Biomimic PDMS Valve Applied in Thermopneumatic Micropump

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Abstract

A passive biomimic PDMS valve applied in thermopneumatic micropump is firstly designed and realized. Unlike the conventional peristaltic pumping configuration, the micropump consists of two stacking layers of PDMS on a glass slide. This sandwich-type structure builds up two chambers. A thermopneumatic actuation chamber consists of a 57 ohm heater on the glass slide; the other fluid chamber is connected with inlet and outlet microchannel. A diaphragm between chambers isolates chamber mediums and transmits the thermopneumatic actuation. More importantly, the fluid chamber connects to microchannels via two passive biomimic PDMS valves. Thus, the fluid is driven and constrained in one way flow by the valves. The two passive biomimic PDMS valves produce one-way flow as the actuation diaphragm squeezing and releasing the pumping chamber. The micropump is driven by 1 Hz AC square wave of 10 volt peak. The thermopneumatic PDMS-based micropump is preliminarily tested and driven for 36 seconds. As the result, the measured flow rate of thermopneumatic micropump is 100 nL/min.

Key Words: PDMS Micropump, Passive Valve, Sandwich-Type Structure, Nano-Liter Manipulation

1. Introduction

In recent years, many researchers proposed design and fabrication technologies of valveless peristaltic micropumps [1–4]. However, valves are one of the most important components in fluidic systems. Various types of microvalves have been extensively developed and demonstrated [5]. Through these techniques, sizes of many microfluidic chips could be reduced. These prior valveless pumps generally utilize three actuation chambers to control fluid in microchannel. Three actuation chambers are driven in turns to imitate a peristaltic motion. These developed micropumps need both sequential control of squeezing pumping chambers and more complex fabrication process. Moreover, the size of the micropump also depends on the design. Once the scale of a peristaltic micropump is unable to reduce, it will be difficult to be integrated into the real applications for lab on chips, like drug delivery, cell culture chip, microfluidic chip, integrated biodetection chip. Thus, a peristaltic micropump is more difficult to be integrated into real application. Furthermore, any malfunction of the three cascaded PDMS pumping diaphragms or chambers denotes the catastrophic failure of the whole peristaltic device.

However, this work proposes a simple and rapid prototyping micropump, shown in Figure 1, employing only one actuation chamber and one pumping chamber with two passive biomimic PDMS valves on a glass slide. Fluid is achieved one-way flow by asymmetric flow resistance due to the pair of passive biomimic PDMS valve. Micromachining technologies including photolithography, e-beam evaporation, PDMS casting, surface treatment of O_2 plasma, PDMS/PDMS/glass bonding are easily accessed for the device fabrication.

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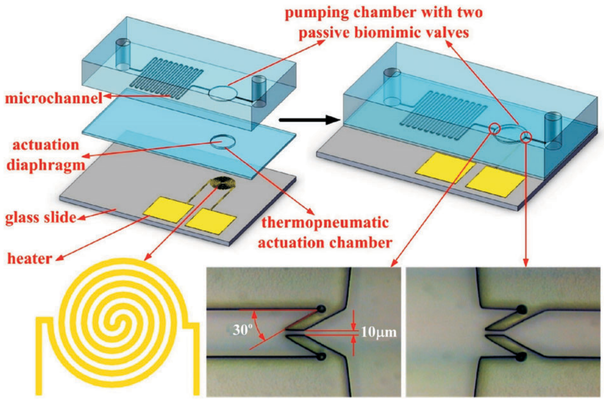

Figure 1. 3-D view of the thermopneumatic micropump.

2. Experimental Methods

2.1 Operating Principle

A valveless difusser pump was first presented by Van De Pol in 1989 [6]. In 1993, E. Stemme and G. Stemme [7] successfully integrated the nozzle and diffuser into the fabrication process of the micro valveless pump. About the performance of nozzle/diffuser micropump, Olsson [8] presented the effect of the nozzle/diffuser. The flow rate depends on the included angle (shown in Figure 2) of the nozzle/diffuser. Due to the scale limitation of the micropump, it is important to design an optimal included angle. The included angle of the nozzle/diffuser can't over 20° [9], or the separation will occur in the nozzle/diffuser. The included angle of the nozzle/diffuser is preliminarily designed to be 8°. Based on the developed theories of the valveless pump, a thermopneumatic valveless micropump with a PDMS-based nozzle/diffuser structure was firstly designed and realized by stacking three layers of PDMS on a glass slide [10]. However, the flow resistance formed by the nozzle and diffuser configuration was not enough to produce a high flow rate. Compared to the valveless micropump fabricated by the hard materials, the valveless micropump fabricated by PDMS is not so efficient on the performance.

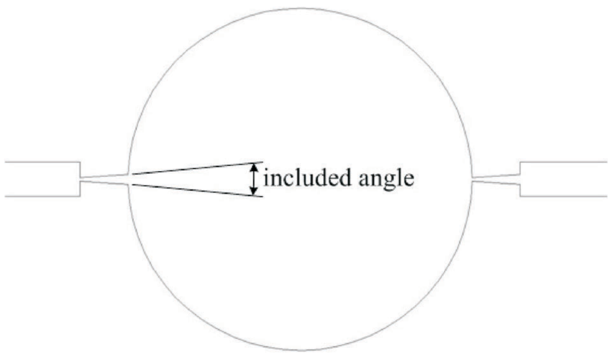

Figure 2. The included angle in the nozzle/diffuser configuration.

In this work, the asymmetric flow resistance of the fluid is not formed by the PDMS-based nozzle/diffuser structure but formed by a pair of passive biomimic PDMS valves. The fluid is driven by the asymmetric flow resistance produced by the configuration of the two passive biomimic PDMS valves. The designed valves are shown in Figure 3. The operating principle is shown in Figure 4. When applying electric power to the heater, the actuation diaphragm can be bent up and squeeze the pumping chamber to extrude the fluid. In the meanwhile, the inlet valve is closed and the outlet vale is opened. The flow rate of the outlet valve is larger than the inlet valve. If electric power is removed from the heater, the actuation diaphragm will bend down. Furthermore, there is backflow produced in the pumping chamber. In the meanwhile, the inlet valve is opened and the outlet vale is closed. Contrary to the diaphragm bending up, the flow rate of the inlet vale is larger than the outlet vale. Therefore, the total flow rate is from the inlet vale to the outlet vale. Fluid is achieved one-way flow.

2.2 Material and Fabrication

In this work, PDMS (Sylgard 184 kit, Dow Corning)

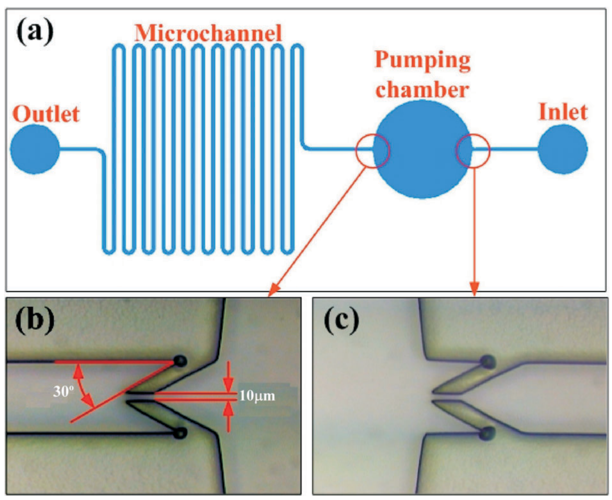

Figure 3. Top view of the micropump: (a) the flow path of the fluid; (b) the outlet vale for decreasing the backflow; (c) the inlet vale for preventing the fluid from out of the pumping chamber.

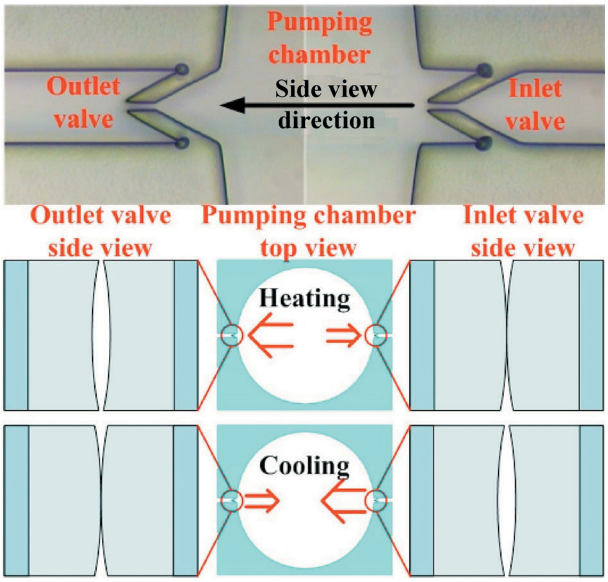

Figure 4. Operating principle of the passive valve.

was used to manufacture the thermopneumatic actuation chamber, the actuation diaphragm, the microchannel and the pumping chamber with the two passive biomimic PDMS valves. The 10:1 of PDMS base and curing agent had been mixed and degassed by vacuum pump for the fabrication and the mixed PDMS was soft-cured at 90 °C in each step of the fabrication. In order to make the surface property of the PDMS change from hydrophobicity to hydrophilicity for PDMS/glass bonding, the plasma cleaner (MODEL PDC-001, Harrick Scientific Corporation) was employed here. The plasma cleaner provides the vacuum plasma and the surface property of the PDMS is treated at 200 mTorr. The detailed fabrication process of the thermopneumatic micropump is depicted in Figure 5. First, the Cr/Au heater was deposited on the glass by e-beam evaporation and patterned by traditional MEMS lift-off process. To obtain a uniform-heat-flux surface, the shape of the heater in the actuation chamber was designed to spiral circle shown in Figure 6. Second, the thermopneumatic actuation chamber PDMS layer with actuation diaphragm was fabricated by spinning PDMS gel on a SU-8 mold. In this step, the actuation chamber layer is controlled to be 200 μm and the actuation diaphragm is 50 μm through tuning the rotational speed. Thirdly, the microchannel and pumping chamber with the passive biomimic PDMS valves were fabricated by PDMS cast on a high aspect ratio (5:1) silicon mold shown in Figure 7. The silicon mold was fabricated by

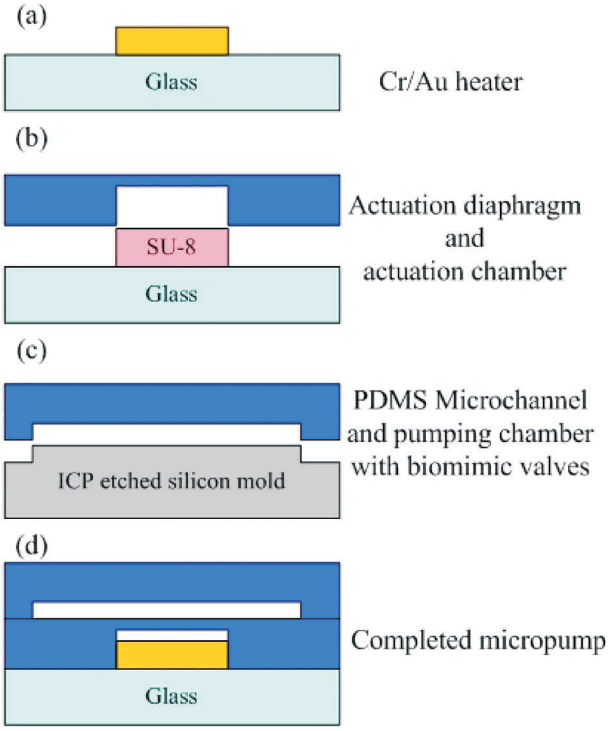

Figure 5. The detailed fabrication process of the micropump.

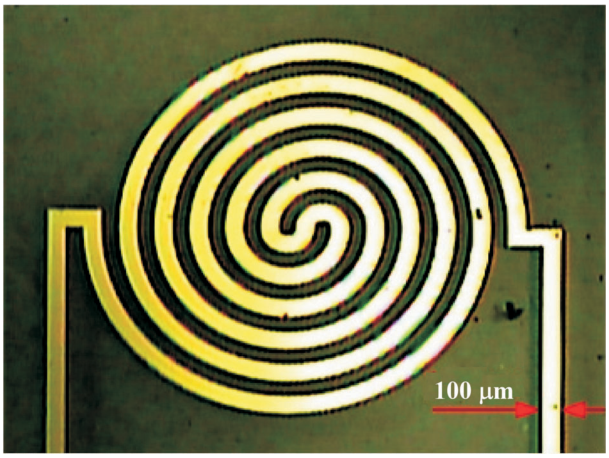

Figure 6. The shape of the fabricated heater.

traditional Inductively Coupled Plasma (ICP) Reactive Ion Etching system. At the end of the etching process, a Teflon-like with 100 nm thickness from C_4F_8 gas of ICP-RIE was deposited on the surface of the silicon mold. The super hydrophobic Teflon makes peeling off the cured PDMS easier. The microchannel structure on the silicon mold is controlled to be 100 μm deep and 100 μm wide, and the pumping chamber is with radius of 1500 μm. The fabricated valve with high aspect ratio is shown in Figure 8. Finally, these components of the

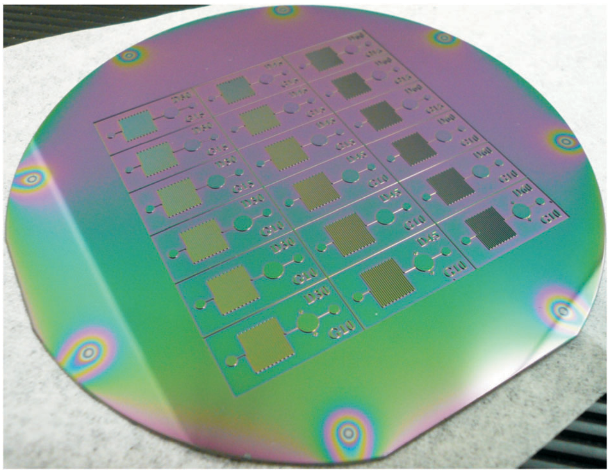

Figure 7. The high aspect ratio silicon mold fabricated by ICP.

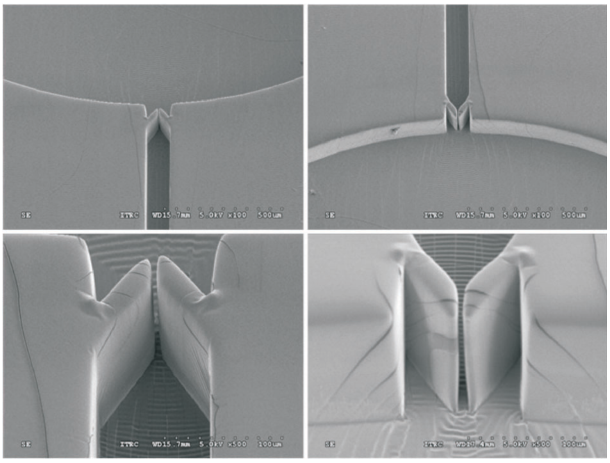

Figure 8. The SEM photographs of the fabricated passive biomimic PDMS valves.

micropump were bonded to each other after oxygen plasma treatment. In the bonding process, actuation chamber layer and microchannel layer were dipped into DI water to align precisely, which can provide smooth interface without aging the surface hydrophilic property [11]. The fabricated device is shown in Figure 9.

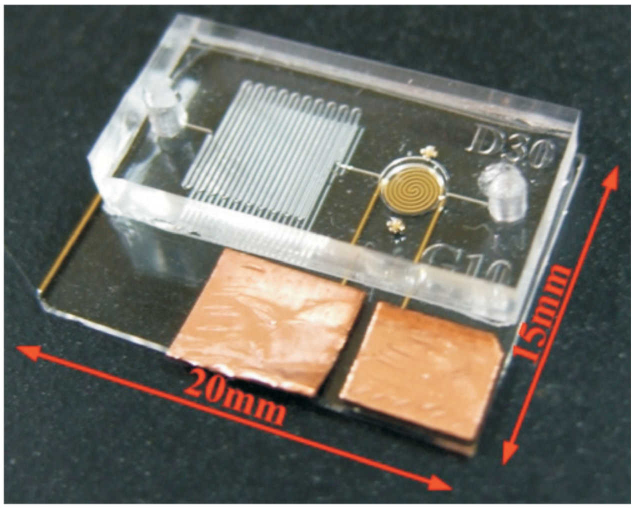

Figure 9. The fabricated micropump with biomimic passive valves.

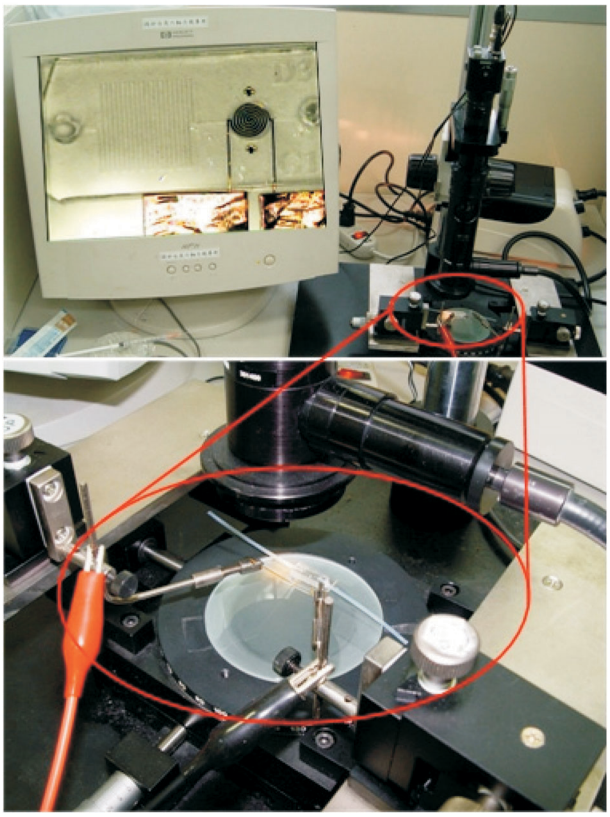

Figure 10. CCD camera recording module.

3. Results and Discussions

For observing the working pump, a CCD camera recording module was set up to measure the flow rate. The CCD module is shown in Figure 10. The module includes a color CCD, a monitor, an optical microscope with zoom lens, a function generator and a pair of 3-axis micropositioner. The frame rate of the CCD is 30 frames per second. The CCD is maimly used to record the positions of the fluid inside the microchannel and the time. In the measurement, all the dimensions of the microchannel are known parameters. Through the position and time of each frame recorded by the CCD, the flow rate of the micropump can be estimated. The 3-axis micropositioner with tip holder was used to connect with the pad of the heater. The tips on the holder can precisely touch the pads through the micropositioner. When applying electric power to the heater, the actuation diaphragm can be bent up to extrude the fluid. The bending actuation diaphragm is shown in Figure 11. From the OM images, the actuation diaphragm was bent up and attached to the top of the pumping chamber with 100 μm deep. By the observation, the deformation amplitude of the actuation diaphragm is larger than 100 μm. The resistance of the heater is measured about 57 ohm. The micropump is driven by an AC square wave of 10 volt peak. The thermopneumatic PDMS-based micropump is preliminarily tested and shown in Figure 12. The dyed DI water in the microchannel is pumped to the initial position at 0 second. After serially applying power to heater, the micropump is driven for 36 seconds. The dyed DI water in the microchannel is delivered for 6 mm. The flow rate is estimated as 100 nL per minute. Compared to the developed thermopneumatic valveless micropump with PDMS-based nozzle/diffuser structure [10], the thermopneumatic micropump with the passive biomimic PDMS valve is more efficient. Most developed valveless micropumps were fabricated by the hard materials and driven by squeezing pumping chamber at a high frequency. Meanwhile, the asymmetric flow resistance formed by nozzle/diffuser structure was fully acted on the fluid. Due to the material properties, the asymmetric flow resistance of the valveless micropump with PDMS-based nozzle/diffuser was not fully acted on the fluid. Instead of pumping efficiently, the deformation was produced in the PDMS-based nozzle/diffuser structure. The soft property became a defect of the PDMS-based nozzle/diffuser structure. Nevertheless, the defect is here contrarily an advantage in the passive biomimic PDMS valve. The deformation produced in the passive biomimic PDMS valve is provided to produce the large asymmetric flow resistance for driving the fluid. The flow rate of the micropump with the passive biomimic PDMS valve can be larger than the micropump with PDMS-based nozzle/diffuser structure for an order.

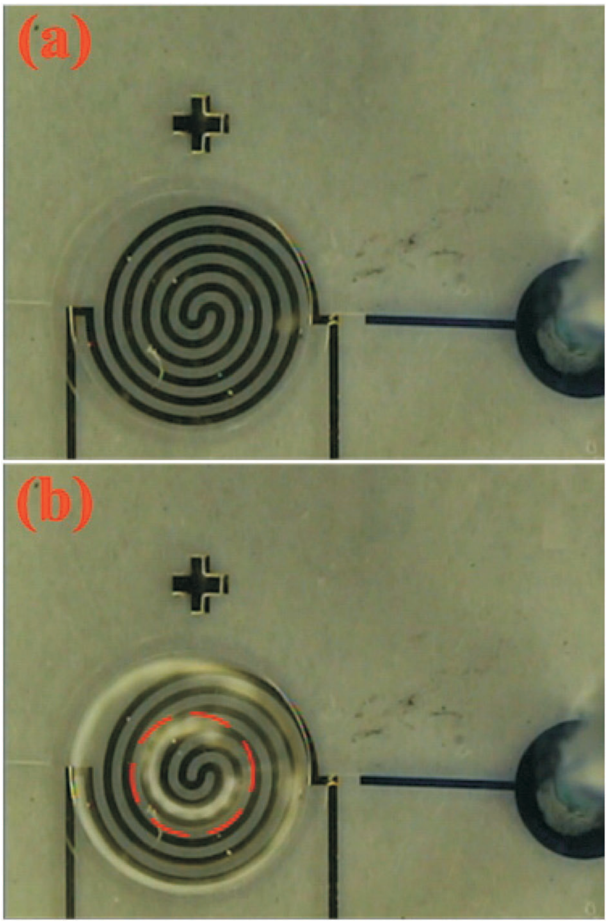

Figure 11. Applying power to heater: (a) before applying; (b) after applying.

4. Conclusion

A novel passive biomimic PDMS valve was pro-

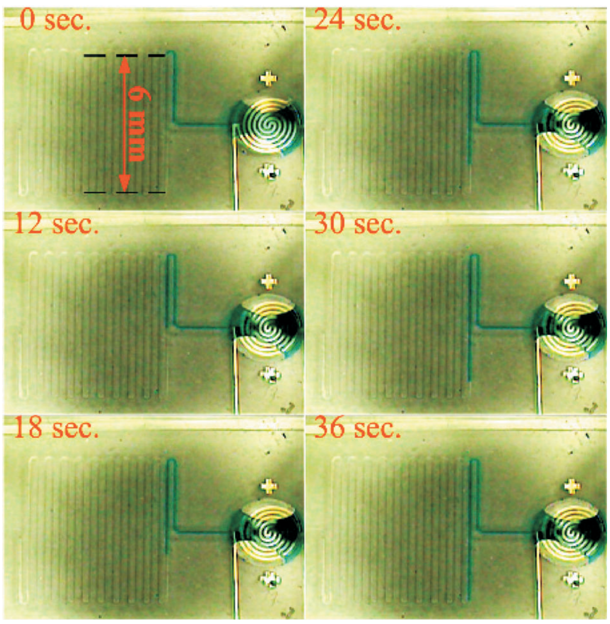

Figure 12. Preliminarily test: pumping for 36 seconds.

posed here. We successfully designed, realized and applied the passive biomimic PDMS valve in the PDMS-based thermopneumatic micropump. The micropump is driven by 1 Hz AC square wave of 10 volt peak. The thermopneumatic PDMS-based micropump is preliminarily tested and driven for 36 seconds. As the result, the measured flow rate is 100 nL per minute. This work provides a simple and rapid prototyping approach to fabricate PDMS-based micropump. The passive biomimic PDMS valve can improve the efficiency of the developed PDMS-based pneumatic and peristaltic micropumps. It is proved to be useful in the scale of nano-liter manipulation. We believe that the micropump with the novel passive biomimic PDMS can provide better integration for lab on a chip and useful applications, like drug delivery, cell culture chip, microfluidic chip, integrated biodetection chip.

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