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Continuous generation of intense aerial ultrasound induced by pulsed laser

パルスレーザ誘起による強力空中超音波の連続発生

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1. Background and Motivation

In ultrasonic nondestructive testing, an intense aerial ultrasound is required to inspect a specimen in a noncontact manner. Recently, the authors reported that an intense aerial pulsed ultrasound was generated when a pulsed laser was irradiated to a solid laser absorber covered with a transparent medium [1, 2)]. However, the solid laser absorber with the transparent medium, which is called as laser target, is not suitable for generating continuous pulsed ultrasound because of serious destruction by first laser irradiation.

Iida et al. have reported that a large stress wave is generated enough for plastic deformation of the metal when the laser pulses are irradiated to the black liquid ink covered with the acrylic plate as transparent medium [3)]. Takayanagi et al. have reported a system that applied the continuous shock waves to cultured cells by irradiating a laser pulse repeatedly to a channel which the black liquid ink is flowing [4)].

From previous reports, continuous generation of aerial pulsed ultrasound can be also expected by continuously irradiating the laser pulses to the flow of the black liquid ink as laser absorber, however, there has never been such reports. To continuously generate the intense aerial pulsed ultrasound, this study investigates the sound pressure and its reproducibility of aerial pulsed ultrasound generated by irradiating a pulsed laser on a transparent tube with the flow of the black liquid ink.

2. Experimental procedure

Figure 1 shows an illustration of the experimental setup. The black liquid ink with solid content of approximately 10% was used for the laser absorber. The black liquid ink is circulated in a 6-mm-diameter transparent tube with inner diameter of 4 mm by using a peristaltic pump (AS ONE, TP-10SA). The transparent tube with the flow of the black liquid ink, which is used as laser target, is horizontally fixed by two holders of 5-mm-thick acrylic plate. The focused laser beam of approximately 3 mm diameter is irradiated perpendicular to the transparent tube through 7-mm-diameter hole opened in the lower acrylic holder. Aerial ultrasound generated by laser irradiation is propagated through a 7-mm-diameter hole opened in the upper acrylic holder. The sound pressure of the radiated aerial ultrasound is measured by a broadband microphone installed on the center axis of the 7-mm-hole, and its waveform is observed by a digital oscilloscope (Iwatsu, DS-5654A) synchronized with the trigger signal from the laser equipment. **Table 1** shows the specifications of the Q-switched Nd:YAG laser and the pressure microphone set used in this experiment.

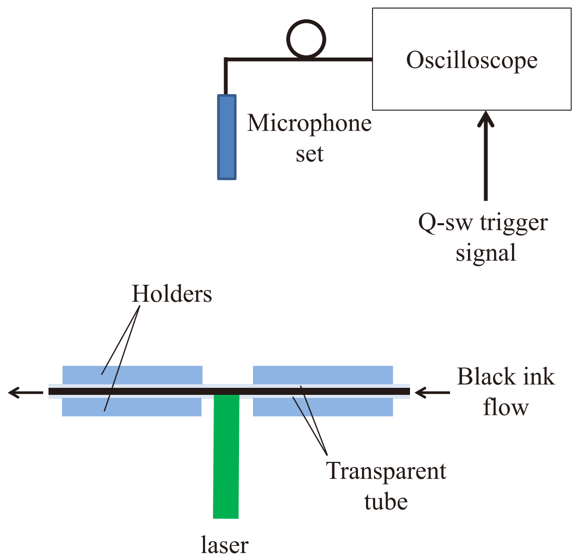

Fig.1 Illustration of experimental setup.

Table 1 Specifications of laser and microphone.

Q-switched Nd:YAG laser (Spectra Physics, LAB-130-10)		Pressure Microphone Set (G. R. A. S, 46DE)	
Wavelength	532 nm	size	1/8 inch
Pulse energy	< 0.2 J	Frequency range	6.5 Hz - 140 kHz
pulse duration	10 ns	Dynamic range	52 dB – 174 dB
Beam diameter	10 mm	Sensitivity	0.62 mV/Pa

3. Results and discussion

Figure 2 shows the first arrival waveform of the aerial ultrasound generated by the irradiation of a single shot laser pulse with the energy of 0.13 J. The distance from the laser irradiation point to the microphone tip is set to 28 mm. In this case, the

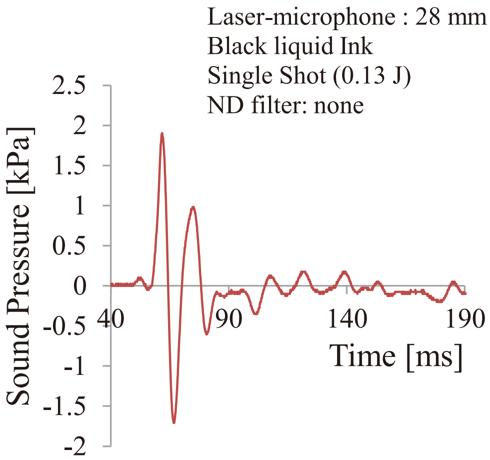

Fig. 2 First pressure waveform arrived at the microphone. A single shot laser pulse was irradiated to black liquid ink flowing in the transparent tube.

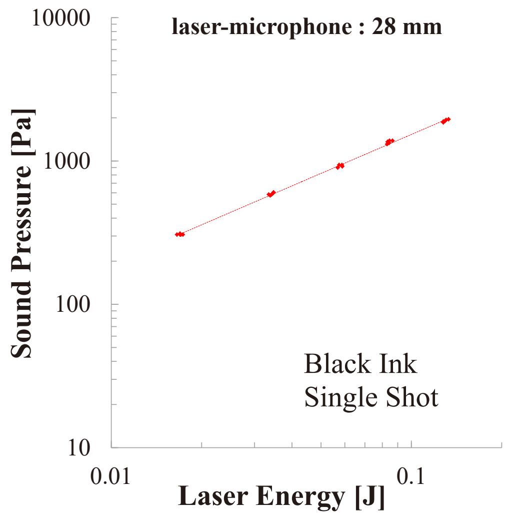

Fig. 3 Variation of maximum sound pressure as function of irradiated laser energy. A dashed line indicates the least-square fitting.

maximum sound pressure was approximately 1.9 kPa (160 dB). As a result of discrete Fourier transform of this waveform, the measured sound pressure waveform contained three frequency components (4 kHz, 14 kHz, and 64 kHz).

Figure 3 shows the variation of the maximum sound pressure as function of the irradiated laser energy. The distance from the laser irradiation point to the microphone tip is set to 28 mm. The measurement of the sound pressure by a single shot irradiation was performed 5 times at which the laser energy was fixed. From this result, the maximum sound pressure varied in accordance with the 0.9-th power of the laser energy. The variation coefficient (the standard deviation divided by the average value) of the measured sound pressure was a few percent or less.

The maximum sound pressure of an aerial pulsed ultrasound generated by irradiating a single shot pulsed laser with an average energy of 0.12 J was measured when the distance from the laser irradiation point was changed from 13 mm to 300 mm. The measured sound pressure varied in almost inverse proportional to distance. The maximum sound pressure of approximately 4 kPa (166 dB) was obtained at the distance of 13 mm, and its variation coefficient was approximately 1.6% in the 5 times measurements.

4. Conclusion

For the purpose of continuous generation of the aerial pulsed ultrasound induced by pulsed laser, the sound pressure of aerial ultrasound generated by irradiating a pulsed laser to a transparent tube with the flow of black liquid ink was measured. Intense sound pressure of approximately 4 kPa (166 dB) and its variation coefficient of approximately 1.6 % were obtained at the distance of 13 mm from the laser irradiation point when a single shot laser pulse with an average energy of 0.12 J was used.

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References

1) K. Aizawa, T. Yamakoshi, and T. Oda, IEICE Tech. Rep. US2019-104 (2020) [in Japanese].
2) K. Aizawa, to be published in Acoust. Sci. Tech.
3) H. Iida, M. Wang, H. Furukawa, M. Tsuyama, M. Kusaba, H. Nakano, and M. Heya, JLPS, **24**, 38 (2017) [in Japanese].
4) K. Takayanagi, K. Nakagawa, S. Sobue, T. Kato, I. Sakuma, A. Tsukamoto, and E. Kobayashi, Proc. (Symposium on Shock Waves in Japan, 2017); Shock Wave Research Society of Japan, 3C1-4 [in Japanese].