Fabrication of freestanding initial patterns for polymer actuated 3D micro-origami structures

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Among 3D fabrication techniques, origami techniques that start with initial 2D shapes which are transformed via a controlled folding sequences into full 3D shapes are of particular interest for micro- and nanofabrication.[1,2] An advantage of these methods is the usage of established planar lithography techniques. The initial structure can thus be fabricated with very high resolution, accurate placement and high throughput. Among the different actuation methods for the transformation from 2D into 3D shapes, actuators based on capillary forces and reflowing polymers as used in this work are of special interest. Due to the slow reflow process as it occurs close to the glass transition temperature[3], the transformation is well controllable.

We have established a polymer reflow process for 3D topography control and shape transformation.[3,4] For example, the capillary forces of specially designed actuators together with thermoplastic softening of a stable pillar can be used to bend this upright standing pillar out of its initial vertical axis (Figure 1). We are using this same method to fold initial 2D structures out of plane (Figure 2). To obtain the required free standing structures before folding, to minimize adhesion to the substrate and to allow for actuation with sufficient force by polymer reflow, we tested several sacrificial layer methods. We tested also liquid phase and vapor phase hydrofluoric acid silicon dioxide release and finally decided for an isotropic silicon inductively coupled dry etch process based on SF_6 (Figure 3). Depending on the internal stress of the polymer layers, out-of-plane deformation might be already present (Figure 4), but it can be minimized. Poly (methyl methacrylate) (PMMA) actuators were patterned by electron beam lithography due the excellent possibility to control the reflow temperature there.[3,4] Both processes are combined at the moment for a controllable out-of-plane folding of 3D boxes.

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[3] A. Schleunitz, V.A. Guzenko, M. Messerschmidt, H. Atasoy, R. Kirchner, and H. Schift, Nano. Converg. **1:7**, 1 (2014)

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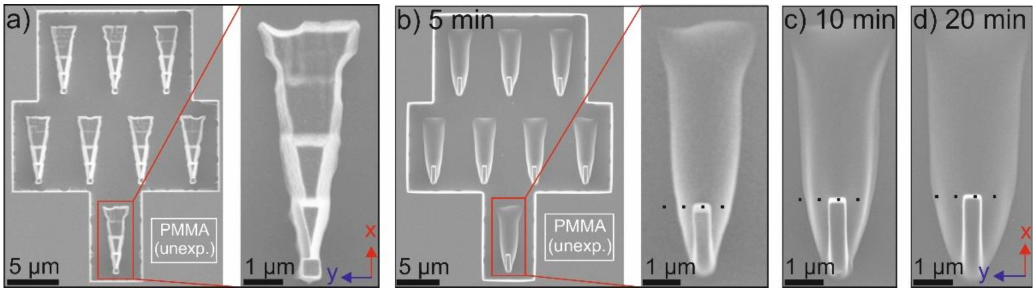

Figure 1: Shape transformation using polymer actuators and reflow for isolated pillars (450 nm x 450 nm x 1800 nm). initial: a) stable pillars and reflowing actuator (both PMMA) fabricated by grayscale electron beam lithography in a single exposure and development step; after thermal reflow at 120°C: b) 5 min (1550 nm x-displacement), c) 10 min (1760 nm x-displacement), d) 20 min (1800 nm x-displacement) with different and well tunable x-displacements. The glass transition temperature of the PMMA was ~ 122°C.

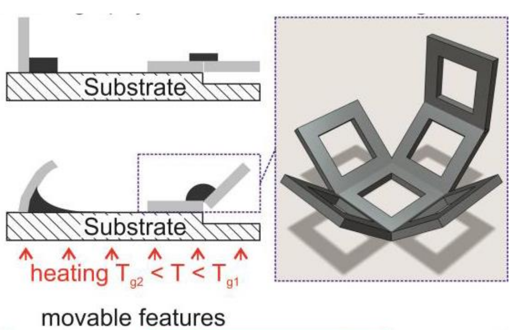

Figure 2: Concept of 3D shape transformation / origami folding of initial 2D frames using polymer actuators (actuator T_{g1} [black]: reflowing, frames T_{g2} [grey]: stable). T_g … glass transition temperature

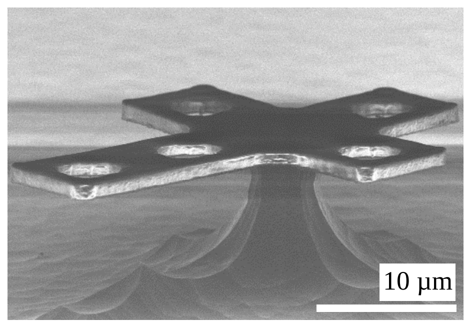

Figure 3: Freestanding initial and 2 µm thick SU8 shape intended for a box (Fig. 2) (without hinges) after dry release etch of silicon using a SF_6 isotropic process.

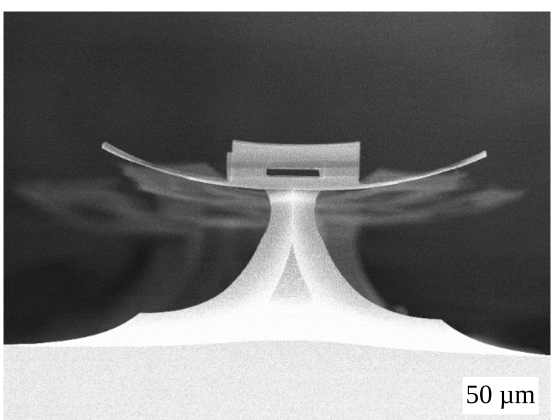

Figure 4: Initial pattern with internal compressive strain due to SU8 shrinkage during polymerization (fabrication without actuators).

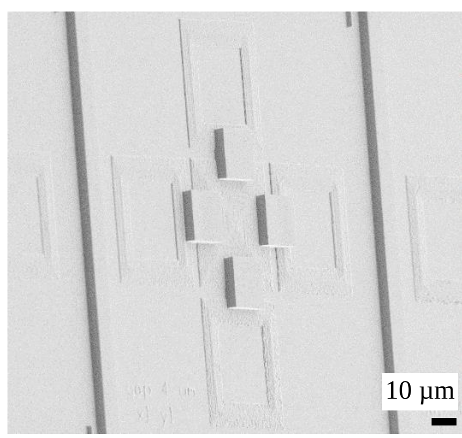

Figure 5: PMMA actuators patterned via electron beam lithography on open polymer frames to be folded via visco-elastic reflow.