Nanometer precise grayscale fabrication using thermal Scanning Probe Lithography

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Thermal Scanning Probe Lithography (t-SPL) [1] is based on local evaporation of a thermally sensitive resist by a heatable scanning tip. It reaches resolutions and throughputs similar to high resolution electron beam lithography.
A unique feature of t-SPL is the nanometer precise fabrication of grayscale patterns, enabled by the precise motion of cantilevers. For absolute control, the tool uses scanning probe imaging to correct the patterning parameters on the fly, resulting in a pattern depth accuracy of 1 nm. [2]
I will present an overview of devices fabricated by others and us and discuss two showcase applications: We fabricated photonic molecules inside a Fabry-Perot microcavity [3], see Fig. 1a, which are building blocks for threshold-less lasers and single photon sources. We demonstrate that the observed energy splitting in the nanoscale devices is exactly as predicted by theory, see Fig. 1b. A similar relation could not be established for devices fabricated by focused ion beam milling.
Moreover, we demonstrated the first experimental implementation of Brownian motors for nanoparticles.[4] We fabricated grayscale sawtooth patterns, which serve as energy barriers for nanoparticles in a nanofluidic slit. Using an AC electric field, the particles experience a zero mean force which powers the transport in the motor. The devices transport nano-particles without net fluid flow, reaching speeds of 30 µm/s. Moreover, by combining two Brownian motors in a single pattern, see Fig. 2a, 60 nm and 100 nm gold particles were separated within seconds, see Fig. 2b.

References

[1] S. Pires et al. *Science* **328**, 732 (2010)
[2] R. Garcia et al. *Nat. Nanotechn.* **9**, 557 (2014)
[3] C. Rawlings, et al. *Sci. Rep.* **7**, 16502 (2017)
[4] M. J. Skaug et al. *Science* **359**, 1505 (2018)

Figures

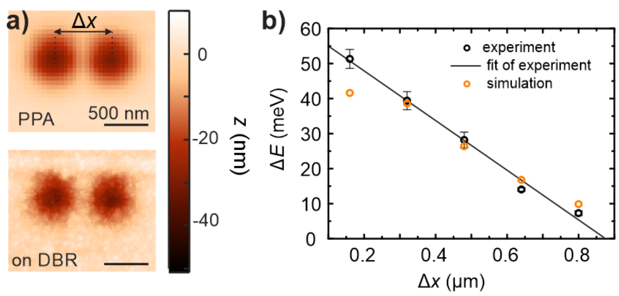

Figure 1: a) A pair of Gaussians patterned into poly-phthalaldehyde (PPA, top) and after transfer to SiO_2 and mirror deposition (bottom). b) The measured energy splitting of the molecules as a function of the spacing between the Gaussians. The experimental results compare well with results from simulations using the target geometry.

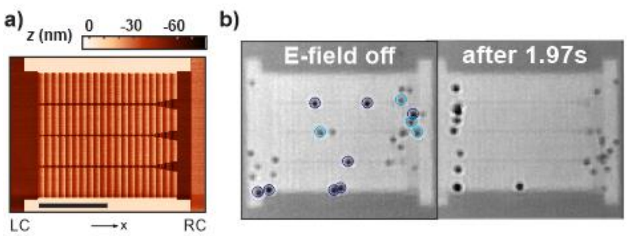

Figure 2: a) Grayscale topography of the sorting device. The device transports bigger particles to the left and smaller ones to the right. b) Optical images of the particle distribution before and after sorting. Left: Particle distribution before powering the device. Right: Sorted particles.