Three-dimensional SU-8 microtiles for fluidic self-assembly

M. Mastrangeli [a,b], A. Martinoli [b], J. Brugger [a]

[a] Microsystems Laboratory (LMIS1)
[b] Distributed Intelligent Systems and Algorithms Laboratory (DISAL)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
e-mail: {massimo.mastrangeli, juergen.brugger}@epfl.ch

Keywords: electroplating, lithography, SU-8, microtiles, self-assembly

Self-assembly (SA) stands as a general bottom-up methodology for the fabrication of heterogeneous micro- and nanosystems [1] and as a key coordination task for distributed swarms of intelligent agents [2]. Analytical studies of SA are therefore highly relevant for many technological applications. The principles of SA are common to all physical scales [3]; yet at each scale the specific hierarchy of force magnitudes imposes dedicated deployments for the investigation and application of SA. Particularly, at sub-millimetric scale surface tension dominates, and a broad variety of innovative functional systems can be assembled by fluidic SA [1]. Nonetheless, studies on dynamics and control of SA in this domain are still scarce [4].

We present an innovative design and fabrication process for three-dimensional polymeric microtiles. Our 200 µm-sized tiles are passive vehicles designed to investigate SA in a microfluidic chamber, as an extension of our centimeter scale studies [5]. They are conceived by superposing two structural layers with inverted chiral patterns and fourfold in-plane symmetry (Fig. 1a). The tiles interact laterally, either at a liquid/liquid interface or in bulk liquid (Fig. 2). The design makes the tiles available for coordination independently of their vertical orientation, unlike e.g. [4]. They also feature a central marker for optical tracking and control (Fig. 1b). The microtiles—with overhanging and straight walls needed for intimate contact—cannot evidently be fabricated by microstereolithography or by simple lithographical patterning.

The wafer-scale fabrication process is illustrated in Fig. 3. A Ti/Ci seed layer (50/100 nm) is thermally evaporated on a 4’’ Si wafer. The first 50 µm-thick SU-8 layer—i.e. with the square hole in the center of the tiles—is spun, lithographically patterned and developed over the dehydrated substrate. A 50 µm-thick Cu sacrificial layer is then electrodeposited from a Cu sulfamate bath. Slow Cu growth minimizes the formation of voids between the Cu layer and the sidewalls of the SU-8 tiles. As expected, non-negligible difference in Cu thickness across the substrate was observed, together with local Cu overplating in proximity of the tiles. A delicate chemical and mechanical polishing step is thus performed to planarize the mixed Cu/SU-8 surface. The second 50 µm-thick SU-8 layer—with chiral tile pattern and central rectangular hole—is then processed with a lower thermal budget to limit stresses in the Cu layer (Fig. 4). The sacrificial layer is subsequently dissolved through a commercial Cu wet etch (Fig. 5a). The geometry of the central markers locally slows down the rate of Cu etch. As a result, the tiles remain anchored to the substrate after dissolution of the sacrificial layer by adhering to central, residual Cu microposts. The exposed surfaces of the SU-8 microtiles are then activated by oxygen plasma and derivatized with hydrophobic, silane-based self-assembled monolayers adsorbed from vapor phase to enhance hydrophobic interactions in polar liquids. The tiles are finally released by ultrasonication in water (Fig. 5b).

The presentation will report full information on background and context of SA studies, microtiles design and fabrication, as well as high-speed video recordings of the microfluidic SA experiments (Fig. 6).

[1] M. Mastrangeli, S. Abbasi, C. Varel, C. van Hoof, J.-P. Celis, K. F. Böhringer, J. Micromech. Microeng. 19 (2009) 083001.
[2] M. Mastrangeli, G. Mermoud, A. Martinoli, Micromachines 2 (2011) 82-115.
[3] G. M. Whitesides, B. Grzybowski, Science 295 (2002) 2418-2421.
[4] M. T. Tolley, M. Krishnan, D. Erickson, H. Lipson, Appl. Phys. Lett. 93 (2008) 254105
[5] G. Mermoud, M. Mastrangeli, U. Upadhyay, A. Martinoli, IEEE Int. Conf. Robotics and Automation (ICRA 2012), Saint Paul (MN), 14-18 May 2012, 4266-4273

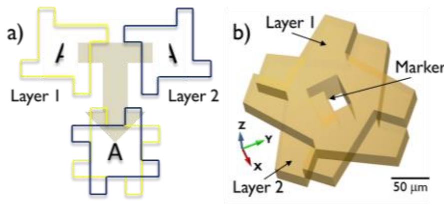

Figure 1. a) Conceptual and b) CAD design of the three-dimensional microtiles for self-assembly.

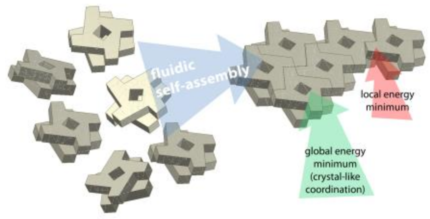

Figure 2. Fluidic self-assembly of the microtiles. The assembly configurations of global and local energy minimum are evidenced.

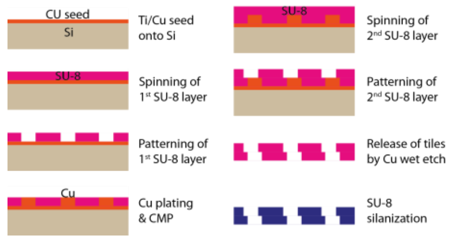

Figure 3. Process flow for the fabrication of the two-layer SU-8 microtiles. A thick sacrificial layer is required to embed the first SU-8 layer of the tiles and support the patterning of the top SU-8 layer.

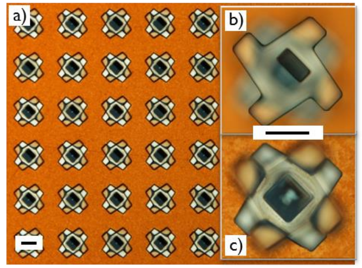

Figure 4. The microtiles embedded in the Cu sacrificial layer after full SU-8 processing. a) Field view; b) second (top) and c) first (bottom) SU-8 layer of a single tile. Scale bars are 100 µm.

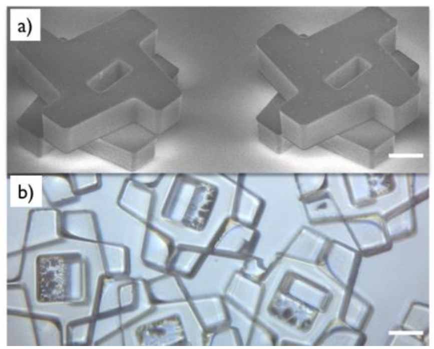

Figure 5. The SU-8 microtiles a) after dissolution of the Cu layer and b) in water after release from substrate by ultrasonication. Scale bars are 50 µm.

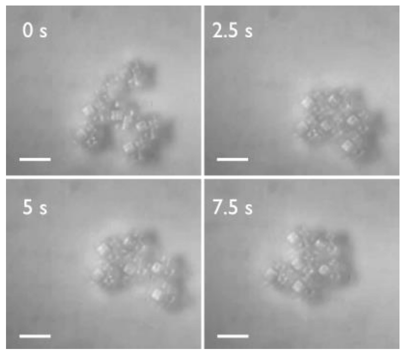

Figure 6. Frames from a high-speed recording of the SU-8 microtiles self-assembling into crystalline aggregates in bulk water. Scale bar is 200 µm.