Performance of unique 3D devices fabricated using thermal Scanning Probe Lithography

A. W. Knoll, C. Schwemmer, C. Rawlings, Y. K. Ryu Cho, M. Skaug, S. Fringes, M. Zientek, D. Urbonas, T. Stoeferle, R. Mahrt,
IBM Research – Zurich, Saeumerstr. 4, 8803 Rueschlikon, Switzerland
ark@zurich.ibm.com

M. Spieser
SwissLitho AG, Technoparkstr. 1, 8005 Zurich, Switzerland

Y. Lisunova, J. Brugger,
Microsystems Laboratory, EPFL, 1015 Lausanne, Switzerland

Thermal Scanning Probe Lithography (t-SPL) has matured into an easy to use, high turnaround, high resolution fabrication technology. The method is based on local evaporation of a thermally sensitive resist. Resolutions of 11 nm half pitch and 7 nm feature size after pattern transfer have been demonstrated. However, the most differentiating feature compared to other nanofabrication techniques is the capability to write grayscale features with nanometer scale accuracy of the pattern depth. Such a precision of the fabrication is critical for two showcases that will be discussed.

First, in an optical cavity formed by two dielectric Bragg reflectors (DBRs), a smooth mesa of Gaussian shape with several 10s of nm height causes a strong confinement of light to the area of the mesa. Since the Gaussian provides a smooth defect shape, light scattering is absent and very high quality factors can be reached, a prerequisite for strong light-matter coupling and applications such as single photon sources, thresholdless lasers, etc. Moreover, if two of such defects are placed close to each other, they start to interact, resulting in photonic molecules with an energy spacing defined by the distance. We demonstrated[1], that using t-SPL we can fabricate such optical devices with a designed energy splitting at will, see Fig. 1 a-c.

A second application is the directed transport and fine separation of nanoscale particles in liquids using rocked Brownian motors. Using t-SPL, we were able to fabricate sawtooth patterns of defined pitch and height, which serve as energy barriers for nanoparticles in a nanofluidic slit. The height of the energy barriers experienced by the particles depends exponentially on the height of the teeth, rendering nanometer precise fabrication critical. Moreover, by combining two Brownian motors in a single pattern, we could separate 60 nm and 100 nm gold particles within seconds, see Fig. 1d-f. Modeling shows that even particles with merely 1 nm radial difference can be separated, just limited by the precision of sawtooth fabrication.

The two examples demonstrate how critical nanometer precise patterning affects applications both in optics and in nanofluidics.

[1] C. Rawlings, et al. *Sci. Rep.* **7**, 16502 (2017)

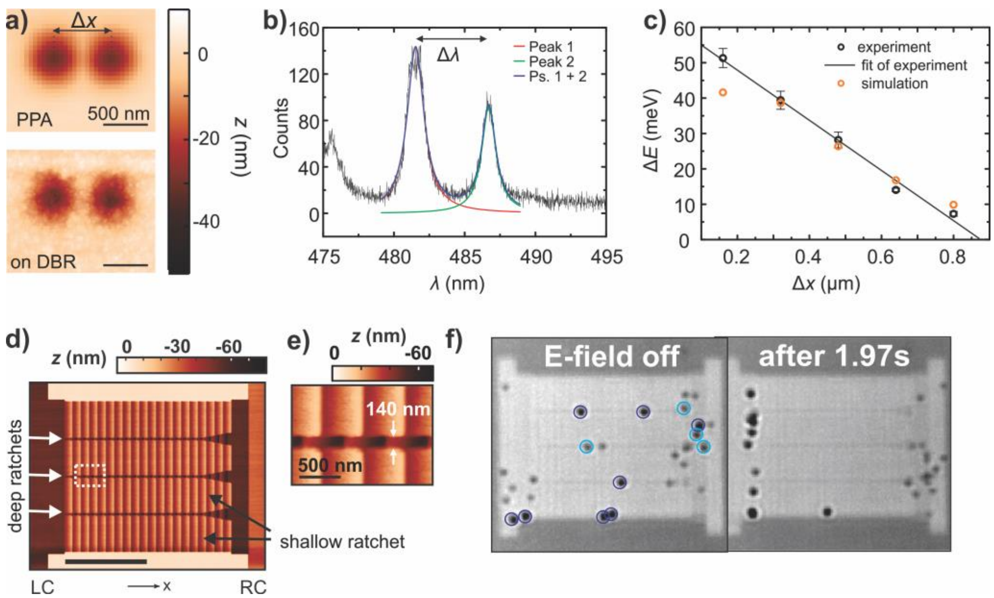

Figure 1: Applications of nanometer precise 3D patterning: a) Two Gaussian defect shapes written at a defined distance of Δx = 400 nm. top: t-SPL result in resist polyphthalaldehyd (PPA); bottom: after pattern transfer into silicon oxide on the DBR. b) Resulting optical spectrum once the defects are inserted between two DBR mirrors and the remaining gap is filled with Cumarine solution. The splitting Δλ corresponds to an energy splitting of ΔE. c) Experimental and simulation results for ΔE as a function of Δx. d) 3D topography required for precise nanoparticle separation. A deep ratchet (width = 140 nm, period = 500 nm, depth =35-60 nm) is embedded in a shallow ratchet (depth = 15-45 nm). e) Close-up of the area marked by a white box in panel d. f) Separation of 60 nm (bright contrast) and 100 nm (dark contrast) particles within 2 seconds. Electrostatic modelling suggests that particles down to 5 nm radius with a radial difference of 1 nm can be separated.