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A novel polydimethylsiloxane microfluidic system including thermopneumatic-actuated micropump and Paraffin-actuated microvalve

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Abstract

A novel microfluidic system is presented using microvalves and a micropump, which are easily integrated on the same substrate, in order to accurately control the fluid flows in a micrototal analysis system and lab-on-a-chip. The system is realized by means of a polydimethylsilxane (PDMS)-glass chip and an indium tin oxide heater. This paper presents a novel microfluidic system including a thermopneumatic-actuated micropump and Paraffin-actuated microvalve. The maximum pumping rate of approximately 1.05 μl/min is observed at the duty ratio of 7% and frequency of 2 Hz, measured at a fixed power of 500 mW. The power at flow cut-off is measured at approximately 300 mW for the microvalve of which channel width and depth are 400 and 140 μm, respectively.

Keywords: Microfluidic system; Micropump; Microvalve; Polydimethylsiloxane (PDMS); Indium tin oxide (ITO)

1. Introduction

Numerous fluidic applications in such areas as medicine, chemistry, environmental testing and thermal transport, have the potential to be scaled down for reasons of simplified structure, device cost or portability [1]. Microfluidic system is one of the most important elements for an application to microchemical analysis systems, such as a micrototal analysis system (micro-TAS) or a lab-on-a-chip [2]. It is essential to develop an integrated microfluidic system including micropump, microvalve, microchannel, mixer and divider, used as parts of an integrated lab-on-a-chip for the control of the chemical and biological solutions. Miniaturized systems for biochemical assays significantly reduce cycle times, reagent costs and labor intensity. This requires the ability to precisely and efficiently control the transport of reagents and samples throughout different parts of the system. Cost-effective fluidic components, including micropump and microvalve, are capable and reliable and are required for such scaled down systems. Since current microfluidic systems have been fabricated on a silicon wafer, some disadvantages exist, such as high cost, complex fabrication procedures and limited controllable range regarding generated pressure, flow and pumping rates [3]. Also, they have complex structures because valve seats or other sealing components are required [4]. Because the integration of microvavles and micropumps require complex structures, the development of lab-on-a-chip has difficulties in integrating with micropumps and microvalves on the same substrate. These technical problems, however, can be avoided by replacing polydimethylsiloxane (PDMS) instead of silicon processing. PDMS replications have flexible and hydrophobic characteristics. The proposed system consists of indium tin oxide (ITO)-coated glass and PDMS layers, therefore, it has advantages in terms of the low cost fabrication process and optical transparency. The PDMS micromolding technique is suitable for fabrication of a disposable microfluidic system for biological and chemical applications. Thus, we have previously reported a new type of miniaturized microfluidic system integrated with the PDMS-based

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micropump and microvalve, which have the same fabrication process as the in-channel structure [5,6]. Actuators of the microfluidic system must be small, operating with low power, and must integrate easily with the system components. The suggested microfluidic system can reduce costs for manufacturing, complexity and size. The micropump and microvalves are installed for dispensing and mixing microliter or nanoliter liquid volumes. The micropump and microvalve are designed to be an integral part of a microfluidic processing system. The primary advantages of the new microfluidic system are in their ability to handle fluids with cells and particles in a microfluidic environmental and simplicity in terms of cost effectiveness and reliability.

In order to examine the optimal operating conditions for the microfluidic system, the pumping rates of the proposed micropump are measured as functions of the frequency and duty-ratio of applied power. The performance of the microvalves is characterized by the applied power of the ITO heater.

2. Design

Fig. 1a is a cross-sectional view of the microfluidic system, and includes micropump and microvalves with the same structure. Fig. 1b presents the cavity of PDMS replica of integrated micropump and microvalves. The diffuser of the micropump has inlet width of 100 μm, length of 2250 μm and divergence angle of 10°. The depth of thermopneumatic chamber below pump chamber and Paraffin chamber below valve seat is 130 μm and the ITO heater measures 2.95 mm × 2.95 mm. The depth and width of microchannel cavity are 140 and 400 μm, respectively.

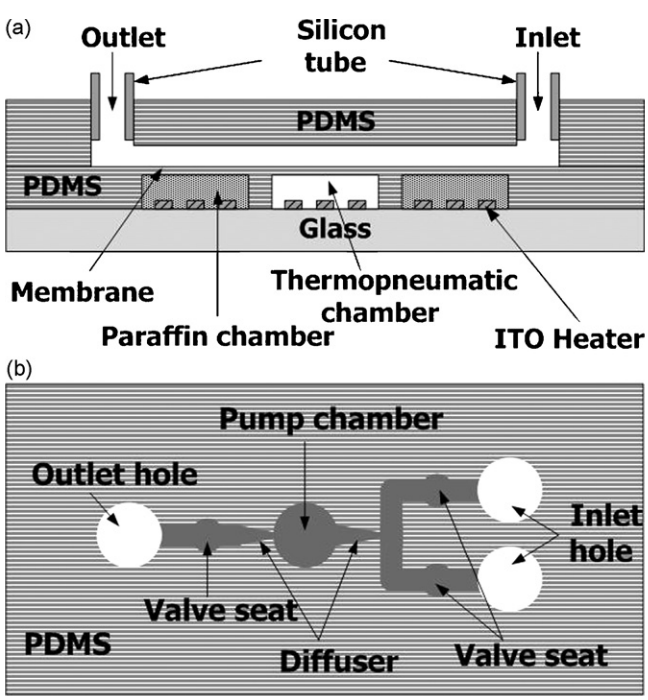

Fig. 1. Configurations of the proposed microfluidic system integrating the micropump and microvalve. (a) Cross-sectional view of the microfluidic system and (b) cavity of PDMS replica of microfluidic system integrating the micropump and microvalves.

In order to verify the relationships of membrane thickness, the PDMS membrane thickness is varied to 300, 390 and 450 μm. In addition, in order to examine the relationships of pump chamber and valve seat properties, the micropump is fabricated with different diameter of pump chambers of 4.0 and 4.5 mm. The dimension of thermopneumatic chamber is varied with the same size of pump chamber while the diameter of the valve seat and dimension of the Paraffin chamber are fixed at 1.5 mm, 3.0 mm × 3.0 mm and 2.0 mm, 3.5 mm × 3.5 mm, respectively.

The conceptual principle of micropump in the proposed microfluidic system is that the air undergoes volume expansion, when the ITO heater heats up the air of the PDMS thermopneumatic chamber. The PDMS membrane is deflected by air volume expansion. Contrariwise, when the ITO heater at power-off cooled down the heated air, the air shrank in volume. The micropump was actuated by the principle of diffuser operation and fluid flow with increasing and decreasing chamber volume [7]. The actuation mechanism of the microvalve depends on the thermally triggered phase change of the Paraffin resulting in volumetric expansion when it transitions from a solid to liquid phases to generate large volume displacement. Paraffin (Yakuri Pure Chemicals Company, Osaka, Japan) has desirable properties such as low thermal and electrical conductivity, low viscosity in the liquid phase and stability through numerous phase change cycles.

3. Fabrication

The proposed microfluidic system can be fabricated by assembling three different parts of PDMS and glass such

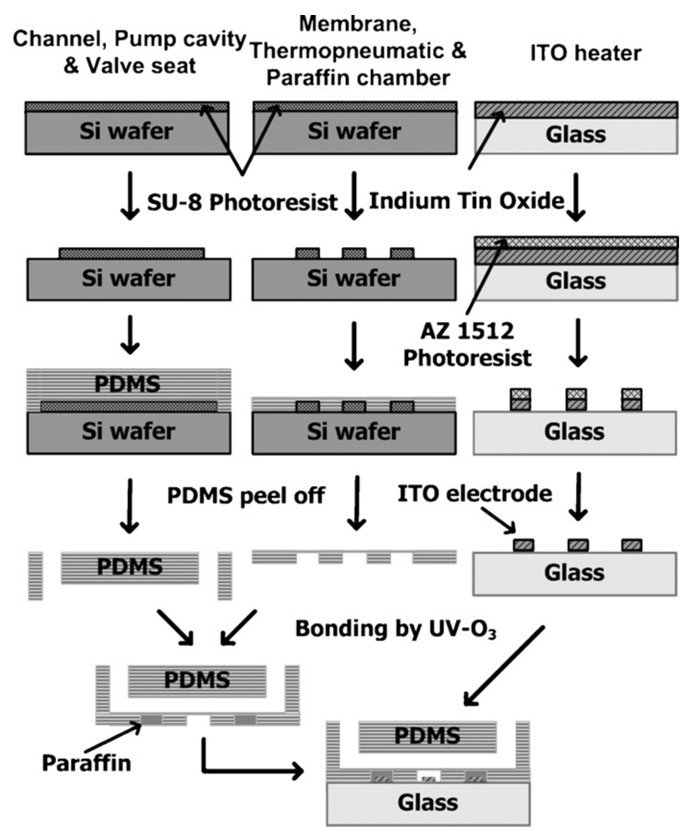

Fig. 2. Fabrication process of the microfluidic system.