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Acoustic manipulation in a microchannel

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ABSTRACT

Noncontact micro manipulation technique is needed in micromachine technology, biotechnology and so on. In the present paper, a standing wave field is generated in a microchannel, it is possible to trap small objects at nodes of the sound pressure distribution in the medium. A microchannel of 1mm x 50 mm x 1mm was made at the center of a glass plate of 50 mm x 50 mm x 5mm. In the experiment, when the liquid water containing alumina particles was injected into the microchannel on glass plate irradiated by ultrasound, the particles flowed along several layers. It was shown that the traveling wave was transmitted into the microchannel and the standing wave field was formed in the microchannel. Moreover, when the frequency of the ultrasound was swept, the particles were spatially shifted. It was able to control the direction of the particle flow by changing the ultrasound frequency in the branched microchannels.

INTRODUCTION

Noncontact micromanipulation technique is needed in micromachine technology, biotechnology, and other fields. The radiation pressure of ultrasound may be used for this purpose as it is possible to trap particles at sound pressure nodes of a standing wave field in the medium [1, 2]. Manneberg *et al*. [3] have studied the manipulation of biological cells in a microchannel on a glass plate irradiated with ultrasound through a metal block. S. Oberti et al. [4] set PZT transducer on a microchannel and manipulated individual particles flowing through the microchannel. Masuda *et al*. [5] have attempted to control a microbubble flow in a blood vessel using acoustic radiation pressure. Yamakoshi and Miwa [6] have analyzed the behavior of a microbubble in a standing wave field generated by two focused-type transducers in water. The authors have realized an acoustic manipulation technique for transporting particles three-dimensionally using a standing wave field generated by four transducers in water [7-9].

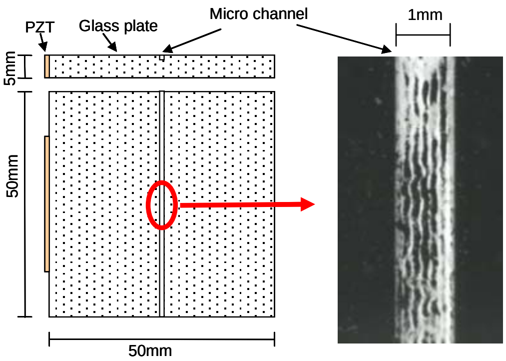
In the present study, a sound wave is generated far from a microchannel in a glass plate, connected to a PZT transducer. The sound wave was transmitted into the microchannel through the glass plate, and a standing wave field was formed in the microchannel. Solid particles were trapped in the sound pressure nodes of the sound field, and the particle flow direction was controlled by changing the frequency. Moreover, when a geometric pattern was set up in the center of the microchannel, the particles exhibized interesting behaivior.

EXPERIMENT

Trapped particles in a microchannel

Figure 1(a) shows a glass plate with a microchannel. The size of the glass plate is $50\times50\times5$ mm^3. A microchannel of $1\times50\times1$ mm^3 was set at the center of the plate. The microchannel is surrounded by three glass walls, and the top surface is open to air. A rectangular transducer of 30×5 mm^2 is adhered to the left end of a glass plate using grease. When a suspension of alumina particles was poured into the microchannel, the alumina particles agglomerated into several layers.

Figure 1(b) shows the experimental result for a frequency of 4.5 MHz; particles agglomerated into six layers in the microchannel. The ultrasound wave propagates into the microchannel through the glass plate, and a standing wave field is formed in the microchannel. As a result, particles were trapped at the sound pressure nodes of the sound field. The microchannel has three surface planes of glass. Although a



(a)The glass plate (b) The experimental result

Fig. 1 The basic microchannel system

complicated sound field is generated in a glass plate, it is considered that the sound wave propagating from the left surface acts predominantly in the microchannel, because there is a sound source on the left of the microchannel.

Control of the particles in a branched microchannel

A microchannel with a branch on the glass plate, as shown in Fig. 2(a), was used. The transducer, which was attached to the left side of the glass plate, was driven at 4.5 MHz and a suspension of polyethylene particles was poured from the upper end of the microchannel at a speed of 16.7 mm/s using a pump.

When the driving frequency was swept from 5.25 to 3.75 MHz every 0.1 s, it was observed that the particles were pushed to the left side of the channel, although particles initially flowed on the right side of the channel. Figure 2(b) shows the behavior at the branch point in the microchannel. In other words, it was possible to control the direction of the particle flow by ultrasound.

With a geometric region in the microchannel

The trace of particles was only partly controlled by changing frequency in the branched microchannel, because the region of the branched space is small. Therefore a geometric space was added in the center of the microchannel and the particle behaviour was observed in the region. Figure 3 shows the particles behavior with a circular region of 5 mm in diameter. The particles were agglomerated in a concentric-like shape.

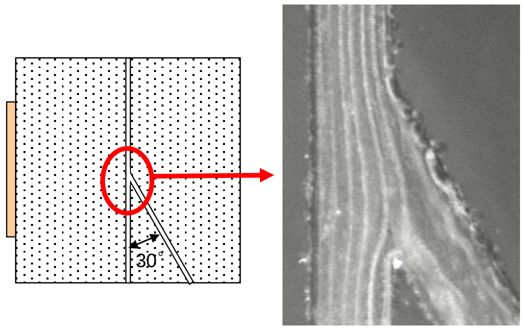
Figure 4 shows the particles behavior with a half circular region of 5 mm in diameter and an additional exit microchannel at the right side. The particles were agglomerated in a geometric pattern (Fig. 4(b)). Moreover, when the frequency was repeatedly swept from 4.2 MHz to 4.6 MHz every 0.2 s, the particles moved to the right as shown in Fig. 4(c). When the frequency sweep was reversed, the particles moved to the left in Fig. 4(d). When the suspension particles were poured from the upper end of the microchannel, the water flowed to both right and lower directions. On the other hand the direction of the particles' flow was controlled by changing ultrasonic frequency.

A triangle region in the microchannel

Changing the frequency, the sound field was changed and it was possible to control the direction of the particle flow. Although the frequency was fixed, the particle movement was observed in the specific shape region. Figure 5 is for the region of triangle pattern under 4.5 MHz ultrasound. Although the frequency was fixed, the particles moved toward the right. In addition, in the experiment with the horizontal axis reversed, it was observed that the particles moved to the left in Fig. 6. When the incident angle is 90 degree to the plane, ultrasound propagates mostly into the region. Thus in Fig. 5 ultrasound propagates from the region to the left. Accordingly travelling wave pushes particles from the right to the left.

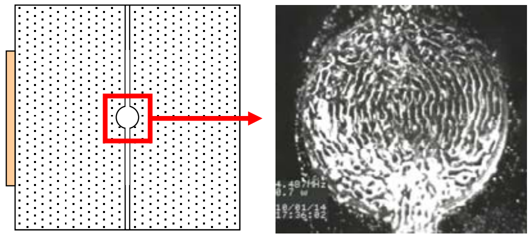
DISCUSSION

The particle agglomerated pattern in the microchannel was of interest. It is difficult to measure the sound pressure in a microchannel by a hydrophonic or Schlieren method. Therefore, numerical analysis was performed by the finite element method (FEM, COMSOL Multiphysics). For the analysis by FEM, It is necessary to divide an object into the micro domains which are smaller than 1/6 of the wavelength. When the frequency is higher, it needs more memory for a calcula-



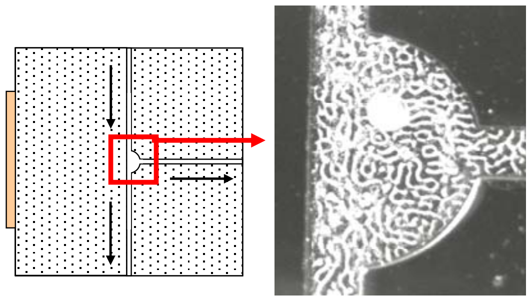
(a) The glass plate (b) The experimental result

Fig. 2 The branched microchannel system

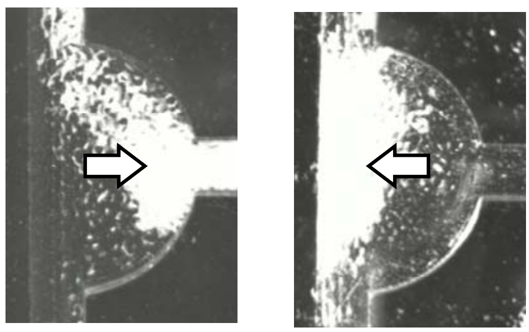


(a) The glass plate (b) The experimental result

Fig. 3 The microchannel system with a circular region

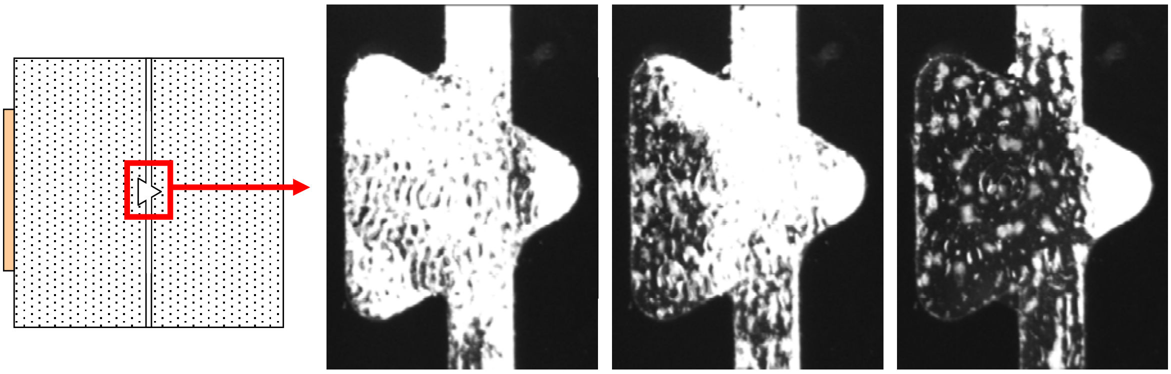


(a) The glass plate (b) The experimental result



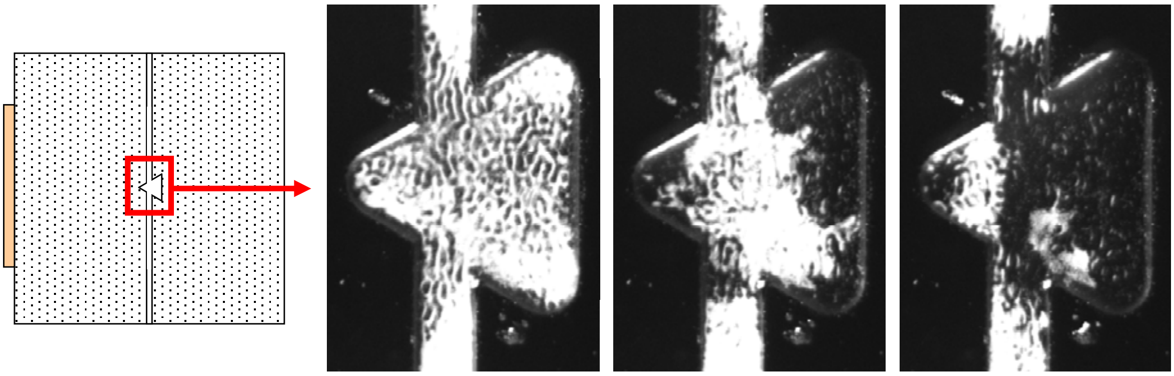
(c)With frequency sweep upward (d)With frequency sweep downward

Fig. 4 The branched microchannel system with a half circular region



(a) glass plate (b) Initial state (c) After few seconds (d) After 10 seconds

Fig. 5 The microchannel with a triangle region

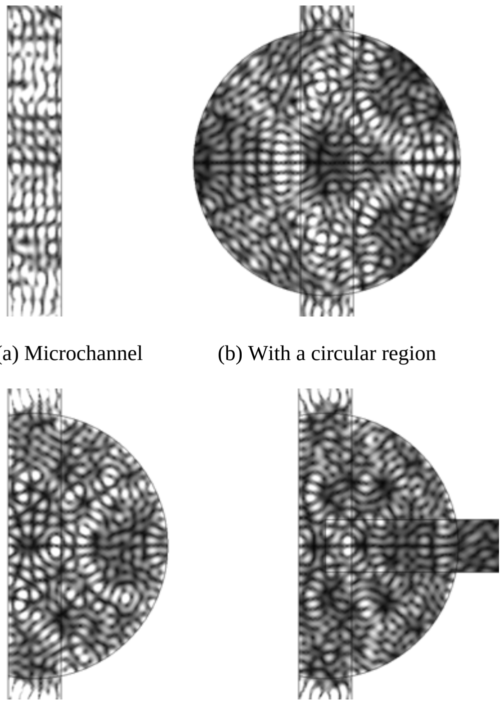


(a) glass plate (b) Initial state (c) After few seconds (d) After 10 seconds

Fig. 6 The microchannel with a reversed triangle region

tion because the object should be divided into smaller domains. S. M. Hagsater et al. [10] compared the calculated result of 2D and 3D, and showed there is few difference between the calculated results of 2D and 3D when the thickness of the object is comparable to or smaller than one wavelength. In the present experiment, the microchannel thickness is 1 mm with the base glass of 4 mm in thickness, and it is desirable to analyze in 3D. However, the 3D calculation was not possible due to the memory limitation for a computer with 8GB memory. Thus, in the present paper the calculated result of 2D is shown. When it will be able to use a computer of the large capacity memory in the future, it will be calculated in 3D.

Figure 7 shows the calculated sound pressure distribution on the horizontal surface of the center of the microchannel at 4.5 MHz. The parameters for the FEM analysis are 1000 kg/m^3, and 1500 m/s for water and 2320 kg/m^3 and 5640 m/s for the glass plate of solid silica glass. Influence of the particles on the acoustic field was neglected in the present calculations. Figure 7(a) is for microchannel only, (b) is with circular region, (c) is with a half circular region and (d) is with a circular region and a right exit microchannel. The scale for pressure distribution in each figure is normalized by the maximum sound pressure. A standing wave field was formed in all cases, the calculated pattern is similar to that of particles experimentally observed.



(a) Microchannel (b) With a circular region

(c) With a half circular region (d) With a half circular region and a exit

Fig. 7 Numerically calculated sound pressure distribution

CONCLUSION

In conclusion, a standing wave field was formed in a microchannel with a 1×1 mm^2 cross section on a glass plate. An ultrasonic wave successfully propagated into the microchannel on the glass plate. When a suspension of particles was introduced into the microchannel, the particles agglomerated into a few layers, each separated by a half wavelength. When a geometric space was added in the center of the microchannel, the particles were agglomerated in a geometric pattern. If the frequency of the ultrasound was swept in the microchannel with a half circular region, the particles were spatially shifted. It was able to control the direction of the particle flow by changing the ultrasound frequency in the branched microchannels. Moreover, in a triangular region, the particle moved towards the top from the base of the triangle with a fixed frequency. A sound field was numerically calculated by FEM in 2D under the experimental conditions and the experimental results were discussed. Although it is desirable to analyze in 3D, it is not possible due to the memory limitation.

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