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Propagation Characteristics of the Shock Waves from a Plane CNTs-coated Optoacoustic Transducer in Water

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1. Introduction

It has been reported that a composite of the light absorbing and the elastomeric materials coated on a transparent substrate can generate high pressure wideband ultrasounds in water when it is illuminated by a pulse laser. To generate the ultrasounds effectively, the carbon-based nanomaterials, such as carbon nanotubes (CNTs) or carbon nanofibers (CNFs) having strong light absorption and high thermal conductivity, and the poly-dimethylsiloxane (PDMS) having high thermal coefficient of volume expansion are used as the materials, respectively.[1-3)] The waves from an optoacoustic transducer made by those materials have waveforms which are asymmetrically distorted with shock fronts of positive phases and trailing longer negative phases, just like blast waves. In this study, we investigate the propagation characteristics of the shock waves in water using a plane optoacoustic transducer made by coating CNTs-PDMS composite on a PMMA substrate. The acoustic wave speed, attenuation and two dimensional fields are measured.

2. Experimental Setup

Figure 1 shows a schematic diagram of the experimental setup and structure of the transducer. A Q-switched Nd:YAG laser (Quanta-Ray, Spectra-Physics Inc.) with 532 nm wavelength, 8 ns pulse width and maximum 160 mJ/pulse with 20 Hz PRF was used as the light source. The radiated laser beam was expended and collimated by two lenses. The region to be illuminated by the laser beam is selected using a slit within Φ=40 mm circular plane area which is the maximum size of the CNTs-coated area. For the transducer fabrication, first we coated the multi-walled CNTs on a PMMA substrate (t=5.0 mm) 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) using the spin coating method. The thicknesses of the CNTs layer was about 7.0 μm and the CNTs-PDMS composite layer was about 9.0 μm. The acoustic pressure was measured by a needle hydrophone (Φ=0.2 mm, Precision Acoustics Ltd.).

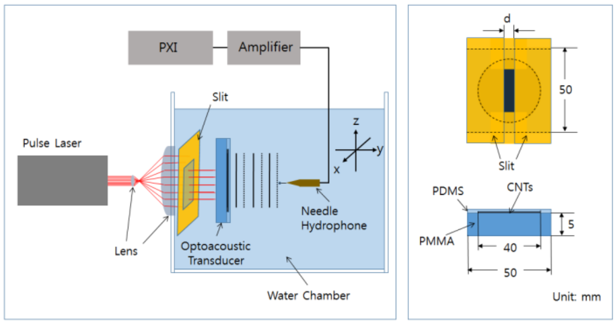
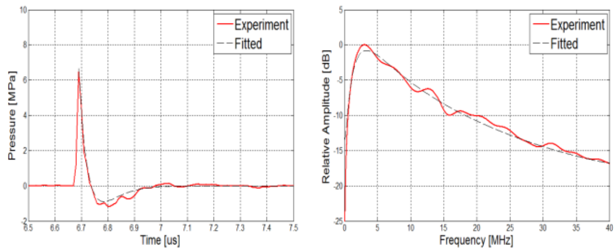


Fig. 1. Schematics of experimental setup and structure of the transducer with a slit.



(a) (b)

Fig. 2. Waveforms (a) and spectra (b) of the shock waves from the plane optoacoustic transducers.

3. Results and Discussions

The waveforms and spectra of radiated shock waves from the fabricated transducers are shown in **Fig. 2.** Those waves were obtained at 10.0 mm from surfaces of the transducers for the laser energy of 120 mJ/pulse, that is, the instantaneous intensity on the transducer surface was about 1.2 MW/cm^2. As shown in the figure, the waveforms and spectra are quite similar with those by Hsieh *et al.*[3)] and those can be fitted well by the Friedlander equation[4)]. From these results, it is revealed that a plane CNTs-PDMS optoacoustic transducer radiates blast waves. The peak pressure is 6.35 MPa in **Fig. 2**, but varies with laser power and measurement position. The variations of delay time according to movement of 0.1 mm distance and the peak pressure of the shock waves along axial distance from 10 to 60 mm in water at 24.5 ℃ are shown in **Fig. 3**. From the

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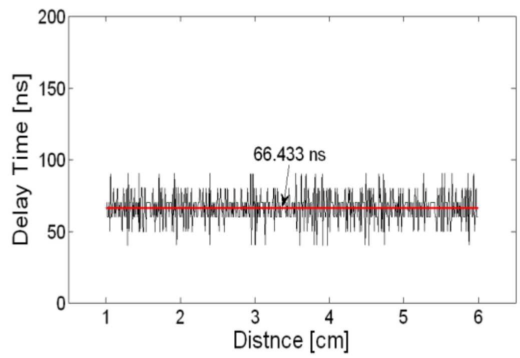
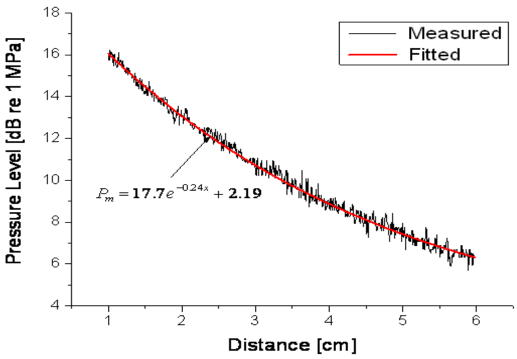
average delay time, the wave speed is obtained by 1505.3 m/s, that is higher than usual sound speed of 1495.7 m/s. As shown in **Fig. 3(a),** there is not a significant variation in wave speed within the range. As shown in **Fig. 2(b)**, the frequency with maximum pressure is 3.05 MHz. However, the attenuation coefficient is $\alpha = 0.24$dB/cm which corresponds to the absorption of 10.5 MHz harmonic plane wave if we deduce it from $25.3 \times 10^{-17}/f^2$ Np/cm [5]. From the fitting curve, we can estimate that the peak pressure on the transducer surface is about 9.89 MPa. It means the radiation pressure is very big and the attenuation of the shock wave is so large that the waveform changes with propagation.



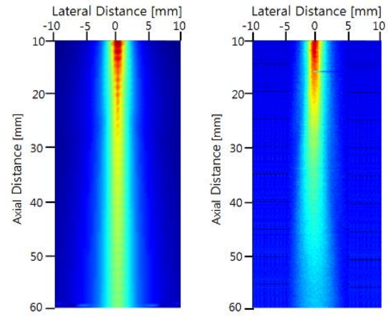
(a)



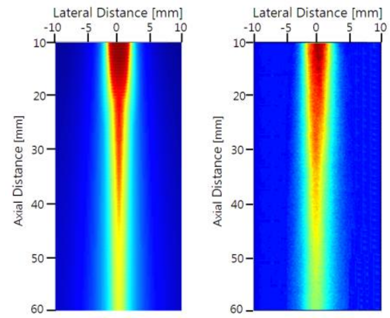
(b)

Fig. 3. (a) Delay time for 0.1 mm movement and (b) variation of the peak pressure of the shock waves

When the transducer is illuminated through a slit with length $l = 10$ mm, width d=3.0 or 5.0 mm, the calculated and measured two dimensional peak pressure fields are shown in **Fig. 4**. In the calculation, we assumed that the transducer has a plane radiation surface having the same dimension as the slit size. It was divided by point sources of which dimensions are less than $\lambda/5$ for 3.0 MHz, and every point source was assumed to generate same blast wave which is given by the Friedlander equation. It is assumed that the peak pressure amplitude on transducer surface is 10.0 MPa and each point source radiates spherical wave. From comparison of the results, it is suggested that the transducer radiates blast waves and the pressure distribution along lateral axis is the Gaussian.



(a) (b)



(c) (d)

Fig. 4. Two dimensional peak pressure fields when the transducer illuminated through a slit: (a) calculated (3 mm), (b) measured (3 mm), (c) calculated (5 mm), (d) measured (5 mm)

4. Summary

In this study, first we confirmed that a plane CNTs-coated optoacoustic transducer generates the shock waves having the similar waveform with blast waves. Then, we showed some propagation characteristics including wave propagation speed and attenuation constant of the shock waves in water. In addition, from comparison between the calculated and the measured two dimensional pressure fields using a slit, it is suggested that the planar blast waves are generated on the transducer surface.

References

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