3D MICROFABRICATION AND MIXING PHENOMENA IN MICROFLUIDICS

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ABSTRACT

Microfluidic devices are currently replacing their macroscopic counterparts in many applications. Controlling the mass transport in the microchannels mostly depends on material used and channel geometry is the key parameter to improve flows speed, reaction sensitivity and surface robustness. As the flow type in the microfluidic channels is laminar, micro-mixers have been using to provide semi-turbulent flow inside the microchannels. In this study, microfluidic molds were fabricated by using 3D printing method and mixing phenomena was observed in different microplatforms with and without micro-mixer geometries to understand the underlying diffusion mechanism, which causes to mixing phenomena in the microchannel.

Keywords: microfluidics, diffusion, micromixer

INTRODUCTION

Microfluidic technology has high potential for developing different applications in medical diagnostics and therapeutic devices as well as in chemical and biological analyzes. Due to its miniature dimensions, it is also open to use in parallel with shorter process times and lab-on-chip technology with a small amount of reactive volume. Among the fabrication methods such as injection molding, chemical etching, reactive ion etching, molding, embossing and engraving techniques, photolithography is the most popular method for producing microplatforms (Bhatia & Ingber, 2014). Yet, though this method is used extensively, it is a costly technique and necessitates organic solvents. Besides, following photolithography, it is necessary to apply an oxygen plasma treatment to build hydrophilic areas. Material selection, available equipment, cost and operating time are factors to determine the production method (McCreedy, 2000). Materials such as glass, metal, elastomer, silicone, polydimethylsiloxane (PDMS), polymethylmethacrylate (PMMA), polycarbonate (PC) and teflon are used in the fabrication of microfluidic devices. As polydimethylsiloxane PDMS is relatively inexpensive and easily manipulatable, it is the most applicable material in production of microfluidic devices (Ren, Chen, & Wu, 2014; Shallan, Smejkal, Corban, Guijt, & Breadmore, 2014). Recently, 3D printer has been considered as another production method for microfluidics. As minimum fabrication skills and materials are required in this method, it overcomes the problem of costly equipment of photolithography. It has been shown that it is possible to produce microfluidic systems without needing any clean room conditions and hazardous chemicals by using polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS) polymers as a source for 3D printing (Erkal et al., 2014; Saggiomo & Velders, 2015; Shallan et al., 2014). The fact that the flow type in the microfluidic channels is laminar makes micro-mixers designs more innovative than the other microplatform members. All micro-mixers have a working principle based on laminar regime and diffusion. The main objective in current micro-mixer designs is to simulate semi-turbulent flow and develop micro-mixers in accordance with diffusion and/or advection applications. In this study, circular shaped microfluidic molds were fabricated by using 3D printing to understand the underlying diffusion mechanism which causes mixing phenomena inside the microchannel.

METHODS

The design of the microchannels to be fabricated by the desktop 3D printer was created with the SolidWorks 2016 Education Edition design program. The spiral shaped platform was designed to have a rotation number of 5 and the width, height and length were 0.4 mm, 0.92 mm, 270 mm, respectively. Operation volume was approximately 100 microliters (Akay et al., 2017).

0.3 µm nozzle was used to extrude ABS polymer. Nozzle temperature was set to 230 °C and bed was heated to 80 °C. Then the desired 3D mold was produced with the help of Prusa i3 3D Printer. Produced ABS mold was then immersed in well-mixed uncured PDMS solution which was prepared at the rate of 10:1 sylgard 184/sylgard 184 curing agent. Then, vacuum was applied to the mixture to remove air bubbles and bubble-free mixture was heated to be cured for 1.5 hours at 80 °C. The cured PDMS was then left for 24 hours in acetone. Finally, to enhance cleaning efficiency, microchannels was filled and cleaned with the help of acetone filled syringes (Figure 1).

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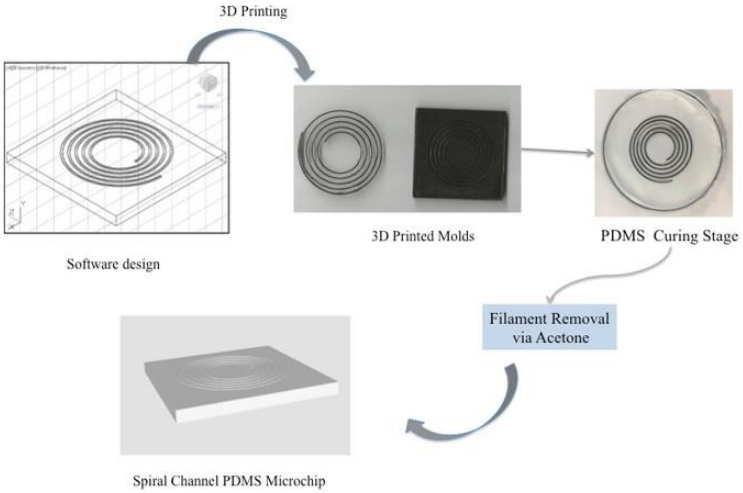

Figure 1. PDMS microplatform production by using 3D printed mold.

SolidWorks 2016 Education Edition software was also used for flow experiments in the microchannel which has two separated inlets. To observe diffusion phenomena inside the channel, aspartate aminostransferase (AST) enzyme, an indicator of liver diseases, was selected. Substrate solution was prepared with L-Aspartate, 2-ketoglutarate, pyridoxal-5'-phosphate and NADH. Distilled water was used to dissolve all substrates, whereas bovine serum albumin (BSA) for AST enzyme.

FINDINGS

Known amount of enzyme was introduced for the reaction and the results were calculated by using following formula;

- $\Delta A/min = \varepsilon l (\Delta C/min)$

It was observed that enzymatic reaction results were similar with enzymes actual levels (Table 1).

Table 1. Actual activity levels and corresponding model estimates of AST.

Actual AST Level ($IU.L^{-1}$)	**Absorbance Model Estimate ($IU.L^{-1}$)**	**$\Delta A.min^{-1}$**
15	16.07	0.010
25	20.90	0.013
49	53.05	0.033
83	80.39	0.050
98	109.32	0.068

According to the simulation results, mixing phenomena was occurred in the spiral shape channel without any help of additional mixer geometry (Figure 2). Enzyme and substrate solutions were loaded simultaneously (Figure 2A) and in a few second, substrate started to diffuse into the enzyme solution. (Figure 2B and Figure 2 C).

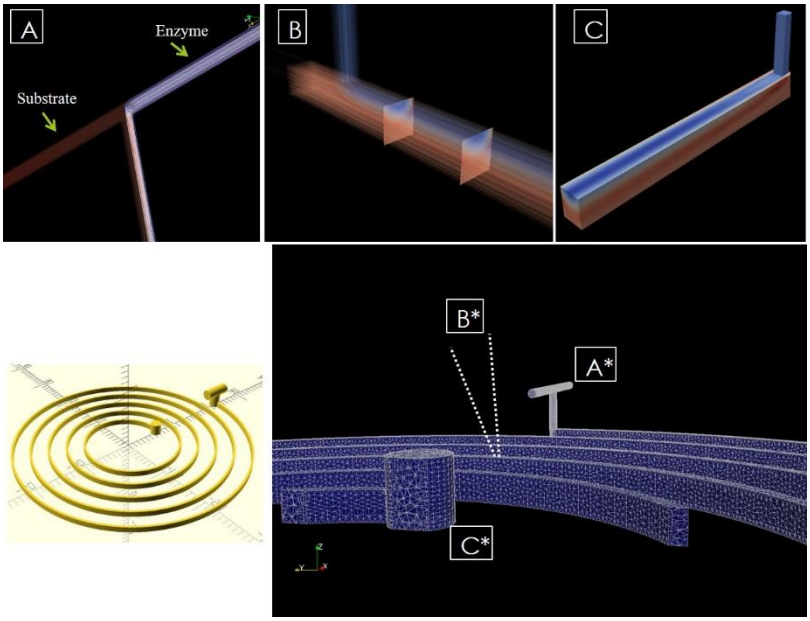

Figure 2. Diffusion phenomena inside the microchannel.

CONCLUSIONS

Recent studies show that developing a cost-effective platform for life science applications is a necessity. 3D printing, as a valuable method for microfabrication, has already started to be used in microfluidics. This study shows that it is possible to use 3D printing for microfabrication instead of costly methods such as photolithography, for diagnostic purposes. Moreover, using 3D printing would provide more cost-effective alternative for polymer and paper-based combined microplatforms.

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