Novel Fabrication of 3D Combined Nanoscale and Microscale Structures Using Functionalized SPEL

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3D integration of nanostructures with microstructures has many important applications in micro/nano fluidics, integrated optics and bio-medical devices. However conventional fabrication of these 3D structures requires multiple and often complicated steps, making it time consuming and expensive. Here we propose and demonstrate a new approach to the fabrication of certain 3D combined nanoscale and microscale structures, which has only a few yet simple steps, hence greatly reducing the fabrication steps, time and cost. The new method, termed functionalized SPEL, is based on local applications of different types of SPEL (self-perfection by liquefaction)—a new way to fabricate nano/microstructures [1-2], to different regions of a substrate to achieve different combination of 3D nanoscale and microscale structures.

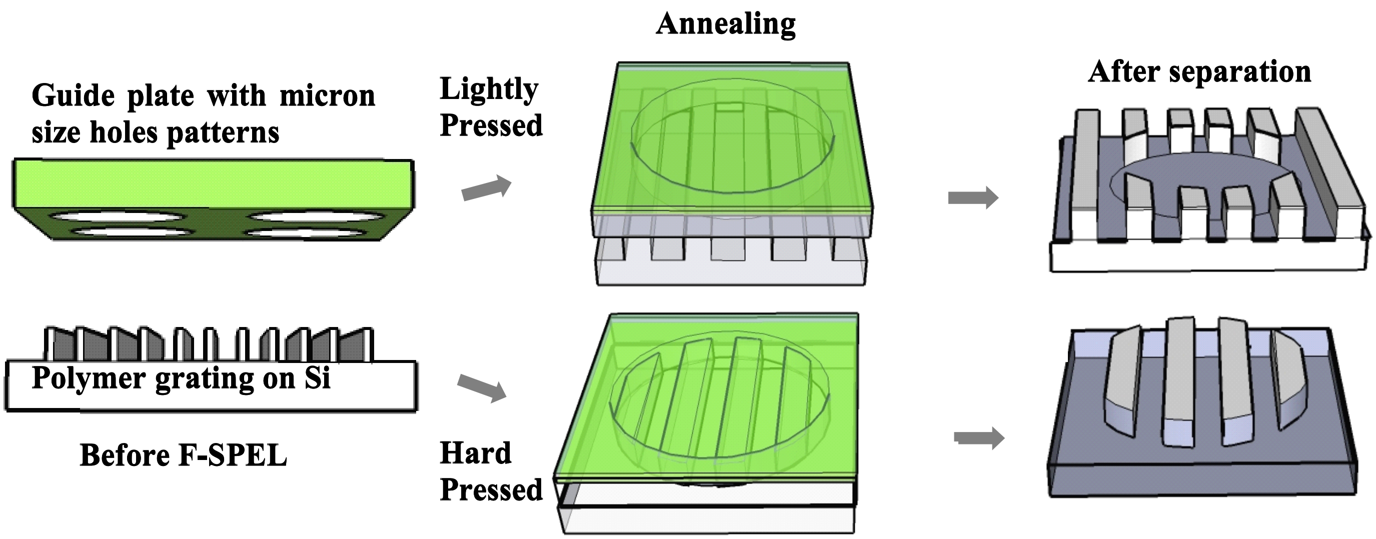
SPEL fabricates nano/micro-structures by selectively melting a prefabricated structure and reshaping it under the guidance of a flat plate. The flat plate can be initially a gap above a structure (which pulls the structure up making it taller and narrower), or on top of it (keep the height and width the same, but smooth LER), or be pressed into it (reduce the height and trench/hole width/ diameter), forming the process respectively termed as guided, capped, and pressed-SPEL [1-2]. In functionalized SPEL, the plat surface is not flat, but patterned with microstructures with certain depth. When the patterned plate is used in a SPEL process on a substrate with nanostructures (Fig. 1), it performs guided, capped, or pressed SPEL locally to form drastically different local 3D patterns, depending upon the microstructures on the plate and process conditions.

Fig. 2 shows examples of functionalized SPEL (F-SPEL), where a plate with 10-µm-diameter and 120-nm-deep holes is pressed onto a grating substrate with period of 1 µm, initial linewidth of 650 nm and height of 208 nm. F-SPEL is performed at a heating temperature of 85˚C with hard pressing (250 psi) and lightly pressing (150 psi) respectively (Fig. 1(b)). With hard pressing, as shown in Fig. 2(b), the gratings inside the holes of top plate remain and have a narrower linewidth (due to guided SPEL) while the gratings outside are pressed flat. But with a lightly pressing, as shown in Fig. 2(c), the gratings inside the holes melted into a flat film due to open thermal flow, while the gratings outside remain due to top plate holding the grating up (capped SPEL). Combining Fig. 2(b) and (c), we can achieve complementary 3-D patterns simply by varying the gap between the top plate and substrate with different pressure.

A variety of micropatterned plates and substrate structures have been tested in F-SPEL. Fig. 3 shows F-SPEL example in which 200-nm-pitch polymer pillar arrays were pressed by a guide plate with the 10-µm-size holes. In Fig. 3(b) and (c), the pillars inside the holes remained with flat top surfaces due to capped SPEL effect while the gratings outside were melt and pressed into a smooth film due to pressed SPEL effect.

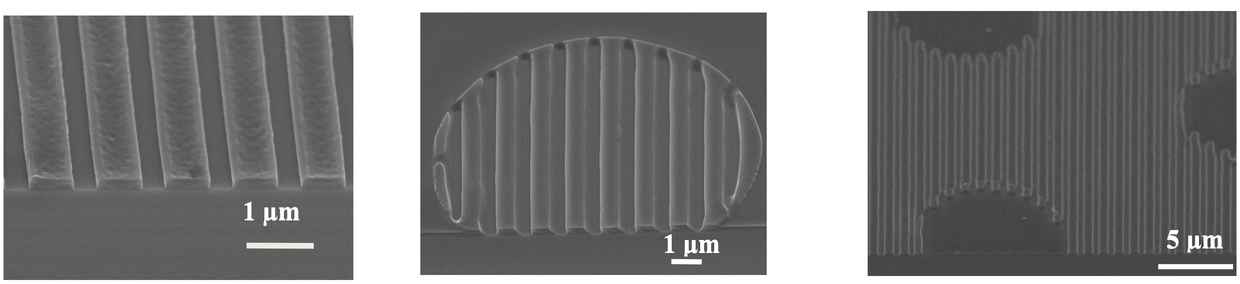
We believe that because of its simplicity, fast turn around and low cost, the functionalized SPEL - new 3D nano/micro-structure fabrication will have many applications in biomechanical sensors, micro/nanofluidics, nanophotonics and displays.

[1] Chou S.Y; Qiangfei X., *Nat. Nanotechnol.* **2008**, 3 (5), 295-300.
[2] Wang Y.; Liang X., Liang Y.; Chou S.Y., *Nano letters.* **2008**, 8 (7), 1986-1990.



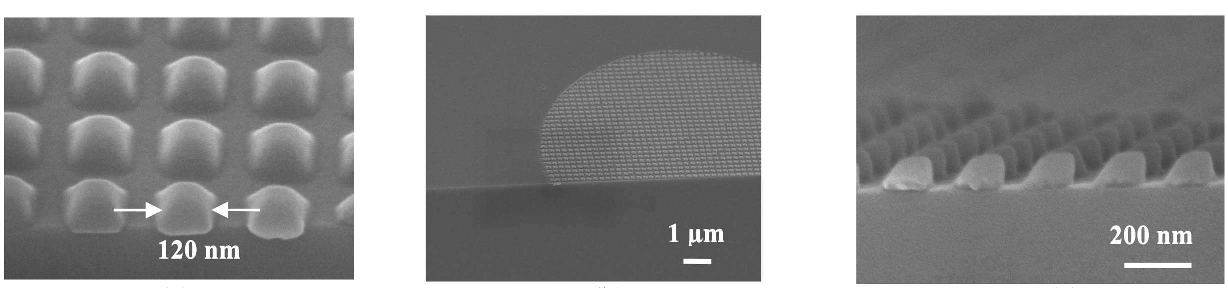
(a) (b) (c)

Fig 1. Schematic of an example of functionalized SPEL process. A rigid plate patterned with tens micron size holes of certain depth is pressed on top of a pre-defined polymeric grating on the silicon substrate while a heating raises the temperature above the glass transition temperature of the polymer. The gratings under and outside of the hole will do capped, guided or pressed SPEL depending upon the gap.



(a) (b) (c)

Fig. 2. SEM images of 500-nm-half pitch uniform grating before (a) and after (b) and (c) functionalized SPEL. (b): The grating under the hole of the top plate remains with narrow linewidth (due to G-SPEL) but the grating outside the holes becomes flat film due to P-SPEL. And (c) when the gap between the substrate and the top plate is large enough, the grating inside hole disappear due to open thermal flow, while the gratings outside the holes remain due the top plate holding the grating up.



(a) (b) (c)

Fig. 3. SEM images of 200 nm pitch uniform pillars before (a) and after (b) and (c) functionalized SPEL. Similar to Fig. 2, (b): The pillars under the hole of the top plate remains (due to C-SPEL) but the pillars outside the holes become flat film due to P-SPEL.