2P1-3

Waveform Characteristics of the Shockwaves from the CNT/PDMS Optoacoustic Transducer

Xiaofeng Fan[1†], Kanglyeol Ha[1], Moojoon Kim[1], Dong-Guk Paeng[2], and Junghwan Oh[1] ([1]Pukyong Nat'l Univ., [2]Jeju Nat'l Univ.)

1. Introduction

Owing to the optoacoustic effect, a composite of light-absorbing and elastomeric materials can generate ultrasound waves when it is illuminated by a pulse laser [1, 2]. However, the waveform of the generated ultrasound waves by the optoacoustic transducers have not been intensively investigated so far. In previous research, the authors confirmed that the measured waves from an optoacoustic plane transducer made of CNT/PDMS composite, which were coated on a poly(methyl methacrylate) (PMMA) substrate, have blast wave-like waveforms.

Those ultrasound waves were measured by a commercial PVDF needle hydrophone or an optical fiber hydrophone. Each hydrophone has wideband characteristics so that the receiving response is flat in the frequency range from the several hundred kHz to the several hundred MHz. But, it has low sensitivity and the skill is necessary to calibrate it well. Furthermore, it is easily damaged and the price is expensive. On the other hand, the NDT transducers have high sensitivity and are robust. Those are widely and practically used in industry because of low price compare to the PVDF needle hydrophones or optical fiber hydrophones.

In this study, the shock waveform of the generated ultrasound by the CNT/PDMS optoacoustic transducer was simulated theoretically and confirmed using NDT transducers with narrow bandwidth considering the receiving impulse responses of the transducers. The results were compared with measured ones by a commercial PVDF needle hydrophone and an optical fiber hydrophone.

2. Thermoelastic theory and results

Acoustic wave generation with thermoelastic effect is governed by two equations: the heat conduction equation and the acoustic wave equation. The heat conduction equation, which determines the temperature distribution, is shown in the following expression [3]:

$$\frac{\partial T}{\partial t} = k\nabla^2 T + \frac{1}{\rho C_p} h(\vec{r}, t) \qquad (1)$$

where, k is the thermal diffusivity, T is the increased temperature above the ambient temperature, ρ is the density, C_p is the specific heat capacity, and h is the rate of energy deposited per unit volume in the medium of the CNT/PDMS composite material.

The wave equation with the heat source which generates ultrasound by the optoacoustic effect is given by [4, 5]:

$$\nabla^2 \emptyset - \frac{1}{c^2}\frac{\partial^2 \emptyset}{\partial t^2} = \frac{3B}{\rho c^2}\alpha_L T \qquad (2)$$

where, $\emptyset$ is the scalar potential, c is the longitudinal wave speed, B is the bulk modulus, α_L is the linear coefficient of thermal expansion in the medium.

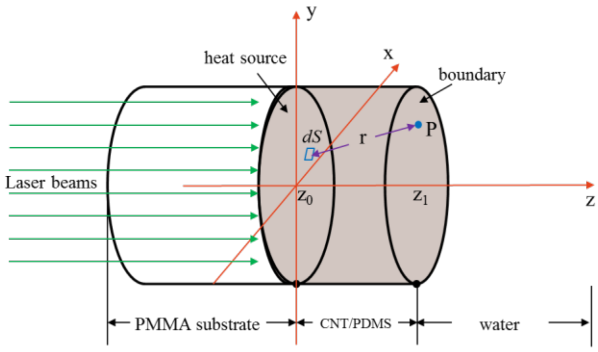


Fig. 1. Coordinate system for sound generation analysis.

Figure 1 shows the Coordinate system for sound generation analysis in the CNT/PDMS optoacoustic transducer. According to Eq. (1) and Eq. (2), the sound pressure at point P on the CNT/PDS and water boundary is obtained as below:

$$p = \frac{1}{4\pi}\frac{3B\alpha_L}{c^2}\Delta x \Delta y \sum_{l=1}^{L}\sum_{m=1}^{M}\frac{\frac{\partial}{\partial t}T(t-\frac{r}{c})}{r} \qquad (3)$$

The temperature profile on the source plane is assumed as following:

$$T(t) = A\,(t - r/c)\exp(-t/T_L) \qquad (4)$$

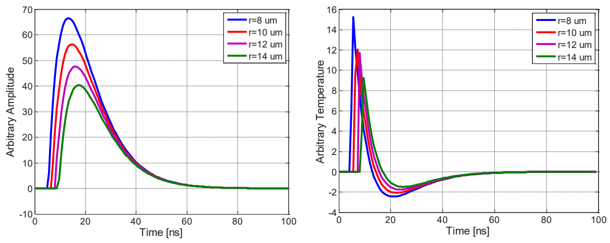
where, $A = 1 \times 10^7$ is a constant, T_L is the duration of the laser pulse, r is the distance from a point on the surface of heat source to a point on the boundary between the surface of the CNT/PDMS optoacoustic transducer and water, and c is the wave speed in the medium.

Figure 2(a) and 2(b) show the simulation results of temperature profiles and sound pressure waveform, respectively, when the distance from a

----

Email: hakl@pknu.ac.kr

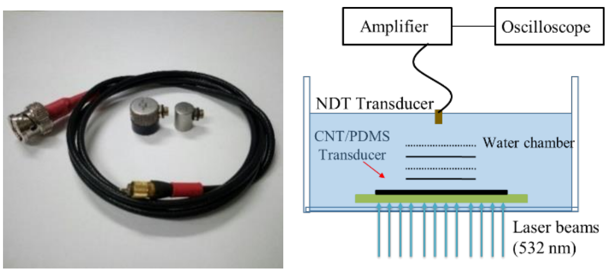
point on the surface of heat source to a point on the boundary are r = 8 μm, 10 μm, 12 μm, and 14 μm. It indicated that the temperature profiles on the surface of heat source increase quickly during the laser pulse duration and decrease after the laser pulse duration. With the increase of distance r, the magnitudes of temperature profiles and sound pressure waveforms decrease respectively, while they keep the same shape.



(a) (b)

Fig. 2. Simulation results of the variation of temperature profiles (a) and sound pressure waveform (b) with distance r.

3. Experimental Setup



(a) (b)

Fig. 3. Photograph of the two NDT transducers (a) and schematics of experiment setup to measure the generated ultrasound waves from CNT/PDMS transducer.

The shock waveform of the generated ultrasound by the CNT/PDMS optoacoustic transducer was measured and confirmed using NDT transducers with narrow bandwidth considering the receiving impulse responses of the transducers. The waveforms of the shock waves were simulated using the PiezoCAD (Version 3.03 for windows, Sonic concepts, Wood-in-ville, WA), and the results were compared with measured ones by a commercial PVDF needle hydrophone and an optical fiber hydrophone. Fig. 3(a) and 3(b) show the photograph of the two NDT transducers and the schematics of experiment setup for measurement of the generated ultrasound waves from CNT/PDMS transducer, respectively.

4. Results and Discussions

Figure 4 shows the calculated waves from the characteristics of NDT-1 and NDT-2 transducers. The calculated waves were compared with the waves measured by the commercial PVDF needle hydrophone and the fiber optic transducer. It is shown that the calculated waves have the waveform of a blast wave-like shock wave, which is similar to the waveform of the shock waves measured by the commercial PVDF needle hydrophone and the fiber optic transducer. The results confirmed that the generated ultrasound waves from the CNT/PDMS optoacoustic transducer when irradiated a pulsed laser are shock waves.

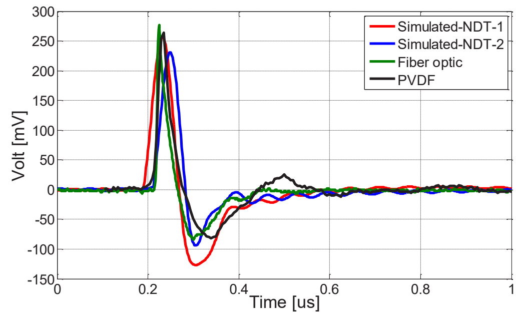


Fig. 4. Calculated waveforms of NDT transducers, and compared with the ones by the commercial PVDF needle hydrophone and fiber optic transducer.

5. Summary

In this study, with the heat conduction equation and the acoustic wave equation, the ultrasound waves generated by optoacoustic effect were simulated theoretically. By considering the receiving impulse responses, the waveforms of the generated ultrasound waves from the CNT/PDMS optoacoustic transducer were confirmed by using the NDT transducers with narrow bandwidth. It is confirmed that the generated ultrasound waves have the blast wave-like waveforms as same as the waveforms by a PVDF needle hydrophone or optical fiber hydrophone. Conclusively, it is known that the ultrasound waves from the CNT/PDMS optoacoustic transducer can be measured by NDT transducers.

References

1. H. W. Baac, J. G. Ok, A. Maxwell, K-T Lee, Y-C Chen, A. J. Hart, Z. Xu, E. Yoon and L. J. Guo: Sci. Rep. **2**, 989 (2012).
2. X. Fan, Y. Baek, K. Ha, M. Kim, J. Kim, D. Kim,H. W. Kang, and J. Oh: Jpn. J. Appl. Phys., 56, 07JB05 (2017).
3. G. C. Wetsel, IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 1986. 33(5): 450-461
4. F. Alan McDonald, Applied Physics Letters, 1989. 54(16): 1504-1506.
5. Yang Hou, Sheng-Wen Huang, Matthew O'Donnell, IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 2007.

Email: hakl@pknu.ac.kr