FABRICATION OF HORIZONTAL, VERTICAL, AND ANGLED PDMS AND IRON-PDMS MICROPILLARS USING A NOVEL AGAR RELEASE TECHNIQUE

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ABSTRACT
In this work we present a low cost, rapid and convenient technique for the fabrication of in-plane and out-of-plane, high aspect ratio polymer and composite polymer micropillars. The micropillars were fabricated with polydimethylsiloxane (PDMS) and iron-PDMS composite as the structural material by using agar as a sacrificial material that was cast against a 3D printed mold. Micropillars of diameters 65 µm, 240 µm and 350 µm with aspect ratios as high as 30 were fabricated by this technique. Following the sacrificial agar release, the fabrication and dimensional consistencies of the micropillars were determined. The fabricated PDMS micropillars showed a dimensional standard deviation of 10.56 µm while the lower dimension iron-PDMS composite micropillars had a standard deviation of 12.2 µm from the targeted sizes. This sacrificial agar technique has been utilized to demonstrate the fabrication of horizontal, vertical and angled polymer micropillars, having potential applications in sensing and actuation processes.

KEYWORDS: PDMS micropillars; Fe-PDMS micropillars; sacrificial agar; horizontal, vertical and angled micropillars, 3D printed mold.

INTRODUCTION
Micropillars have versatile applications as sensors and actuators in high-throughput screening platforms [1], shear-stress sensors [2], electrochemical sensors [3], cell separators [4], microfluidic mixers [5] and flow sculptors [6]. Micropillars are fabricated via photolithography, laser ablation, Focused Ion Beam Etching (FIBE), Reactive Ion Etching (RIE) and soft lithography. However, photolithography and RIE techniques are limited by the requirement of multiple processing steps and inability to fabricate out-of plane multi-angled structures simultaneously. Laser ablation and FIBE are serial processes and require specialized equipment to fabricate structures with complex geometries. Soft lithography introduces mechanical stresses, and suffers from feature losses during the demolding of micro/nano structures. In this work, we introduce a novel technique to fabricate precise and high aspect ratio polydimethylsiloxane (PDMS) and Iron-PDMS (Fe-PDMS) micropillars and microbridges with different orientations using agar as a sacrificial material.

EXPERIMENTAL
The schematic of the sacrificial agar fabrication technique is illustrated in Fig. 1. A 3D-printed structure (Fig. 1a-i) with sidewall through-holes (diameter d =800µm) was manufactured. Guide rods of diameters 65µm, 240µm and 350µm, acting as master molds for the sacrificial agar were pre-installed (Fig. 1a-ii) into the cylindrical pathways of the 3D-printed structure. A 4% agar solution was prepared and poured into the 3D-structure assembly (Fig. 1a-iii). After the agar was cured, the guide rods were carefully removed (Fig. 1a-iv), and the agar replica was de-molded and transferred to a petri dish, exposing the cylindrical voids within the agar gel. PDMS pre-polymer (10:1 elastomer-curing agent ratio) and 30wt% Fe-PDMS were prepared and cast into respective dishes containing the sacrificial agar replica, subsequently filling the voids via capillary flow to form the micropillars (Fig. 1a-v,vii). Since the PDMS completely enveloped the cured agar, there was no shrinkage observed due to loss of water content in agar at room temperature. Following PDMS curing at 37ºC for 24 hours, the sacrificial agar was thermally released by introducing the entire structure into a 100ºC water bath (Fig. 1a-vii) and dried.
to form suspended micropillar structures (Fig. 1a-viii). The vertical and angled micropillars were fabricated using the same technique as shown in Fig. 1b with appropriately angled guide rods.

![Diagram of micropillar structures](image)

**Figure 1:** Schematic of the sacrificial agar technique to fabricate (a) horizontal and (b) vertical and angled PDMS and Iron-PDMS micro-pillars.

**RESULTS AND DISCUSSION**

Horizontal, vertical, and angled PDMS and composite Fe-PDMS micropillars were fabricated by using guide rods of 65 µm, 240 µm and 350 µm with the sacrificial agar technique as illustrated in Figure 1. Scanning Electron Microscopy (SEM) images of the fabricated PDMS and composite PDMS micropillars with the above mentioned dimensions in horizontal (Fig. 2 a-f), vertical (g) and angled (h) directions were obtained (aspect ratio=30).

![SEM images of micropillars](image)

**Figure 2:** Scanning Electron Micrographs of PDMS pillars: (a) 65µm, (b) 240 µm, (c) 350 µm; composite Fe-PDMS pillars: (d) 65µm, (e) 240 µm, (f) 350 µm with scale bar of 1300 µm; (g) vertical PDMS micropillar and (h) angled PDMS micropillar (with aspect ratios of ~30) with the respective scale bars of 1110 µm and 1580 µm.

The micropillars were imaged by a PointGrey Grasshopper 3 USB camera mounted on a BIM-500FL inverted microscope. Fabrication consistency of horizontal micropillars was investigated optically by comparing the measured average thicknesses of three micropillar samples (using SEM) against their respective guide rod thicknesses (Fig. 3). The thickness of the fabricated PDMS micropillars showed an
average reduction of 14.8% from the thickness of the guide rods (Fig. 3a). The reduction in the thickness of the PDMS micropillars may be due to the high water content in the agar and the hydrophobicity of PDMS that causes the repelling of PDMS against the agar sidewalls due to the low surface energy. While no trend was observed between the thickness of the fabricated Fe-PDMS micropillars and their respective guide rods (Fig. 3b), the lower dimension micropillars showed a higher precision in fabrication with a standard deviation of 12.2 µm from the guide rods. This dimensional inconsistency for higher dimension composite micropillars is due to the size range of the iron particles (1-75 µm) used to prepare the composite. Uniform particle size would ensure better consistency in micropillar thicknesses.

![Figure 3: Comparison of measured thicknesses of the guide rods vs. fabricated horizontal (a) PDMS, and (b) Fe-PDMS Composite micropillars](image)

**CONCLUSION**

While conventional microfabrication requires cumbersome and prolonged techniques to fabricate vertical and angled micropillars, our sacrificial agar technique achieves rapid, low-cost and simple fabrication of polymer and polymer composite microbridges and micropillars. The thermal release of the sacrificial agar eliminates any mechanical stresses while demolding and mitigates feature losses. We demonstrated the fabrication of horizontal, vertical and angled micropillars with PDMS and composite iron-PDMS as the structural material and further measured the fabrication consistency of the micropillars. Improvement of the fabrication consistency of composite polymer micropillars is currently under investigation. This sacrificial agar technique enables the fabrication of high aspect ratio composite polymer micropillars with broad sensing and actuating applications (e.g. strain and temperature sensors).

**REFERENCES**


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