NanoFrazor Lithography Applications

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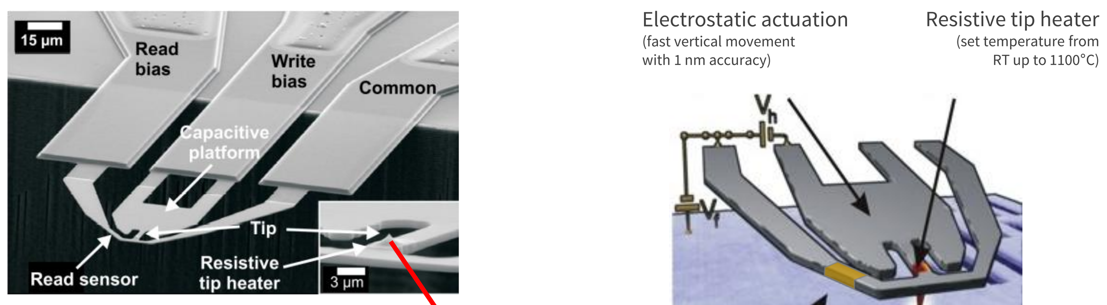
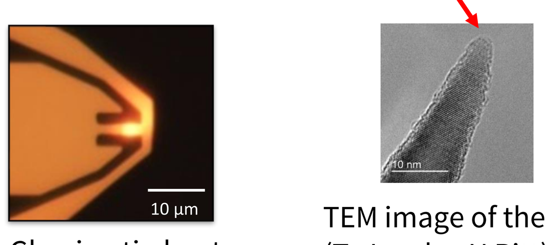
Thermal Scanning Probe Lithography (t-SPL): introduction

Thermal Probe

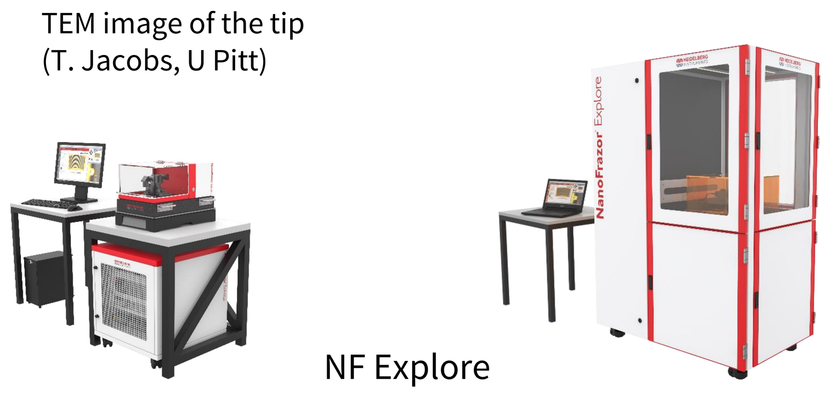


Heatable cantilevers



Glowing tip heater

TEM image of the tip (T. Jacobs, U Pitt)



NF Scholar

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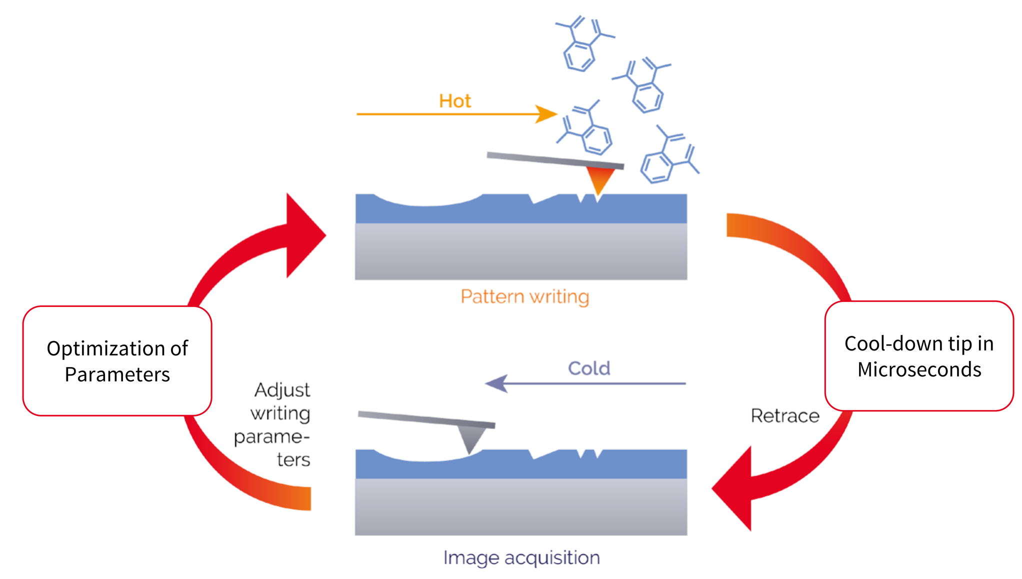
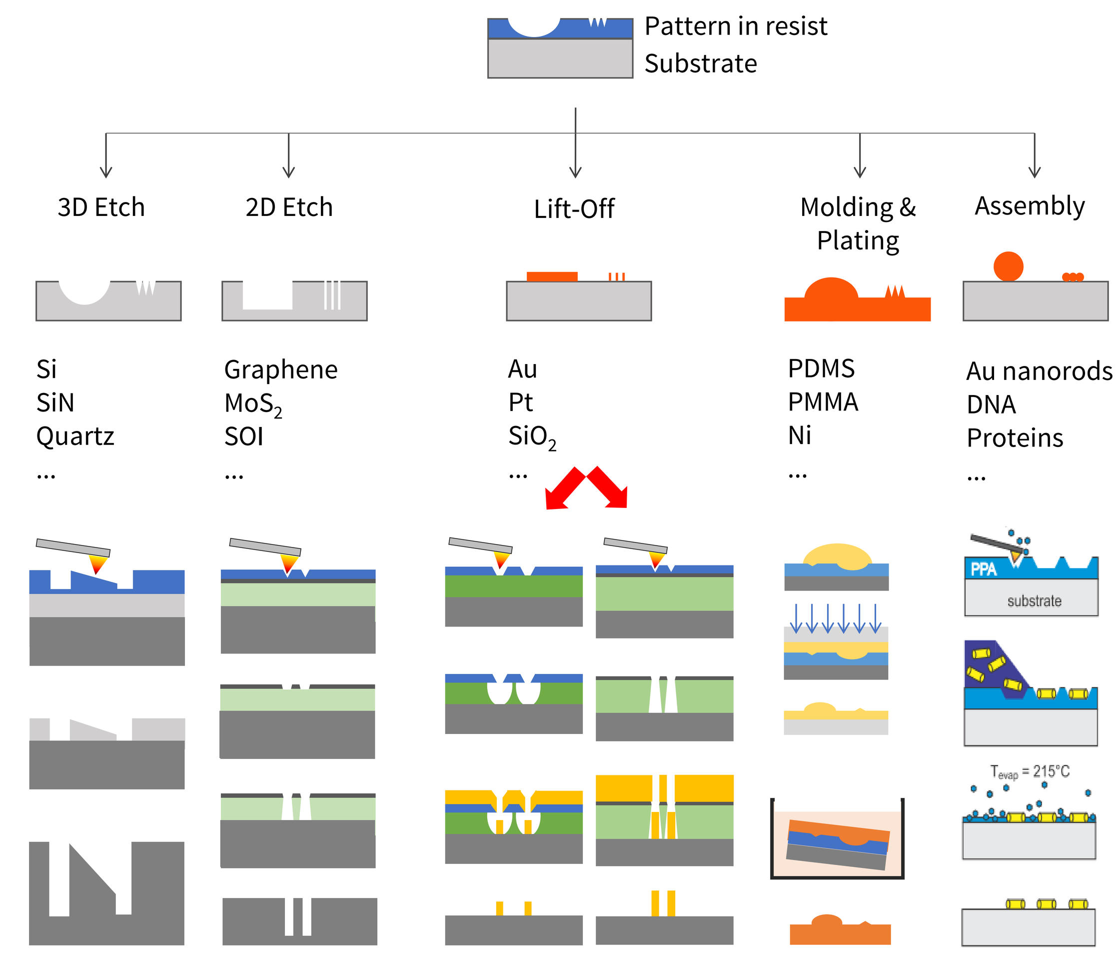
Closed-Loop Lithography

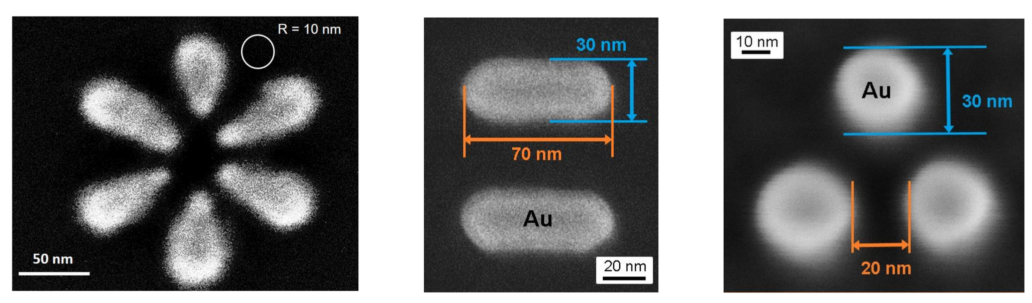


Polyphthalaldehyde (PPA) decomposes upon heat impact
PPA commercially available as Phoenix81 from AllResist, Germany

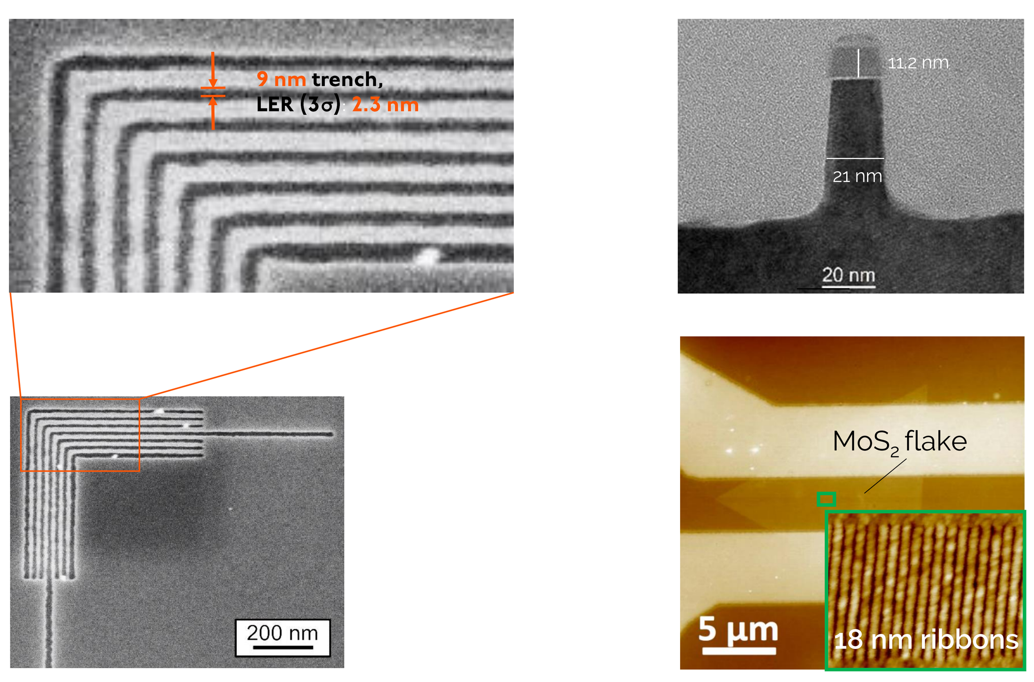
Pattern transfer



High resolution 2D patterns

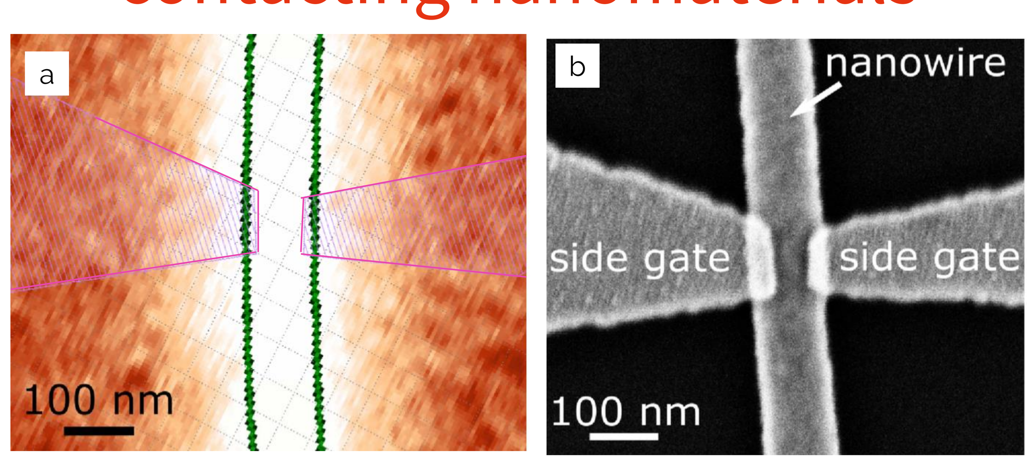


The ultra-sharp tip enables patterning at extremely high resolution. Due to absence of proximity effects, writing complex geometries is straightforward. High-resolution patterns like this find applications in nanoplasmonics and nanoelectronics. The left image shows Au structures made by lift-off and the right two images by Au etching.



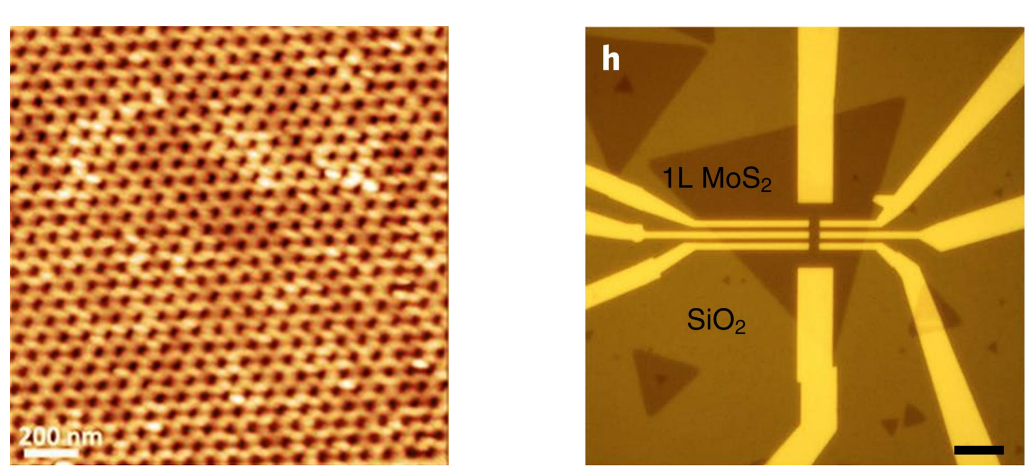
A broad range of high-resolution applications with sub 20-nm features can be addressed by NanoFrazor technology. **Left:** Narrow trenches etched into Si [1]; **Right:** Top cross-section silicone ribbon after etching benefitting from sequential infiltration synthesis (SIS) enhancing the PPA selectivity [2]. Bottom homogeneously etched nanoribbons all the way through the MoS2 flake

Accurate markerless overlay for contacting nanomaterials



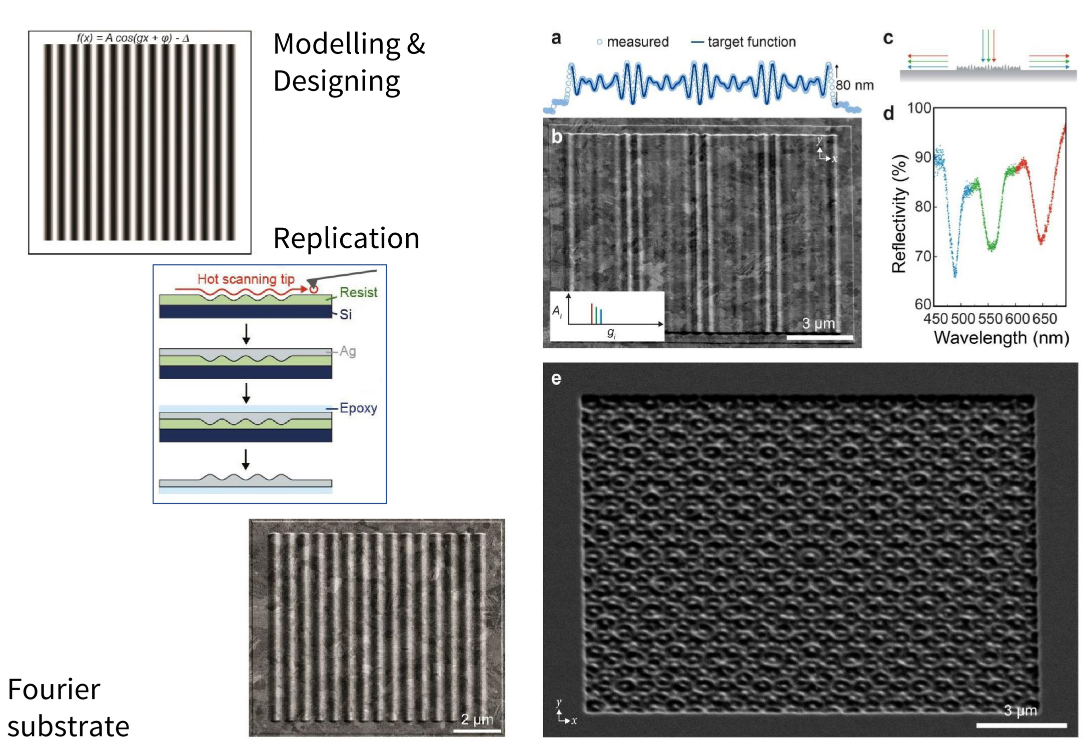
Nanowires or even atomically thin 2D materials can be easily detected through the resist stack (e.g. LOR + PPA) allowing for painless adaptation and alignment of contact electrodes over them. Sub-10 nm overlay accuracy is achieved.
Left: In-situ image of nanowire with electrodes design; **Right:** SEM of final device

No damage to sample

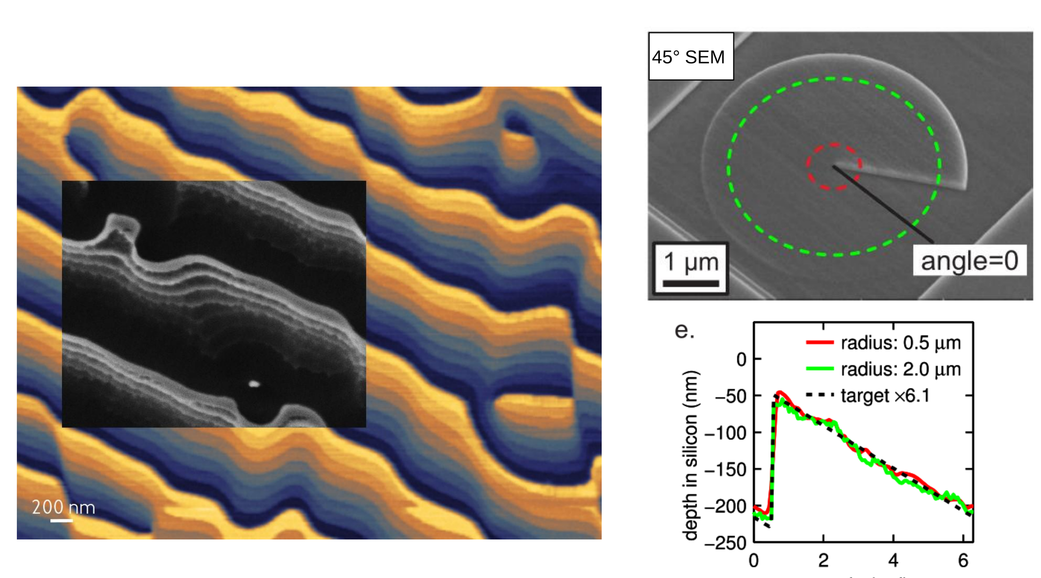


Electron or ion beam lithography can damage the sample by introducing vacancies or unwanted charges into it. T-SPL avoids such damage as it uses heat for removing the thermal resist locally. **Left:** This approach allows studying the intrinsic properties of sensitive nanomaterials such as graphene nano-dot arrays; **Right:** Device with MoS_2 flakes and metal electrodes for testing [3].

3D/Grayscale lithography Optical devices

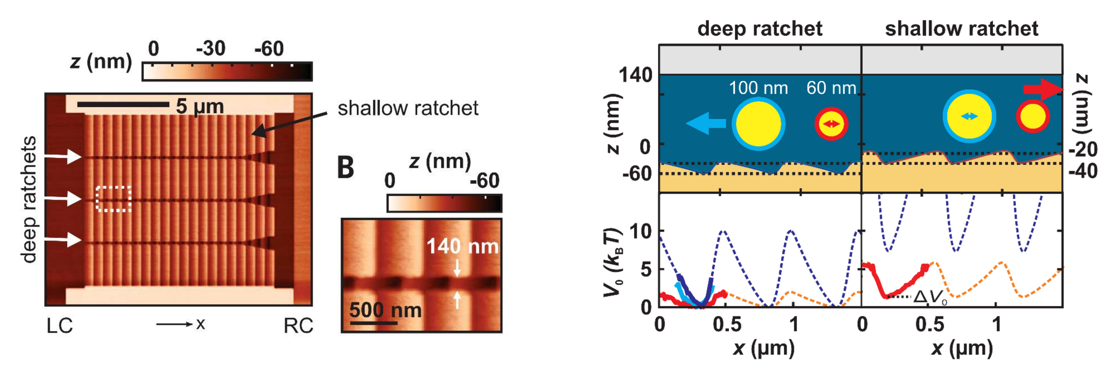


Patterned surfaces (gratings or holograms) can tailor optical signals by diffraction.
Left: principal device generation containing a Fourier surface made of Ag.
Right: a-d) device with three 1D sinusoids that couples red, green, and blue photons at normal incidence to surface-plasmon polaritons; e) SEM (45° tilt) of a 12-fold rotationally symmetric quasicrystal, defined by 12 1D-sinusoids, etched into Si. [4]



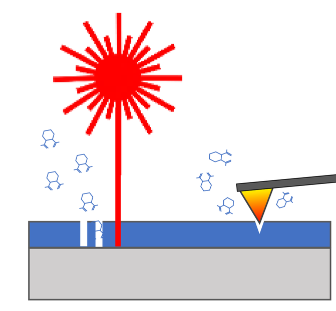
The precise grayscale features patterned by NanoFrazor lithography can be transferred into the underlying material with high precision via reactive ion etching (RIE). **Left:** Here, an 8-level computer generated hologram was etched into a silicon substrate. During the process, the depth of the pattern was amplified by a factor of 10 (from 64 nm to 700 nm). **Right:** Spiral phase plate etched into Si; The AFM profiles acquired along the pattern confirm a high uniformity and smoothness of the transferred pattern.[5]

Nanofluidics for Brownian motors

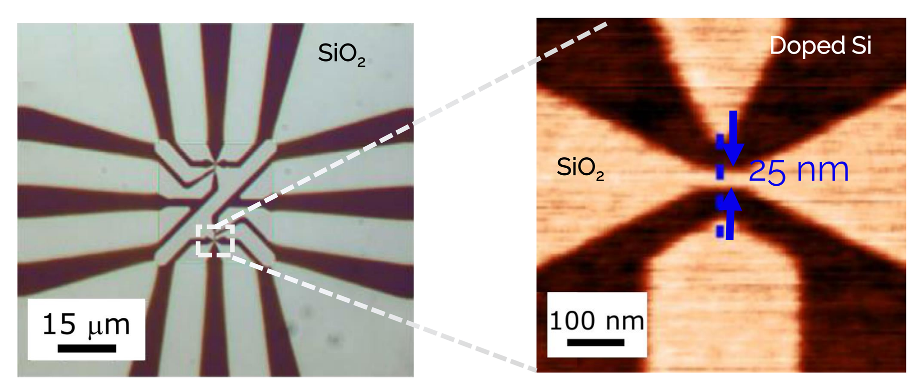


Nano PPA ratchets for sorting 60-nm and 100-nm Au nanoparticles. The ratchets design was first simulated for optimizing the nanoparticle separation. Subsequent it was patterned into PPA; **Left:** Device topography made by t-SPL.
Right: Top: device schematics, roughly to scale with experimental conditions.
Bottom: corresponding measured (solid) and modelled (dashed) static energies. [6]

Direct Laser Sublimation for large area patterning

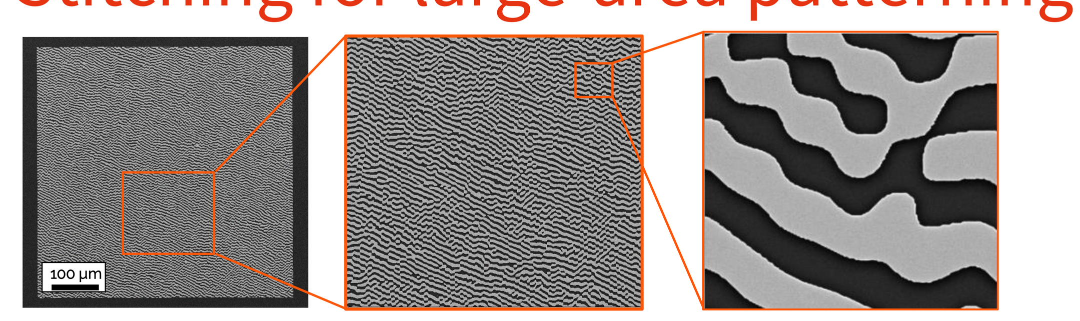


- Mix & match; no new processing steps needed
- λ = 405 nm
- Resolution ~1 µm → faster throughput for writing e.g. contact pads
- Seamless stitching with t-SPL written patterns

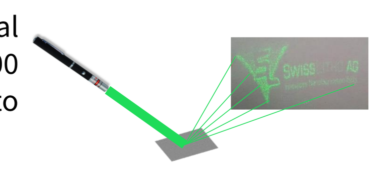


A single-electron transistor fabricated by the mix & match approach. [6] The contacts were patterned by a laser and the high-resolution features by t-SPL.

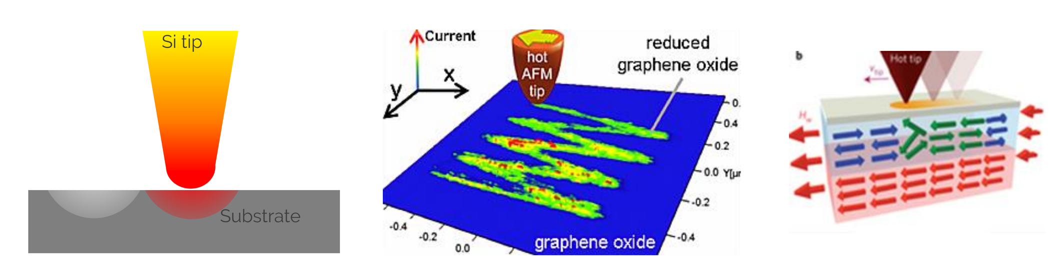
Stitching for large-area patterning



Large patterns can be realized by stitching several write fields together with high accuracy. Here, 100 fields sized 50x50 um² each were stitched together to form a 2-level hologram pattern.

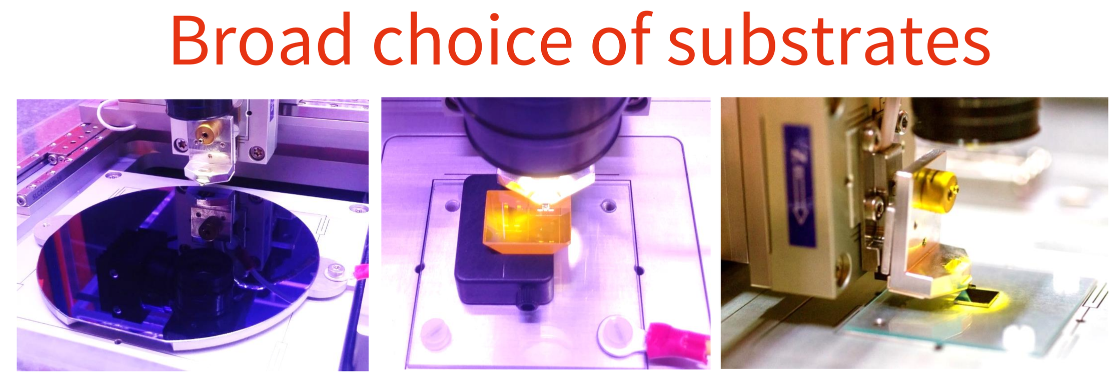


Thermochemical nanolithography



NanoFrazor tips can also be used for triggering chemical reactions, phase transitions, crystallization etc. at the nanoscale (left). Reduction of graphene oxide (middle, [8]) and domain switching in magnetic materials (right, [9]) are further examples of the versatility of this approach.

Broad choice of substrates



As NanoFrazor lithography works in ambient environment, outgassing of materials is not an issue. Almost any substrate can be patterned: conducting, insulating, magnetic, etc.

References

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[2] Marneffe et al *ACS Nano*, 12, 11, 11152-11160 (2018)
[3] Zheng *et al.*, *Nat. Electron.*, 2,17–25 (2019).
[4] Lassaline et al, arXiv:1912.09442 [physics.optics] (2019)
[5] Hettler et al, *Micron*, 127,102753 (2019)
[6] Skaug et al., Science, 359, 1505–1508 (2018),
[7] Rawlings et al., *Nanotechnology*, 29, 505302 (2018)
[8] Wei et al., *Science*, 328, 1373-1376 (2010).
[9] Albisetti et al, *AIP Advances*, 7, 055601 (2017)