3-D microfabrication based on a glass transition temperature selective thermal reflow - towards optical applications

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Complex three-dimensional (3-D) surface profiles are highly desirable for many optical applications, e.g. in display backlighting, where diffractive and refractive properties have to be controlled in close vicinity to each other. However, the generation of optical 3-D elements with (sub-)micrometer dimensions by means of mass replication needs versatile mastering methods. Recently, we presented a suitable approach [1]: 3-D structures were generated in 1 µm thick poly(methyl methacrylate) resist layers (PMMA) by combination of standard grayscale electron-beam lithography (EBL) with a thermal reflow process at moderate temperatures. The reduction in molecular weight (M_w) of the EBL exposed resist leads to a decreased glass transition temperature (T_g) of the exposed areas, which enables the selective transformation of multi-stepped contours into smooth linear slopes with inclination up to 45°. Vertical, stepped and inclined contours in the same resist were subsequently fabricated by defining two process windows resulting in locally different T_g's for a selective profile transformation. The process capabilities were further extended by reducing the M_w of the commercially available PMMA from initially 950 to 120 kg/mol (with a measured number average molecular weight M_n of 40 kg/mol), which eased pre-patterning of the resist by nanoimprint lithography (NIL) [2].

Supplementing our empirical findings, we have now analyzed the correlation between the M_n and resulting T_g according to the doses applied during grayscale EBL for the 120 kg/mol PMMA resist (Fig. 1). Contrary to our previous assumption of a distinct threshold for M_n at 10 kg/mol, we found a rather smooth transition in T_g. This leads to the development of a new process, which is based on aligned double exposure. First, two identical multistep structures were generated by EBL. Then one of them was flood exposed in a second exposure with homogeneous dose prior to thermal reflow. This enabled the generation of complex prismatic structures, as needed for optical applications, with decreased technical efforts and improved slope characteristics (Fig. 2).

The new process can be used to generate master stamps for a backlighting device by pattern transfer into a polymer light guide using UV-NIL (Fig. 3). A further advantage of the new process is that the local flood exposure and subsequent reflow step can also be applied to imprinted multistep structures, which facilitates the selective modification over large area patterns.

[1] A. Schleunitz and H. Schift, J. Micromech. Microeng. **20**(9)(2010) 095002
[2] A. Schleunitz et al., J. Vac. Sci. Technol. B **29**(6)(2011) 06FC01

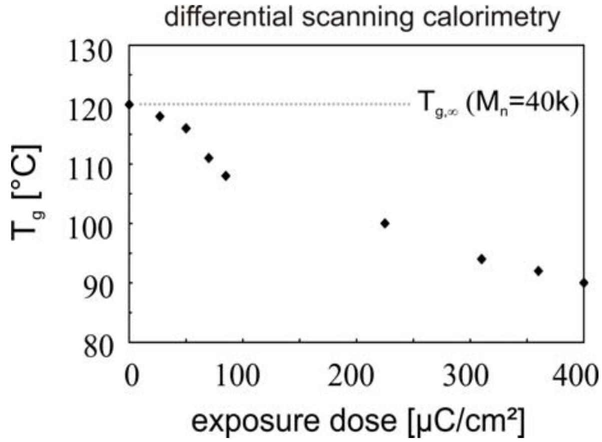

Figure 1: A molecular weight reduction of PMMA resist upon electron-beam exposure (100 keV) results in a dose dependent development and a continuous reduction of the glass transition temperature T_g of 30°C.

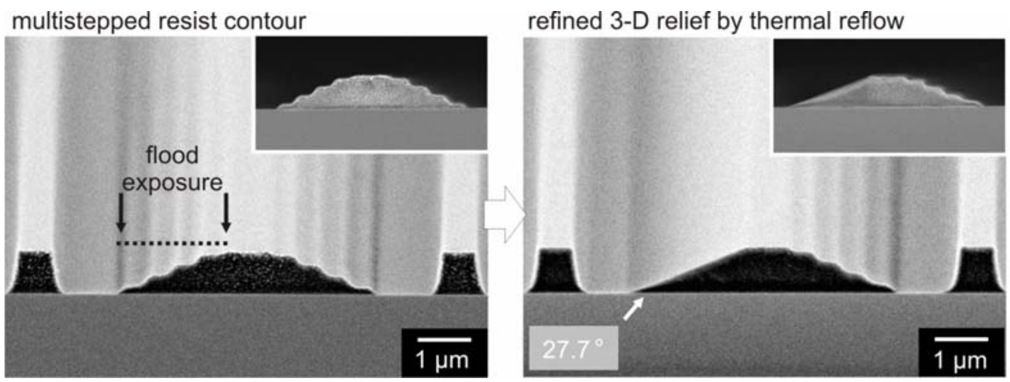

Figure 2: A 1 µm thick 5-level 120 kg/mol PMMA resist with 500 nm wide steps was flood exposed in a confined area for a local reduction of T_g. Upon thermal treatment, the exposed PMMA was selectively transformed into a sloped profile.

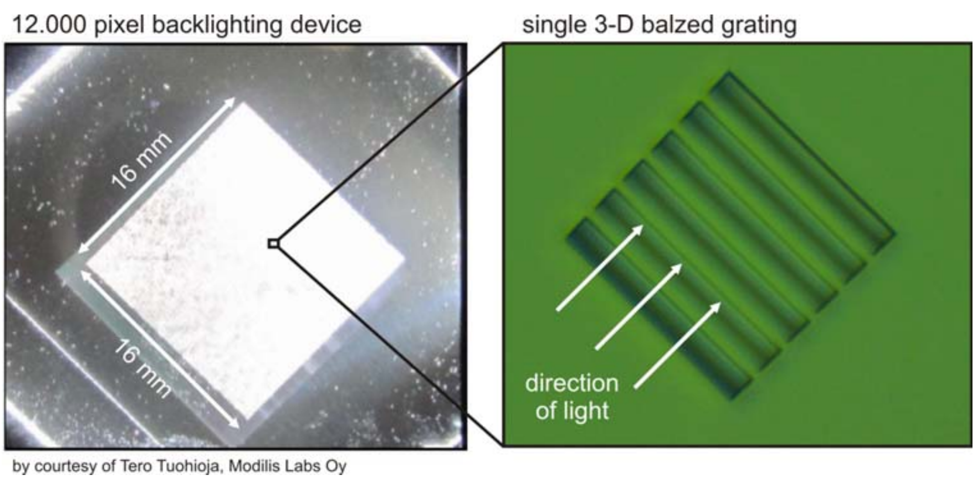

Figure 3: Master stamps for arrays of prismatic 3-D structures with vertical and sloped sidewalls were fabricated. This way, pixelized light guide surfaces for backlighting devices were manufactured.