Effect of residual stress on replication fidelity with nanoimprint

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Cantilevers from SU-8 are easy to prepare by lithography. They are nice solutions towards all-polymer sensing elements[1]. To detect the deflection an integrated optical grid may be used. Such a grid can easily be prepared on the cantilever surface by use of a soft stamp[2] made from PDMS before exposure to define the cantilever geometry. The final shape is obtained by crosslinking of the SU-8 during the post exposure bake (PEB). High quality grids with high aspect ratio are obtained (Fig. 1). These results are in contrast to experiments with T-NIL where reflow occurred during PEB[3]. This poses the question whether residual stresses in the polymer after T-NIL are responsible for this difference.

The ‘picture’ is given in Fig. 2. With a ‘hard’ imprint the almost rigid stamp forces the polymer into the cavities, and residual stress may remain locally in the deformed layer. Such stress will drive local polymer recovery. With a ‘soft’ imprint the polymer remains almost stress-free, as the stamp is able to absorb local stresses by deformation.

To verify this picture imprints with soft stamps and hard stamps were performed. Different imprint times were chosen to vary the residual stress level. Beyond SU-8 also typical imprint polymers were used (PS, PMMA). The latter were thermally annealed to provoke polymer recovery – with SU-8 the anneal is the PEB. Here the results with SU-8 are given, a minimum effect being expected due to crosslinking that counteracts recovery and reflow. Fig. 3 shows that all imprints feature a high quality (only slightly rounded contours with ‘soft’ imprint) independent of processing time. After crosslink no distinct changes are visible with the ‘soft’ imprint. In contrast, with a ‘hard’ imprint a distinct local elastic recovery is visible; its strength is in accordance with a local residual stress being most prominent with short imprint times.

Obviously, ‘hard’ imprint may result in residual stresses which lead to recovery. Such recovery is detrimental during subsequent steps like plasma etching, hybrid lithography or reflow, in particular when an evaluation is envisaged[4]. We will show the impact of layer thickness, stamp geometries and imprint time on residual stress with SU-8 and typical imprint polymers.

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[2] K. Y. Suh and H. H. Lee, Adv. Funct. Mater. 12, 405 (2002)
[3] M. Wissen et al, Proc. SPIE 6792, ISBN 978-3-8007-3079-7, 383 (2008)
[4] E. Rognin, S. Landis and L. Davoust, Phys. Rev. E 84, 041805-1 (2011)

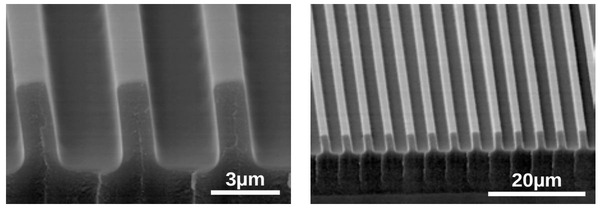

Figure 1: To provide the surface of a SU-8 cantilever with an optical grid to visualize deflection, a 'soft'-imprint with a PDMS stamp was performed. Optical lithography (160 mJ/cm^2) defines the geometries of the cantilever. A post exposure bake at 100°C for 5 min completes the crosslinking. Even with high aspect ratios (see SEM) a high quality grid is obtained. The edges are slightly rounded, but no distinct reflow due to PEB is observed.

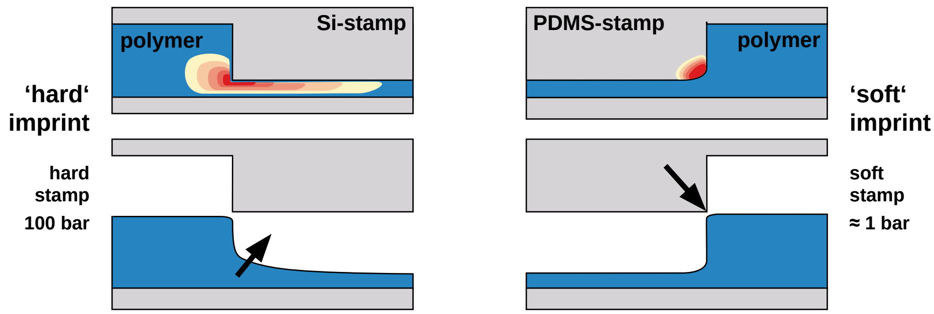

Figure 2: Stress/strain situation during imprint (top) and after stamp release and anneal (bottom). With a hard stamp (Si) residual stress is provoked in the imprinted polymer as indicated (red), which may result in local elastic recovery of the imprinted polymer (arrow). With a soft stamp (PDMS) the polymer is free from stress, but stamp deformation may result in less well-defined edges. Then only the stamp relaxes.

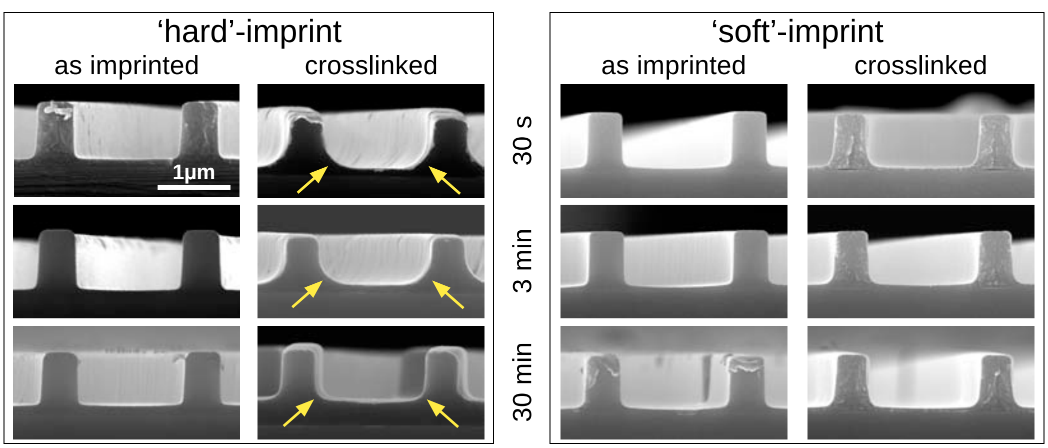

Figure 3: Imprint results obtained with SU-8 at 95°C with different imprint times, 30 s, 3 min and 30 min. To crosslink the structures the SU-8 was fully exposed (200 mJ/cm^2) and post exposure baked at 95°C for 2 min. Independent of the imprint time all imprints feature a high quality.

With the 'hard' imprint the elastic recovery decreases with increasing imprint time (arrows). This is a consequence of the stress relaxation in the polymer with time. With a 'soft' imprint no such recovery is detected due to the lack of stress.