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Refractive index change and acoustic cavitation in water by high-intensity ultrasound radiation in the VHF range

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1. Introduction

The refractive index in water is changed near the surface of an ultrasound transducer when high-intensity ultrasound in the 100-MHz range is radiated[1]. Acoustic cavitation bubbles generated by the ultrasound are currently under investigation as they are considered to play an important role in this phenomenon. The threshold value of negative sound pressure for generation of the acoustic cavitation bubble depends on the ultrasound frequency, and the pressure threshold increases with ultrasound frequency[2]. To the best of our knowledge, there are few reports that investigates the generation of acoustic cavitation bubbles using high-frequency ultrasound in the 100-MHz range. In this report, acoustic cavitation bubbles generated by high-intensity ultrasound in the 100-MHz range was observed, and its size distribution was investigated.

2. Experimental methods

2.1 High-frequency high-intensity ultrasound transducer

An ultrasound transducer with a $KNbO_3$ piezoelectric thin film deposited by hydrothermal method was used to radiate high-frequency high-intensity ultrasound into water. A $KNbO_3$ piezoelectric thin film (Diameter: 4 mm) with a thickness of approximately 70 µm and surface gold electrodes on both sides was bonded to the end of a 6 mm diameter cylindrical copper pipe (Fig. 1). A function generator (T3AFG500, TELEDYNE) was used to generate a continuous sine wave signal with a frequency of 160 MHz, which was amplified by 50 dB using a high-frequency amplifier (ZCA5050-9K250M-OR, RAD) before being applied to the $KNbO_3$ ultrasound transducer.

2.2 Observation of acoustic cavitation

An ultrasound transducer was placed in a glass cell (10 × 10 × 45 mm) filled with ultrapure water and high-frequency high-intensity ultrasound (frequency: 160 MHz; input voltage: 101 V_{pp}) was radiated into the water. Acoustic cavitation bubbles generated near the surface of the ultrasound transducer by ultrasound radiation was observed using a high-speed camera (k8-USB, KATO KOKEN).

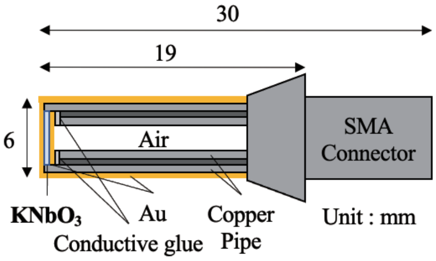

Fig. 1 $KNbO_3$ ultrasound transducer.

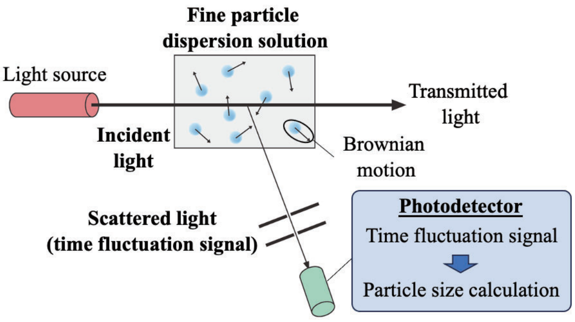

Fig. 2 Measurement principle of dynamic light scattering method.

2.3 Evaluation of the size distribution and zeta potential of bubbles

The size distribution and zeta potential of nano-meter-sized cavitation bubbles generated by ultrasound were measured using dynamic light scattering (DLS) and electrophoretic light scattering (ELS) measurement systems (ELSZ-2000, Otsuka Electronics), respectively. DLS is a method to estimate the particle size distribution from time fluctuation of the scattered light from fine particles with Brownian motion in the sample (Fig. 2). ELS is a method to measure zeta potential (electric potential near the surface of a bubble) from frequency change of the scattered light from electrophoretic fine particles by applying an electric field to the sample. A glass cell was filled with ultrapure water, and high-frequency high-intensity ultrasound (160 MHz, 101 V_{pp}) was radiated continuously for 60 s. The ultrasonication was repeated 50 times totally, and the size distributions of the bubbles generated in the glass cell was measured every ultrasonication. Dissolved oxygen (DO) in the cell was measured

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under the same conditions using a dissolved oxygen meter (FDO380, AS ONE) to investigate the relationship between the ultrasound radiation and the dissolved oxygen. The zeta potential, which is an indicator of the stability of the bubbles, in the sample was also measured by ELS after 50 ultrasound radiations.

3. Results and discussion

Figure 3 shows photographs near the surface of the transducer before and after ultrasound radiation. Compared with the initial condition before ultrasonication at $t = 0$ (Fig. 3a), the image brightness was changed near the surface of the transducer by ultrasonication at t = 2.4 s (Fig. 3b). (The same phenomenon was observed in our previous study[1]). After 5.8 s, microbubbles with an average size of approximately 0.2 mm appeared on the transducer surface and remained after switching the ultrasonication off (Fig. 3d). These results suggest that cavitation bubble clouds generated near the surface of transducer under ultrasound radiation induce change in the refractive index in water.

Changes in the bubble size with respect to the number of ultrasound radiation measured by DLS measurement is shown in Fig. 4. Two peaks in the size distribution of cavitation bubbles appeared; the first and second peaks ranged from 100 to 200 nm and from 800 to 900 nm, respectively. Seo et al. reported that the size of cavitation bubbles generated by 5-MHz ultrasound range from 150 to 200 nm[3], and the first peak in this report corresponds to this value. We intend to clarify the physical mechanism where the two peaks appeared in the size distribution of nanobubbles. It should be noted that the first peak shifted to a larger size with an increase of the number of ultrasonication (from 25 to 39 times of ultrasound radiation). This fact implies that the nanobubbles would coalesce due to the secondary Bjerknes force acting on the bubbles and form larger nanobubbles[4]. The DO result indicates that the amount of DO decreases as the number of ultrasound radiation increases. This is because the larger bubbles formed by coalescences of the cavitation nanobubbles were released to the atmosphere. The zeta potential of the sample after 50 ultrasound radiations was -23.9 mV; Lee et al. reported that the surface of nanobubbles in water is negatively charged between -13 to -21 mV[5], and these values corresponds to our results.

4. Conclusion

Acoustic cavitation bubbles generated in water by high-intensity ultrasound in the 100 MHz range were discussed. Our experimental results by the high-speed camera, DLS, ELS, and DO implies that ultrasound radiation generates cavitation nanobubble clouds in water, and larger bubbles would be produced by the coalescence of the cavitation nanobubbles.

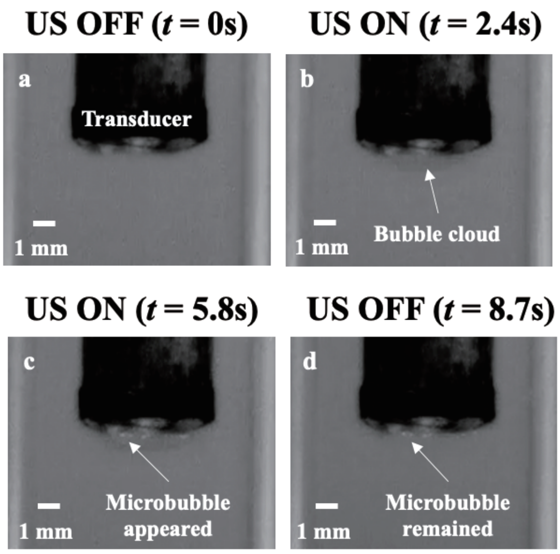

Fig. 3 Photographs of the cavitation bubbles near the surface of the ultrasound transducer.

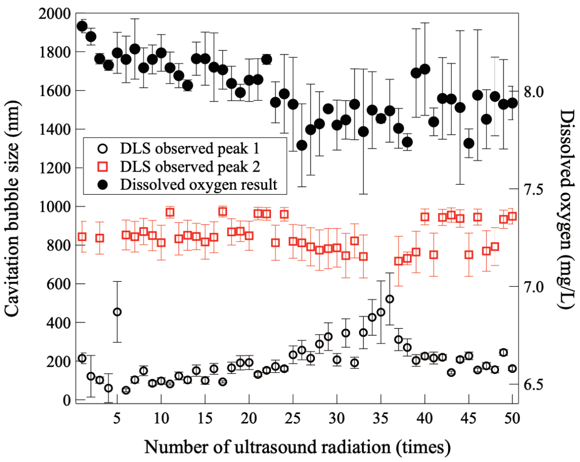

Fig. 4 Relationships between the number of ultrasound radiation, the peak values of the bubble size, and dissolved oxygen in the sample.

Acknowledgment

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