Combining nanoimprint lithography and a molecular weight selective thermal reflow for the generation of mixed 3-D structures

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The fabrication of 3-D structures often requires combined processes because they enable the simultaneous or subsequent generation of patterns which are not or very difficult to achieve in one single process. Here we present a combination of three different processes: Nanoimprint lithography (NIL) for pre-patterning of a nanorelief on top of a resist, grayscale electron beam lithography (EBL) and wet development for the generation of stepped 3-D structures, and thermal reflow for exclusively transforming these stepped structures into continuous slopes. Thus micro- and nanostructures with sloped and vertical sidewalls can be combined in one single resist. The process is sketched in Figure 1.

Two prerequisites have to be fulfilled: firstly a resist patterning is allowed using both, NIL and EBL, and secondly a selective processing of the exposed structures is enabled while imprinted patterns stay unaltered. Thus, if poly(methyl methacrylate) (PMMA) resist is used, a certain molecular weight (M_w) of the polymer is required, which is low enough to facilitate a patterning by using standard NIL parameters and high enough to guarantee a sufficient selectivity for the M_w dependent reflow after EBL. The latter is due to a reduction of the initial M_w during exposure which leads to a local variation of the glass transition temperature T_g [1]. Thus by thermal post-processing at a temperature near the initial T_g, e.g. on a hot plate, the difference in viscosity between exposed and non-exposed areas allows the locally defined reflow of structures. Due to surface tension, stepped structures of low M_w are converted into slopes with smooth surfaces.

With the hybrid approach described above, exemplary mixed 3-D structures (see Figure 2) were successfully generated using PMMA with an M_w of 120 kg/mol. A binary nanograting (height, width and distance is 250 nm) was imprinted for 10 min at 180 °C and 15 MPa into 1050 nm thick PMMA, exposed using a 100 keV Vistec EBPG 5000+ and post-processed at 120°C. A functional optical 3-D structure was created, as shown in Figure 3, which consists of macroscopic prisms integrated into a line grating, e.g. as needed by backlight devices [2]. Upon reflow, the difference in M_w of exposed and non-exposed structures results in a selective transformation of the multilevel profile with only a few steps into a continuous slope. Surface tension during reflow leads to a self-perfection in the sub-µm range (steps and roughness are smoothened out) and allows the generation of surfaces suitable for optical applications. In case of the prisms, both smooth surfaces and sharp features assure light redirection with minimized diffraction loss.

A key advantage of using nanoimprint lithography for the pre-patterning of (EBL compatible) PMMA resist is the possibility to easily generate a large area grating (e.g. for anti-reflection or wavelength filtering) before complex 3-D structures are only added to specific locations determined by the intended functionality. Once such structure with a complex 3-D surface relief is generated, it can be transferred into a working stamp and used for direct replication

[1] A. Schleunitz and H. Schift, J. Micromech. Microeng. **20**(9)(2010) 095002.
[2] T. Mäkelä, Proc. of NNT 2010, Øresund & Copenhagen, October 13-15, 2010.

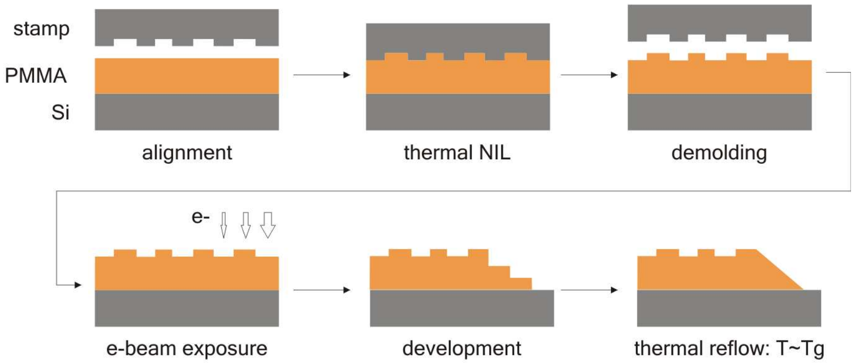

Figure 1 Process sequence using combination of NIL, EBL and selective thermal reflow. Due to M_w dependent development and reflow, stepped sidewalls are transformed into smooth slopes while the binary grating on top of the resist stays unaffected.

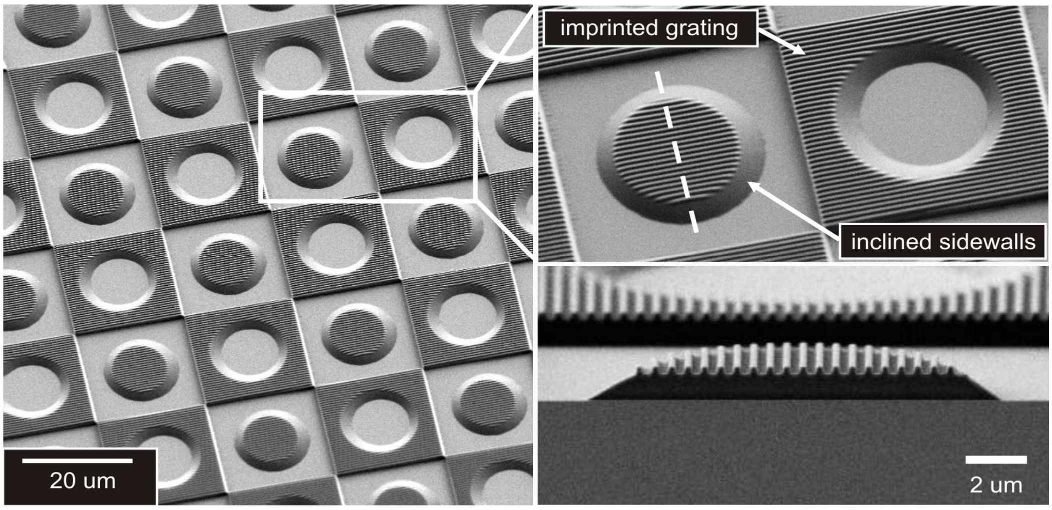

Figure 2 SEM micrograph of structures illustrating the current process capabilities to generate mixed 3-D pattern in PMMA. A binary grating (height, width and distance: 250 nm) is placed on top of a resist with vertical and sloped sidewalls (inclination ~ 30°).

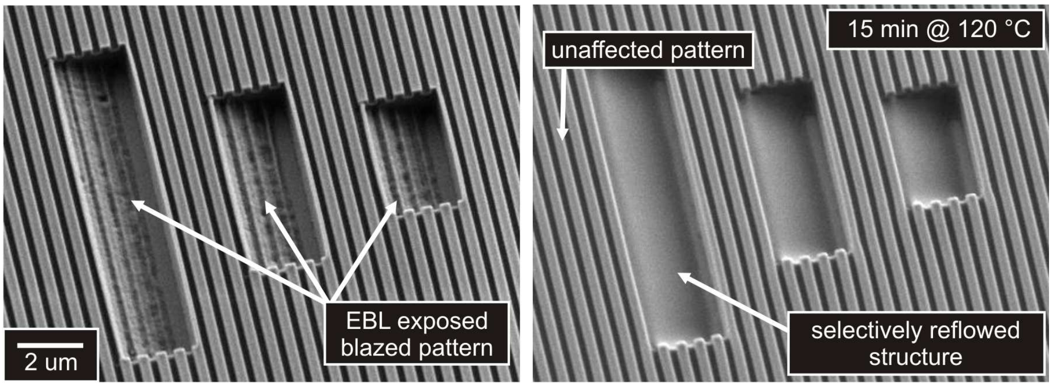

Figure 3 SEM micrograph of a functional optical 3-D structure consisting of prisms integrated into a line grating, e.g. as needed by backlight devices. Continuous slopes (right side) are generated from multilevel profiles (left side) allowing the outcoupling of light from a slab waveguide into vertical direction with lower loss.