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Effect of dynamic behavior of single-bubble on acoustic emission spectra

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1. Introduction

Acoustic cavitation bubbles are generated by the irradiation of intense ultrasound in liquid. The expansion and contraction of cavitating bubbles produce acoustic waves called acoustic emission (AE). In a spectrum of AE generated from a multi-bubble field, many frequency components, i. e. harmonics, subharmonics, ultraharmonics, and broad-band noise are observed. The origin of each component has been discussed elsewhere [1], and the most unknown component is the broad-band noise although it has been used as a measure of the strength of cavitation event. To investigate these component, it is profitable to employ a single-bubble field because individual AE signals are difficult to distinguish and correlate with a particular bubble in a multi-bubble field. A single sonoluminesce bubble (SBSL bubble) is spatially stable and emits light and shock waves when the amplitude of driving acoustic pressure is in a specific range [2, 3]. The dynamic behavior of the single bubble changes depending on the acoustic pressure. When the acoustic pressure is decreased, the bubble does not exhibit SL with maintaining spatial stability. When the acoustic pressure is further decreased, the bubble becomes spatially unstable and dances because of the disintegration into daughter bubble and succeeding coalescence. This type of bubble is known as dancing bubble.

We investigated AE spectra from SBSL bubble to correlate the spectral components with dynamic behavior of SBSL bubble.

2. Methods

Figure 1 shows the experimental system used for AE measurement of SBSL bubble. A cylindrical cell made of a quartz glass with 64 mm inner diameter and 66 mm height serves as an acoustic resonator. A sandwich-type piezoelectric transducer with a fundamental frequency of 28 kHz was glued to the bottom of the cell. The sample liquid was deionized water with the volume of 202 mL, which was degassed until the dissolved-oxygen content reached 1.5 mg/L. A continuous sinusoidal signal with a frequency of 28.4 kHz supplied by a function generator (Tektronix, AFG 3022) was amplified using a power amplifier (NF Design 4005, gain 37 dB), impedance matched with a transformer, and then applied to the transducer.

A bubble nucleus was created by momentarily pricking the liquid surface with an injection needle. The generated bubble was trapped at the antinode of standing waves at the height of 52 mm. Acoustic signals were detected with a homemade hydrophone of 4 mm in diameter, which employs a 1-MHz PZT sensor (1.286μV/Pa). The location of the hydrophone was approximately 10 mm diagonally above the bubble. This location was the closest we could obtain acoustic signals without disturbing the bubble stability significantly. The acoustic signals was observed with an oscilloscope (Agilent DSO5052 A, 4G Sa/s). We measured acoustic signals for the three stages of bubble dynamic behavior: dancing bubble, SBSL bubble and spatially stable but no SL bubble (referred to as stable bubble).

The bubble oscillation was examined by a light scattering technique. A laser beam (Thorlabs CPS 635F, cross section of 1 mm×3 mm) irradiated the bubble, and the scattered light from the bubble was detected by a photomultiplier and observed with the oscilloscope. The scattered light intensity is proportional to the cross section of the bubble.

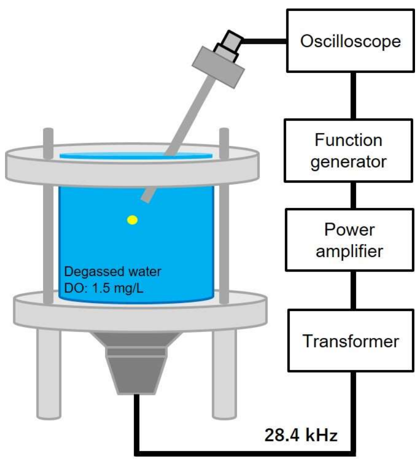

Fig. 1 Schematic diagram of the experimental system of AE measurement.

3. Results and discussion

Figure 2 shows the results of scattered-light measurements from SBSL bubble (c), dancing bubble (a) and stable bubble (b) for an acoustic cycle. The inset shows enlarged signals in the time region

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where bubble contracts. Three signals are superimposed. **Figure 3** shows the results of the AE measurements from the three stages of the single bubble. The acoustic signals can be obtained with existing bubble and no bubble under the same acoustic pressure, which are indicated by red line and black line, respectively. The difference between them is shown in blue line. The large peaks periodically observed in Fig. 3(c) are due to shock wave caused by the collapse of SBSL bubble. Two small pulses observed 2 μs after the large peaks are associated with the rebounds observed in scattered light signal in Fig. 2.

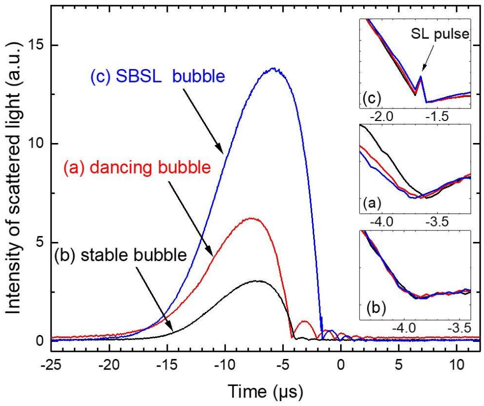

Fig. 2 Scattered-light signals from a dancing bubble (a), a stable bubble (b), and SBSL bubble (c) for one acoustic cycle. Inset: scattered-light signals enlarged in the time region where bubble contracts.

The power spectra were calculated for AE signals of Fig.3(a) and (c) by applying the fast Fourier transform, and shown in **Figure 4**. The blue lines (upper curves) indicate the spectra of AE difference signals shown in Fig.3. The comparison of the spectra between dancing bubble (a) and SBSL bubble (c) suggested that only fundamental (f_0) and harmonics (nf_0) are prominent in the spectrum of SBSL bubble, while subharmonic $(f_0/2)$, ultraharmonics $(nf_0/2)$, and the broad-band noise increase in the spectrum of dancing bubble.

High-speed photography of dancing bubble demonstrated that a few daughter bubbles are frequently generated and coalesced. These events may cause the variance in the AE interval timings. The inset of Fig. 2(a) also indicates that the timings of bubble collapse differ among three cycles. The subharmonics and broad-band noise may be caused by these multi-bubble interactions.

The origin of AE signals has not been fully elucidated. Effects of the shock wave reflection from the cell wall or hydrophone should be considered. Further research needs to be conducted.

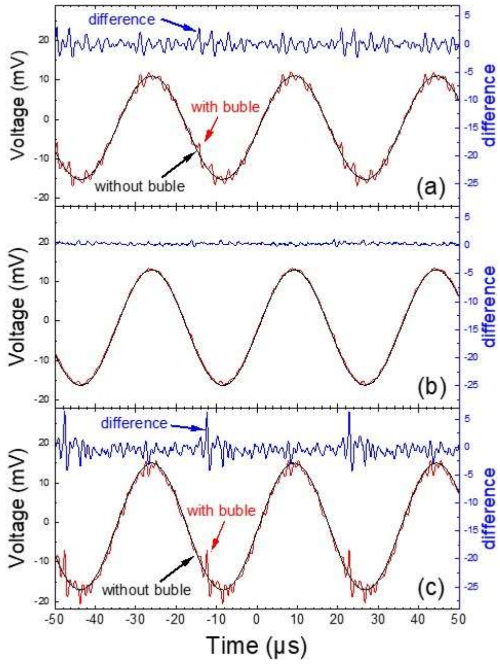

Fig. 3 AE signals from a dancing bubble (a), a stable bubble (b) and SBSL bubble (c), respectively.

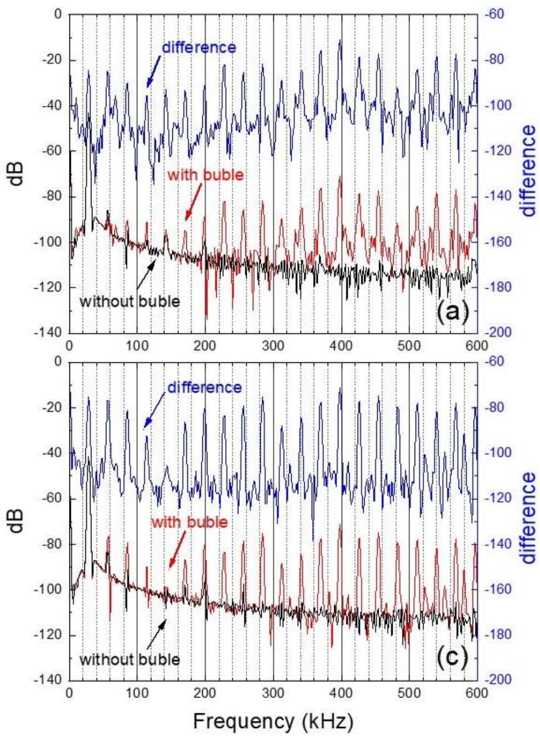

Fig. 4 Power spectra calculated from AE signals of (a) a dancing bubble and (c) SBSL bubble in Fig.3.

References

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