INTEGRATED PARYLENE ELECTROSTATIC PERISTALTIC PUMP

Jun Xie, Jason Shih and Yu-Chong Tai
Caltech Micromachining Lab, California Institute of Technology, USA

Abstract
Here we present a new Parylene surface-micromachining technology and its application to an electrostatically actuated peristaltic micropump. CVD Parylene is used as the structural material; photoresist as the sacrificial material; and Cr/Au as the electrode material. This versatile process enables a peristaltic pump design in which the electrical field does not pass through the fluid. Testing shows an electrostatic pull-in voltage of 150 V for a 200 µm diameter pumping membrane. 3 and 6 phase peristaltic actuation sequences are used and pumping of both water and ethanol is demonstrated. A peak pumping rate of 2 nL/min (flow velocity of 100 µm/sec) is achieved at 60 Hz for ethanol. Higher flow rates (> 10nL/min) are feasible with an improved design.

Keywords: Micropump, Electrostatic Actuation, Peristaltic, Parylene

1. Introduction
Many previously developed micropumps [1-5] either are bulk micromachined, power thirsty, or require complex packaging. Because of these reasons, they are largely unsuitable for total integration into microfluidic systems. Here we present a totally integrated electrostatic peristaltic micropump for lab-on-a-chip applications. This device is based on a Parylene surface-micromachining technology that has produced many other microfluidic devices, including valves and flow sensors [6, 7]. Process compatibility between these devices enables total integration into a microfluidic system.

Figure 1. Design and operation principle of the peristaltic micropump using electrostatic actuation. (a) cross section of micropump design, (b) 3-phase actuation sequence, (c) micrograph of the fabricated micropump.
2. Design and Fabrication

Figure 1a and 1b show the design and operation principle of the micropump. The peristaltic pump has three pumping chambers connected in series. Each pumping chamber has an electrostatic actuator directly underneath a fluid chamber. A composite moving membrane separates the actuator and the fluid chamber. The fluid only passes through the top fluid chamber while the actuator gap is filled with air. The electrostatic actuator comprises of two electrodes. The bottom electrode is fixed on the substrate and covered by Parylene. The top electrode is inside the moving membrane and is sandwiched between two Parylene layers. When an actuation voltage is applied, the electrostatic force will pull the moving membrane down and cause the volume of the fluid chamber to increase. When the three pumping chambers are actuated using the 3-phase or 6-phase actuation sequence [6], the peristaltic motion will induce pumping of the fluid. Figure 1c shows the fabricated device.

Fabrication of the micropump is shown in Figure 2. Parylene (4 layers) is used as the mechanical material; photoresist and sputtered Si as the sacrificial material; and Cr/Au as the electrode material. The bottom Cr/Au electrode is 300 nm thick. The top electrode is 150 nm thick and is sandwiched between two 1 μm Parylene layers to form a composite membrane. The gap between the electrodes is defined using a 300 nm sputtered Si layer and a 4 μm photoresist sacrificial layer. A 5 μm photoresist and 4 μm Parylene layers then create the fluid channel. The photoresist is released using acetone. Releasing is followed by an isopropanol rinse. Because stiction can happen during the drying process, the sputtered Si layer is etched away using gas phase BrF₃ etching to produce a freestanding membrane.

3. Results and Discussions

A 5 kHz AC drive signal is used for the electrostatic actuation. An AC signal eliminates DC charging and stiction problems during actuation [6]. The peak voltage of
Figure 3. The testing of the micropump. (a) each video snapshot shows one phase of the 3-phase actuation sequence. (b) highlighted 1 μm particle shows a pumping rate of 2 nL/min when the peristaltic pump is actuated at 60 Hz. (c) pumping flow rate vs. actuation frequency. Actuation voltage is 140 V.

The drive signal is 100-200 V. The pull-in voltage depends on the membrane thickness and diameter. For a 200 μm diameter and 2 μm thick composite Parylene membrane, the pull-in voltage is about 150 V. We have explored both 3 and 6 phase peristaltic actuation sequences. A 1-70 Hz control signal varies the actuation sequence frequency. Figure 3a shows the actuation of the micropump using the 3-phase sequence. For flow visualization, micron-sized beads are placed in the fluid. Bead movement is tracked to calculate the flow rate. Figure 3b shows sequential snapshots of a pumping test. The pump is actuated at 140 V, using a 60 Hz 3-Phase sequence. Bead velocity is measured to be 100 μm/sec, which translates to a flow rate of 2 nL/min. Figure 3c shows the pumping rate vs. actuation frequency for 3-phase actuation at 140 V. It can be clearly seen that at lower frequencies the pumping rate increases with the increasing frequency. The pumping rate reaches a maximum of 1.7 nL/min at 60 Hz and decreases at higher frequencies. At these higher frequencies, the moving membrane is not fast enough to keep up with the actuation signal. Measuring the pumping pressure proves to be difficult. Preliminary testing shows that the pumping pressure is smaller than 5 kPa. Based on theoretical calculation, restoring force of the moving membrane after being pulled down by the electrostatic force can be larger than 20 kPa. The reason for the low pumping pressure is that there is always a gap that exists between the moving membrane and the ceiling of the fluid channel. Low pumping efficiency and low pumping pressure result from this poor sealing. If a thinner fluid channel is adopted, then the pumping efficiency can be improved due to improved sealing. Higher pumping rate (>10 nL/min) and pumping pressure (>20 kPa) should be feasible then.

4. Conclusions

An electrostatically actuated peristaltic micropump, fabricated using a 4-Parylene-layer surface-micromachining technology has been successfully developed.
Figure 4. A microfluidic chip made by the multilayer Parylene surface micromachining technology. The chip (center picture) is mounted and wire bonded to a PCB board. The microfluidic devices shown in the picture: (from top right, clockwise) peristaltic micropump, micro flow controller, capacitive flow sensor, thermal flow sensor.

Both electrostatic actuation and fluid pumping are demonstrated. Since the micropump shares the same fabrication technology as many other fluidic devices that we have developed, a microfluidic system including all these devices can be integrated on a single chip, as shown in Figure 4.

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References