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POLYMER HOT EMBOSSING WITH SOFT STAMPS

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ABSTRACT

Microfluidic channels are fabricated in thick polycarbonate (PC) substrates by hot embossing using soft poly(dimethylsiloxane) (PDMS) stamps. The embossing force is in the range of 2.5–3 kN for a 4-inch diameter substrate, and the embossed microchannel is 70 μm deep. We investigate the influence of soft stamp precursor and curing agent mix ratio, and post thermal treatment on embossing conditions. Experimental results show that a soft stamp fabricated with 5:1 mix ratio and post-annealed at 150°C results in better embossing properties than conventional un-annealed stamps.

INTRODUCTION

In recent years, many polymer-based microfabrication techniques have been explored for application in bio-MEMS and microfluidics. Current major polymer microfabrication techniques include hot embossing,[1] injection molding [2] and soft lithography.[3] Among them, hot embossing is the most attractive as it offers high replication accuracy for micron-scale features. The basic principle of hot embossing is heating a polymer substrate above its glass transition temperature (T_g), *pressing it with a mold* or master stamp and gradually cooling it well below the glass transition temperature where patterns from the mold are completely transferred to the polymer substrate. The mold pattern is then permanently transferred to the substrate upon cooling. The hot embossing process exploits differences in thermomechanical properties between the stamp and the substrate. Typically, stamps can be either hard or soft. For hard stamps, which are made of silicon or nickel, fragility, thermal mismatch and cost are

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the main concern. On the other hand, soft stamps made of polymers such PDMS or epoxy resins can more practical.[4–7] The use of soft stamps made out of polymers as a replication tool would potentially reduce the cost and be more durable, compared to fragile hard stamps. Hot embossing using soft PDMS stamps has been successfully developed by several research groups in recent years,[4–7] and their practicality has been demonstrated.

PDMS is a common elastomeric material widely used in the fabrication of microfluidic devices because the devices made in this material can be readily fabricated by replica molding or soft lithography. PDMS is stable to a temperature of up to 300°C, it has moderately high physical toughness and relatively low modulus. In this paper, we report on the fabrication of microfluidic channels in thick PC substrates by hot embossing using PDMS soft stamps. The effects of PDMS precursor, curing agent mix ratio and post thermal treatment on the stamp performance are investigated for different embossing conditions.

EXPERIMENTAL

Soft lithography technique was used to fabricate soft stamp. Briefly, features on a chrome photomask were transferred onto a silicon wafer using conventional photolithography. The photoresist-defined silicon wafer was then anisotropically etched to a desired depth using Oxford Plasma Lab 100, which is an excellent machine for silicon deep reactive ion etching (Bosch process). After silicon DRIE, photoresist stripping was carried out by soaking the wafer in acetone followed by IPA and DIW rinse. Following photoresist stripping, anti stiction coating was applied, in a glove box, using silane (trichloro, 1H, 1H, 2H, 2H-perfluorooctyl).

The Sylgard 184 (Dow Corning) was used to fabricate soft stamps. First, the precursor and the curing agent were well mixed and poured onto a silicon mold fabricated as outlined above. The mold was generated having the negative replica of the desired features. Curing of the soft stamp was typically performed overnight at room temperature to allow effective elimination of bubbles in the precursor mixture. The flatness and proper leveling of the precursor mixture and mold while curing, was critical to ensure that the soft stamp has uniform thickness throughout. This was important to evenly replicate the structures during the embossing step.

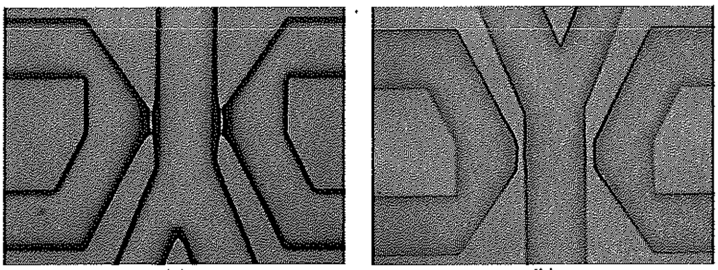
The hot embossing process was carried out using EVG hot embosser (520HE). Table 1 shows an overview for the process parameters used for the hot embossing of microfluidic channels in PC substrates. The PC substrate diameter and thickness were 4-inch and 1 mm, respectively. Multiple embossing processes were carefully carried out without damaging the stamp.

Table 1: Hot Embossing Process Parameters

Stamp	*Stamp Ratio*	*Post Annealing*	*Embossing Conditions*			
			Force (kN)	*Temperature (°C)*	*Time (min)*	*Vacuum*
PDMS	10:1	No	3	165	10	No
PDMS	5:1	No	2.5	165	10	No
PDMS	5:1	Yes, overnight @150°C in oven.	2.5	165	10	No

RESULTS AND DISCUSSION

PDMS stamp hardness is typically sensitive to stamp mix ratio and curing temperature/post-annealing.[8] We exploited this PDMS property to fabricate soft stamp for successful embossing of micro-scale features in PC substrate. The soft stamp, which was fabricated using 5:1 stamp ratio and post-annealed overnight at 150°C, resulted in successful embossing of 70 μm deep microchannels in PC. Figure 1(a) shows microscopic image of embossed microchannel using 5:1 stamp mix ratio. The embossing force was 2.5 kN for a 100 mm diameter substrate. The microscopic inspection of embossed microchannels showed sign of partly connected microchannels. Figure 1(b) shows microscopic image of fully embossed microchannels using stamp prepared with 5:1 mix ratio and post-annealed overnight at 150°C. It is clear from successful embossing that post-annealing of PDMS stamp at 150°C improves stiffness/hardness of the stamp and results in excellent embossing properties. Figure 2 (a)–(b) shows a 3D optical image of the PDMS soft stamp and the embossed microchannels in PC, respectively. The replication accuracy for the embossed microchannels, which was measured by a surface profilometer, was better than 5% after 20 embossing cycles, confirming the practicality of the stamp for mass production.



(a) (b)

Fig. 1: Microphotographs of Embossed Microchannel in PC Using (a) 5:1 Stamp Ratio, (b) 5:1 Stamp Ratio and Post Annealed Overnight at 150°C

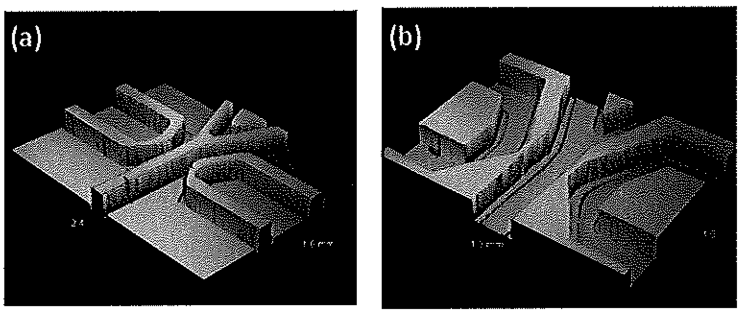


Fig. 2: 3D Optical Image of the (a) PDMS Soft Stamp and (b) Embossed Microchannel in PC

CONCLUSIONS

Microfluidic channels in thick polycarbonate substrates have been fabricated by hot embossing using PDMS stamps. The effects of PDMS stamp precursor, curing agent mix ratio, and post thermal treatment on embossing conditions have been investigated. A soft stamp has been fabricated with 5:1 mix ratio and post-annealed at 150°C resulting in much better embossing properties than un-annealed counterparts.

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