1P1-1

Deep tissue optical absorption spectroscopy using laser-induced ultrasonic pulse

Keisuke Kodama[‡], Yusuke Oshima, and Takashi Katagiri[*]
(Graduate School of Pharma-Medical Sciences, Univ. of Toyama)

1. Introduction

Optical absorption spectroscopy is widely applied for measurements of biological tissues and intravascular blood. This method noninvasively quantifies trace constituents contained in biological tissues based on absorbance measurements. However, acquiring the absorbance characteristics of deep biological tissues with both high sensitivity and high spatial resolution is challenging.

Recent research aims to enhance sensitivity in deep tissue measurements using acoustic wave light confinement[1)]. This is achieved through acoustic wave propagation, creating a refractive index distribution within the biological tissue that forms a virtual optical waveguide.

Our research group is focusing on virtual waveguides formed by photoacoustic waves. Photoacoustic waves are pressure waves generated when pulsed laser light is irradiated on a strongly absorbing material. In this study, we investigated the influence of photoacoustic waves on optical measurements from experiment and simulation.

2. Method

2.1 Experiment

Figure 1 shows the experimental setup. An absorber target, placed at the bottom of the phantom, is irradiated with the second harmonic of Nd:YAG laser at a wavelength of 532 nm, pulse width of 8 ns, pulse energy of 23 mJ, and repetition frequency of 20 Hz to generate photoacoustic waves. The three-layered optical phantom is made of a 4% gelatin solution with a 1 mm thick absorbing layer with gold nanoparticles in the center. A laser light with a wavelength of 462 nm and spot diameter of 30 µm is irradiated from the side of the phantom. The transmitted light intensity is detected by an avalanche photodiode with AC coupling output through a hexagonal light pipe.

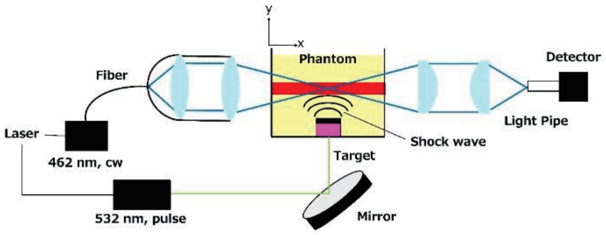

Fig. 1 Experimental setup

2.2 Simulation

We constructed a model of light propagation in a focused Gaussian beam based on a simulation code developed by L. Wang et al[2)]. This is achieved by giving the initial state of the incident photon such that the weight W of the ballistic photon at the beam waist satisfies the following equation.

$$W = exp\left[-\frac{2r^2}{w_0^2} - \frac{2\theta^2}{\theta_0^2}\right] \tag{1}$$

Here, r is the distance from the optical axis, θ is the radiation angle, w_0 is the beam waist radius and θ_0 is the beam divergence. We confirmed that the beam radius $w(z)$ of the simulation model agrees with the theoretical value of Gaussian optics shown in the following equation for light propagation in a homogeneous medium without scattering.

$$w(z) = w_0\sqrt{1 + \left(\frac{\lambda(z - z_0)}{\pi w_0^2}\right)^2} \tag{2}$$

In the simulation, we examined the impact of the refractive index distribution formed by photoacoustic waves on optical measurements. A measured refractive index distribution shown in **Fig. 2** was used in calculation.

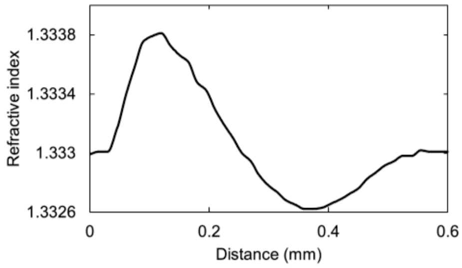

Fig. 2 Refractive index profile

E-mail: [‡]m23e1308@ems.u-toyama.ac.jp,
[*]katagiri@eng.u-toyama.ac.jp

3. Result and discussion

Figure 3 shows the temporal waveform measured around the absorbing layer. In the result at 0.5 mm, which corresponds to the upper surface of the absorbing layer, a negative peak occurs at t = 6.3 µs, and a positive peak appears immediately after that. On the other hand, the result at -0.5 mm, which corresponds to the lower surface of the absorbing layer, shows a positive peak at t = 5.6 µs, and a negative peak appears. The phase inversion is observed on the upper and lower surfaces of the absorbing layer. This means that the detection of internal absorption properties is occurring due to the deflection of light within the phantom.

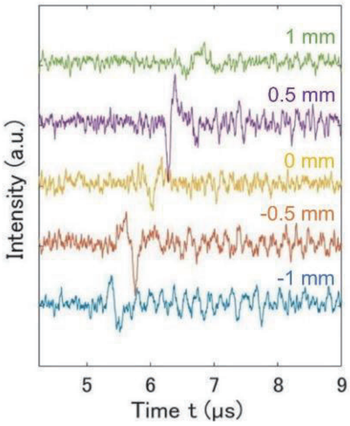

Fig. 3 Measured waveform

Figure 4 shows the transmitted light intensity distribution estimated by using DC and AC components. In the DC mode, the average intensity of the DC component is plotted. In the AC mode, the transmitted light intensity distribution is estimated by accumulating the peak-to-peak intensities of the AC component. In both modes, a decrease in intensity was observed around y = 3.6 mm, near the location of the absorbing layer. This indicates that it is possible to estimate internal absorption properties by using the internal light deflection.

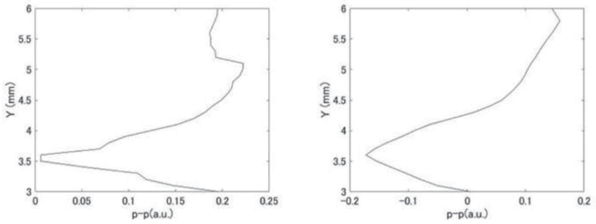

Fig. 4 Transmitted light intensity distribution
Left : DC mode Right : AC mode

Figure 5 shows the simulation results when the peak of the photoacoustic wave reached y = 1.04 mm. The simulation assumed the same laser light conditions as in the experiment, focused on y = 1 mm and z = 5 mm. Absorption coefficient of 0.055 mm^{-1} is set at y > 1 mm. The relative optical absorption in the layered medium is showed in a color map. This figure shows how the light is deflected by the photoacoustic waves. **Figure 6** shows the change in transmittance when the photoacoustic wave propagates along the y direction. It was confirmed that light is deflected and absorbed in the medium as the acoustic waves propagate, and a peak waveform appears in the transmittance.

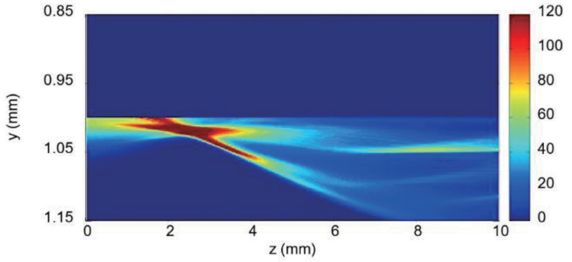

Fig. 5 Light absorption distribution

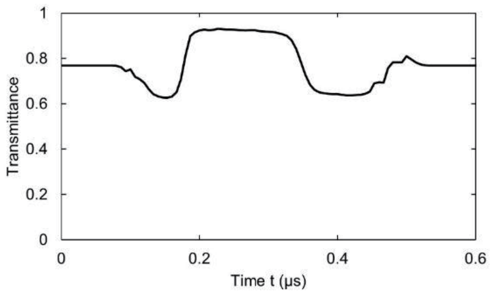

Fig. 6 Transmittance

4. Conclusion

We conducted experiment and simulation to investigate the effect of photoacoustic waves on optical measurements. In the experiment, we observed fluctuations in transmitted light intensity due to the propagation of photoacoustic waves. It was shown that the transmitted light intensity distribution can be estimated from the measured waveform of transmitted light by accumulating the peak-to-peak intensities of the AC component. In the simulation, transmittance waveforms similar to the experimental results were obtained.

References

1) M. Chamanzar et al, Nat. Commun. **10**, 92 (2019).
2) L. Wang, S. L. Jacques, and L. Q. Zheng, Comput. Methods Programs Biomed. **47**, 131 (1995).