Investigation of low-fluence photoacoustic spectroscopy for non-invasive blood glucose monitoring

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Introduction

Photoacoustic spectroscopy (PAS) is being investigated for non-invasive blood glucose monitoring owing to its success in in-vivo quantitative measurement [1, 2]. However, the high laser intensity typically required in PAS—pulse energy of 100 mJ over a pulse width of several nanoseconds—requires a large instrument with a complicated configuration. To develop a small and simple PAS system, we investigated PAS using a low-optical intensity laser with pulse energy on the order of 1 mJ. To obtain an acoustic signal with detectable intensity, we employed a long pulse width of over several microseconds. In this paper, we present the resulting acoustic waves generated by various pulse widths and discuss optimizing the pulse width to obtain a maximally intense acoustic signal.

Experiment and results

A schematic of the experimental setup is shown in Fig. 1. Laser light from a wavelength tunable laser (TSL550, Santec Co.) is amplified by an erbium-doped optical fiber amplifier (AEDFA, Amonics). The light is ON/OFF-modulated by an optical switch (high-speed optical switch, EOSPACE), and then it irradiates the sample through a collimator. One percent of the laser light is split and monitored by a photodetector. The sample is deionized water kept in an isothermal bath. An acoustic sensor (M204, Fujicera) placed 5 mm away from the collimator detects the photoacoustic signal. The repetition frequency of the laser light pulse was 1 kHz, and we varied the width of the pulse from 100 ns to 50 μs.

The representative recorded acoustic waveforms in Fig. 2 show that a single laser light pulse generates two acoustic waves at the start and end of the incident laser pulse. The tales of the wave come from the acoustic source distribution due to the distribution of laser light absorption. The length of the tales is few microseconds. Then, in the case of a 7 μs laser pulse, there is interference between the two acoustic waves. Figure 3 shows the relationship between the pulse width and acoustic wave amplitude. The experimental results also have good agreement with simulation results. The simulation, which models the acoustic source distribution by an array of monopole acoustic sources, implies that the optimum pulse width is 1.7 μs. Additionally, the signal-to-noise ratio can be increased by 87% from the long-pulse case by the optimizing pulse width.

Conclusion

We investigated PAS signals generated by laser light with sub-nanojoule pulse power. A laser pulse generates two acoustic waves with an opposite phase, which can potentially interfere with each other at small pulse widths. We use this interference to optimize the laser pulse width to achieve high PAS signal. In future work, we will explore how these techniques can be used to make low-power PAS and imaging feasible with current sensor technology.

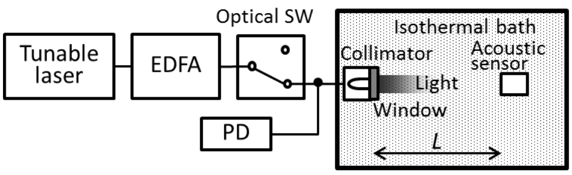

Figure 1. *Schematic of experimental setup. Laser light is ON/OFF-modulated by optical switch.*

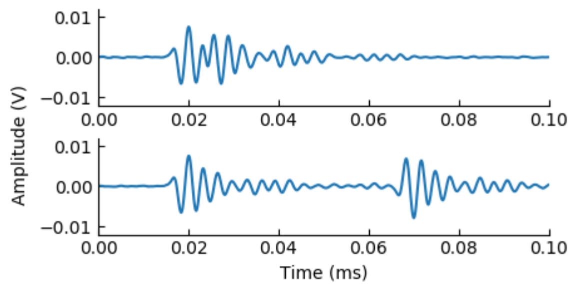

Figure 2. *Representative acoustic waves. Top and bottom show acoustic waves generated by the laser with pulse widths of 7 and 50 μs, respectively.*

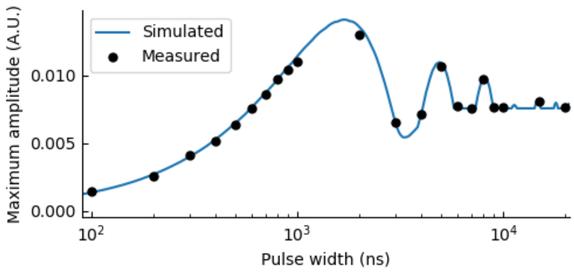

Figure 3. *Relationship between pulse width and acoustic wave amplitude.*

References.

[1] Y. Tanaka, T. Tajima; M. Seyama, "Acoustic Modal Analysis of Resonant Photoacoustic Spectroscopy with Dual-Wavelength Differential Detection for Noninvasive Glucose Monitoring". IEEE Sensors Letters, 1.3, 1-4., 2017
[2] M. Xu and L. V. Wang, "Photoacoustic imaging in biomedicine," *Review of Scientific Instruments 77*, no. 041101, 2006