

# Sonoluminescence in the initial bubble growth process

## 初期気泡成長過程におけるソノルミネッセンス

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### 1. Introduction

Sonoluminescence (SL) during the ultrasonic irradiation of water can be used to obtain information regarding the physical and chemical properties of cavitation bubbles. In addition, SL intensity measurements under various solution conditions can provide insights into bubble dynamics, such as the growth and size of cavitation bubbles. Ashokkumar et al. observed the temporal change of SL intensity during irradiation with pulsed ultrasonic waves and reported that the presence of a surfactant affected the initial growth of SL<sup>1</sup>. Furthermore, J. Lee et al. investigated the relationship between SL intensity and the bubble growth process using pulsed ultrasound and reported the influence of surfactant addition on bubble coalescence<sup>2</sup>. However, previous observations of the initial SL have been performed using pulsed ultrasonic waves, and examination of the initial SL under continuous ultrasonic irradiation has received comparatively little attention.

The purpose of this study was to elucidate the growth time and size of cavitation bubbles by observing the initial growth of SL under continuous irradiation with ultrasonic waves. The influence of sodium dodecyl sulfate (SDS), a common surfactant, on the bubble growth process was also examined. Furthermore, the change in the liquid volume in a capillary cell was measured to evaluate the total volume and size of the bubbles generated during ultrasonic irradiation.

### 2. Materials and methods

Pure water and 2 mM SDS aqueous solution were degassed under reduced pressure (0.1 MPa) with stirring and then left for 2 h under Ar atmosphere. **Fig. 1** presents a schematic diagram of the experimental sonication apparatus. A custom-built stainless-steel cylindrical reactor was equipped with a lead zirconate titanate disk-type transducer (4Z30D-ES,  $\phi 30$  mm, Fuji Ceramics Corporation, Japan) with a resonance frequency of 410 kHz. The sample volume was 149 mL. The acoustic power was measured using the calorimetric method and kept constant at  $10 \pm 1$  W. The temperature of the sonicated sample solution was maintained at  $13 \pm$

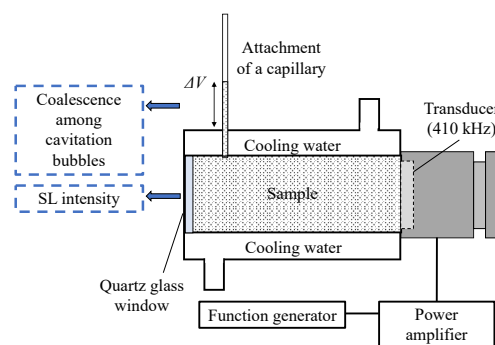


Fig. 1 Experimental apparatus for sonication.

$1^{\circ}\text{C}$  by circulating cooling water through the water jacket surrounding the reactor. The SL intensity was measured using a photomultiplier (H7732-01, Hamamatsu Photonics, Japan). The intensity of the initial SL was measured using a memory high logger (LR8431, Hioki, Japan) for 120 s from the start of ultrasonic irradiation. The liquid volume change  $\Delta V$  was measured by attaching a capillary cell with an inner diameter of 0.6 mm to the upper part of the sample tank. The volume change was calculated from the liquid height before and after ultrasonic irradiation to obtain the total bubble volume. This volume change  $\Delta V$  can be regarded as an indicator of the relative bubble size<sup>2</sup>. All experiments were performed in triplicate and the results were averaged to ensure reproducibility.

### 3. Results

**Fig. 2** shows the temporal changes in SL intensity and total bubble volume for pure water during the first 0.6 s of ultrasonic irradiation. The volume change  $\Delta V$  and SL intensity were normalized to the values observed when the SL intensity reached a steady state, which occurred after 0.25 s of ultrasonic irradiation. The volume change  $\Delta V$  initially increased with the SL intensity and then continued to increase in proportion to time after the SL intensity had reached the steady state.

**Fig. 3** shows the temporal changes in SL intensity and total bubble volume for 2 mM SDS aqueous solution during the first 120 s of ultrasonic irradiation. Both the SL intensity and  $\Delta V$  exhibited the same tendency as observed in Fig. 2. However,

the time required to reach a steady state was significantly delayed compared to pure water. Moreover, comparison of the steady-state intensities in pure water and SDS aqueous solution revealed that the latter afforded a higher emission intensity.

## 4. Discussion

### 4.1. Initial bubble growth process and SL intensity

The obtained results demonstrate that a certain irradiation time was required for the SL intensity to reach a steady state. SL-emitting bubbles are active bubbles that undergo Rayleigh contraction. Bubble nuclei in the liquid grow at the same time as ultrasonic irradiation<sup>3</sup>. It is considered that the SL intensity became constant because the number of active bubbles increased with increasing irradiation time before reaching a certain amount. The volume change  $\Delta V$  represents the state of bubble growth during ultrasonic irradiation. As the SL intensity increased over time,  $\Delta V$  also increased, where the latter parameter indicates the relative volume of minute bubble nuclei present in the liquid as described above. When the SL intensity reached a steady state,  $\Delta V$  continued to increase monotonically with a constant slope, presumably owing to the repeated coalescence of a large number of existing bubbles. It was previously reported that the SL intensity decreases during continuous ultrasonic irradiation<sup>4</sup>. It is suggested that this behavior can be ascribed to an increased proportion of large bubbles that do not emit light, relative to the active bubbles, owing to repeated bubble coalescence. This is supported by the finding that  $\Delta V$  continued to increase with a constant slope.

### 4.2. Influence of SDS addition

It is generally regarded that SL occurs with high emission intensity in SDS aqueous solution. The difference between the two systems is readily apparent from comparison of the steady-state SL intensities in Fig. 2 and Fig. 3. SDS acts as a surfactant that is adsorbed on the surfaces of cavitation bubbles, thereby blocking bubble coalescence via electrostatic repulsion<sup>4</sup>. Owing to this phenomenon, the bubble growth process is restricted to rectification diffusion. The significant increase in the time required for the SL intensity to reach a steady state in the SDS aqueous solution is considered to be attributable to the longer irradiation time required for the bubble nuclei to grow into active bubbles. The observation that  $\Delta V$  also increased over a prolonged period, like the SL intensity, suggests that a longer irradiation time was necessary to generate active bubbles.

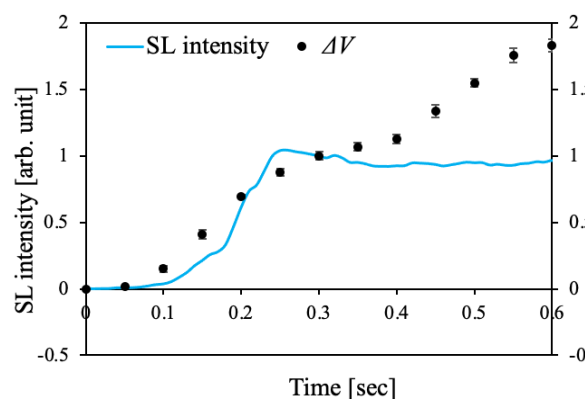


Fig. 2 Relative SL intensity and relative  $\Delta V$  during ultrasonic irradiation of Ar-saturated water.

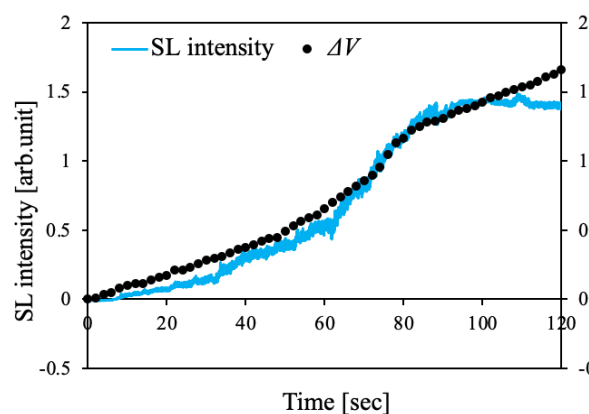


Fig. 3 Relative SL intensity and relative  $\Delta V$  during ultrasonic irradiation of 2 mM SDS aqueous solution.

## 5. Conclusion

During the bubble growth process immediately after initiation of ultrasonic irradiation, a correlation was confirmed between the increase in SL intensity and the increase in total bubble volume. The obtained results also demonstrate that the SL intensity increased upon the addition of a surfactant, although the system required longer to reach a steady state owing to the suppression of bubble growth.

## References

1. M. Ashokkumar and F. Grieser: J. Phys. Chem. B **101** (1997) 10845.
2. J. Lee, S. E. Kentish and M. Ashokkumar: J. Phys. Chem. B **109** (2005) 5095.
3. M. Ashokkumar and F. Grieser: Phys. Chem. Chem. Phys. **9** (2007) 5631.
4. K. Shiba, Yu Takemura, Yoshiteru Mizukoshi and Ken Yamamoto: Jpn. J. Appl. Phys. **58** (2019) SDGG14.