SHAPE-MEMORY POLYMER MICROVALVES

Hiroaki Takehara[1,2], Koichiro Uto[3], Mitsuhiro Ebara[3], Takao Aoyagi[3] and Takanori Ichiki[1]
[1]School of Engineering, The University of Tokyo, Japan
[2]Research Fellow of the Japan Society for the Promotion of Science, Japan
[3]Biomaterials Unit, National Institute for Materials Science (NIMS), Japan

ABSTRACT

A novel shape-memory polymer (SMP) microvalve suitable for integration into micro-TAS devices has been developed. This valve has compatibility with electronics and is considered to be applicable to low-cost disposable chips. The valve has a simple design and is constructed with two adjacent microchannels and a polymeric sheet valve with a thin-film heater, but can provide either normally open (N/O) or normally closed (N/C) valve functions. We also demonstrated a field-programmable valve array (FPVA) with 8×8=64 valves that enables the custom design of microfluidic devices by analogy with a field-programmable gate array (FPGA) in LSI technology.

KEYWORDS

Shape-memory polymers, valve, poly(epsilon-caprolactone)

INTRODUCTION

Although extensive research has been conducted on microvalve technologies [1,2], the development of a simple and robust microvalve remains a challenging issue. In this paper, we report a microvalve that is actuated by the shape recovery of an SMP. An SMP is a material that can temporarily memorize shapes but reverts to its permanent shape upon exposure to an external stimulus such as heat. Compared with well-known metallic shape-memory alloys, SMPs show large deformability and changes in the elastic modulus at their response temperature, which are highly advantageous for the simple design and reliable actuation of microvalves.

EXPERIMENT

Figure 1 shows the proposed SMP microvalve. Poly(epsilon-caprolactone) (PCL) was used as the SMP. PCL can memorize the shape of microstructures at the submicrometer level [3] and reverts to its original shape near 50°C. Valve actuation was inspected by cross-sectional imaging (Figure 2). Each valve operated at an electrical potential of 5 V applied to a microheater on a chip. As shown in Figure 3, each valve actuated within 150 ms when sufficient heat (>13.5 mJ) was applied.

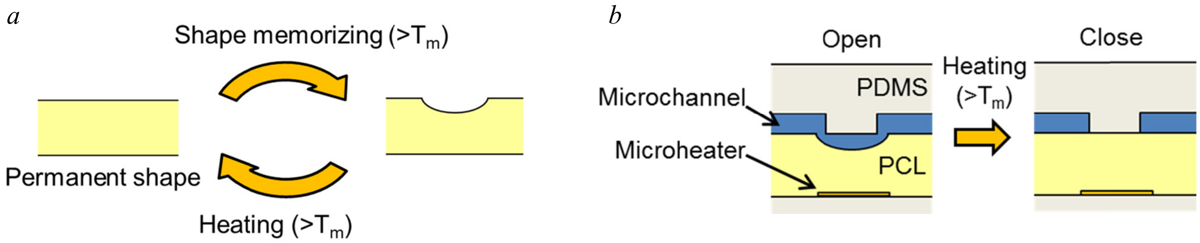

Figure 1. (a) Schematic of an SMP. (b) Schematic of proposed SMP microvalve (N/O valve). An N/O valve has a concave shape as its temporary shape and a flat shape as its permanent shape. Valve actuation was controlled by heating using a microheater.

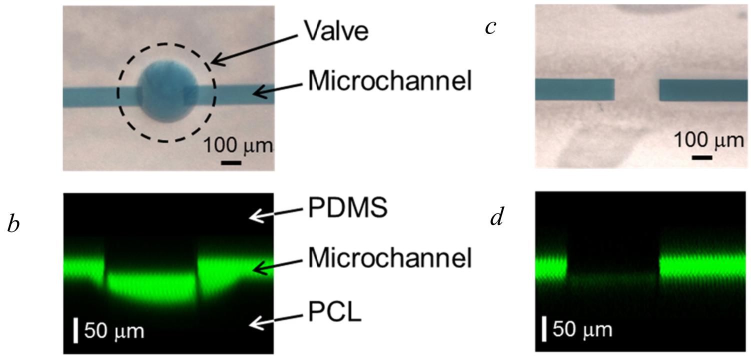

Figure 2. (a) Optical micrograph of an SMP microvalve in the open state. (b) Cross-sectional image of (a). Fluid can flow through the concave shape of the PCL layer. (c) Optical micrograph of a valve in the closed state. (d) Cross-sectional image of (c). The concave shape of PCL recovered to a flat shape.

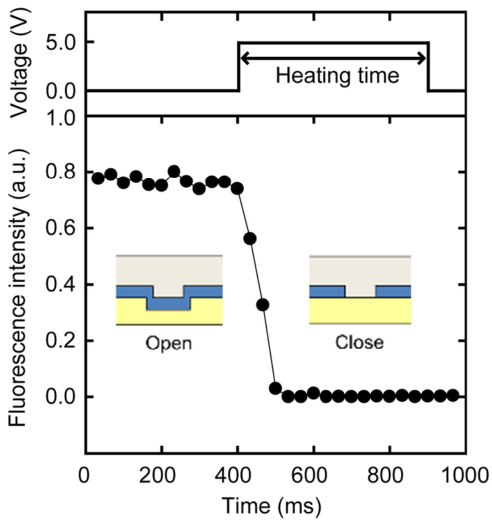

Figure 3. Time response of an SMP microvalve. Heating time is the duration of applying a voltage to a microheater. Valve opening was measured by determining fluorescence. The square area between the adjacent microchannels was monitored. The valve actuated within 150 ms.

Figure 4 shows N/O and N/C valves arranged in tandem. An N/O valve has a concave shape as its temporary shape and a flat shape as its permanent shape, and vice versa for an N/C valve. Tandemly arranged valves can actuate in sequence from a closed state to an open state and finally to a closed state. This sequence is one of the most frequently used sequences for performing the batch processing of liquid samples on a chip.

a

b

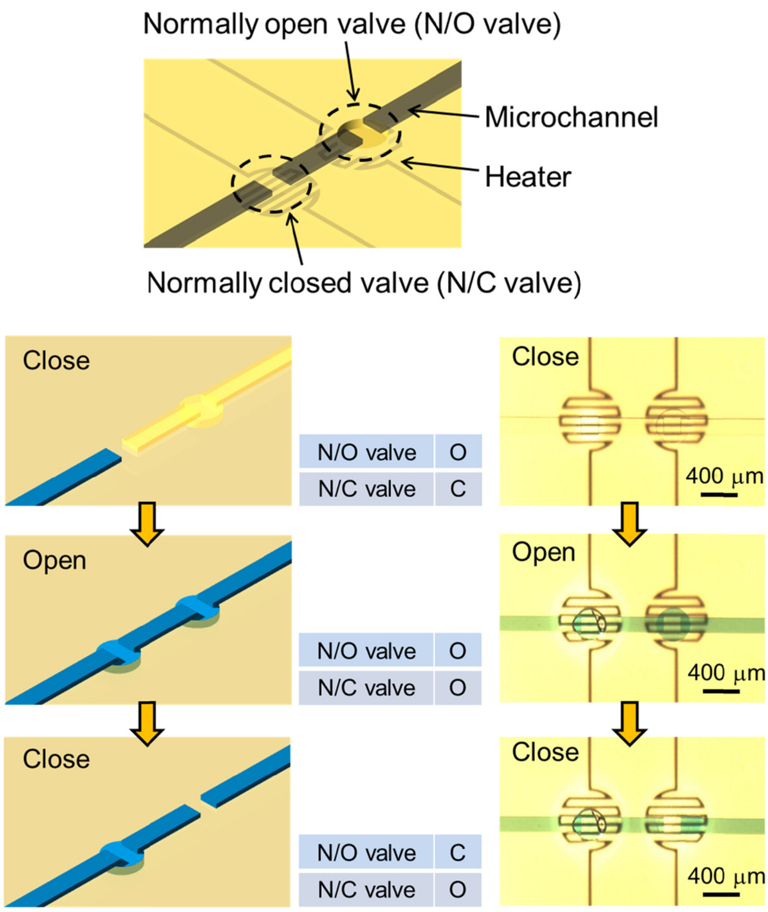

Figure 4. (a) Schematic of N/O and N/C valves arranged in tandem. An N/O valve has a concave shape as its temporary shape and a flat shape as its permanent shape. An N/C valve has a flat shape as its temporary shape and a concave shape as its permanent shape. (b) Tandemly arranged N/O and N/C valves can actuate in sequence from a closed state to an open state and finally to a closed state.

Finally, we fabricated an FPVA as shown in Figure 5. This FPVA is analogous to an FPGA, which is a programmable integrated circuit that interconnects several logic modules [4]. In contrast, the FPVA has a microchannel network that interconnects microfluidic components such as chambers, mixers and sensors. Valves are arranged at each crossing point of the microchannel network. Selective valve actuation enables the on-demand formation of an arbitrary microfluidic network.

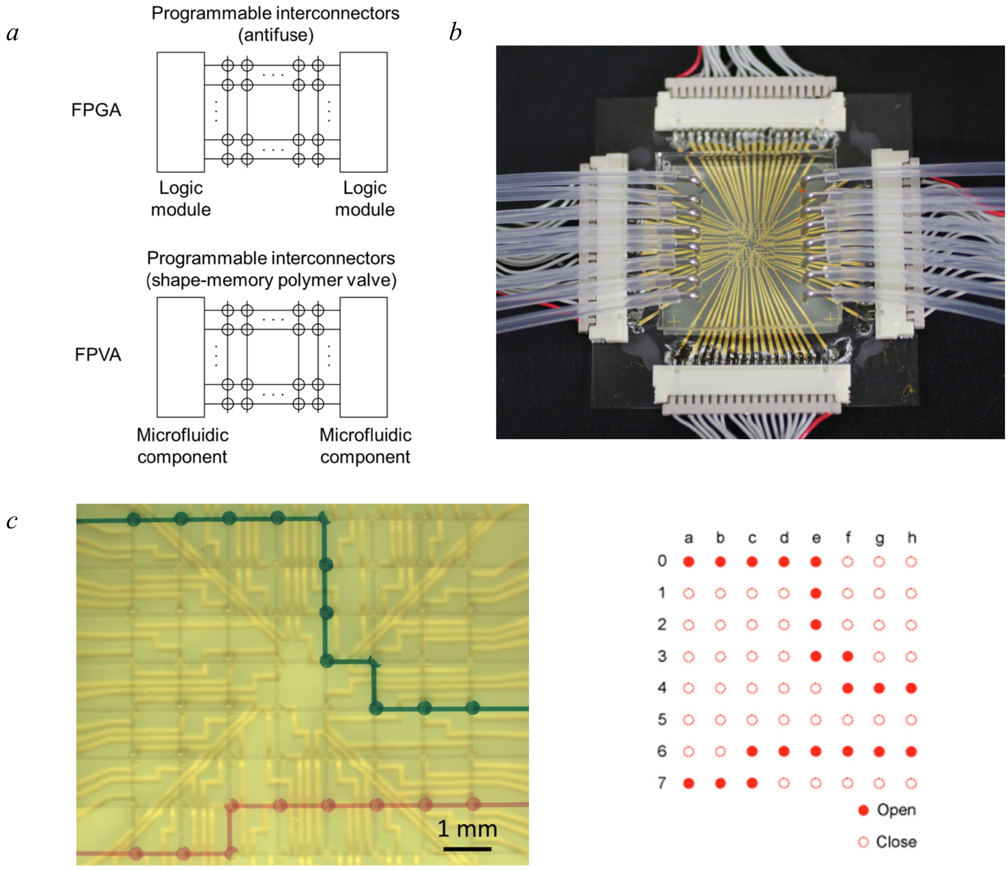

Figure 5. (a) Schematic architecture of FPGA and FPVA. (b) Optical micrograph of the FPVA device. (c) Optical photograph of programmed microchannel networks and schematic of programmed valve opening and closing (8×8=64 valves). Selected valves were closed, and the designed blue and red fluid lines were successfully observed.

CONCLUSION

We developed a novel SMP microvalve that can operate as either N/O or N/C valves and fabricated an FPVA with 8×8=64 valves to demonstrate the suitability for integration into a microfluidic network. The simple valve design and applicability of low-cost fabrication technology such as plastic molding and circuit printing are advantageous for use in disposable chips. Also, the electronically controllable feature is expected to be useful for realizing full-scale micro-TAS devices.

ACKNOWLEDGEMENTS

This research was supported by Grant-in-Aid for JSPS Fellows (22-8063) and Funding Program for-World-Leading Innovative R&D on Science and Technology (FIRST Program).

REFERENCES

[1] Shoji, S. and M. Esashi, Microflow devices and systems. Journal of Micromechanics and Microengineering, vol. 4, pp. 157-171. (1994).

[2] Unger, M.A., *et al.*, Monolithic microfabricated valves and pumps by multilayer soft lithography. Science vol. 288, pp. 113-116 (2000).

[3] Ebara, M., *et al.*, Shape-Memory Surface with Dynamically Tunable Nano‐Geometry Activated by Body Heat. Advanced Materials, vol. 24, pp. 273-278 (2012).

[4] Hu, C., Interconnect devices for field programmable gate array. Technical digests of IEDM 1992 , pp. 591-594 (1992).

CONTACT

Hiroaki Takehara, tel: +81-3-5841-1180; h-takehara@bionano.t.u-tokyo.ac.jp