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Fabrication of Polymer Microfluidic Devices with 3D Microfeatures that have Near Optical Surface Quality

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Abstract – A low cost manufacturing method for creating polymer microfluidic devices with microfeatures that have near optical surface quality is described in this paper. The manufacturing method involves laser micromachining, partial hot embossing, and molding (LHEM) to create polymethylmethacrylate (PMMA) mold masters for device replication. A metallic hot intrusion mask with the desired microfeatures is first machined by laser and then used to produce the mold master by pressing the mask onto a PMMA substrate under applied heat and pressure. The resultant 3D micro-reliefs have near optical quality surface finishes. Design parameters such as the height and width of the extruded features are investigated in this study. The experimental results demonstrate that different heights of the extruded features of a mold master can be fabricated using a single mask at a set of process parameters. Examples of curved microchannels of the PMMA mold masters and an integrated microchannel/microlens of the mold master are presented to illustrate the proposed methodology.

Keywords – microfluidics; hot intrusion; micromold; microfeatures; surface quality

I. INTRODUCTION

Miniaturization of laboratory processes into a single total analysis system (μ TAS), Lab-on-a-chip (LOC), microfluidic devices, or analytical microsystems have been a topic of intensive research in recent years. Benefits of microsystems include increased speed of analysis, high level of system integration, portability, and lower operating cost due to small amount of reagents consumption. These devices are often disposable and used only once to avoid sample contamination. Practical methods for their mass production are therefore essential for cost-effective manufacturing and reducing the concept-to-market development cycle.

Recently, polymer-based microfluidic devices attract attention from both academia and industry due to its lower fabrication cost. A number of methods for mass production of these microfluidic devices have been explored in the past, such as hot embossing [1, 2], and microinjection molding [3, 4]. These methods require mold masters and those are usually costly to fabricate.

The well-known methods for fabrication of mold masters are the LIGA (lithography, galvanofforming and plastic molding) and soft-lithography techniques. The LIGA method produces high-resolution mold masters using X-ray lithography

to transfer microchannel patterns onto PMMA resist. The resulting PMMA microstructures are electroplated using nickel or nickel-based alloys (NiCo, NiFe). Then the metal master is released by dissolving the PMMA resists. The advantage of this method is that high aspect ratio masters can be produced, but its limitation is the high-cost of the process [5, 6]. Soft-lithography [7–12] is the most popular method for rapid mold master prototyping, where the masters are made from SU-8 photoresist and the fabrication method requires a number of steps to create the positive relief of mold masters [8].

Another rapid prototyping method was presented in [13] where mold masters were fabricated via laser cutting of microchannel features from a metallic sheet and then laser welded onto a metal substrate to form the mold masters. The advantage of this method is that it involves only a few fabrication steps.

Mold masters made by LIGA and soft-lithography methods are usually 2-1/2 D devices. For some applications, 3D micro-reliefs are desirable. Lee K. et al. [14] used the hydrophilic property of the uncured PDMS material to fabricate rounded microchannels for 3D serpentine mixer. Chen C. et al [15] used gray scaled photo-lithography method to fabricate 3D microstructures. Furthermore, the near optical grade surface finishes is a desirable property of microfeatures which increases resolution of optical detection of microfluidic devices such as micro capillary electrophoresis CE devices [16, 17]. The LHEM (Laser micromachining, partial Hot embossing, and Molding) method is a simple method that can be used to fabricate micromold masters with near optical surface quality and it involves laser micromachining and hot intrusion (partial hot embossing) process [18]. Furthermore, this method produces mold masters with non-rectangular microchannels.

In this paper, we report our efforts in using the LHEM method to fabricate 3D micro-reliefs with near optical surface finishes for microfluidic devices. The demonstration focused on the out-of-plane microchannel structure of a PMMA mold master.

The LHEM method is illustrated in Section 2. Section 3 describes the setup of experiments. Section 4 presents the experimental results and discusses the fabricated 3D microchannels. Concluding remarks are given in Section 5.

II. THE LHEM METHOD

The fabrication of the PMMA mold masters by the LHEM method involves only two major steps: a) fabrication of the hot intrusion mask by laser micromachining of the desired microchannel structure in a thin metallic sheet (cut through), and b) applying heat and pressure (hot intrusion process) onto the mask and the Poly(methylmethacrylate) PMMA substrate to form the mold master. This mold master is then used to mold PDMS (polydimethylsiloxane)-based microfluidic devices.

Fig. 1 illustrates formation of the micro-reliefs by the LHEM method. Fig. 2 shows an SEM view of typical micro-relief of the PMMA mold master of a Capillary Electrophoresis (CE) microfluidic devices fabricated by the LHEM method.

Key advantages of the LHEM method are its simplicity, cost-effectiveness, and near optical surface finish of the created micro-relief. These properties make the method an attractive option for both small and large batch fabrication applications.

Fig. 1 Rapid fabrication of micromold master by the hot intrusion process. The process forms contactless microreliefs.

Fig. 2. An SEM view of the Capillary Electrophoresis (CE) micromold master fabricated via LHEM method.

III. EXPERIMENTS

The objective of the experiments was to determine the relationship between the height (H) and width (W) of the extruded profile and how this H - W relationship can be utilized to fabricate out-of-plane microstructures. For that purpose a mask with various widths, from 25 to 200 μm , of microchannel features was fabricated and used to produce a number of mold masters under a chosen process parameters. The process parameters were fixed at 125 $^{\circ}\text{C}$ with 275 kPa (40 Psi), and time 10 minutes. The material was PMMA. The mask was laser micromachined using the AVIA UV laser from Coherent Inc., USA. The hot intrusion was conducted using the Multi-purpose Press from GEO Knight & Co. Inc.

Based on the experimental observation (see Section IV), a strong positive correlation between the height and width of the extruded profiles was determined. 3D features of the fabricated microstructures were also observed.

To evaluate the surface finish (average roughness, R_a) and the varying height of micro-reliefs of the PMMA master, we used the Wyko NT1100 optical profiling system from Veeco Instruments Inc., NY, USA.

IV. RESULTS AND DISCUSSION

Fig. 3 shows a strong positive correlation between the height and width of the profiles extruded under the chosen process parameters. The heights of the extruded profiles range from 10 to 65 μm and the relationship appears to be linear. The implication of this result is that we can fabricate different heights of microfeatures by choosing corresponding widths of features of the hot intrusion mask and thus fabricating 3D shapes of micromold master is possible. Figs. 4, 6, 8, 9, and 10 show examples of such 3D microstructures.

Fig. 4 shows a 3D microchannel that was formed by a mask with three connected circular holes. Fig. 5 shows the profile of the microchannel measured by optical profiler along its axis. Continuous varying heights of microstructure are clearly visible.

Fig. 6 shows another example of a 3D microchannel and its profile is shown Fig. 7. Fig. 8 shows a more complex microchannel with varying (3D) profile.

The surface finish quality in all examples was measured using Wyko optical profiler and the measurements were $R_a = 10$ to 40 nm. This means that the fabricated microchannels have walls with near optical quality finish.

Fig. 9 and 10 show two cases where the top of the microchannels were flattened when the softened material reaches the top press plate (see Fig. 1). This can be achieved by choosing appropriate process parameters and can be useful in some applications.

Fig. 3. The positive correlation between height and width of the extruded profiles at 125 °C ($T_g + 25$ °C), 275 kPa, and 10 mins.

Fig. 4. A microscopic view of the microfeatures of microlens/microchannel PMMA mold master.

Fig. 5. The measurement, taken by Wyko optical profiler, of the PMMA mold master shown in Fig. 4.

Fig. 6. A microscopic view of the microfeatures, 3D nozzle connected to a reservoir, fabricated from the LHEM method.

Fig. 7. The measurement, taken by Wyko optical profiler, of the 3D micronozzle feature of the PMMA mold master shown in Fig. 6.

Fig. 8. A microscopic view of a section of the 3D microchannel PMMA mold master.

Fig. 9. Two microscope views of microchannels of the master fabricated under different process conditions: a) applied a higher pressure, b) optimal pressure to produce near optical finishes.

Fig. 10. A microscopic view of a PMMA mold master had large flatted surface connected to three microchannels.

V. CONCLUSION

In this paper, the near optical quality of 3D microchannel features of PMMA mold masters were demonstrated using the LHEM method. The positive correlation between height and width of the extruded microreliefs was identified and appears to be linear. Using such relationship, we can fabricate various heights of 3D microchannel features of PMMA mold masters. However, the disadvantage of the LHEM method is that it only fabricates low aspect ratio of microfeatures.

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