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Broadband noise of acoustic emission from a dancing single bubble

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1. Introduction

Acoustic emission (AE) from liquid irradiated by high-intensity ultrasound reveals the characteristics of cavitating bubbles [1], and hence has been used to monitor the extent of acoustic cavitation in cleaning and sonochemical applications. The dynamics of cavitating bubbles exhibit various aspects, including nonspherical oscillation, chaotic oscillation, fragmentation, coalescence, and clustering. These phenomena result in harmonics, subharmonics, ultra-harmonics and broadband noise in the pressure spectrum of hydrophone signal. In particular, broadband noise has been used as a measure of cavitation intensity, although the origin of broadband noise has not been identified because of the complicated bubble dynamics [2]. To clarify the origin of broadband noise experimentally, the use of a single-bubble system is advantageous over a multi-bubble system which has been employed in previous works.

This study investigates broadband noise from a dancing bubble observed in single-bubble sonoluminescence (SBSL). High-speed shadow-graphy was performed to correlate with the results of the AE measurements.

2. Methods

Figure 1 shows an experimental system. A rectangular quartz glass cell with 65 mm in width, 65 mm in depth and 90 mm in 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 250 mL, which was degassed until the dissolved-oxygen content reached 1.3 mg/L. A continuous sinusoidal signal with a frequency of 28.42 kHz supplied by a function generator (Tektronix, AFG 3022) was amplified using a power amplifier (NF Design 4005, gain 37dB), impedance matched with a transformer, and then applied to the transducer. 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 15 mm diagonally above the bubble, where the bubble stability was not disturbed. The liquid surface was covered with a 0.1 mm thick polyethylene terephthalate (PET) film with two holes, one for bubble nucleation and one for the hydrophone. SBSL intensity was measured by a photomultiplier (Hamamatsu Photonics H7422-01) and observed with an oscilloscope (Agilent DSO5052 A, 4G Sa/s). The AE power spectra was analyzed with a spectrum analyzer (Tektronix RSA306B). High-speed photography of cavitating bubble was captured using a high-speed video camera (Photron, SA3) with a frame speed of 25 k fps with an exposure time of 40 μs.

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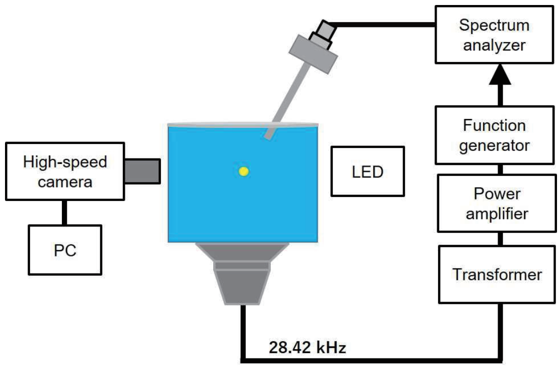

Fig. 1 Schematic diagram of the experimental system.

3. Results and discussion

Figure 2 shows SBSL intensity as a function of the driving voltage of the function generator. At the low acoustic pressure (457 mV_{pp} in driving

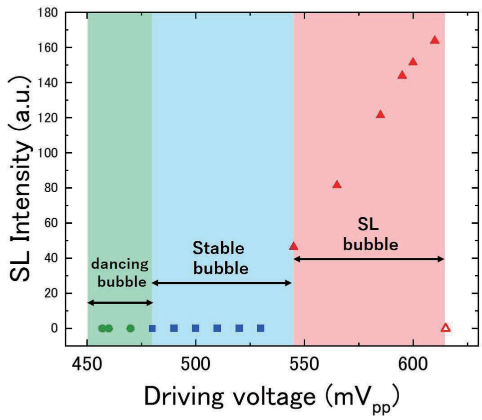

Fig. 2 Intensity of SBSL from deionized water as a function of driving voltage.

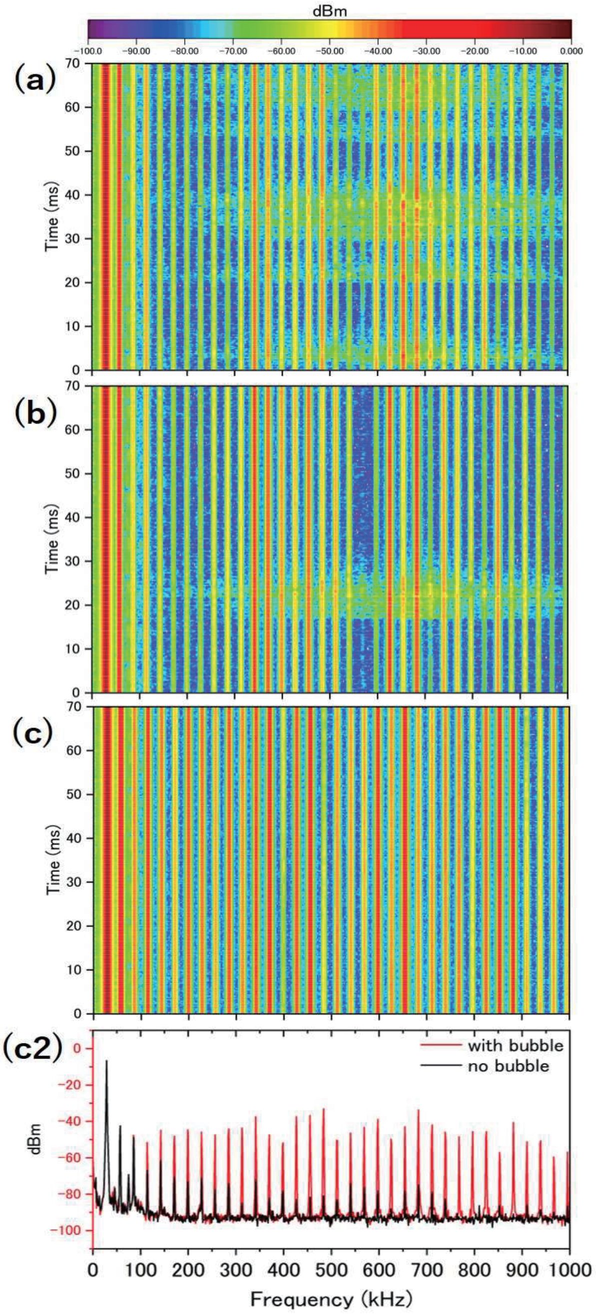

Fig. 3 Spectrogram of the AE power at the three stages: (a) frequent-dancing bubble, (b) occasional-dancing bubble, (c) SBSL bubble and (c2) an averaged spectrum of SBSL bubble. Yellow horizontal areas indicate the broadband noise. The spectrograms are composed of 244 lines of spectra .

voltage), the bubble exhibited dancing frequently, and a few daughter bubbles are frequently generated and coalesced. When the driving voltage increased to 460 mV_{pp}, the bubble became spatially stable while showed the dancing occasionally. When the driving voltage increased to 470 mV_{pp}, the bubble became spatially stable. The bubble emitted bluish white light at 545 mV_{pp}, and SBSL intensity increased with increasing driving voltage. At the highest acoustic pressure of 615 mV_{pp}, the bubble completely disappeared. We performed AE measurement at the driving voltage of 457 mV_{pp}, 460 mV_{pp} and 570 mV_{pp}, at which bubble are referred to as frequent-dancing bubble, occasional-dancing bubble and SBSL bubble, respectively.

Figure 3 shows the spectrogram of AE power giving the frequency distribution over 70 ms at the three stages: (a) frequent-dancing bubble, (b) occasional-dancing bubble and (c) SBSL bubble. The comparison of these spectrograms suggests that only fundamental (f_0) and harmonics (nf_0) were observed in (c) SBSL bubble, and the broadband noise was prominent in dancing bubbles in (a) and (b). Apparently, the broadband noise was observed frequently in (a) frequent-dancing bubble more than (b) occasional-dancing bubble.

Figure. 4 shows selected images of high-seed photography captured from frequent-dancing bubble during 9 ms. Numbers in the images denote frame number and the frame interval is 40 μs. A bubble emitted a daughter bubble in frame 4. The two bubbles coalesced in frame 54. The total time of bubble-bubble interaction was 2 ms. In Fig. 3(a), the duration of the broadband noise was 2-10 ms which values are consistent with the bubble interaction time observed in high-speed images in Fig.4.

At the low acoustic pressure, the increase in shape oscillation and distortion of a bubble cause the emitting of daughter bubbles or bubble fragmentation, exhibiting a dancing bubble [3]. The present results suggest that the interaction of the two or three bubbles is responsible for the generation of broadband noise. The measured spectra inferred that the shape oscillation may take part in the harmonics of AE signal. Effects of the shape oscillation to broadband noise should be clarified in a future work

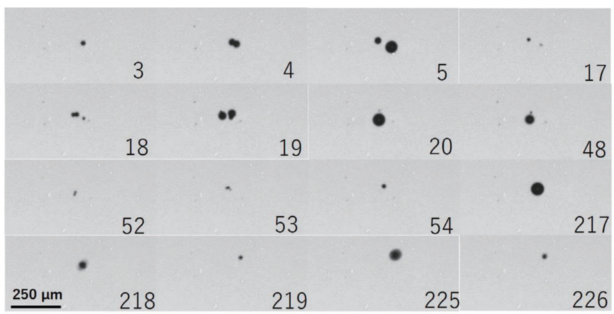

Fig. 4 Selected images of high-speed photography captured for (a) frequent-dancing bubble. The numbers in the images are a frame number and the frame interval is 40 μs.

References

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