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Multi-manipulation modes of ultrasonic tweezers by DPLUS

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Abstract

This report presents a DPLUS (Double Parabolic refLectors wave-guided high-power Ultrasonic tranSducer) based ultasonic twezzers, which can achieve multi manipulation modes in the water. During the manipulation, a needle probe of DPLUS, which vibrates along the axis of needle, is vertically immersed in the water, The DPLUS can excite low (154.4 kHz) and high frequency (1.49 MHz) vibration modes. Depending on different vibration modes, various manipulation types can be achieved, which include non-contact, contact and high frequence release mode. The manipulation principle was clarified by finite element method.

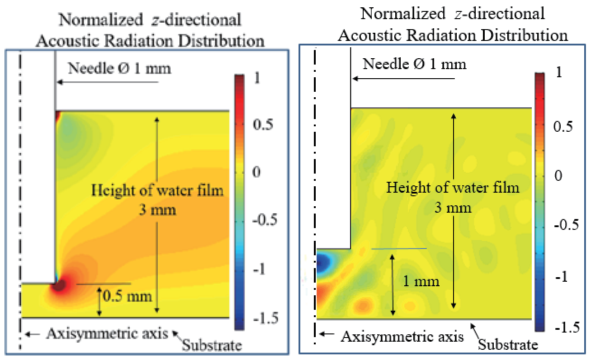
1. Introduction

Micro/nano manipulation has huge potential applications in the self-assembling of micro/nano materials [1], crystal growth [2], and culture of artificial tissues [3], etc. Micro-object manipulation can be achieved by dielectrophoresis, mechanical, optical, ultrasonic, magnetic methods, etc. [4-5]. As one of the major micro-object manipulating devices, ultrasonic tweezers have attracted lots of attentions, as they have the merits such as wide selectivity to material properties, simple structure, and easy control of the trapping force [6].

In previous work, some of authors proposed and developed an ultrasonic transducer named as DPLUS [7], which can realize low-loss and high-power transmission of ultrasonic vibration energy. In this work, The DPLUS device can excite low (154.4 kHz) and high (1.49 MHz) vibration modes. High frequency has many advantages, such as high power, excellent directivity. Using the high frequency, DPLUS can implement the concentration, non-contact transport and controllable release of micro-object. The manipulation strategy at low driving frequency was also presented. In the low frequency mode, samples could be trapped to the tip of needle, which is contact type manipulation. In addition, for some materials which have adhesion effect, it is not easy to release them. A new strategy using both the low and high frequencies is presented to manipulate adhesive material. Samples used in this the work include micro copper wires, TiO2 and yeast cells powder. Also, the operation principles were analyzed by the FEM computation.

2. Experimental Principle

In this work, acoustic radiation force on yeast cell around the needle tip was computed by the FEM to analyze the manipulation mechanism. To simplify the computation, only the needle and water film were included in the two-dimensional axisymmetric FEM model.



(a) 154.4 kHz (b) 1.49 MHz
Fig. 1 Normalized Acoustic Radiation Force.

Figure 1 (a) and (b) show the normalized distribution of computed +z-directional (axial direction of needle) acoustic radiation force on yeast cell, when the frequencies are 154.4 kHz and 1.49 MHz, respectively. The color denotes the magnitude of the acoustic radiation force, and the white stripe denotes the DPLUS needle. As shown in Fig. 1 (a), in the tip of needle, acoustic radiation force is upward and has maximum value, which means the trapping of micro-objects at the tip of needle. In Fig. 1 (b), when the distance between the vibrating needle tip and substrate equals one wavelength (in water) under 1.49 MHz, the acoustic radiation force has the opposite directions below and above the sound pressure nodal plane, which makes the levitation and trapping of a micro-object possible.

3. Experimental Setup

Figure 2 shows the experimental setup. The experimental phenomena were observed by a

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microscopy. The DPLUS's needle tip was vertically inserted into water to manipulate the samples on the plastic substrate. Mirco particle samples used in the experiments include copper wire with a diameter 60 µm and length of 0.5-2 mm, TiO_2 powders which are about 15-50 nm and yeast cell with a diameter of 3-10 µm.

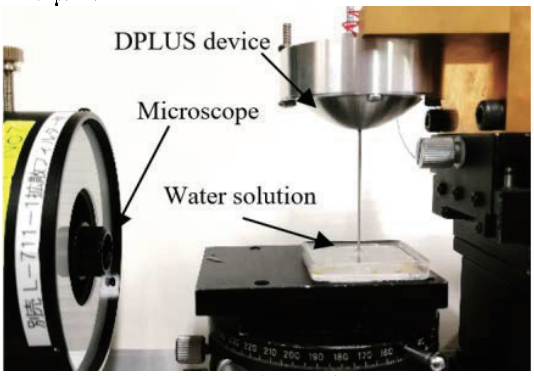
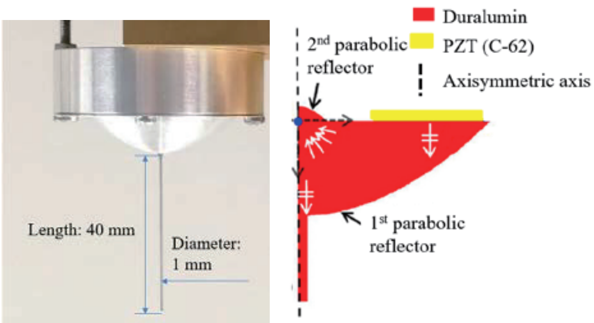


Fig. 2 Experimental setup.

Figure 3 shows DPLUS proposed by some of authors [7]. In Fig. 3(b), after the first parabolic reflection and focus, the ultrasound is guided by the second parabolic reflector, then, focused ultrasound is transferred to the needle. This double parabolic reflectors structure concentrates the acoustic pressure greatly at the needle tip and transmit powerful ultrasound.



a) Photo of DPLUS b) Principle of DPLUS
Fig. 3 DPLUS device.

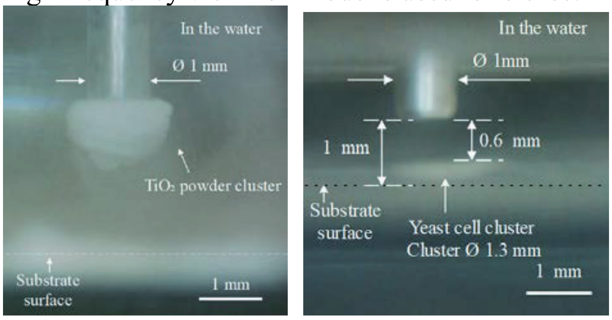
4. Experimental Results and Discussion

Due to the different driving frequencies, there are 3 different manipulation modes.

For the contact mode, the driving frequency was 154.4 kHz, and the driving voltage was 50 Vp-p. Fig. 4(a) shows a cluster of TiO_2 powders was concentrated and attached to the tip of vibrating needle, which can be explained in Fig. 1(a).

For Non-Contact mode, the driving frequency was 1.49 MHz, and the driving voltage was 15 Vp-p. Fig. 4(b) shows that under the vibrating needle, yeast cells were concentrated to a cluster, and the cluster of yeast cells was levitated in water between the needle tip and substrate, which can be explained in Fig. 1(b).

For adhesive materials, it is not easy to release them after trapping. A new manipulation strategy using both the low and high frequency was proposed; the low frequency vibration mode of DPLUS is used to capture the sample; then, the materials could stay on the tip on needle; then, the high frequency vibration mode is used to release.



(a) Trapping of TiO2 (b) Trapping of yeast cells
Fig. 4 Manipulation phenomena of Contact typeand Non-Contact type.

5. Conclusions

A DPLUS based micro manipulation system was presented in this work. Manipulation principle was numerically calculated and analyzed. The FEM calculation results of the sound pressure field near needle tip can well explain the different manipulation modes under high and low frequency. The manipulation methods can be applied in the fabrication of micro/nano sensors, culture of artificial tissues, micro/nano assembling, etc.

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