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A novel thermo-pneumatic peristaltic micropump with low temperature elevation on working fluid

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ABSTRACT

This work presents a novel thermo-pneumatic peristaltic micropump with low temperature elevation on working fluid. The proposed device, which consists of two separate zones for air-heating and fluid-squeezing, is realized by using micromachining techniques. Also, the device can be operated by using a small and simple actuation circuitry with low applied voltages. Under similar operational conditions, the proposed micropump shows similar fluid-pumping performance when compared with the conventional design of thermo-pneumatic micropumps. However, for the proposed design, the temperature elevation on the fluid-pumping area is as small as about 2.0 K, which is less than 8% of that generated by the conventional design. Furthermore, by applying higher voltages, larger flow rate can be achieved with relatively small increase in temperature elevation. Due to low temperature elevation on working fluid, the proposed device is suitable for the applications such as DNA chips or protein chips. In addition, because of its small size and simple actuation scheme, potentially the proposed device can be integrated into the devices for point-of-care applications.

1. Introduction

Micro-electro-mechanical systems (MEMS) technologies are widely employed to realize microfluidic systems for biomedical applications. Typical microfluidic devices include micropumps for fluid driving, microvalves for fluid switching, and micromixers for fluid blending [1]. The advantages of these microfluidic devices include rapid response, small size, and significant reduction in reagents. In general, micropumps can be sorted into two types: mechanical type and non-mechanical type [2]. In terms of pumping-power-delivery schemes, micropumps can be classified as displacement type and dynamic type [3]. Peristaltic micropumps, which can be categorized as the mechanical type as well as the displacement type, utilize vibrating diaphragms in successive peristaltic sequence. Numerous actuation mechanisms have been proposed for continually generating peristaltic series on diaphragms to convey fluid in a desired direction. Piezoelectric actuation scheme is one of the well-known approaches for actuating displacement pumps [4–8], while it requires relatively complex, and possibly bulky, driving circuits. Pneumatic actuation by compressed air is another popular approach [9–14]. This method is considered to be robust and harmless for biomedical applications. However, an external compressor, which might be noisy and bulky, is indispensable for system operation. Electrostatic actuation ensures smoother flow at high operating frequency, but relatively high driving voltages are needed [15,16]. Magnetic actuation with an electromagnetic motor is simple and robust, but requires a complex external mechanism for handling rotary motions [17,18].

On the other hand, thermal actuation possesses the advantages of simple device structure, simple actuation scheme, relatively low actuation voltage, and small system size. Therefore, it has the potential for incorporation in portable equipment, such as the devices for the point-of-care (POC) applications. A thermo-pneumatic peristaltic micropump was proposed and developed in [19]. In [20], the characterization and dynamic modeling of thermo-pneumatic peristaltic micropumps were presented. Also, the proposed pumps can be integrated with a tiny circuit module of small foot-print. In these previous works, on-chip thermal heaters are integrated into the system for device actuation. By heating air sealed in the chamber, the thermally induced volume change of air deforms the diaphragm to convey fluid toward a desired direction. However, when the thermo-pneumatic actuation scheme is used in microfluidic devices, high temperature elevation might damage the content of working fluid. For example, excess device temperature elevation might cause coagulation of protein. Therefore, temperature elevation is a critical issue for employing thermo-pneumatic pumps in biomedical applications.

In this paper, we propose a thermo-pneumatic peristaltic micropump, which consists of two separate zones for air-heating and fluid-squeezing. The temperature elevation on working fluid can be significantly reduced because the fluidic channel surface is

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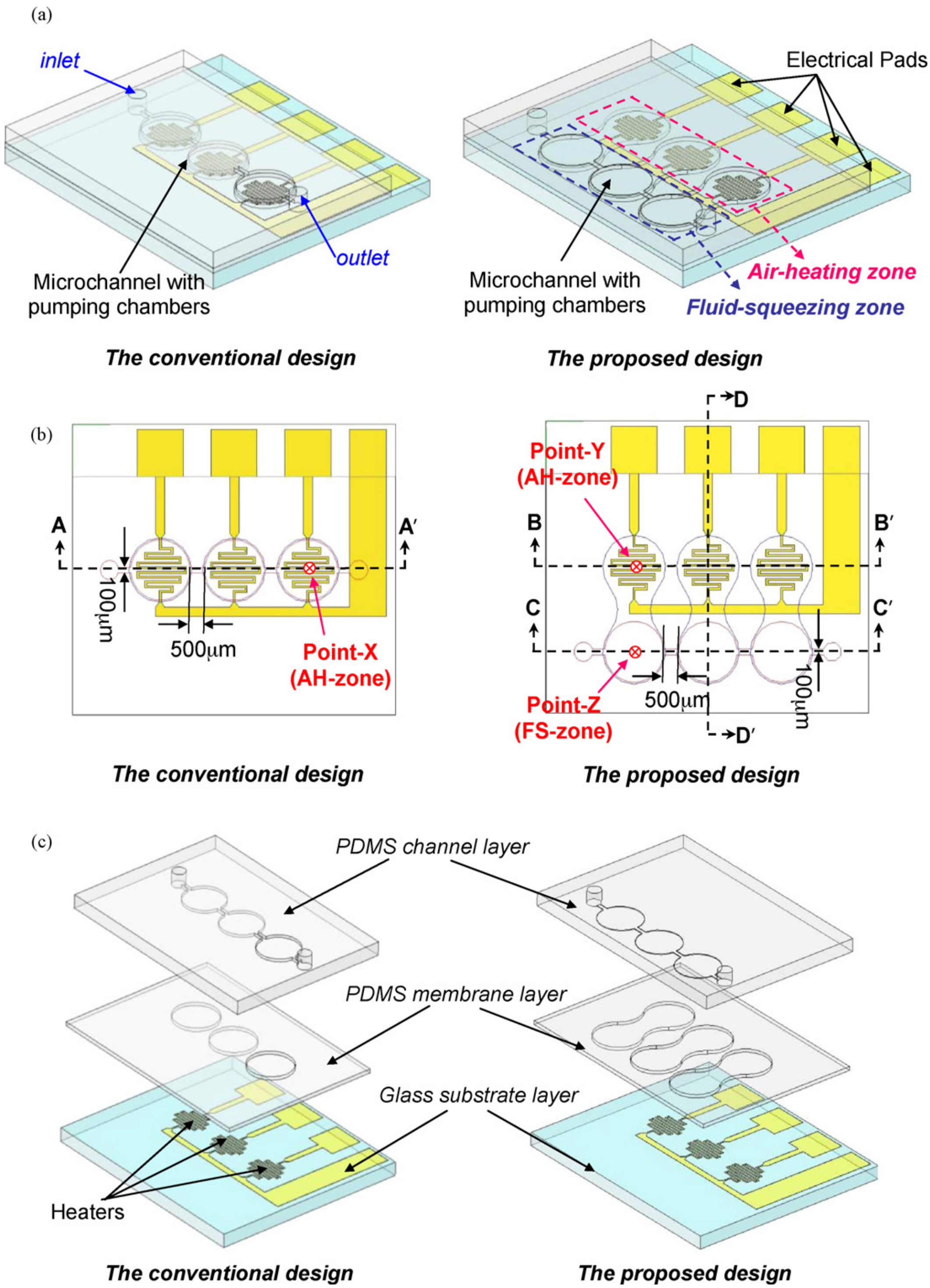

Fig. 1. Schematic illustrations of the proposed and the conventional designs: (a) the 3D model, (b) top view, and (c) exploded view.

away from the heater, which reduces the possibility of damaging the content in the working fluid by high temperature. Furthermore, the flow rate performance of the pump can be improved by increasing the applied voltage, while insignificant temperature elevation on working fluid is induced. The device can be realized by standard micromachining processes such as the soft-lithography process [21] and the lift-off process. Also, the device only requires a simple and small external circuit for independent operation [20]. Therefore, the proposed device can be potentially integrated in a portable system for POC applications [22].

2. Design

2.1. Configuration and operational principle

In order to fully describe the design and operational principle of the proposed device, we start with the description of the *conventional design* of thermo-pneumatic peristaltic micropumps [19,20]. The *left column* of Fig. 1 shows the schematic view, top view and the exploded drawing of the conventional design. Fig. 2 is the corresponding cross-sectional view along line AA′ indicated in Fig. 1(b).