High fidelity 3D thermal nanoimprint with UV curable PDMS stamps

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Replication of 3D microstructures with soft lithography is an industrially accepted cost effective approach.[1] PDMS micro-molding techniques provide low energy surface for easy demolding and an elastic material that does not fracture during imprinting. PDMS stamps also provide the unique advantage of imprinting on flexible substrates and replicating features with undercuts and are thus industrially relevant.[2] Although it excels in reproducing smooth features below 50 nm using UV-nanoimprint (NIL), replication of high fidelity structures with sharp corners and high-resolution features (nano-on-micro) is a challenge.

PDMS micro-molding technique has been used for replicating micro-needles[3] and micro-fluidic devices. Rounding of sharp corners and tips has been a problem that plagues the development of this technique for diffractive and mixed optic devices including nanoscale features. To an extent this problem can be solved by using a newly developed UV curable PDMS[4] which promises very little shrinkage and higher strengths for better tip retention.

In this study we have evaluated the influence of process parameters during hot embossing (T-NIL) into PMMA with PDMS stamps and its influence on the replication of sharp/high fidelity structures, residual layer thickness, and features with undercuts. Master structures were fabricated with 2-photon polymerization process (Fig. 1 a). PDMS precursor is casted over the master structure and exposed with UV light for 3 minutes and left to cross link for 12 hours. After demolding, the front side of the PDMS is exposed again for 3 minutes (Figs. 1 b & c). Since PDMS has very high thermal expansion coefficient compared to glass or silicon substrate even small heating step leads to huge shrinkage. Here we avoid any heating step to cross link PDMS. AFM measurements were carried out after each step in the process flow on circular staircase design to analyze the roughness evolution (Figs. 2 a-c). 50 μm large lenses with sharp corners and fine surface textures were faithfully reproduced in PMMA when moderate pressures were applied during embossing (Fig. 2 e), shows the potential for replicating hybrid structures.

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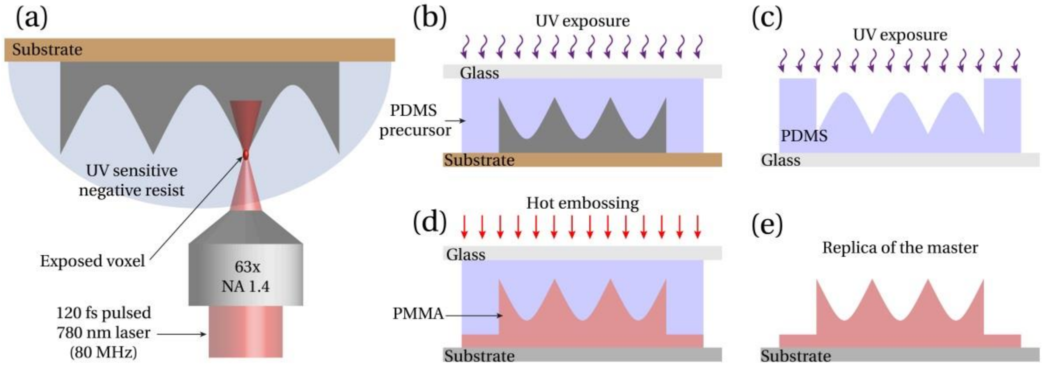

Figure 1: (a) Schematic illustration of 2 photon polymerization written in 'DipIn' mode. (b) Drop casting of PDMS precursor over the master structures and UV exposure for 3 minutes to cross link. (c) After curing for 12 hours at room temperature (for low shrinkage) and demolding, front side is exposed for 3 minutes. (d) PDMS stamp is used to hot emboss into PMMA film. (e) PMMA replica of the master structure

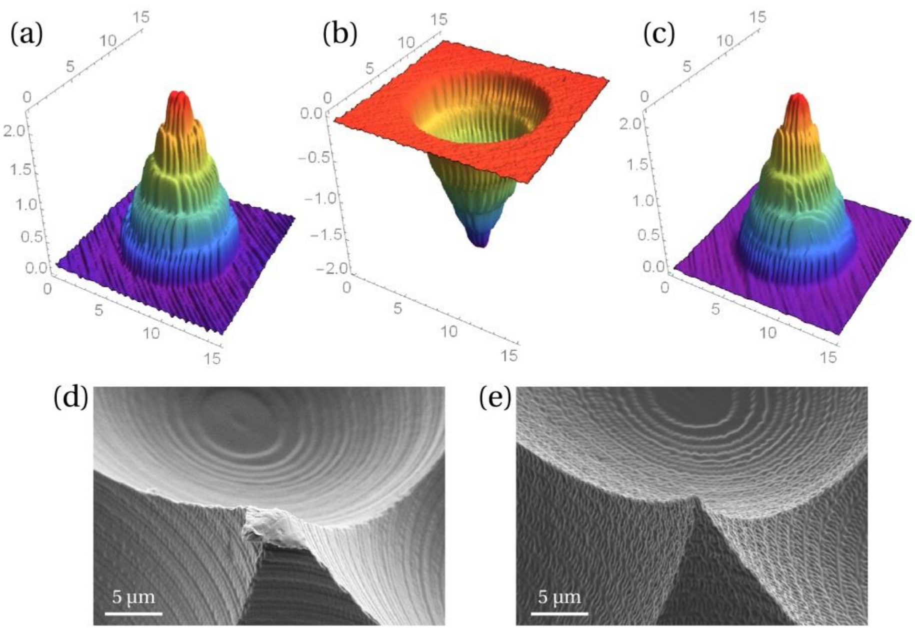

Figure 2: (a) AFM image of circular staircase structure written with 2 photon polymerization (R_{rms} = 27 nm). (b) Copied stamp in UV curable PDMS (R_{rms} = 20 nm). (c) Replicated into PMMA by hot embossing (R_{rms} = 18 nm). (d) SEM image of a micro lens tip in PMMA where the embossing pressure was too high and (e) where the embossing pressure is optimum.