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Fabrication and Drive Test of a Peristaltic Thermopnumatic PDMS Micropump

Ok Chan Jeong
Center for Promotion of the COE program, Ritsumeikan University,
1-1-1 Nojihigashi, Kusatsu, Shiga 525-8577, Japan
Sin Wook Park, Sang Sik Yang*
Division of Electrical and Computer Engineering, Ajou University,
San 5 Wonchun-Dong, Yeongtong-Gu, Suwon 443-749, Korea

This paper presents fabrication and drive test of a peristaltic PDMS micropump actuated by the thermopneumatic force The micropump consists of the three peristaltic-type actuator chambers with microheaters on the glass substrate and a microchannel connecting the chambers and the inlet/outlet port The micropump is fabricated by the spin-coating process, the two-step curing process, the JSR (negative PR) molding process, and etc The diameter and the thickness of the actuator diaphragm are 2 5 mm and 30 μm, respectively The meniscus motion in the capillary tube is observed with a video camera and the flow rate of the micro pump is calculated through the frame analysis of the recorded video data. The maximum flow rate of the micropump is about 0 36 μL/sec at 2 Hz for the zero hydraulic pressure difference when the 3-phase input voltage is 20 V.

Key Words: PDMS (Polydimethylsiloxane) Micropump, Peristaltic Micropump, Thermopneumatic Force, Flow Rate

1. Introduction

Recently, various micro fluidic devices with no mechanical moving part have been fabricated with PDMS (Polydimethylsiloxane) for applications in bio-chip and lab-on-a-chip because of its key merits such as transparency, biocompatibility, and low production cost (McDonald and Whitesides, 2002; Griscom et al, 2002) However, a study on the micropump with a mechanical actuator fabricated by means of multi-stacked PDMS molding technique hardly ever reported even though some advantages of the PDMS elastomer like the remarkable flexibility and the simple fabrication process including the reliable bonding process between PDMS-to-PDMS or PDMS-to-glass (Juncker et al, 2001)

Sim et al (2003) described the membrane-type micropumps with various actuators The advantages and disadvantages of each micropump are also discussed from the viewpoint of the power consumption, the integration method, the response time, the operation frequency and voltage, the fabrication process, the actuation efficiency and etc For the simple fabrication process and the large volume stroke of the micropump, the thermopneumatic actuation method is suggested

The micropump requires a micro valve unit for the one-way flow rate of the working fluid Microvalves are classified into the passive valve and the active valve (Esashi et al, 1989, Selvaganathy et al, 2003) The active valve is useful to control the flow rate under the some pressure difference, but its fabrication process is

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* Corresponding Author,
E-mail ssyang@ajou ac kr
TEL +82-31-219-2481, **FAX** +82-31-212-9531
Division of Electrical and Computer Engineering, Ajou University, San 5 Wonchun-Dong, Yeongtong-Gu, Suwon 443-749, Korea (Manuscript **Received** August 24, 2004, **Revised** December 3, 2004)

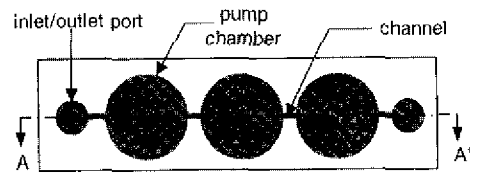
complicated. The passive check valve operates only to the forward pressure and has simple structures compared to the active valve. However, with the passive check valve, the control of reverse flow rate under the pressure difference is impossible.

In this paper, as new approaches for the fabrication of the membrane-type micropump and its associated components, the peristaltic micropump using the thermopneumatic actuation has been fabricated through a simple PDMS molding and bonding process. The peristaltic-type actuators can be operated as a dynamic valve and controlled easily by the applied electric input power without any additional process for the microvalve unit.

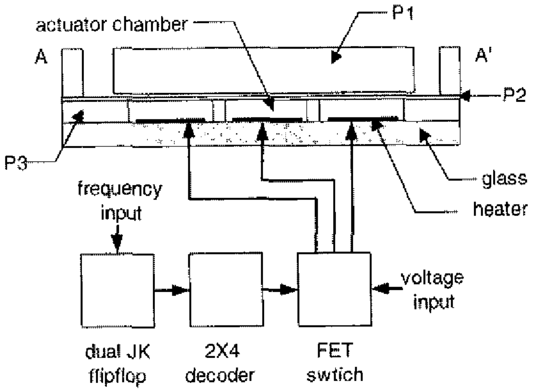
2. Structure and Working Principle

Figure 1 shows the top view and the structure of the micropump. The micropump consists of microchannels, connecting three pump chambers and an inlet/outlet ports, and three peristaltic actuators operated by a three-phase input power. The diameter and thickness of the actuator diaphragm are 2.5 mm and 30 μm, respectively. The height of the actuator chamber is 500 μm. The length, the width and the depth of the microchannel are 500 μm, 100 μm and 47 μm, respectively. The height of the pump chamber is 47 μm. The volume of unit pump chamber is 0.23 μL.

Figure 2 illustrates the working principle of the peristaltic micropump. If the three-phase electrical power is applied to the micro heater, the pressure in the sealed actuator chamber is varied by the ohmic heating and the natural cooling of the air in the actuator chamber. The magnitude of the electric power determines the pressure change amount. The three-phase motions of the actuator diaphragms convey the fluid in the pump chamber. Because two pump chambers are always closed, no backward flow is allowed. The working fluid is sucked into the inlet chamber and spouted from outlet chamber between phase I and phase II.



(a) Top view



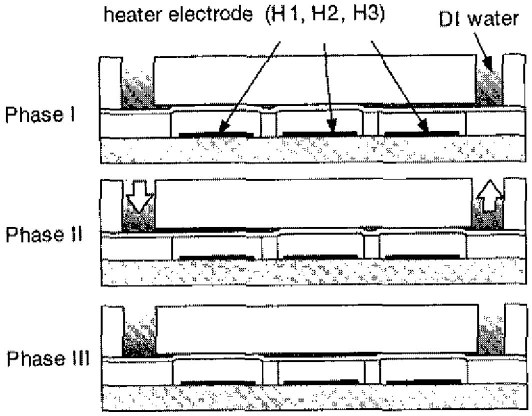
(b) Cross sectional view and drive circuit

P1 : actuator chamber PDMS layer

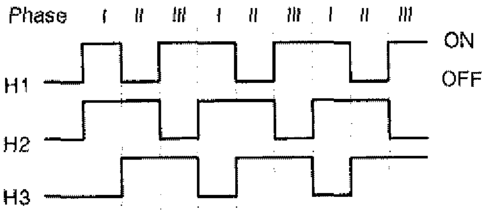
P2 : actuator diaphragm PDMS layer

P3 : microchannel PDMS layer

Fig. 1 The schematic view of the micropump



(a) 3-phase actuation



(b) 3-phase input signal

Fig. 2 The working principle of the peristaltic micropump with three actuators

3. Fabrication Process

Figure 3 shows the fabrication process of the micropump. The actuator chamber layer, the diaphragm layer and the cavity layer is fabricated through the sequential spin coating, soft curing, and bonding process of PDMS elastomer. The thickness of the PDMS layer can be controlled by the spin coating condition.

First for the actuator chamber layer, a 10 : 1 mixture of PDMS pre-polymer and curing agent is stirred thoroughly and degassed in the vacuum chamber. As shown in Fig. 3(a), the prepared PDMS mixture is poured on a silicon wafer, spun at 500 rpm for 10 seconds, and cured at 65℃ for 15 minutes. The cured 500 μm-thick PDMS layer is peeled off and three throughholes of 2.5 mm diameter which will be the actuator chamber are punched out. After O2 plasma treatment the actuator chamber layer is bonded with Pyrex glass (#7740) where a Cr/Au (500Å/1500Å) heater is fabricated. For the 30 μm-thick actuator diaphragm layer the PDMS mixture on the silicon wafer for is spun at 3000 rpm for 10 seconds, and then softly cured. Also for the layer of the pump chamber and the channel, the pre-polymer mixture is poured onto a 47 μm-thick mold of JSR negative PR as shown in Fig. 3(c). This PDMS layer is 3 mm thick and is peeled off from the JSR mold after soft curing. After punching out the inlet and outlet throughholes, we lay the actuation cavity layer onto the actuator diaphragm layer as shown in Fig. 3(d). The flexibility of PDMS enables the actuation cavity layer to contact tightly with the actuator diaphragm layer and prevents any bubbles from forming at the interface. The stacked PDMS layers are irreversibly bonded by curing at 65℃ for 10 minutes and peeled off from the substrate. The peeled PDMS layers are bonded onto the actuation chamber layer of Fig. 3(b) by curing at 65℃ for 10 minutes as Fig. 3(e). Finally, the entire PDMS layers are cured at 100℃ for 60 minutes.

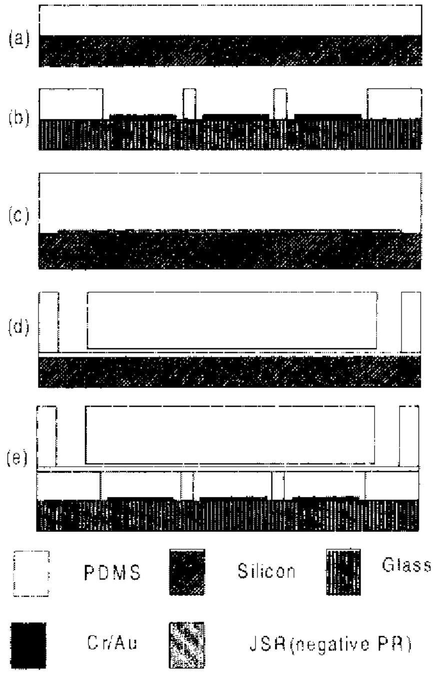
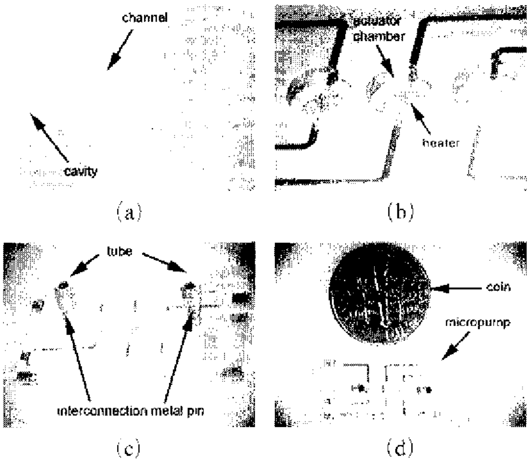


Fig. 3 The fabrication process of the micropump (a) Soft curing of the actuator chamber layer, (b) Glass plate with heater and actuator chamber layer bonding, (c) Actuator cavity (channel) casting, (d) Actuator chamber layer and diaphragm bonding, (e) Entire structure bonding

Figure 4 shows the photographs of the fabri-



(a) (b)

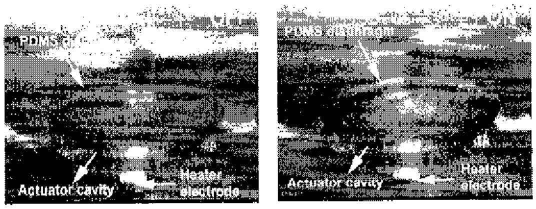
(c) (d)

Fig. 4 Photographs of the fabricated micropump : (a) the channel and cavity, (b) the actuator chamber and Cr-Au heater electrode, (c) the fully assembled micropump, (d) comparison with a dime cated micropump. The heater resistance is about 72 Ω at the room temperature.

4. Measurement

Since all layers of the micro actuator are transparent, it is impossible to measure the deflection of the actuator diaphragm by using a conventional measurement system like a laser displacement sensor. In this paper, the deflections of the micro actuator are approximately measured by the frame analysis of the recorded high speed video camera images.

Figure 5 shows the captured images of the actuator diaphragm when the input voltage of 20 V DC was applied to the heater electrode. Figure 6 shows the measured deflections and the temperature changes of the heater electrode on the glass substrate measured with the non-contact infrared thermometers. The mechanical sensitivity of the micro actuator with the PDMS diaphragm is about 5.2 μm/V.



(a) (b)

Fig. 5 The captured video clips showing the deformed PDMS diaphragm ; (a) before actuation, (b) 3 seconds later

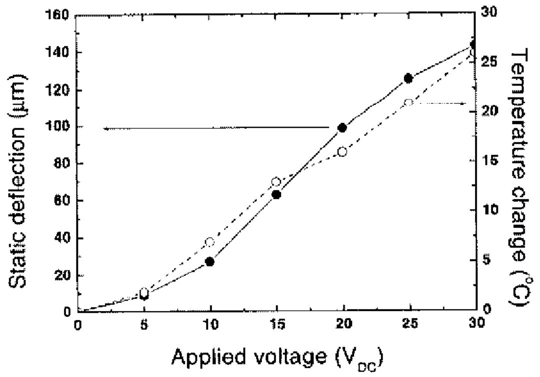


Fig. 6 The measured deflection and the temperature change

Figure 7 shows the measured peak-to-peak deflections and the DC offset deflection when the applied voltage is 20 V. As the frequency increases, the peak-to-peak deflection decreases while the DC offset deflection increases. It means that the actuator diaphragm is not fully recovered during the off-state at high frequency because of the thermal resistance and the thermal capacity of actuator chamber.

Figure 8 shows the measurement set-up for the measurement of the flow rate of the micropump.

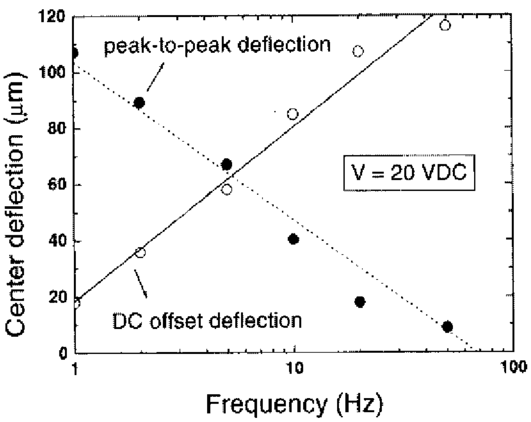


Fig. 7 The measured peak-to-peak deflection and the DC offset deflection of the actuator diaphragm

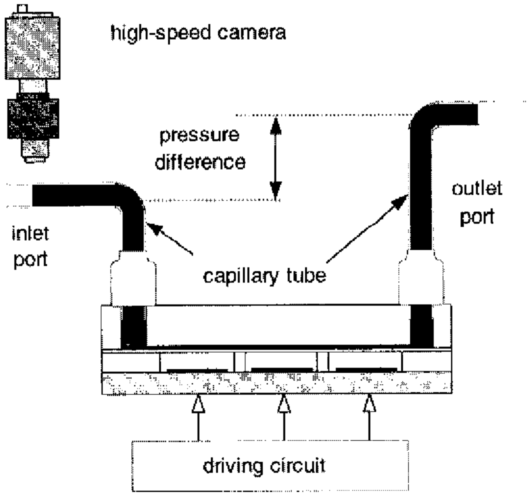


Fig. 8 The measured set-up for the measurement of the flow rate of the micropump

The pressure difference of this paper is defined as the height difference between the menisci of the outlet port and the inlet port. The displacement of the meniscus in the capillary tube is observed and recorded with a video microscope (Hi-scope KH-2200, HiRox) and a videocassette recorder.

Figure 9 shows the measured flow rate of the micropump versus the frequency. The volume injected from the micropump during one cycle at 1 Hz is 0.22 μL. The maximum flow rate is about 0.36 μL/sec at 2 Hz when the hydraulic pressure difference is zero. Figure 10 shows the measured flow rate of the micro pump for several pressure differences at 2 Hz. As the height of the outlet port increases, the flow rate of the micropump decreases.

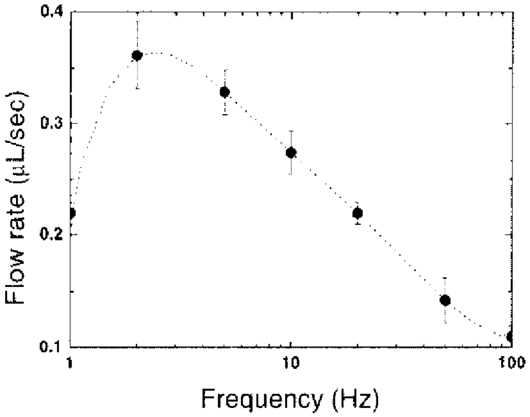


Fig. 9 The measured flow rate of the micropump under the zero hydraulic pressure difference

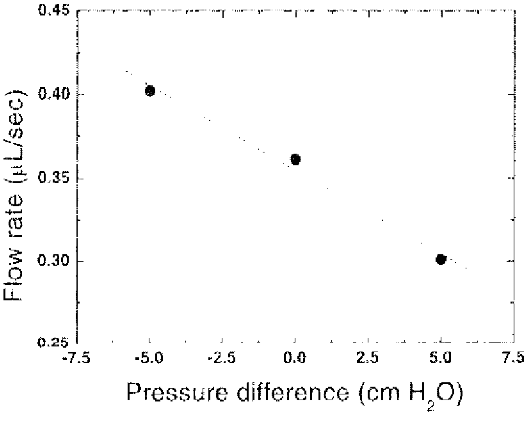


Fig. 10 The measured flow rate of the micropump for several pressure differences

5. Conclusions

In this paper, a thermopneumatic peristaltic-type PDMS micropump has been fabricated through several processes of spin coating, curing and irreversible bonding. The peristaltic motion of the fabricated micropump was observed through the transparent structure and the flow rate of the micropump in the frequency domain was measured at the zero pressure difference. The maximum flow rate is about 0.36 μL/sec when the input voltage is 20 V and frequency is 2 Hz.

PDMS elastomer is useful material to make membrane-type micropumps because of several advantages such as transparency, flexibility, simplility of the fabrication process and the low production cost. The performance of the device is applicable to nanoliter-level or microliter-level fluid control systems such as drug delivery systems.

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