ELECTRICALLY-ACTUATED PDMS MICROVALVES AND PUMPS FOR VLSI MICROFLUIDICS
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ABSTRACT
We present a polydimethylsiloxane (PDMS)-metal pump/valve technology that can actuate in liquid (water and oil) and air. The devices operate by AC electrostatic gap-closing (4-5 MHz 15-20 V) of a modified PDMS microchannel. The presented pump and valve process is compatible with standard PDMS microfluidics [1] and devices have actuation voltages low enough to be driven by a standard USB-interface microcontroller and IC amplifier, which makes possible the design of very-large-scale integration (VLSI) [6] microfluidics which requires no external pneumatic connections to operate.

Keywords: VLSI-microfluidics, polydimethylsiloxane, low power, micropump/valve

1. INTRODUCTION
Micropumps and valves are essential elements in Micro Total Analysis Systems (Micro-TAS); among various types pneumatic polymer-based pumps are the most popular found in most microfluidic systems [1, 2, and 3]. The electrostatic PDMS micropumps and valves we developed (Figure 1) can actuate water, oil, and air at low voltage. This makes possible the design of fluidic systems with many actuated components each driven by digitally synthesized control signals. Moreover, since the actuation is based on MHz frequency electrostatics, the devices: a) are scalable into the nanofluidic regime, and b) can be driven by conventional CMOS electronics.

2. THEORY
Electrostatic actuation is widely used in most dry MEMS devices. Using an AC driving signal in MHz frequency range it is applicable in wet environment because a) screening by electrical double layer is significantly reduced and b) electrolysis is avoided. Considering a membrane with a residual stress $\sigma$, the pull-in voltage can be expressed as [4, 5]:

$$ V_{\text{pull-in}} = \sqrt{\frac{8k(g + t_{\text{ox}})\epsilon_r/\epsilon_{\text{ox}}}{27\epsilon_0\epsilon_rA}} \left(1 + \frac{2(1 - V^2)\sigma/R}{9Et^2} \right) $$

where: $k =$ spring constant; $t_{\text{ox}} =$ oxide thickness; $g =$ gap; $\epsilon_{\text{ox}} =$ oxide permittivity; $A =$ capacitor area; $\epsilon_a =$ dielectric permittivity; $V =$ Poisson’ ratio; $E =$ Young’s modulus, and $t =$ membrane thickness. The calculated pull-in voltage of our device is about 16.6 volt.

Figure 1. Conceptual View of the micropump
3. EXPERIMENTAL

A. Fabrication

Figure 2 shows the fabrication flow of a basic valve. Indium tin oxide (ITO) electrodes (1000Å) were patterned and insulated by 4000Å PECVD oxide [2]. Oxide was etched to expose the contact pads. Photoresist (AZ-9260, 10 μm) was used as microchannel mold for subsequent metal and PDMS deposition. The metal layer was composed of Cr/Au/Cr (150/5000/150 Å) and the PDMS was Dow Corning WL-5351. The size of this PDMS-metal membrane was 300 μm by 300 μm. The total thickness of the PDMS-metal membrane was 7.2 μm. The embedded metal flexure formed the top capacitive plate and the ITO electrode formed the other.

B. Experiment Setup

The circuit diagram is shown in Fig. 3. A programmable USB interfaced micro controller (BS1USB, Parallax) was used to control and provide a MHz signal (1.5 volt peak-to-peak) for actuation. This signal was two-stage differentially amplified to 35-40 volt peak-to-peak by IC amplifiers (AD815), and switched by photovoltaic AC relays. All fluidic measurement was made with fluorescent microscopy (Figure 4). Flowrate was measured by particle imaging method on an inverted fluorescent microscope (Nikon TE2000-U). Pressure sensors (40PC150, Honeywell) were connected both upstream and downstream of the micro valve or pump to measure pressure difference across the devices.

4. RESULTS AND DISCUSSION

Figure 5a, b shows the basic valve operation. As the valve closed, the PDMS-metal membrane collapsed and the microspheres were either expelled or trapped by the valve. Expelled microspheres accumulated at the valve boundary. Pump and valve performance compares well with previous technologies [1, 3]. Our current devices can hold a 6 psi (41.37 kPa) pressure (Figure 5c). Figure 6a shows a three-valve peristaltic pump. Maximum pumping rate is 4.44 valve volumes/min (1 nL/min) at 1.6 Hz (Figure 6b), with an actuation voltage of 35 volt peak-to-peak at 5 MHz. After this critical frequency point...
the flowrate decreases as pumping frequency increases. The peak current measured was less than 1 μA.

**Figure 5.** Valving characterization. (a) Inverted microscopy of open and closed valve. The valve was off at \( t = 0 \) s. Microspheres flow freely. The valve was actuated at \( t = 1 \) s. The PDMS-metal roof collapsed and the microspheres were trapped under the PDMS-metal membrane. When closed, the microspheres outside the valve chamber accumulated at the entrance of the valve chamber (arrows.) Scale bar, 20 μm. (b) Fluorescent image of fluorophore-filled open and closed valve showing valve deflection. (c) Leak rate vs. pressure. The valve is effective till the pressure is above 6 psi (41.37 kPa).

**Figure 6.** Pumping characterization. (a) Time frame pictures of free-flow pumping. Microspheres (diameter = 0.5 μm) were used for flow indication and flowrate measurement. The pump was activated (pump frequency = 1.6Hz) at \( t = 1 \) s. Scale bar, 20 μm. (b) Free-flow flowrate vs. pumping frequencies. The maximum flowrate (1nL/min) was achieved at 1.6Hz actuation.

5. CONCLUSIONS

A low-voltage electrostatic microvalves and pumps were designed and tested. These devices are compatible with PDMS-based microfluidics and complicated VLSI microfluidics.

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REFERENCES