Probe nanopatterning: Towards a smarter lithography technology

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A novel probe-patterning method based on the local removal of organic resist materials has been developed at IBM [1,2]. The resist responds to the presence of a hot tip by local material decomposition and desorption (see Figure 1). Thereby arbitrary 2D- and 3D-shaped patterns can be written in the form of a topographic relief. The combination of fast 'direct development' patterning of resist and the *in-situ* metrology capability of the AFM setup allows the typical turnaround time for nano-lithography to be reduced to only minutes.

Owing to the increasingly difficult challenges of the foreseen Next Generation Lithographies (NGL), such as extreme UV (EUV) lithography and e-beam-based MaskLess Lithography (ML2), the economy of these technologies is increasingly being questioned. One alternative that is seen as a way to circumvent the cost of lithography is NanoImprint Lithography (NIL). However, all these NGLs have a major drawback in common: they rely on an open-loop patterning process, which inherently makes it challenging to control the patterning with nanometer precision at high throughput, as they have no *in-situ* means for adapting the process to the particular conditions present during the process. Therefore, utmost perfection in controlling all the parameters that influence the lithography process is necessary to achieve the required yield, which significantly impacts the cost of ownership of the lithography.

IBM Scanning Probe Lithography (SPL) with *in-situ* metrology offers a path to a closed-loop lithography concept. We have shown the potential of the technology by successfully patterning of complex 3D nanostructure as illustrated in Figure 2 and achieving a 15-nm half-pitch patterning resolution. More recently, we have demonstrated throughput competitive with e-beam technology for <30 nm resolution (Figure 3). Our system is able to write at a pixel rate of 0.5 MHz and scanning speed-up to 20 mm/s with 10-nm position accuracy [3]. Moreover, thanks to the *in-situ* metrology capability, field stitching with <10 nm matching accuracy has been achieved. Finally, this probe nanopatterning technique has been used for fabricating nanostructures in silicon and silicon oxide as well as of templates for capillary self-assembling of Au nanorods [4]. Its unique features open a path toward a smarter way of doing lithography, with greater control of the process, lower cost, higher versatility, and new applications.

[1] D. Pires *et al.*, *Science* **328**, 732 (2010).
[2] A.W. Knoll *et al.*, *Adv. Mat*. **22**, 3361 (2010).
[3] Ph. Paul *et a.l*, *Nanotechnology* **22,** 275306 (2011).

[4] F. Holzner *et al*., *Nano Lett.*, **11**(9), 3957 (2011).

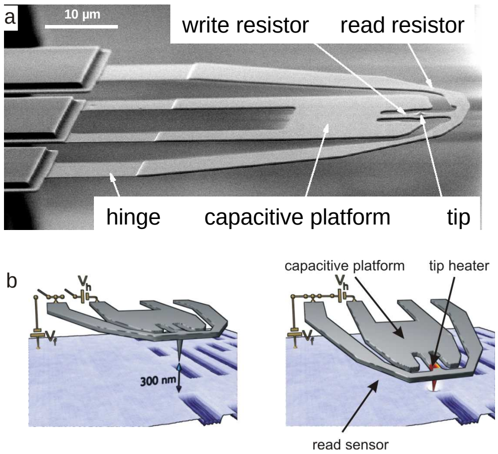

Figure 1. a) Cantilever structure comprising two heaters for heating the tip and sensing the topography. b) Schematics of the writing process. The heated tip is positioned above the surface and electrostatically pulled into contact for a write event.

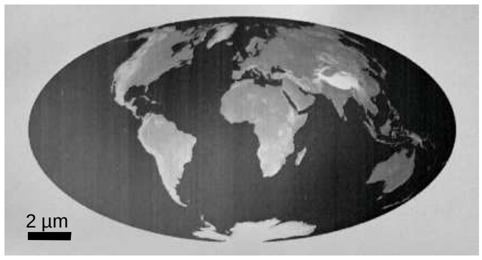

Figure 2. Topgraphical relief image of a 3D world map written into PPA resist. Patterning depth: ~ 30 nm. The pixel clock was 60 µs, and the writing of the pattern took 143 s.

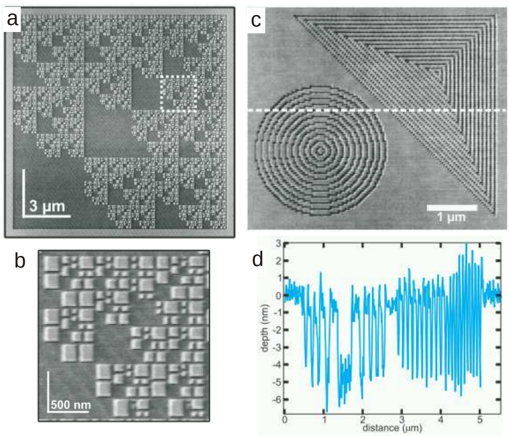

Figure 3. Writing at 0.5 MHz pixel clock. a) and b) Fractal carpet pattern written in less than 12 s.
c) and d) Pattern written at 20 mm/s scan speed. Each pixel is resolved. Patterning time is less than 1 s.

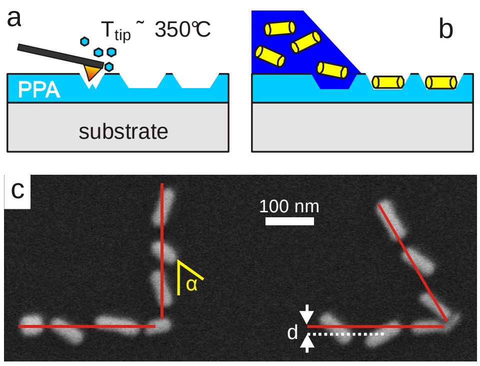

Figure 4. Positioning of gold nanorods at predefined orientation. a) Shape-matching structures are written into PPA resist. b) Capillary assembly is used to deposit the nanorods. c) SEM image after removal of the polymer. A positioning accuracy of ~10 nm is achieved on the target substrate.