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Peristaltic Micro-Pump with Normally Deflecting Membrane Fabricated using Glass Based Master Mold

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ABSTRACT

In this project, a Peristaltic fluid micro pump having normally deflecting membrane on a glass based master mold is developed. The developed peristaltic micro-pumps consists of three or more pump membranes connected sequentially. This structure is primarily aimed for enabling high pumping stroke of fluid hence increasing the flow rate. Besides the main purpose, this method can simplify the fabrication reducing the steps of the membrane transfer from master mold to membrane spacer. In this study, the flexible membrane that forms a curved dome-shaped is fabricated implementing a glass rod as the master mold with diameter and height of 4 mm and 2 mm, respectively. The membrane layer was made by pouring in PDMS at the top of mold master. This technique enables to produce a membrane in a normally deflecting form even though there is no interference with the membrane. Apart from that, the membrane can be adjusted to obtain expected flow rate and certainly the size of the membrane diameter. The structures have been successfully fabricated using soft-lithography technique. The functionality test of the fabricated pump system shows that the fluid was able to flow from the inlet to the outlet on the other side of the pump membrane without leaking. The result of this research is expected to be applied as fluid injection system in biomedical instrumentation that need high fluid rate.

Keywords: Peristaltic, Master Mold, Membrane, Flow Rate, SU-8 Photoresists.

1. INTRODUCTION

Peristaltic micro-pumps are expected to produce a high flow rate compared to other types of micro-pumps, such as piezoelectric [1], thermo pneumatic [2], electromagnetic [3] [4] and shape memory [5]. This is because the peristaltic micro-pump uses the squeezing of the fluidic channel to transport the fluidic substance at high volume and does not need valves to regulate the fluid flow. In operating the peristaltic micro-pump, there are several stages of pumping condition, such as actuating chamber and inlet/outlet [6] and the movement settings of each pump membrane using a microcontroller. While the operation of peristaltic micro pump is based on synchronous compression of microfluidic channels [7]. This mechanism is can be replaced with the use of 3 or more planar pumping membrane that working sequentially.

The current problem in micro-pump fabrication is the structure pattern process (lithography), particularly for making the channels. The lithography process is divided into two main namely photolithography used in Integrated Circuit (IC) fabrication and soft-lithography including micro contact printing, micro transfer molding, replica molding, micro molding in capillaries and injection molding [8]. Furthermore, a photolithography in micro-pump fabrication is also used to make a master mold with SU-8 photoresist as the photosensitive material. The advantage of this photoresist is that it is biocompatible, mechanically and chemically stable [9], on the other hand,

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the SU-8 master mold is that it can only produce horizontal membrane shapes. Another way to make master mold is to use 3D printing techniques [10][11].

The aim of this research is to fabricate the mold structure of the pump membranes having normally deflection structure by utilizing molded structure from glass that form dome shape to produce deflections that can be adjusted in accordance with the shape of the dome. The membrane layer is made using a mixture of polydimethylsiloxane (PDMS) and agent with a ratio of 10: 1. PDMS is used since it has a Young PDMS modulus of 750 kPa and a density of 970 kg/m3, biocompatible [13], and optical transparent [12].

Another problem in making the channels is the mechanical pill-off to transfer the molded layer from the master mold to membrane spacer that causes the change in size and shape of the channel. Therefore, in our fabrication such transfer process is avoided and replaced by using lift-off technique. In order for the device to be lifted off by itself from the master mold, the top of the master mold is coated with water-soluble PolyAcrylic Acid (PAA) [14]. So, the other purpose of this research is to eliminate the membrane transfer process from the mold to the membrane spacer.

Thus, a three-stage peristaltic micro-pump was successfully created with a master mold membrane made from a glass rod. This structure is very necessary to enable a high flow rate micro-pump. Moreover, another success in this research is to reduce the channel transfer process by directly fabricating channels.

2. MATERIAL AND METHODS

To obtain the objective of this study, there are several steps are necessary to follow, such as the design of the material and structure, fabrication and test. In the first step, an explanation about the materials used to make the Peristaltic Micro-Pump is described. The second step is to create the peristaltic micro-pump structure design which is followed with the soft lithography process, in the last stage, the leakage test is conducted to ensure that the channel and pump membrane can be working properly. Each step will be more explained below.

2.1 Materials

The materials used to fabricate the micro pump structure consist of a glass rod, a borosilicate glass plate, Polydimethylsiloxane (PDMS) along with a curing agent, SU-8 photoresist, PolyAcrylic Acid (PAA), and small diameter tubing for input and output lines and some chemicals for cleaning process, such as Aceton and Propanol.

2.2 Pump Design and Structure

Figure 1a shows the geometry of the pump system. It consists of 3 pump chambers, inlet and outlet connectors and fluids channels having the curved shape. The fluid channel with curved shape is designed to increase the channel length and to prevent leak if it is too close. The pump system occupies the total area of 314 mm^2. The pump chamber and channel have the diameter of 4 mm and width of 4 mm, respectively.
The structure of a peristaltic micro-pump is shown in figure 1b. The parts of the micro-pump include the main molds, spacers, membranes, channels, bonding contacts, channel-tubing connectors and chambers.

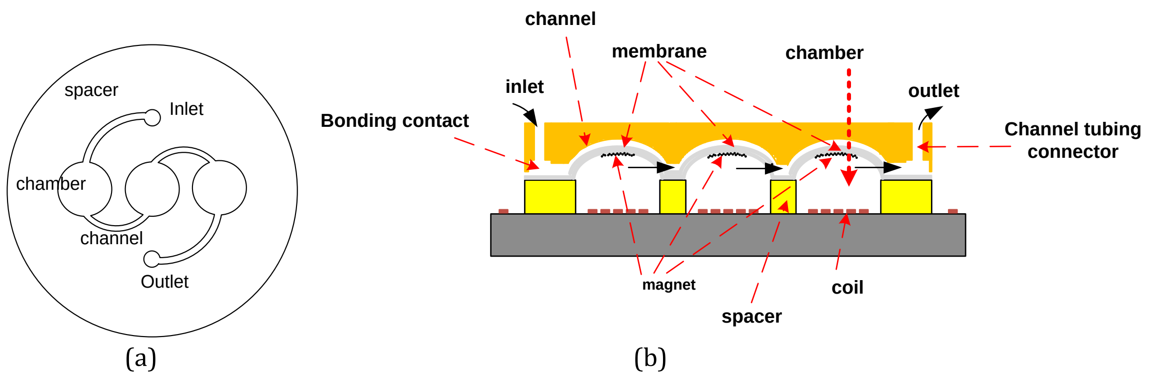


Figure 1. The geometry (a) and the structure of peristaltic micro-pump (b).

Curved membrane layer "normally deflection" of 2 mm. The chamber itself is designed in the form of a half ball, then by using calculations for one chamber, obtained by a volume of [15]:

$$V = \frac{2\pi}{3} y_o R^2 \tag{1}$$

The result of the volume is 1,675e-8 m3, using the vibration frequency at each 10 Hz membrane and the liquid discharge is 10 ml/minute. Three chambers are used because of the peristaltic 3 chambers so that the total discharge is 30 ml/minute. The channel that is made has a width of 500 um and a circular shape. Selection of channel width so that liquid can laminar into the chamber and there is no trap against the channel wall [16].

2.3 The Fabrication of the Micro-Pump

The fabrication steps of the peristaltic pump is shown in figure 2. The Membranes are made of PDMS that were chosen because of the ease of fabrication and optical transparency. As compared to silicone, this material is cheaper. In addition, soft lithography is an inexpensive and useful method for manufacturing PDMS devices [17, 18].

The fabrication process begins with creating a master mold made of glass rod with a diameter of 4 mm. This master mold is formed as shown in figure 3(a) where the edges of the glass are made dome. Then, the distance between one pillar and another is varied between 1 mm to 3 mm.

The master glass mold is initially cleaned by using Aceton then rinsed with DI-H_2O and then dried using N_2. To facilitate removal of the device from the master mold, the master mold is put into the PAA solution, then dried on a hotplate for 10 minutes. Meanwhile, PDMS and curry agent are mixed and stirred for 10 minutes, then deglassed in the desiccator for 30 minutes to remove the air bubbler. Furthermore, PDMS is poured on top of the master mold to produce spacers until the PDMS spills out. To strengthen the spacer is heated on a hotplate at a temperature of 100^{o}C for 20 minutes. Apart from that, PDMS is poured to get the membrane then spined at 500 rpm for 50 seconds. The next process is heated on a hotplate at a temperature of 100^{o}C for 10 minutes. Unfortunately, the resulting membrane is too thin, therefore, this step is repeated.

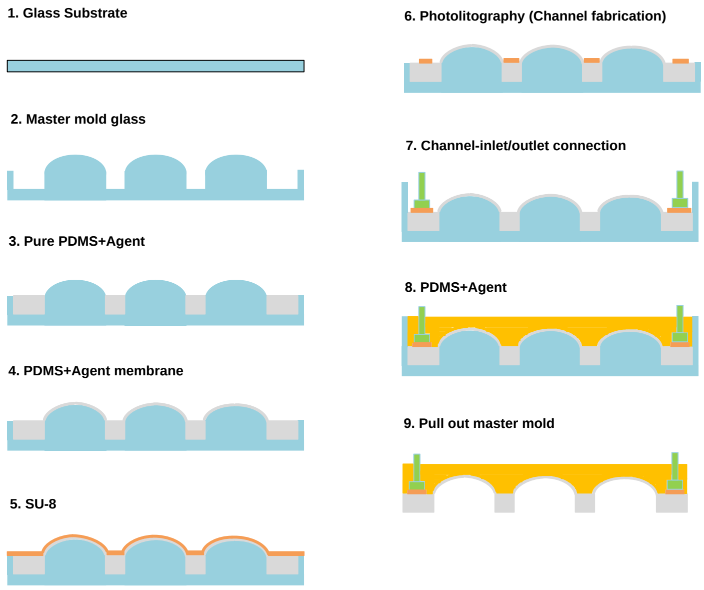


Figure 2. Fabrication process steps.

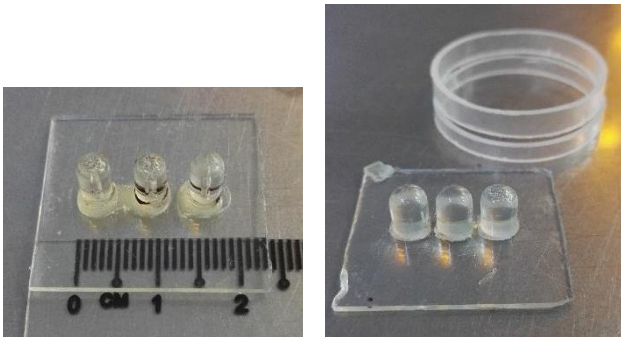
To create the channels, photoresist SU-8 is poured on top of PDMS and then spined at 500 rpm and 750 rpm for 10 seconds and 50 seconds respectively. Afterwards, soft bake for 5 minutes and 45 minutes at 65°C and 95°C, respectively. The coating layer is then fully exposed for 60 seconds using the MJB 3 Kurrl Suss aligner mask and followed with post bake to strengthen the SU-8 structure, the post bake process is carried out at the same temperature and time as the soft bake.

To get rid of the unwanted parts, the next process is put into the SU-8 developer solution for 45 minutes. The developer process causes the strength of the SU-8 to reduce, therefor, the hard bake process is carried out for 40 minutes at a temperature of 120°C. The connection is made between the channel and the input and output pipes using the SU-8 photoresist, then heated on a hotplate for 30 minutes at a temperature of 100°C. The next process is forming chamber by pouring PDMS on top of PDMS then heating at 120°C for 1 hour or leaving it for 24 hours at room temperature.

To strengthen the bonding between the PDMS spacer and the PDMS chamber, corona discharge is used for 30 seconds. Finally, the last process is to input the device into DIH_2O for 6 hours to make the device peel from the master mold.

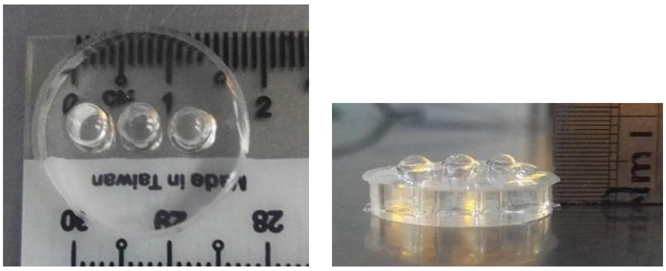
3. RESULTS AND DISCUSSION

The master molds with three pillar structures are shown in Figure 3a and 3b. The diameter of each pillars is 4 mm and the distance between pillars varies from 1 mm to 3 mm. The size of the bottom glass plate is adjusted to the edge mold to pillar stand and edge border. Spacers and membranes made of PDMS and agents are shown in Figure 4. Separator is useful for separating between chambers, PDMS membrane has been formed in accordance with the dome shape of the master mold.



(a) (b)

Figure 3. Master mold made of glass (a) and (b) master mold and side mold.

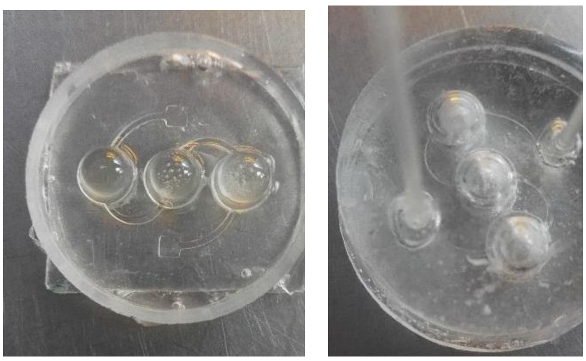


(a) (b)

Figure 4. Membrane by scale (a) top view (b) side view.

Figure 5 shows the fabricated micro chamber with curved channel on the grounds. It can be seen that the fluid cannels with curved channel geometry have been successfully fabricated. Large channel size due to large dome micro-pump. If there is a lot of liquid in the chamber with a micro-pump working with high frequency, the fluid needs a proportional channel so that the water that comes out is laminar and does not falter. Besides, the suspended fluid particles are well focused on the sidewall of the main channel at a high aspect ratio between width and height [17]. Another cause is that the initial fabrication of this bonding treatment between the PDMS spacer and the PDMS chamber has not been maximized.

Figure 5 shows the connection between the channel and tubing at the inlet and outlet. To increase the quality, hard cured SU-8 photoresist is formed around the tubing end and connector contact.



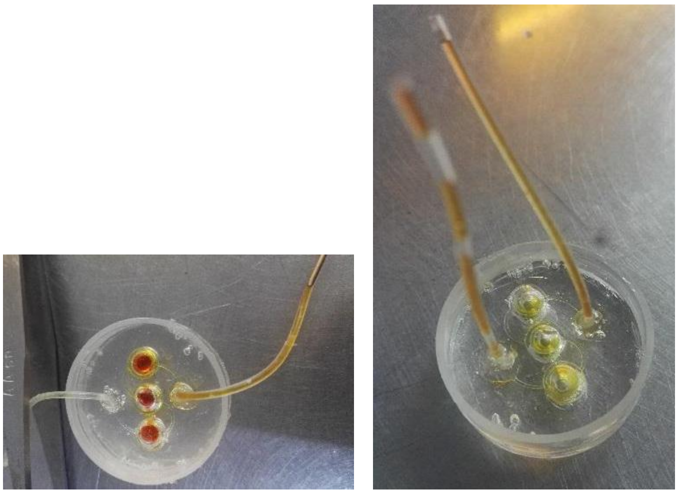
(a) (b)

Figure 5. (a) curved channel formation (b) pump channel with installed input-output tubing connector.

In the final step of the fabrication, the fabricated pump system is tested by injecting red coloring liquid. A 3-stage peristaltic micro-pump device made as a whole with liquid entering on one side and exiting on the other side is shown in Figure 6 and Figure 7.

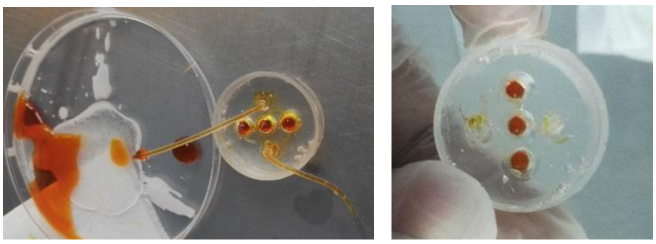
It can be seen that the preliminary peristaltic micro-pump with three membranes was successfully fabricated and tested by proven colored liquid which was injected at one inlet side and out at the other side. There is no leaking is observed indicating that good bonding has been established.

The advantage of the fabrication method is that can be done straight forward without making master molds to make a membrane, which is different from the technique to fabricate the micro-pump in general.



(a) (b)

Figure 6. Micro-pump device (a) and (b) top view.



(a) (b)

Figure 7. Micro-pump device (a) when given liquid on one side, out on the other side
(b) Liquid is trapped in the chamber.

4. CONCLUSION

The initial fabrication of three-stage peristaltic micro-pumps with dome-shaped membranes has been experimented. The soft-lithography (micro molding) process is used to create the pump membrane where the master mold is patterned using standard photolithography process of SU8. The channel creation is carried out continuously without creating different channels. The leaking test showed that the colored fluid substance liquid injected on one side of the input has passed through the chamber and comes out on the output side that show that the channel has been produced properly. Meanwhile no leaking was observed indicating that good bonding has been established. The developed peristaltic micro-pumps and the technique would be promising for the development of high flow-rate fluid pumping for biomedical use.

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