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Microbubble Measurement Using Optical Spectrometer

光スペクトロメータを用いるマイクロバブル計測

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1. Introduction

Acoustic cavitation bubbles are generated by high-intensity ultrasound radiation into aqueous liquid. These bubbles oscillate volumetrically and produce extreme environment with temperatures of up to several thousand Kelvins and pressures of up to about 1000 atm[1)]. In such environment, various chemical reactions, referred to as sonochemistry, are produced. It is important to observe and analyze behaviors of oscillating bubbles in study of sonochemistry[2)]. However, it is not easy to observe this phenomenon, because small bubbles, called microbubbles, change its volume in short period. Thus, high-speed camera and microscope are used to observe the phenomenon but it is still remains difficult to catch up microbubbles moving at random because it has no broad visual field.

In this paper, we study on a measurement method for oscillating microbubbles using optical spectrometer. This method is expected to solve the problem of the method using the high-speed camera. In order to ascertain the observation possibility of oscillating microbubbles using this method, we theoretically examine the spatial spectrum of microbubbles and confirm its validity by the experiment.

2. Principle of Measurement

The experimental setup is shown in **Fig. 1**. Microbubble as measuring object is located on input plane x_i-y_i and illuminated by a parallel light which passes through the aperture of the window. The spatial spectrum of the object appears on the back focal plane x_o-y_o of the convex lens #2. When the spatial frequency of the microbubble is higher enough than that of the aperture of window, the microbubble can be considered to be a complementary circular aperture by the Babinet principle. Therefore, the Fourier transform spectrum, $g(x_o, y_o)$, is given by

$$g(x_o, y_o) = C\left(\frac{d}{2}\right)^2 \frac{J_1(\pi dr/\lambda f)}{\pi dr/\lambda f}, \tag{1}$$

$$r = \sqrt{{x_o}^2 + {y_o}^2}, \tag{2}$$

where C, d, λ, f, r and J_1 are proportionality coefficient, the diameter of aperture, the wavelength of laser light, the focal length of lens #2, the distance from the light axis on the back focal plane, and the first order Bessel function of the first kind, respectively. Thus, a light intensity distribution measured at the focal plane, $I(r, d)$, is given by

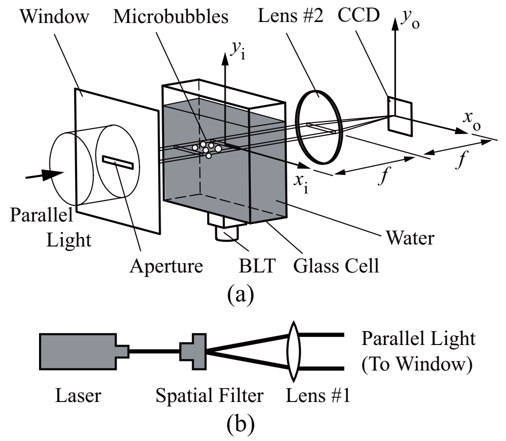

Fig. 1 Schematics of experimental system (a)Fourier spectrometer (b)Apparatus for generating parallel light

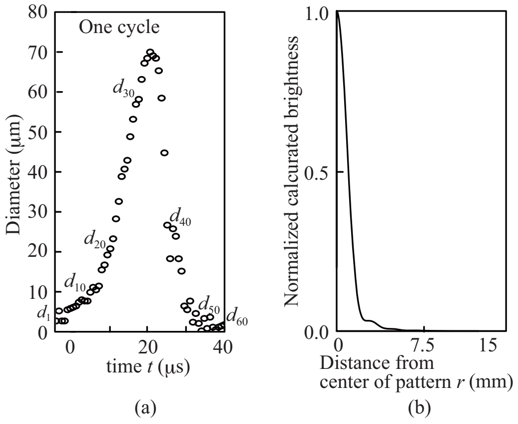

Fig. 2 (a)Measured diameter fluctuation of microbubble cited from Ref. 2 Fig. 3-(III) (b)Normalized intensity distribution calculated from eq.(4)

$$I(r, d) = C^2\left(\frac{d}{2}\right)^4 \left(\frac{J_1(\pi dr/\lambda f)}{\pi dr/\lambda f}\right)^2. \tag{3}$$

We assume that the diameter of the microbubble fluctuates by ultrasound shown in **Fig. 2(a)**[2)]. Therefore, when the spectrum is observed with the imaging device like Charge Coupled Device (CCD), the intensity distribution of the observed image, $V(r)$, is proportional to summation of intensity distribution at observation time as follows[3)],

$$V(r) \propto \sum_{n=1}^{60} I(r, d_n)\Delta t, \tag{4}$$

where d_n are each value shown in Fig. 2(a). Figure 2(b) shows the normalized intensity distribution calculated from eq.(4).

The spectrum of two or more bubbles is given by superposition of spectrums of each bubble when the bubbles are randomly distributed. Thus, when the diameters of the bubbles in the observation area are uniform, the measured spectrum is proportional to the spectrum of a single bubble.

3. Experimental Verification and Discussion

3.1 System configuration

Parallel light generated by a He-Ne laser (05-LHP-151, Meles Griot) operating at a vacuum wavelength of 632.8 nm passes through the spatial filter, and convex lens #1, and irradiates window with rectangular aperture of 1×20 (mm^2).

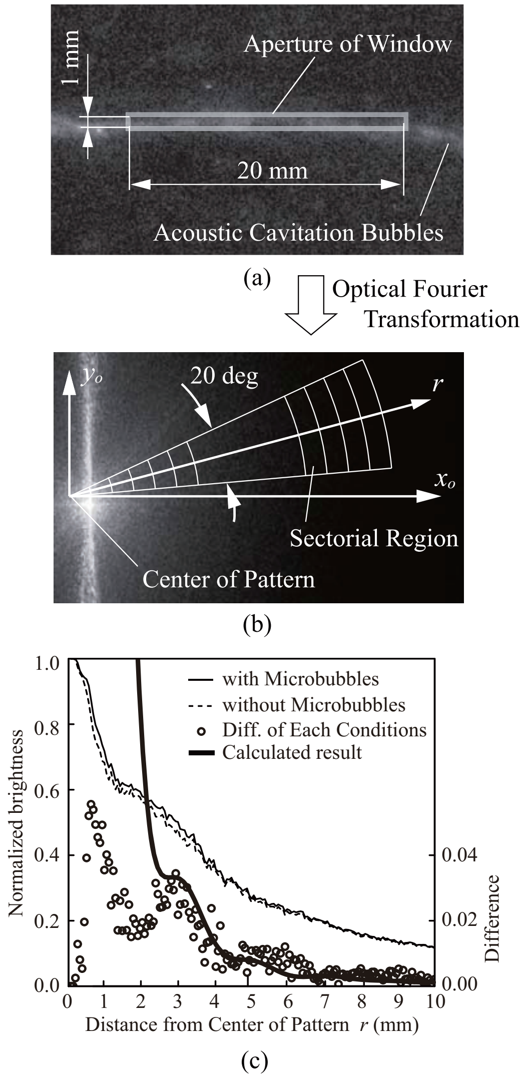

Fig. 3 Experimental result (a)Close up image of microbubbles and size of aperture of window (b)Optical Fourier transformation image of oscillating microbubbles (c)Radial distribution of intensity of optical Fourier transformation

The outgoing light from aperture irradiates microbubbles and enters the convex lens #2 whose focal length is 200 mm. The image of spatial spectrum is acquired by the CCD put on the back focal plane of lens #2.

A grass cell whose size is 100×35×125 (mm^3) is irradiated by the ultrasound generated by a bolt clamped Langevin type ultrasound transducer (BLT). A sinusoidal voltage whose frequency is 50.8 kHz generated by a function generator (DF 1905, NF Electronic Instruments) is amplified with a power amplifier (4010, NF Electronic Instruments). The amplified voltage is input to BLT attached to the bottom of grass cell. The water depth is 120 mm.

3.2 Experimental Results

The close up image of acoustic cavitation bubbles taken by a digital still camera (D80, Nikon) is shown in **Fig. 3(a)** and the spatial spectrum of microbubbles aquired by the CCD is shown in Fig. 3(b). Figure 3(c) shows the radial intensity distributions of measured spatial spectrum with microbubbles, that without microbubbles, and the difference between both conditions is also plotted. The calculated intensity distribution shown in Fig. 2(b) is also plotted. The intensity value is a mean value at each sectorial region in Fig. 3(b).

As shown in this figure, the difference of measured intensity approximates the calculated intensity distribution at $r \geq 3$ mm. On the other hand, the difference differs substantially from the calculated result at $r < 3$ mm. This is attributable to the saturation of the CCD with high-intense light near the light axis. Accordingly, the difference is expected to originate in the spatial frequency of microbubbles. Thus, the observation possibility of microbubbles in oscillation using optical spectrometer is indicated.

4. Conclusion

We theoretically examined the spectrum of oscillating microbubbles and confirmed the observation possibility of microbubbles using the optical spectrometer. We calculated the spectrum of microbubbles and compare that with the experimental result. As a result, the validity of calculated result was shown and observation possibility of microbubbles using optical spectrometer is indicated.

References

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