Modeling, Vibration Analysis and Fabrication of Micropumps Based on Piezoelectric Transducers

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The parametric and vibrational characteristics of PZTs (Piezoelectric Transducers) with different diameters before and after coupling are discussed by finite element analysis. It is shown that the vibration stability of the piezoelectric transducer decreases with increasing driving frequency. The PZT’s variation of maximum displacement with frequency shows the same trend for different driving conditions according to vibration measurement under conditions of both free and forced vibration (before and after sealing with the pump body). The maximum displacement under forced vibration is less than that under free vibration. The maximum displacement is inversely proportional to the diameter of the transducer and directly proportional to the driving voltage under both free and forced vibration. Micropumps with diffuser/nozzle microvalves are designed and fabricated with different external diameters of the PZTs. Finally, the flow rate and pressure of the micropumps are measured, which are consistent with the vibrational results. Moreover, the maximum displacement is larger under a square-wave driving signal, followed by a sine-wave signal, and then a triangle-wave signal. For a PZT with an external diameter of 12 mm, the maximum flow rate and pressure value are 150 µl/min and 346 Pa, respectively, under sine-wave driving at 100 Vpp driving voltage.

1. INTRODUCTION

Piezoelectric transducers are the devices that use the piezoelectric properties of some crystals or other materials to convert one type of energy to another one. Moreover, piezoelectric transducers are often used as driving devices for actuating microfluidic systems, since flow inside a microfluidic device could be affected by vibration. Therefore, it is important to study the behavior of piezoelectric transducers, especially when they are coupled with microfluidic devices. Specifically, in practical applications, it is very important to understand the influence of transducer vibration on microfluidics performance. For example, Liu studied the coupled vibration of a sandwich piezoelectric transducer using an approximate analytical method. The results showed that the resonant frequencies obtained from the coupled resonant frequency equations are in good agreement with those from numerical methods, and super harmonic resonant frequencies can also be obtained. Zhu et al. simulated and analyzed the behavior of a piezoelectric flexible plate using MATLAB and ANSYS software. The vibration control experiments were performed based on an APDL (the design language of ANSYS) program. The designed controller had good vibration suppression performance according to the analysis and experimental results. Catarino et al. proposed a microfluidic mixing device with two different piezoelectric materials. The mixing-time reduction for both materials, above 90% for PZT and above 80% for β-PVDF, were tested according to numerical simulations and experimental studies. Huang et al. studied a piezoelectric harvester’s resonant frequencies and voltage output equation at various excitation frequencies according to numerically calculated results as well as experiments, which showed a high level of voltage output.

Piezoelectric micropumps are popular in microfluidic systems. They have been used in medicine, agriculture, and aviation, among other applications. Therefore, it is extremely important to study how to improve the performance of micropumps, and researchers have made a lot of efforts in studying the performance of a common piezoelectric material: Lead Zirconate Titanate (PZT). Aggarwal et al. fabricated and studied two different sizes of piezoelectrically actuated microgated silicon valveless micropumps with a vertical diffuser/nozzle microchannel, and the flow rate and the back pressure were evaluated. Cheng et al. fabricated an impedance micropump with nickel electroforming components, a stainless steel vibration plate, and a piezoelectric actuator. The flow rate of 0.24 ml/min and back pressure of 2.35 kPa were demonstrated with a 200 Vpp driving voltage. He et al. presented a new type of valveless piezoelectric micropump with synthetic jet and Coanda effect to achieve larger and bidirectional flow rate. An optimal frequency of 50 Hz and a Reynolds number of 1000 was identified for a maximum flow rate of 6.8 ml/min. Wang et al. presented a Finite Element Analysis (FEA) micropump model actuated by a piezoelectric actuator. The maximum displacement of the PZT ceramic disk was found to vary along with the diameter ratio, membrane thickness and the diameter of the chamber. Kang and Auner designed a piezoelectrically actuated check valve diaphragm micropump and studied the average displacement of the diaphragm. The relationship between the stroke volume and backpressure were simulated with an FEA tool. Singh et al. fabricated and tested a piezoelectrically actuated polydimethylsiloxane (PDMS) planar valveless micropump. The predictions of the analytical model and numerical simulations in terms of flow rate versus frequency, voltage and pressure-flow matched with experimental data (within 20%). Zhang presented a self-sensing piezoelectric pump with a bimorph transducer. The output flow and pressure could be achieved through a single piezoelectric element, and the simultaneous function could be achieved by the other PZT disk.

We can see that previous research has concentrated on FEA modeling of piezoelectric transducers and new structures of micropumps.