A PHASE CHANGE MICROVALVE USING A MELTABLE MAGNETIC MATERIAL: FERRO-WAX

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Abstract

This paper presents a novel phase change microvalve using a paraffin-based ferrofluid plug (called "Ferro-Wax"). The Ferro-Wax plug is essentially leak-proof because of the phase change nature of the material; once the plug is solidified, it forms a solid seal. The meltable magnetic plug changes the phase from solid to liquid by an on-chip heating and moves remotely in a channel by a magnetic actuation. The reversible microvalve performed excellently up to 50 psi. The ease of fabrication and integration makes this microvalve invaluable for a next generation lab-on-a-chip device for on-chip sample preparation and label-free detection, which is currently underway.

Keywords: Ferrofluid, Microvalve, Paraffin Wax, Phase change, Nanoparticle

1. Introduction

A phase change microvalve using a meltable magnetic material, which is paraffin-based ferrofluid [1], has been designed and tested. Previously two groups have reported thermally actuated paraffin microvalves: A reversible microvalve with external pneumatic air/vacuum systems [2] and an irreversible microvalve without external pneumatic air/vacuum systems [3]. Our novel microvalve using the paraffin-based ferrofluid plug enables reversible operation without pneumatic air/vacuum systems. The plug changes the phase from solid to liquid by an on-chip heating and moves remotely in a channel by a magnetic actuation.

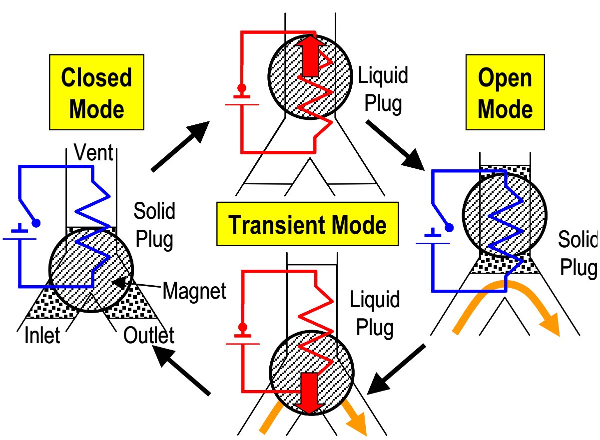

Fig. 1 Schematic diagram of the phase change microvalve operation: The valve is opened by addressing an electronic power to an integrated heater, changing the phase of the plug from solid to liquid, and moving the plug away from the Y-junction by the magnetic actuation. Closing the valve involves moving the liquid plug to the junction magnetically thereby sealing the main channel.

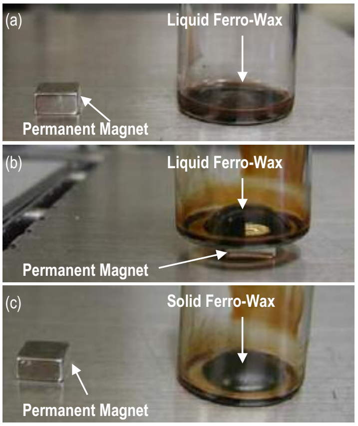

Fig. 2 Feasibility demonstration: (a) the liquid Ferro-Wax heated to 80 ℃ on the hot plate, (b) the liquid Ferro-Wax in the presence of the magnet at 80 ℃, and (c) the solid Ferro-Wax after cooled to room temperature in the presence of the magnet.

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2. Feasibility Test

Fig. 1 shows the schematic diagram of the reversible microvalve operation. The microvalve is opened by activating an integrated heater, changing the phase of the plug from solid to liquid, and moving the plug away from the Y-junction by the magnetic actuation. Closing the microvalve involves moving the liquid plug to the junction magnetically thereby sealing the main microchannel. Once positioned in either the closed or the open mode, the phase of the plug is changed to solid.

We utilized a paraffin-based ferrofluid, which is a colloidal suspension of ferromagnetic nanoparticles of 10 nm in a paraffin wax carrier and is immiscible in water, for the phase change plug. The paraffin-based ferrofluids conform to the channel shape, potentially providing very good seals, and respond to external localized magnetic forces, providing easy actuation. The new meltable magnetic material, the paraffin-base ferrofluid ("Ferro-Wax"), was formed by mixing ferrofluids and paraffin waxes with a volume ratio of 1 to 2 (Fig. 2) [5]. The Ferro-Wax materials can be engineered from various ferrofluids and paraffin waxes with different volume ratios, to control the saturation magnetization, viscosity, and melting temperature. Since the melting temperature of the Ferro-Wax that we used in this work was in the range of 68 to 74 ºC (Fig. 3), the operation temperature of the microvalve was set to 80 ºC.

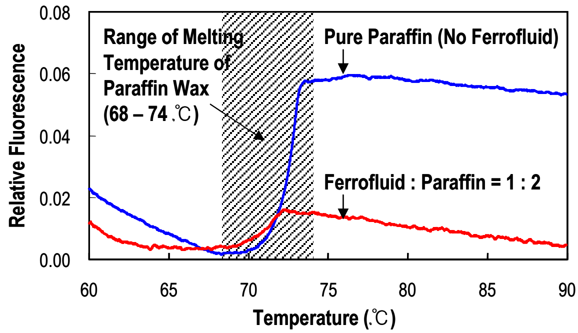

Fig. 3 Melting curves of the pure paraffin wax and the Ferro-Wax were measured by slowly heating from 60 to 90 °C by using a GenSpector® Micro PCR system [4].

3. Design and Fabrication

The simple active phase change microvalve was fabricated on a silicon-glass hybrid device as shown in Fig. 4. For injection of the paraffin-based ferrofluid plug, the chip (20 mm x 20 mm x 0.8 mm) was heated to 80 ºC on a hot plate and the plug of 0.2 μL

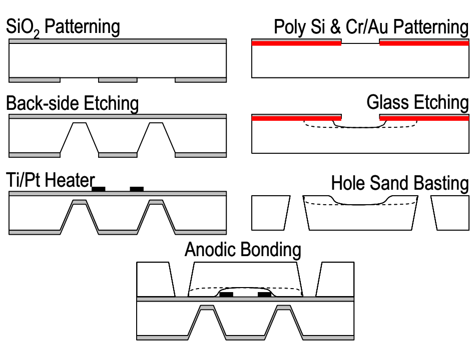

Fig. 4 Fabrication process flow for the silicon and glass sides of the microvalve.

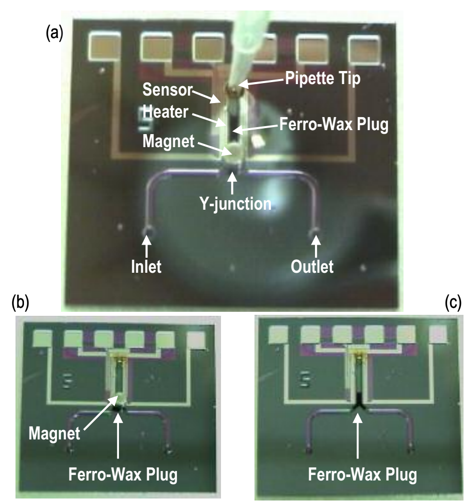

Fig. 5 (a) The chip was heated to 80 ℃ on the hot plate and meltable magnetic plug of 0.2 μL was being loaded into the vent hole, (b) the molten plug was stopped at the Y-junction in the presence of the magnet, and (c) the plug was solidified after cooled to 60 ℃.

was loaded into a vent hole (φ 500 μm). A magnet (φ1.5 mm x 1.5 mm) was placed on the top of the Y-junction. Then, the molten plug moved into the microchannel (300 μm x 150 μm) by capillary force and stopped at the intersection (Fig. 5).

4. Result and Discussion

The microvalve was characterized by measuring the maximum resistant pressure across the valve and the leakage flow in response to the upstream pressure (Fig. 6). For the closed valve state, no detectable leakage was observed up to 50 psi, which was the maximum pressure that we could apply using a pressure regulator (Cole-Parmer, USA). The Ferro-Wax plug is essentially leak-proof because of the phase change nature of the material; once the plug is solidified, it forms a solid seal.

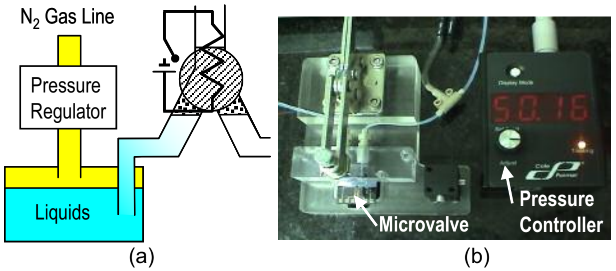

Fig. 6 (a) Measurement set-up for the maximum resistant pressure and the leakage flow in response to the upstream pressure. (b) The upstream pressure was controlled by the pressure regulator up to 50 psi.

5. Conclusion

In conclusion, we have designed and tested the novel phase change microvalve using the paraffin-based ferrofluid. The microvalve was simple to operate by the electronic addressing and the magnetic actuation. The reversible microvalve performed excellently up to 50 psi. Using the new meltable magnetic materials, Ferro-Wax, is invaluable for a next generation lab-on-a-chip device for on-chip sample preparation and label-free detection, which is currently underway.

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