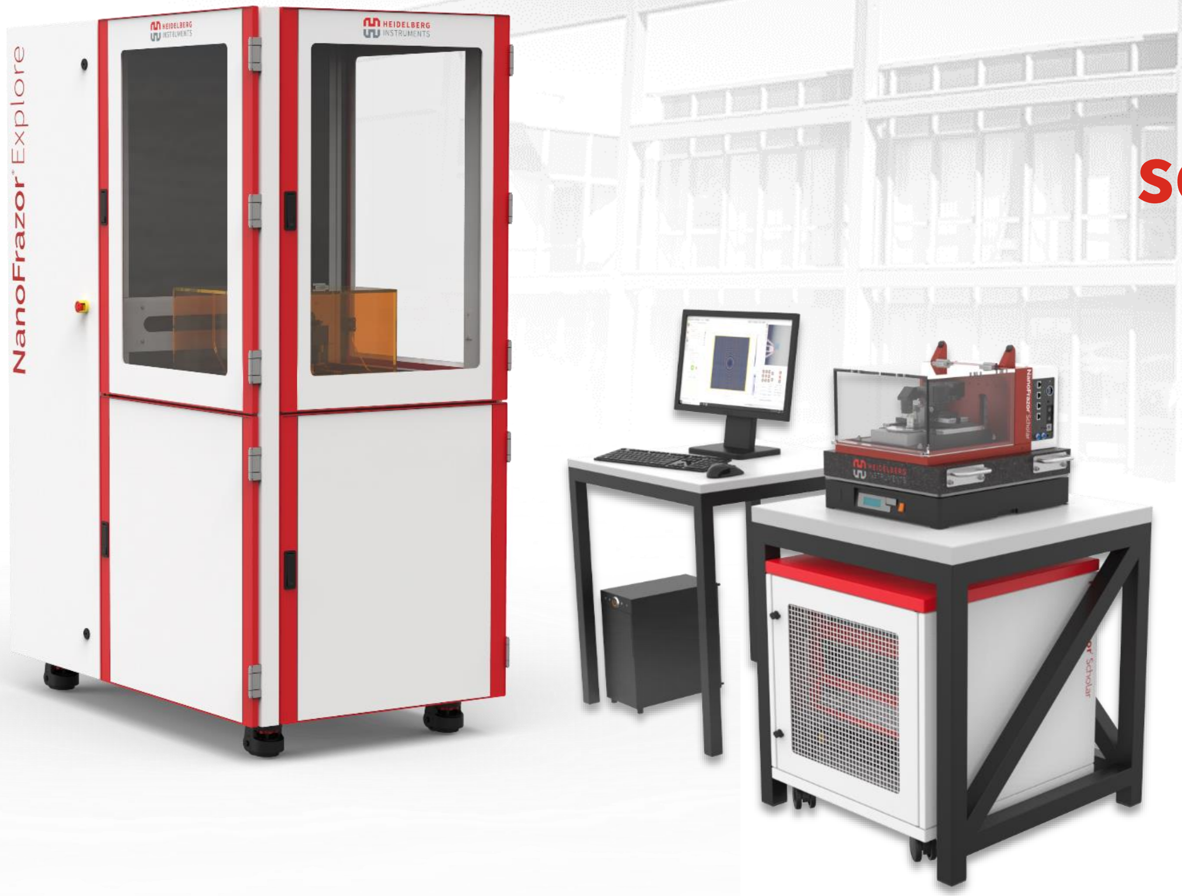
HEIDELBERG
INSTRUMENTS

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



BEAMeeting

April 10th 2024

Dr. Cathelijn van Nisselroy

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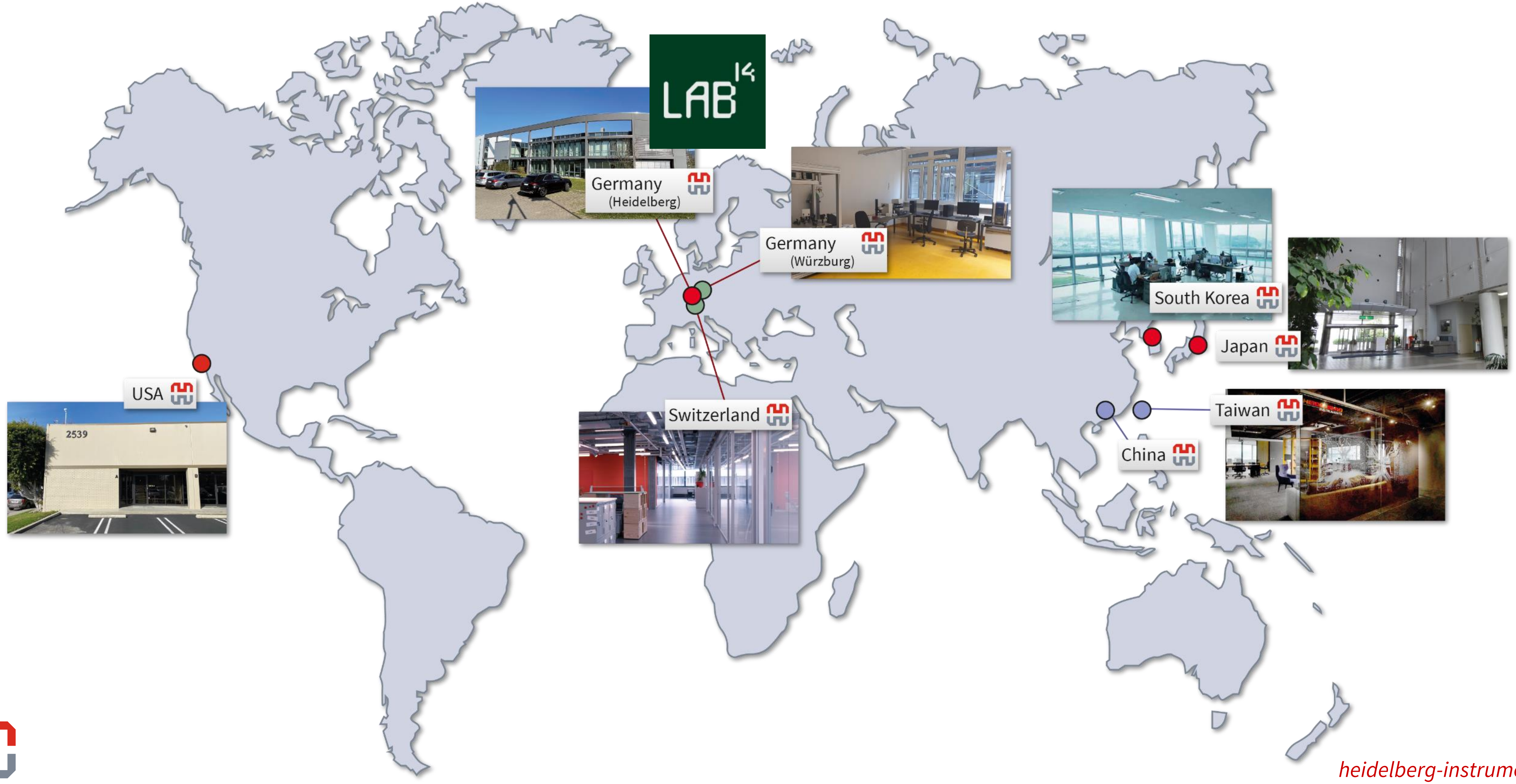
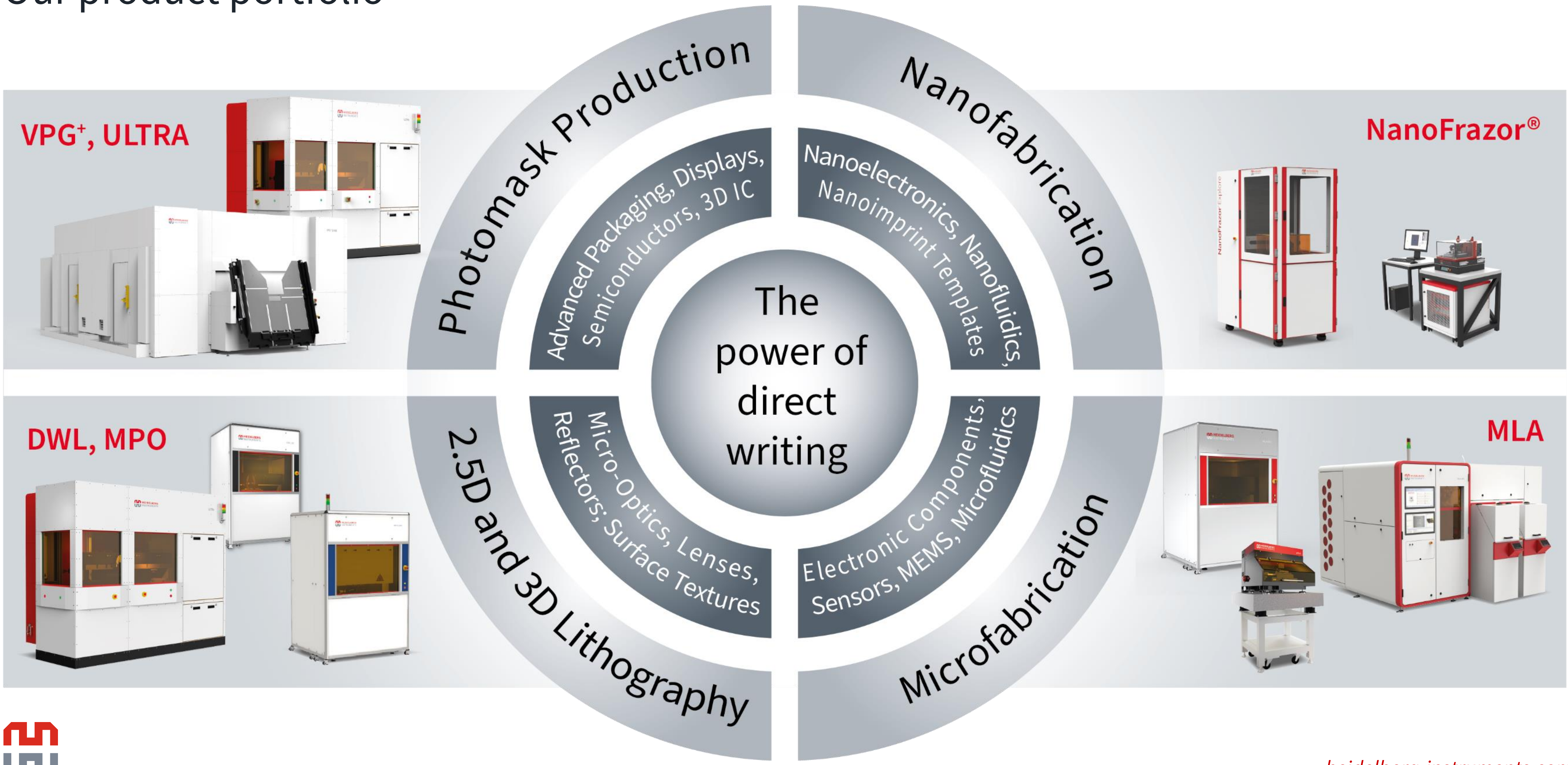
MEMS Develoment Engineer

Heidelberg Instruments worldwide



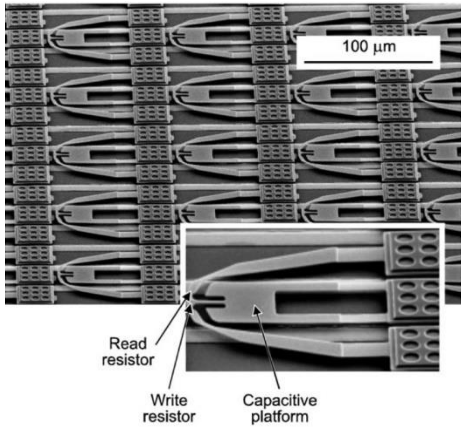
Our product portfolio

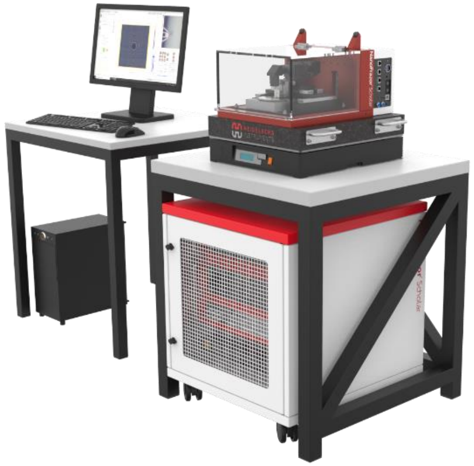


NanoFrazor by Heidelberg Instruments Nano

Origin of our technology

IBM





NanoFrazor Scholar

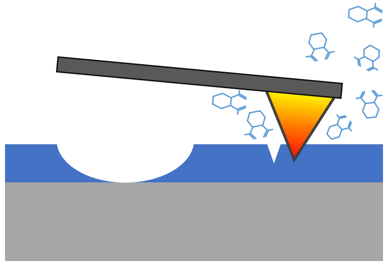
NanoFrazor Explore

1995 – 2007	2014	2018	Now
IBM Millipede	Nanofrazor (SwissLitho AG) becomes commercial	SwissLitho AG joins Heidelberg Instruments	~25 employees in Zurich on NanoFrazor technology

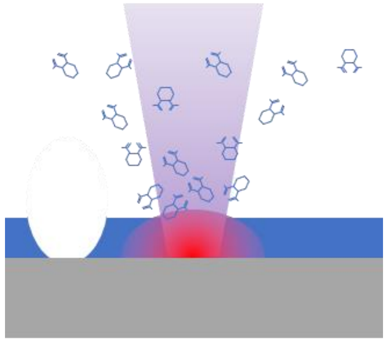
Principle of the NanoFrazor technology

Writing

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

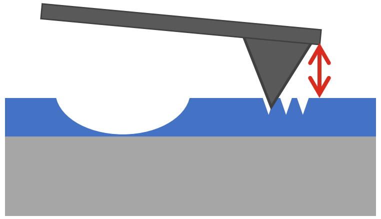


- Direct Laser sublimation
  - Micrometer resolution
  - Larger area coverage
  - 100x faster (than tip)



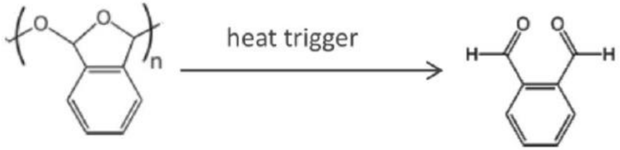
Reading

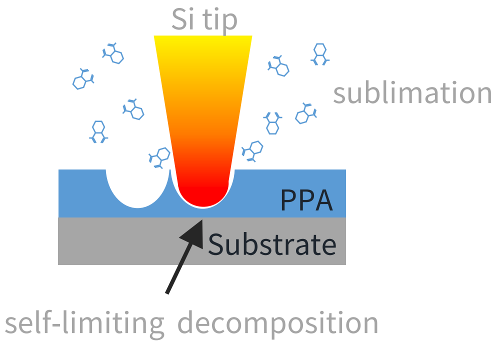
- Integrated topography sensor
  - *In-situ* inspection and metrology
  - Overlay & Stitching
  - Level plane & autofocus
  - Drift corrections
  - Other calibrations



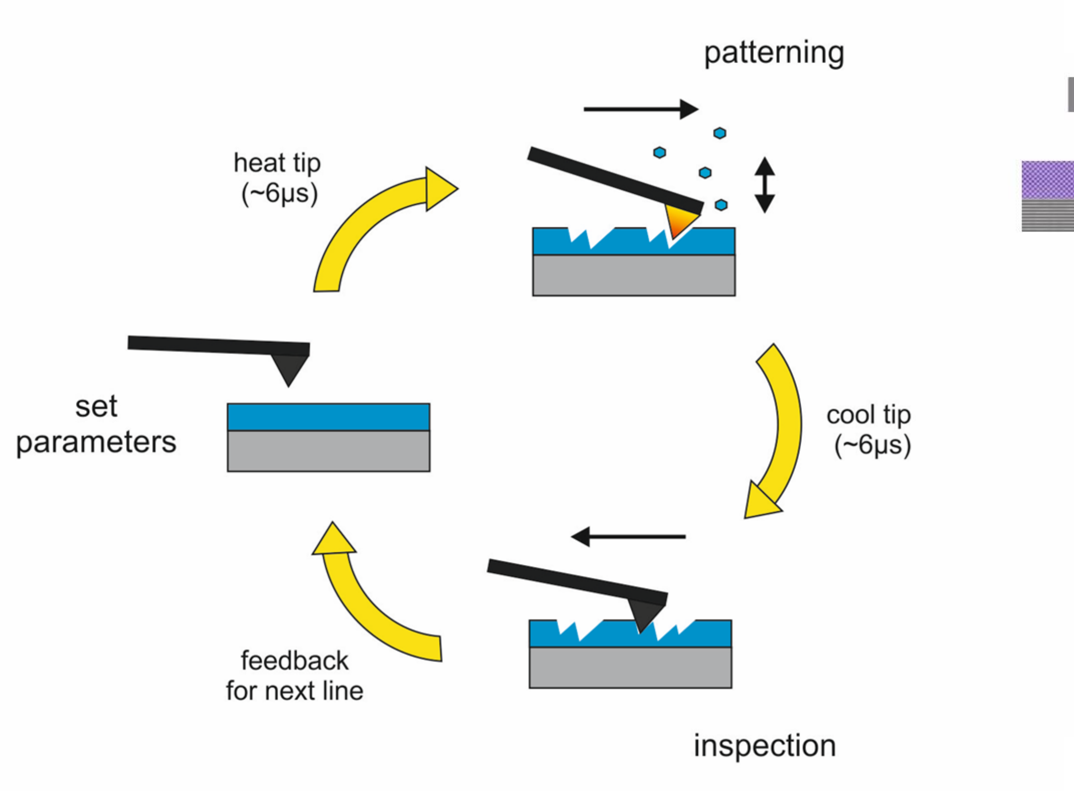
Thermally-sensitive resist

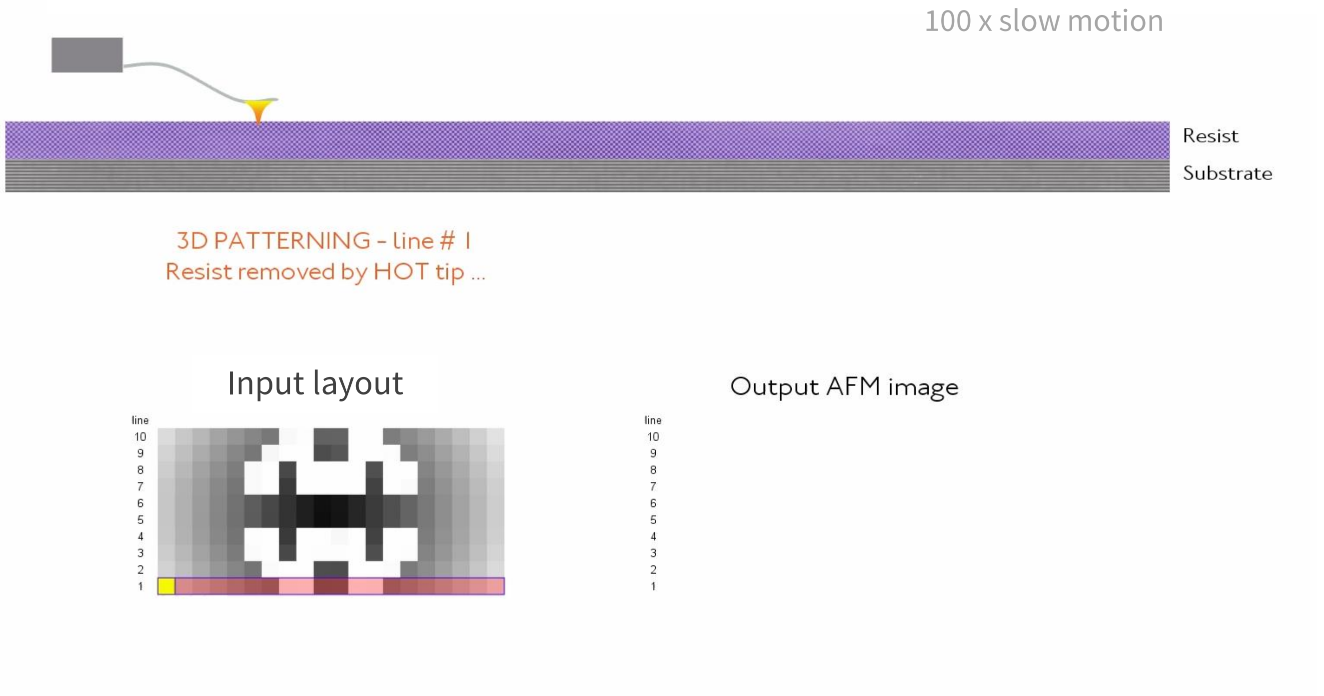
- Polyphthalaldehyde (PPA)
- PPA resist sublimates by heated tip
- Endothermic reaction prevents spread of heat
- No proximity corrections





Closed-loop lithography: patterning & imaging

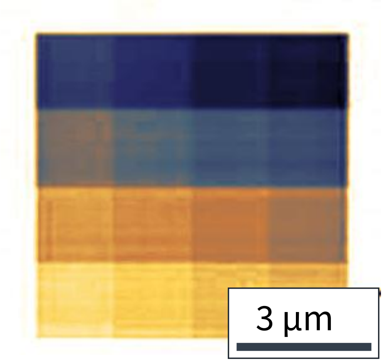




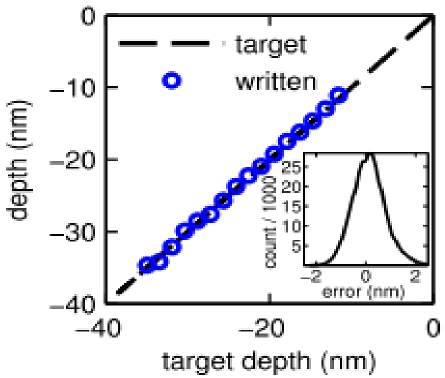
- *In-situ* metrology: no separate metrology necessary after lithography
- Automation: online adaption of patterning every few ms
- Enables: short fabrication time, increased accuracy & reliability, stitching & overlay of designs

High resolution grayscale lithography

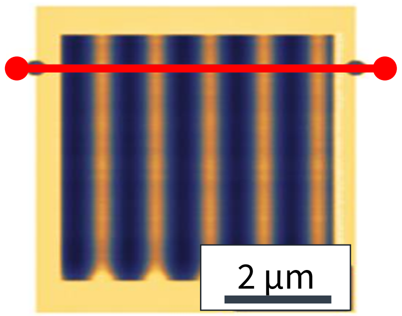
Sub-nm vertical resolution



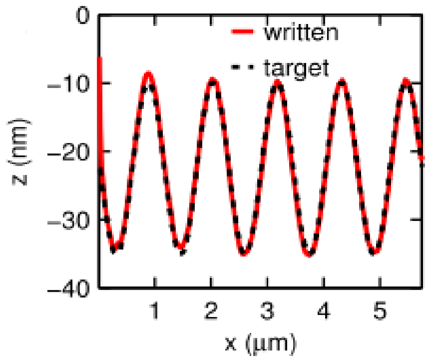
Discrete levels (1.5 nm)



error (1σ): **0.69 nm**



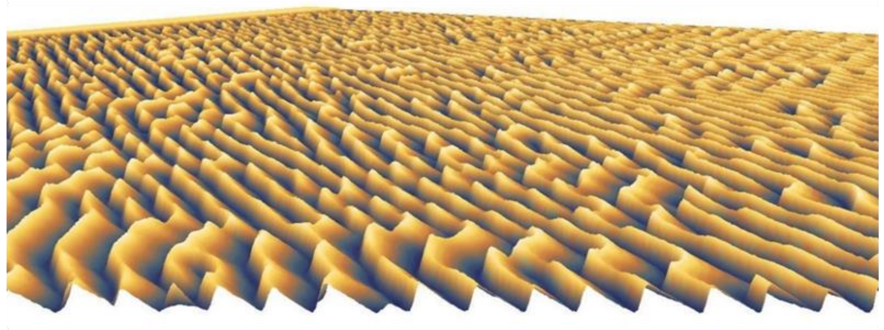
Continuous sine wave



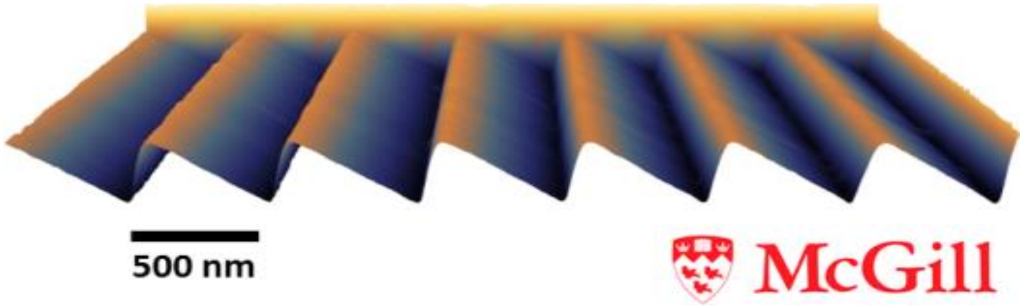
error (1σ): **0.85 nm**

Rawlings et al., Nat. Scientific Reports, 2017

Grayscale high-resolution patterning examples



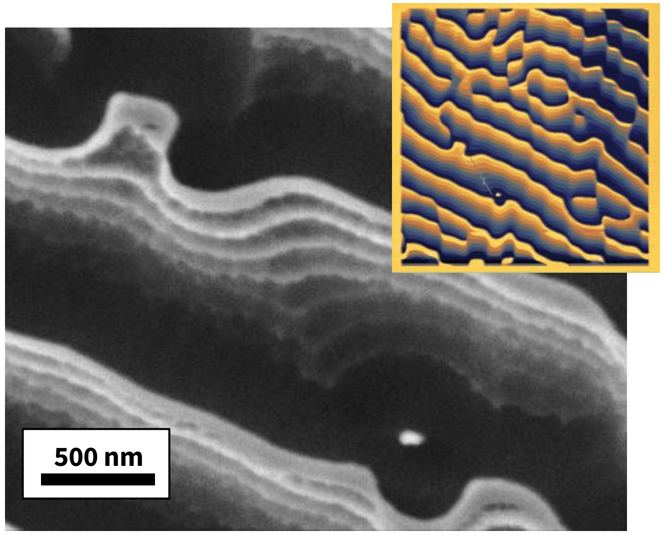
3D hologram in PPA, Kulmala et al, SPIE Adv. Litho., 2018



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

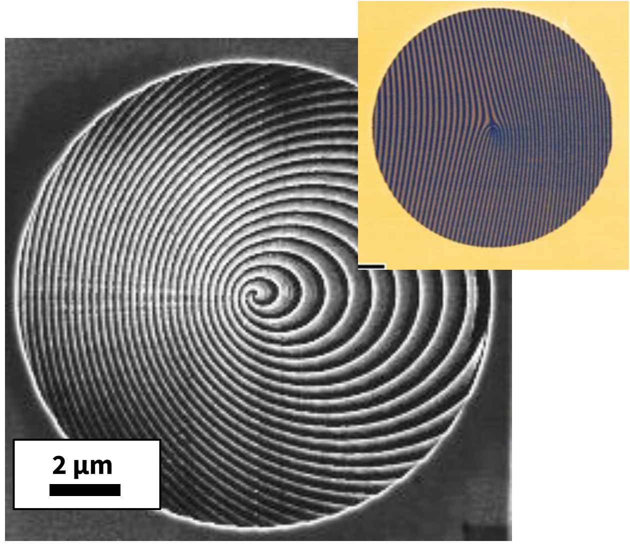
Applications in grayscale: applications in photonics

Hologram in Si (700 nm deep)



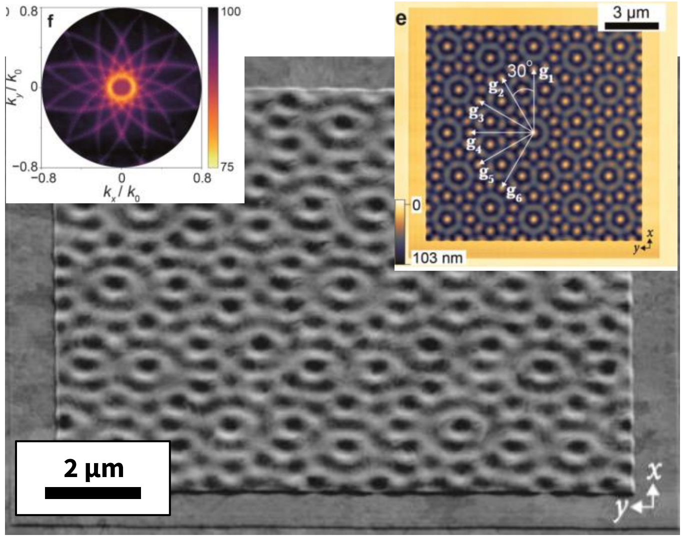
Kulmala *et al.*, SPIE, 2018

Phase Plates in SiN membranes



Hettler *et al.*, Micron, 2019

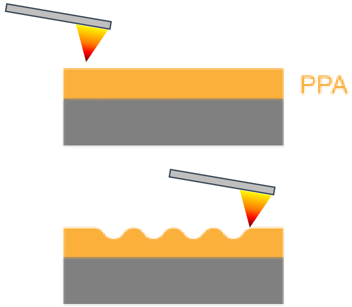
Optical Fourier Surfaces

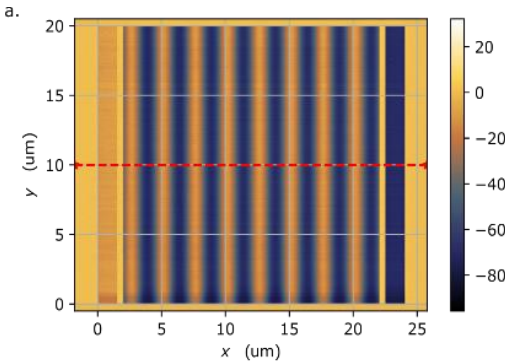


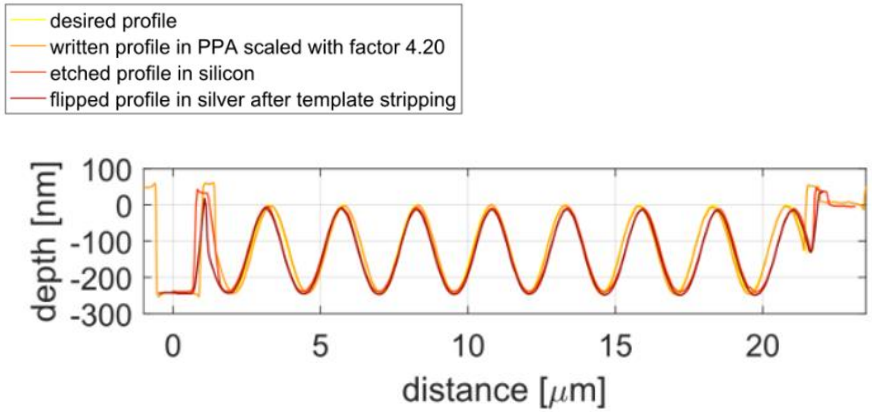
Lassaline *et al.*, Nature, 2020

Post processing of sine waves in arbitrary materials

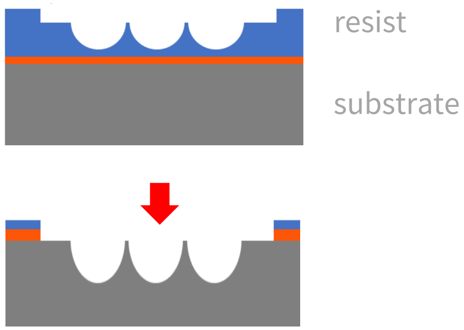
Pattern in resist



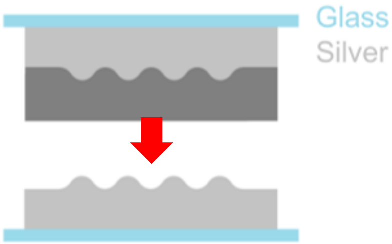




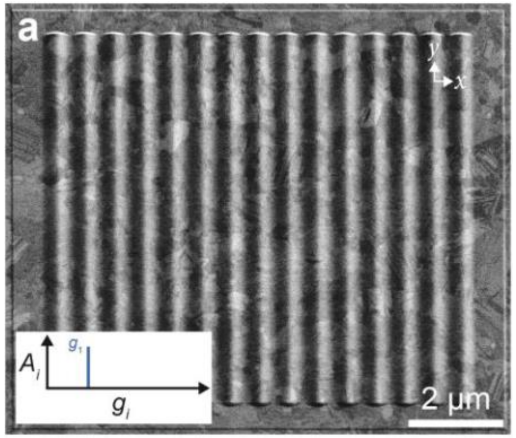
Etching



Template Stripping



SEM inspection

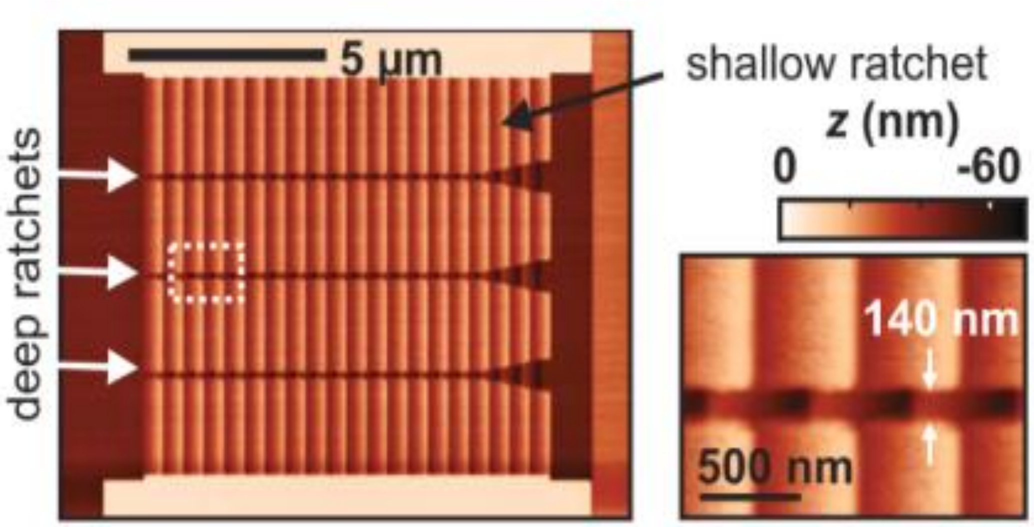


Grating made of Ag by template stripping

Lassaline *et al.*, Nature, 2020

Applications in grayscale: nanofluidics and nanobiology

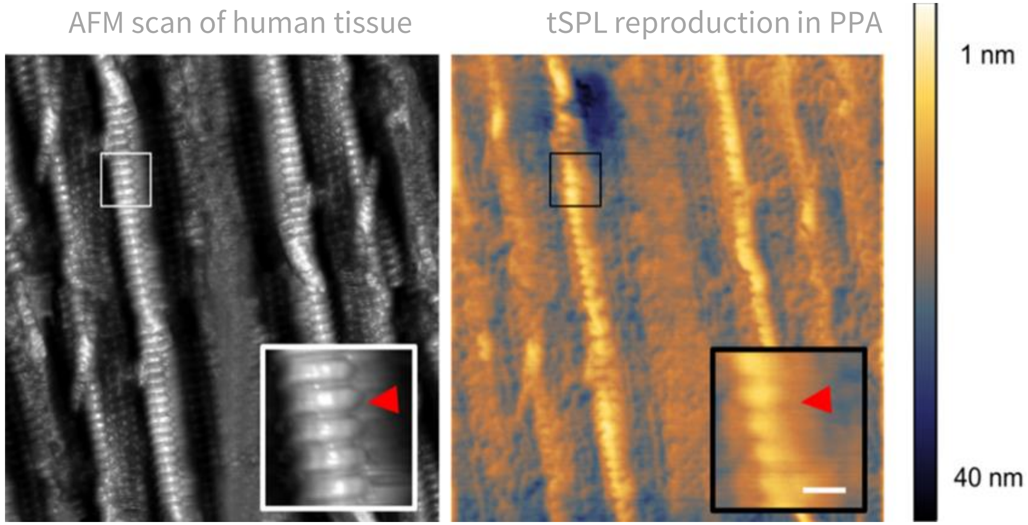
Nanofluidic Brownian Motors



Skaug et al., Science, 2018

- 3D channels with 1 nm accuracy
- Precise sorting of bioparticles

Topographies for stem cells study



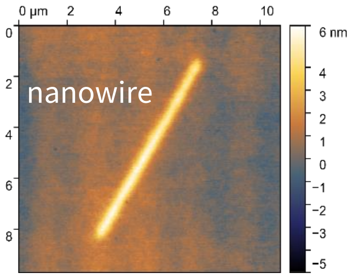
Tang *et al.*, ACS Appl. Mat., 2019

- NanoFrazor-generated topography in PPA mimics tissue microenvironment
- Directly cultured stem cells on PPA

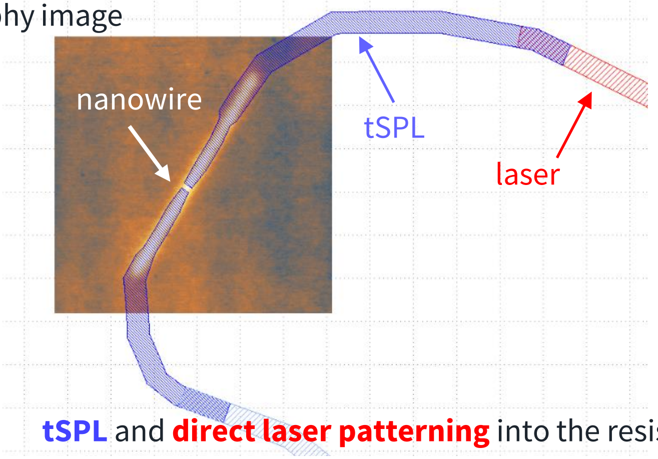
Contacting nanowires: markerless overlay principle for a nanowire quantum device

Inside the NanoFrazor:

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



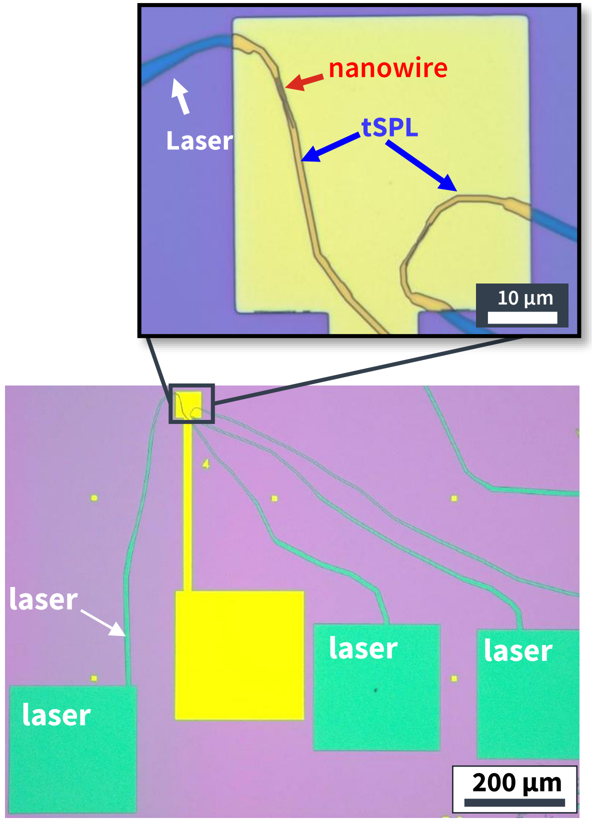
Manual markerless overlay: place design pattern directly on topography image



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

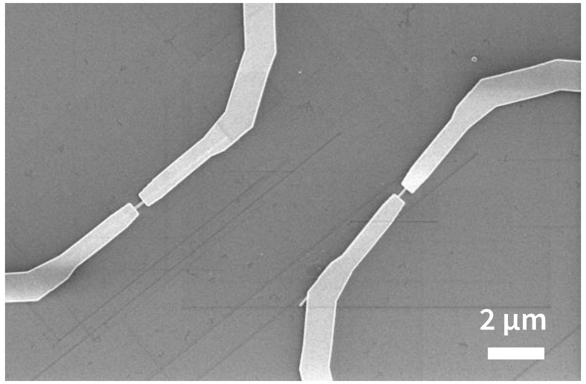
Optical images after NanoFrazor patterning:

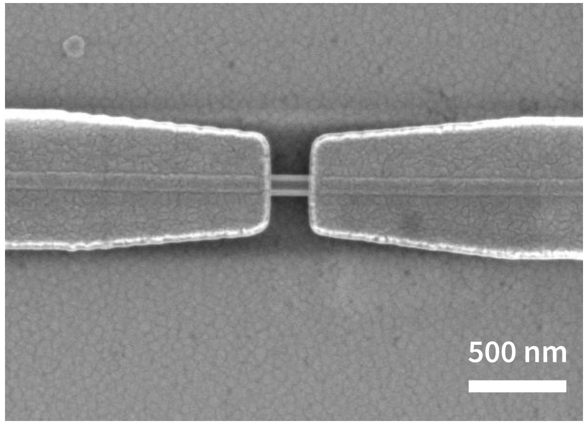
tSPL+ laser hybrid lithography, device <1h



After metallization and lift-off:

Optical and SEM images

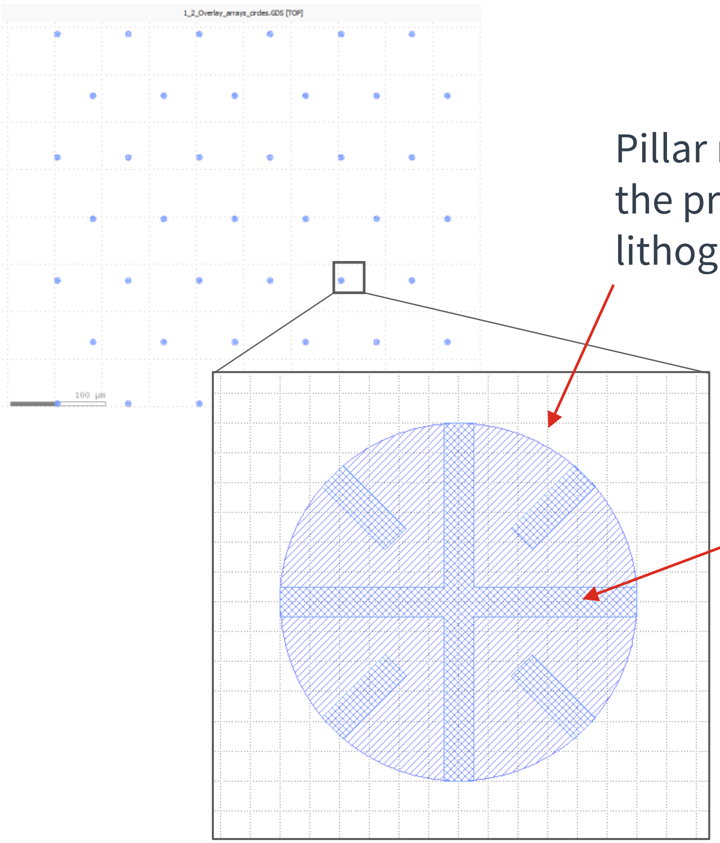




L. Shani, J. Chaaban *et al* 2024 *Nanotechnology* **35** 255302

From manual to automated markerless overlay

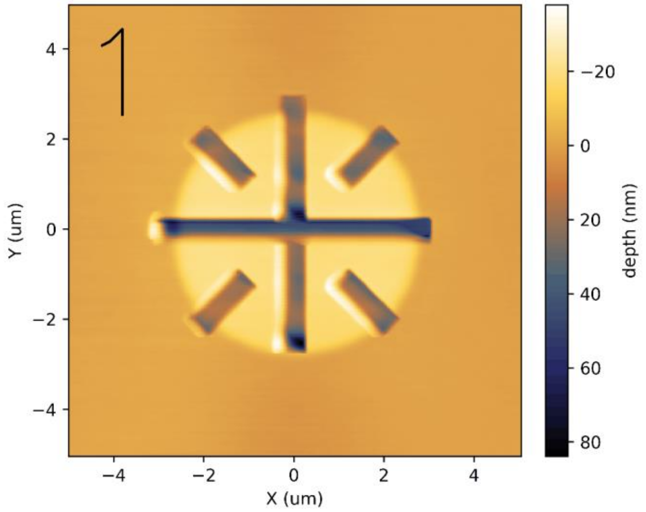
.GDS Design



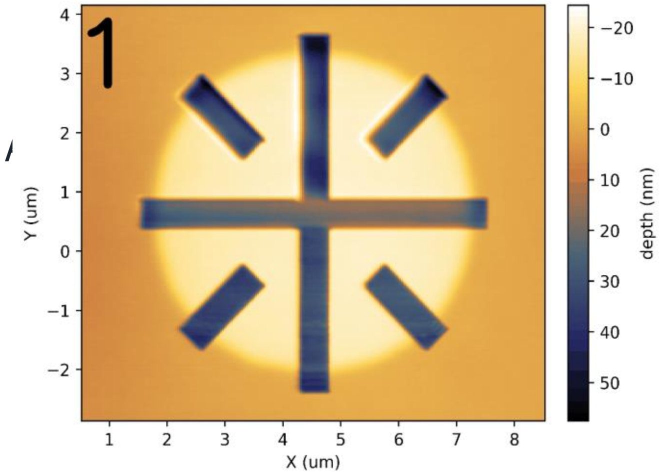
Pillar made during the previous lithography step

Cross that needs to be precisely aligned on the pillar

Without automatic overlay



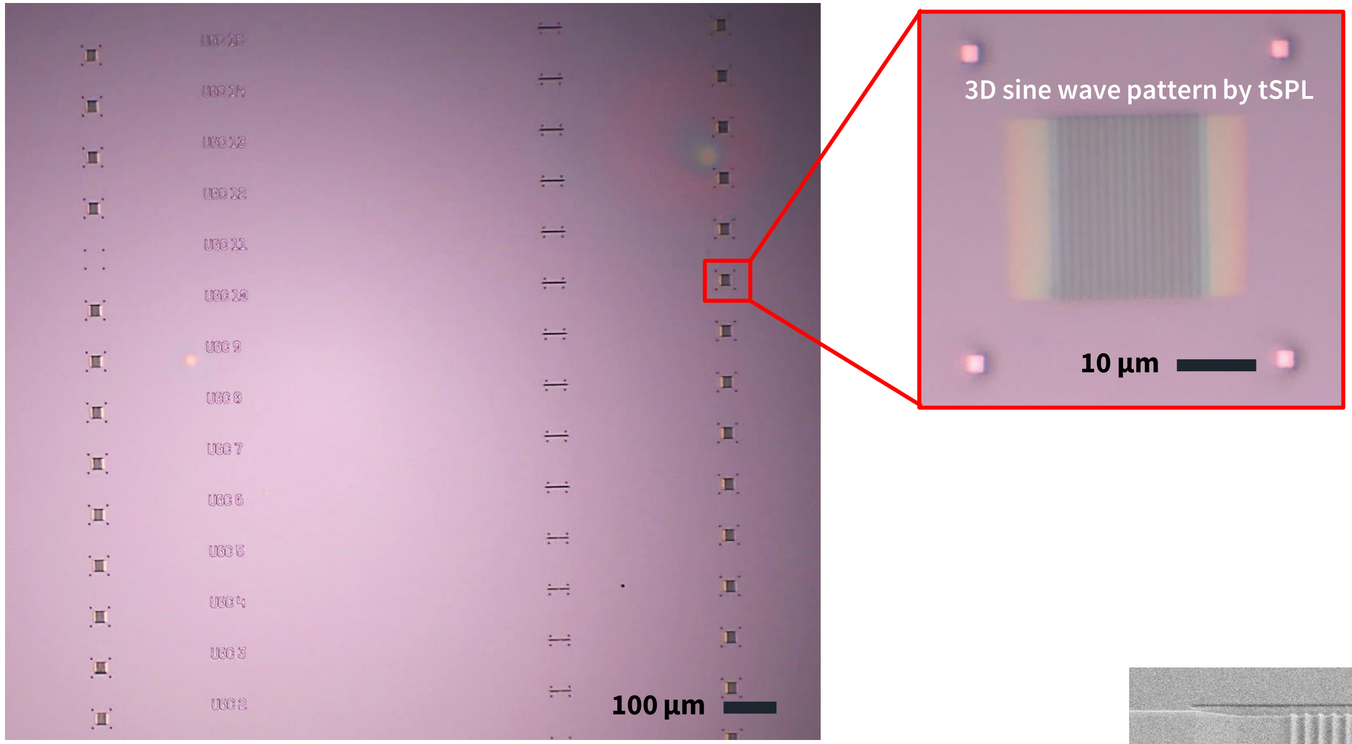
With automatic overlay



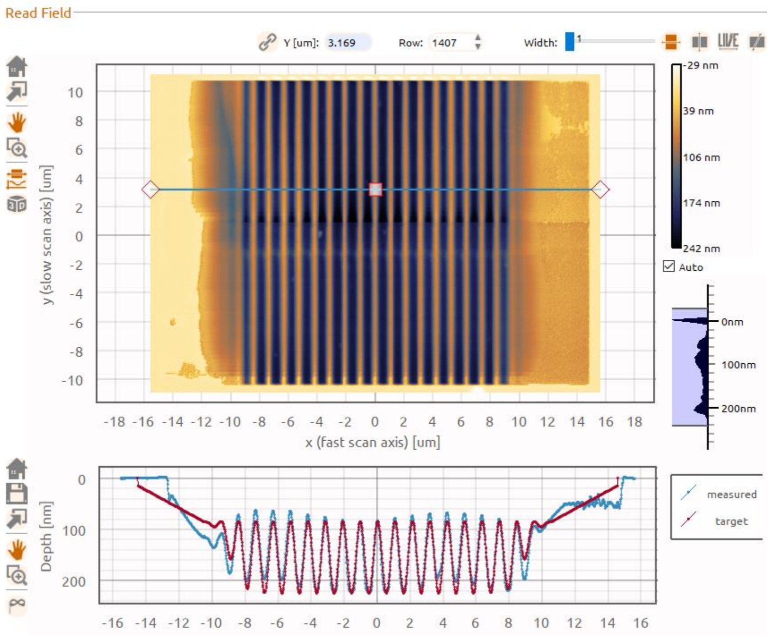
Overlay accuracy < 25 nm

A more challenging design: automated overlay of grayscale sine waves

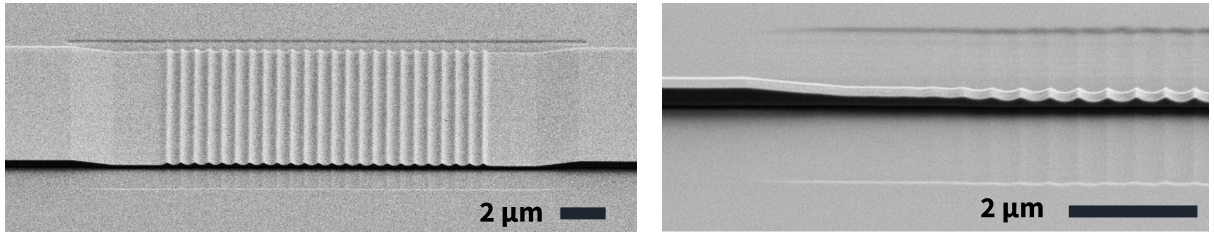
- Automatic overlay: align and pattern 45 grayscale sinewave gratings across markers on a 1.4 x 1.4 mm^2 sample



Optical microscope images after automatic overlay of 45 sine waves patterns across sample area of 1.4 x 1.4 mm^2



SEM image of sinewave gratings in a Si waveguide after pattern transfer



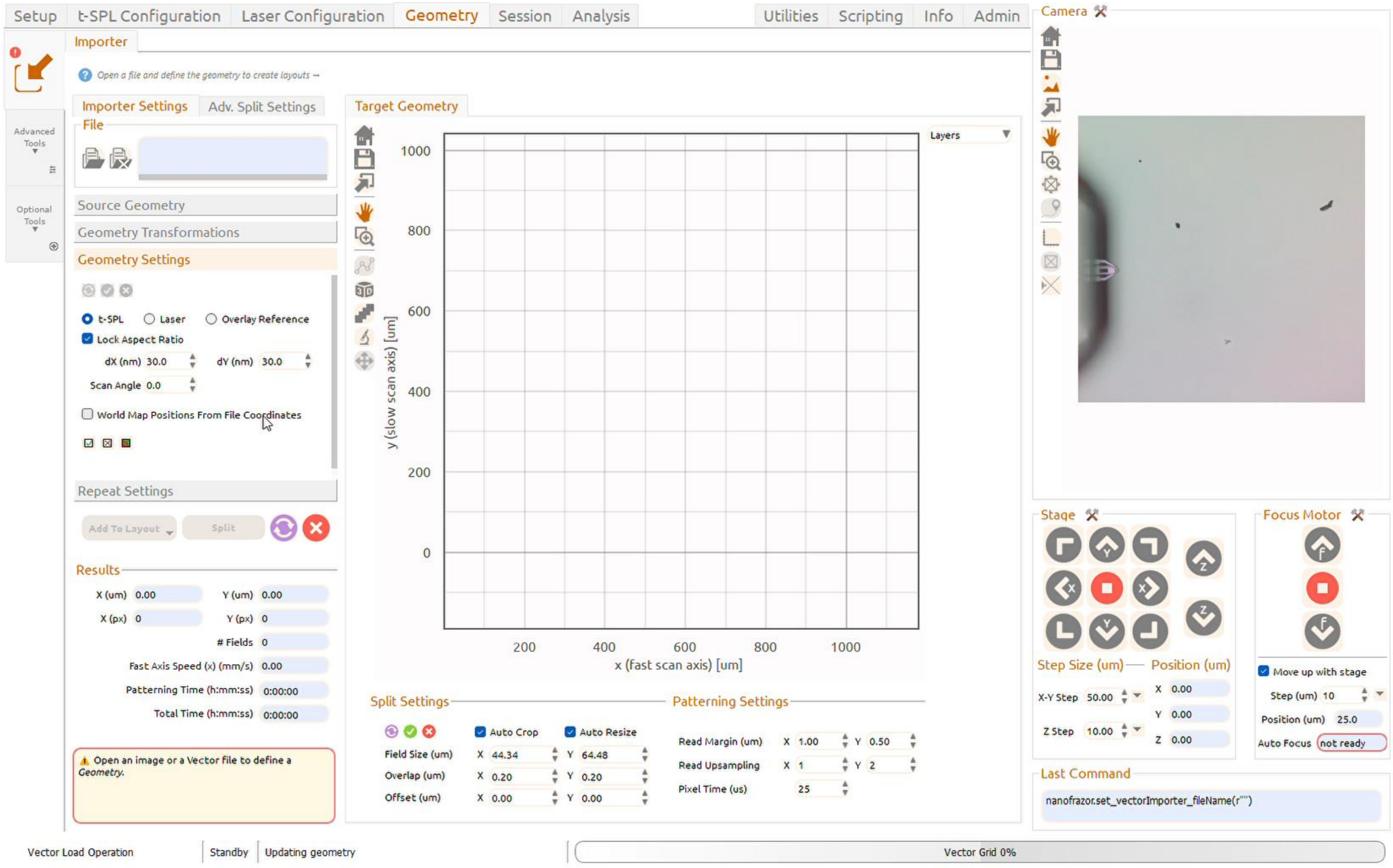
Daniel Petter, Yannik Glauser, Nolan Lassaline, ETH Zurich

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



NanoFrazor technology – summary and outlook

- Thermal scanning proble lithography (tSPL) is a high resolution read & write technology
  - 20 nm lateral resolution, 1 nm vertical resolution (grayscale)
  - 30 µm x 30 µm / min throughput
- Integrated direct laser writer with sub-µm 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

HEIDELBERG INSTRUMENTS

Acknowledgements

Yann Mamie, Software Engineer

GenISys engine integration

Jana Chaaban, Head of Process & Applications Laboratory

GenISys importer testing & benchmarking

Robin Erne, Reliability Engineer

GenISys importer testing & benchmarking

THANK YOU!

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