Thermal wrinkling of nanoimprinted SU-8 with masked UV-exposure

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In the majority of cases spontaneous wrinkling of a surface should be avoided, not only in macroscopic structural mechanics systems but also in nanotechnology, where thin layers are involved. When wrinkling is induced in a controlled way[1], it can, however, be used e.g. for optics, in bioengineering, as device templates or for stretchable electronics[2]. Wrinkling is well-known with PDMS[3] (poly-dimethylsiloxane) and was also shown with PS[4] (polystyrene); usually a hard metal layer is deposited on top of the soft material after heating or mechanical expansion. The wrinkles result from cool-down or from the release of mechanical stress during unloading. Alternatively, Efimenko et al.[5] replaced the deposited top layer by a UV-ozone treatment of the PDMS surface, modifying the material quite surface-near.

We used SU-8, a chemically amplified negative tone photoresist popular with MEMS-applications. In previous work[6] we demonstrated wrinkling of SU-8 induced by exposure with an excimer lamp (DUV, $\lambda = 172$ nm). Due to the short wavelength the SU-8 is exposed surface-near, only. After PEB a hard, cross-linked layer develops on top of the thick, un-exposed (and thus soft) layer, and wrinkling develops during the post exposure bake.

To control the wrinkles, we used conventional photolithography (UV-L) to provide a well-defined area for wrinkling. As shown in Fig. 1, only the regions non-exposed during UV-L will develop wrinkles. By varying the UV-L exposure dose, we change the 'boundary conditions' for wrinkling; this results in a systematic change of the wrinkling pattern observed (Fig. 2). In addition, a pre-pattern changes the wrinkling – in Fig. 3 the pre-pattern was created by capillary force lithography with a PDMS-stamp during prebake, as indicated in Fig. 1.

The actual investigation addresses the impact of the geometrical boundary conditions induced by UV-L when, in addition, the SU-8 surface has been nanoimprinted with different structures beforehand. The experimental results will be substantiated by theoretical considerations.

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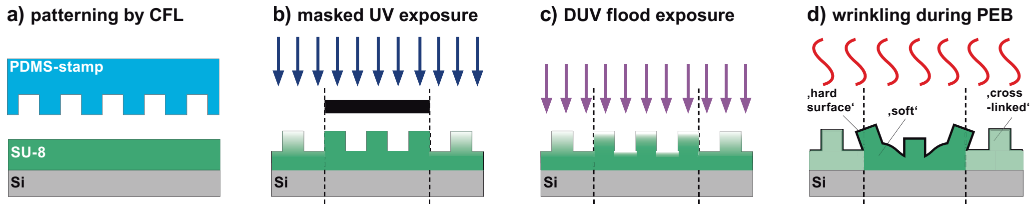

Figure 1: Processing sequence: a) Patterning of the SU-8 surface by capillary force lithography (CFL) with a PDMS-stamp during the prebake step (1 min, 95°C); b) photolithography; c) surface-near exposure by DUV (172 nm); d) post exposure bake (PEB, 1 min, 160°C); wrinkles develop within the areas not exposed during photolithography.

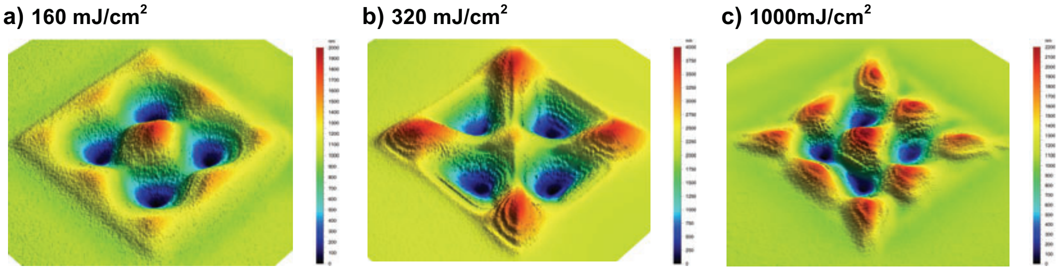

Figure 2: Impact of UV dose: Wrinkles obtained with 5 µm thick SU-8, masked area 50 µm x 50 µm, DUV exposure for 7 min. a) UV-dose 160 mJ/cm^2; b) 320 mJ/cm^2; c) 1000 mJ/cm^2. Change of the 'boundary condition' results in a differing wrinkling pattern (maximum height a) 2 µm, b) 4 µm, c) 2.2 µm).

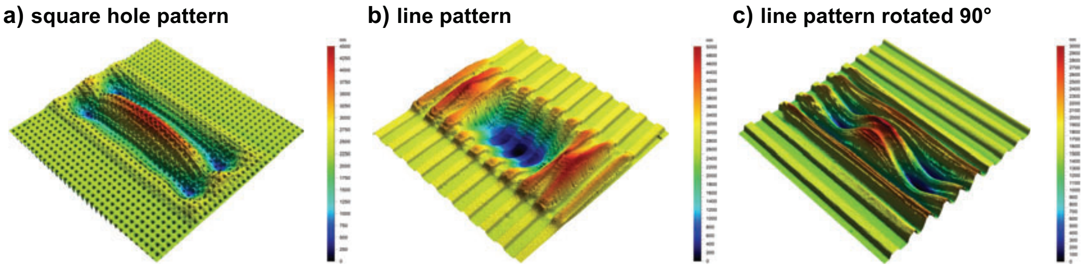

Figure 3: Impact of pre-patterning by nanoimprint: Wrinkles obtained in 5 µm thick SU-8, masked area 50 µm x 100 µm, UV-dose 320 mJ/cm^2, DUV exposure for 3 min. a) Square hole pattern, 1 µm deep, diameter 1 µm; b) and c) line pattern, 400 nm deep, width 5 µm. The imprinted pre-pattern modifies the wrinkling pattern obtained (maximum height a) 4.5 µm, b) 5 µm, c) 3 µm).