

Design and Fabrication of Polydimethylsiloxane Based Low Cost Microfluidic for Ultra-Fast Diagnostic Applications

S. R. Balakrishnan^{*1,2}, U. Hashim², M. Sahrim¹, I. Ismail¹, J. Jamaludin¹,
W.Z.W. Ismail¹, V. Perumal³, R. Haarindradas⁴, S. Mahalingam⁵

¹Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia (USIM), Bandar Baru Nilai, 71800, Nilai, Negeri Sembilan, Malaysia.

²Institute of Nano Electronic Engineering, University Malaysia Perlis (UniMAP), 01000 Kangar, Perlis, Malaysia.

³Centre of Innovative Nanostructure & Nanodevices, Universiti, Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia.

⁴Faculty of Applied Science, Department of biotechnology, AIMST University, Jalan Bedong-Semeling, 08100, Bedong, Kedah

⁵Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia.

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Abstract: Diagnostic tools such as Point-of-Care (POC) analysis usually requires an on-site testing and measurements. Hence, to ease the fluid sample handling, microfluidics technology has been opted frequently to be incorporated with lab-on-chip (LOC). Therefore, an easy and conventional method of design and fabrication of the microfluidic device implemented. In this study, the device is fabricated with Polydimethylsiloxane (PDMS) and SU-8 using soft lithography technique. Herein, we focus on fluid transportation which is applied in clinical diagnostics and the transfer rate to the desired position as well as the fluid leakage during the transportation. Hence, the microfluidic sample transport channeling provides a practical solution for POC technological advances to study the biological systems that yield a better result in quantitative measurements and providing researchers new tools for life science research.

Keywords: Lab-on-Chip, Microfluidic, PDMS, SU-8, Point-of-Care.

1. Introduction

The domain of microfluidics technology is the backbone of wide variety of embodiments and applications which has conquered the field of biotechnology and engineering. For that reason, the inspiration of its use in biomedical and life science research can be focused into two areas [1–3]. One of the reason is the size of the device itself is getting small which is the current trend in engineering. While another key inspiration point is the use of the small sized device that makes it ideal platform for portable and point-of-care diagnostic devices. In spite being small, microfluidic devices are easy to use, cheap to fabricate and operate, require very little sample, and they can be easily disposed. For these reasons, the handheld diagnostic device has been recognized as a potential killer application of microfluidic and is the inspiration for much of the research effort in microfluidic technology development.

Advancements in microfluidic technology has realized the advantage of Lab-on-Chip (LOC) systems for analyzing small samples sizes to achieve the complex laboratory functions in biological applications [4]. Recently, considerable attention has been paid to point-of-care (POC) diagnostic which can be performed at the

bedside or in the clinic [2], [5], [6]. The realization of POC requires not only fast, sensitive and selective detection, but also small, cheap and integrated device [7]. The used method is known as in vitro diagnostic (IVD), which does not involve the use of laboratory staff and facility to provide the result. Besides, advancements in microchip fabrication technology provides convenience in integrating IVD to transmit results wirelessly, which could connect the patient and medicals in distance. As the result, these miniature LOC devices that made portable as POC diagnostic tools are currently dominating the pharmaceutical and health care market. This point has been made clear by the Global Industry Analysts (GIA), that by the year 2015, US\$12 billion revenue is generated by POC industry [8]. With that, application of nanotechnology, promises fast, ultra-high sensitive method to measure signal transduced from biological elements [9]. These devices are capable of analyzing the activity of biological systems which can be applied in many areas such as disease detection [10], clinical diagnosis, environmental quality monitoring [11] and food processing [12].

Up to now, several methods have been demonstrated for the fabrication of microfluidic, including polydimethylsiloxane (PDMS) [13], SU-8 [14], polymethylmethacrylate (PMMA) [15], waveguide pattern

[16] and paper based [17]. PDMS and PMMA are often the best choices to fabricate microfluidic devices since it is cheap to construct, easy handling, non-toxicity, disposable because of its polymerization characteristics and multifunctional instead of glass and quartz based microfluidic [18]. Paper based microfluidic devices are also commonly used and extensively investigated in numerous studies [17]. Then, waveguide based microfluidic devices more likely to have disadvantages too, which the transmission of signals could be affected based on the waveguide shape [19].

Using PDMS and SU-8 (negative photoresist) is the most known procedure in fabrication of different microfluidic which known as soft lithography method. SU-8 typically used because of its high aspect ratio employs as a master for molding and the PDMS accounts as a molding material that should be cured after pouring on the master [10]. High-aspect-ratio SU-8 molds for the fabrication of PDMS based microfluidic devices has been reported in numerous researches [20]. Devices fabricated from PDMS have proved to be more versatile and popular in many analytical applications [21]. Hydrophobicity of a surface is critical for protein attachment in the device [22]. The manipulation of surface properties ranging from hydrophobic to hydrophilic, charged or uncharged, smooth to rough, are important in defining biocompatibility [21]. In this paper we present a simple and inexpensive method to fabricate microfluidic based microchannels on oxide grown silicon wafer in order to achieve smooth and deep microchannels [23]. By using PDMS and SU-8 cast and peel method, the proposed design is fabricated under cleanroom environment. This covers the preliminary study to develop LOC device that practices microfluidic based fluid transport. In addition, the fluid flow and leakage is also analyzed by dropping aqueous solution into the inlet of the channel.

2. Experimental Setup

2.1. Material, Design and Specifications

The disposable PDMS based microfluidic module, which is the upper part of the LOC device, is first designed using AutoCAD software tool. It is a convenient tool for low cost mask design which is readable by multiple translators and able to convert it into industry standard mask making formats. The design of the microfluidic module is idealized based on fluid separation concept as in Figure 1(a); therefore, the final design made up of an inlet for fluid flow through a channel which eventually separated into three individual channels that lead to outlets. The designed microfluidic module is sent for outsourced chrome mask fabrication. Once the mask is prepared as in Figure 1(b)-(c), it can produce 20 individual die modules in a single 100 mm silicon wafer. From the specification illustrated in Figure 2, the microfluidic has an inlet and three outlets for fluid flow through each channel. The length is 12 mm and the width is 20.21 mm which makes it smaller than thumb size. Further, the radius of the inlet is 1.58 mm, which is suitable for a drop of sample. The fluid outlets are much smaller than the inlet at 1.31 mm

radius. Whereas, the dimensions of the microfluidic arc length measured at 6.31 mm outwards and 5.47 mm inwards. To ensure the capillary effect is enhanced the channel width were designed at 0.5 mm for a fast fluid transport to the biochip.

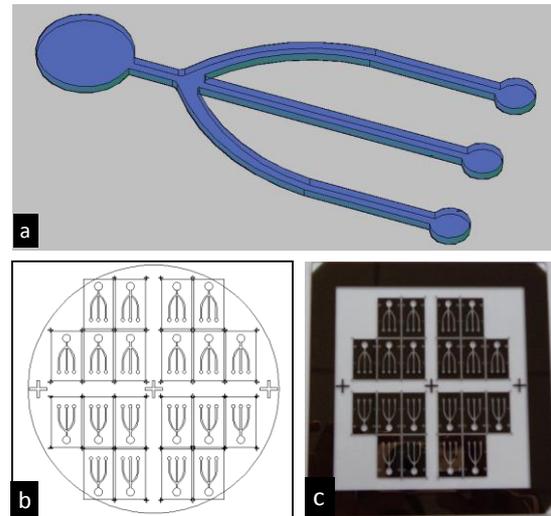


Fig. 1: The mask design and specifications of the microfluidic; (a) The designed microfluidic channels in AutoCAD. (b) Schematic design of microfluidic mask (c) The fabricated chrome mask design.

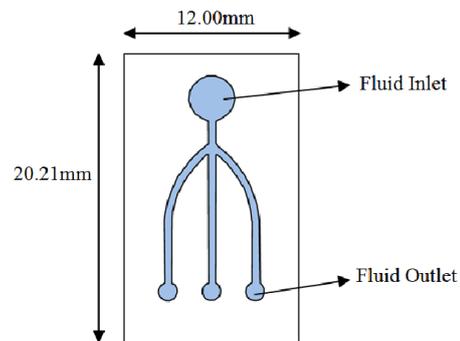


Fig. 2: Design and specifications of the microfluidic.

2.2. Soft Lithography Fabrication

The process flow of fabricating the SU-8 microstructure is briefly illustrated in Figure 3. The SiO₂ grown wafer substrate is first cleaned in acetone and DI water. Then, the negative photoresist of SU-8 (MicroChem, USA) is spin-coated onto the substrate to form 300 μm thick layer. It is then followed by soft-bake at 65°C for 10 min and at 95°C for 30 min. A conventional lithography process of exposure dose of 600 mJ cm⁻² is performed followed by a post-exposure bake process at 65°C for 3 min and at 95°C for 10 min. As the finishing step, the exposed resist is developed and cured which results a microstructured SU-8 casting module template as in Figure 5 (a). In Figure 4, the process steps for PDMS moulding is shown. A mixture in specific ratio (10:1) of silicone elastomer and elastomer curing agent (Sil-More

Industrial Ltd, USA Sylgard 184A and Sylgard 184B) is poured onto the SU-8 microstructure mold. The moulding is then cured at 70°C overnight and then finally cut and peeled off as seen in Figure 5 (b)-(c).

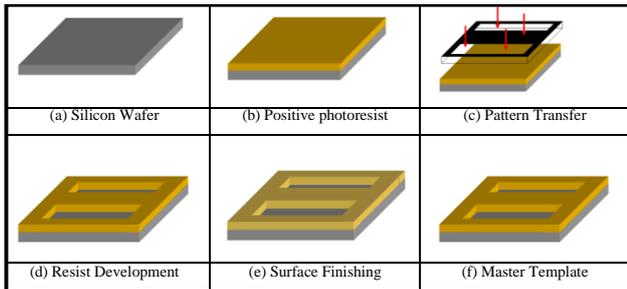


Fig. 3: Master Template Fabrication process flow.

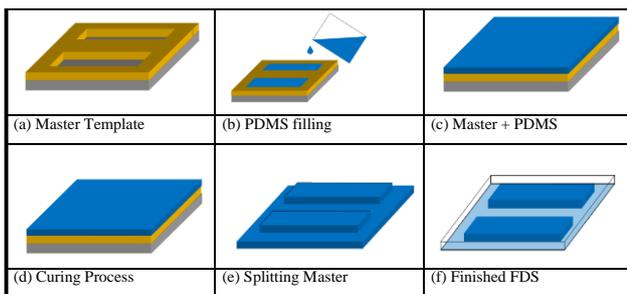


Fig. 4: PDMS microfluidic layer moulding process flow.

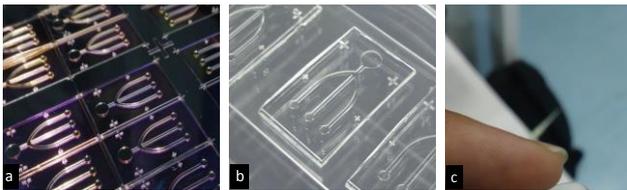


Fig. 5: PDMS layer moulding process flow. (a) The fabricated SU-8 microstructure template. (b) The moulded PDMS layer with master template. (c) The size and elasticity of the PDMS based microfluidic.

3. Result and Discussions

3.1. Fluidic Channel Fabrication

In the microfluidic fabrication method presented here, the fabrication quality was analysed based on the resist development process by using high power microscope as shown in Figure 6. From the observation, the SU-8 resist microstructure profile is clearly shows the difference in resist development. Figure 6 (a) shows an underdeveloped profile and partially developed profile in Figure 6 (b), (c) and (e) which is the undesired results. This non-developed profiles might be due to low etching time and this would further cause imperfection in the microfluidic channel depth. Whereas, the resist profile in Figure 6 (d)-(f) shows fully developed structure that occur due to the correct etching time and thus, yields a suitable surface for PDMS moulding. Hence, the PDMS layer that is filled in SU-8 mould, could be easily removed after the curing process.

This is due to the low surface energy characteristics of the PDMS which is realized by controlling the curing time. Besides that, the resulting shape of the microfluidic layer agrees well with the SU-8 mould that has been hardened to realize the shape. Here, the process parameters that applied is at 30 min curing under 65°C.

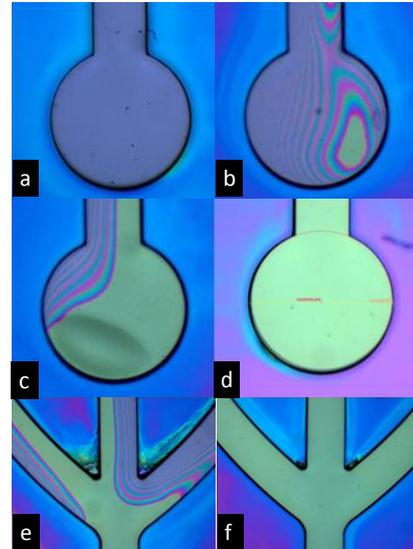


Fig. 6: The master template soft-lithography fabrication process flow. An underdeveloped (a), partially developed (b, c and e) and fully developed (d and f) SU-8 microstructure.

3.2. Microfluidic Channel and Flow Analysis

The inspection of the PDMS microfluidic device were also carried out morphologically to observe the channel depth and irregularities. Figure 7 (a)-(b) shows the channel depth and width inspected with high power microscope. The channel depth is measured at 300 μm . With this small depth of the connecting microchannel and since PDMS is a good elastomer, it is very easy to seal this microchannel during the bonding step by applying proper pressure onto this region. Figure 7 (c)-(d) depicts the leakage test after (c) and before (d) plasma bonding. It is noticed that before bonding the fluid has undergo leakage when mounted onto a glass slide. The bonding causes the PDMS microfluidic layer to bond firmly on the glass slide, and further reducing the hydrophobicity characteristics which causes leaking. For a better result, adhesive based or liquid PDMS pre-polymer could be applied to all the side ends of the bonded device followed by sufficient curing (UV and/or thermal curing) for better hermetic seal. Due to its high hydrophobicity, PDMS absorbs some organic solvents and some hydrophobic analytes, causing fouling of the material. These disadvantages greatly limit the variety of analytes that can be separated on PDMS devices, and generally results in relatively lower separation efficiency [18]. The fluid flow rate into the microfluidic channels were also studied as shown in Figure 8. Small sized holes were punctured through the inlet and outlets to make sure fluid flow in uninterrupted. In Figure 8 it is

observed that the fluid takes less than 1 second to reach the outlet and this further shows the fabricated microfluidics functions as desired and fluid flow based on the capillary effect which does not require further pressure to flow the liquid. Since, the research does not involve any surface modification on microchannels and fabricated under micro-scale technology, the usage of PDMS is an outstanding choice for disposable devices.

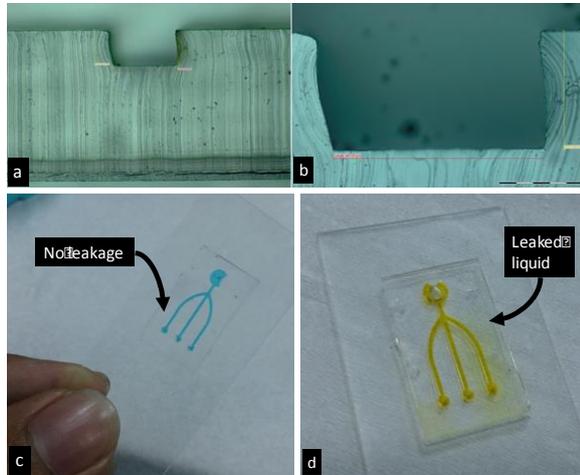


Fig. 7: Morphological channel depth and leakage analysis of the microfluidic.

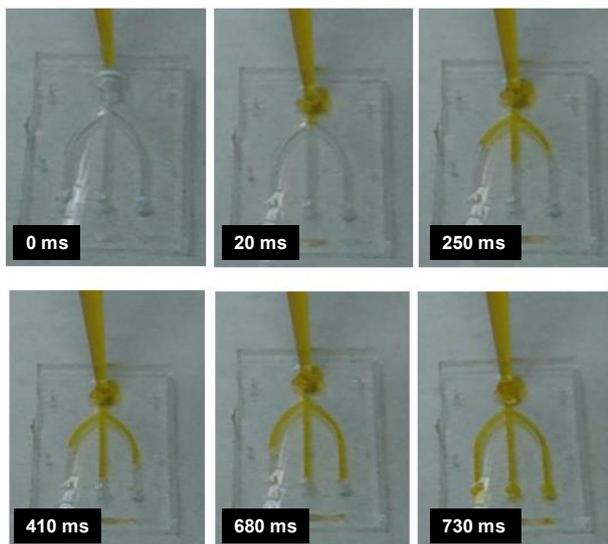


Fig. 8: Fluid flow analysis using coloured water to test the leakage and flow. A liquid reservoir is attached to the inlet to allow the fluid flow.

Conclusion

The microfluidic design and fabrication analysis allowed us to choose dimensions and materials for the microstructure fabrication. Microfluidic devices using this fabrication approach must therefore be careful to assure that the desired operation matches the real functionality of the device. Since, SU-8 and PDMS are widely used in

microfluidic fabrication, it is proven that this method is suitable and cheap.

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