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Initial Growth and Subsequent Unstable Oscillation of Single Bubble

単一気泡の初期成長過程とそれに続く不安定振動

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1. Introduction

Single bubble sonoluminescence (SBSL) is a well-established experimental technique to investigate bubble oscillation in liquids. Since the report by Gaitan *et al.*[1], many experimental findings have been obtained, such as the relationship between bubble oscillation and the sonoluminescence (SL) intensity, and the relationship between physical properties of liquids and bubble stability[2]. In the experimental system of SBSL, the bubble oscillates at a fixed point, and the bubble oscillation is measured by the laser scattering method. The experimental results of the oscillation measurements can be easily compared with the results of numerical analysis of differential equations representing bubble radial oscillation, such as the Keller-Miksis equation, and have expanded our knowledge of bubble dynamics. However, most of the experiments and the numerical analysis have been performed under the condition that the bubble is in a steady state, and there are few reports on the oscillation of transient or unstable bubbles. Most of the bubbles in general acoustic cavitation fields, which mean the multi-bubble system, are not in a steady state, and it would be interesting to clarify the detail of bubble oscillations under such conditions. By measuring the bubble oscillations in the multi-bubble system and comparing the results with those in the single-bubble system, we can gain more insight into the characteristics of bubbles in the multi-bubble system. In this study, the initial growth immediately after bubble formation and the oscillation of unstable bubble is measured in the SBSL experimental system.

2. Experimental Setup and Procedure

Figure 1 shows the experimental system for the measurement of single bubble oscillation. A single bubble is trapped at the antinode of a standing ultrasound field in water in a glass vessel with standard procedure. The standing wave is formed by driving a bolt-clamped Langevin-type transducer (BLT). The sinusoidal driving voltage of the BLT is generated by a function generator (FG) and amplified by a power amplifier. The frequency of the driving voltage is 28 kHz and the inner cross-sectional dimension of the vessel is 51×51 mm^2. The water depth is adjusted so that the standing ultrasound field to be resonance.

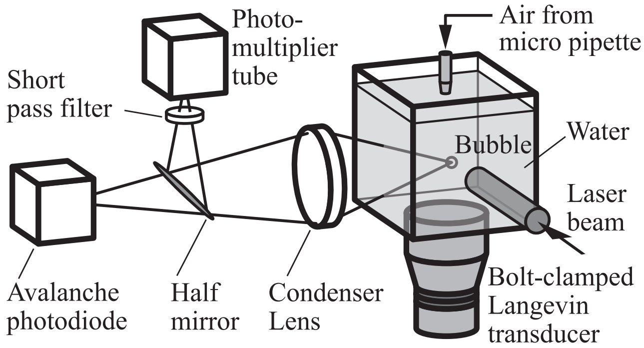

Fig. 1 Experimental setup.

A Gaussian laser beam with 5 mm in diameter and 632 nm in wavelength irradiates the trapped bubble. The scattered light and SL from the bubble are focused by a condenser lens. The converging lights from the lens are split by a half mirror and detected by an avalanche photodetector (APD) and a photomultiplier tube (PMT). The scattered light entering the PMT is blocked by an optical short pass filter with a cut-off wavelength of 550 nm. The light intensity of SL is significantly weaker than that of the scattered light and SL is interrupted by the filter. Thus, the APD mainly detects the scattered light and the PMT mainly detects the SL. The scattered light intensity from the bubble is proportional to the square bubble diameter [3)]. Therefore, the bubble oscillation can be analyzed from the scattered light intensity measured by APD.

The output signals from the APD and the PMT are recoded by a computer via an analog to digital converter (ADC). The acquisition of the signals is triggered when the output of the APD exceeds the threshold level just above the maximum noise voltage. Accordingly, the acquisition starts when the bubble nuclei, which are injected from the nozzle in contact with the water surface, intersects the laser to generate scattered light. The ADC sampling frequency is 31.25 MHz and the number of samples to be acquired is 2^{29}, which is corresponds to the acquisition time of 17.18 s.

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3. Results and Discussion

Figures 2(a) and 2(b) show the square root of the APD output, which is proportional to the bubble radius, and the SL intensity. Both signals are normalized with their maximum values. The SL intensity is calculated as the PMT output near the time when the bubble radius, which corresponds to the APD output, has a local minimum value. The output amplitude of the FG was set to slightly exceed the condition that the bubble oscillates stably and exhibits SL. Time 0 corresponds to the time when the output of the APD exceeds the threshold and recording starts. This figure shows only the waveform during 350 ms from the start of recording because the scattered light is no longer detected. After 350 ms, the bubble is thought to have undergone fragmentation, dissolved into the water, and disappeared. Since the period of the ultrasound is 35.7 μs, the bubble radius change in that time scale cannot be observed from these figures, but the temporal change in amplitude of the bubble radial oscillation is observed.

Figure 3(a) and 3(b) shows the enlarged view around 170 ms, which is the time when maximum bubble radius is seen, of Fig. 2. Figure 3(a) shows that the bubble emits the SL between 169 ms and 169.8 ms, and the SL intensity varies from period to period. In addition, the maximum diameter of the bubble increases slightly in each cycle. After that, at 169.9 ms, the oscillation mode of the bubble changes, and the SL is no longer observed. Figure 3(b) shows an enlarged view of the region around 169.9 ms. The waveforms before 169.9 ms are similar to the well-known oscillation waveform of bubbles exhibiting the SBSL, but the waveforms after 169.9 ms are very different from that oscillation mode. It is thought that the bubble increased its equilibrium diameter by rectified diffusion, and then began to oscillate in a non-spherical manner, leading to its collapse. Depending on the conditions, the daughter bubbles generated by the collapse will grow again and show SL. By collecting enough knowledge about the growth, unstable oscillation, and collapse obtained with this system and comparing it with the knowledge of bubble oscillation in a multi-bubble system[4], we will be able to obtain further findings of the bubble in a multi-bubble system, such as bubble lifetime.

4. Conclusion

The bubble radial oscillation and SL in a single bubble system are simultaneously measured. The time variation of the bubble radius and the SL of unstably oscillating transient bubble immediately after bubble generation are observed.

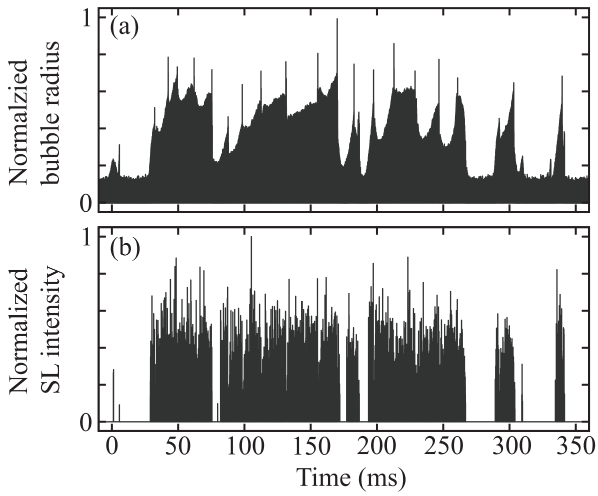

Fig. 2 Experimental results (a) Normalized bubble radius as square root of APD output. (b) SL intensity.

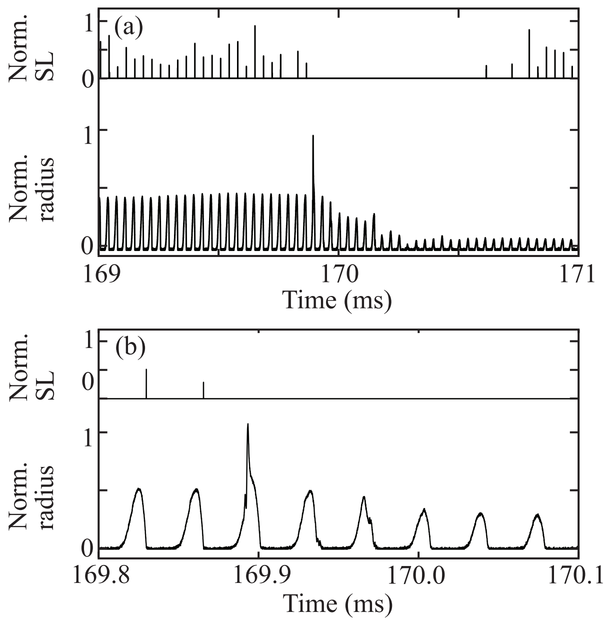

Fig. 3 Enlarged view of Fig. 2.

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