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EDITORIAL

Acoustic Micro/Nano Manipulations: An Editorial Review

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ABSTRACT

Acoustic micro/nano manipulation is a technology to handle or actuate micro/nano objects in a controlled way by physical effects of sound waves. In this editorial review, principles employed by acoustic micro/nano manipulations are listed and briefly explained, and the manipulation functions based on these principles are described. Also, the technological challenges in acoustic micro/nano manipulations are pointed out.

Key words: Manipulation; Micro/Nano; Sound

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EDITORIAL

With the development of fields such as biomedicine, micro/nano fabrication, nanoscience and nanotechnology, material engineering, renewable energy, etc., more actuation functions for micro/nano objects are being required[1,2]. They include trapping (or capture), orientation, transfer, release, sorting, revolution, spin, removal, concentration, assembly, etc. These actuation tasks are also called manipulations. However, most of the above listed manipulations cannot be effectively and efficiently realized by the conventional actuation technology, which have limited driving forms and operating principles[2].

To fulfill the micro/nano manipulation functions, researchers in various academic areas have proposed and investigated lots of strategies. These strategies can be classified as optical[1,3], magnetic[4], electric[5], mechanical[6], AFM[7], microfludic[8] and acoustic methods[9-15], based on the physical principles which they use.

The acoustic micro/nano manipulation technology utilizes physical effects of sound to manipulate micro/nanoscale solids, and micro/nanoliter droplets and bubbles. It has the features such as no selectivity to material properties of manipulated samples, little heat damage to manipulated samples (in some methods), diverse manipulation functions, simple and compact device structures, etc. Operating frequency in acoustic micro/nano manipulations may be in the ultrasonic range (>20 kHz) or several ten to several hundred Hz (in audible sound range).

Physical effects of sound, employed by the acoustic micro/nano manipulation technology, include the acoustic radiation force[2,16-19], acoustic streaming[19-21], vibration based frictional driving[22], Chladni effect[23,24], acoustic cavitation[25,26], Bjerknes forces[2,27-29], and sound induced intermolecular force decrease[2,30-34]. So far, the acoustic radiation force and acoustic streaming are two mostly utilized physical effects in acoustic micro/nano manipulations.

The acoustic radiation force is mainly used to manipulate micro objects. It may be generated by the standing wave[2,5,9,19,35-37], focused beam[10] and travelling wave[2,11,17]. The standing wave may be generated by the radiation face-reflector structure[2] or SAW (surface acoustic wave) device[19]. The acoustic radiation force generated by a standing wave can push micro objects in the acoustic field to the sound pressure nodes (or anti-nodes) and make them concentrating at the positions. It is quite effective in concentrating multiple micro particles in a standing wave. However, the standing wave method is not fit for the manipulations of individual micro objects and

relatively complicated manipulation functions such as the controlled assembly of micro components. The focused beam method uses the focal point of an ultrasonic beam to trap a single micro object or several micro objects. The trapped micro object(s) can be transferred by simply moving the ultrasonic transducer generating the ultrasonic beam. However, the stability of the trapped micro object is poor owing to the noncontact working principle, and strong ultrasound at the focal point may cause a high temperature rise to damage the biological samples and other heat sensitive samples. The travelling wave method utilizes large spatial gradient of sound field near a radiation point, line or surface vibrating in-plane to generate the acoustic radiation force to attract micro objects onto the radiation source. It has the capability of trapping and rotating single or multiple micro objects, and the stability of the trapped sample(s) is better. However, wet and soft samples trapped by this method may stick to the manipulating probe, and releasing the sample(s) from the manipulating probe in a controlled way is still a big challenge[38,39]. Another technological challenge in the travelling wave method is how to decrease the temperature rise in the manipulation part.

The acoustic streaming generates the manipulating force required by acoustic nano manipulations. At the present stage, almost all of the acoustic nano manipulations rely on the acoustic streaming[2]. It can be generated by the spatial gradient of Reynolds stress and the 2nd order sound pressure in a sound field, collapse of acoustic bubbles, or elliptical motion of a micro manipulation probe. Realized functions of the acoustic nano manipulations include trapping, orientation, positioning, transfer and rotation of individual nanowires in deionized water, and concentration of nanowires and nanoparticles in deionized water[2,15,40-42]. In the acoustic nano manipulations, the temperature rise at the manipulation area is usually very low, and can be lower than 0.1℃[15]. This feature makes the acoustic nano manipulation technology very competitive in the handling of biological and heat sensitive samples. In the acoustic nano trapping, a trapped nano object may be in contact or not in contact with the manipulation probe[2,15,40,42]. The acoustic nano concentration can be implemented in a water droplet on an ultrasonic stage in vibration[2,43], or in a water film excited by an acoustic needle suspended above stationary substrate[2,44]. To enhance the devices' manipulation performance, acoustic streaming fields in the devices need to be quantitatively analyzed, and vibration control methods of the ultrasonic transducers need to be explored.

Other physical effects of sound such as the vibration based frictional driving, Chladni effect, acoustic cavitation, Bjerknes forces, and sound induced intermolecular force decrease also have applications in acoustic micro/nano manipulations. In the vibration based frictional driving technique, the elliptical motion of solid surface with a travelling wave is employed to drive micro objects on the surface of a substrate. Methods of generating the travelling wave may be found in Refs[22-24]. The vibration based frictional driving of micro objects may be used in particle transportation and separation[45,46], rotary driving of micro mechanical components[23-24], etc. In the Chladni effect, the impact between a vibration surface and particulate matters on the vibration surface is used to drive the particulate matters to the vibration nodes of the vibration surface. The Chladni effect provides a positioning force in the travelling wave based rotary driving around vibration nodes of a plate in the flexural twisting vibration mode[2,23-24]. The acoustic cavitation is a well known physical effect of ultrasound, in which micro bubbles are generated in a sound field in liquid[25-26]. Its recent applications include the pore size increase of cells and the dispersion of micro/nano particulate matters in solution[47]. The Bjerknes forces are a special acoustic radiation force acting on vibrating bubbles in liquid[27-29]. This force is useful in the concentration of micro particles in liquid. Acoustic vibration in liquid can cause the decrease of intermolecular cohesive force such as Van Der Walls force and Hydrogen bonding among liquid molecules[2,30-32,34], no matter whether the acoustic cavitation has occurred or not. This effect has been employed in the driving of micro fluid[30-33], merging of micro droplets[34], etc. Compared with the acoustic radiation force and acoustic streaming, physical effects such as the vibration based frictional driving, Chladni effect, acoustic cavitation, Bjerknes forces, and sound induced intermolecular force decrease still haven't been explored sufficiently. They are worthy of being investigated thoroughly in basic principle, device design theory and applications, due to their potentials in micro/nano manipulations.

Acoustic micro/nano manipulation technology is an emerging academic field, generated by the merging of Acoustics and actuation technology, to meet the diversified requirements of handling micro/nano scale objects. Although it has very large potential applications in the fields such as biomedicine, micro/nano fabrication, nanoscience, material engineering, renewable energy, etc., researches on the principle, structure design, and application of the devices are still superficial and insufficient. Constructive experiments and in-depth theoretical analyses, which are key to achieve the breakthroughs, are needed and will definitely push acoustic micro/nano manipulation technology forward.

CONFLICT OF INTERESTS

There are no conflicts of interest with regard to the present study.

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