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Plasma-confined structure for continuous generation of pulsed laser-induced airborne ultrasound

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1. Introduction

Intense airborne ultrasound is used for applications such as non-contact and non-destructive testing, non-contact measurement, non-contact transport, and non-contact heating. We consider that pulsed laser-induced ultrasound can be applied to an airborne ultrasound source with high intensity and small size.

In general, when a medium is irradiated with intermittent light, elastic waves are generated by the photoacoustic effect [1]. When the intense laser light is irradiated to the medium, ablation plasma is generated and expands at the surface of the medium [2], moreover, the elastic wave intensity is enhanced when the medium transparent to the laser light is confined near the surface [3]. In this case, it has been reported that elastic waves exceeding 100 MPa are induced and propagate in the solid medium [4]. If a short-pulse laser is used as a light source, pulsed elastic waves with frequency components of ultrasound are induced in the medium, and then a part of the elastic wave energy is radiated toward the air in contact with the medium.

We have previously reported that ultrasonic pulses with a maximum sound pressure exceeding 15 kPa were radiated into the air when a black rubber thin film covered with transparent resin, which is called as laser target, was irradiated with a laser pulse with incident energy of 125 mJ focused at a diameter of about 3 mm [5,6]. However, it is found in this experiment, stable and continuous generation of airborne ultrasonic pulses is not possible due to residual plasma pressure and catastrophic damage to the laser target. Recently, when black ink was used as laser target, we found that airborne ultrasonic pulses were radiated in response to the pulsed laser irradiation to the black ink flow confined in the transparent tube [7]. In this case, however, thermal damage to the transparent medium is one of serious problem.

In this study, we used circulating water as the transparent medium to solve the problems caused by residual plasma pressure and thermal damage to the transparent medium. We investigated the sound pressure variation of airborne ultrasonic pulses generated when a laser target placed in circulating water was repeatedly irradiated with a high-intensity pulsed laser.

2. Experimental procedure

In this experiment, pure water filled between the laser target and the focusing lens is circulated as shown in Fig. 1. This configuration enables confinement of the ablation plasma during laser irradiation, removal of bubbles generated on the target surface, and cooling of the target. The temperature of the circulating water and the flow rate during the experiment were kept about 30 °C and 3.7 L/min, respectively.

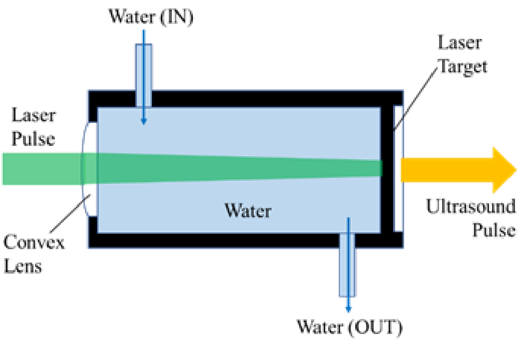

Fig. 1 An experimental illustration in which the space between the laser target and the focusing lens is filled with circulating water. Pulsed ultrasound is radiated from outside the laser target to the air when a pulsed laser is irradiated to the target surface.

The laser target was fabricated by epoxy bonding a black fluororubber (FKM) of either 0.1-mm or 0.5-mm-thick film to a 1-mm-thick polycarbonate (PC) plate. A single-sided and non-reflective surface coated convex lens (Sigma, SLM-30-100PM) with a focal length of 100 mm was used as the focusing lens. In the experiment, a second harmonic pulse light (wavelength 532 nm, pulse width 10 ns) of an Nd:YAG laser (Spectra-Physics, LAB-130-10) is irradiated through the convex lens onto the FKM surface of a laser target fixed in circulating water. The energy of the laser beam emitted from the laser system is separated by a beam sampler (Sigma, BS4-30C03-10-550) and measured by an energy detector (Gentic, QE25LP-D-MB-QED-DO). From the detected values, the laser energy incident on the convex lens was calculated using the results of a previously determined calibration curve, and this calculated value was used

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as the incident energy. Sound waves emitted from the laser target into the air were detected by a 1/8-inch size microphone (G.R.A.S., 46DE, bandwidth 6.5 Hz to 140 kHz) placed on the central axis of the target. The signal from this microphone was amplified by a preamplifier, and then monitored by a digital oscilloscope (Iwatsu, DS-5654A) synchronized with the trigger signal of the laser device.

3. Experimental Results

Figure 2 shows typical sound pressure waveforms for a laser target composed of a 0.5-mm-thick FKM and 1-mm-thick PC plate laser without and with circulating water. The distance between the outer surface of the laser target and the microphone tip was about 10 mm. From these results obtained at an incident energy of about 113 mJ, the maximum sound pressure was 10.2 kPa with circulating water, which is more than 20 times higher than that without circulating water. The maximum sound pressure of the laser target using a 0.1-mm-thick FKM became about 1.5 times higher than that using a 0.5 mm thick FKM when the circulating water was used.

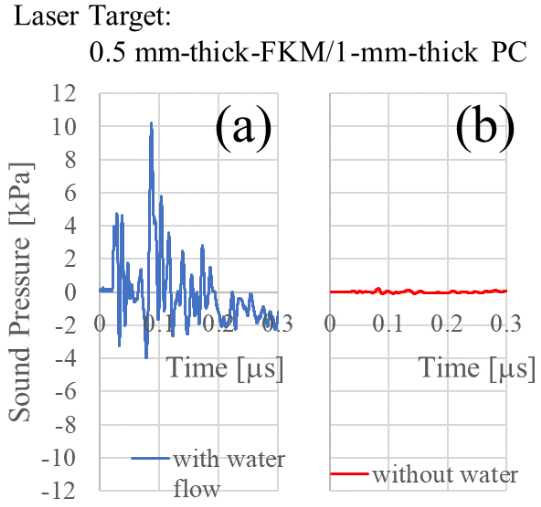

Fig. 2 Typical measured sound pressure waveforms (a) with and (b) without circulating water, when a pulsed laser is irradiated to the target composed of a 0.5 -mm-thick FKM and 1-mm-thick PC plate.

In the presence of circulating water, the variation of the maximum sound pressure as a function of the shot number of laser pulse was measured in which a single laser pulse was repeatedly irradiated to a 0.5-mm-thick FKM. The sound pressure (*P*) decreased gradually with the number of irradiations up to 100 times, however, the incident energy (*E*) also decreased simultaneously. As a result, the average value of the P/E ratio was stabilized at 0.0417 kPa/mJ±6.2 % up to 60 times of irradiation.

4. Conclusion

In this study, using circulating water as the confinement of the ablation plasma, we have confirmed that the high-intensity airborne ultrasonic pulses can be stably and continuously generated when a high-intensity pulsed laser is repeatedly irradiated to a laser target with a black fluoro rubber/PC structure placed in the circulating water.

Acknowledgment

This study was conducted with the cooperation of Mr. Shun Kikuchi of Kanazawa Institute of Technology, and then partly was supported by a Grant-in-Aid for Scientific Research (21K04202).

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