CHARACTERIZATION OF PIEZOELECTRIC MICROPUMP DRIVEN BY TRAVELING WAVES

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Abstract

We report on a fabrication of a piezoelectric micropump driven by traveling waves and the flow characteristics in a microchannel. The microacuator for the fluid flow was composed of PZT bimorph beams which were allocated with a gap of 0.2 mm alternately and traveling waves were generated on the surface of the microchannel. We evaluated the conversion efficiency between vibrational energy of the channel wall and kinetic energy of liquid flow, and obtained high energy efficiency of 12%. This result indicates that the pumping system using traveling waves shows high efficiency which is suitable for the mobile microfluidic devices of μ-TAS applications.

Keywords: micropump, piezoelectric, travelling wave

1. Introduction

A variety of micropumps has been reported for bio-medical applications in μ-TAS since the micropumps are indispensable devices for the transportation and manipulation of liquid on a chip. Most of conventional micropumps have been equipped with diaphragm structure which generates differential pressure between inlet and outlet ports. In such systems, further miniaturization of the pumps is difficult because of increase of dead volume of stroke [1]. On the other hand, pumping system using acostic waves on the surface of the channel wall has been proposed and its efficiency was investigated [2,3]. In such pumps, traveling waves were generated in the microchannel on diaphragm by piezoelectric thin films with IDTs. These pumps are very simple and useful for integration into chips, however, the pumping force is relatively weak because the actuation by piezoelectric films are not generated in the microchannel directly. We have also developed piezoelectric micropumps driven by traveling waves but they are generated on the surface of the channel wall directly to obtain the adequate oscillation force of liquid flow. We have reported smooth and well-controlled liquid flow in microchanel using this micropump[4]. In this study, we measured the flow characteristics in detail, and particularly investigated the energy conversion efficiency of the pump.
2. Experimental

Schematic illustration of the micropump is depicted in Fig. 1. The pump was fabricated on a glass plate with the microchannel and piezoelectric actuators. The microchannel was made of silicone rubber. For the microfabrication of the channel, SU-8 was used as a mold and the silicon rubber was filled over it. After the SU-8 mold was removed, the top of the microchannel was covered with thin silicon rubber layer which was so flexible that the wall could be deformed easily. The dimension of the microchannel was 100 μm in width and 200 μm in depth. It was a very simple process for the fabrication of microchannel with flexible walls.

The microactuator was composed of nine PZT bimorph beams of 16×1.0×0.4 mm and they were allocated with the gap of 0.2 mm alternatively. The PZT cantilevers were individually operated by the sine wave signals with the phase difference of π/2 from the adjacent cantilever in order to induce traveling wave on the top wall of the channel. Clear traveling wave was obtained by superposition of standing waves with different phases as illustrated in Fig. 2. For an efficient transmission of the vibration, top wall was connected with PZT bimorphs through small bumps as shown in Fig. 3. The tip deflection of the PZT cantilevers was observed using laser Doppler vibrometer. The microchannel was filled with ethanol which was supplied from the fluid tanks equipped at the end of the microchannel. For the flow rate measurement, we added microbeads with the diameter of 10 μm into ethanol and observed their motion with CCD camera.

3. Results and discussion

The deflection of the PZT bimorph was measured by laser Doppler vibrometer. Figure 4 shows the tip displacement of the PZT cantilever with applied voltage 15 V as a function of frequency. Although almost constant displacement was observed below 750 Hz, it gradually increased near the resonant frequency about 1.2 kHz. Broad resonance was due to the ambiguous fixed edge of the cantilever. The flow velocity in the microchannel was observed by monitoring the microbeads in the fluid. The flow velocity
increased with the driving frequency of the bimorph as shown in Fig. 5, that was analogous to the deflection of the bimorph.

Considering these results, we evaluated the relationship of the energy between traveling wave and liquid flow. The average energy of the traveling waves $E$ can be defined as

$$E = \frac{1}{2} \rho_i (A\omega)^2$$  \hspace{1cm} (1)

where $\rho_i$ is the density of the oscillation wall, $A$ is the amplitude of traveling wave, and $\omega$ is the angular frequency.

On the other hand, the kinetic energy of the fluid $K$ is written as

$$K = \frac{1}{2} \rho_f U^2$$  \hspace{1cm} (2)

where $\rho_f$ is the density of fluid, and $U$ is the average spatiotemporal velocity of fluid. Then the velocity of fluid can be expressed using the energy conversion factor $\alpha$ by

$$U = \alpha \sqrt{\frac{E}{\rho_f,(A\omega)}}$$  \hspace{1cm} (3)
The relationship between $U$ and $A$ is shown in Fig. 6. The densities of silicon rubber and ethanol with microbeads are 1.25 g/cm$^3$ and 0.785 g/cm$^3$ respectively, therefore the energy conversion factor between traveling waves on the silicon rubber and average fluid velocity is calculated to be 12 %. The conversion factor was derived from rough estimation with disregard to the flow profile in microchannel as well as the practical energy budget with the electric energy applied into the bimorphs. However, it could be said that the fluid flow by traveling wave is practical method for the mobile applications of micropumps from the viewpoint of kinetic energy efficiency. The micropumps using surface acoustic waves by IDTs are similar fluid transportation system by traveling waves, however they are actuated by the IDTs away from the microchannel. On the other hand, traveling waves in our system are generated on the microchannel directly. The traveling waves induced by direct vibration are attributed to high efficiency of the micropump.

4. Conclusions

We characterized a piezoelectric micropump driven by traveling waves. The clear traveling waves were generated by coupling the standing waves of 9 bimorph cantilevers. The maximum flow velocity was 0.7 mm/s at the driving frequency of 1.2 kHz for the cantilevers. The energy conversion efficiency between vibration of the channel wall and liquid flow was calculated to be 12 %. This result indicates that the pumping system using traveling waves was suitable for the microfluidic devices of μ-TAS applications due to its high energy efficiency.

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References