Piezoelectric materials and their applications in the microfluidic drive technology

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Abstract: Piezoelectric materials have the merits of fast response speed and high precision. They have been widely used in MEMS and optoelectronic devices. Here piezoelectric materials are applied in the microfluidic drive technology. The proposed microfluidic drive technology has the advantages of small volume, simple structure and fast response speed. The researching results show that at 150V, the elongation length of the piezoelectric material is 18.556 μm, the maximum driven displacement of fluid is 4.761 mm, and the driven volume of fluid is 0.714 μl. Our work can promote the applications of piezoelectric materials in microfluidics.

1. Introduction

Piezoelectric materials mainly include the piezoelectric crystal, the piezoelectric ceramic, and the organic piezoelectric material. They have the inverse piezoelectric effect and the positive piezoelectric effect, where the former shows that piezoelectric materials deform under the action of the electric field provided. Piezoelectric materials [1] have been widely applied in MEMS and optoelectronic devices. Among them, the piezoelectric ceramic has high piezoelectricity and dielectric constant and can be processed into any shape. Therefore, the piezoelectric ceramic has become one of the research hotspots of materials. Microfluidics is to establish a chip laboratory by controlling fluid. Microfluidic drive technology generally works by utilizing the surface tension [2], heat [3], convection [4], light [5], magnetism [6]. However, the current drive technologies still exit some problems such as low physical or chemical stability, complex structure, insufficient operability [7], and slow response speed. These problems can hinder the development of microfluidics.

In this paper, a microfluidic drive technology with the piezoelectric material is given. The lengths of the piezoelectric material are measured by the Michelson Interferometer, and we achieve the driven displacement of fluid at different voltages. The proposed drive technology has the advantages of small volume, simple structure, fast response speed, and easy operation.
2. The structure and working principle

The structure of the microfluidic drive technology with the piezoelectric material is shown in Fig.1. It is constructed by two layers. The first layer is the cover layer. It is composed of the piezoelectric material and an outlet for electric wires. The piezoelectric material is embedded in the cover layer and is controlled efficiently by the external DC power. The second layer is the working layer. It consists of the microchannel, the liquid storage tank, the membrane and the insulated thin wafer bonded with piezoelectric materials. The cover layer is assembled with the working layer together by the plasma-assisted bonding [8]. The chip can be made of the Polymethyl Methacrylate (PMMA) [9].

![Fig.1. Structure of the proposed drive technology with the piezoelectric material](image)

When the voltage is applied, the piezoelectric material is elongated and depresses down the insulated thin wafer and the membrane, then to drive the fluid of the liquid storage tank into the microchannel. Therefore, we can adjust the elongation length of the piezoelectric material by the applied voltage, then to control the fluid in the microchannel.

The proposed drive technology has the advantages of small volume, simple structure, fast response speed, and easy operation. It has great potential in many applications and can be applied in various fields including biology, medicine, optical imaging, and communication.

3. Theoretical research

Here piezoelectric materials are the piezoelectric ceramic. The theory about the piezoelectric ceramic is discussed. “Comsol Multiphysics” software is used to perform the simulation of the fluid velocity distribution at different times.

3.1 Theory

The proposed microfluidic drive technology utilizes two effects of the inverse piezoelectric effect and the electrostriction effect [10]. Assuming the elongation length of the experimental material is \( x \), then.

\[
x = dE + ME^2
\]

where \( d \) is the piezoelectric coefficient, \( M \) is the electrostriction coefficient, and \( E \) is the electric field intensity.

Owing to the equation of the area of the insulated thin wafer and the basal area of the liquid storage tank, the reduction of liquid volume in the liquid storage tank is equal to the increment of liquid volume in the microchannel. Assuming that the elongation length of the piezoelectric ceramic is \( x \), the
radius of the liquid storage tank is \( R \), the across area of the microchannel is \( S \), and the driven displacement of fluid in the microchannel is \( L \), then.

\[
\pi R^2 x = SL
\]  
\( \text{(2)} \)

By Eq. (2), the drive displacement of fluid is

\[
L = \frac{\pi R^2 x}{S}
\]  
\( \text{(3)} \)

By the elongation length of the piezoelectric ceramic, we can achieve the relation of the drive displacement of fluid and the applied voltage.

3.2 Fluid velocity distribution

With the action of electric field provided, the piezoelectric ceramic is elongated and then drives the liquid in the microchannel. The fluid flow rate is not uniform in the microchannel.

The distribution of liquid velocity at different times is shown in Fig.2. At 10\( \mu s \), fluid in the microchannel starts to flow and the fluid velocity is small. At 125\( \mu s \), the fluid velocity increased significantly and the maximum speed is up to 11.8 mm/s. The above results show that the proposed drive technology has a fast response speed that is up to \( \mu s \)-scale.

4. Experiment and discussion

The elongation length of the piezoelectric ceramic is measured by Michelson Interferometer. The experimental setup is shown in Fig.3. The laser is set on a three-dimensional adjustment stage. The piezoelectric ceramic is stuck behind the mirror \( M_1 \) and is controlled by DC source. The size of the piezoelectric ceramic is \((3 \times 3 \times 18) \text{ mm}^3\).
With the action of electric field, the piezoelectric ceramic is elongated and M₁ moves following it. And the interference rings on the screen will retract inward or pop up outward, where a changed ring corresponds to the optical path difference of $\lambda/2$. Assuming that $N$ is the number of changed rings, then the elongation length of the piezoelectric ceramic is

$$x = N \frac{\lambda}{2}$$  \hspace{1cm} (4)

where $\lambda$ is the wavelength of the laser. The experimental result is shown in Fig.4.

**Fig.4.** Elongation length of the piezoelectric ceramic at different voltages

When the voltage is 90V, the elongation lengths of rising voltage and falling voltage are 12.33$\mu$m and 13.55$\mu$m respectively. The elongation length is 18.56$\mu$m at the voltage of 150V. Due to the hysteresis effects in the piezoelectric ceramic [11], the elongation curve of rising voltage is not coincident with that of falling voltage, as shown in Fig.4.

**Fig.5.** Maximum displacement of fluid ($L$) at different voltages, where the cross-sectional area of microchannel is (300×500) $\mu$m², the radius of liquid storage tank $R$ is 3.5mm, and $T=298K$

**Fig.6.** Driven volume of fluid at different voltages
As shown in Fig.5 and Fig.6, the maximum displacement of fluid are 3.16\text{mm} at 90V and 4.76\text{mm} at 150V respectively. The driven volume of fluid is up to 0.714\text{μl} at the voltage of 150V. It is found that the drive capability of the proposed drive technology is powerful.

5. Conclusion

Here piezoelectric materials are applied in the microfluidic drive technology due to their excellent dielectric, piezoelectric and optical properties, where the piezoelectric ceramic is chosen in theoretical and experimental research. The piezoelectric ceramic has the advantages of high piezoelectricity and dielectric constant, and can be processed into any shape. The microfluidic drive device with the piezoelectric material and its working principle are introduced. The researching results show that at the voltage of 150V, the elongation length of the piezoelectric ceramic is 18.556\text{μm}, the maximum displacement of the driven fluid is 4.761\text{mm}, and the driven volume of fluid is 0.714\text{μl}. The work here can promote the application of piezoelectric materials in microfluidic technology.

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