A Fully-differential Electrostatic Micropump with Anti-pull-down Feature

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Abstract

In this poster, a fully-differential electrostatic micropump with anti-pull-down feature is proposed. The micropump has glass-silicon-silicon-glass compound palindromic symmetry structure. Its double membranes can be activated to vibrate simultaneously. Compared to the traditional single-membrane design, the chamber volume and the pumping rate can be doubled. Besides, to overcome pull-down limitation, the proposed micropump has a special design to extend displacement of the membrane without triggering the pull-down effect. The proposed micropump can be used for lab-on-a-chip and micro drug delivery applications.

Introduction

Micropumps based on MEMS (Microelectromechanical Systems) technology have been widely used in Lab-on-a-chip, micro drug delivery system and many other applications. There has been various category of micropumps applied in different fields; however, the electrostatic actuation is the most prevalent for micropump activation because of its quick response, easy operation, low energy consumption and good compatibility with VLSI fabrication.

In 1992, R.Zengerle and A.Ritcher firstly came up a electrostatic micropump leading to a long-term stability. But the pull down effect was another serious challenge limiting the efficiency of the devices for its medical application. Specifically, when the membrane moves and voltage keeps increasing to the pull-down point, the potential electrostatic force increases more quickly than the linear elasticity stored in membrane. If the voltage keeps increasing beyond the pull-down point, the membrane would be pulled into the aluminum plate, causing the short-circuit and failure of the device.

In the following, we will first explain the pull-down effect of perpendicular electrostatic actuation through mathematic method using MEMS piston actuator as an example. Then we will propose a new micropump design with anti-pull-down feature. The proposed micropump consists of three key parts—orifice, anti-pull-down actuators and valves namely. Its working principle will be discussed.

Principle of Operation

In the piston movement, the membrane is driving by electrostatic force F and restoring force F_k simultaneously. And them can be expressed as:

$$F = \frac{\varepsilon A u^2}{2(d_0-x)^2},$$

where ε is the permittivity, surface area A and distance d_0 between the electric plate and the membrane, driving voltage u.

$$F_k = \mathrm{kx}.$$

K is the spring constant. In equilibrium,

$$\text{thus: } \frac{\varepsilon A u^2}{2(d_0-x)^2} = \mathrm{kx},$$

solve which we can gain

$$\mathrm{u}=\sqrt{\frac{2kx(d_0-x)^2}{\varepsilon A}}.$$

According to $\frac{du}{dx} = 0$, we can have equation:

$$\frac{1}{2}\left(\frac{2(d_0-x)^2\cdot \mathrm{kx}}{\varepsilon A}\right)^{-\frac{1}{2}} \cdot \frac{2k}{\varepsilon A}\left((d_0-x)^2 - 2(d_0-x)x\right) = 0.$$

In practical situation, only $(d_0-x)^2 - 2(d_0-x)x = 0$

Solve the above equation x1=d_0 and x2=$\frac{1}{3}d_0$.

The above means that if the displacement of the membrane moves over a critical value (d_0/3), the restoring force will not be able to balance the electrostatic force and the membrane will be pulled-down to the electric plate.

Structure Design

The structure diagram of the fully-differential electrostatic micropump is shown in Figure 1. It consists of four separate layers bonded together: glass, silicon, silicon and glass. The micropump has inlet and outlet valves in both sides. The overall dimension of each layer of the micropump is 10mm×10mm×0.52mm.

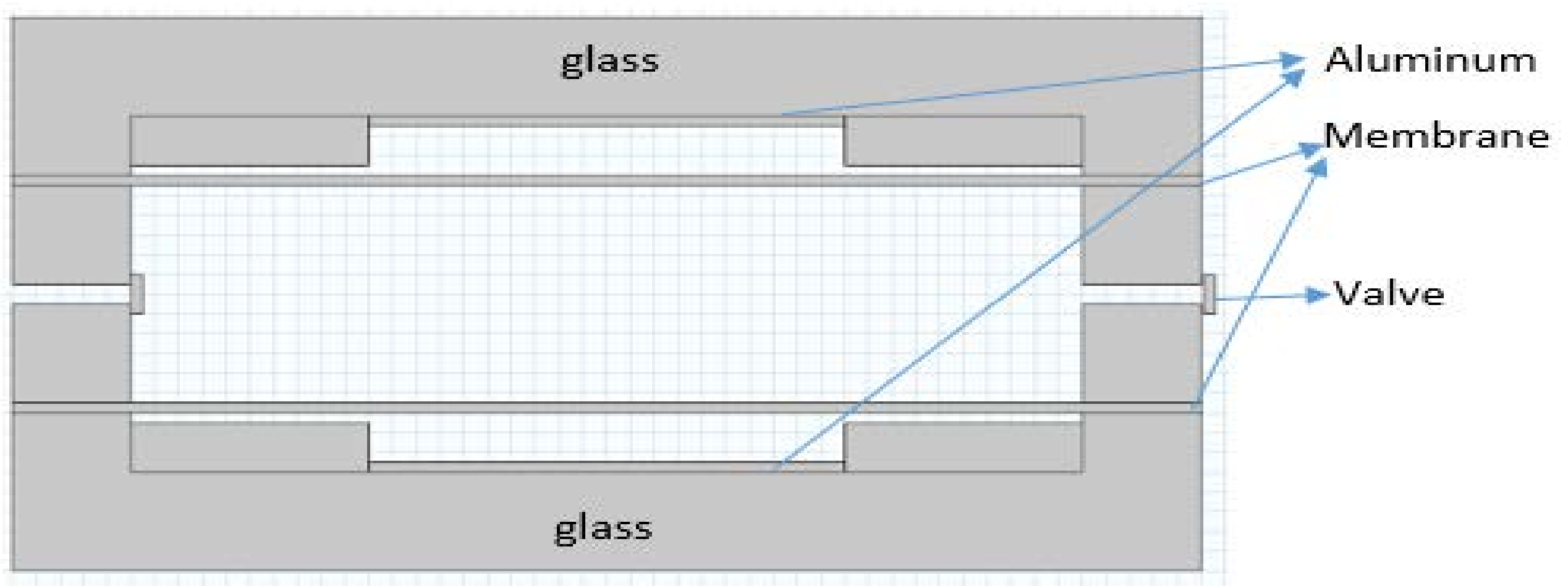


Figure.1. Structure diagram of the fully-differential electrostatic micropump.

The working principle of the fully-differential electrostatic micropump is explained as follow. A periodic sinusoidal voltage is applied between both membranes and both driving electrodes on glass wafers. When non-zero driving voltage is applied between the built-in aluminum electrodes and the membrane, the electrostatic force causes the top membrane to bend upwards and the bottom membrane to bend downwards. In this way, the pump chamber volume increase and it sucks liquid from inlet. If the driving voltage reduces to zero, the electrostatic force disappears and the membranes become flat. As a result, the pump chamber volume decrease and the liquid is pressed out from the outlet. The inlet and outlet vales regulate the proper flow direction of the fluid inside the micropump. When periodic sinusoidal voltage is applied, the micropump will repeat above pumping cycle and the microfluid will be continuously pumped in from inlet and pumped out from outlet. Traditional micropump has only one membrane. Due to the double-membrane structure, the proposed micropump can double the pumping rate, leading to improved efficiency.

Design and Simulation

The comparison of traditional micropump and the proposed micropump with anti-pull-down feature is shown in Figure 2. The proposed micropump has a surrounding frame to prevent the membrane from touching the bottom electrode. In this way, the driving voltage can be larger and bending displacement can be extended beyond (1/3)d$_0$.

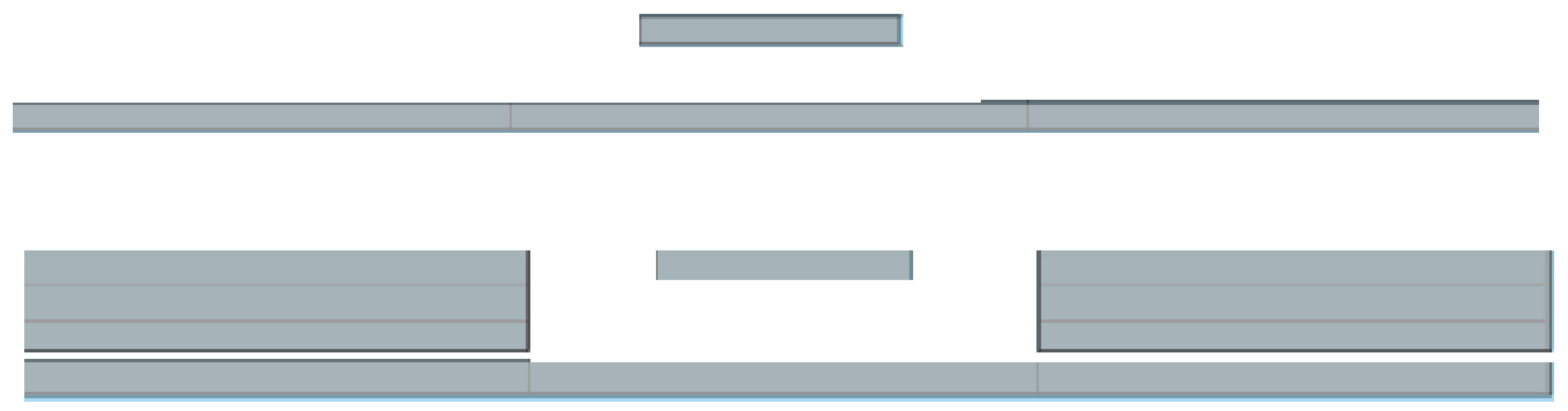


Figure 2. Traditional actuator and actuator with anti-pull-down feature

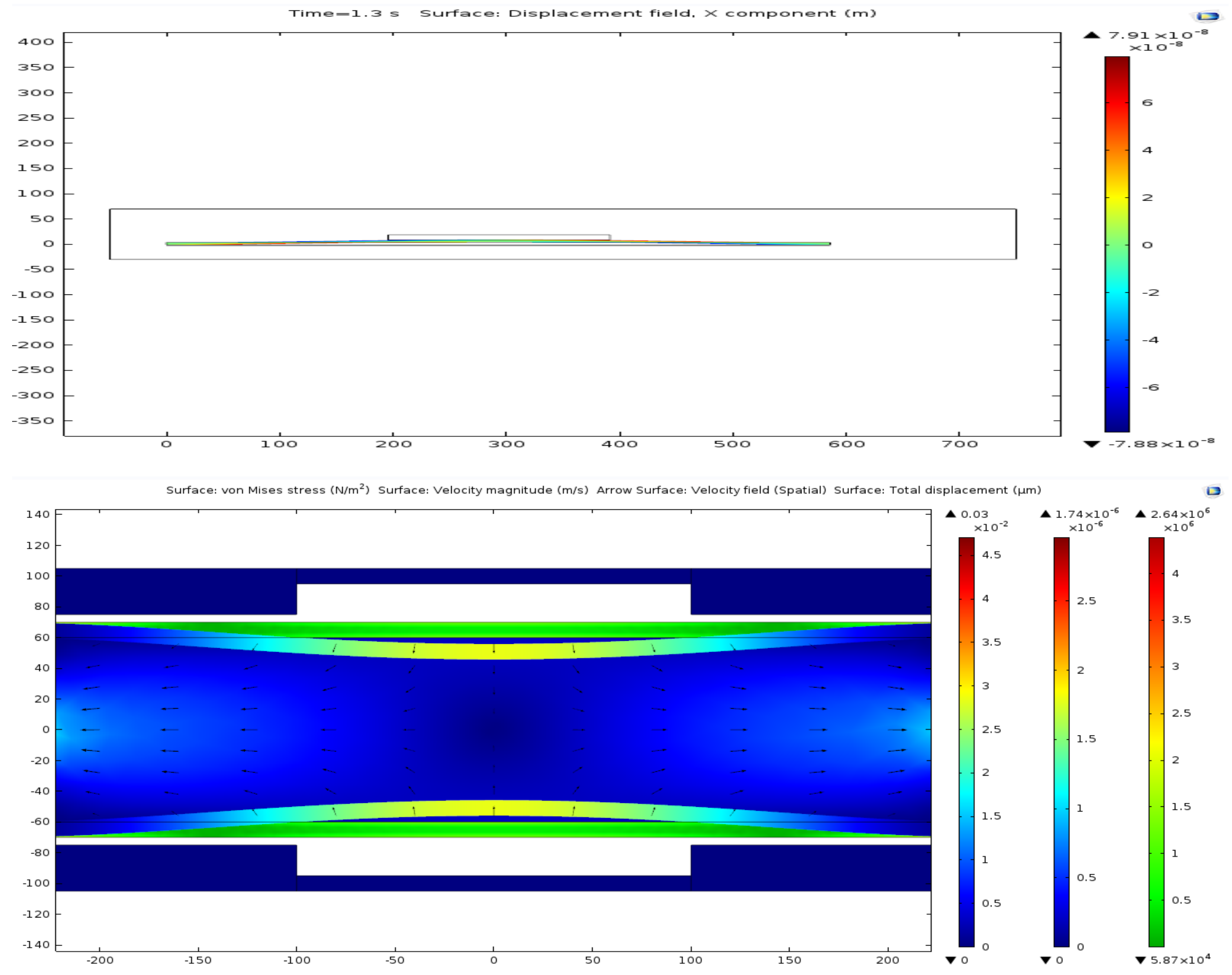
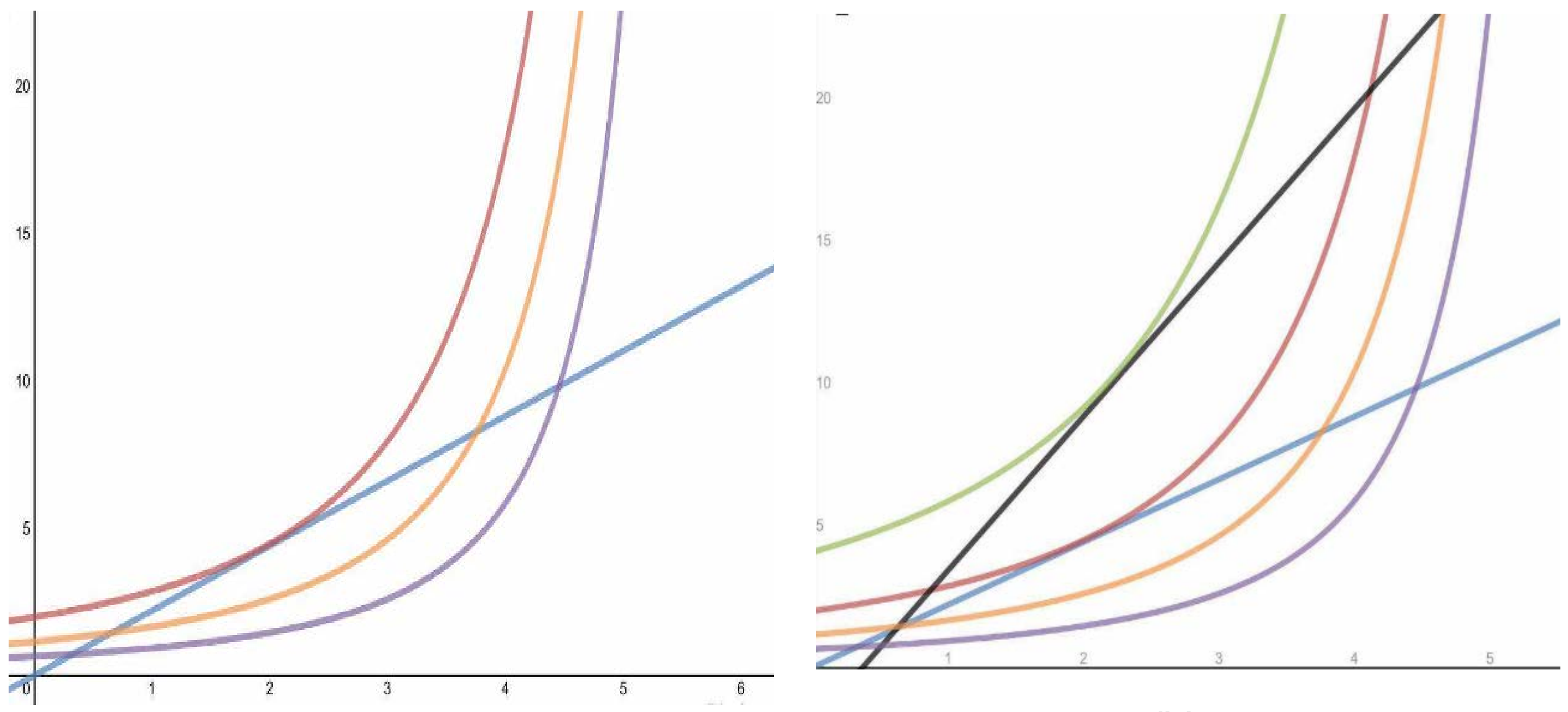


Figure 3. COMSOL simulation of traditional pump and proposed pump

The bending shape of the pump membrane of both the traditional pump and the proposed pump are shown in Figure 3. The flow vector of the microfluidic inside the pump chamber is also potted. Due to the surrounding frame, the membrane will first land on the frame, and then continue to bend toward the top/bottom driving electrode. This will increase the maximum controllable displacement of the membrane without inducing pull-down effect. If we plot both the electrostatic force and membrane restoring force as a function of bending displacement in the same coordinate system, we can see that the proposed micropump structure effectively shifts the equilibrium point beyond (1/3)d0. That is, the maximum controllable bending displacement without pull-down effect is extended.



(a). (b).

Figure 4. Equilibrium between electrostatic force and restoring force of membrane for (a). Traditional micropump, (b). Proposed micropump with anti-pull-down feature.

According to the simulation result, the maximum displacement is increased by 10.7% to nearly 44% of the distance between the two parallel plates, which is 1.98μm in our micropump design. Due to this extension, the stroke volume has been increased by 12%. Furthermore, the fully-differential double-membrane structure effectively double the pumping rate of the micropump. The bending of the micropump membrane in static mode and working mode are shown in Figure 5.

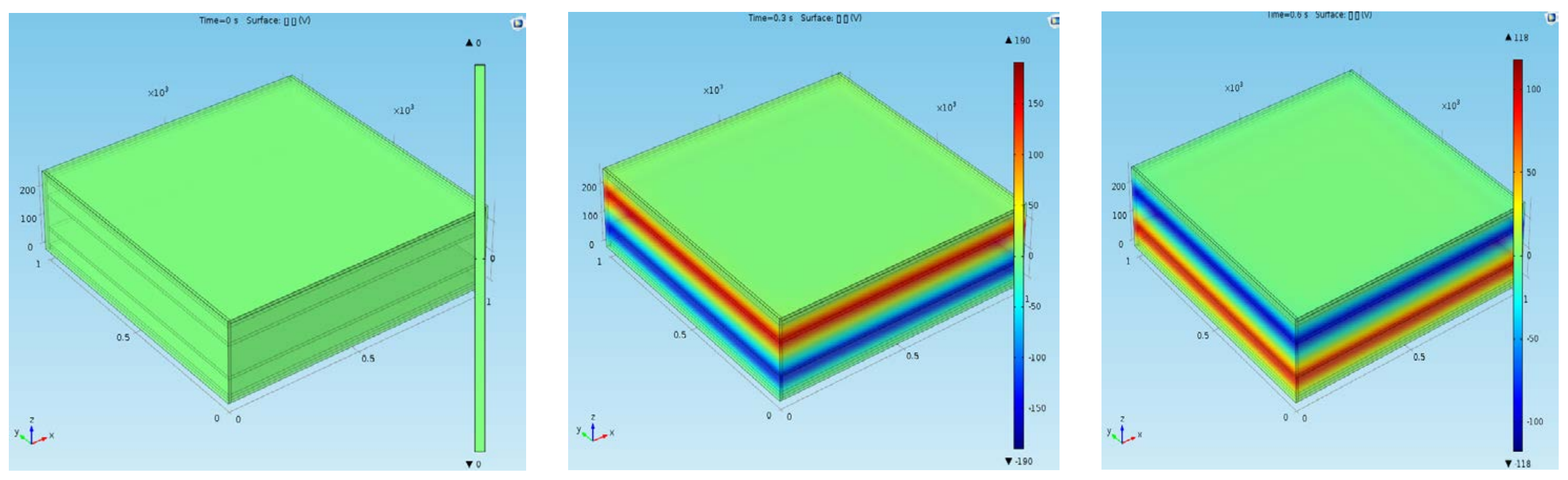


Figure.5. COMSOL simulation of the proposed micropump.

Conclusions and Future Work

In the poster, a fully-differential electrostatic micropump with anti-pull-down feature is proposed. Due to its fully-differential double-membrane structure, it can double the pumping rate of the micropump. Furthermore, due to its unique surrounding frame structure, it can effectively prevent pull-down effect and extend the maximum controllable bending displacement beyond (1/3)d0. COMSOL simulation verifies the correct function of the micropump. In the future, we will further design the fabrication flow of the micropump.

References

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