Using epoxy resin to fabricate a master for microfluidic devices in poly(dimethylsiloxane)

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ABSTRACT

This paper presents a method for the fabrication of UV epoxy resin masters for the replication of PDMS-based microfluidic chips. The master is produced simply by exposing a layer of UV epoxy resin coated on a glass substrate. Fabrication of the master in UV epoxy resin is easy, and it reduces the time, complexity, and cost of prototyping manufacturing. The experimental results show that the epoxy resin masters enable the mass production of PDMS replicas with highly precise geometrical tolerances. The experimental results show that the epoxy resin masters enable the mass production of PDMS replicas with highly precise geometrical tolerances. A series of electrokinetic focusing experiments are performed using PDMS microchips of various configurations replicated from the current epoxy resin masters. The experimental results obtained for the width of the electrokinetically-focused sample stream under different focusing ratios are found to be in good agreement with the theoretical predictions. The sample handling characteristics of the microfluidic chips are also investigated. It is shown that the sample flow can be electrokinetically pre-focused into a narrow stream and then guided to the desired outlet port by applying a simple voltage control model.

Keywords: UV epoxy resin, Microfluidics, Poly(dimethylsiloxane), Electroosmotic flow

1 INTRODUCTION

A major aim of the microfluidics field is to develop low cost, disposable devices capable of replicating the performance of their large-scale counterparts. However, manufacturing microchips using conventional substrate materials such as glass, plastic or silicon is expensive since the fabrication process requires multiple photolithographic and etching steps [1, 2]. In addition, the manufacturing process lacks the flexibility to support rapid design changes during the microchip development stage. However, polymeric materials represent a viable low-cost alternative to these traditional substrate materials for the fabrication of microfluidic devices [3, 4] and supply a suitable alternative to glass or silicon as the substrate material for microfluidic devices because their surface chemistries can be tailored to suit the particular type of chemistry being performed in the current microfluidic device. Furthermore, a wide variety of polymeric materials are available, and hence their use as a substrate material enables the fabrication of microchips with a range of surface/material properties. Importantly, polymeric materials are compatible with a range of different fabrication techniques, including casting [5], embossing [6], injection molding [7] and laser ablation [8]. In some cases, a simple photolithography process is all that is required to create a single master which can then be used repeatedly to replicate a large number of polymeric devices.

The rapid prototyping and fabrication of microfluidic devices is particularly important in a research environment, in which it is frequently necessary to carry out multiple design, fabrication and testing cycles within a short period of time. Hot embossing techniques have attracted considerable interest as a means of imprinting a large number of structures of identical form and features in polymeric substrates using a single preformed master or tool. Therefore, this paper proposes two alterative methods for the fabrication of UV epoxy resin masters for the replication of PDMS (polydimethylsiloxane)-based microchips. In the first method, the master is produced from a negative glass template manufactured using a conventional lithography technique and a wet chemical etching process. However, in the second method, the master is produced simply by exposing a layer of UV epoxy resin coated on a glass substrate using a UV light source and a transparent patterned mask. The reproducibility characteristics of the two epoxy resin masters are investigated by replicating 30 PDMS structures. Finally, the flow focusing, flow switching and electrokinetic instability characteristics of PDMS microchips of various configurations fabricated using the current epoxy masters are investigated experimentally.

2 MATERIALS AND FABRICATION METHODS

2.1 Fabrication of positive epoxy resin master

UV epoxy resin has many favorable properties, including a high adhesion strength, a low electrical conductivity, high transparency, cationic polymerization reaction, and so forth. Due to the resin belong to cationic polymerization reaction, therefore the oxygen has no effect on the polymerization process, and hence vacuum conditions are not required. Figure 1 presents a schematic illustration of the basic fabrication procedures.

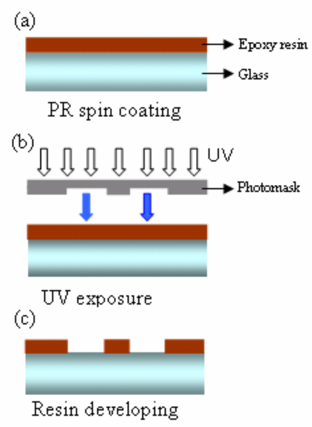


Figure 1: Fabrication of Epoxy resin master

The positive epoxy resin master was fabricated directly on a glass substrate using standard photolithography procedures. Having cleaned the glass substrate, a commercial plastic 1 ml syringe was used to coat the surface with a carefully controlled volume of UV epoxy resin. The coated substrate was then placed on a hot plate and heated at a temperature of $100^{\circ}C$ without ramping for 1 min to cause a self-planarization of the epoxy resin. The substrate was then removed from the hot plate and left to cool at room temperature for 10 min prior to UV exposure. UV lithography was performed using a conventional UV lamp and a high-resolution transparency photomask. Following the photolithography process, the exposed substrate was developed in an acetone solution. Finally, a UV lamp (365 nm) was used to prompt a cross-linking of the epoxy resin. In general, when developing a polymer material, the solubility characteristics of the developer solution can be improved by using a solvent with similar solubility characteristics to those of the polymer [9]. As shown, the solubility of acetone (9.77) is close to that of UV epoxy resin (10.90). Hence, an acetone solution was chosen to develop the exposed substrate in the current case.

2.2 Fabrication of PDMS microchips

Positive epoxy resin masters fabricated using the procedures outlined in Section 2.1 was used to manufacture PDMS-based microchips of various configurations. The PDMS was supplied in the form of a base material and a curing agent. The two components were mixed together in a ratio of 10:1 (v/v) (base:curing agent), prompting the silicon hydride in the curing agent to react with vinyl groups in the base material to form a cross-linked, elastomeric solid. A PDMS replica was produced from the UV epoxy resin master by placing the master in a Petri dish and then pouring the liquid pre-polymer solution over its surface such that the solution accurately replicated its features. The solution was then cured by placing the Petri dish on a hot plate. Significantly, the cured PDMS structure does not adhere to the master, and hence it can be easily separated without the need for a releasing agent. Finally, the PDMS structure was sealed with O_2 plasma.

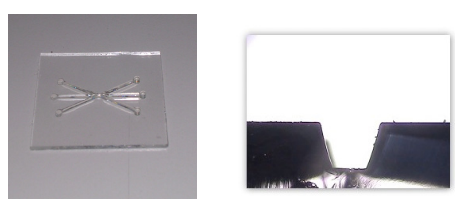
2.3 Detection system

During the experimental trials, the fluid sample manipulations within the microchip were observed by mercury lamp induced fluorescence using a charge-coupled device camera (CCD, model SSC-DC50A, Sony, Japan). The electrokinetic driving forces were generated using a computer-controlled high-voltage power supply. The experimental images were captured by an optical microscope (model Eclipse 50I, Nikon, Japan), filtered spectrally, and then measured by the CCD device.

3 RESULTS AND DISCUSSION

3.1 UV epoxy resin master

The masters produced in this study are fabricated using OPAS 825 (Taiwan) UV epoxy resin, which is characterized by a cationic polymerization reaction. As a result, the polymerization process is unaffected by the presence of oxygen and can therefore be performed under normal ambient conditions. The epoxy resin used in this study does not polymerize under visible light (400 nm ~ 740 nm), and hence the entire fabrication process is not need in yellow room of clean room environment. Accordingly, as described in Section 2.2, the positive epoxy resin master can be produced more rapidly, and with less expense, simply by using the epoxy resin directly as a negative photoresist layer. In this way, the entire fabrication process can be completed in a general laboratory environment; typically within 40 min. Figure 2(a) presents an optical image of the positive master consisting of epoxy resin patterned on a glass plate. Figure 2(b) shows the cross-section of the channel in the PDMS replica produced using this master.



(a) (b)

Figure 2: Optical images of: (a) original master consisting of epoxy resin patterned on glass substrate; and (b) cross-section of channel in PDMS replica.

To assess the reproducibility characteristics of the PDMS replication process, the channel widths of seven PDMS replicas were measured at equivalent locations and compared to the channel width of the epoxy resin master at the same location. The corresponding results are shown in Table 1 in the form of a width variation ratio. Note that in this table, rows 1 and 5 correspond to the first and 30th PDMS replicas produced from the same epoxy master, respectively, while the remaining rows relate to replicas chosen at random between these two replicas. The results demonstrate that the epoxy resin master enables the fabrication of replicas with a high-degree of dimensional precision. Furthermore, it can be inferred that the fabrication process used to produce the master results in good rigidity and robustness characteristics, i.e. no discernible degradation in the dimensional accuracy of the replicas is observed as the number of replications increases.

PDMS NO.	The variation ratio of width (%)[(a)]
1	2.5
2	0
3	0
4	2.5
5	2.5

W_e, W_p delineate the channel width of the same location on epoxy resin master and PDMS replica.

[(a)] The variation ratio represents $\frac{W_p - W_e}{W_e} \times 100\%$

Table 1: Dimensional accuracy of PDMS replica produced using epoxy resin master.

3.2 Sample focusing experiments.

Achieving the precise control of focused streams is a fundamental requirement in many microfluidic applications. It has been shown that the width of a focused cell stream can be reduced to the order of cell size. Furthermore, various researchers have presented microfluidic injection systems which enable the volume of the injected sample to be regulated by adjusting the width of the focused stream. Yang *et al* [10] applied potential flow theory to develop a theoretical flow focusing model in which the width of the electrokinetically-focused stream was expressed as a function of the focusing ratio.

In the current study, a cross-form PDMS device with an average channel width of 200 μm and a separation of 2 cm between the reservoirs at either end of the two channels was fabricated from the epoxy resin master and used in a flow focusing investigation based upon the flow focusing technique shown in Figure 3. Figure 4 compares the experimental and theoretical results obtained for the width of the electrokinetically-focused sample stream at various focusing ratios (ϕ_2 / ϕ_1). In this figure, the experimental data represent the average of three separate measurements and the error bars indicate the minimum/maximum values of each set of measurements. It is apparent that a good agreement exists between the two sets of results. Previously, Yang *et al.* (2005) reported that the normalized width of the focused stream has a value of d / D = 1 / 3 for a focusing ratio of ϕ_2 / ϕ_1 = 1.0. From an inspection of Figure 4, it is clear that the present experimental results are consistent with this prediction.

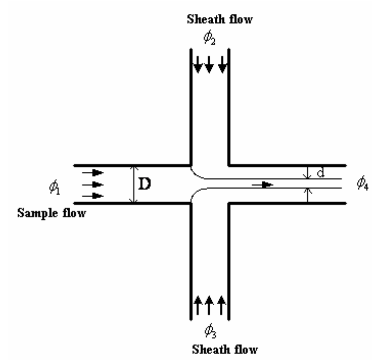


Figure 3: Schematic illustration of electrokinetic flow focusing technique.

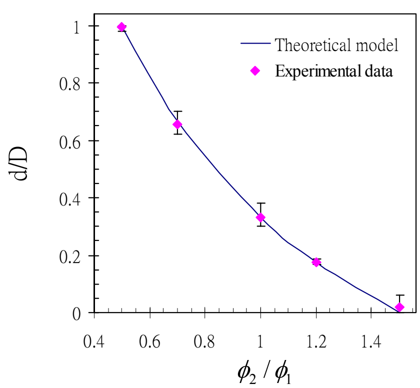


Figure 4: Comparison of experimental and theoretical results for relationship between width of electrokinetically-focused sample stream and focusing ratio (ϕ_2 / ϕ_1).

3.3 Sample flow switching experiments

When performing bio-analytical assays it is necessary to guide precise amounts of the sample fluid to a specified outlet port. In the microchips used to carry out such assays, the forces required to manipulate the sample flow are commonly generated electrokinetically. From electrokinetic theory, the driving force caused by the interaction between the net charge density and the applied electric field occurs only between the inlet ports and outlet channel. Figure 5(a) presents an optical image of a microchip produced using one of the current positive UV epoxy resin masters. Figures 5(b)-(d) illustrate the continuous injection of the sample stream into the three output ports of the microchip in a single electrical potential. In practice, the sample can be switched continuously between these ports by manipulating the potential conditions (i.e. isolated or grounded) of the various outlet channels (1, 2 and 3). The experimental images confirm that the replicated chip provides the continuous sample injection capability in a single electrical potential applied to each inlet ports (A, B and C).

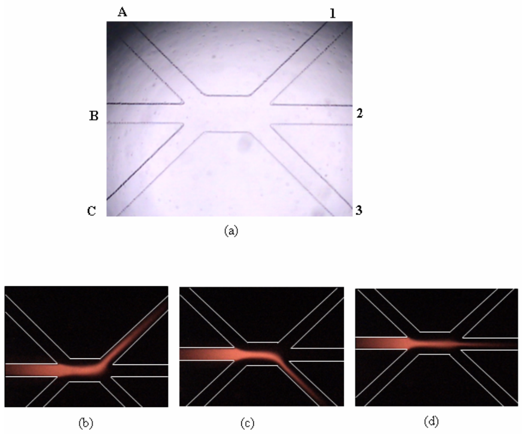


Figure 5: PDMS replica obtained from epoxy resin master, and experimental results for different flow injection modes in multiple sample continuous injection system.

4 CONCLUSIONS

This study has proposed a method for fabricating UV epoxy resin masters for the replication of PDMS microfluidic devices. The epoxy resin used in the current study (OPAS 825 (Taiwan)) does not polymerize under visible light, and hence fabricating positive epoxy resin master process is not need in yellow room of clean room, and therefore this study has proposed a cheaper and more rapid procedure for fabricating the positive epoxy resin master. In the proposed approach, epoxy resin is coated on a glass substrate and is used directly as a negative photoresist layer. Adopting this approach, the entire fabrication procedure can be completed within 40 min in a general laboratory environment.

Microfluidic devices of various configurations have been replicated from the positive UV epoxy resin masters. The microchips have been used in a series of flow focusing, and flow switching,. In general, the experimental results have demonstrated the successful operation of the microfluidic chips, and therefore confirm the feasibility of the proposed UV resin master fabrication processes.

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