3P3-10

Numerical Study of Microparticle Separation in a Microfluidic Channel Driven by Surface Acoustic Waves

Yu-Chun Chen[1†] and Jin-Chen Hsu[1] ([1]Department of Mechanical Engineering, National Yunlin Univ. of Sci. and Tech.)

1. Introduction

In the past decade, noninvasive manipulation of immersed objects has garnered great interest [1]. Specifically, acoustic manipulation in microfluidic channels has emerged to serve as a powerful tool in microfluidics to manipulate micron-sized objects in chemical, medical, and biological applications [2]. Pure and controllable mechanical forces involved in the acoustic manipulation method exhibit a minor negative impact on viability and functionality of biological cells [3]. One of acoustic manipulation methods involves creating a standing acoustic-wave field across a microfluidic channel and employing the resulting acoustic pressure field to trap, separate, pattern, or sort particles suspended in microfluids. Various types of acoustic-wave modes were utilized to produce desired acoustic-wave fields including ultrasonic bulk acoustic waves, surface acoustic waves (SAWs), and Lamb waves (LWs) [4,5]. With respect to the design of efficient and reproducible devices, increasing attention has been focused on SAW-based microfluidic devices owing to their simple geometry, accessible precise definition of dimensions by microfabrication, and integratability with channels composed of soft polymers.

In many chemical and biological applications, simple and efficient particle separation methods are of fundamental importance. To date, many particle separation methods in microfluidic systems have been demonstrated, including centrifugal, magnetic, electrokinetic, dielectrophoretic, and hydrodynamic methods. Recently, acoustic-wave-based techniques based on bulk and surface acoustic waves have also enabled the separation of microparticles of different sizes and densities in microfluidic channels. This approach uses acoustic transducers to generate bulk or surface acoustic waves. Waves are then coupled into a silicon or polymer microchannel with a width related to half of their wavelength. The resonance or interference of acoustic pressure waves inside the channel results in a standing acoustic field with a pressure node in the channel. Particles injected along the specific position of the channel subjected to lateral acoustic forces whose magnitudes depend on the particle size, density, and compressibility. These differing forces reposition the particles with different lateral displacements to achieve particle separation. This approach is notably advantageous because it requires no pretreatment of the particles and can be applied to various kinds of particles with different physical or chemical properties [6].

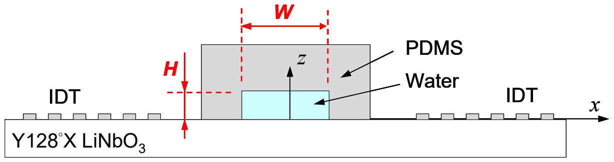

Fig. 1 Schematic of cross section of the SAW microfluidic device for microparticle separation.

In this work, we present a numerical study of separation of different microparticles achieved by SAW-based acoustophoresis method in microfluidic channels. Separability and separating efficiency of the microparticles with different materials and sizes are numerically studied. The separation mechanism and design method are discussed.

2. Method

Figure 1 shows the schematic illustration of cross section of the SAW microfluidic device for the mixing particle separation. The structure includs a microfluidic channel located between two IDTs patterned on a $LiNbO_3$ substrate. When excited by an AC signal, the IDTs convert an electric field into SAWs. As the IDTs are designed to have a specific pitch, and a corresponding input frequency of the

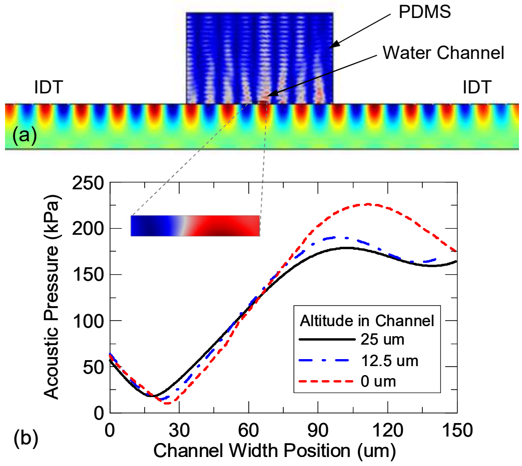

Fig. 2 (a) SAW and acoustic pressure fields in the device. (b) The acoustic pressure along the channel width (150-um wide) at three altitudes.

Corresponding author's Email: hsujc@yuntech.edu.tw

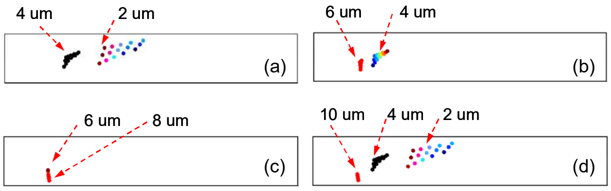

Fig. 3 Separation of microparticles containing different sizes of polystyrene beads in the channel driven by the acoustic pressure field for 1 second.

AC signal is given to excite SAWs and generate an acoustic pressure field in the water channel. Several parameters can be used to tailor the pressure field, including the IDT pitch, microchannel position and geometry, phase difference between the two IDTs.

We use the finite element method to calculate SAW and acoustic pressure fields and the coupling. A moving particle exposed to the standing acoustic wave field is subjected to a time-averaged acoustic radiation force, Stokes' drag force, buoyant force, and gravity. Considering all the acting forces in the Newton's second law of motion, the trajectory and position of the particle can then be obtained.

3. Results and Discussion

Figure 2 shows the numerically excited SAW and acoustic pressure fields of one of our designs of the SAW microfluidic devices. Each IDT contains eight pairs of electrodes, and the pitch is 398 um. The input frequency of the AC signal is 10.02 MHz with a 16-V voltage amplitude. An enlarged view of the acoustic pressure field is shown in the inset of Fig. 2(b) where a pressure node and an anti-node are generated inside the channel. The variation of the acoustic pressure field in Fig. 2(a) can be used to drive the microparticle of different sizes to move at different rates. **Figure 3** shows the results of particle separation. We release the mixing particles (from ~70–90 um from the left end of the channel) with several size combinations. We assume a 1-s actuation. It can be observed that larger particles are driven farther. As a result, particles with different sizes can be separated. However, Fig. 3(c) shows the 8 and 6-um mixing particles are not effectively separated by 1-s actuation. The mechanism can be used to separate mixing particles with three sizes, as shown in Fig. 3(d). But this is also subjected to the condition of the composition of the particle sizes. To increase the separability, tuning actuation time and using a two- or multi-step separation driven by different acoustic pressure fields are possible ways.

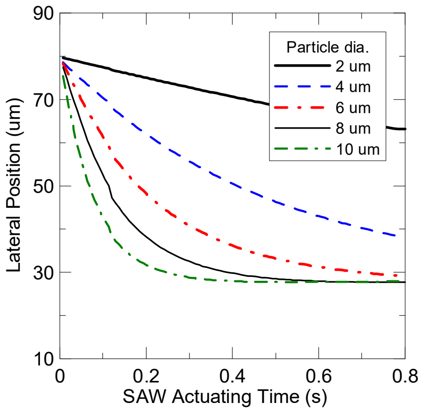

Fig. 4 Lateral position of particles with different sizes driven by the acoustic pressure field under different SAW actuating times.

To discuss the separability of mixing particles by the SAW microfluidic device, **Fig. 4** shows the lateral position of particles of different sizes driven by the acoustic pressure field under different SAW actuating times. It can be seen that during the 0.8 s actuating time, the separability increases with time and is better for mixing particles with small/small (e.g. 2 um/ 4 um) or small/large (e.g. 2 um/8 um) combination. For large/large (6 um/8 um or 8 um/10 um) combinations, a shorter actuating time such as 0.2 s is more suitable for their separation.

4. Conclusions

In this study, we have employed a solid-fluid coupling model based on a finite element method to numerically study the microparticle separation in a SAW microfluidic channel. Microparticles mixed with two or more different sizes can be separated in the designed device. Separability and methods for increasing the efficiency have been discussed. High separability for particles of sizes range from 2 to 6 um can be observed with the used design. A suitable actuation time can increase the efficiency for the separation when using the standing SAW scheme.

Acknowledgment

This work was supported by MOST, Taiwan. Grant numbers: MOST 103-2221-E-224-002-MY3 and MOST 106-2628-E-224-001-MY3

References

1. G. Destgeer and J. S. Hyung: Lab Chip **15** (2015) 2722.
2. J. Friend and L. Y. Yeo: Rev. Mod. Phys. **83** (2011) 647.
3. M. A. Burguillos, C. Magnusson, M. Nordin, A. Lenshof, P. Augustsson, M. J. Hansson, E. Elmér, H. Lilja, P. Brundin, T. Laurell, and T. Deierborg: PLoS One **8** (2013) e64233.
4. Z. Mao, Y. Xie, F. Guo, L. Ren, P.-H. Huang, Y. Chen, J. Rufo, F. Costanzo and T. J. Huang: Lab Chip **16** (2016) 515.
5. J.-C. Hsu, Y.-W. Huang, and C.-H. Hsu, Jpn. J. Appl. Phys. **56** (2017) 07JD05.
6. J. Shi, H. Huang, Z. Stratton, Y. Huang, and T. J. Huang: Lab Chip **9** (2009) 3354.