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Microfluidic Flow of Dyed Water in the PMMA Microchannels

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Abstract
In this work, total three individual polymethylmethacrylate (PMMA) microfluidic devices are fabricated by the maskless lithography, hot embossing lithography, drilling, direct bonding technique and chip separation technique. Dyed water is the working liquid. One sudden expansion microchannel and two microchannel bends are tested by dyed water. The surface-driven capillary flow is recorded by the CMOS camera. This work will be useful in the fabrication of PMMA lab-on-a-chip systems for microfluidic applications.

Keywords: *PMMA, lithography, water, capillary flow, direct bonding*

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INTRODUCTION

Surface-driven capillary flow is created by the surface tension forces at the solid-liquid-gas interfaces inside any microchannel [1–3]. Surface-driven capillary flow has no requirement of any external circuit to be attached with the microchannel [1–3]. But, in any active capillary flow, the external circuits are required to be connected with the microchannel for desired microfluidic flow [4]. The surface-driven capillary flow is highly useful for different microfluidic applications [5–8].

The common methods to fabricate the microfluidic devices are maskless lithography, hot embossing lithography, soft lithography, X-ray lithography, injection molding, and laser photo-ablation [9–14]. Direct bonding techniques are especially useful to fabricate the leakage-free microfluidic devices [15]. SU-8, polymethylmethacrylate (PMMA) and polydimethylsiloxane (PDMS) are the major polymeric materials to fabricate microfluidic devices [9, 16–24]. In this research paper, the surface-driven capillary flow of dyed water is individually recorded in one sudden expansion microchannel and in two microchannel bends. This work will be useful in the fabrication of PMMA lab-on-a-chip systems for different microfluidic applications.

EXPERIMENTAL TECHNIQUES

One sudden expansion microchannel and two microchannel bends are drawn on a computer screen of 1024×768 pixels to facilitate the maskless lithography [12]. These designs of microchannels are saved in the individual 24-bit Bitmap files as 'FileName.bmp'. The circular inlet and outlet reservoirs have 2 mm diameters individually. The channel width of the narrower section of sudden expansion microchannel is 100 micron uniform along the first half (5 mm long) of channel length according to the design. The wider section of sudden expansion microchannel is 400 micron uniform along the second half (5 mm long) of channel length according to the design. Therefore, the expansion ratio of this sudden expansion microchannel is 1:4. Microchannel bend has channel 1 connected with the inlet reservoir and has channel 2 with channel 3 connected with different outlet reservoirs (Figure 1). The channel 1, channel 2 and channel 3 have equal channel widths in any particular microchannel bend. In this work, one microchannel bend has channel width of 75 micron and another microchannel bend has channel width of 400 micron.

RESULTS AND DISCUSSION

Maskless lithography

SU-8 based silicon stamp is fabricated by the maskless lithography using SF-100 instrument

(Intelligent Micropatterning, LLC, Florida) in the cleanroom laboratory of class 1000 standard according to the Federal Standard 209E. The stamp is used to fabricate the PMMA microchannel structures by hot embossing lithography [12, 18].

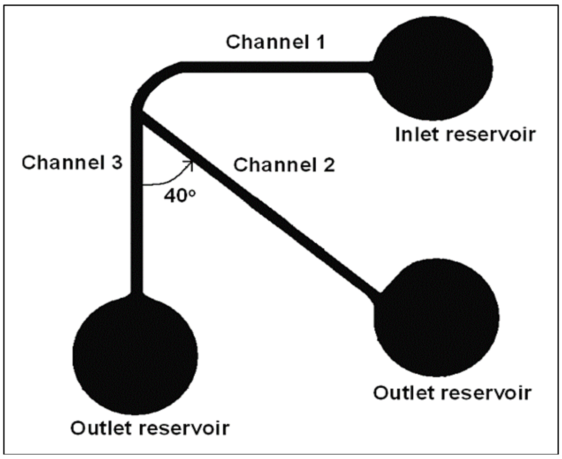

Fig. 1: *Schematic Diagram of the Microchannel Bend is Shown (top view).*

At first, the silicon wafer (Mi-Net technology Ltd., UK) is cleaned by the piranha solution (H_2SO_4+H_2O_2) to clean the organic residues from the wafer surface. Next, the wafer is cleaned by acetone and deionized (DI) water. Then, the wafer is dehydrated on the digital hot plate (Cole-Parmer, USA) at 120°C for 5 minutes. After that, the wafer is cooled down on the digital hot plate up to the cleanroom temperature of 26°C. Negative photoresist SU-8 50 (CHESTECH Ltd., England) is coated on the silicon wafer by a spin speed of 2500 RPM in a SCS G3 Spin Coater (Specialty Coating Systems, Indiana, USA). Next, the coated wafer is soft baked on the digital hot plate at 65°C during 15 minutes. After that, the temperature of the digital hot plate surface is ramped from 65°C to 95°C and the coated wafer is soft baked at 95°C during 30 minutes.

In the next phase, this soft-baked sample is used in maskless lithography by SF-100 [12]. The baked sample is placed on the exposure bench in the SF-100 to expose the soft baked SU-8 layer to the UV light of 365 nm for 35 seconds in SF-100 at a radiation intensity of 307 $\mu W.cm^{-2}$ measured by an Ultra Violet Intensity Meter (UVX Digital UV Intensity Meter, Cole-Parmer, USA). All the portions of this soft baked sample are exposed by one after another UV-exposure of equal exposure-time and UV-intensity in the SF-100. After that, post-exposure bake is performed. Finally, the SU8 development and hard baking steps are performed.

Hot Embossing Lithography

The PMMA microchannel structures are fabricated by pattern transfer on the PMMA substrate (Engineering and Design Plastics Ltd., UK) in EVG520HE system (EV Group, Austria) using the fabricated stamp. At first, the stamp is placed on the PMMA substrate inside the embossing chamber of EVG520HE system. Next, the vacuum pressure is created as 0.4 mbar inside the embossing chamber. Then, 10 kN embossing force is applied on the stamp for the pattern transfer on the PMMA substrate at 125°C during 2 minutes. The vacuum pressure is maintained at 0.4 mbar inside the embossing chamber during the pattern transfer. After the pattern transfer, the main PMMA substrate containing the microchannel structures along with the stamp are placed on the cooling pad besides the embossing chamber.

Direct Bonding Technique

In direct bonding technique, no adhesive layer is required [15]. In the direct bonding, the PMMA lid substrate is maintained in proper contact with the PMMA microchannel substrate. Before starting direct bonding, 2 mm circular holes are drilled accurately on a PMMA main lid in the Mechanical Engineering Workshop. After drilling, the PMMA dusts are removed by washing the main lid substrate using distilled water in an Ultrasonic Sonicator Bath (Branson Ultrasonics, USA). At the temperature of 90°C, the bonding force of 10 kN is applied for 4 minutes inside the embossing chamber. After all the steps of direct bonding, the PMMA microfluidic devices are separated as microfluidic chips from the sealed main substrate using a hot wire cutter instrument (PROXXON 37080 Hot Wire Cutter Thermocut, USA) producing the size of each rectangular microfluidic chip of 18 mm in length, 14 mm in width, and 2 mm in height.

Video Recording of the Surface-driven Capillary Flow

In this work, the dyed water is prepared by mixing 5 mL red dye (Super Cook Red

Colouring 38 mL, British Supermarket Worldwide, England) with 50 mL distilled water. The dyed water is used for the proper visualization and recording of each surface-driven capillary flow through the two individual microchannels because PMMA is an optically transparent polymer. 8 µL of dyed water is dispensed at the inlet reservoir of each microfluidic device using the non-electrical micro-syringe pump. The surface-driven microfluidic flow of dyed water is recorded in each of the three microfluidic devices using the CMOS camera. The CMOS camera has a digital video capture speed of 25 frames per second with a corresponding resolution of 0.04 second. A fresh cleanroom tissue paper is placed on the device stage for white background before placing the microfluidic device. In the Figure 2, the surface-driven capillary flow of dyed water in sudden expansion microchannel is clearly recorded. Also, the water filled microchannel bends are captured by the CMOS camera as shown in Figure 3.

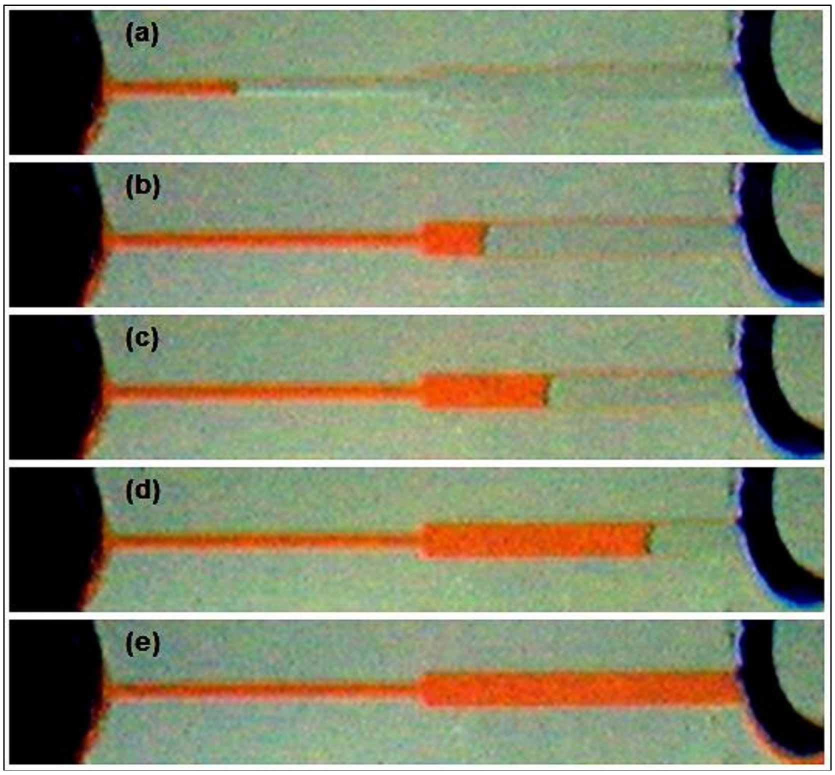

Fig. 2: *A Representative-group of Snapshot Images is Showing the Surface-driven Capillary Flow of Dyed Water in the Sudden Expansion Microchannel with Expansion Ratio of 1:4.*

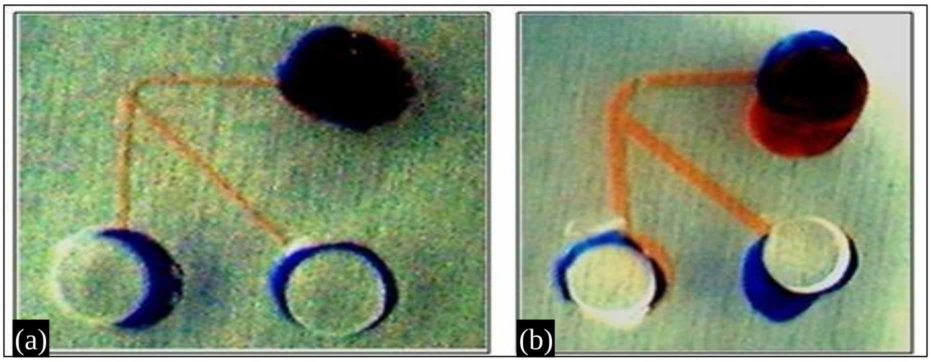

Fig. 3: *Image (a) Shows the Water Filled Microchannel Bend of 75 micron Channel Width. Image (b) Shows the Water Filled Microchannel bend of 400 micron Channel Width. In both of the Images, the Natural Wrinkles of Cleanroom Tissue Paper are Prominent According to the Adjusted Focus of the CMOS Camera.*

CONCLUSIONS

Total three individual PMMA microfluidic devices are fabricated by the maskless lithography, hot embossing lithography, direct bonding, and chip separation. The capillary filling of these devices by dyed water are recorded by CMOS camera. Completely leakage-free capillary flows are recorded in these three PMMA microfluidic devices. This work will be useful to fabricate the PMMA lab-on-a-chip systems for different microfluidic applications.

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