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Photoacoustic Performance and Resonance Characteristics of the Liquid-Filled Thin Glass Capillary Embedded in a Soft Material

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1. Introduction

The photoacoustic contrast agent is a hot topic because of its effectiveness in improving the imaging quality[1)] and possibility to expand the application area. Sensitivity of developed contrast agents has been evaluated using photoacoustic imaging machines. However, the results were significantly affected by the design of the imaging machine such as the laser pulse width, center frequency of receiving transducer, signal processing, and imaging algorithm. As a first step evaluation, the physical understanding of the photoacoustic capability of samples is thought to be important. Our group developed a first prototype of evaluation instrument being based on intensity modulated semiconductor laser and lock-in detection[4)]. But its working frequency was far lower than that used in practical imaging machines.

Thus, in this paper, in order to prove the results obtained through the low frequency evaluation setup, we developed a new platform based on a pulsed laser and a MHz-range transducer. Then, we investigated the frequency dependence of the mechanical structure of the samples on the photoacoustic performance.

2. Experiment

2.1 Sample preparation

We prepared a phantom of 21 mm in length, 21 mm in width, and 20 mm in height (H00-600J, Exseal co.), filled in a uncovered acrylic box. The phantom is adjusted to exhibit acoustic characteristics similar to human tissue. A glass capillary (WPI-TW100F-4, WPI co.) of 1.0 mm in outer diameter and 0.75 mm in inner diameter is embedded in the phantom horizontally, keeping the distance of 3.5 mm from the upper surface. The capillary is filled with black ink, which is thought as a primary photoacoustic absorber.

2.2 Excitation and detection

Fig. 1 shows the experimental setup and the sample's geometrical setting. Pulsed light of 129 ns in pulse width and 1 W in peak power was generated using a solid state light source (NPL64C, Thorlabs) and focused with an objective lens (x10)

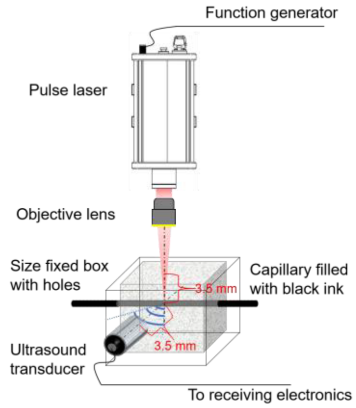

Fig. 1 Experimental setup and sample's geometrical setting.

from the vertical direction. The center wavelength is 640 nm. Generated photoacoustic signal is received using a non-focused piezoelectric transducer with the center frequency of 5 MHz (5K5I, Japan Probe co.) from the side surface of the phantom.

We focused the excitation light on the center of the capillary. The central axis of the ultrasonic transducer is maintained to cross the light's focusing point. The light source was triggered with a function generator (WF1946, NF corp.) at the repetition rate of 1000 Hz. Output signal of the transducer was amplified using a 40-dB low noise amplifier (SA-240F5, NF corp.) and the receiving circuit of a pulser-receiver (5900PR, Panametrics). The setting for the pulser-receiver were 1 kHz, 20 MHz, 20 dB, and 54 dB in high pass and low pass frequencies, attenuation, and gain, respectively.

3. Results and Discussion

3.1 Resonance Characteristics

The upper figure in **Fig. 2** shows an example of signal captured with this platform. The red curve is the result processed with a high pass filter of 5-MHz cut-off frequency. The sound speed was 1122 m/s, which was calculated by dividing the distance between the capillary and the transducer by the interval between the origin and the arrival time of the first peak. The sound speed is close to the value 1192 m/s measured through the time-of-flight between the transducer and the boundary of the plastic box. From this coincidence in the sound speed, the observed signal is considered as the photoacoustically excited signal which propagated in the phantom. The two peaks of the frequency domain signal in the middle of Fig. 2 could be explained by the resonant acoustic modes of the ink filled in the capillary[3)]. The simulated frequencies are noted in the figure with vertical lines. The lower one (1.31 MHz) stands for the mode (1,0) (1st angular order and 0th radial order) and the higher one (2.17 MHz) represents the mode (2,0). Here, the sound speed of 1492 m/s and inner diameter 0.67 mm were used for the calculation. The sound speed of the ink was measured separately through the time-of-flight method. The capillary's inner diameter was measured by filling up the liquid inside the 100 mm long capillary. Note that we found that the actual inner diameter was smaller than the one stated in 2.1, but in the deviation range indicated in the datasheet of capillary.

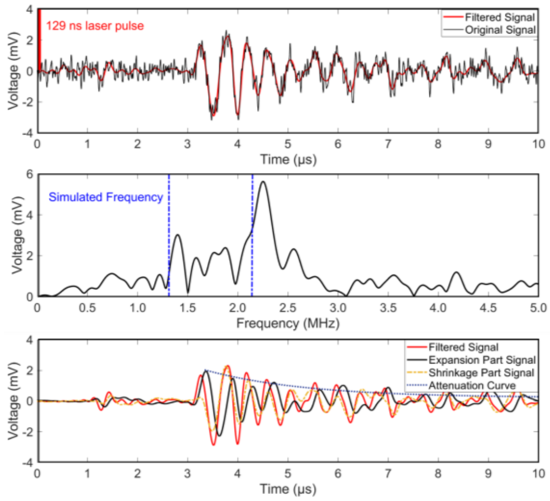

Fig. 2 Recorded signal in time domain (upper), frequency domain (middle), and expansion from the filtered tube-experiment signal (lower).

3.2 Temporal Waveform Simulation

In order to explain the obtained waveform, we conducted simulation based on experimental data for a silicon tube whose inner diameter was 0.5 mm and outer diameter was 1.0 mm. The upper figure in **Fig. 3** shows the signal for the silicon tube. The waveform is similar to the results in Hoelen's paper[3)] which exhibit one strong pulse followed by weak vibrations instead of periodic vibrations in Fig. 2. Here, black curve indicates the original signal, while the blue signal is the low-pass filtered result with the cut-off frequency of 5 MHz.

We superposed ten experimental signals obtained for the silicon tube by keeping the time interval of 0.45 µs which is the reciprocal of the main frequency (2.23 MHz) observed in the previous experiment for the capillary. At the same time, we made each latter signal 0.78 times smaller than the former one in amplitude. This coefficient is derived from the mean attenuation rate of the expansion part signal as shown in the lower figure in Fig. 2. The expanded part was extracted from the filtered signal by assuming the photoacoustic signal was the sum of two opposite signals: 'expansion and shrinkage' with the pulse interval according to the theory by J. M. Sun[4)].

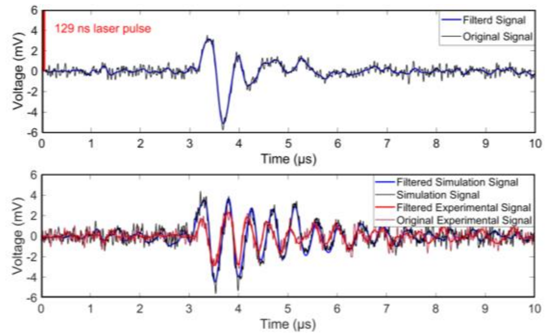

Fig. 3 Recorded signal in soft tube experiment (upper) and simulation result (lower).

This simulated result matches well with the experiment in amplitude and frequency. The particular performance that the amplitude of second positive peak behaves larger than the first one in the capillary experiment is well explained. Furthermore, the amplitude attenuation of simulated waveform is consistent with the experiment waveform as well.

4. Conclusions

In this report, we developed a compact platform to obtain basic physical understanding of photoacoustic signal using liquid-filled thin glass capillary embedded in a phantom. The captured signal waveforms and resonance characteristics were discussed. The peak frequencies were properly explained by the liquid resonance inside the capillary and the temporal waveform shape was illustrated by the simulation result based on silicon tube experiment.

Acknowledgment
This work was supported by JSPS KAKENHI Grant Number 18H01449.

References
1. A. B. E. Attia et al.: Photoacoustics. **16** (2019) 100144.
2. X. Zeng et al.: Acoust Sci Technol. **39** (2018) 3.
3. C. G. A. Hoelen and F. F. M. De Mul: J. Acoust. Soc. Am. **106** (1999) 695.
4. J. M. Sun and B. S. Gerstman: Phys Rev. **59** (1999) 5.