Asynchronous Optical Sampling, Terahertz Impulse Radar

Y. Ohgi, Y. Kabetani, T. Yasui, S. Yokoyama, and T. Araki

Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan
E-mail: ohgi@sml.me.es.osaka-u.ac.jp

Abstract: Rapid THz impulse radar was achieved by combination of time-of-flight measurement of THz pulse and asynchronous optical sampling technique. The precision of 354 μm was achieved in the displacement measurement.

Keywords: terahertz, radar, time-of-flight, asynchronous optical sampling

1. Introduction

Radar (radio detection and ranging) technique has a wide variety of applications in military and commercial fields. Recently, commercial radar plays an important role in the field of automobile driving such as adaptive cruise control systems for driving assistant and collision mitigation systems for safe driving support. Automobile radar using an infrared laser light provides precise distance measurement, however, this method is affected by light scattering caused by bad weathers (rain, snow, and fog) and contaminated surface of a target. On the other hand, automobile radar using millimeter wave can be used under bad weathers and applied to contaminated surface of the target whereas the precision of distance measurement is relatively low. In this way, the conventional methods of automobile radar have their own merits and demerits. If merits of both methods are combined with each other, ideal automobile radar will be achieved. One possibility to combine merits of both methods is use of THz wave as a radar wave because THz wave lies at a boundary between infrared light and millimeter wave, and possesses both characteristics of them.

Conventionally, THz impulse ranging (THz-IR) based on time-of-flight measurement of THz pulse has been used for scale model simulator of microwave radar [1]. For example, detection of small-scale model of fighter aircraft has been demonstrated. However, when this technique is applied for automobile radar, there are two problems. One is requirement of mechanical stage scanning for time delay, resulting in long measurement time. Therefore, the conventional THz-IR has been only applied to stationary objects. Another problem is to coincide the optical path length between the THz pulse and the probe light. Therefore, it is difficult to detect a target at an unknown distance.

One promising method to overcome the two problems is asynchronous optical sampling (AOS) method using two mode-locked lasers with slightly mismatched mode-locked frequencies [2]. Recently, the AOS method has been effectively applied for terahertz time-domain spectroscopy (THz-TDS) to achieve rapid data acquisition and high spectral resolution [3]. In this paper, we proposed real-time THz-IR system based the AOS method, namely AOS-THz-IR.

2. Experimental setup

We modified a transmission setup used in the AOS-THz-TDS into a reflection setup for AOS-THz-IR. The experimental setup is shown in Fig. 1. We used two mode-locked Ti:Sapphire lasers for generation and detection of THz pulse (ML-Ti:S #1 and #2). The mode-locked frequencies of the two lasers (f_1 = 81.8 MHz, f_2 = 81.8 MHz + 10 Hz) and the difference frequency between them ($\Delta f = f_2 - f_1$ =10Hz) are well stabilized by a laser control system. Portions of the two laser lights are fed into a SFG (sum-frequency-generation) cross-correlator using a nonlinear optical crystal, and the resulting SFG signal is used for time origin for the AOS measurement. Residual of the two laser lights are incident on to photoconductive antennas (PCA) for THz generation and detection, respectively. The THz pulse radiating from a THz-PCA emitter is collimated by an off-axis parabolic mirror, and then directed to a target object at a distance of 1 m by a mirror. Reflected and/or scattered THz pulse at surface of the object is collected and focused onto a THz-PCA detector by another off-axis parabolic mirror. After passing through a high-gain current preamplifier, the signal is measured at a scan rate of Δf with a fast digitizer triggered by the time origin signal from the SFG

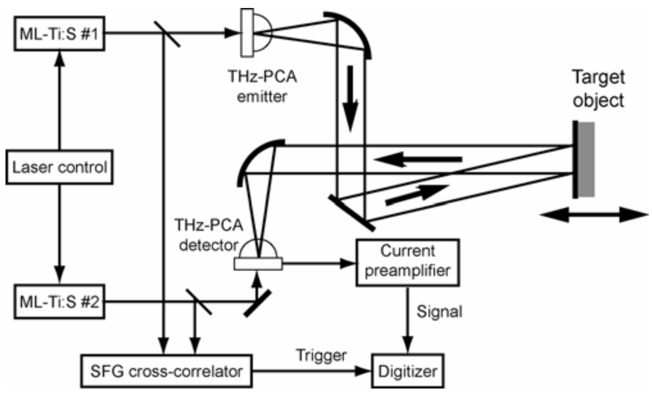

Fig. 1. Experimental setup.

cross-correlator.

3. RESULTS

Fig. 2 compares of temporal waveforms of THz echo signal returned from various materials of object (metal, stone, wood, polyethylene, and rubber) placed at a distance of 1 m. The measurement time of 10 sec is required for signal integration of 100 temporal waveforms. Pulse width was 0.89 ps, which corresponds to distance resolution of 267 μm. Although surface of all the objects is optically rough, good signal-to-noise ratio was achieved due to insensitivity of the THz wave to optically rough surface. This comparison indicates applicability of the AOS-THz-IR for various targets in real world.

To evaluate precision of AOS-THz-IR, we measured displacement of a target object (Al plate) while moving it by a translation stage. Black plots in Fig. 3 show a relationship between target displacement and measured displacement. One can confirm a linear relationship between them. Error between target displacement and measured displacement is shown as red plots in Fig. 3. When we defined mean of the error as measurement precision, the measurement precision of this demonstration was 354μm within a displacement range of 20 cm.

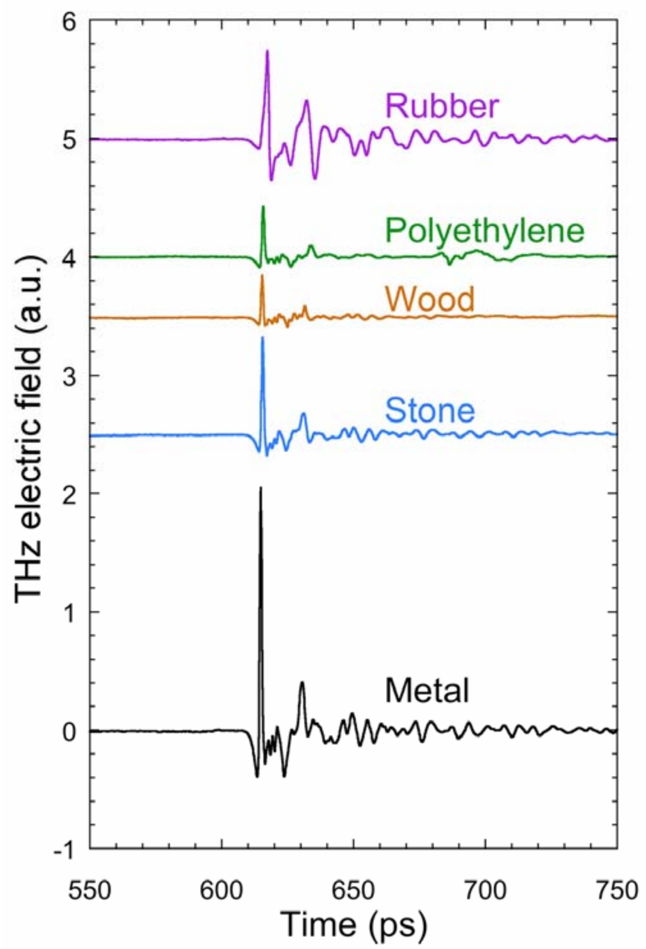

Fig. 2. Temporal waveforms of THz echo signal returned from various materials of object.

4. CONCLUSIONS

We proposed THz impulse radar at a sweep rate of 10 Hz using the AOS method. This method not only achieves the real-time measurement but also enables remote detection of a target at an unknown distance.

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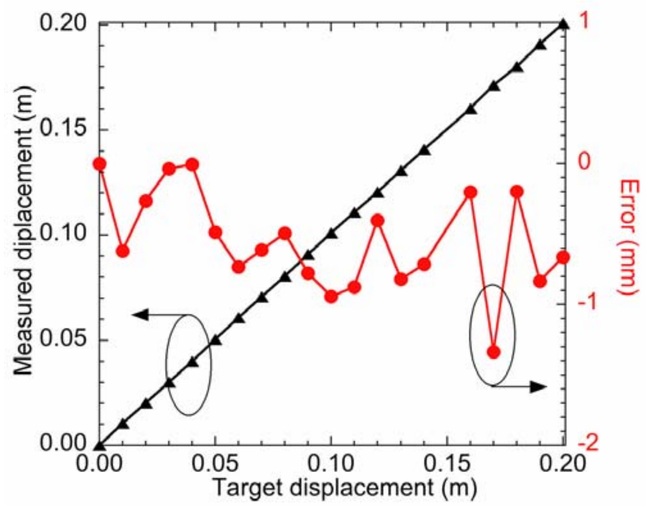

Fig. 3. Relationship between target displacement and measured displacement.