Thermal Probe Nanolithography: closed-loop, high-speed, high-resolution, 3D

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Heated tips (see Figure 1) offer the possibility to create arbitrary high-resolution nanostructures by local decomposition and evaporation of resist materials [1,2]. Closed-loop lithography and turnaround times of minutes are achieved with this patterning method due to the high-speed direct-write process and an in-situ imaging capability [3]. A marker-free stitching method [4], compatibility with CMOS processes [1,2,5] and high precision 3D patterning [1,2,5,6] complement this novel nanolithography concept. The technology has been developed at IBM and is now commercialized by SwissLitho, a spinoff company of ETH Zurich.

Conventional lithography methods lack the means of in-situ monitoring of the patterning quality and a corresponding adaption of the conditions during the lithography process. This leads to the challenge (and consequently high costs of ownership) to achieve perfect control of all the various parameters that influence the lithography process of high resolution patterns. Thermal Scanning Probe Lithography (tSPL) comprises a robust closed-loop lithography scheme and has become a cost-effective extension and alternative to conventional mask-less lithography technologies like E-beam lithography.

Dense features with 10 nm half-pitch can be written into thermally decomposable resist materials using tSPL (see Figure 2a). The patterning speed of tSPL has been increased far beyond usual scanning probe lithography technologies and approaches the speed of E-Beam writer for <30 nm resolution. Figure 2b shows a complex pattern that was written in less than 1 s using a single tip with a pixel rate 500 kHz, a linear scan speed of 20 mm/s and 10 nm positioning accuracy over a range of 10 µm. Moreover, a novel scheme for stitching was developed to extend the patterning area beyond the 100 µm range of the piezo stages [4]. This method makes use of the in-situ imaging capability and the uniqueness of the roughness of the spin-coated surface. A stitching accuracy of 10 nm is obtained (see Figure 3) without the use of markers. Furthermore, we demonstrated an all-dry tri-layer pattern transfer concept to create high aspect ratio structures in silicon. Dense fins and trenches with a 27 nm half-pitch and a line edge roughness of 1 nm were fabricated.

Finally, the patterning depth can be controlled independently and accurately (~1 nm) at each position. Thereby, arbitrary 3D structures can be written in a single step (see Figure 4). This novel nanofabrication capability already led to new applications in archival data-storage [5], directed alignment and placement of nanoparticles [6] and concepts for novel optical micro cavities with improved performance.

References
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a) b)

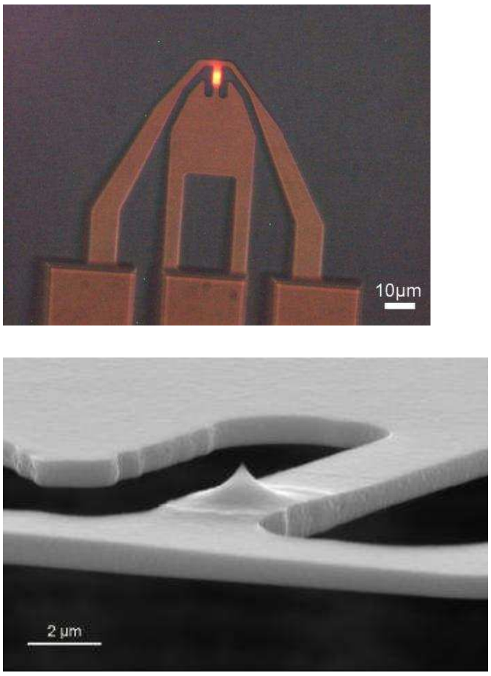

Figure 1: Heatable cantilevers
The Si cantilevers consist of two micro-heaters to heat the tip and sense the topography. A capacitive platform is used for electrostatic actuation of the cantilever.
(a) Optical micrograph of a cantilever showing the tip heating glowing micro-heater (T=850 °C). (b) SEM image of the tip conus with 5 nm radius at the tip apex.

a) b)

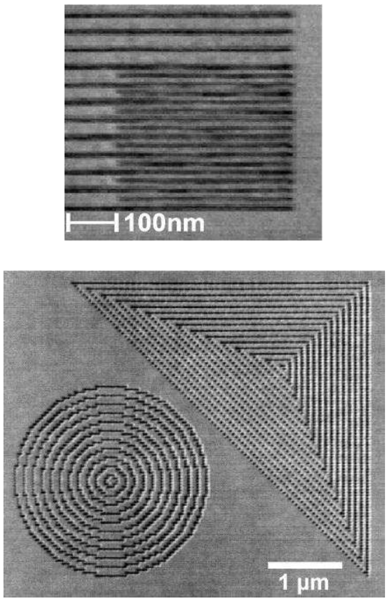

Figure 2: Resolution and speed.
(a) Parallel lines with 10 nm half-pitch and 4 nm depth written into polyphthalaldehyde (PPA).
(b) Pattern written with 500 kHz pixel rate and a scan speed of 20 mm/s. The pattern was written in 0.7 s. [3]

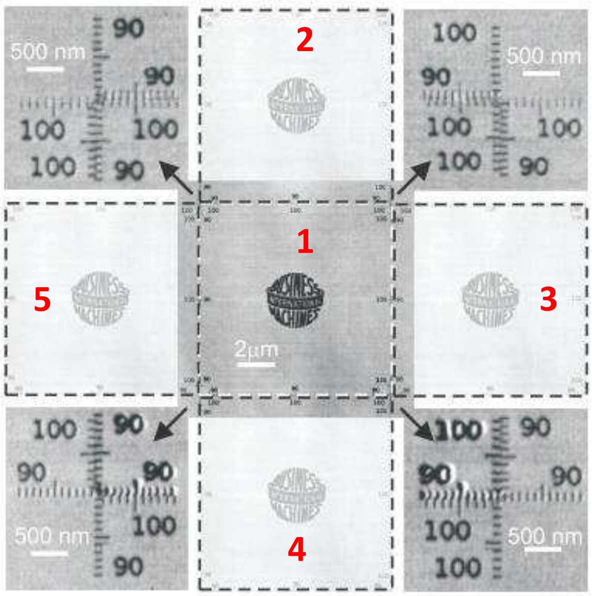

Figure 3: Field-stitching
Four fields stitched around a central pattern. The in-situ imaging capability and the natural surface roughness of the polymer were used for the stitching process. The Vernier dials in the corners of the fields reveal the achieved stitching accuracy of around 10 nm. [6]

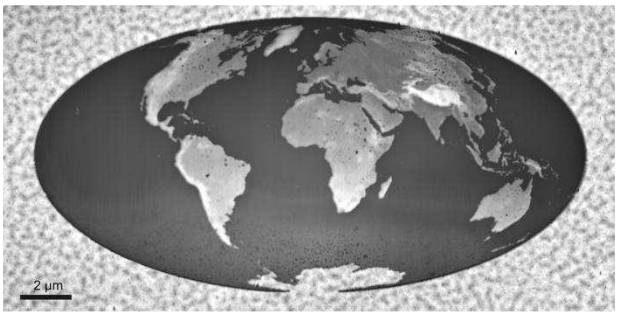

Figure 4: Direct-write of 3D nanostructures
Topographical world map consisting of $5 \cdot 10^5$ pixels with a pitch of 20 nm. The depth of the oceans is 80 nm, the patterning depth of the land corresponds to the respective altitude. [2]