Mechanism of piezoelectric micropump with four flexible valves

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Abstract. A piezoelectric micropump with four flexible valves is proposed and its mechanism is researched. In the micropump chamber four asymmetric flexible valves are used to achieve single direction flow. The instantaneous velocities are analyzed and the peak input and output velocities are 0.14 m/s and 0.2 m/s respectively. The net flow rate is calculated, which is about 2.5 × 10⁻¹¹ m³/s. Due to the low operating frequency, flexible valves structure, no heat and no restriction on transport fluid type, this kind of micropump can be used for liquid transport and other biological sample containing DNA.

1. Introduction
In recent years, microfluidic systems have been widely used in various fields. Micropumps are the key components of microfluidic systems with applications ranging from biological fluid handling to microelectric cooling [1]. The traditional valve micropump usually utilizes mechanical parts to achieve rectifying [2]. The unidirectional performance is satisfactory, but miniaturization and service life are limited because of moving parts. Especially the cells in the biology sample may be damaged by the valve[3,4]. In this paper, a piezoelectric micropump, with flexible material flaps as valves, is proposed. Due to the low operating frequency, flexible valves structure, no heat and no restriction on transport fluid type, this kind of micropump can be used for liquid transport and other biological sample containing DNA.

This paper researches the mechanism of piezoelectric micropump with four flexible valves. Flow pattern in the micropump chamber is analyzed. The input velocity, output velocity and net volume are calculated. The conclusions can provide theoretical guidance to further analysis.

2. Model and Principle

2.1. Model Geometry
The designed model geometry is shown in Figure 1. The micropump chamber is 600 um in length and 100 um in high. The piezoelectric material, 80 um in length and 10 um in thickness, is put on the middle
The top of the chamber. The left of the chamber is inlet and the right is outlet. Four tilted flexible flaps are attached to the top and the bottom of the channel to obstruct the counter-flow along the channel length. They are all angled at 45 degrees to the horizontal channel edge.

![Image of the designed model geometry](image1)

**Figure 1.** The designed model geometry

### 2.2. Driving Principle

To achieve sustained flow in a single given direction, four flexible material flaps are used along the chamber length. When the membrane is constricted by the piezoelectric material, the chamber is constricted and the fluid will be push out of the inlet and the outlet. The two flaps of the left will be stand highly to obstruct the flow to inlet and the two of the right will be down to let flow out to the outlet. While the membrane is expanded, the principle is same as above. The flow pulled into the chamber from the inlet is more than the outlet. Although there are both in and out flow in inlet and outlet, in a period the outflow in outlet and inflow in inlet is one direction, it is from inlet to outlet along the chamber length.

### 2.3. Analysis configuration

The micropump mechanism is simulated by COMSOL. The physics required for the model is configured within the Fluid-Structure Interaction interface. The Linear Elastic Material feature is applied to the four tilted flaps, and then the Fluid-Solid Interface Boundary feature is automatically assigned to the boundaries between the flaps and the fluid in the channel. A sinusoidal driving voltage with a period of 1 s is applied to the piezoelectric electrode via a user input expression. Inlet and Outlet boundary feature are applied to the left and right boundaries of the chamber. The mesh is configured to be tightest around the tilted flaps, in order to resolve the stress within the bending flaps. The mesh is shown in Figure 2. A single time dependent study is performed over a duration of 2 seconds, which corresponds to two full oscillations of the driving voltage.

![Image of the mesh of the model](image2)

**Figure 2.** The mesh of the model
3. Results and Analysis

3.1. Flow Pattern in the Micropump Chamber
The mechanism by which the flow direction is regulated can be observed in the Flow and Stress default plot group. During the down stroke, when fluid is pushed from the chamber into the channel, the right-hand flaps are bent down towards the wall of the chamber whilst the left-hand flaps are bent away from the chamber wall. This configuration is shown in Figure 3, which shows the solution at a time of 0.3 s which corresponds to when the vibration amplitude of the piezoelectric material is almost at its maximum. Due to the asymmetric bending of the flaps, fluid can more easily flow out of the right-hand outlet. During the upstroke, when fluid is drawn from the channel into the chamber, the flaps are bent in the opposite directions. This configuration is shown in Figure 4, which shows the solution at a time of 0.8 s. Now the right hand flaps restrict the flow more than the left-hand flaps, and the majority of the fluid that is drawn into the chamber is from the left-hand inlet.

3.2. The Input and Output Velocity
When the vibration amplitude of the piezoelectric material is 0.96 m/s and the driving frequency is 1Hz, the average velocity at the inlet and the outlet in two periods is calculated as shown in Figure 5. As can be seen, during the first half period, the peak of the input velocity is -0.06 m/s, while the peak of the output velocity is 0.2 m/s. So the fluid pushed out of the micropump chamber is more than the fluid pushed into. During the second half period, the peak of the input velocity is 0.14 m/s, while the peak of
the output velocity is -0.02 m/s. So the fluid pushed into the micropump chamber is more than the fluid pushed out.

3.3. The Net Flow of the Micropump
The net volume of fluid that is pumped from left-to-right is shown in Figure 6. As expected, the gradient of the curve, which is the net flow rate, varies sinusoidally with a period equal to the vibration frequency of the piezoelectric material. The maximum gradients occur at intervals of odd multiples of 0.5 s, which correspond with the peaks in the magnitude of the vibration amplitude. From the curve, the net flow rate is about $2.5 \times 10^{-11} \text{m}^3/\text{s}$, surely that is not large enough in many application fields. To achieve larger flow, larger driving voltage and driving frequency may be considered to utilize.
Figure 6. The net volume pumped from left-to-right

4. Conclusion
A piezoelectric micropump with flexible valves is proposed and its mechanism is analyzed. The peak input and output velocities are 0.14 m/s and 0.2 m/s respectively. The net flow rate is about $2.5 \times 10^{-11}$ m$^3$/s. Compared with other microfluidic driving methods, this kind of micropump has several advantages and has many possible applications in microfluidic systems. For example, this device could be used to deliver fluid from a droplet reservoir connected to the left-hand outlet into a microfluidic pathway connected to the right-hand outlet. Alternately, this device could be used to create a circulating system where a fluid is pumped around a continuous loop to cool a microelectronic system.

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