Nanometer-Scale Direct-Write 3D-Patterning using Probes

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Thermomechanical molding is a widely used technique for nanometer scale patterning of soft-organic materials. Examples are nano-imprint lithography[1] and thermomechanical probe data storage[2]. The techniques rely on thermally softening and displacing a suitable organic medium by a heated master or stylus. Normally one observes volume conservation of the material, resulting in filling of the master or pile-up of material next to the indented structures, respectively. We have discovered that organic molecular glasses can be reproducibly removed with nanometer scale precision using heated probes, which opens up new perspectives for nanopatterning.

In our experiments a thin film of 10-100 nm thickness is deposited on silicon by spin-coating or evaporation. The material is locally desorbed by heating the tip to 300-500 ºC and applying a mechanical force of 50-100 nN for a duration of 5 μs, leaving behind a well defined void. By laterally displacing the probe and repeating the process any arbitrary pattern can be written whereby the resolution of the process is determined by the apex dimensions of the probe.

The pattern shown in Figure 1(a) exemplifies the quality of the process. The patterns were written with a pitch of 29 nm, corresponding to 5×10^4 written marks, resulting in uniformly recessed structures of 8±1 nm depth. The volume of material contained in the box amounts to 0.2 μm^3, yet no traces of material displacement or redeposition of the material can be found. Similarly, no material pick-up by the tip could be detected by SEM after writing.

The structured glass can be used without any development step as a selective etch mask. Using a three layer technique and exploiting etch rate selectivities between organic materials and silicon/silicon oxide, we were able to transfer the structure into silicon with excellent shape conformity, see Figure 1(b).

Material removal can be cumulated thereby enabling the fabrication of three-dimensional structures as shown in Figure 2. The replica of the Matterhorn was accomplished by consecutive removal of molecular glass layers with defined thickness. The almost perfect conformal reproduction of the original proves that the final structure is a linear superposition of well defined single patterning steps.

With this new technology one is able to fabricate complex three-dimensionally textured substrates, e.g. for the guided and directed assembly of shape-matching objects. The technique also offers a competitive alternative in terms of resolution and speed to high-resolution electron beam lithography.

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[1] Chou S Y, Krauss P R, and Renstrom P J, *Science* **272** 85 (1996)
[2] Vettiger P et al, *IEEE Trans. Nanotechnol.* **1** 39 (2002)

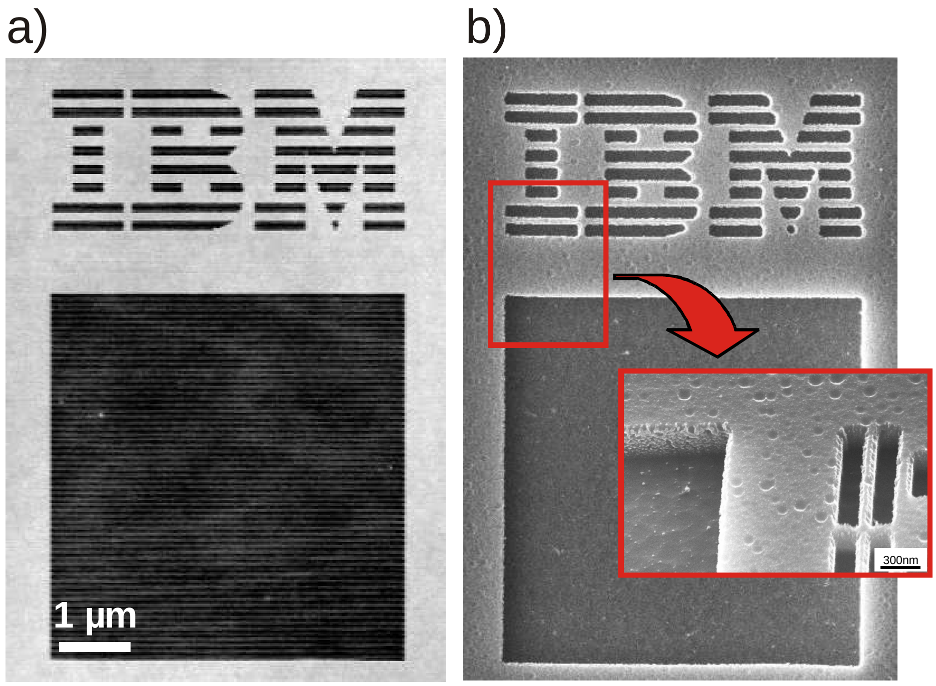

Figure 1: a) AFM scan of a 8 nm deep pattern written into the molecular glass using a patterning pitch of 29 nm. The gray-scale range is 12 nm. b) Same pattern transferred 400 nm deep into silicon.

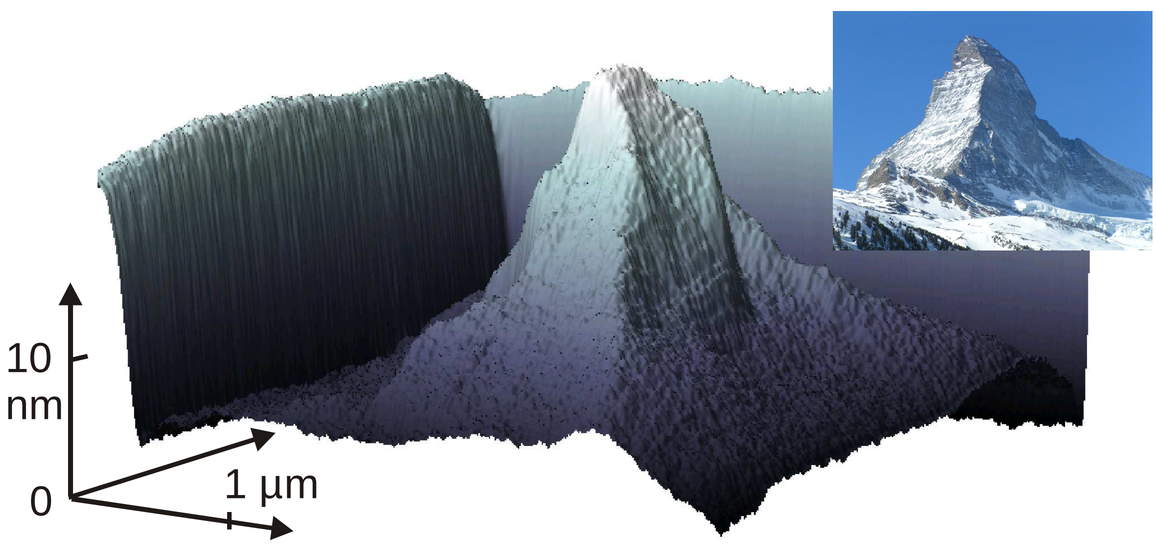

Figure 2: AFM scan of the replica of the Matterhorn written into the molecular glass (3D data source: geodata © swisstopo). A photograph of the original is shown in the inset (photographer: Marcel Wiesweg; source: Wikimedia). The structure was written by layer by layer removal using 120 layers.