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Design, Simulation and Fabrication of 3D Printing Mold for Rapid Production (PMRP) of Microfluidic Channel

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***Abstract*— Since the 2000s, microfluidic technology has developed quickly, and presently it is well-liked by academic researchers. However, employing lithography to produce microfluidic devices is an expensive, difficult, and time-consuming operation. Microfluidic facilities must be built at a significant cost because everything is imported. As a result, microfluidics is limited in Malaysia. Therefore, a new method to create a microfluidic mold for quick production using three-dimensional (3D) printer technology has been described in this study. This method is more cost-effective than lithography facilities. Anyone can create their own microfluidic channel using computer-aided design (CAD) design software by using 3D printing technology, which can be used for a variety of purposes. To predict the channel's behavior, the finite element method (FEM) is simulated using COMSOL Multiphysics. A syringe pump is connected to the channel in order to observe the fluid flow. The results of the test, simulation, and theory were all highly congruent.**

Keywords*— Microfluidics, PDMS, Rapid Prototyping, 3D Printer, PCB Printer.

I. INTRODUCTION

A microfluidic device is a set of micro-channels that are molded into glass and silicon such as poly-dimethylsiloxane (PDMS) [1]. This micro-channel can be formed by sandwiching the glass and PDMS. It is used to allow a small volume of fluids to flow inside the micro-channel. PDMS has been frequently used for rapid prototyping in comparison to other materials (fabricating microfluidic devices) because of its physicochemical features (short curing time and innocuous fabrication procedure) [2].

The reduced costs and improved fabrication times in microfluidic manufacturing technology in the early 2000s led to an increasing number of researchers in the field of microfluidics. Microfluidic devices have generated a lot of attention among researchers in the biomedical engineering sector because of their high throughput, automation possibilities, and inexpensive manufacturing costs. [1,2]. Microfluidic technology is applicable in various fields including biological, medical, and chemical as the miniaturization process is able to increase the precision of an experiment. Examples of recent biomedical applications include organs-on-chip manufacturing, point-of-care diagnostics, gradient concentration creation, and cell sorting. [3-6].

Photolithography on a silicon wafer is the technique that is most frequently used to create a master template for polymer casting [7-9]. The soft-lithography technique was developed as an alternate fabrication process in the early stages of the creation of microfluidics devices [10-14]. This process makes it possible to create casting molds with great resolution. In soft lithography, a pattern transfer (replication) from features in the master template occurs when an elastomeric material (PDMS) is cast against a positive relief master. However, the process requires expensive facilities and well-trained workers to handle the facilities. In addition, lithography is a complex process and takes hours to complete the process. To improve this procedure, numerous new fabrication techniques have been created [15]. Previous researchers have proposed various alternative methods for master fabrication to accelerate and simplify the entire design and manufacturing process due to the limitations and drawbacks such as a time-consuming process, needing a cleanroom environment and trained personnel, and no flexibility for the fabrication of new microfluidics designs.

In this paper, microfluidic molds were produced using a 3D printer and the PDMS is used in the fabrication. Hence, the aim of this study is to design a new technique as an alternative to lithography by implementing 3D printer technology to produce a microfluidic mold for rapid production.

II. METHODOLOGY

A. Method of Simplified fabrication

A newly proposed method for building the microfluidic channel is shown in Fig. 1. (a), and Fig. 1. (b) shows the conventional method utilized in the photolithography process.

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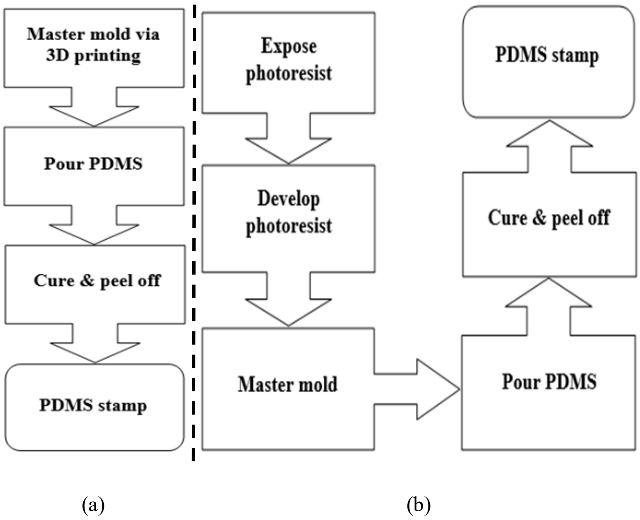


Fig. 1. (a) Newly proposed streamlined fabrication process (b) Regular photolithography technique

B. 3D Printing Fabrication methods

CAD software is used in the designing of the microfluidic channel. Next, the molds used for casting the PDMS are printed using Cura Software and the Anycubic i3 Mega 3D printer with Polylactic Acid (PLA) filament. Before printing, it is necessary to adjust the printer setting to get the best output. In order to obtain the smoothest surface of the microfluidic mold, the layer height of the 3D printer setting must be set as low as the printer can support it, and in this case, 0.1mm is the lowest value. If the layer height is set to 0.5mm, a rough surface of the microfluidics mold is produced and it cannot be used in the fabrication of the PDMS process. The Sylgard silicon elastomer, also known as PDMS is mixed with a curing agent using a ratio of 10:1. It will be stirred until the mixture produced a lot of bubbles, which means the mixture is well blended. The mixture will be poured into the microfluidic mold and placed inside the glass desiccator to remove bubbles.

Next, the Plasma bonding process is needed to convert the hydrophobic surface into a hydrophilic surface. The hydrophobic surface repels the water drop while the hydrophilic surface is a surface that absorbs the water drop. In this process, the PDMS and glass slides will be attached naturally without the use of any type of glue.

C. Laminar Flow Simulation

The microfluidic channel is modeled using the COMSOL Multiphysics simulation tool using the specifications presented in Fig. 2. and Table 1. For microfluidics channel simulations, laminar flow and extremely fine physics-controlled meshes are employed. Instead of seven cycles, the simulation process is run once to reduce calculation time.

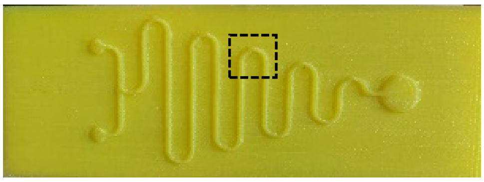


Fig. 2. Computational Fluid Dynamics (CFD) simulation of the U-Shape of microfluidics channel (300 um & 500 um)

TABLE I. SPECIFICATIONS OF MICROCHANNEL USED in simulation setting

Zone	Length (mm)	Width (um)	Height (um)
A	5.0	300	300
B	5.0	500	500

Fig. 3. displays the mesh model that was used in the research. To determine the fluid velocity profile and the residence time in a microfluidic channel, respectively, stationary and time-dependent simulation is used. The fluid velocity at the inlet is set to 0.00246 m/s. The simulation of residence time is run from 0 to 12 seconds in 0.01s stages. The simulation uses water as the fluid, and all of the material attributes are derived from the COMSOL material library.

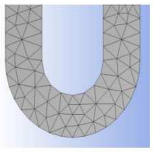


Fig. 3. After the Mesh model of the U shape microchannel.

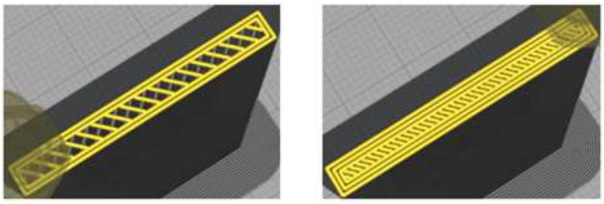
III. RESULTS AND DISCUSSION

A. Master molds fabrication

In this study, the layer height of the Anycubic i3 Mega 3D printer is set to 0.1mm to obtain a smooth microfluidic mold.

B. Master molds characterization

Infill density (InD) is the inside layer of the microfluidic mold. The higher the percentage of infill density (InD), the more rigid the structure of the mold. Based on the results, the minimum value of infill density (InD) percentage should be 40% and higher. Fig. 4. (a). and (b). show the microfluidic mold with infill density of 40% and 100% respectively.



(a) (b)

Fig. 4. (a) Microfluidic mold with infill density of 40%, (b) Microfluidic mold with infill density of 100%

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Layer height (LH) is the gap between the line surface and the 3D printer nozzle. The lower the value, the smoother the surface of the microfluidic mold as shown in Fig. 5. (a) and Fig. 5. (b). The microfluidic mold in Fig. 5. (a) is smoother compared to Fig. 5. (b).

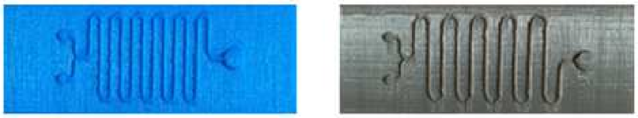
(a) (b)

Fig. 5. (a) Microfluidic mold with LH-0.06 mm
(b) Microfluidic mold with LH-0.1 mm

Channel width (CW) is the width of the micro-channel printed on the microfluidic mold. The tested values are 0.3mm, 0.4mm and 0.5mm. Due to the nozzle size of the 3D printer that has been used for this research being 0.4mm, the micro-channel only can be printed at 0.5mm. If the channel width is set to 0.4mm and lower, the micro-channel produced will lose some of the parts, as highlighted in Fig. 6. (a). While Fig. 6 (b) shows the better microfluidic mold.

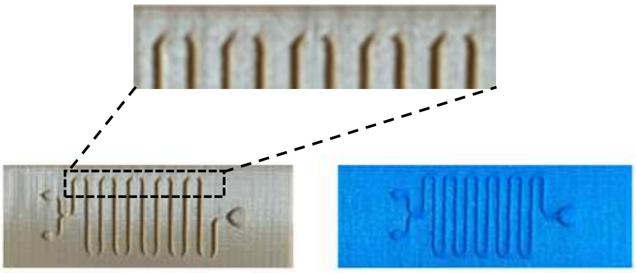
(a) (b)

Fig. 6. (a) Microfluidic mold with CW-0.3 mm (b) Microfluidic mold with CW-0.5 mm

A channel gap (CG) is a gap between each of the micro-channel that has been printed on the microfluidic mold. The tested values are 1mm, 2mm and 3mm. All the tested values are successfully printed only for the channel width of 0.5mm, as shown in Fig. 7. (a) and Fig. 7. (b).


(a) (b)

Fig. 7. (a) Microfluidic mold with CG-1 mm (b) Microfluidic mold with CG-3 mm

Channel height (CH) is the height of the microchannel that will be printed on the microfluidic mold. Tested values used in this research are 0.3mm, 0.4mm, and 0.5mm. If the value is set to 0.5mm, the 3D printer is able to print good quality micro-channel, if the values are set to 0.4mm and lower the 3D printer unable to print the micro-channel correctly and the micro-channel will lose some of the parts, as shown in Fig. 8. (a). While Fig. 8. (b) is a better microfluidic mold for CH of 0.5mm.

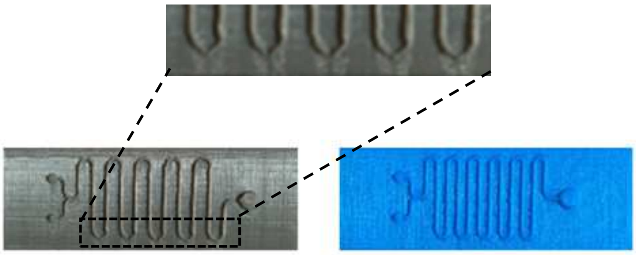
(a) (b)

Fig. 8. (a) Microfluidic mold with CH-0.4 mm (b) Microfluidic mold with CH-0.5 mm

A microscope nanometric scale has been used to check the micro-channel width of the printed microfluidic mold. From the result obtained, the 3D printed mold's micro-channel width has approximately equal to the actual scale, as shown in Fig. 9.

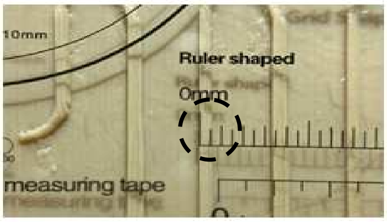

Fig. 9. Replica size of 0.5mm

C. Replication of Microfluidics

Next, is the replication process using PDMS. The replication process can be done by mixing the PDMS and curing agent in a ratio of 10:1. The function of the curing agent is to break the polymer bond inside the PDMS and transform the PDMS from a liquid into a solid state. The mixture of the PDMS then will be poured onto the microfluidic mold. A smoother surface of the microfluidic mold will produce a better microfluidic. The smoother and rough PDMS replicas are shown in Fig. 10. (a) and Fig. 10 (b). respectively.

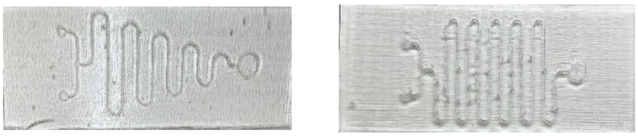
(a) (b)

Fig. 10. (a) PDMS (Layer Height of 0.06mm) (b) PDMS (Layer Height of 0.1mm)

D. Plasma Bonding Effect

To test the plasma bonding effect on the attached PDMS and glass slide, red fluid has been injected into the microfluidic. A good attachment will allow fluid to flow smoothly without any leakage inside the micro-channel as shown in Fig. 11. (a), while a poor attachment causes leakage inside the micro-channel as shown in Fig. 11. (b).

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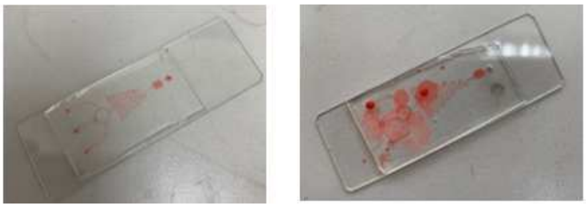

(a) (b)

Fig. 11. (a) Microfluidics - Good attachment (b) Microfluidics -Poor attachment

E. Laminar Flow Analysis

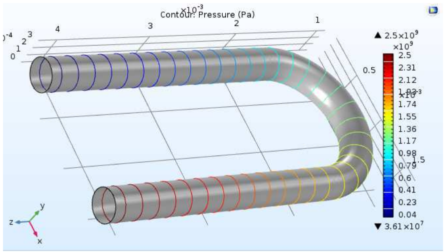

Fig. 12. Pressure simulation along the channel width (0.3mm)

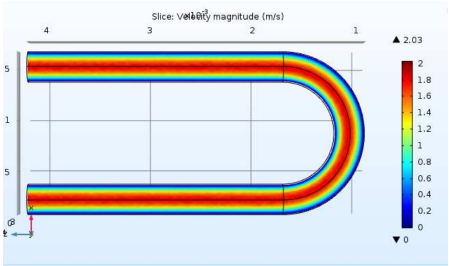

Fig. 13. Velocity simulation along the channel width (0.3mm) – 3D

Fig. 12 and Fig. 14 show the pressure found in the channel width of 0.3mm and 0.5mm respectively. The blue scale indicates slow pressure and the red scale indicates high pressure. When the fluid has flowed through the microfluidic then the magnitude of Velocity CW will affect the pressure on the fluid. If the CW size is small the pressure will be high and when the CW size is large the pressure will be less.

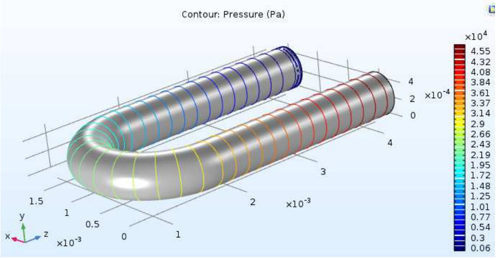

Fig. 14. Pressure simulation along the channel width (0.5mm)

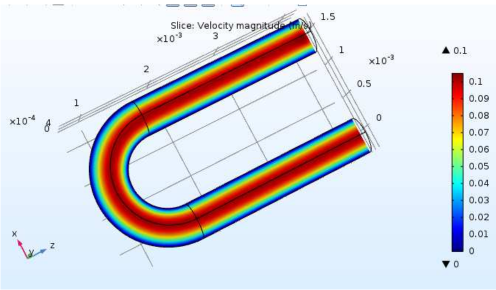

Fig. 15. Velocity simulation along the channel width (0.5mm) – 3D

Velocity magnitudes shown in Fig. 13. and Fig. 15. have different colors as seen in the legend representing differences in velocity according to the position in the pipe. The average velocity is decreasing when the laminar flow closer to the wall. The maximum velocity occurs at the pipe centerline. This shows that the fluid element in the middle of the pipe will travel at a higher speed than that closer to the wall.

IV. CONCLUSIONS

At the end of this research study, the objectives to produce a Microfluidic mold utilizing 3D printer technology for rapid production are successfully achieved. Besides, an alternative method that is less time, cost-efficient, and simple compared to the lithography process has been proposed. However, to produce a very precise microfluidic channel mold, current 3D printer technology still have some limitation. But 3D printer technologies are getting better in the near future and have a high potential to completely replace the lithography process to produce a precise microfluidic mold for rapid production. This project is suitable for those involved in micro-sampling such as taking blood and sample of river water because it needs only a small amount of fluid for microfluidic to react with the samples. Currently, microfluidic is only used by professional researchers since they have lithography facilities, but with this new technique, microfluidic can be explored by many people and researchers.

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