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Threshold pressure of focused ultrasound at 1 MHz in sonochemiluminescence
ソノケミルミネセンスの集束超音波音圧しきい値

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1.Introduction

Sonoluminescence(SL) is light emission from high-pressure and high-temperature conditions inside a cavitating bubble under intense ultrasounds [1]. These conditions produce OH radicals formed by pyrolysis of water molecules. OH radicals diffuse out of the bubbles and react with foreign molecules. The reaction with luminol causes bluish light, called sonochemiluminscence (SCL). The intensity of SCL is larger than that of SL by two-orders of magnitude. This point is useful for detecting the cavitation event to occur.

Aoustic cavitation by focused sound waves has been interested in association with its medical applications. SCL by focused sound waves in water has been studied by several authors [2,3]. The spatial distribution of SCL obtained in these studies was complicated depending on the sound field condition, i. e., progressing wave or standing wave. In a practical purpose, it is important to know the threshold pressure for the cavitation inception. We have determined the threshold pressure for sonochmeiluminescence in 1 MHz-focused field. Sound pressure was measured by using optical deflection effect.

2. Experimental

Argon-saturated luminol solution with a concentration of 1 mM at pH 12 was contained in a stainless vessel (width: 140 mm, depth: 84 mm, height: 84 mm) with glass windows. 1.0 MHz ceramic transducer with a curvature radius of 40 mm and diameter of 30 mm was mounted at the side of the cell. A signal from a function generator was amplified by 53 dB using a power amplifier (E & I, 2100L). SCL was captured using a digital camera (Nikon D500) equipped with F1.2, 50mm lens. The exposure time was 30 s.

For making a progressing wave condition, an absorbing rubber plate (>40 dB, Eastek EUA101A) was positioned at the end of the vessell to minimize the reflection. For making a standing wave condition, a stainless-steel concave reflector having the same size and curvature radius as the transducer was opposed confocally with respect to the transducer.

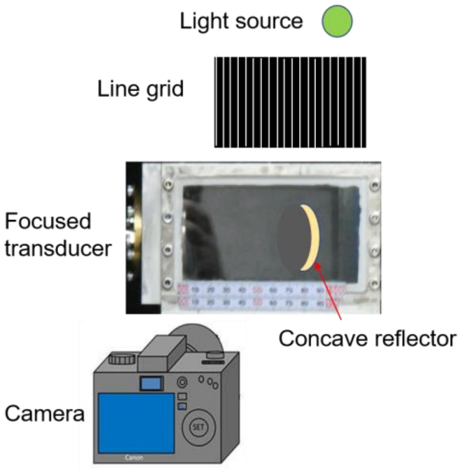

Fig. 1 Experimental system for measuring acoustic pressure using optical deflection effect.

The measurement of acoustic pressure was performed using the effect of light deflection by ultrasound [4]. As shown in Fig.1, a pattern of transparent lines with the width of 0.2 mm and interval of 1.5 mm are projected by a green LED source. The pattern is viewed by a camera located on the other side of the ultrasound cell. The pattern image is blurred after passing through the spatial variation of refractive index caused by ultrasound. The deflection angle θ of light is given by

$$\sin\theta = \frac{2\pi L}{\lambda}\left(\frac{dn}{dp}\right)P_0 \qquad (1)$$

where λ is the wavelength of sound, L is the interaction length of light and sound, n is the refractive index of water, and P_0 is the sound pressure amplitude. The blurred image gives the time average of the deflection effect, providing the sound pressure amplitude. We can also obtain a rough image of focused field distribution by subtracting the sonicated and non-sonicated pattern images.

3. Results and discussion

Typical photographs of SCL are shown in Fig.2 for the input voltage of 200 mV, 100 mV and 58 mV. The electrical power at the voltage of 100 mV was measured to be 1.8 W, corresponding to approximately 0.9 W of acoustic power. The inception of acoustic cavitation exhibits a hysteresis effect with respect to input voltage because of the difference in cavitation nuclei. When the voltage of 200 mV, which is much larger than a threshold value, is applied, the distribution of SCL covers nearly whole acoustic field. At 100 mV, the distribution of SCL is confined to pre-focal region. At 58 mV, which is closed to the threshold voltage, the distribution of SCL is very small and located just front side of the focal region. These results are contrast to those in the progressing wave condition, where the SCL distribution is almost located in the post-focal region. Another difference is the existence of streaming in the progressing wave. The excessive streaming may push away cavitating bubbles, causing no luminescence.

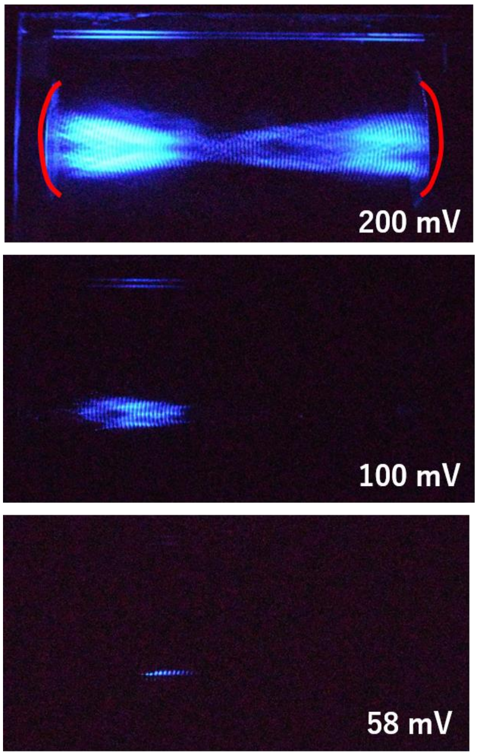

Fig.2 Sonochemiluminescence in a standing focused field at an input voltage of 200 mV, 100 mV and 58 mV.

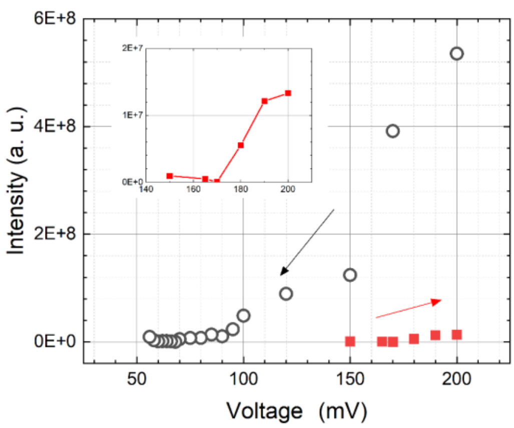

Fig.3 Integrated SCL intensity as a function of input voltage. The open circles denote the intensity as decreasing the input voltage, and the closed squares denote that as increasing the input voltage. The closed squares are plotted in an expanded scale in the inset.

Figure 3 shows the dependence of the input voltage on the integrated SCL intensity. The threshold voltage is 56 mV in the case of decreasing voltage, and 152 mV in the case of increasing voltage. This difference is explained by the number of cavitation nuclei. In the case of decreasing voltage, many cavitation bubbles survive and act as nuclei. In the case of increasing voltage, little nuclei exist before sonication, and the threshold depends on how the liquid was prepared and hence it has little reproducibility [5]. In the present experiment, no special caution was paid in the preparation of sample liquid except the use of deionized water with 2 μm filtering.

The acoustic pressure corresponding to the threshold of SCL should be known with non-invasive method. Figure 4 demonstrates the color-coded image of focused sound field obtained by the optical deflection method. The optical deflection was resulted from the integration through the range of interaction with ultrasound. The phase of ultrasound is nearly constant near the focal region, so that the magnitude of deflection reflects the pressure amplitude at least at the focal point. We measured the pressure amplitude at several input voltages and obtained the value of 1.6 atm at 56 mV by extrapolation. The absolute value of sound pressure should be compared with that by other technique.

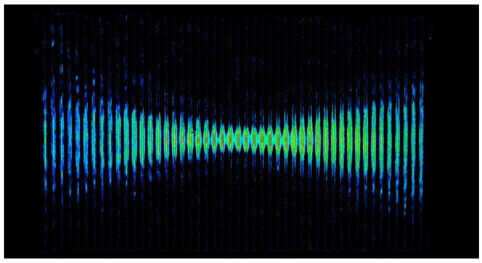

Fig.4 Image of focused sound field measured by optical deflection method. Subtraction between sonicated and non-sonicated images was processed.

References

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