Low-cost Fabrication of PDMS Microfluidic Chamber using Digital Cutter Machine

I Anshori¹*, S Harimurti¹, M S Hartono¹, R R Althof¹, L N Rizalputri¹, M Handayani², Tati L. E. R. Mengko¹, B Yuliarto³,⁴
¹Lab-on-a-Chip Laboratory, Department of Biomedical Engineering, School of Electrical Engineering, Institut Teknologi Bandung
²Research Center for Metallurgy and Materials, Indonesian Institute of Sciences (LIPI)
³Advanced Functional Material (AFM) Laboratory, Department of Engineering Physics, Faculty of Industrial Technology, Institut Teknologi Bandung
⁴Research Center for Nanoscience and Nanotechnology (RCNN), Institut Teknologi Bandung

* E-mail: isa_anshori@stei.itb.ac.id

Abstract. Microfluidic chamber or channel is one important tool in the lab-on-a-chip (LoC) technology, which usually serves as a platform to contain liquid analytes. The conventional method to fabricate microfluidic chamber is based on photolithography technique. However, it is a high-cost process and requires special equipment, such as mask aligners and expensive photosensitive resist material. In this work, we fabricated the microfluidic chamber and channel using a much simpler and lower-cost technique that is using PDMS as the main material and polyimide tape as the mold. Using this method, the diameter of the microfluidic pattern (channel/chamber) could be made up to as small as 1 mm and the height of the flow channel was down to tens or hundreds of µm scale - depending on the thickness of the tape. The flow test results showed that low cost and simple microfluidic fabrication method had a good performance and could potentially be further used for real analyte flow test.

1. Introduction
Lab-on-a-chip (LoC) for sensing method has been developed by various researchers to put forward the speed of the test results and reduced the needs of the reagents’ volume as small as possible. Thus, a test conducted using LoC technology becomes more practical and effective. Microfluidic platform is a part of LoC which deliver the solution of preparing the small container/chamber for the reagent. This platform is capable to do sample collection and pre-processing sample (such as mixing, splitting, etc.) that will be analysed afterward. Microfluidic is defined as a way of handling fluids by using technology that can accommodate and manipulate fluids in small quantities (micro-dimension) [1-2]. Microfluidic develops rapidly due to several advantages possessed, such as accelerating the reaction, reducing the number of samples needed, and also reducing overall costs [2]. In addition, microfluidic can help analysis faster, and make the detection process easy to control. The commonly used material is Polydimethylsiloxane (PDMS) that is a silicon-based organic polymer with its superiority in optically clear, inert, non-fluorescent, biocompatible, non-toxic, and non-flammable [1].

Microfluidic fabrication in general is not simple. By using the photoresist and lithography methods, the mold is printed and becomes a microfluidic flow design. The method with
photolithography uses high energy and ultraviolet light which is projected onto the photomasks in photoresist (SU-8) to make a mold pattern [5]. However, this technique has drawbacks, which require a special room with the lighting that is safe with the photoresist material. Another disadvantage is that it takes a long time and required expensive set of instruments and chemicals [6].

In this paper, a simple and low-cost method for microfluidic fabrication was presented. PDMS was used as the main material for the microfluidic platform, and we use the combination of polyimide sheet and tape to make the microfluidic pattern. This method makes it easy for researchers to test various microfluidic designs easily and inexpensively. In addition, this flexible microfluidic platform can be applied further to the use of wearable sensors.

2. Experimental

2.1. Materials
The microfluidic fabrication was performed using SYLGRAD 184 Silicone Elastomer Kit that consists of main material and the curing agent to produce PDMS (polydimethylsiloxane) as microfluidic main materials. Magnetic sheet, polyimide sheet and polyimide tape were purchased from local store. For cleaning pretreatment for acrylic mold, ethanol 100% was obtained from Sakura Medical Store (Indonesia).

2.2. Instruments
Mold pattern in polyimide was performed using digital cutter machine by Silhouette Cameo 3, USA. Acrylic board and the cutting process were conducted by local cutting service. Air desiccator device and the oil pump were obtained from local laboratory store.

2.3. Fabrication Method
The main property proposed by this study was fabrication simplicity. The overall process consisted of mold pattern fabrication and pattern transfer on PMDS. Microfluidic mold was fabricated from 2 parts of acrylic board that stacked to form a pit-shaped square with a 3 x 4 cm width and length size and a depth of 0.5 cm. Ethanol was used to clean the mold from dust. Microfluidic pattern was printed on a 3-layered polyimide tape using a digital cutter machine. Then, the formed tape pattern was placed on to the pit of the acrylic mold. The displacement process from cutting board to the acrylic mold should be done carefully. This process will determine the microfluidic result quality.

The next step was the microfluidic fabrication with desired design created on previous step. First, PDMS polymer was mixed with curing agent using 1:10 (%w/w) ratio. Air bubble that caused by the mixing process agent was removed by using centrifuge force for about 5 minutes. The mixture then poured into the pit that already has the polyimide tape mold on the bottom surface of the pit. The drying process can be done through heat treatment, but it should be accompanied with the use of air desiccator to compensate the bubbles formed. Another alternative simpler method is to wrap it up using plastic wrap to prevent the dust and just kept it overnight. After the PDMS was in dried condition, it will easily release from mold by peeling it off. The overview of this experimental procedure is illustrated in Figure 1.
2.4. Testing

In this study, microfluidic performance testing was performed quantitatively. Flow testing was conducted on fabricated microfluidic channel or chamber. The main specifications that will be analyzed were fluid flow and leakage fluid on the outside of pattern. Before testing, microfluidic was placed on a clean glass. For better adhesion and irreversible sealing, oxygen plasma treatment can be performed on microfluidic surface before the displacement on to the glass by reducing hydrophobicity [7]. In this research, reversible sealing was chosen due to the need of repeated experiment. Reversible sealing would also be beneficial for later application due to reusability of the microfluidic platform.

3. Results and Discussion

3.1. Streamline design as a fluid chamber

The first mold pattern was a streamline design with an inlet and outlet at two ends as a chamber, i.e. for analyte collection on biosensors. The streamline design can reduce the angle that will interfere the sample flow process and avoid any left portion of fluid remained on the chamber when the solution was drawn out. A polyimide tape with streamline pattern was placed in an acrylic master, as shown in Figure 2(a). The desired chamber thickness was then adjusted from the number of layers of stacked polyimide tape. The thickness of the polyimide tape was 0.05 mm. In this work, 3 layers of tape were used so the microfluidic pattern thickness was 0.15 mm. This thickness will determine the amount of sample volume that can be contained in microfluidic chamber. A narrow gap between the top and the bottom of the microfluidic chamber is important in electrochemistry besides the small analyte volume needed. The advantage of this narrow gap is that it would reduce diffusion distances and diffusion times of sample significantly and increase the sensitivity and speed of the sensor response [8].

![Fabrication process of the microfluidic chamber.](image)
PDMS and curing agent mixture was poured into the acrylic mold as in Figure 2(b). Besides streamline pattern, two different patterns were also made for comparison. After being left overnight, the cured microfluidic was peeled off from the mold as shown in Figure 3. A careful and neat treatment will produce clear microfluidic platform.

3.2. Chamber design testing
The microfluidic chamber was then tested by flowing a liquid to the chamber. The inlet and outlet were made using puncher with a diameter of 1 mm. Then, the microfluidic was placed on the glass substrate. By using a micropipette, a coloured liquid was injected from the inlet and flown out through the outlet (Figure 4). The result from this observation was the fluid did not leak and well remained in its fluid track. The fluid volume that can be accommodated in the chamber of Figure 4 was 15 microliters. One of further streamline pattern application in biological field is trapping technique and isolation for single cell study [9].
3.3. Y-design as a mixing channel

The next idea is to fabricate a quite more complex microfluidic design. The tricky procedure was needed in term of polyimide tape pattern displacement on to the acrylic mold. Instead of cutting the polyimide tape using the digital cutter machine, peel the polyimide sticker off, and placed the tape onto the pit made from acrylic, we decided to place the polyimide tape on the polyimide sheet first on the cutting process. This strategy solved the problem of peeling the cut tape and place the tape to the acrylic pit. When the design of the polyimide tape is very complex, it is almost impossible to have a perfect shape of tape on the acrylic pit.

“Y” design as in Figure 5, was our simple test of microfluidic channel which cannot be perfectly placed on the acrylic pit without polyimide sheet utilization, because it easily twisted and cut. This design was smaller compared to the first one. The width of the channel is 1 mm on both inlet and outlet. Using such strategy, it is very possible for polyimide tape (pasted on the polyimide sheet) which has been cut, to be moved to acrylic container with far more complex design and/or has a fragile structure. Therefore, polyimide sheet was used as the base when the cutting process using digital cutter was conducted.

Figure 4. Flow testing in microfluidic chamber.

Figure 5. Mold for another microfluidic channel design (one inlet and two outlet).
We could also prepare thin plate of acrylic as the base for polyimide tape cutting process. However, it is not easy to obtain thin acrylic plate on the market. If the acrylic plate is too thick, it cannot fit with the digital cutter machine when we want to cut polyimide tape. It is our reason why we used polyimide sheet that the thickness can still fit with common digital cutter machine. The use of polyimide sheets as a base made mold fabrication simpler and allows pattern with more complex designs.

3.4. Y-design channel testing

**Figure 6** shows PDMS fabrication results which has been produced in Y shape. The Y canal was neatly printed and the microfluidic channel formed has good pattern as we expected. Similar with the previous test, flow test was conducted using coloured liquid and micropipette. Both inlet and outlet was punched using a puncher. Flow test was conducted by injecting coloured liquid on 1 side of inlet and the liquid leads to two outlets. The results could be very well observed and the technique was worked well. This design structure was basic implementation of passive mixing function in microfluidic platform. More advance pattern for passive mixing of two or more fluids are zig zag pattern with controlled angle [10]. The complex design can be expected and be tested in the future with same simple fabrication method.

![Figure 6. Flow testing in Y-design microfluidic channel.](image)

4. Conclusion

Fabrication of microfluidic chamber and channel molds using polyimide tape and digital cutter made the microfluidic fabrication (with PDMS as the main material) process become simpler, easier, and cheaper. The use of polyimide sheet as a base on polyimide tape mold allowed the creation of complex microfluidic design. Microfluidic platform fabricated in this work were functioning properly and no leak was confirmed. Such fabrication method can be used as the initial development of microfluidic fabrication with more complex functions, such as mixing and splitting. However, the smallest dimension of microfluidic channel is limited, depending on the smallest scale that can be used in the digital cutter machine.

**Acknowledgments**

The authors acknowledge financial grants provided by Indonesia Ministry of Education and Culture. This work is also partially supported by the Lembaga Pengelola Dana Pendidikan (LPDP), Ministry of Finance of Indonesia.
References

[1] Mata A, Fleischman A and Roy S 2006 Biomedical Microdevices 7 281-93
[2] Faustino V, Catarino, S O, Lima R, Minas G J. Biomech. 2016 49 2280–2292
[3] Nguyen H T, Ha T, Roy E, Khon H and Perrauli C M T 2018 Micromachines 9 461
[4] McDonald J C, Whitesides G M 2002 Accounts of Chemical Research 35 491-499
[5] Nie Z, Kumacheva E 2008 Nat. Mater. 7 277–290
[6] McDonald J C, Duffy D C, Anderson J R, Chiu D T, Wu H, Schueller O J, Whitesides G M, 2000 Electrophoresis 21 27-40
[7] Giorgio G, Nicholas C, Amanda M 2020 Analytica Chimica Acta 1135 150-174
[8] Garg M, Christensen M, Illes A, Sharma A, Signh S, and Pamme N 2020 Biosensors 10 92
[9] Allan G, Aditi S, Richard S, and Zhenyu L 2015 Biomicrofluidics 9 24103
[10] Chia T and Xin Y 2019 Micromachines 10 583