

Wafer-scale Micromolding of Unitary Polymeric Microstructures with Simultaneously Formed Functional Metal Surface

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ABSTRACT

This paper reports a wafer-scale technique to fabricate a unitary thermoset 3-D high-aspect-ratio microstructure (HARMS) with simultaneously-formed functional metal surface by means of metal transfer reactive casting from lithographically-defined mold masters. Such unitary structures are particularly suited to function as “daughter molds” in subsequent aggressive replication environments. This wafer scale approach spans five orders of length scale, from a 100mm wafer to molded 1 μ m dimple features. The fabricated unitary structure is mechanically rigid and robust, and the transferred gold layer functions as a wetting enhancement layer as well as a good separation layer both during the daughter structure fabrication step and for subsequent cell scaffold fabrication.

Keywords: Cell-culturing, Metal transfer, Replica molding, Wafer-scale

1. INTRODUCTION

Micromolding is an attractive approach to achieve complex 3-D scaffolds at low-cost and high-volume, with the advantage that both microtexturing and the use of tissue-friendly materials are preserved [1]. One of the key steps in successful micromolding is the fabrication of a suitable mold master. Mold masters should be sufficiently robust to withstand the multiple usages that are required for mass-manufacturing. However, due to different thermal and mechanical properties of the structural material and the substrate, the mold-master often experiences mechanical failure after only a few uses. This paper describes a wafer-scale technique to fabricate a unitary thermoset mold master with simultaneously formed functional metal surface. The initial micromachined master can be preserved and reused, which leads to faster turnaround time and the potential for cost-effectiveness.

2. EXPERIMENTAL

Figure 1 illustrates the fabrication process flow. An SU-8 master for a cell-culturing scaffold has been fabricated by using a double-layer photolithography technique [2]. As shown in Figure 2, the master contains 10, 5, and 2 μ m protrusion features on top of 150 μ m-tall columns with small salient features of 10, 5, and 2 μ m along the column sidewall, respectively. Polydimethylsiloxane (PDMS) is cast against this master and then cured (Figure 1a). The PDMS mold is then placed on top of a glass plate, and a 60 nm-thick gold layer is deposited on the PDMS mold (Figures 1b and 3). Polyurethane (PU) and crosslinker are

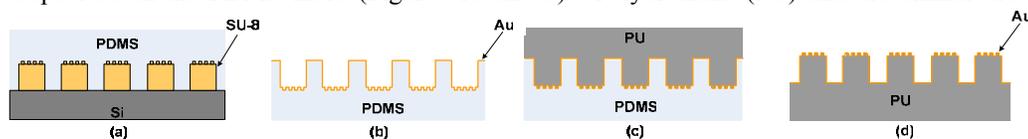


Figure 1. Process flow for unitary mold masters with functional metal surface

mixed and cast into the PDMS mold (Figure 1c) and cured. Upon separation of the cast PU part from the PDMS mold, the deposited gold layer is completely transferred to the PU side (Figure 1d). Figure 4 shows the molded PU structure bearing 10, 5, and 2 μm snow-flake transferred from PDMS mold with high fidelity. Figure 5 shows the different length scale of the PU structures (from left): a 4 inch wafer scale, a unit array of 15 mm in diameter, a magnified snow-flake array, and a single snow-flake with salient features of 5 μm on the sidewall and protrusions on the top surface.

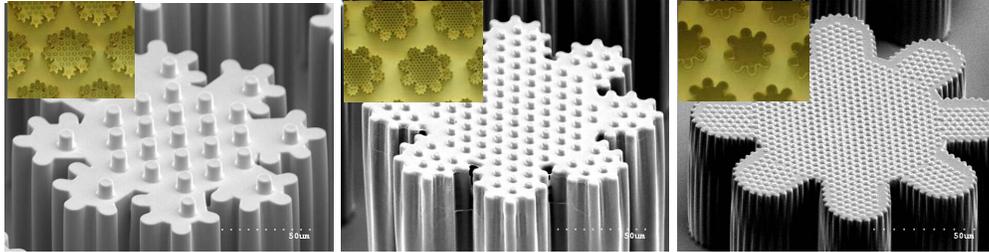


Figure 2. SU-8 master structure on silicon substrate: 150 μm -tall columns with 10 μm , 5 μm , and, 2 μm salient features on sidewall and protrusions on the top surface (from left)

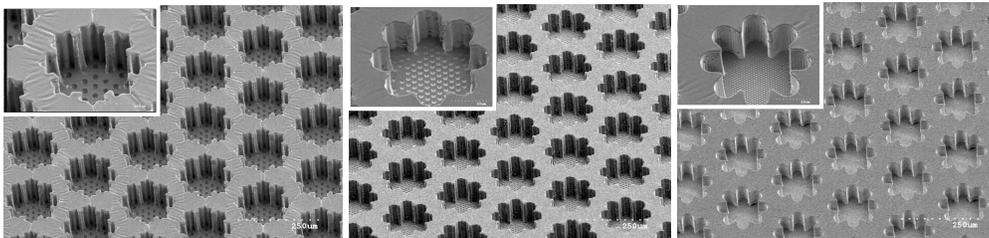


Figure 3. Elastomeric PDMS mold coated with 60nm Au: column wells with 10 μm , 5 μm , and 2 μm salient features on sidewall and dimples on the bottom (from left)

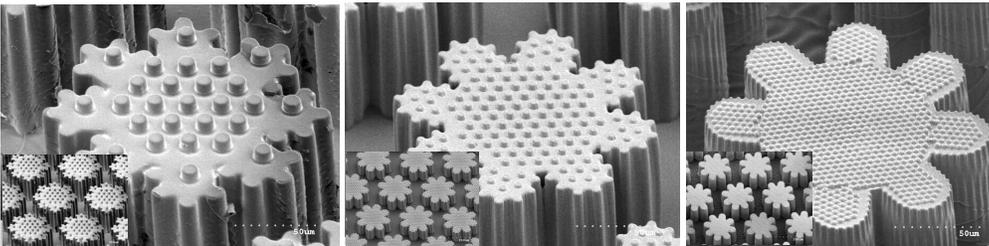


Figure 4. PU structure from Au coated PDMS mold with metal transfer with 10, 5, and 2 μm salient features on sidewall and protrusions on the top surface (from left)

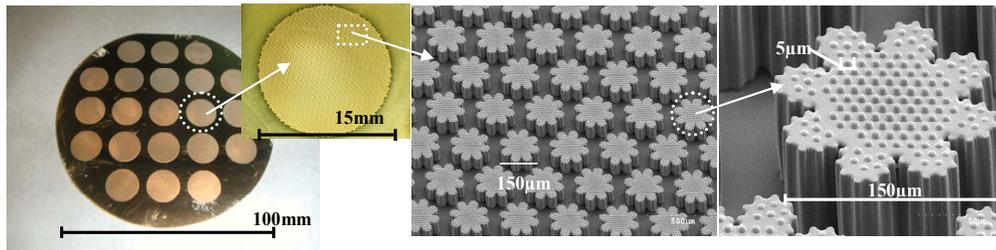
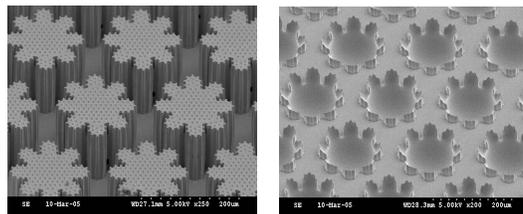


Figure 5. Unitary PU daughter master structures in 4-inch wafer scale

4. RESULTS AND DISCUSSION

Due to the extremely low viscosity of the cast oligomer (160 cps), complete filling of the high-aspect-ratio structure can be achieved. Moreover, by virtue of the 100% solid material being used in the reacting system, excellent dimensional fidelity can be obtained. Gold layer deposition as a way to alter the hydrophobicity of PDMS surface is an attractive alternative to either chemical modification, surface treatment by plasma, or UV/ozone, since it does not increase the adhesion between the casting material and the PDMS surface. Figure 6a shows a wafer-scale replica utilizing the Au technique and following the mold master with high fidelity, while Figure 6b shows an unsuccessful PU structure from a bare PDMS mold with poor wettability, resulting in only partial replication of the columns. This metal transfer



(a)

(b)

Figure 6. (a) PU cast from Au coated PDMS mold with metal transfer and (b) from a PDMS mold without metal coating

technique can be considered an extension of previous 2-D metal transfers from PDMS to polymer surfaces (e.g., nanotransfer printing as shown in [3]) to the third dimension. The transferred Au film shows good adhesion to PU and withstands a Scotch™ tape adhesion test. We chose to fabricate these masters out of thermoset polymers to take advantage of ease of molding, varieties in choice of material, low cost, and solvent resistance. In addition to PDMS and PU, other thermoset polymers that are potential candidates for metal transfer reactive casting include unsaturated polyesters, epoxies, polyurethane acrylate, etc.

5. CONCLUSIONS

In this work, a wafer-scale metal transfer micromolding technique was demonstrated to fabricate unitary thermoset mold masters for cell-culturing scaffold. The advantage of the thermoset mold master as an alternative to the photopatterned or Si micromachined mold master are: 1) its mechanical robustness with which it withstands subsequent aggressive replication environments; 2) its easy wettability with the cast material; and 3) its easy separation from the cast material upon completion of the molding step.

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