

Sonoluminescence from Na atom and characteristic bubble dynamics in ethylene glycol solution

エチレングリコール中のNaソノルミネセンスと特徴的気泡運動

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1. Introduction

Sonoluminescence from alkali-metal ion solutions has been investigated because the location of alkali-metal atom emission is of interest as well as how non-volatile ions are reduced and electronically excited. SL pulse width of Na emission was measured by Giri and Arakeri [1]. They observed SL from NaCl solution in ethylene glycol at low acoustic amplitude near 1 atm, and reported the pulse width of 62 ns in argon saturated solution, which value depended on saturated rare gases. The purpose of the present report is to clarify the pulse width of Na emission from ethylene glycol solution in comparison with that from aqueous solution. We observed multiple-peaked pulses from ethylene glycol solution with each peak width being 1.4 ns and peak interval being about 4 ns, which has not been reported before. High-speed photography of bubbles and high-speed SL movies were also obtained for elucidating the multiple-peaked pulse.

2. Experimental

1 M NaCl solution in ethylene glycol was carefully degassed while stirring and saturated with Xe gas under 1 atm. The sample cell used was 300 mL cylindrical quartz flask. A 28 kHz sandwich transducer was bonded to the bottom of the flask. A signal from function generator was amplified and matched for impedance to the transducer. Applied acoustic power was 5.6 W corresponding to acoustic pressure of 2.3 atm. SL emission was filtered and detected using a photomultiplier (Hamamatsu H7422-01) having a rise-time of 750 ps and a digital oscilloscope (Agilent DSO5052A) with 4 G sampling/s. Single-shot waveforms of SL pulse were obtained with triggering by itself. Two optical filters were used: a sharp-cut filter transmitting wavelength over 580 nm for detecting Na emission, and a blue filter transmitting wavelength in the range of 300-500 nm for detecting a continuum emission. A preliminary pulse-width measurement on SBSL from water showed a full width at half-maximum (FWHM) of 1.4 ns. This is nearly equal to an instrumental width of our system.

Shadowgraph movies of cavitating bubbles

in ethylene glycol solution were captured using a high-speed video camera (Shimazu, HPV-2) with a maximum speed of 1,000,000 fps. Further, assembling the high-speed video camera with an image intensifier unit (Hamamatsu, C9546) enabled us to obtain a SL movie at the speed of 32,000 fps. A rectangular glass cell was used in this experiment.

3. Results and discussion

Sonoluminescence from NaCl-ethylene glycol solution saturated with Xe is separated by two kinds of optical filters, which yields a continuum-emission pulse and Na-emission pulse as shown in Figs. 1 and 2, respectively. The pulse width (FWHM) of the continuum emission observed was 1.46 ns. Measurements of laser pulse with femto-second width provided that the instrumental width of our system is 1.38 ns. Then true pulse width of the continuum emission was obtained to be 0.44 ns, which agrees with the result by Matula et al. [2]. Unlike the single pulse of the continuum emission in Fig. 1, the Na-emission pulse in Fig. 2 shows a multiple-peaked shape. The width of individual peaks in Fig. 2 is nearly the same as that of the continuum emission and the peak intervals are about 4 ns. The multiple-peaked pulse was observed at the incident rate of 50% among the total events of 500. The other 50% are single pulses with the width of 1.45 ns. This width is nearly the

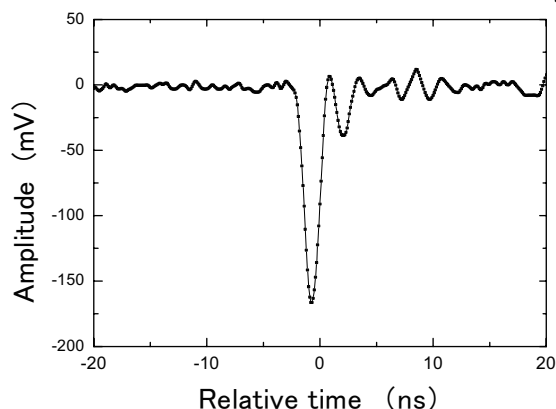


Fig. 1 Single shot waveform of continuum-emission pulse obtained with a blue filter transmitting wavelength in the range of 300-500 nm

same as that of the continuum emission. It is plausible that the multiple-peaked pulse is caused by the superposition of sonoluminescence from different bubbles having some correlation.

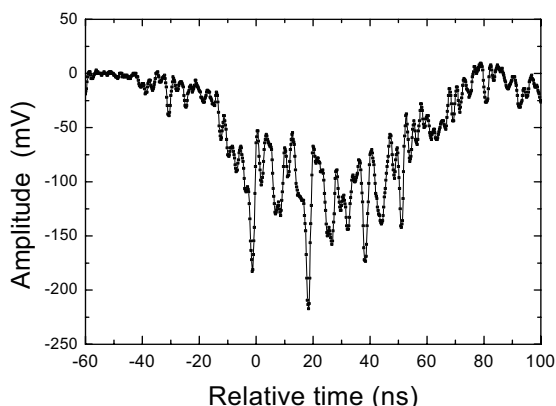


Fig. 2. Single shot waveform of multiple-peaked pulse of Na-emission obtained with a sharp cut filter (>580 nm).

We obtained shadowgraph movies of bubble dynamics in 1 M NaCl-ethylene glycol solution. The salient feature of the bubble dynamics in the present solution is bubble fragmentation. Figure 3 is one shot of cavitating bubbles photographed at the speed of 2000 frames per second. A large bubble (about $250\ \mu\text{m}$ in diameter at a maximum size) indicated as “A” in the figure is translating in the direction denoted as an arrow. Immediately before this event, the bubble “A” coalesced with a bubble and changed its direction. After the coalescence the bubble “A” fragmented into many tiny daughter bubbles denoted as “B”. A term “leakage” may be appropriate instead of “fragmentation” to describe this event. There are two characteristics which have not been observed in water. One is that large size of bubbles over $200\ \mu\text{m}$ are frequently seen. This is associated with the fact that noble gas can dissolve

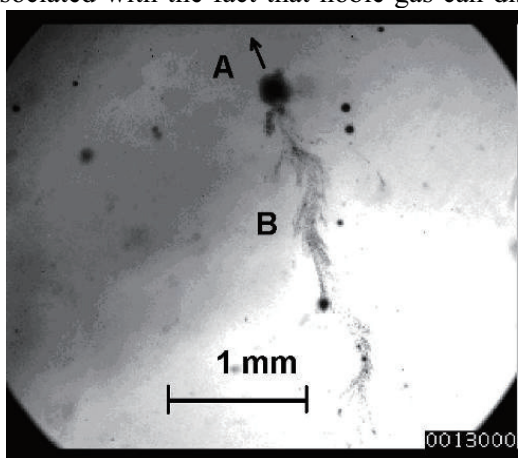


Fig.3 Shadowgraph of characteristic bubbles translating in the direction denoted by an arrow. A large bubble “A” leaks many tiny bubbles “B”, which occurs immediately after coalescence with a bubble. The frame speed is 2000 fps.

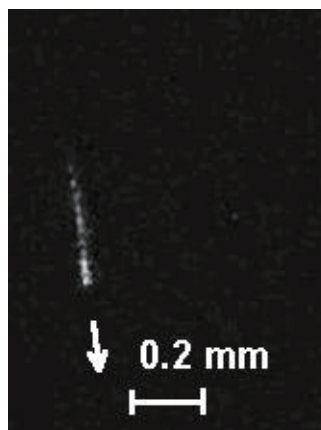


Fig.4 SL image of Na emission photographed at the speed of 32,000 fps. Each luminescent point corresponds to a SL event from a bubble occurring in an ultrasonic period. This image suggests that the multiple-peaked pulse is resulted from many tiny bubbles shown in Fig.3.

in ethylene glycol much more than in water. Rectified diffusion of gas into bubble is activated and this increases the bubble size. A large bubble stays a long time in the solution since viscosity is large in ethylene glycol. The other is the “leakage” of tiny bubbles. The maximum size of these bubbles is less than $10\ \mu\text{m}$. The smallness may be caused by the magnitude of surface tension which is 66 % of that of water. We propose that these tiny bubbles characteristic to the present solution are responsible for the multiple-peaked pulse observed.

In order to capture the SL movie, we used an image intensifier unit using two-stage micro-channel plates in front of the high-speed video camera. With this system we succeeded in taking SL movie at the speed of 32,000 fps. Figure 4 shows a shot of SL of Na emission. Eleven luminescent points propagate cooperatively in the direction denoted by an arrow, while the number of luminescent point increases from one to eleven in a time of 0.48 ms. The ultrasonic frequency of 28 kHz is nearly equal to the frame speed of 32,000 1/s, which means that an exposure time of one shot is nearly equal to an ultrasonic period. Since one event of SL occurs every ultrasonic period, the luminescent point in the shot corresponds to one event of SL by one bubble considering the size and separation of bubbles shown in Fig. 3. Thus the shot of Fig. 4 represents the SL from tiny bubbles indicated by “B” in Fig. 3, which confirms that the multiple-peaked pulse is resulted from tiny bubbles fragmented from a large bubble.

References

1. T. J. Matula et al., *J. Acoust. Soc. Am.* 101(1997)1994.
2. A. Giri and V. H. Arakeri, *Phys. Rev. E* 58(1998) R2713.