ONE-STEP MULTI-DEPTH POLYSTYRENE MOLDS FOR PDMS SOFT-LITHOGRAPHY THROUGH LASER-INDUCED BUMPING

Huawei Li, Yiqiang Fan and Ian G. Foulds

Electromechanical Microsystems & Polymer Integration Research (EMPIRe) Group
King Abdullah University of Science and Technology (KAUST), Physical Sciences and Engineering Division, Thuwal 23955-6900. Saudi Arabia

ABSTRACT

In this article, we report a mask-less and cleanroom-independent technique to fabricate Polydimethylsiloxane (PDMS)-based multi-depth microfluidic devices using a polystyrene (PS) mold with laser-induced multi-height bump patterns for PDMS soft-lithography. This technique offers a rapid and low-cost alternative to conventional PDMS mold creation, which requires more complicated mask-based photolithography process, and it also eliminates the cumbersome precise alignment/bonding of microchannel layers to fabricate a 3D structure [1]. This paper reports the first use of this new laser bumping technique for creating multi-height molds for soft-lithography.

KEYWORDS

Multi-depth microchannel, bump, PDMS, microfluidic.

INTRODUCTION

High power CO_2 lasers have widely been used to fabricate microchannels on polymers such as Poly(methyl methacrylate) (PMMA) [2], PDMS [3], Polycarbonate (PC) [4], and Polytetrafluoroethylene (PTFE) [5] through thermal ablation process. Inversely, positive relief "bumps" rather than channel profiles have been shown in nanoscale on Si and polystyrene using 248 nm KrF laser [6, 7], and nanobumps have also been shown on silicate glasses fabricated by CO_2 laser [8]. These nanobumps occur when the laser power is below the vaporization threshold of the materials.

In our previous work [9, 10], we created laser induced bumps higher than 3µm on PS sheet by laser heating below the ablation threshold using a commercially available CO_2 laser system (Universal PLS6.75), which emits a wavelength of 10.6 µm with a maximum output power of 75 W and maximum speed of 300 mm/s.

In this study, we succeeded to increase the bump height on PS by multiple laser scans, which has allowed us to grow the height of the CO_2 laser-induced bumps on the polystyrene sample to dozens of microns. This technique offers a rapid and low-cost method to fabricate multi-depth PDMS microfluidic devices using the PS mold with multi-height bump pattern.

EXPERIMENT

Material and apparatus

1.2 mm thick Polystyrene sheet with molecular weight of 267.8 kDa purchased from Goodfellow Cambridge Limited, England was studied in this work. The CO_2 laser system (Universal PLS6.75) emits a wavelength of 10.6 µm, and the laser beam is focused by a lens with a focal length of 60 mm to a spot with a 0.127 mm diameter. The laser power can be set from 0 to maximum 75 W along with scanning speed from 0 to 300 mm/s.

The micromachining pattern on the sample can be prepared by computer aided design programs, and CorelDraw was used in this work. The profile of the microchannels was measured by a Veeco DEKTAK 150 profiler system.

Bump formation on PS

A photothermal process happens during the CO_2 laser scanning across PS surface. Decomposition and vaporization will happen when the laser power is above the vaporization threshold of PS. Inversely, bump rather than void on PS may appear if the laser power is below the vaporization threshold of PS. The fabrication of straight-line bump pattern on PS by CO_2 laser scanning is shown schematically in figure 1.

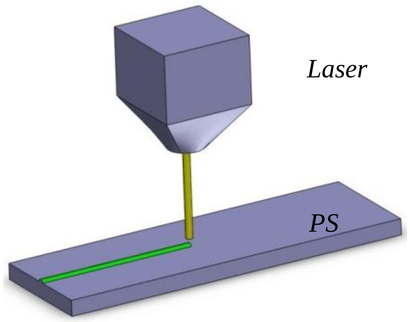

Figure 1. Bump fabrication by laser heating.

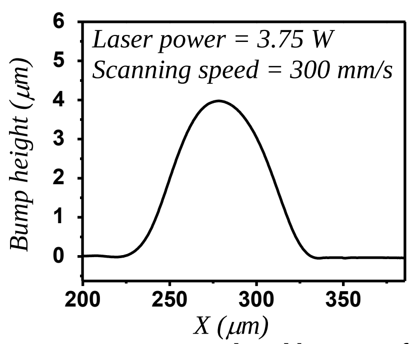

Figure 2. Laser-induced bump profile.

The profile of PS bump along the laser path depends on the laser power and scanning speed, and the bumps occur because of the net volume increase, which has previously been explained by the fast cooling effect after laser irradiation [4] and is more highly pronounced in polymers. Figure 2 shows one PS bump in our study which is fabricate using a laser power of 3.75 W at the scanning speed of 300 mm/s.

Bump growth induced by multiple laser scan

In this study, we found that bumps grew and increased in height when multiple laser scans with a power lower than the vaporization threshold were applied atop the previous ones, as shown in figure 3. To make it simple, all the laser scans have the same power of 3.75 W and the same scanning speed of 300 mm/s. In our study, the bump height grew from 4 µm to 33 µm, corresponding to 1 scan and 21 scans respectively, as shown in Figure 4.

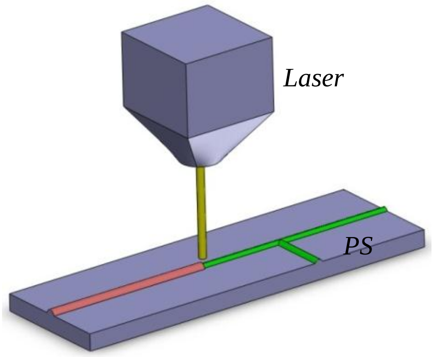

Figure 3. Bump growth induced by multiple laser scans.

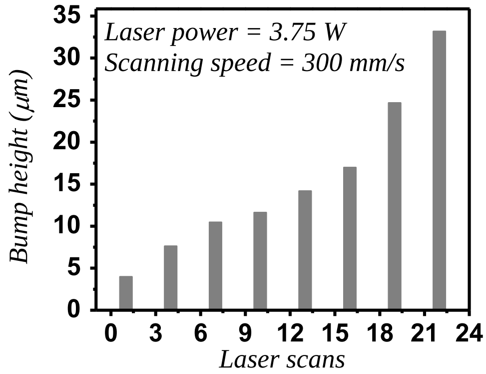

Figure 4. Bump height dependence on laser scans.

Fabrication of multi-depth PDMS microfluidic devices

In our previous work, single-depth microchannels on PDMS were fabricated using laser-induced uniform bump on PS. The laser-induced bump growth on PS offers a new method to fabricate multi-depth microchannels on PDMS using the PS mold with multi-height bump patterns. To show how it works, we fabricated a multi-depth PDMS droplet generator using PS bump mold. First a T-junction multi-height bump is patterned on PS, as shown in Figure 3, by multiple scans of laser with power of 3.75 W and scanning speed of 300 mm/s. The 15 µm high bump in green color was fabricated by 15 laser scans, while the 33 µm high bump in pink color by 22 laser scans. Then PDMS prepolymer (Dow Corning Sylgard 184, 10:1 parts A and B, fully mixed and then degassed in vacuum for 30 minutes) was poured atop the PS mold, followed by curing at 80 ^{o}C for 1 hour. Finally the PDMS layer with multi-depth microchannels was demolded, as shown in Figure 5, and then bonded onto a piece of glass by O_2 plasma to form closed channels.

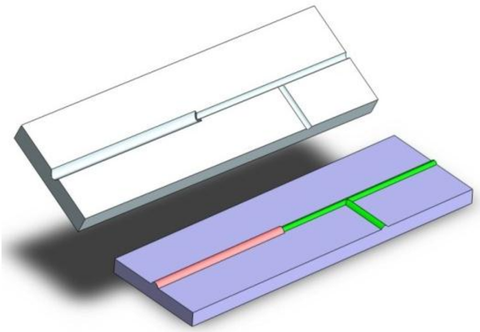

Figure 5. PDMS layer with multi-depth microchannels demolded from the laser bumped PS master.

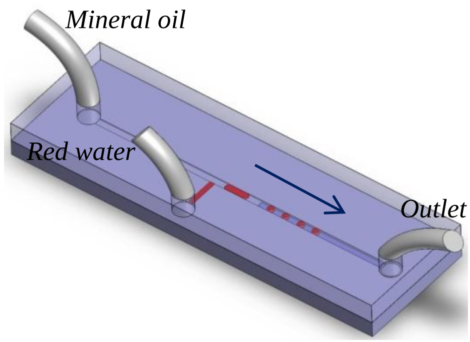

Figure 6. Experimental setup for droplet generation.

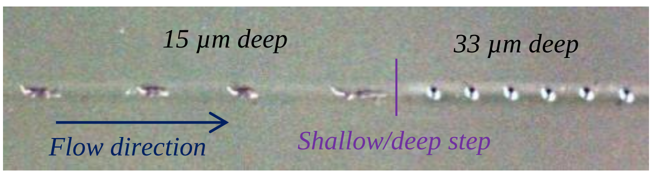

Figure 7. Droplets passing from shallow channel to the deeper channel and their reshaping.

To test the multi-depth PDMS droplet generator, light mineral oil (SIGMA-ALDRICH) and water which was dyed by red ink were injected into the channel through the inlet holes with flow rate of 0.05 µl/min, as depicted in Figure 6. The long rod-like red water droplets were generated at the T-junction as shown in Figure 7, and then the water droplets changed into ball shape when they entered from the 15µm deep microchannel into the 33µm deep microchannel.

In this work, we demonstrate a rapid and low-cost method to fabricate multi-depth PDMS droplet generator. The PS mold is fabricated within a few minutes and can be used repeatedly. More complicated PDMS multi-depth microchannel networks can be easily done using PS mold with a corresponding bump pattern, and it will help to further expand the multi-depth microfluidic devices' applications.

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CONTACT

Huawei Li +966-2-8084389 or huawei.li@kaust.edu.sa