HOT EMBOSSING OF PLASTIC MICROFLUIDIC DEVICES USING POLY(DIMETHYLSILOXANE) MOLDS

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ABSTRACT

We present a poly(dimethylsiloxane) (PDMS)-based hot embossing process for low-cost rapid prototyping of plastic microfluidic devices. Unlike conventional hot embossing process, the process presented here uses a 2 mm thick PDMS mold fabricated *via* soft lithography, two ¾” wide binder clips, two standard 1 mm thick 1” × 3” microscope glass slides and an oven. Micro-scale features were successfully replicated in 1.5 mm thick polystyrene slides from various PDMS molds. Also, PDMS molds can be reused for many replications without any damages.

KEYWORDS: Poly(dimethylsiloxane) (PDMS), Hot embossing, Rapid prototyping, Plastic microfluidic device

INTRODUCTION

Using poly(dimethylsiloxane) (PDMS) as a mold presents several advantages. Because of PDMS elasticity and low surface energy, de-molding process after embossing is straight forward without any special mold designs. Thus, complex structures, which cannot be accomplished with a metal mold, can be replicated with PDMS molds. Also, topographical features at nano-scale can be replicated as demonstrated by Choi and Park [1]. Choi and Park demonstrated a process to pattern curved surfaces with a 200 µm thick PDMS mold to generate feature sizes in the submicron domain. Although lines of 350 nm and 1 µm width, and dots of 400 nm and 1 µm diameter were successfully replicated on the curved surfaces, their patterning process may not be suitable for larger feature sizes that typically microfluidic devices would have. Russo *et al.* presented a PDMS-based hot embossing method for fabricating polystyrene replicas approximately 150 µm thick by using glass spacers together with four 5 cm wide binder clips and by heating to 210 °C for 20 – 60 minutes [2]. However, their initial attempts to use thin polystyrene film for larger structure (6 µm × 20 µm bars, 20 µm high) resulted in poor pattern transfer and rounded features. Thus, they had to employ an alternative method to overcome this problem.

In this paper, we present a user friendly, quick and low-cost PDMS-based hot embossing process that utilizes PDMS molds as the replication tool for replicating plastic microfluidic devices with large structures. With the described process, we have successfully demonstrated that micro-scale features can be replicated in 1.5 mm thick polystyrene slides from various 2 mm thick PDMS molds. Also, the PDMS molds can be reused for many replications without any damages.

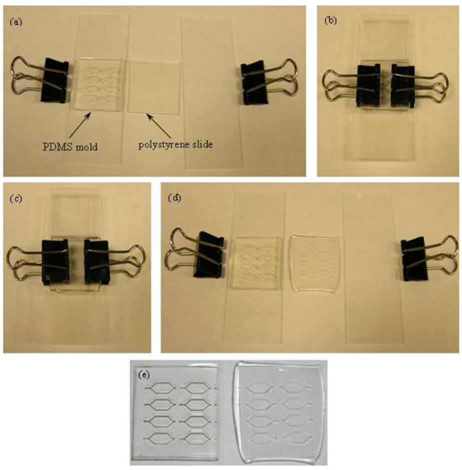

Figure 1: PDMS-based hot embossing setup. (a) Components before assembly before embossing. (b) Assembled components before embossing. (c) Assembled components after embossing. (d) Disassembled components after embossing. (e) PDMS mold (left) and embossed polystyrene slide replica (right).

EXPERIMENTAL

After fabricating 2 mm thick microstructured PDMS molds *via* soft lithography [3, 4], each PDMS mold was brought into conformal contact with a 1.5 mm thick polystyrene slide (Fig. 1a and 1b). Two standard 1 mm thick 1” × 3” microscope glass slides were used to sandwich the PDMS mold and the polystyrene slide. The assembly was clamped together by two ¾” wide binder clips (Officemate International Corporation, Edison, NJ, USA) which were used to generate the force required for the PDMS-based hot embossing process. For larger devices, multiple binder clips can be used. Then, the whole assembly was placed inside a 155 °C preheated oven (Isotemp Oven, Fisher Scientific, Pittsburgh, PA, USA) and held at that temperature for 15 minutes. With the binder clips still clamped to the slides, the whole assembly was cooled down to room temperature and the PDMS mold was carefully peeled off from the embossed polystyrene slide to avoid tearing or ripping of the PDMS mold (Fig. 1c – 1e). Finally, organic solvent assisted bonding was used to enclose the open structure of the polystyrene slide replica with a 120 µm thick polystyrene film [5].

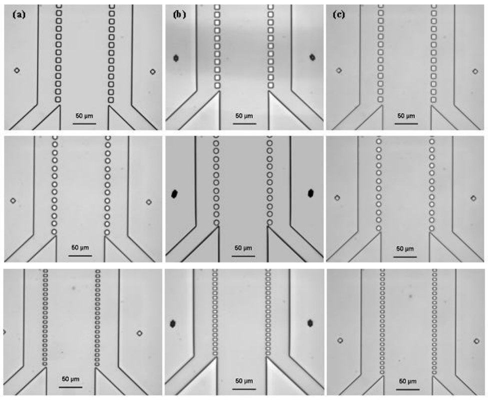

Figure 2: Microscopic images of PDMS molds and their polystyrene replicas. (a) PDMS molds before hot embossing. (b) Polystyrene slide replicas after PDMS-based hot embossing. (c) PDMS molds after fourth hot embossing.

RESULTS AND DISCUSSION

PDMS cell perfusion-culture devices with three different shapes of micropillars (square, circular and rectangular) were used as PDMS molds for hot embossing of polystyrene slides (Fig. 2). The PDMS cell perfusion-culture devices were similar to the one described by Toh *et al.* [6]. The scalloping effect [7] on the sidewalls of the micropillars revealed very good replication of the PDMS molds from the pattern silicon wafers (Fig. 3). After the PDMS-based hot embossing process, the polystyrene slide replicas showed good replication from the PDMS molds as revealed in the microscopic, scanning electron microscope (SEM) and confocal images (Fig. 2, 4 and 5). The sidewall surface roughness caused by the scalloping effect was clearly replicated in the polystyrene slide replicas (Fig. 4). Because of the PDMS thermal stability (up to 200 °C) and elastomeric mechanical properties, the PDMS molds remained undamaged after repeated hot embossing cycles (compared Fig. 2a with Fig. 2c). The height of the micropillars and the depth of the holes were measured using a confocal microscope. A fluorescent dye was used to cover the samples and the confocal microscope was used to measure the fluorescent signal. For the depth measurements, the holes were filled with fluorescent dye before confocal images were taken. The confocal images confirmed that both the height of PDMS molds and the depth of the polystyrene replicas were the same indicating good replication from the PDMS molds (Fig. 5).

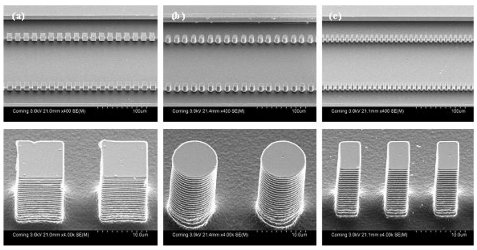

Figure 3: SEM images of PDMS molds depicted in Fig. 2a. A carbon coating was applied before SEM images were taken. (a) 10 µm × 10 µm square and 15 µm tall micropillars with two magnifications. (b) 10 µm circular and 15 µm tall micropillars with two magnifications. (c) 5 µm × 7.5 µm rectangular and 15 µm tall micropillars with two magnifications.

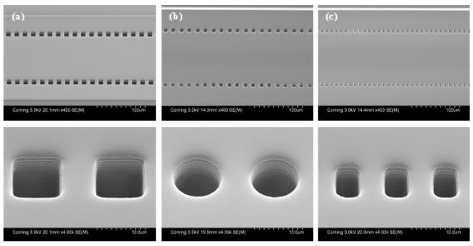

Figure 4: SEM images of polystyrene slide replicas depicted in Fig. 2b. A carbon plus gold (Au)\platinum (Pd) coating was applied before SEM images were taken. (a) 10 µm × 10 µm square and 15 µm deep holes with two magnifications. (b) 10 µm circular and 15 µm deep holes with two magnifications. (c) 5 µm × 7.5 µm rectangular and 15 µm deep holes with two magnifications.

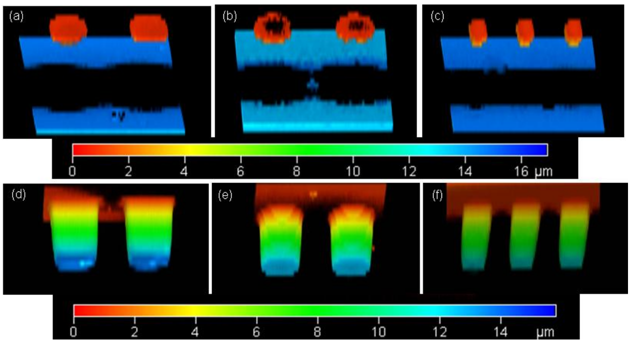

Figure 5: Confocal images of (a) – (c) PDMS molds depicted in Fig. 3 and (d) – (f) polystyrene slide replicas depicted in Fig. 4. (a) and (d) Square micropillars and holes, respectively. (b) and (e) Circular micropillars and holes, respectively. (c) and (f) Rectangular micropillars and holes, respectively.

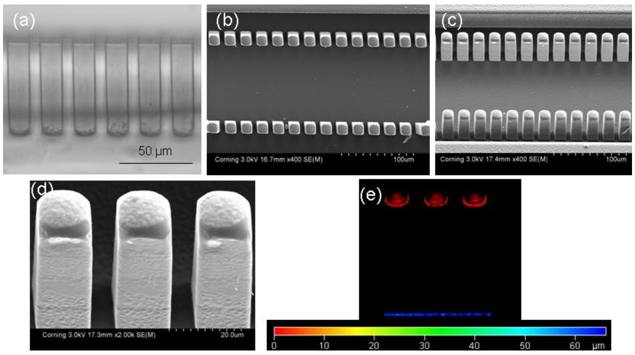

Figure 6: (a) Microscopic image of inversed PDMS mold along the cross-section of 15 µm × 15 µm square and 60 µm deep holes. (b) – (d) SEM images of polystyrene slide replica. 15 µm × 15 µm square and 60 µm tall micropillars. A carbon plus gold (Au)\platinum (Pd) coating was applied before SEM images were taken. (b) Top view. (c) 30° tilted view. (d) Magnified image of (c). (e) Confocal image of micropillars from the polystyrene slide replica.

Next, the microstructures of a PDMS cell perfusion-culture device with 15 µm × 15 µm square and 60 µm tall micropillars were inversed (*i.e.*, microchannels become ridges and micropillars become holes) and was used as a PDMS mold for hot embossing of polystyrene slides (Fig. 6a). The polystyrene slide replica showed good replication of the inversed PDMS mold with a sharp vertical micropillar profile and no evidence of leaning as evidence in the SEM images (Fig. 6b – 6d). Also, confocal image confirmed the height of the replicated micropillars (Fig. 6e) matched the depth of the holes in the inversed PDMS mold (Fig. 6a).

CONCLUSION

The PDMS-based hot embossing process demonstrated here simplifies the existing hot embossing process and can be used in regular laboratory settings. Elastic properties of PDMS material result in several advantages of using PDMS molds for hot embossing process; these include lower operational pressure required for structure replication and ease of mold separation without special model design.

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