Microfabrication of bifurcated microchannels with PDMS and ABS

Milena Rašljić, Ivana I. Gađanski, Milče M. Smiljanić, Novica Z. Janković, Žarko Lazić, Katarina Cvetanović Zobenica

Abstract— This paper describes fabrication technique for building three-dimensional (3D) microstructures in polydimethyl siloxsane (PDMS) elastomer using sacrificial microstructure of acrylonitrile butadiene styrene (ABS). 3D microstructure of ABS was made by Ultimaker 2 and Printrbot Simple printer. ABS microstructure was immersed in liquid PDMS and after curing, ABS was dissolved using solvent acetone. Also we performed well-known smoothing techniques for ABS macrostructures to achieve better optical visibility.

***Keywords*—microfabrication, microfluidics, 3D printing, ABS, PDMS**

I. Introduction

In recent years, the microfluidic devices are largely used in chemistry, physics, biology, biomedical research, tissue engineering [1 – 8]. Advantage of these devices is a small consumption of solutions in reactions or biological specimens (liquids) that should be observed. In this way, we can get a better understanding of various processes and effects. Also consumption of small amount of expensive solutions allows considerable savings.

The main idea in microfabrication is to produce cheap and, if possible, a disposable microdevice. Microfluidic devices are fabricated using various technological processes developed for sensors and actuators [2]. The most known are the ones made by anodic bonding of micromachined silicon and Pyrex glass [7]. New types of microfluidic structures are fabricated using recently developed technique [8] based on curing of polydimethyl siloxsane (PDMS) and sacrificial dissolution of a template produced by FDM 3D printing with acrylonitrile butadiene styrene (ABS).

PDMS is a low-cost material. The main advantages of PDMS are its optical properties. PDMS is transparent from 230 to 700 nm wavelength and has a refractive index of 1.4, close to the one of glass [9]. It is impermeable to water, nontoxic to cells and permeable to some gases (O_2, CO_2 etc.) which is very useful for majority of biological applications [9]. Also, it is elastic, so it can be used for making micro pumps and valves as parts of the microfluidic devices [10]. But its best quality is that it can be fabricated and moulded by easy technological processes. In the previous years, fabrication of microfluidic devices with 3D channels using PDMS was very difficult because multiple layers of PDMS had to be fabricated to achieve 3D structures. 3D mirochannels in PDMS were fabricated using the previously made molds [2]. Recently, 3D FDM printing has been used for sacrificial structures for PDMS devices [8].

ABS is a thermoplastic that is frequently used as a filament in FDM (fused deposition modeling) 3D printing [11-12]. As a thermoplastic, it has the characteristics of becoming soft and moldable when heated and then returning to a solid state when cooled again. The majority of commercially available desktop 3D printers perform technique known as fused deposition modeling, whereby a solid thermoplastic filament is forced through a computer-driven extrusion nozzle. In the Cartesian XY hotend, Z baseplate printers, as the Ultimaker 2 and Printrbot Simple we have tested, the heated nozzle (hotend) melts the thermoplastic, moves in XY coordinates and deposits line with determined diameter on a baseplate. As the material hardens the hotend moves to the next layer to form a three-dimensional solid shape [12]. ABS is a polymer which contains three monomer units: Acrylonitrile, Butadiene and Styrene. ABS grades ranges from 15-30% acrylonitrile, 5-30% butadiene and 40-60% styrene. The melting temperature of ABS filament is from 180 to 260 °C.

In this paper we fabricated bifurcated microchannels using modified technique described by Saggiomo and Velders [8] based on curing of PDMS and sacrificial dissolution of ABS. As a main solvent for ABS we used acetone. Acetone swelling ratio for PDMS is as low as 1.06 [13]. Also we examined well-known smoothing techniques for ABS macrostructures to obtain microchannels with as little grooves as possible, since these could influence the fluid flow. Smooth

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microchannel cavity also provides better optical visibility of the microparticles in fluids injected through the fabricated microchannels.

II. EXPERIMENT

Technique for building microchannels in PDMS using sacrificial 3D microstructure of ABS was performed in two steps. First, ABS sacrificial microstructure was 3D printed by Ultimaker 2 and Printrbot Simple. The example of ABS sacrificial microstructure is shown in Fig. 1. Diameter of the ABS line is about 400 µm. Sacrificial structure was immersed in liquid PDMS, as shown in Fig. 2.

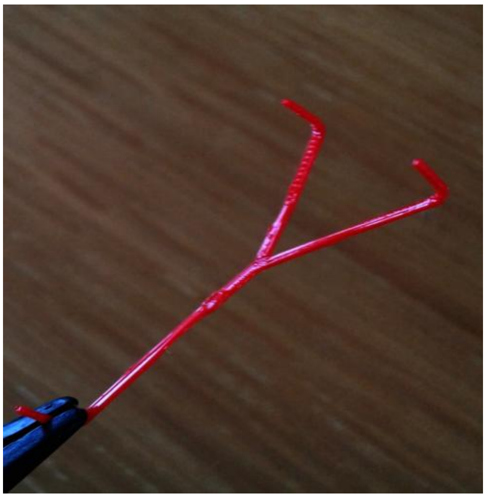

Figure 1. Example of red ABS bifurcated microstructure.

We used Dow Corning Sylgard 184 Silicone Elastomer Clear as two component 10:1 mix ratio. After polymerization of PDMS at the room temperature for 24h ABS was dissolved in acetone for 12h, also at the room temperature. After dissolution of ABS, microchannels were rinsed with acetone and distilled water and then dried with a flow of compressed air. As a result, we have gotten the bifurcated microchannels in a single block of PDMS, as shown in Fig. 3 and 4. Diameter of the channels is about 400 µm. The red food color was used to show flow of fluid through the microchannels.

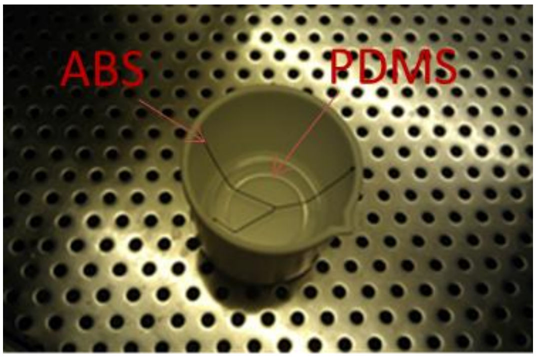

Figure 2. Blue ABS 3D microstructure immersed in liquid PDMS.

Disadvantage of this technique is a rough surface of ABS microstructure obtained by 3D printing [14]. PDMS has ability to map surface on which it aligns. In our case roughness of ABS surface is mapped to surface of the fabricated cavity in PDMS. This effect can affect a visibility of microparticles in fluids in fabricated microchannels which is very important for various microfluidic topics [6, 15]. Effect of low visibility of microparticles was not noticed by authors [8]. However, as it can be seen in Fig. 3 and 4, fluid in microchannels flow freely despite roughness of microchannels' surface.

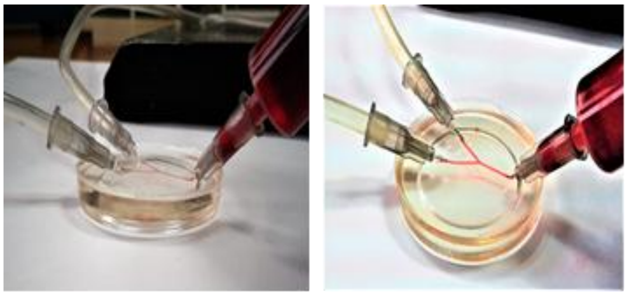

Figure 3. Microfluidic device made as the bifurcated microchannels. Photograph of lateral side of PDMS block.

We performed well-known smoothing techniques for ABS macrostructures to achieve better optical visibility. We examined if it is possible to apply these techniques to the ABS micro lines. The main goal was to achieve microchannels with smooth surface.

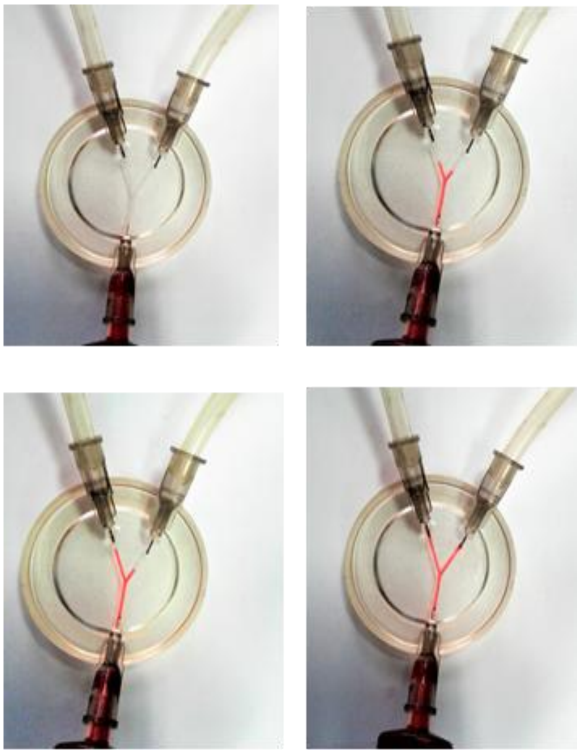

Figure 4. Microfluidic device made as the bifurcated microchannels. Diameter of the channels is about 400 µm. The red food color was used to show flow of fluid trough the microchannels.

Roughness of the ABS and microchannel surfaces were observed by optical microscope (″Carle Zeiss″, Epival – Interphako, Jena, Germany).

In the first experiment, we used concentrated acetone to make smooth surface of ABS. We put ABS microstructure for 20s in concentrated acetone. After that time roughness was still noticeable and microstructure of ABS lost its primary shape. In the second experiment, we used diluted acetone (50% distilled water solution). ABS was kept in that solution for 10 minutes and the result was not satisfying. The diameter of the ABS microstructure increased and the roughness was still noticeable.

In the third experiment, we used temperature to smooth out surface. 3D printer's nozzles melt ABS filament applying temperature from 180 to 260°C. ABS microstructures were put in oven on 200°C and 100°C for 30 and 5 minutes, respectively. Surface of the ABS microstructure was not so rough anymore, but 3D shape was completely distorted. Another two microstructures of ABS were immersed in PDMS in our fourth experiment. They were also put in oven on 200°C and 100°C for 30 and 5 minutes, respectively. After polymerization of PDMS we again used acetone for dissolving ABS microstructure. Result was the same for the both microstructures, shape was not distorted, but roughness of the microchannels was still on surface.

In the last experiment, we used acetone vapor to make smooth surface of ABS, as shown in Fig. 5. Acetone evaporates on room temperature very easily. ABS bifurcated microchannel was put in the closed box with acetone vapor for 10 minutes at the room temperature. After 10 minutes, we obtained smooth surface of ABS and shape did not change.

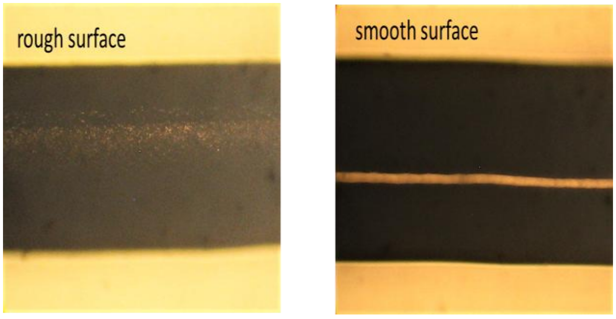

Figure 5. Rough and smooth surface of ABS line before and after treatment with acetone vapor.

But when we immersed ABS in PDMS and heated in oven on 100°C for 5 min, microstructure has lost his primary shape, as shown in Fig. 6. This is probably because of acetone which remained in ABS. We noticed that this technique gives the best results for smoothing of ABS surface. The further development of this technique will be our next work.

III. Conclusion

This paper describes fabrication technique for building microchannels in PDMS using sacrificial 3D microstructure of ABS. We have fabricated bifurcated microchannels and shown performance of this microfluidic device. We noticed that roughness of ABS surface is transferred on the surface of the fabricated cavity in PDMS. We examine several techniques which were used for smoothing 3D ABS macrostructures. We did not obtain satisfying smooth surface of the ABS and microchannels. Technique using acetone vapor gives the best results for smoothing of ABS surface. In our future work, we will further develop this technique.

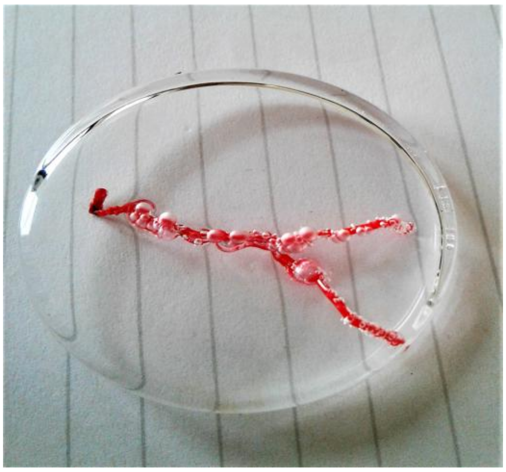

Figure 6. Distorted red ABS microstructure with residues of acetone after 5min at the temperature of 100°C in oven.

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References

[1] L.-H. Hung and A. P. Lee, "Microfluidic devices for the synthesis of nanoparticles and biomaterials," *Journal of Medical and Biological Engineering*, vol. 27, p. 1, 2007.

[2] B. Ziaie, A. Baldi, M. Lei, Y. Gu, and R. A. Siegel, "Hard and soft micromachining for BioMEMS: review of techniques and examples of applications in microfluidics and drug delivery," *Advanced Drug Delivery Reviews*, vol. 56, pp. 145-172, 2/10/ 2004.

[3] D. Erickson and D. Li, "Integrated microfluidic devices," *Analytica Chimica Acta*, vol. 507, pp. 11-26, 4/1/ 2004.

[4] S. M. Kim, S. H. Lee, and K. Y. Suh, "Cell research with physically modified microfluidic channels: A review," *Lab on a Chip,* vol. 8, pp. 1015-1023, 2008.

[5] H. Andersson and A. van den Berg, "Microfluidic devices for cellomics: a review," *Sensors and Actuators B: Chemical,* vol. 92, pp. 315-325, 7/15/ 2003.

[6] P. Sajeesh and A. K. Sen, "Particle separation and sorting in microfluidic devices: a review," *Microfluidics and Nanofluidics,* vol. 17, pp. 1-52, 2014.

[7] E. Y. Erdem, "Microfluidic Reactors for the Controlled Synthesis of Monodisperse Nanoparticles," Ph.D. dissertation, Mechanical Engeneering, University of California, Berkeley, USA, 2013.

[8] V. Saggiomo and A. H. Velders, "Simple 3D Printed Scaffold-Removal Method for the Fabrication of Intricate Microfluidic Devices," *Advanced Science,* vol. 2, pp. 1500125-n/a, 2015.

[9] S. K. Sia and G. M. Whitesides, "Microfluidic devices fabricated in poly(dimethylsiloxane) for biological studies," *Electrophoresis,* vol. 24, pp. 3563-76, Nov 2003.

[10] W. H. Grover, A. M. Skelley, C. N. Liu, E. T. Lagally, and R. A. Mathies, "Monolithic membrane valves and diaphragm pumps for practical large-scale integration into glass microfluidic devices," *Sensors and Actuators B: Chemical,* vol. 89, pp. 315-323, 4/1/ 2003.

[11] B. M. Tymrak, M. Kreiger, and J. M. Pearce, "Mechanical properties of components fabricated with open-source 3-D printers under realistic environmental conditions," *Materials & Design,* vol. 58, pp. 242-246, 6// 2014.

[12] A. Tojeira, S. S. Biscaia, T. Q. Viana, I. S. Sousa, and G. R. Mitchell, "Controlling Morphology in 3D Printing," in *Controlling the Morphology of Polymers: Multiple Scales of Structure and Processing*, G. R. Mitchell and A. Tojeira, Eds., ed Cham: Springer International Publishing, 2016, pp. 181-207.

[13] J. N. Lee, C. Park, and G. M. Whitesides, "Solvent Compatibility of Poly(dimethylsiloxane)-Based Microfluidic Devices," *Analytical Chemistry,* vol. 75, pp. 6544-6554, 2003/12/01 2003.

[14] A. R. Torrado Perez, D. A. Roberson, and R. B. Wicker, "Fracture Surface Analysis of 3D-Printed Tensile Specimens of Novel ABS-Based Materials," *Journal of Failure Analysis and Prevention,* vol. 14, pp. 343-353, 2014.

[15] B. Kuswandi, Nuriman, J. Huskens, and W. Verboom, "Optical sensing systems for microfluidic devices: A review," *Analytica Chimica Acta,* vol. 601, pp. 141-155, 10/10/ 2007.