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Characteristics of Shock Waves by CNT Coated Laser Generated Ultrasound Transducers

Xiaofeng Fan[1], Kanglyeol Ha[1†], Moojoon Kim[1], Jung-Hwan Oh[1], Hyunwook Kang[1], Jungsoon Kim[2] and Duckjong Kim[3]
([1]Pukyong Nat'l Univ., [2]Tongmyong Univ., [3]KIMM)

1. Introduction

Recently it has been reported that the laser generated ultrasound transducer (LGUT) made of carbon nanotube (CNT) and poly-dimethylsiloxane (PDMS) coated on a transparent substrate radiates high frequency ultrasounds effectively. Baac et al.[1)] demonstrated successfully that the laser generated focused ultrasound by a concave lens can be used for high precision target therapy. However, the characteristics as well as the generation mechanism of the strong shock waves near the focal point is not clarified, even though they explained it is caused by nonlinear propagation of the finite amplitude pulses. The waveform shows very high and short positive but not so low and relatively long negative phase. This asymmetric distortion was assumed to be related with generation of cavitations. However, the similar waveforms of the shock waves were also obtained from plane LGUTs.[2)] For the cases, the waveform deformation is hardly explained by nonlinear propagation. In this study, we demonstrate that the waves are kinds of the blast waves through analysis of the waveforms, and show some characteristics of them by using LGUTs fabricated by coating CNT and PDMS on the substrates of PMMA.

2. Experiment

Figure 1 shows a schematic diagram of the experimental setup. A Q-switched Nd:YAG laser (Quanta-Ray, Spectra-Physics Inc.) with 532 nm wavelength and about 8 ns pulse width was used as a light source. The laser can radiate maximum 160 mJ per pulse with 20 Hz PRF. To make parallel beam with maximum 40 mm diameter, the laser beam was expended by a lens(NT55-582, Edmund Ltd.) after passing an iris. It was collimated by a plano-convex lens with 50 mm diameter and 36 mm focal length. The illuminated area could be changed by the iris and the laser power was measured by a power meter(PM100D, Thorlabs Inc.) with detector(S370C, Thorlabs Inc.). **Figure 2** shows the structure of the LGUT fabricated for this study. First, the multi-walled CNT was coated on a PMMA substrate by the filtering and transition method using an anodic aluminum oxide (AAO) filter. Then, the surface of the CNT film was coated with the elastomeric PDMS(Sylgard 184, Dow Corning Co.) using the spin coating method. Different thickness of the CNT and PDMS films was obtained by control of the amount of CNT solution and the iteration numbers during the spin coating, respectively. Those thicknesses were measured by a surface profiler(Profilometer, Alpha-Step). The generated ultrasound pressure was measured by a needle hydrophone(Φ=0.2 mm, Precision Acoustics Ltd.) with a 8 dB preamplifier in water and recorded by a digital oscilloscope and a PC. The measurement position was changed by a stepped x-y-z scanner.

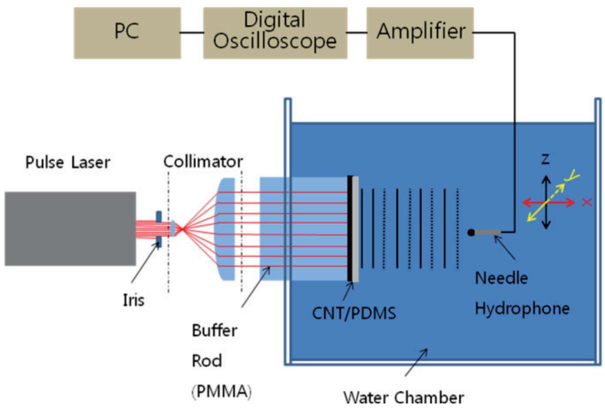

Fig. 1 Experimental setup for shock wave generation and measurement.

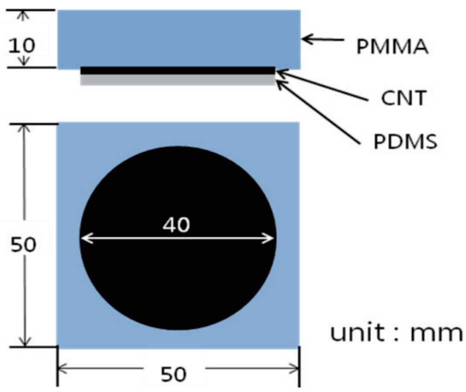

Fig. 2 Structure of the fabricated LGUT.

Email: hakl@pknu.ac.kr

3. Results and discussions

A blast wave in water is the pressure and flow resulting from the deposition of a large amount of energy in a small volume. The simplest waveform of it could be described by the Friedlander equation[3], that is given as following:

$$p = p_0 e^{-\frac{t-t_0}{T_0-t_0}} \left(1 - \frac{t-t_0}{T_0-t_0}\right) , \qquad (1)$$

where, p_0 is the peak pressure. t_0 and T_0 are the times when the shock wave begins and the pressure first becomes zero before the negative pressure, respectively. The eq. (1) represents the pressure variation with time after detonation at t_0 . The typical waveform of radiated shock wave from a fabricated LGUT in this study is shown in **Fig. 3.** It is compared with the calculated one by eq. (1). Here, $p_0 = 3.0\ MPa$, $T_0 = 13.369\ ns$ and $t_0 =\ 13.333\ ns$, respectively, and the profile for $t < t_0$ is linearly fitted as rising time before detonation . The pressure wave was measured at the position 1.0 cm apart from the center of the LGUT. It is known that the -6 dB pulse duration is about 15 ns and two waveforms are quite similar.

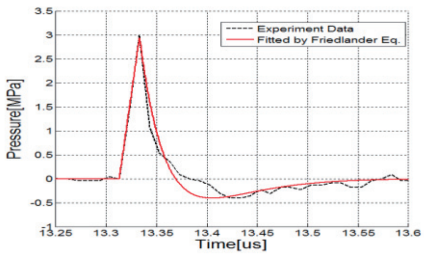

Fig. 3 Comparison of measured typical waveform with calculated one by Friedlander equation.

The variations of the waveforms and power spectra of the shock waves with the time averaged laser intensity are shown in **Fig. 4**. It is noted that the pressure waves vary with the laser intensity, but all of them keep the patterns of the blast wave shown in Fig. 3.

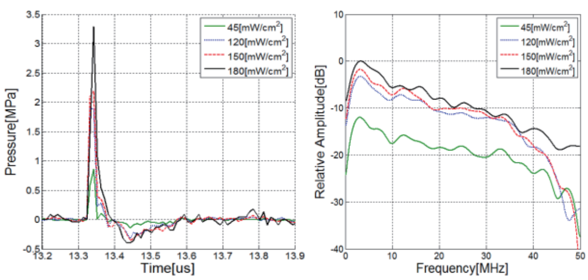

Fig. 4 Variation of waveforms (a) and power spectra (b) with laser intensity.

Figure 5 show the variation of the peak pressure according to laser intensity. And, the variation of the pressure with arrival time and the axial distance from a LGUT surface is shown in **Fig. 6**. In addition, the waveforms and power spectra of the shock waves were measured and analyzed according to the CNT and the PDMS thickness. It was noted that there were not significant differences in waveform as well as power spectrum.

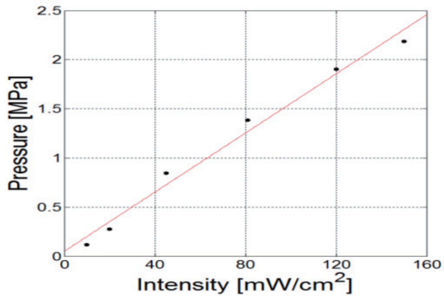

Fig. 5 Variation of the peak pressure with laser intensity.

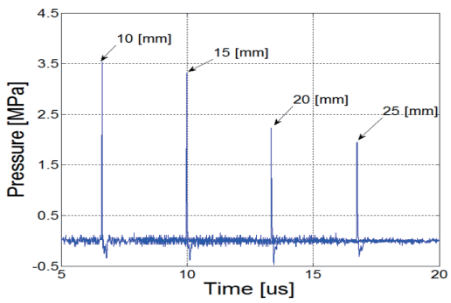

Fig. 6 Peak pressure variation with arrival time and axial distance.

4. Summary

In this study, to demonstrate that the shock wave from LGUTs fabricated by coating CNT and PDMS on a PMMA substrate is a kind of the blast wave, the pressure waveforms were compared with the calculated one. And, some characteristics of the shock waves were given. Hereafter, we will investigate the propagation characteristics of the waves including sound speed and attenuation in detail.

Acknowledgment
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