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Influence of the frequency of superposed supersonic wave on laser ablation plasma produced in water
水中レーザーアブレーションプラズマに対する重畳超音波の周波数の効果

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Laser ablation of a solid target was carried out in water in the presence of supersonic wave. The optical emission intensity from the ablation plasma was examined as functions of the phase of the supersonic wave at the timing of the laser irradiation and the frequency of the supersonic wave between 32 and 135 kHz. The enhancement of the optical emission intensity was observed when a laser pulse irradiated the target at a negative phase of the supersonic wave at all the frequencies.

1. Introduction

Laser ablation in liquid-phase has been investigated as a novel effective method for synthesizing crystalline nanoparticles [1-3]. In this process, a dense plasma with a high temperature and a high pressure is induced in the vicinity of the target by the irradiation of an intense laser pulse onto a solid target immersed in liquid [4-5]. It is pointed out that the inside of the ablation plasma with the unique special state and the interface between the plasma and the liquid play important roles as reaction fields in the synthesis of crystalline nanoparticles [6-8]. We have proposed adding acoustic pressure by exciting supersonic wave in ambient liquid as a method for controlling the dynamics of the reaction field [9]. To date, chemical reactions and physical phenomena caused by supersonic wave in water have been investigated in the field of sonochemistry [10]. It is reported that acoustic cavitation in water induces the formation of active hydrogen and hydroxy radicals, and enhances chemical reactions [11-13]. Hence, we expect that the characteristics of nanoparticles synthesized by liquid-phase laser ablation are controlled by supersonic wave. In this paper, we examined the effect of the acoustic pressure on the change in the plasma state. In particular, we focused our interest on the influence of the phase of the supersonic wave at the timing of the laser-pulse irradiation and the frequency of the supersonic wave on the optical emission intensity from the ablation plasma.

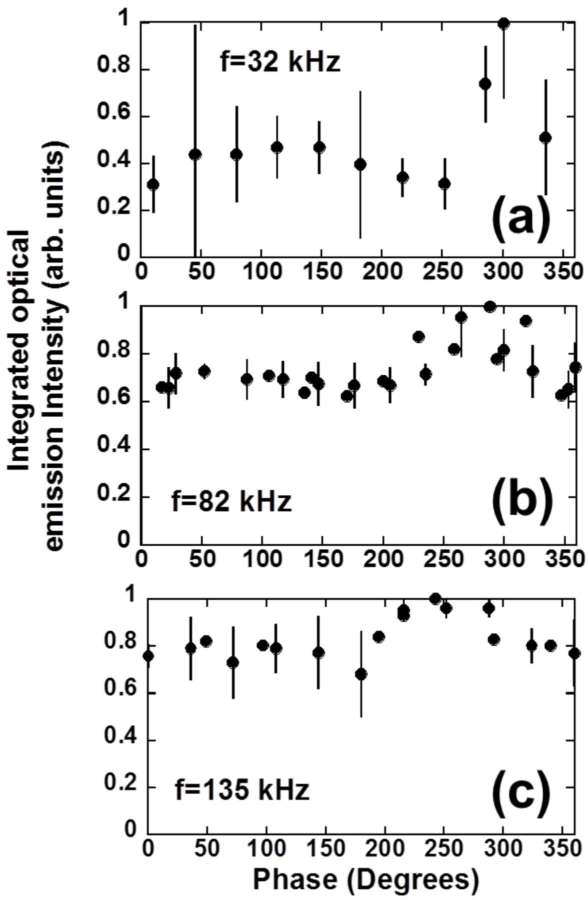

Fig. 1. Variations of integrated optical emission intensity from ablation plasma as a function of the phase of the supersonic wave.

2. Experimental

The details of the experimental apparatus have been reported elsewhere [9]. Briefly, a rectangular container was filled with distilled water. A Ti target was immersed in water and was irradiated by YAG laser-pulses with an energy of 360 μJ/pulse at a wavelength of 1064 nm from the normal direction. The supersonic wave was propagated in water from the bottom of the container toward the top. The frequency of the supersonic wave ranged between 32 and 135 kHz. A supersonic power of 30 W was used. We observed the optical emission image from the ablation plasma using an ICCD camera. The phase of the supersonic wave at the timing of the YAG laser irradiation was controlled using a digital delay system. An image of the optical emission intensity was obtained by accumulating signals for 1000 laser shots.

3. Results and discussion

Figures 1(a)-1(c) show the variation of the optical emission intensity from plasmas as a function of the phase of the supersonic wave. The optical emission intensity was obtained by the spatial integration of the optical emission image. We observed the enhancement of the optical emission intensity at the negative phase of the supersonic wave in all the supersonic frequencies between 32 and 135 kHz. The magnitude of the enhancement decreased with the frequency. In the case of 32 kHz, the widths (FWHM) of the optical emission image were examined at different phases as shown in Figs. 2(a) and 2(b). We observed no change in the spatial distribution of the optical emission intensity with the phase, indicating that the stronger optical emission was not attributed to the more significant expansion of the plasma at the negative phase of the acoustic pressure. Hence, we speculated that gases dissolved in water contributed to the strong optical emission. In a previous paper, we reported the enhancement of the optical emission intensity by pressurizing water using nitrogen gas [14]. Dissolved gas was the key for the enhancement of the optical emission intensity. In the case of this experiment, the boiling temperature of water becomes low at the negative phase of the acoustic pressure, resulting in the significant degassing of dissolved gas from water. The amplitude of the acoustic pressure driven at the laser-irradiation position was larger at a higher frequency of the supersonic wave. Indeed, we observed more significant formation of bubbles on observation windows of the container at a higher frequency of the supersonic wave. Therefore, the weaker optical emission intensity at a higher supersonic frequency may be attributed to a smaller amount of dissolved gas in water.

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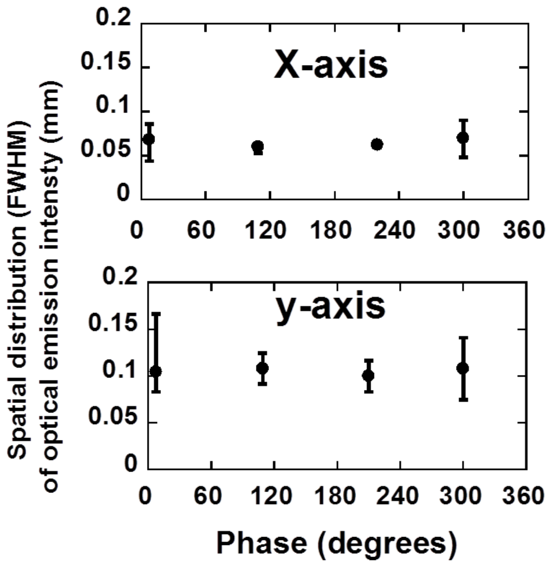

Fig. 2. Width of optical emission intensity as a function of the phase of the supersonic wave.

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