

# Towards automation and parallelization in thermal scanning probe lithography with the NanoFrazor

BEAMeeting

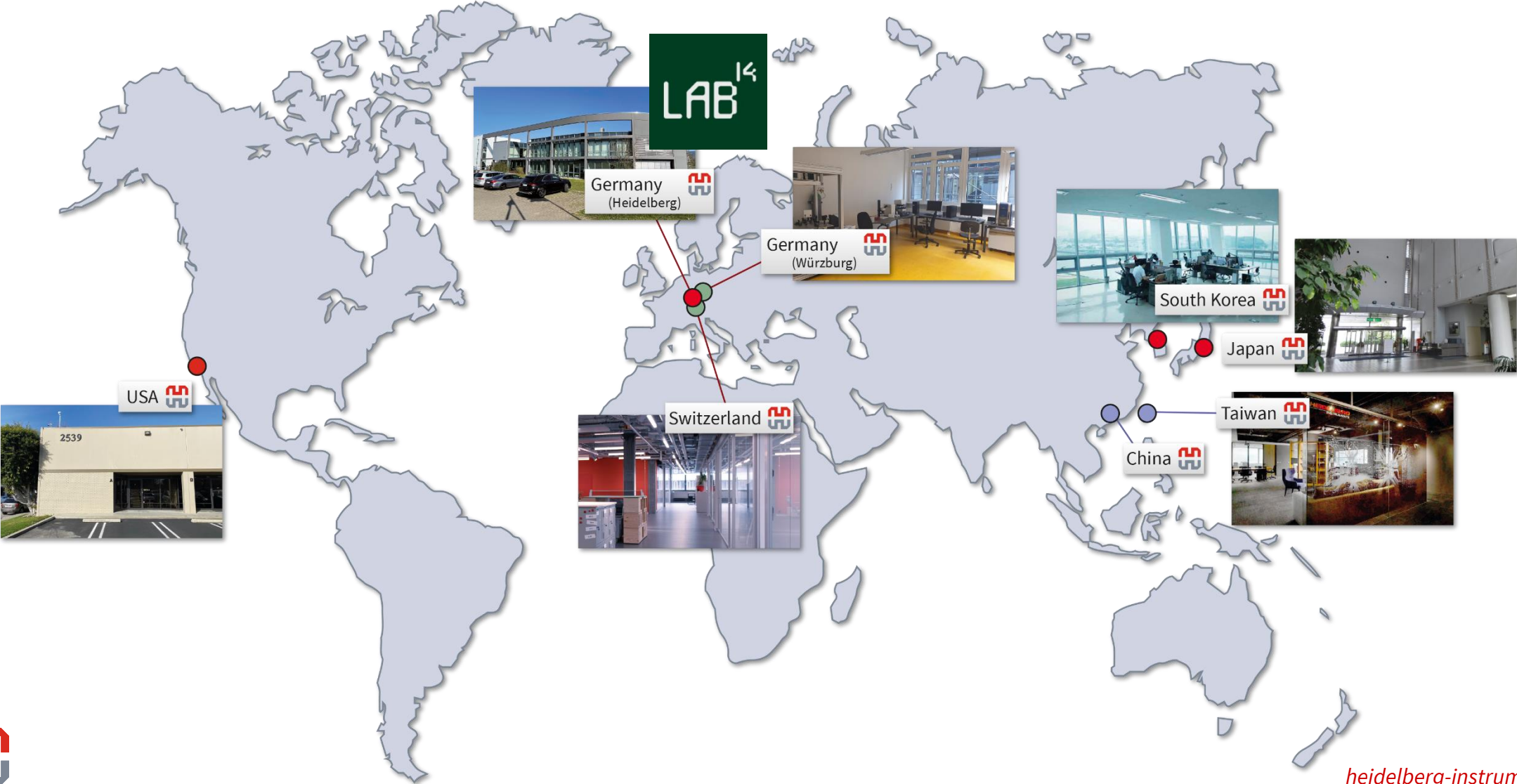
April 10<sup>th</sup> 2024

Dr. Cathelijn van Nisselroy

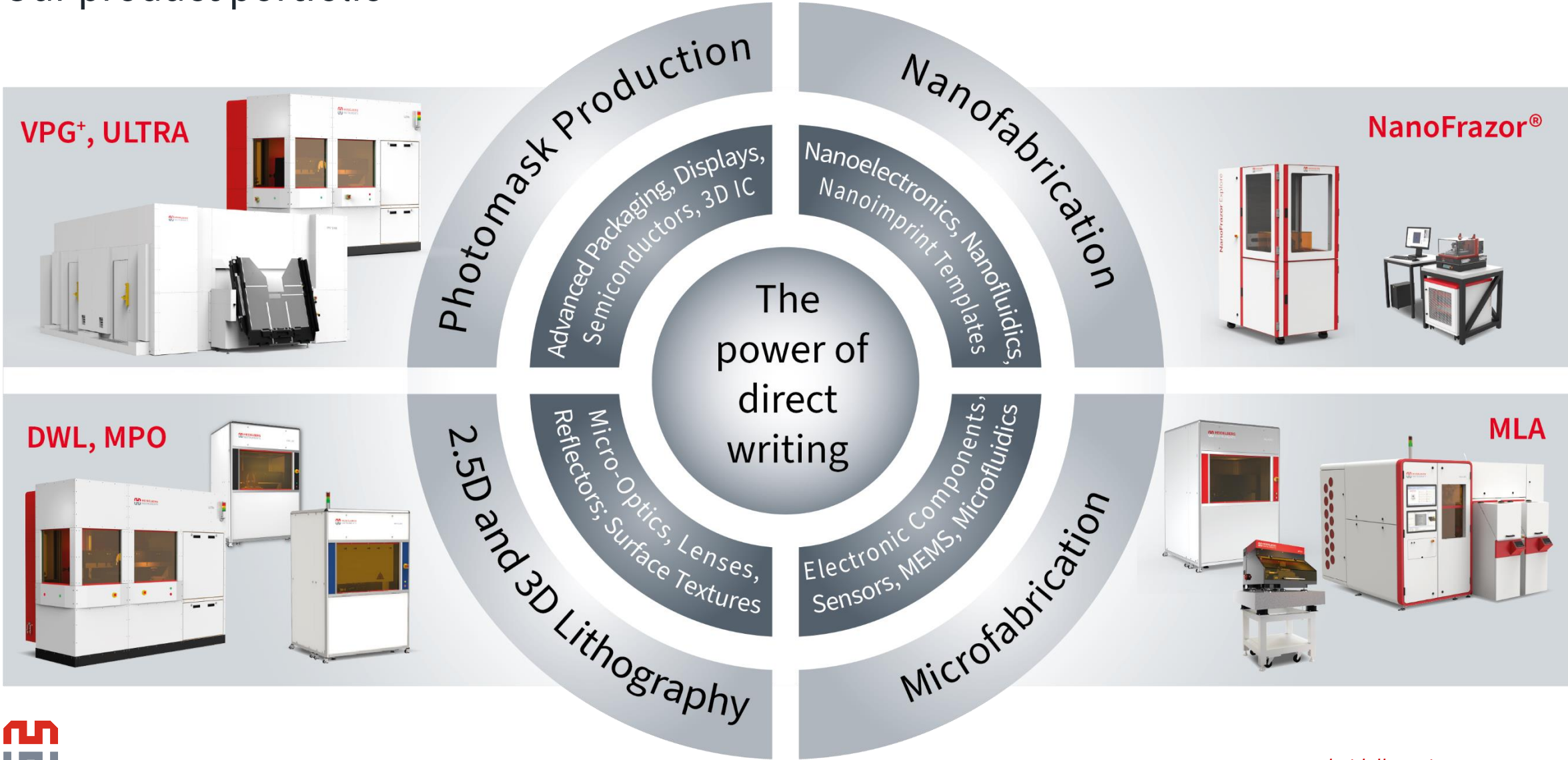
[cvn@himt.ch](mailto:cvn@himt.ch)

MEMS Development Engineer

# Heidelberg Instruments worldwide

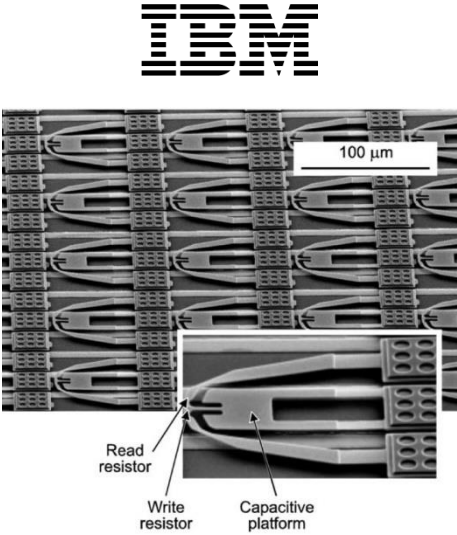


# Our product portfolio



# NanoFrazor by Heidelberg Instruments Nano

## Origin of our technology



NanoFrazor Scholar



NanoFrazor Explore

1995 – 2007

2014

2018

Now



IBM Millipede

Nanofrazor (SwissLitho AG) becomes commercial

SwissLitho AG joins Heidelberg Instruments

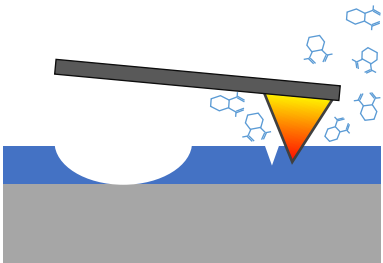
~25 employees in Zurich on NanoFrazor technology



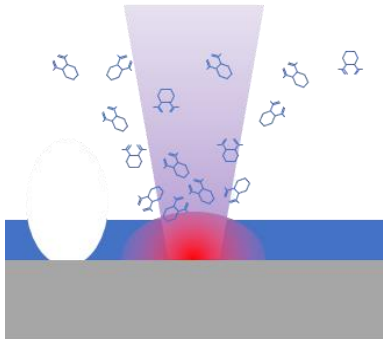
# Principle of the NanoFrazor technology

## Writing

- Thermal cantilever
  - Silicon probe, 10 nm sharp tip
  - Integrated tip heater

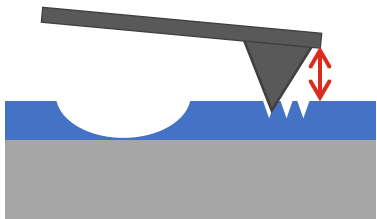


- Direct Laser sublimation
  - Micrometer resolution
  - Larger area coverage
  - 100x faster (than tip)



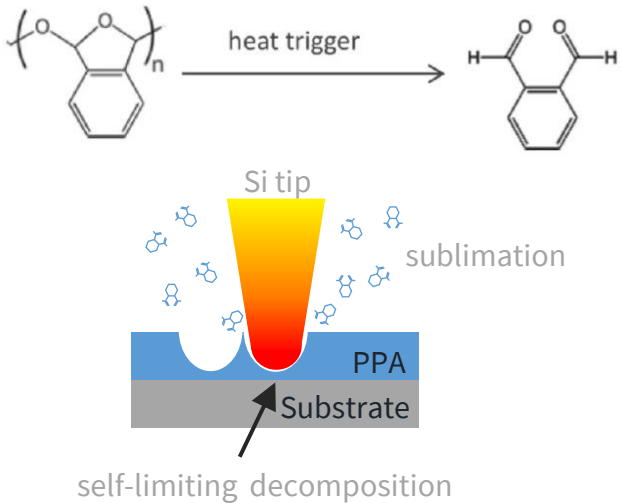
## Reading

- Integrated topography sensor
  - *In-situ* inspection and metrology
  - Overlay & Stitching
  - Level plane & autofocus
  - Drift corrections
  - Other calibrations

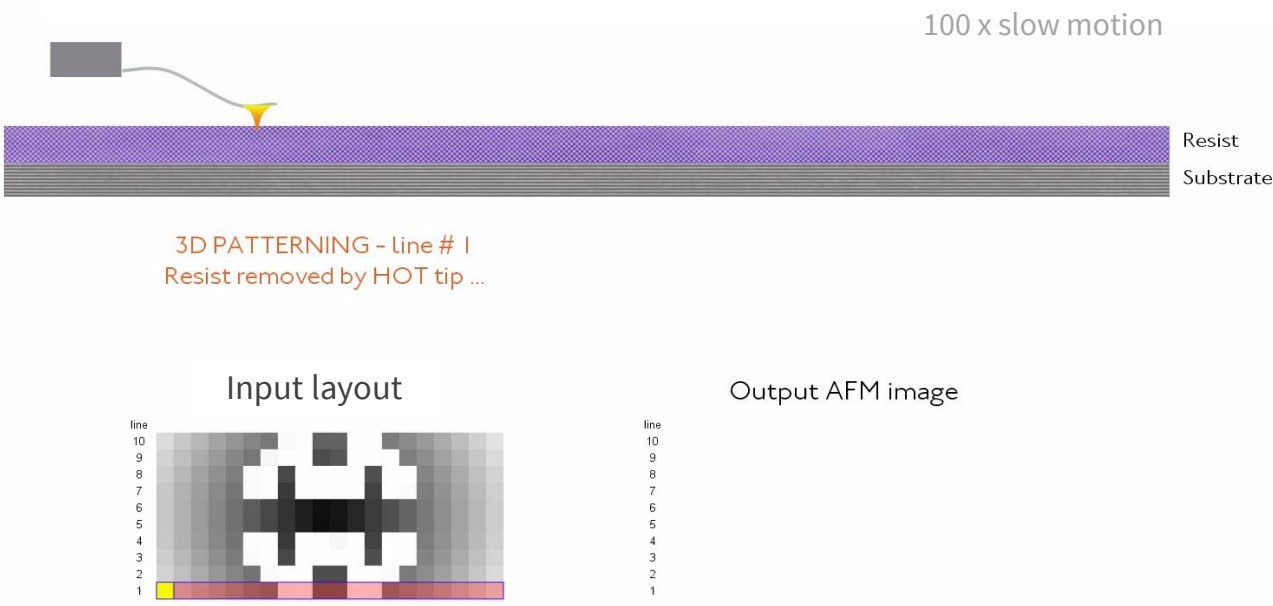
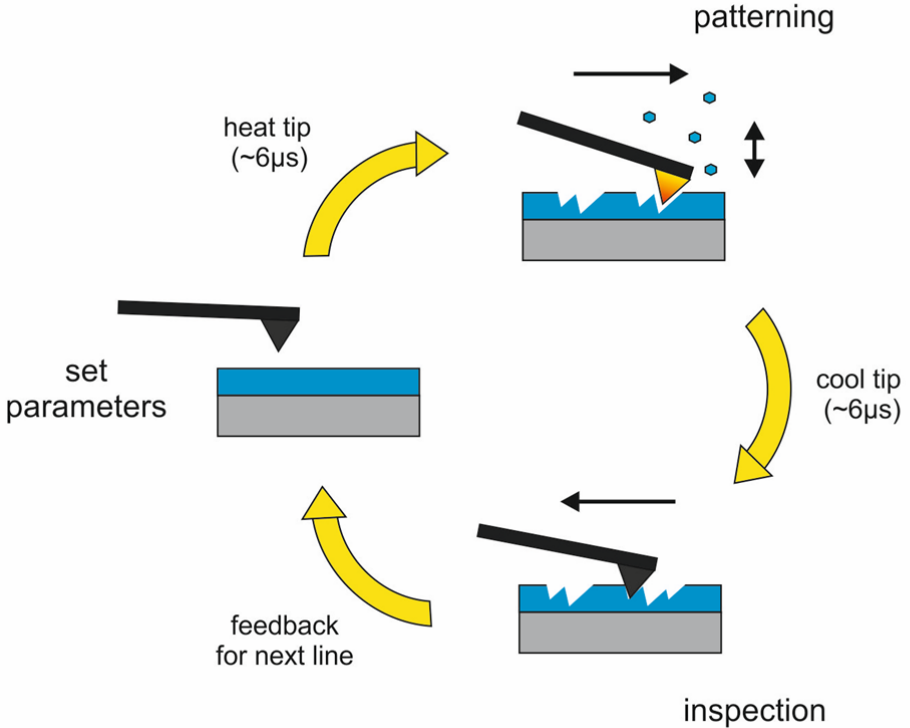


## Thermally-sensitive resist

- Polyphthalaldehyde (PPA)
- PPA resist sublimates by heated tip
- Endothermic reaction prevents spread of heat
- No proximity corrections



# Closed-loop lithography: patterning & imaging

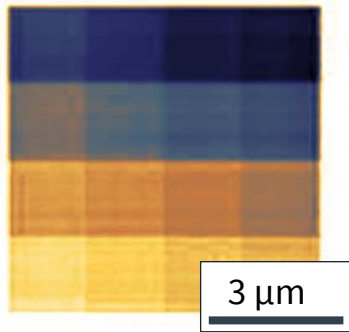


- *In-situ* metrology: no separate metrology necessary after lithography
- Automation: online adaption of patterning every few ms
- Enables: short fabrication time, increased accuracy & reliability, stitching & overlay of designs

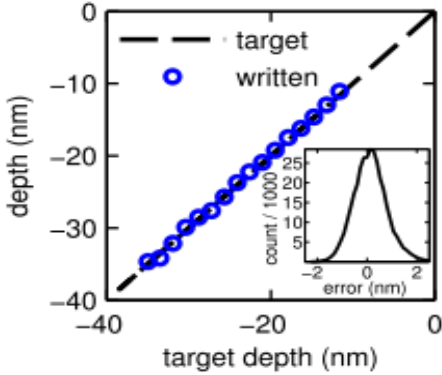


# High resolution grayscale lithography

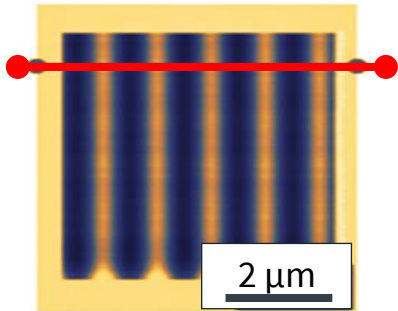
## Sub-nm vertical resolution



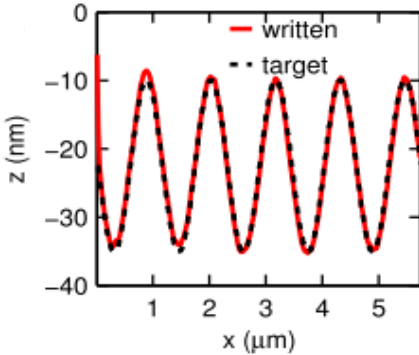
Discrete levels (1.5 nm)



error (1σ): **0.69 nm**

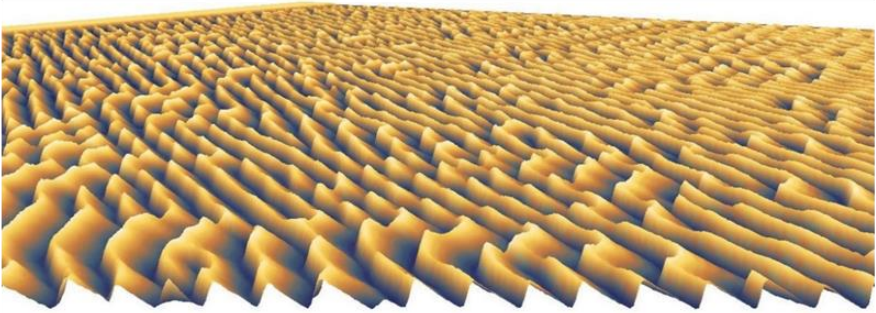


Continuous sine wave

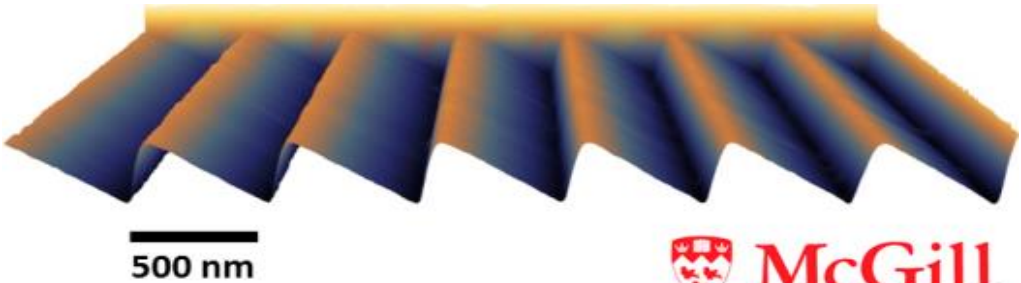


error (1σ): **0.85 nm**

## Grayscale high-resolution patterning examples



3D hologram in PPA, Kulmala et al, SPIE Adv. Litho., 2018



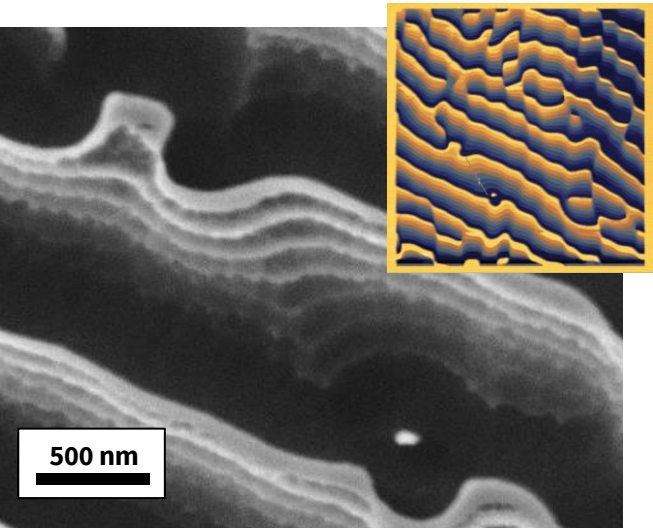
Blazed grating in PPA, Ristic et al, OSA Tech Digest, 2015



Rawlings et al., Nat. Scientific Reports, 2017

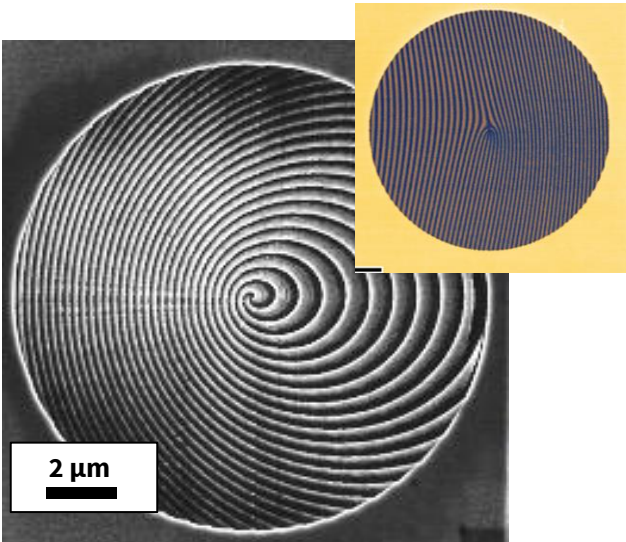
# Applications in grayscale: applications in photonics

Hologram in Si (700 nm deep)



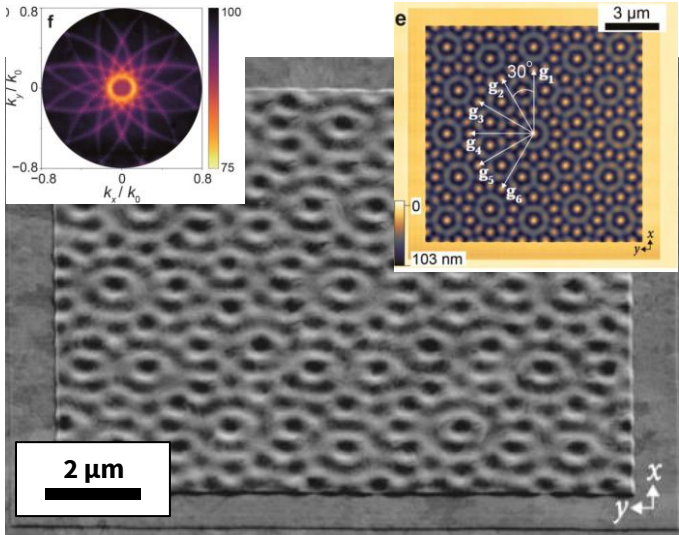
Kulmala *et al.*, SPIE, 2018

Phase Plates in SiN membranes



Hettler *et al.*, Micron, 2019

Optical Fourier Surfaces



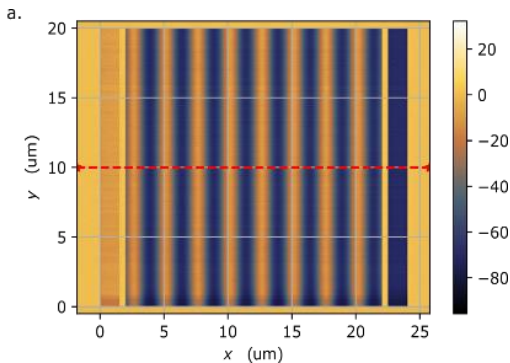
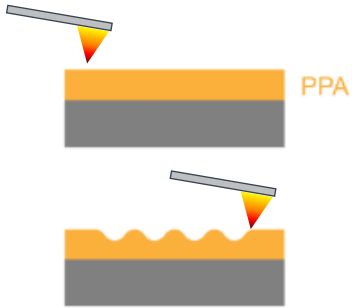
Lassaline *et al.*, Nature, 2020



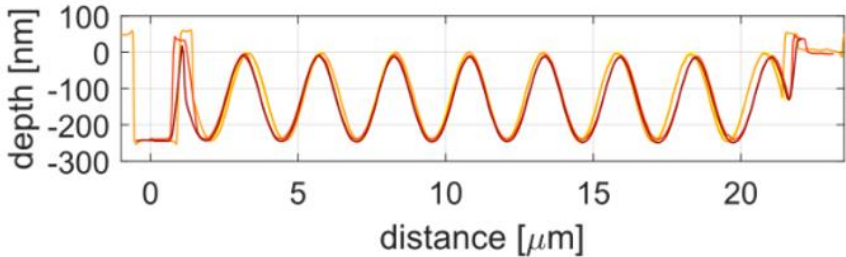


# Post processing of sine waves in arbitrary materials

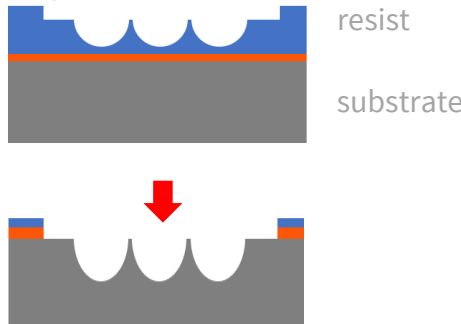
## Pattern in resist



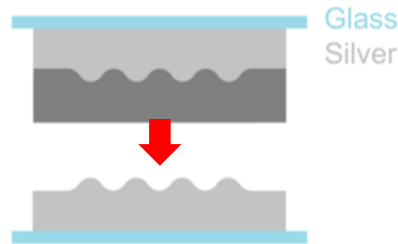
- desired profile
- written profile in PPA scaled with factor 4.20
- etched profile in silicon
- flipped profile in silver after template stripping



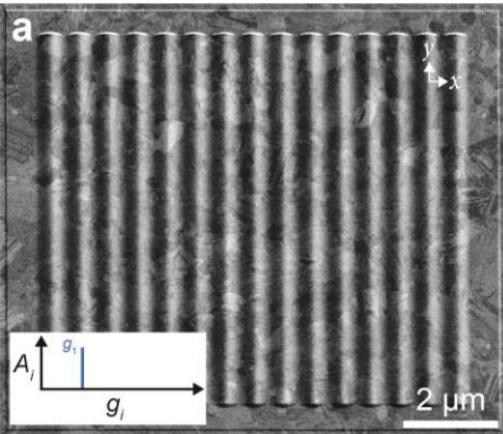
## Etching



## Template Stripping



## SEM inspection

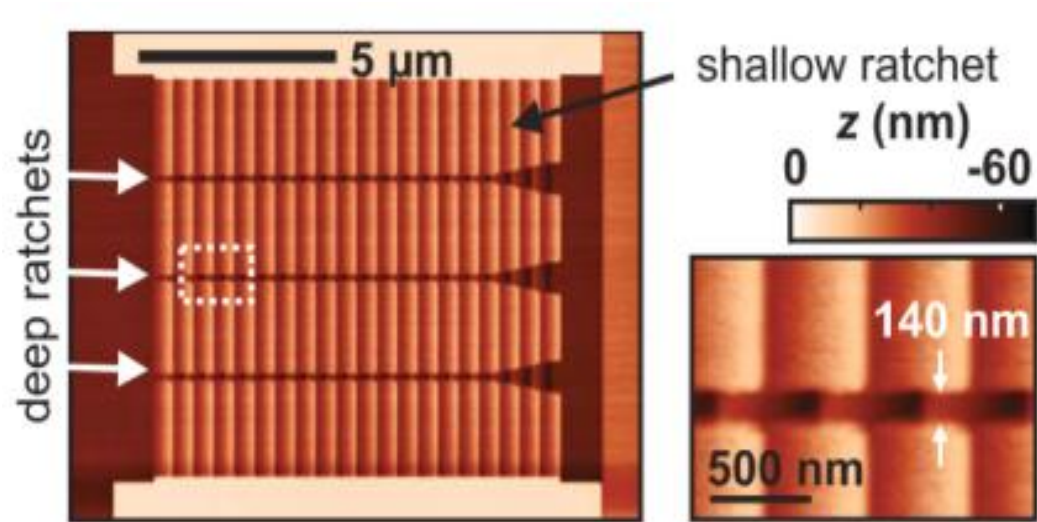


Grating made of Ag by template stripping  
Lassaline *et al.*, Nature, 2020



# Applications in grayscale: nanofluidics and nanobiology

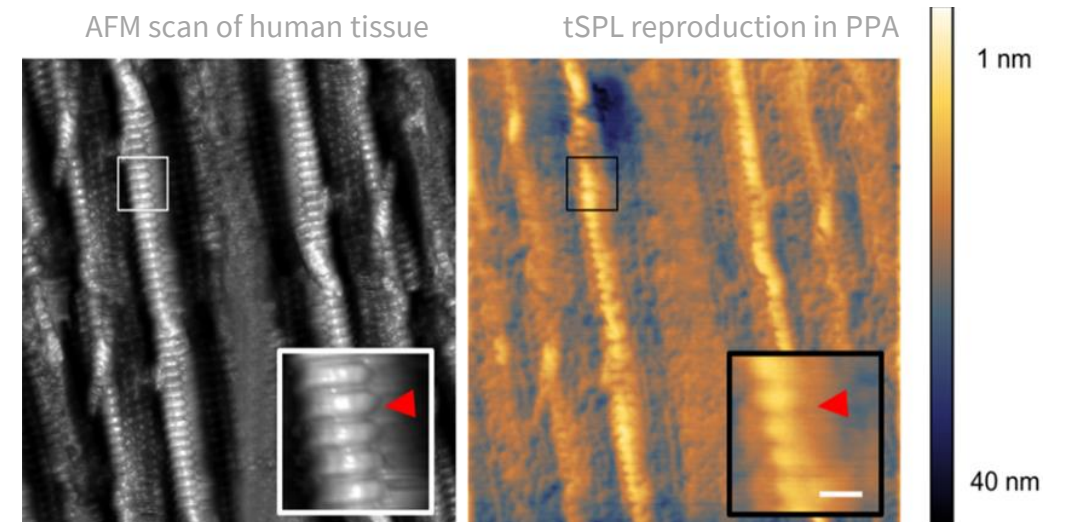
## Nanofluidic Brownian Motors



Skaug et al., Science, 2018

3D channels with 1 nm accuracy  
Precise sorting of bioparticles

## Topographies for stem cells study



Tang et al., ACS Appl. Mat., 2019

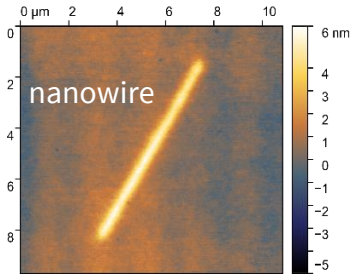
NanoFrazor-generated topography in PPA mimics tissue microenvironment

Directly cultured stem cells on PPA

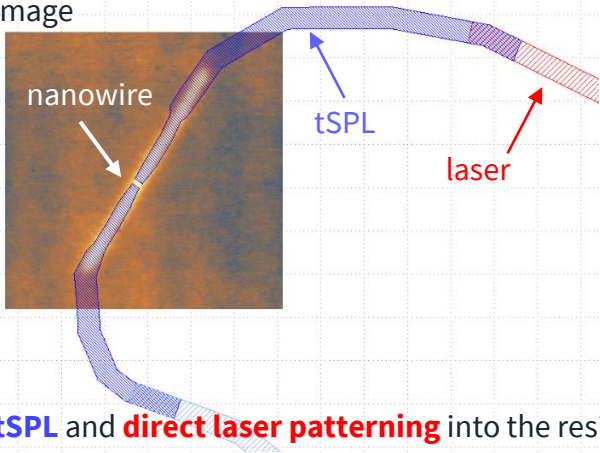
# Contacting nanowires: markerless overlay principle for a nanowire quantum device

### Inside the NanoFrazor:

*In-situ* reading of InSb nanowire buried under ~ 300 nm of resist



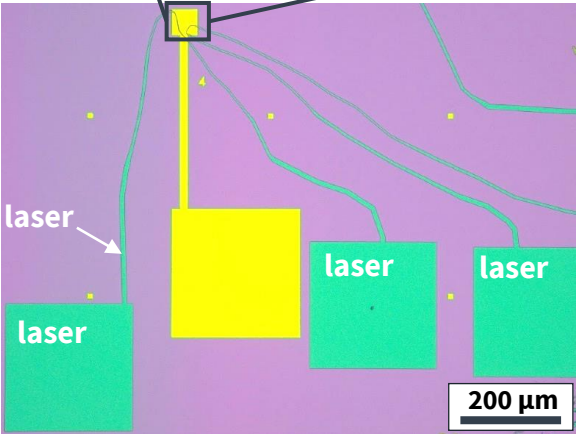
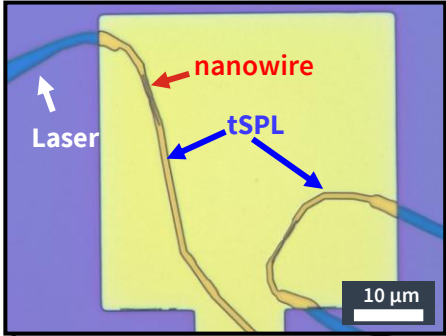
**Manual markerless overlay:** place design pattern directly on topography image



tSPL and **direct laser patterning** into the resist

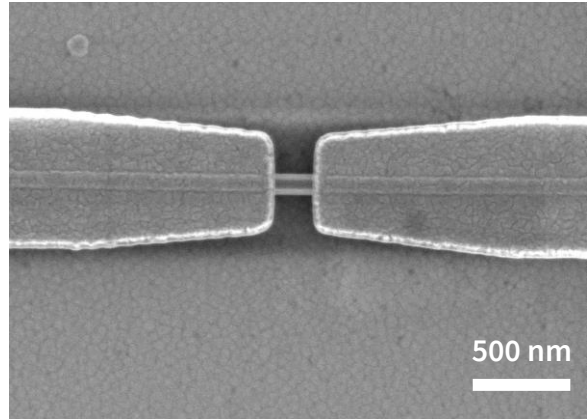
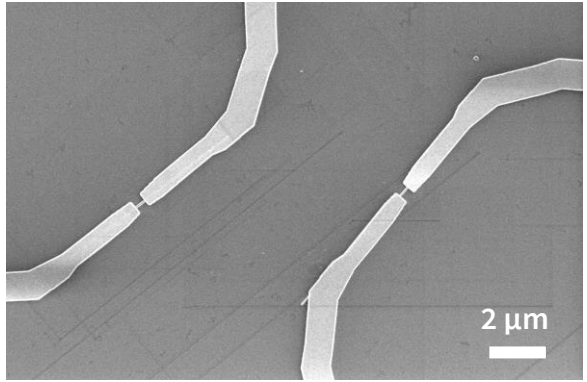
### Optical images after NanoFrazor patterning:

tSPL+ laser hybrid lithography, device <1h

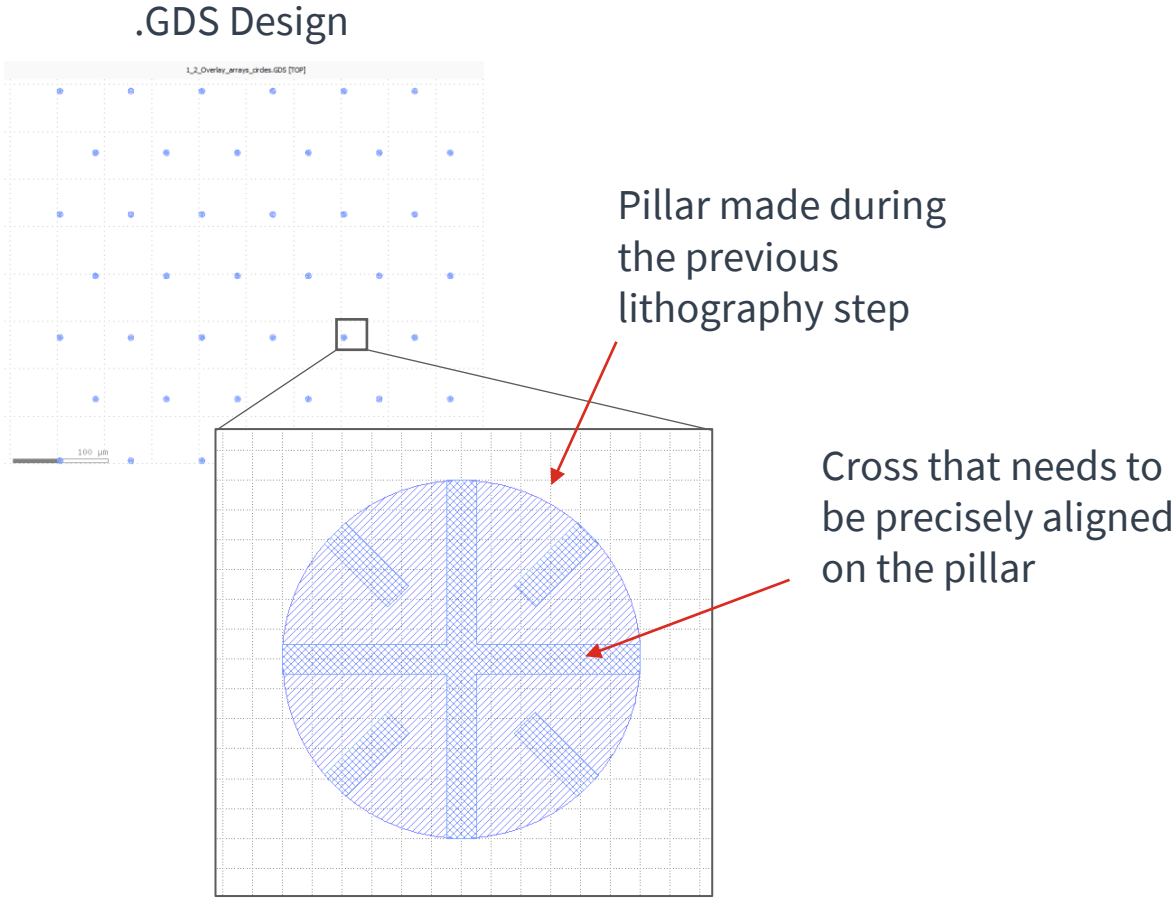


### After metallization and lift-off:

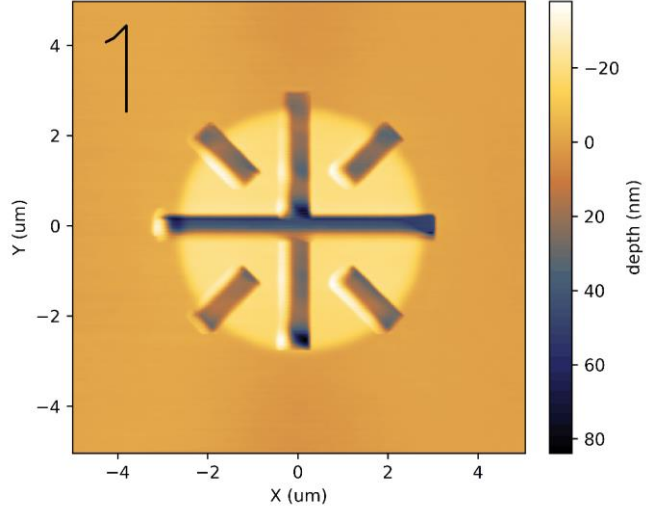
Optical and SEM images



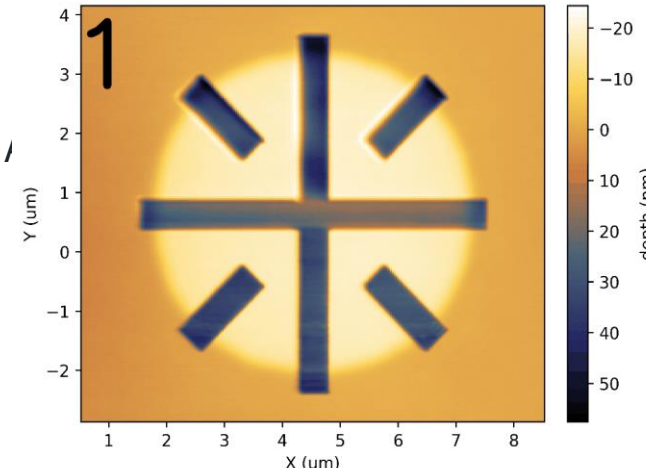
# From manual to automated markerless overlay



Without automatic overlay



With automatic overlay

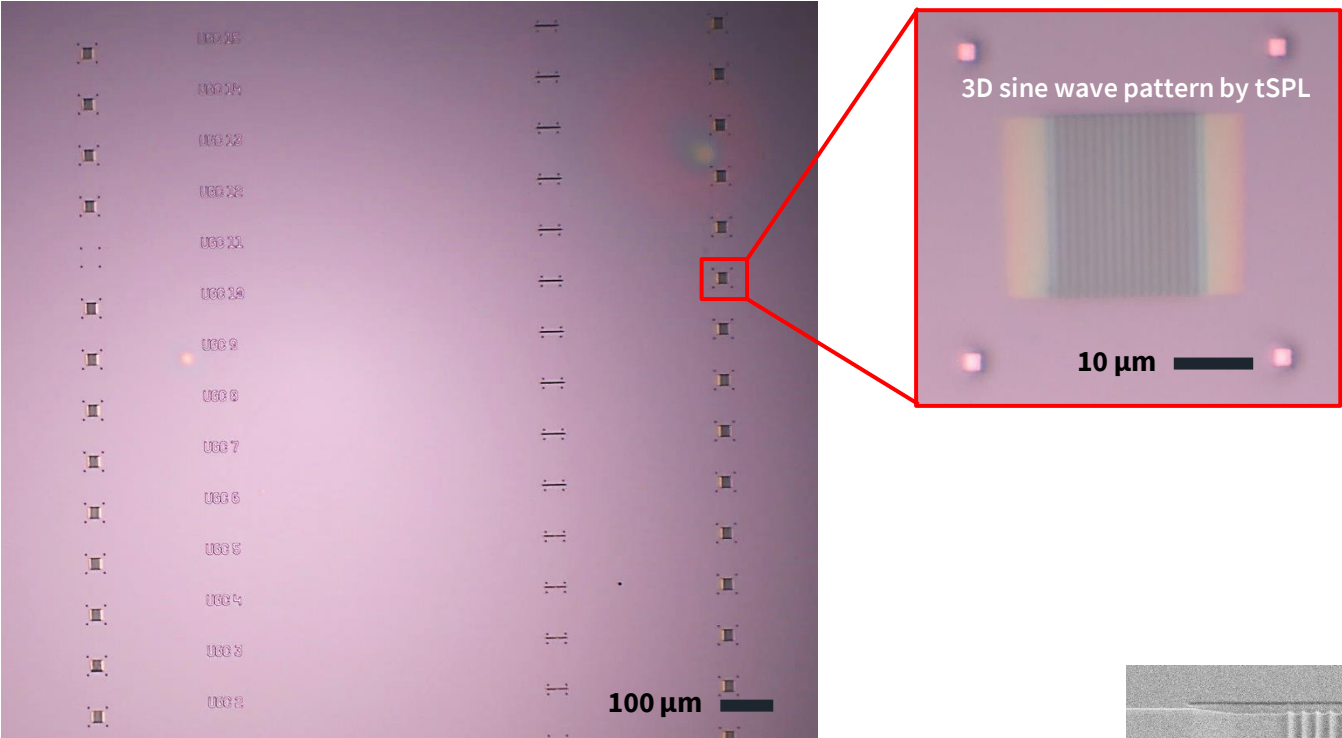


Overlay accuracy < 25 nm

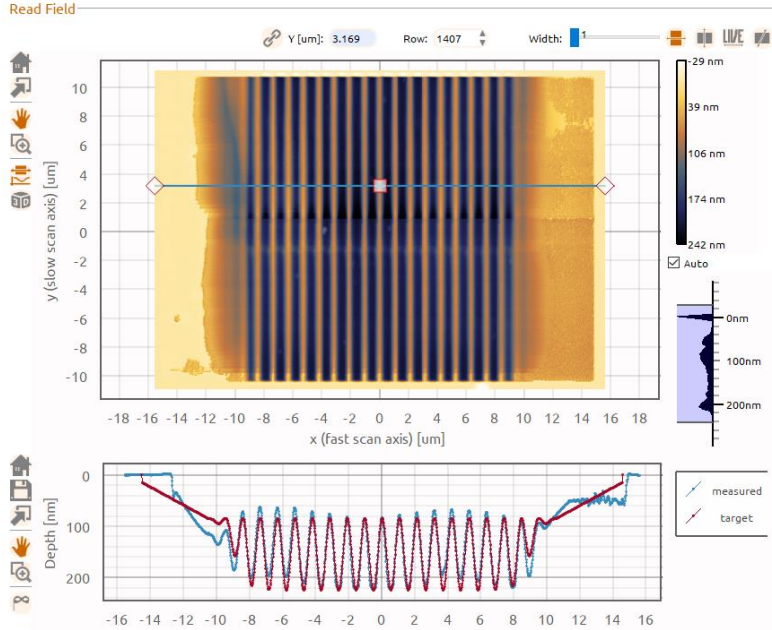


# A more challenging design: automated overlay of grayscale sine waves

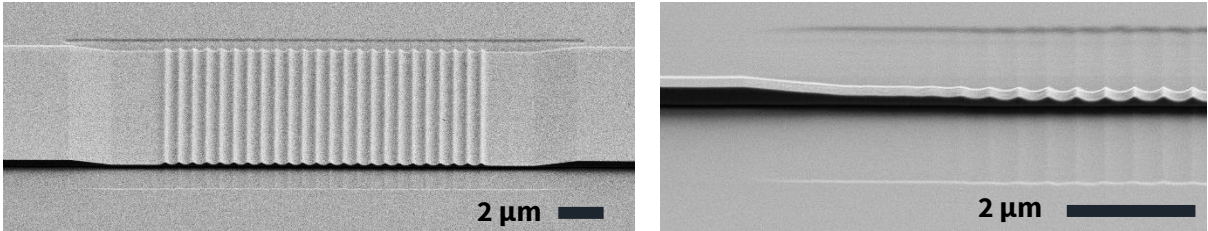
- Automatic overlay: align and pattern 45 grayscale sinewave gratings across markers on a 1.4 x 1.4 mm<sup>2</sup> sample



Optical microscope images after automatic overlay of 45 sine waves patterns across sample area of 1.4 x 1.4 mm<sup>2</sup>



SEM image of sine wave gratings in a Si waveguide after pattern transfer



Daniel Petter, Yannik Glauser, Nolan Lassaline, ETH Zurich

[heidelberg-instruments.com](http://heidelberg-instruments.com)



## How do we handle large and complex lay-outs in a smart manner?



Partnering up with GenISys

- Implement an existing importer (GenISys BEAMER engine) within the NanoFrazor software
- Enable use of advanced GenISys functionalities through the NF software, notably:
  - Fields creation modes: Fixed, Floating and Follow-Geometry
  - Ordering of fields
  - Region selection and application of local rules
- With the new functionalities, create new applications and NanoFrazor workflows



# Smart splitting and field ordering of electrical contacts to contact a nanowire device

The screenshot displays the 'Geometry' configuration window in the Nanoscope software. The interface is divided into several functional areas:

- Importer Settings:** Includes options for 'File', 'Source Geometry', and 'Geometry Transformations'. Under 'Geometry Settings', there are radio buttons for 't-SPL', 'Laser', and 'Overlay Reference', with 't-SPL' selected. A 'Lock Aspect Ratio' checkbox is checked. Numerical inputs for 'dx (nm)' and 'dy (nm)' are both set to 30.0, and 'Scan Angle' is 0.0. There is also a checkbox for 'World Map Positions From File Coordinates'.
- Target Geometry:** A large grid representing the scanning area, with axes labeled 'x (fast scan axis) [um]' and 'y (slow scan axis) [um]', both ranging from 0 to 1000.
- Results:** A section showing current parameters: X (um) 0.00, Y (um) 0.00, X (px) 0, Y (px) 0, # Fields 0, Fast Axis Speed (x) (mm/s) 0.00, Patterning Time (h:mm:ss) 0:00:00, and Total Time (h:mm:ss) 0:00:00.
- Split Settings:** Includes checkboxes for 'Auto Crop' and 'Auto Resize', both checked. It also lists 'Field Size (um)' (X: 44.34, Y: 64.48), 'Overlap (um)' (X: 0.20, Y: 0.20), and 'Offset (um)' (X: 0.00, Y: 0.00).
- Patterning Settings:** Lists 'Read Margin (um)' (X: 1.00, Y: 0.50), 'Read Upsampling' (X: 1, Y: 2), and 'Pixel Time (us)' 25.
- Stage and Focus Motor:** On the right, there are directional controls for the stage and focus motor. The 'Focus Motor' section has a 'Move up with stage' checkbox checked, 'Step (um)' 10, 'Position (um)' 25.0, and 'Auto Focus' status 'not ready'.
- Camera:** A live camera view of the nanowire device with a purple contact tip positioned over it.
- Bottom Status Bar:** Shows 'Vector Load Operation', 'Standby', 'Updating geometry', and 'Vector Grid 0%'.



## NanoFrazor technology – summary and outlook

- Thermal scanning probe lithography (tSPL) is a high resolution read & write technology
  - 20 nm lateral resolution, 1 nm vertical resolution (grayscale)
  - 30  $\mu\text{m}$  x 30  $\mu\text{m}$  / min throughput
- Integrated direct laser writer with sub- $\mu\text{m}$  resolution (100x speed increase)
- Low-damage lithography compatible with many materials to create novel 1D, 2D and 3D devices and applications
- Easy-to-use and versatile (automated) markerless overlay functionality
- Capability to handle large layouts thanks to the GenISys engine integration
- Smart splitting feature increases the user friendliness and lowers (pre)patterning times





## Acknowledgements

**Yann Mamie**, Software Engineer

GenSys engine integration

**Jana Chaaban**, Head of Process & Applications Laboratory

GenSys importer testing & benchmarking

**Robin Erne**, Reliability Engineer

GenSys importer testing & benchmarking

**THANK YOU!**

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