ELECTROSTATICALLY DRIVEN VALVELESS PERISTALTIC GAS MICROPUMP WITH MULTIPLE ELECTRODES

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ABSTRACT

An electrostatically driven valveless peristaltic micropump with multiple electrodes (4, 8, and 16 electrodes) has been developed for pumping gases through microsystems. The pump was fabricated on a silicon substrate with a metalized polyimide (PI) diaphragm as the actuator. With a single chamber and multi electrodes design, the operating frequency for maximum flow rate is determined by the number of electrodes. In case of 4 electrodes, a maximum flow rate of 40 µl/min was measured at 14 Hz of clock frequency. For micropumps with 8 and 16 electrodes, the maximum flow rates were observed at 25 Hz and 1400 Hz respectively. The maximum flow rates were about 80 µl/min for 8 electrodes and from 250 µl/min for 16 electrodes.

KEYWORDS: Gas micropump, Peristaltic, Valveless

INTRODUCTION

In this study, an electrostatically driven peristaltic micropump has been designed, built and characterized. A schematic of the mechanical structure of the micro pump is given in Figure 1(a). The pump has a chamber fabricated on a silicon substrate and a polyimide diaphragm with electrodes for electrostatic actuation. As shown in Figure 1(b), 4-phase actuation sequence creates a peristaltic motion of the diaphragm and it pumps the fluid in one direction. The peristaltic motion eliminates the need for valves or a nozzle/diffuser design for flow control [1-4].

We previously reported the development and performance of a micropump with a single chamber and four-electrode design [5, 6]. This design helps reduce dead volume and the need for valve timing, but at the expense of increased electrical driving complexity [5, 6].

In this study, we present the effect of the number of the electrodes on the characteristic and performance of the micropump [7]. With a single chamber design, the number of electrode determines the volume of divided cell and the characteristic frequency, which produce maximum flow rate.

Figure 1: (a) Schematic of the micropump is shown with the experimental setup. (b) Four-phase signal sequence is used for actuation of the PI diaphragm.

FABRICATION

The fabrication process flow is shown in Figure 2. The pump chamber was etched by potassium hydroxide (KOH) etching and the inlet and outlet were etched by deep reactive ion etching. The pump chamber could be etched by deep reactive ion etching or XeF\textsubscript{2} etching. The chamber size is 5 mm (W) $\times$ 32 mm (L) $\times$ 15 µm (D). A Cr/Au layer was deposited on the chamber floor. For the polyimide diaphragm, polyimide was spincoated on the coverglass and cured. A Cr/Au/Cr layer was sputtered and patterned on the cured PI layer. Another PI layer was spincoated on the metal layer. Finally, before bonding the PI diaphragm to the Si chamber, an anti-stiction layer, CF\textsubscript{n} film, was deposited on both the...
chamber and the PI diaphragm. After bonding, the coverglass was released by soaking in 80°C water. For different electrode design, the pattern of the metal layer on PI layer was changed.

**EXPERIMENTAL**

The experimental schematic for the flow-rate measurements is shown in Figure 1(a). A four-phase sequence signal was generated by a custom-made logic circuit before being amplified and applied to the device. The signal was repeated twice and 4 times for 8-electrode, 16-electrodes [7]. A gas flow meter (Omega, FMA 1615A) was connected to the outlet of the micropump to measure the flow rates.

**RESULTS AND DISCUSSION**

Figure 3 shows the test results of the micropump. The 4-electrode and 8-electrode micropumps were operated at 100 V while 16-electrode micropump required 160 V to operate. As the number of electrode increases, the area of the each electrode decrease as well as the electrostatic force to pull down the diaphragm to the chamber floor. Therefore, the higher voltage is needed for the smaller electrode to compensate the reduced area.

As shown in Figure 3(a), 4-electrode micropump reaches the maximum flow rate at 14 Hz a maximum flow rate of 40.28 µl/min. For 8- and 16-electrode micropump, the maximum flow rates are about 80 µl/min and 250 µl/min at 25 Hz and 1400 Hz.

**Figure 3: (a) Testing results show that the characteristic frequencies of the micropump increase as the number of electrodes increase. (b) Testing results show the flow rates as a function of number of electrode.**
The reason why the characteristic frequency increase along with the number of electrodes is because the volume of the cell divided by the electrode decreases as the number of electrodes increases. With a smaller chamber volume, the fluidic resonance occurs at the higher frequency. And at the fluidic resonance, the flow rate can be maximized.

Figure 3(b) shows the maximum flow rates of each micropump as a function of the number of the electrodes. The flow rate of the micropump is usually proportional to the operating frequency and the stroke volume. Although the micropump with more electrodes has the smaller stroke volume, it can be operated at the higher frequency and it can pump more fluid as a result [7].

CONCLUSION
With a single chamber and multiple electrode design, the characteristic frequency depends on the number of the electrode which determines the volume of divided cell. As the volume of the divided cell decrease, the micropump can be operate at higher frequency. As the number of electrodes increases, the volume of divided cell and the stroke volume de-
crease. evertheless, since the characteristic frequency increases along with the number of the electrode, the flow rate of the micropump increases when the number of electrode increases.

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