A LOW-COST VALVE AND PUMP WITH POLYPROPYLENE (PP) FABRICATED BY UV/OZONE-ASSISTED THERMAL FUSION BONDING

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ABSTRACT

A membrane microvalve and pump have been fabricated with polypropylene (PP) film bonded between poly(methyl methacrylate) (PMMA) microfluidic layers by Ultra-Violet/Ozone (UV/O3) assisted thermal fusion bonding. The developed PP-PMMA microfluidic device has been fully characterized and compared with a conventional PDMS-membrane device which is bonded between glass substrates. The developed PP-membrane device successfully demonstrated a comparable valving and pumping performance with the PDMS-membrane device. In addition, the suggested fabrication technique allowed a geometrically selective bonding to prevent the membrane from bonding with a valve seat, which has been a hurdling issue in a membrane microvalve.

KEYWORDS

Micro valve, Micro pump, Polypropylene membrane, Lab on a chip

INTRODUCTION

A lab-on-a-chip (LOC) technology has been extensively utilized to accurately analyze a small volume of sample according to a variety of purposes. Because the LOC device is comprised of a plurality of microfluidic channels and chambers, multiple laboratory tests could be systematically performed for a target sample. However, to construct a robust and reliable LOC device, an on-chip microvalve and micropump is essential, so that a sample and a reagent could be accurately provided at desired positions in the microfluidic device. Among a various types of the developed microvalves, a monolithic microvalve has been widely adopted due to its reliable valving performance and highly dense integration with microfluidic channels [1]. In this work, the monolithic microvalve and pump for low-cost applications have been simply implemented with PP membrane and PMMA substrate by the UV/O$_3$ assisted fusion bonding. The PP-PMMA device demonstrated a comparable valving and pumping performance with PDMS-glass device. Thus, the developed device can be widely applicable for mass-producing disposable LOC applications.

EXPERIMENT

Device fabrication

The operation principle of membrane microvalve is illustrated in Figure 1 (a) and (b). The flow of sample fluid is controlled by applying the pneumatic pressure to the membrane. As shown in Figure (c), the membrane is sandwich-bonded between the fluidic layer and the pneumatic layer. So, the flow path is blocked when the positive pressure is applied to the membrane. On the other hand, when the vacuum pressure is applied to the membrane, the sample solution could flow through the valve region.

A polypropylene (PP) film was utilized as a membrane of the microvalve. The PP film was bonded to injection-molded PMMA substrates, where one had fluidic channels and the other had pneumatic channels. To ensure a flexibility of the membrane, the 50 um thick PP film was utilized. The fluidic layer and the pneumatic layer were fabricated with PMMA by plastic injection molding on the microstructure patterned nickel (Ni) mold.

UV/Ozone assisted Thermal Fusion Bonding

After injection molding the fluidic and pneumatic substrates with PMMA, each plastic layer was thermally fusion-bonded with PP film membrane.
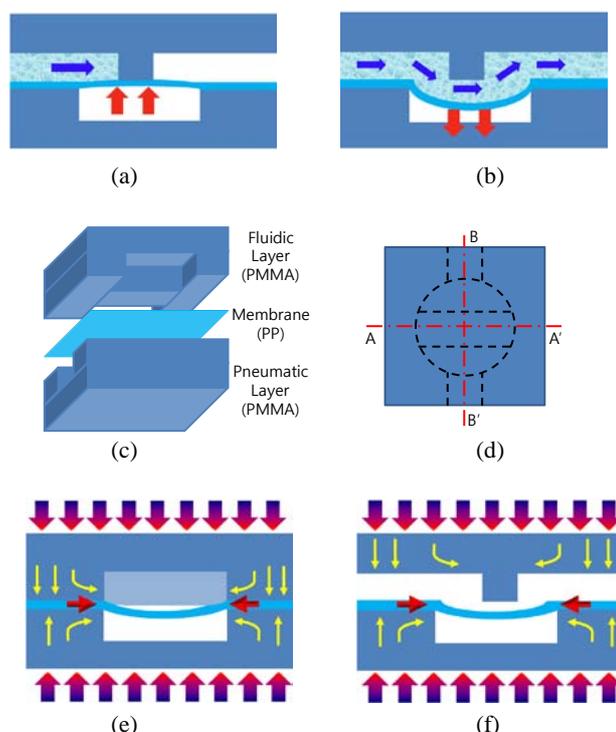

Fig. 1. Schematic illustrations of PP membrane microvalve. . (a) valve close, (b) valve open, (c) Device configuration, (d) top view, (e) cut view (A-A'), and (f) cut view (B-B').
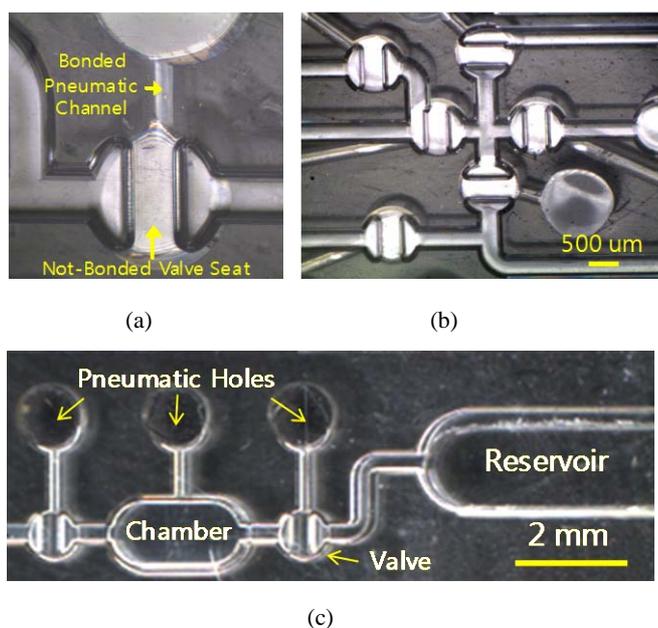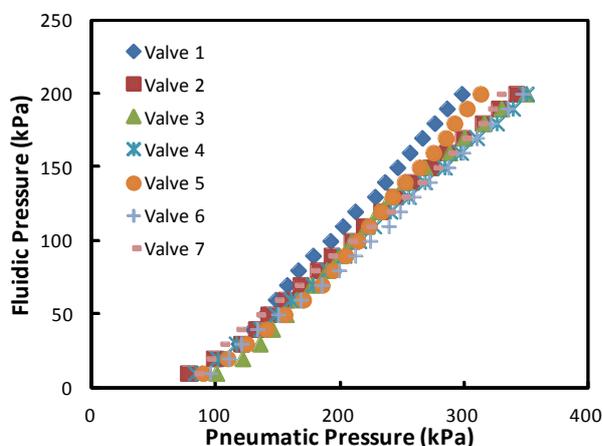
Fig. 2. Microscopic images of fabricated micro valve. (a) Geometrically selective bonding for actuating the membrane of micro valve. Bright region due to a light reflection shows a not-bonded part of membrane. (b) Array of selectively bonded micro valve.

The thermal fusion bonding widely utilized to bond two polymer materials which are same material or have a same Tg. Generally, heterogeneous materials with different Tg is not strongly bonded by common thermal bonding procedures. Even though UV/O$_3$ assisted bonding was previously introduced [2], the bonding materials were limited to the same materials such as COC to COC and PMMA to PMMA. In this work, a robust bonding between the PP film and the PMMA substrate was attained by UV/O$_3$ treatment. The UV/O$_3$ assisted thermal-fusion bonding enables bonding between two different thermoplastics at low bonding temperature below their Tg. The bonding surfaces of PP and PMMA were treated by UV/O$_3$ for 5 minutes (Zeolite Inc, USA). Then, the pneumatic layer and the PP film were bonded by an automatic hot press (CARVER Inc., USA) at the temperature of 55 °C.

Geometry-selective bonding

Three layers of heterogeneous polymers, PMMA-PP-PMMA, was bonded together to implement the membrane microvalve. While the membrane was bonded to the fluidic substrates and the pneu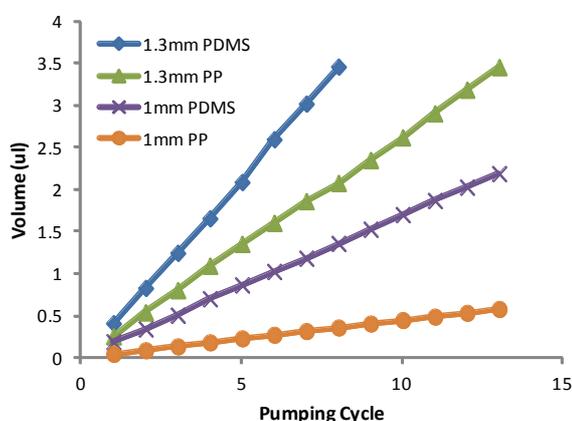matic substrates, the membrane could be easily bonded to the valve seat at the fluidic layer. Once the membrane was bonded to the valve seat, the flow path was permanently blocked. To prevent this failure during the bonding procedure, the selective bonding technique was developed in this work by utilizing a geometry of the pneumatic layer and the polymer deformation. To achieve the thermal fusion bonding, both heat and pressure should be applied to the thermoplastic materials. Because the pneumatic layer had a pattern of pneumatic chamber for the pneumatic actuation above the valve seat of the fluidic layer, the pressure was not applied to the membrane at the valve seat region. So, the membrane at the valve is not bonded to the valve seat of the fluidic layer due to the absence of the bonding pressure. Also, during the bonding process, PMMA substrate was slightly deformed in arrow directions as illustrated in Figure 1 (e) and (f). While the deformed PMMA substrate was extruded to the empty space of the chamber pattern, the sandwiched PP film was also pushed to the valve region. As a result, the PP film was set apart from the valve seat with a curvature shape, so that the membrane was selectively not-bonded to the valve seat. Figure 2 (a) and (b) show the microscope pictures of the selectively bonded membrane between the pneumatic layer and the fluidic layer. To show the difference between a bonded region and a not-bonded region, the microscope images were taken while the fabricated chip was inclined, which made the not-bonded regions brighter than the bonded region by a light reflection.

Valving performance and characterization

The valve performance was evaluated by measuring a valve closing pressure (VCP) as shown in Figure 3 (a). The VCP was defined to be a minimum pneumatic pressures to block the air flow with the fluidic pressure. While the

Fig. 3. (a) Measurement of valve closing pressure (VCP) which is the minimum pneumatic pressure to block the air flow with the fluidic pressure. (b) Chip-to-chip variation of VCP for blocking the fluidic pressure of 100 kPa.
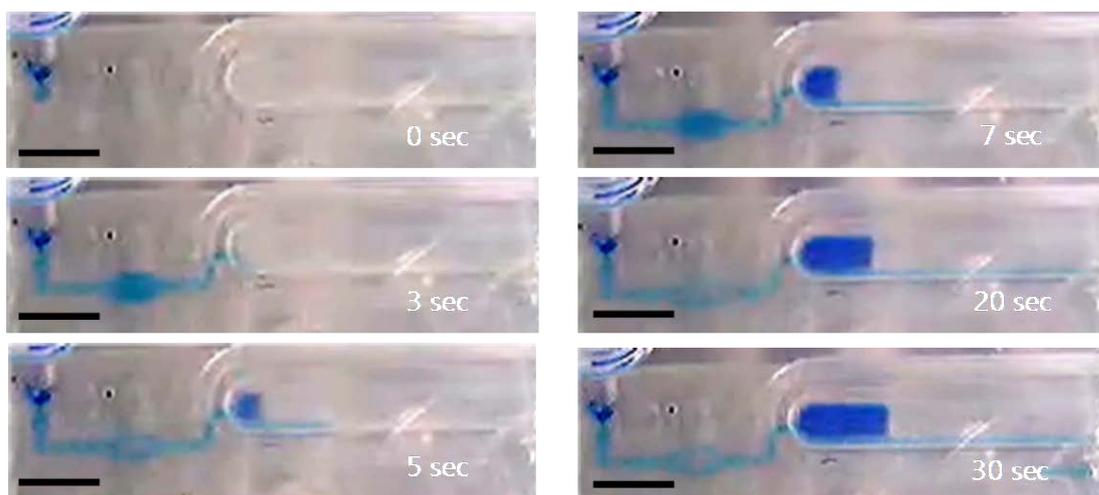
Fig. 4. Operation images of the PP-membrane micropump to a reservoir (3mm scale bar)

pressured air was supplied to the inlet of microchannel, the tube connected to the microchannel outlet was submerged in DI water to check the air bubble due to the valve leakage. Until the air bubble at the end of the outlet tube was detected, the pneumatic pressure was slowly reduced. The minimum pressure for blocking the pressurized air without the leakage was recorded as VCP for each fluidic pressure. As the fluidic pressure increased, the pneumatic pressure increased for closing the valve with a linear relationship. Additionally, the tested valves showed the small deviations to block the air flow at the same fluidic pressure, enabling a stable valve operation when the developed valve would be applied to the device with multiple valves.

Pumping performance characterization

The monolithic micropump with the PP membrane was implemented by sequentially operating 2 valves and 1 chamber. Also, the result was characterized in comparison to the PDMS-membrane micropump. Since the membrane deflection and the pumping volume were dependant on the pump size, two sizes of pump with dimensions of 1 mm by 2mm and 1.3 mm by 2.6 were tested. Figure 4 shows sequential pictures of reagent movement by the membrane micropump. The developed micropump resulted in the reagent flow to the reservoir which had cross-sectional dimensions of 1 mm wide and 0.7 mm high. The reagent with 3.5 ul volume was successfully delivered to the reservoir within 30 seconds, which was desirable pumping rate for microfluidic LOC applications.

As plotted in figure 3 (b), the pumping volumes of the PP device were compared to the PDMS device according to the pumping cycle. Because the elasticity of PP film was lower than the PDMS, the membrane deflection of PP film was smaller than the PDMS at the same pneumatic pressure. Thus, the pumping rate of the PP film micropump was lower than the one with PDMS. However, the large diameter of pump caused the higher pumping rate, because the pumping volume was dependant to the diameter of the membrane. In addition, even though the PDMS membrane was more easily deflected than the PP membrane, the membrane deflection was limited by the height of the chamber pattern. As depicted in Figure 3 (b), the PP-film pump provided 60 % of pumping rate than the PDMS-film pump at 200 kPa of the pneumatic pressure.

Conclusions

In this work, the monolithic microvalve and pump have been developed with PP membrane and PMMA substrate by the UV/O$_3$ assisted fusion bonding technique. Because the material price of PP and PMMA is very low and the fabrication process is simple and inexpensive, the highly functional Lab-on-a-chip can be produced in a low-cost manner. In addition, the PP-PMMA device demonstrated comparable valving and pumping performance with PDMS-glass device. As a result, the developed device is very desirable to implement various applications of polymer LOC such as a disposable type of device for clinical diagnosis.

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