Fabrication of Polymer Structures with Undercuts by Reverse Imprint Lithography

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Surface patterns of biological objects do exhibit wonderful features with a large potential for future technical applications. The morphology of micro- and nanometer sized objects can e.g. influence optical, mechanical or electromagnetic properties of the interface they are applied to. Further, the wetting behavior of solid surfaces considerably depends on present patterns and their nano- and microscopic dimensions. Springtails (Collembola) are wingless arthropods that are impressively adapted to cutaneous respiration in temporarily rain flooded and microbially contaminated habitats. To avoid pollution or wetting of their skin, in any case, it is entirely covered by granular surface features that exhibit overhangs at the top of the asperities (fig. 1). It was recently found that these overhangs afford a robust wetting resistance, even for polar and non-polar low-surface-tension liquids [1]. For the artificial generation of patterned surfaces exhibiting overhangs, various strategies, mostly using silicon as substrate material, were proposed [2]. Herein, a strategy for the translation of the wetting-responsible features of the collembolan skin into a polymer material using top-down manufacturing methods commonly used in the microelectronic industry is presented, which is applicable to various substrate materials.

The fabrication method as depicted in Fig. 3 includes the patterning of a silicon master mold with multiple height levels. The fabrication process is similar to [3] and includes multiple steps of aligned contact lithography. The silicon master is subsequently cast two times in an UV-transparent perfluoropolyether dimethacrylate PFPEdma (Fomblin MD40, Solvay Solexis) to perform a tone-inversion. Due to the low surface free energy of the mold material, a liquid pre-polymer poly(ethylene glycol) diacrylate (PEGda, 700 g/mol, Sigma-Aldrich) applied by dip-coating was pinned only at the structure edges and did only fill the grooves. Hence, a subsequent reverse imprint did not involve any residual layer. After PEGda cross-linking, the polymer structure was transferred to a water-air interface where it floated by means of surface tension effects [4]. Finally, the free-floating polymer structure could be immobilized on solid substrates, i.e. a silicon surface, by withdrawing the substrate from the aqueous phase. Using the presented fabrication process, polymer structures with various lateral dimensions have been produced. Smallest hole diameters, obtained so far, are 2 µm with an overlay accuracy of about 500 nm as it can be expected from contact lithography. Scanning electron micrographs of a fabricated polymer structure exhibiting residual layer free holes and undercuts in the vertical direction are shown in figure 3a and 3b, respectively. The replicated polymer structures with field sizes of up to 7.5x7.5 mm² could be obtained but are just limited by the masks available and will be extended in the future. The wetting behavior of the fabricated polymer structure was studied with contact angle goniometry (fig.4). Further, various efforts are currently taken to shrink the dimensions of the available structures.

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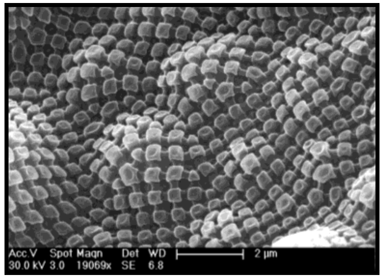

Figure 1. Granular surface patterns on the skin of *Tetrodontophora bielanensis* (springtail)

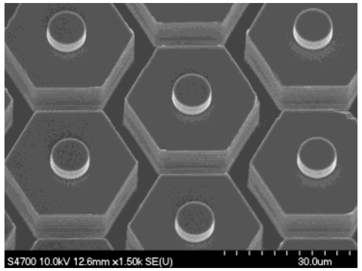

Figure 2.Multilayer silicon master structure for the fabrication of T-shaped polymer structures.

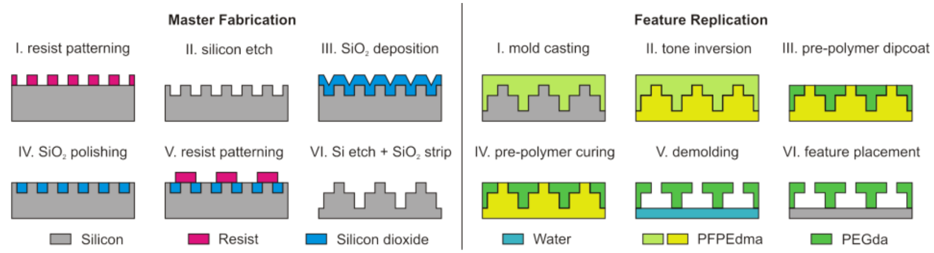

Figure 3. Fabrication Process for multilayer silicon molds and the feature replication process to obtain polymer structures with undercuts.

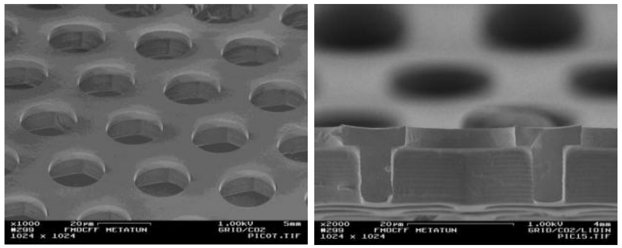

Figure 3. SEM of a top view (a) and a sectional view (b) of the fabricated polymer structures showing undercuts.

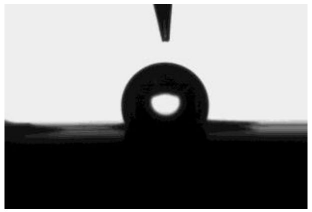

Figure 4.Micrograph of the apparent contact angle between water and the fabricated membranes