the **resist** and the **quality of the diffraction gratings' masks**



Interference Lithography

EUV Resist Testing at PSI

SLS- XIL beamline hutch



Exposure vacuum chamber

Automatic developer

Spin coater

Wet bench

Control room

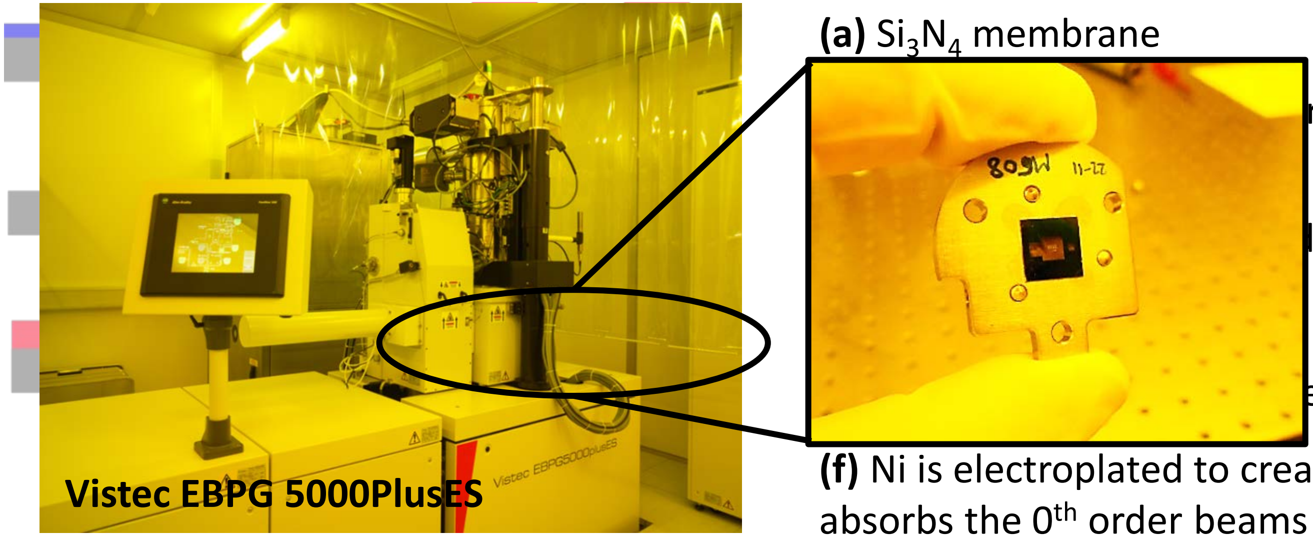
Process room

Exposure room

On-site cleanroom for pre- and post-processing of wafers

Diffraction Grating Masks Fabrication

(a) Si_3N_4 membrane



Vistec EBPG 5000PlusES

rned by e-beam lithography

exposed by EBL

erformed lift-off

(f) Ni is electroplated to create the photon stop that absorbs the 0th order beams

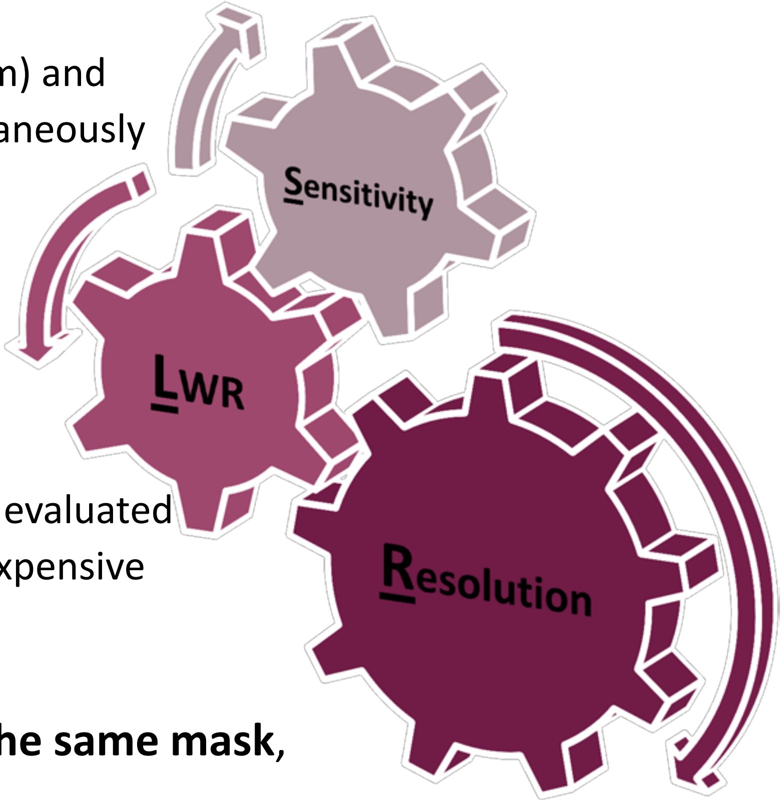
EUV Resist Challenges

- Resolution (R, HP in nm), line width roughness (LWR, 3σ in nm) and sensitivity (S, dose in mJ/cm^2) :challenging to improve simultaneously

→ RLS trade-off

  - ☐ Higher photon density → better LWR → high dose (S)
  - ☐ Small Blur → better resolution (R) → high dose (S)
  - ☐ Larger Blur → lower roughness (L) → loss of resolution (R)

- Highly sensitive resists to increase throughput
- CARs and other state-of-art EUV resists platforms need to be evaluated future technology nodes→ access to EUV scanners limited, expensive

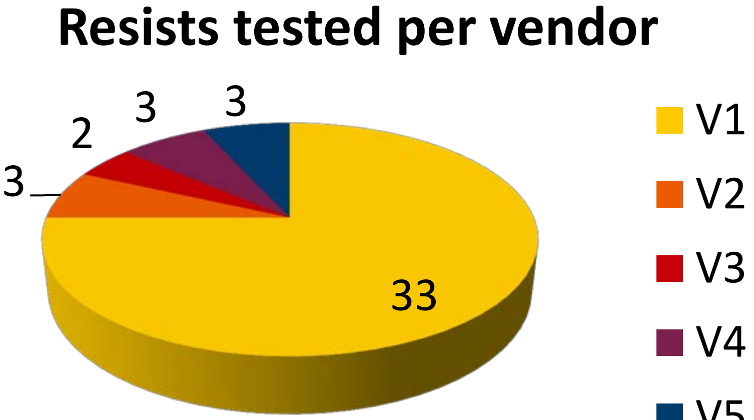


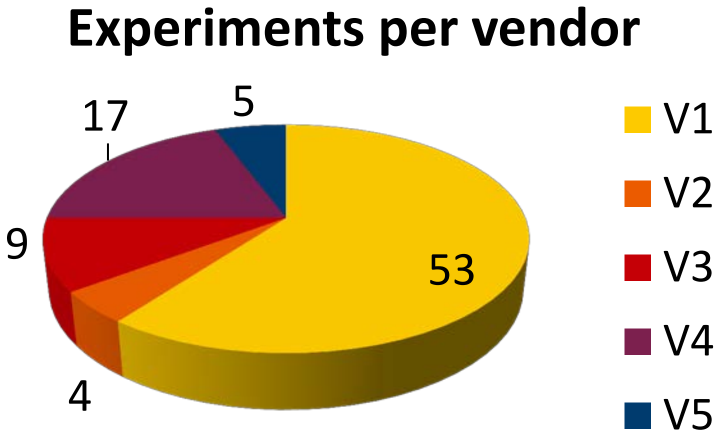
tested **several state-of-the-art resist platforms** with **the same mask**, under **the same process conditions** when possible.

Overview of the Resist Screening Program 2018

- Standard Resist Screening with ASML for 13 nm LS and beyond :
  - get a snapshot of the current status from all resist suppliers
  - support EUV resist development
  - evaluate exploratory alternative EUV resist platforms

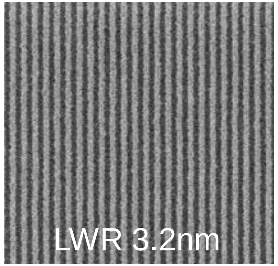
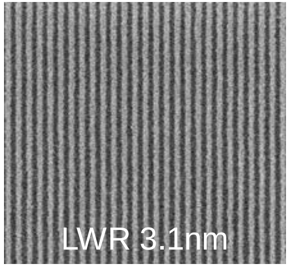
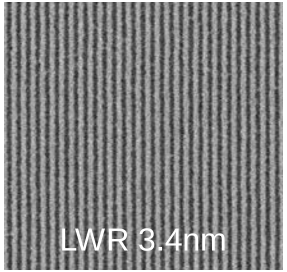
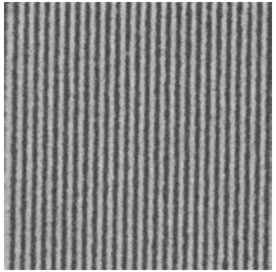
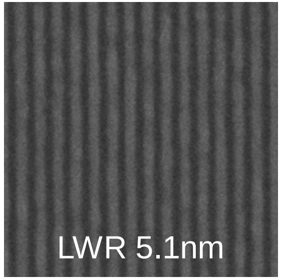
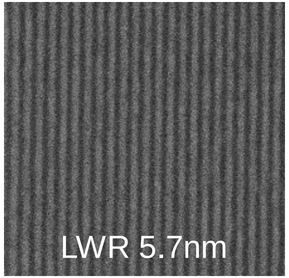
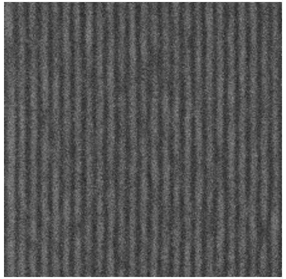
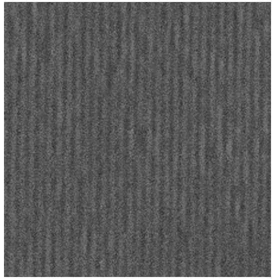
Overview of 2018 Q1-Q3





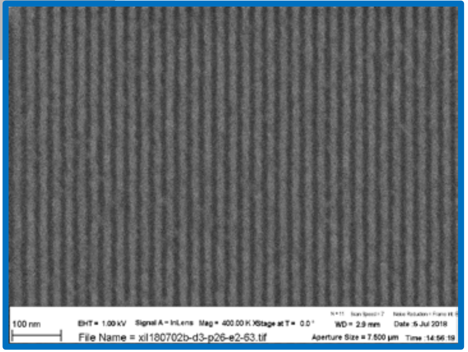
Highlights of the Resist Screening Program- 2018

Best performing high resolution EUV resists exposed on EUV-IL

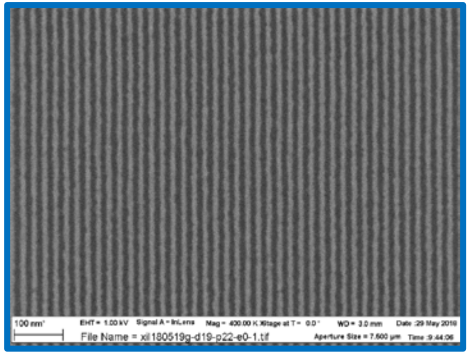
Resolution [hp]	13nm	12nm	11nm	10nm
Inorganic resist	 LWR 3.2nm	 LWR 3.1nm	 LWR 3.4nm	
Dose (mJ/cm^2)	67	67	77	67
CAR	 LWR 5.1nm	 LWR 5.7nm		
Dose (mJ/cm^2)	43	55	57	71

Resist screening 2018

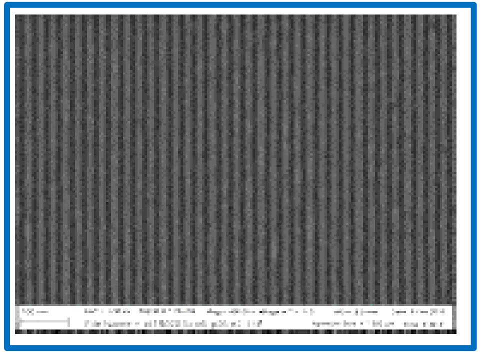
Maximum achieved resolution per resist type (Q1-Q3 2018)



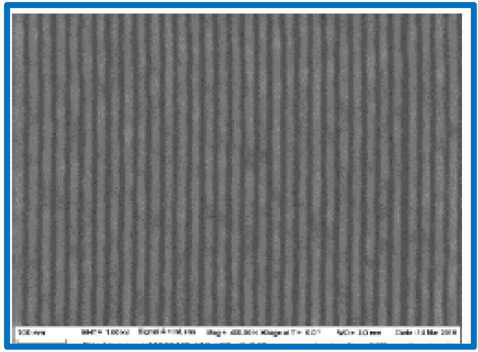
Molecular Resist
13 nm HP
~ 33 mJ/cm^2



Inorganic Resist
11 nm HP
~ 65 mJ/cm^2



CAR
13 nm HP
~ 98 mJ/cm^2



CAR-metal
14 nm HP
~ 54 mJ/cm^2

SPIE. PHOTOMASK TECHNOLOGY + EUV LITHOGRAPHY

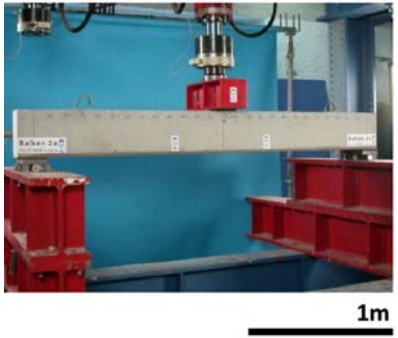
Monterey Conference Center and Monterey Marriott
Monterey, California, United States
17 - 20 September 2018

Part 2:
Semiconductor Nanowires for Sensor Applications

Challenges at the nano-scale

- misalignment of the sample with the testing device
- manipulation of small samples
- difficulty in applying/ measuring small forces and displacements

macro -scale



?
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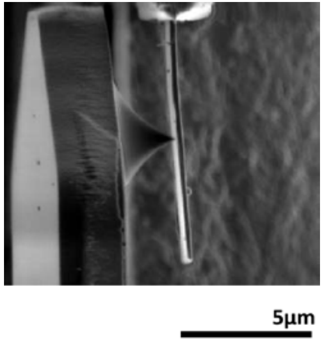
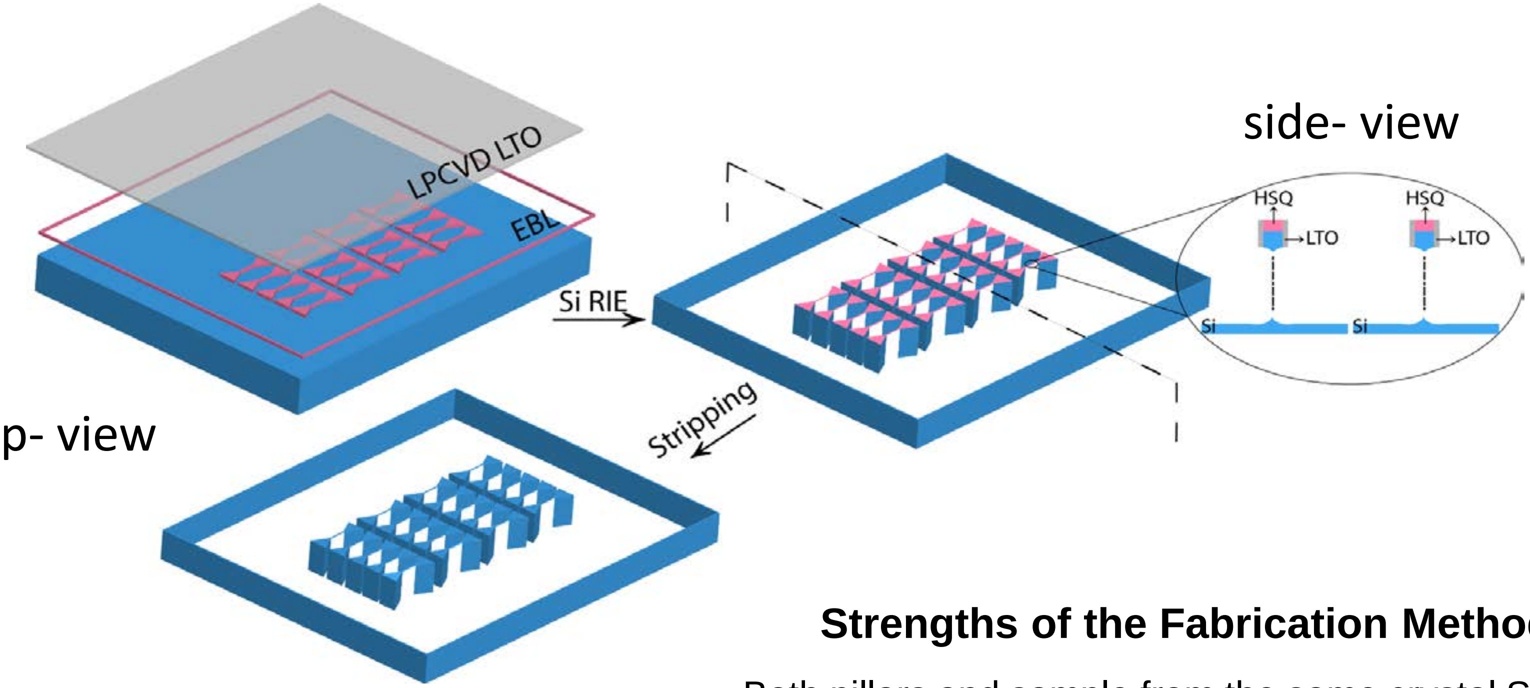
micro / nano -scale



Novel Method: Sample Fabrication for Nanomechanical Measurements



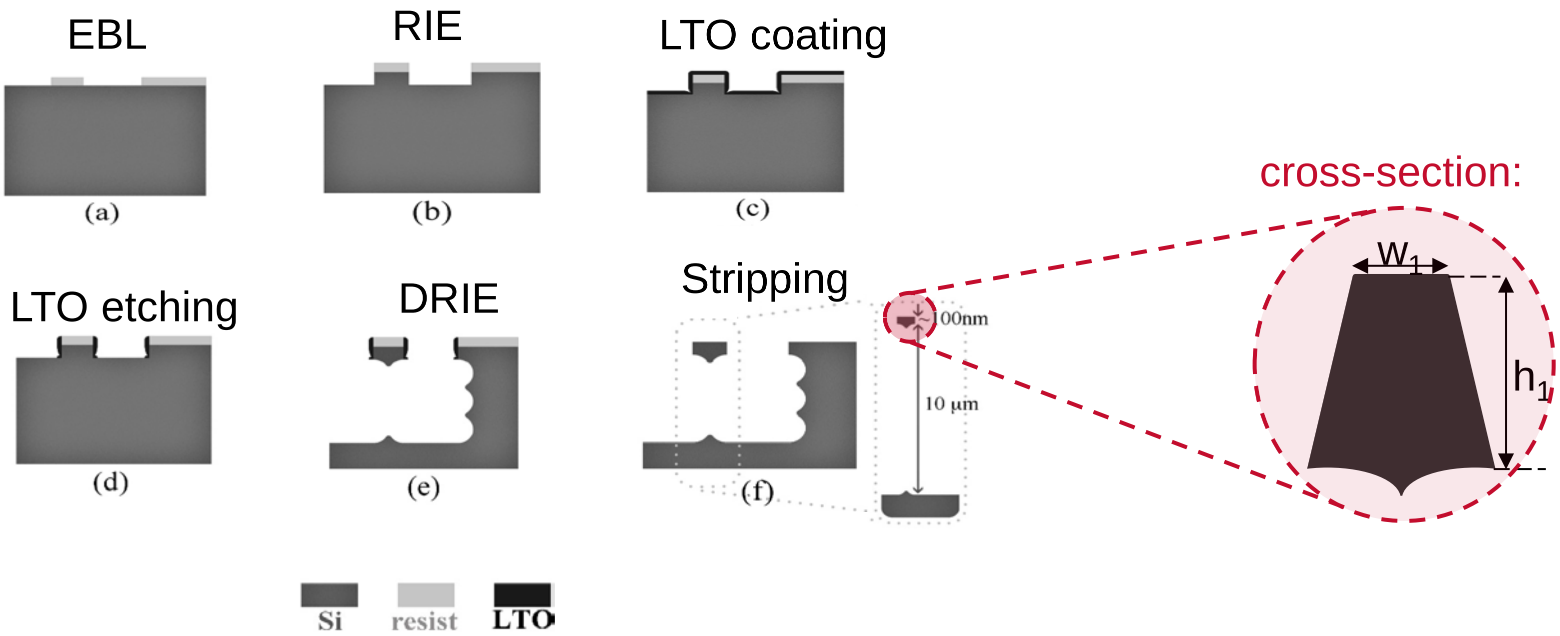
side- view

top- view

Strengths of the Fabrication Method

- Both pillars and sample from the same crystal Si
- No interface effects
- Sample is at the top of the surface, easy to reach from the top

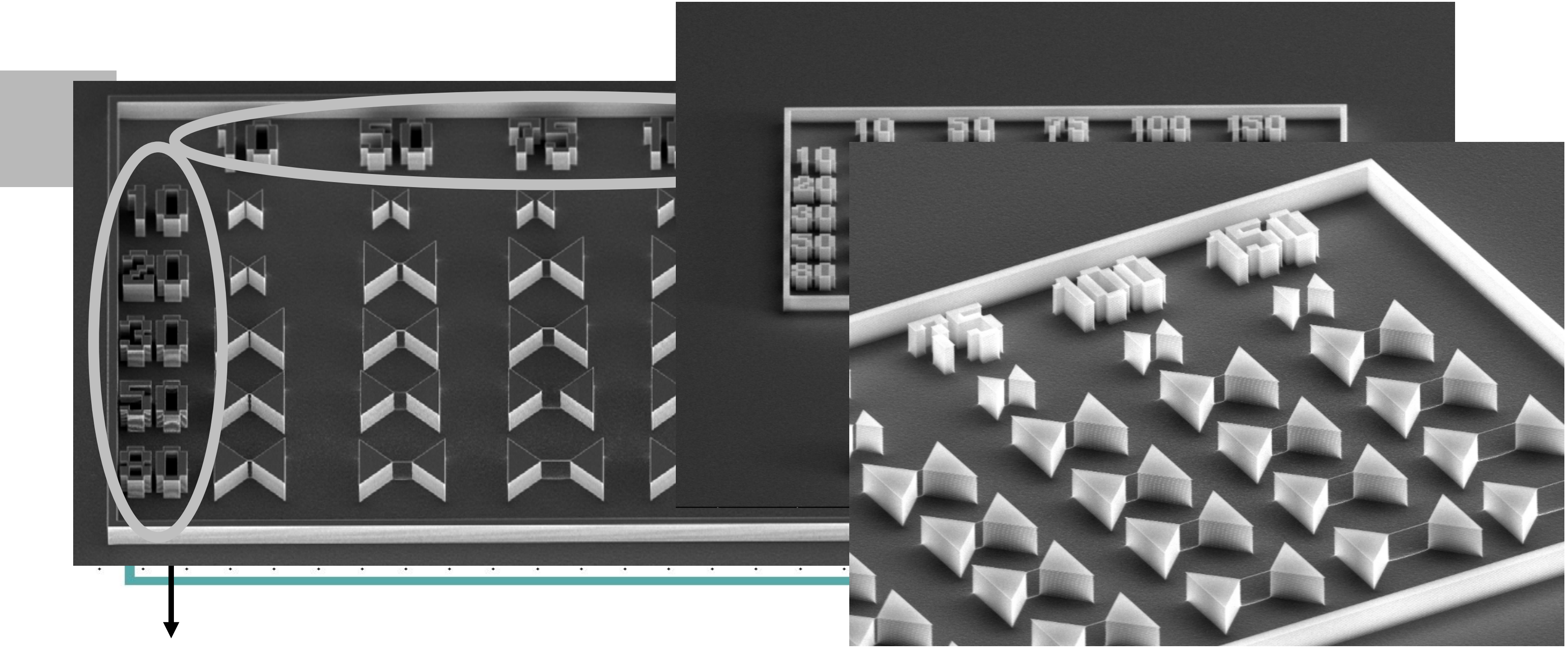
Fabrication Process Flow



Key Process Parameters

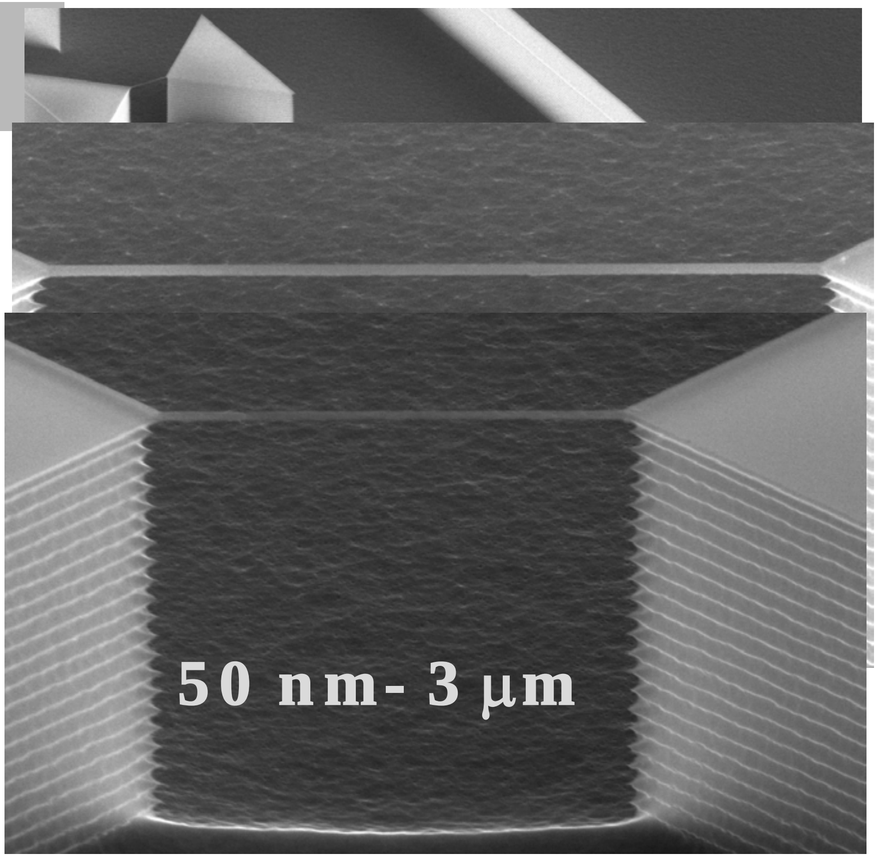
- Step (a) → NW width, w_1
- Step (b) → NW thickness, h_1
- Step (e) → NW bottom shape

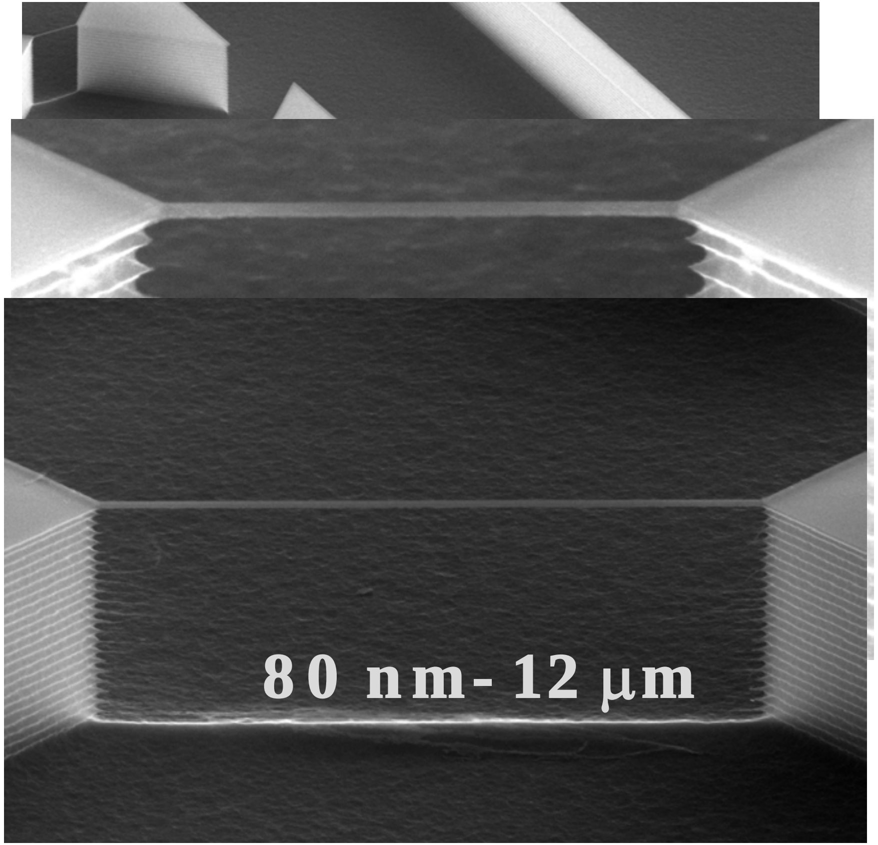
Resulting NWs



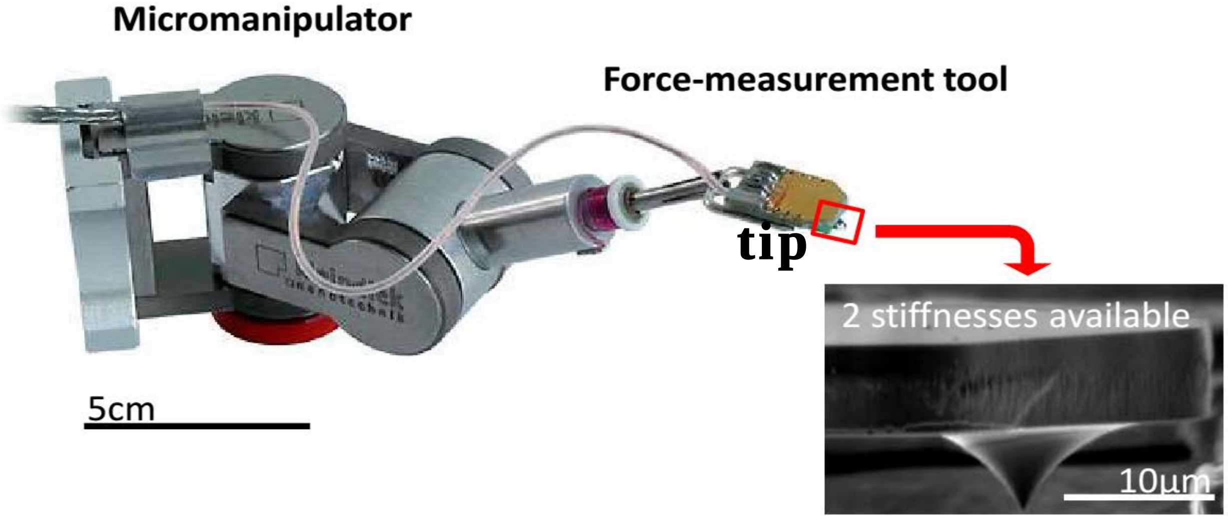
width in nm

Fab. characterization

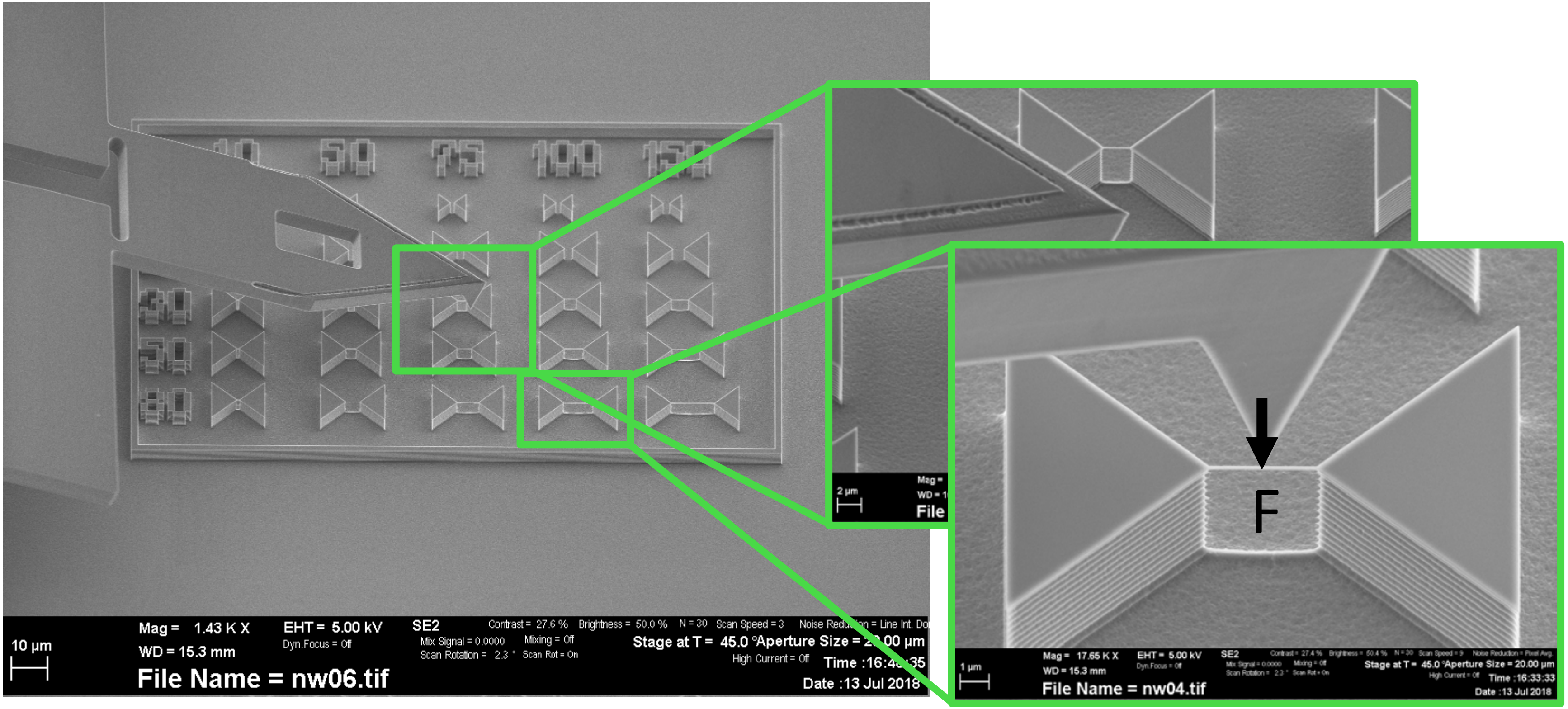

50 nm- 3 μm


80 nm- 12 μm

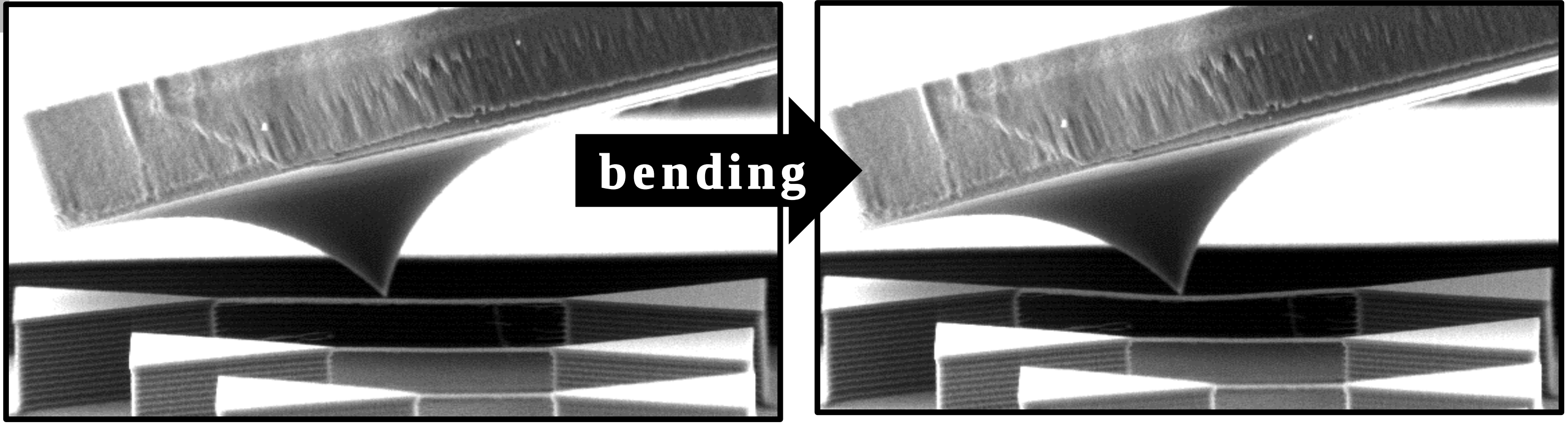
In-situ force sensor measurements



In-situ measurements

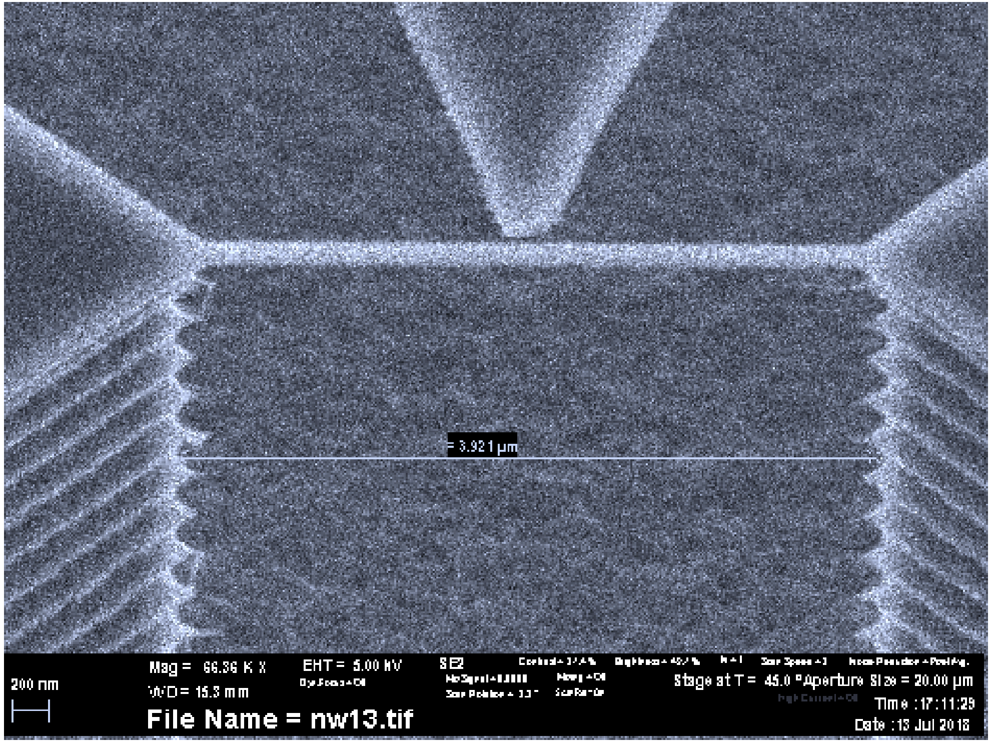


In-situ measurements

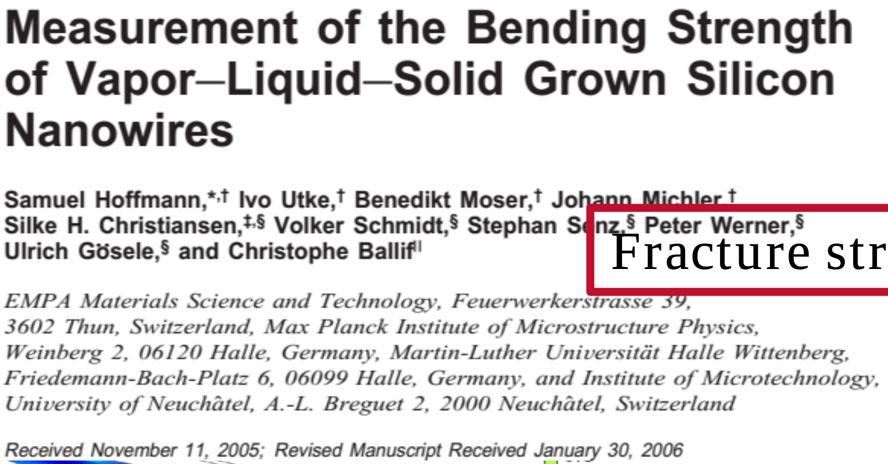


bending

In-situ measurements



Bending strength by FEM



Measurement of the Bending Strength of Vapor–Liquid–Solid Grown Silicon Nanowires

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NANO
LETTERS

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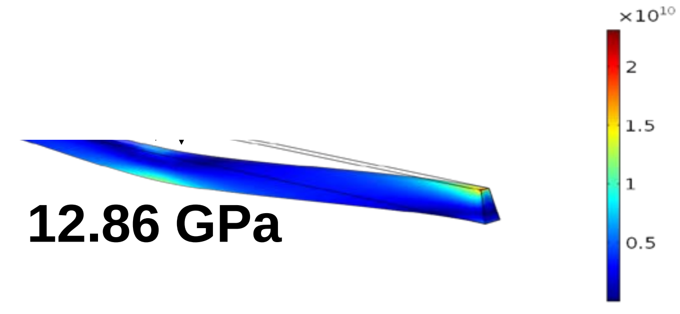
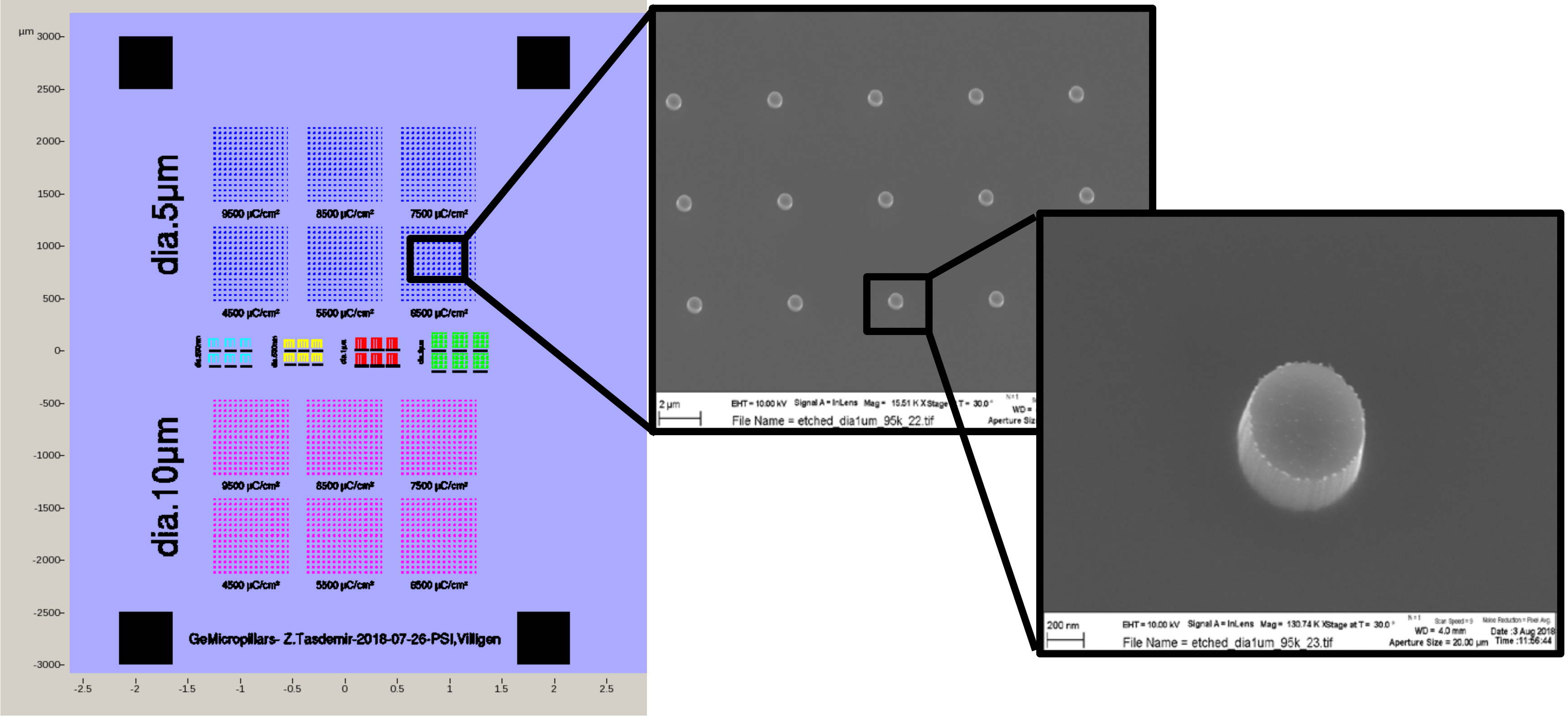
Fracture strength ~ 12 GPa

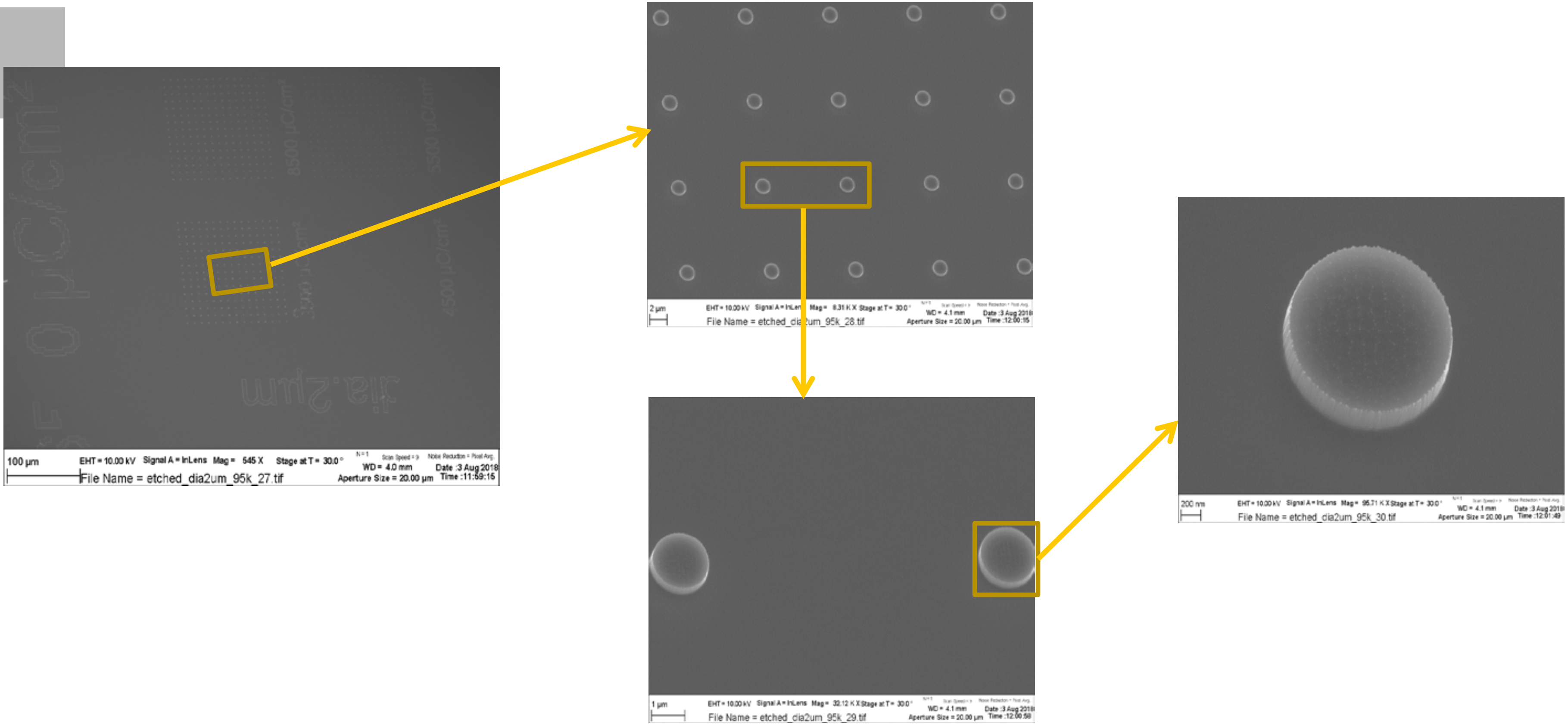


Bending Strength ~ 8.27 GPa- 12.86 GPa

Different Semiconductor: Ge Pillars



Dia. 2μm


dia.2um
100 µm
EHT = 10.00 kV Signal A = InLens Mag = 545 X Stage at T = 30.0 °
WD = 4.0 mm Date :3 Aug 2018
File Name = etched_dia2um_95k_27.tif
Aperture Size = 20.00 µm Time :11:59:15
2 µm
EHT = 10.00 kV Signal A = InLen Mag = 8.31 K X Stage at T = 30.0 °
WD = 4.1 mm Date :3 Aug 2018
File Name = etched_dia2um_95k_28.tif
Aperture Size = 20.00 µm Time :12:00:15
1 µm
EHT = 10.00 kV Signal A = InLens Mag = 32.12 K X Stage at T = 30.0 °
WD = 4.1 mm Date :3 Aug 2018
File Name = etched_dia2um_95k_29.tif
Aperture Size = 20.00 µm Time :12:00:58
200 nm
EHT = 10.00 kV Signal A = InLens Mag = 95.71 K X Stage at T = 30.0 °
WD = 4.1 mm Date :3 Aug 2018
File Name = etched_dia2um_95k_30.tif
Aperture Size = 20.00 µm Time :12:01:49

Conclusions and Outlook

- **EUV- IL at PSI** is an effective tool for EUV resist evaluation
- In our global screening program in 2018, we have tested so many resists
- EUV- resist vendors are **actively participating** in the screening
- **Semiconductor nanowires (Si and Ge)** fabrication has been developed and realized
- Nano-mechanical measurement of **Si NWs** has been done with *in-situ* force sensor measurement method
- The same method will be applied to **Ge pillars** and then **Ge NWs** in the future

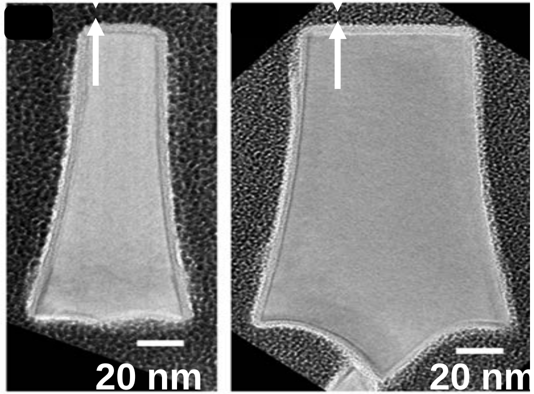
Acknowledgments

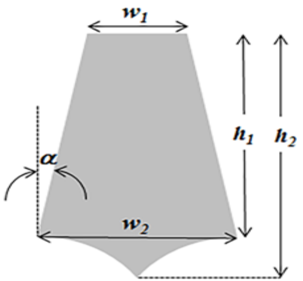
- ***Team of PSI- LMN and PSI- SLS***
- ***Team of ASML***
- ***This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 701647.***

Thank you for your attention!

Cross-sectional study by HR-TEM

native oxide layer ~ 4nm

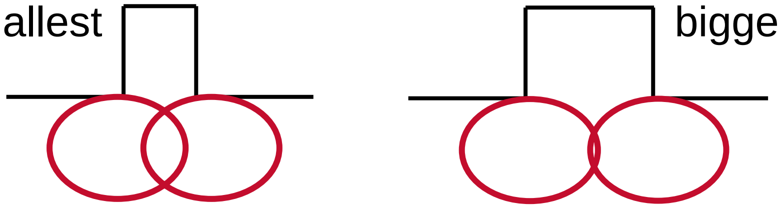




smallest

biggest

	w_1= 35 nm	w_1= 74 nm
w_2 (nm)	66	112
h_1 (nm)	168	
h_2 (nm)	168	198
α (^{0})	5.27	6.45



smallest

biggest

So far…

LETTERS

Mechanical properties of ultrahigh-strength gold nanowires

BIN WU[1]*, ANDREAS HEIDELBERG[1,2]* AND JOHN J. BOLAND[1]†
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*These authors contributed equally to this work
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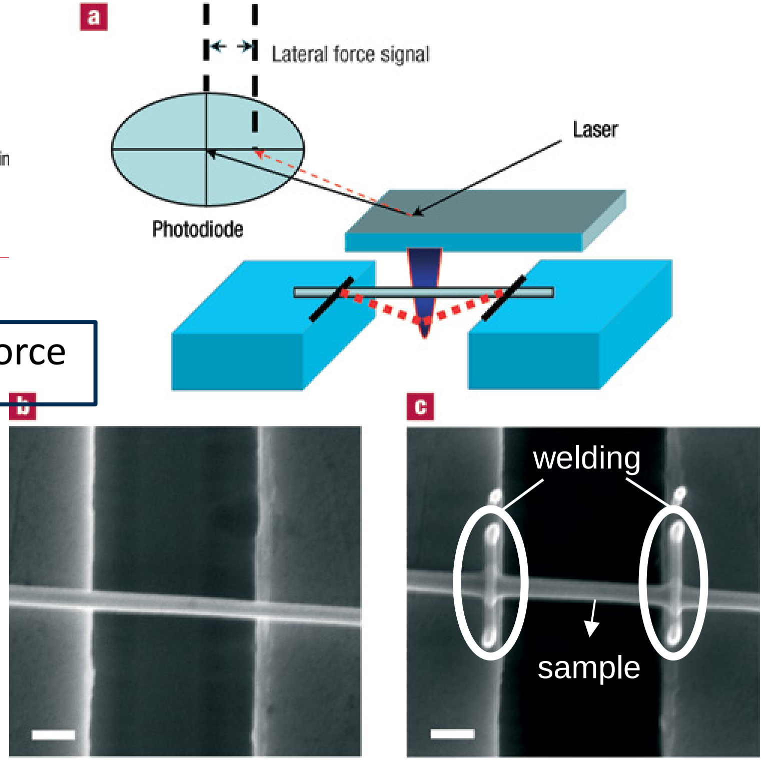


Different sample- support interface ➡ loss in the applied force

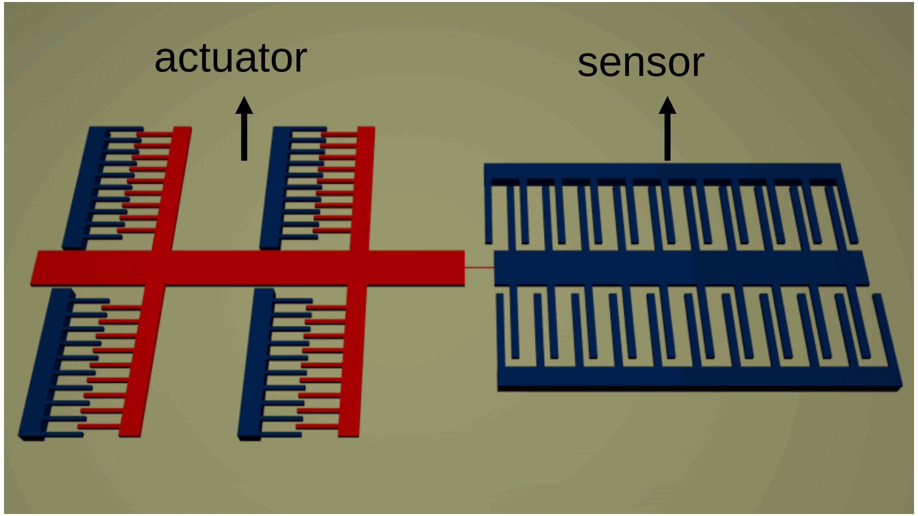
⬇

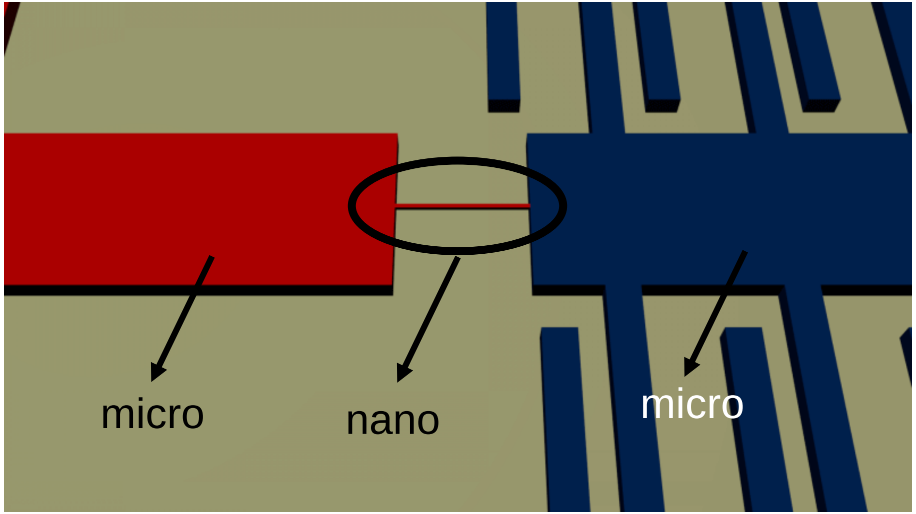
Non-accuracy of the measurement

Solution:

- Monolithically Integrated Tensile Testing Device
  - MEMS force sensor (μm) & actuator (μN)
  - Sample to be investigated: Silicon nanowire

Both the measurement device and sample are made from the same material- silicon: no different interface





Monolithic Integration of Micro and Nano-Scale Features