Rapid, Ultrahigh-resolution Terahertz Time-domain Spectrometer Based on Asynchronous Optical Sampling Method

Eisuke Saneyoshi, Takeshi Yasui, and Tsutomu Araki
Graduate School of Engineering, Osaka University

Terahertz time-domain spectroscopy (THz-TDS) is one of important measurement methods in THz science and technology. In conventional THz-TDS, temporal waveform of a pulsed THz electric field is measured by scanning a time interval between a THz pulse and a probe pulse using a mechanical stage. Fourier transform of the resulting temporal waveform gives spectrum of THz amplitude and phase. Since frequency resolution in THz-TDS is defined as reciprocal of the measured temporal window, there is an inherent trade-off between frequency resolution and measurement time in the conventional THz-TDS method using mechanical time delay. In this paper, we proposed asynchronous optical sampling THz-TDS (AOS-THz-TDS) to overcome such trade-off and reconcile ultrahigh frequency resolution and rapid data acquisition.

Figure 1 shows an experimental setup of AOS-THz-TDS, which is composed of AOS femtosecond laser source, SFG (sum-frequency-generation) cross-correlator, and THz-TDS system. In the AOS femtosecond laser source, difference ($\Delta = f_1 - f_2$) of mode-locked frequency between two mode-locked Ti:Sapphire lasers (mode-locked freq. $= f_1, f_2 \approx$ 82.8 MHz) is stabilized at 108±0.1 Hz via control of laser cavity length in one laser. Portions of two lasers lights from the AOS laser source are fed into a SFG cross-correlator using a nonlinear optical crystal (NLC) to generate a time origin signal in AOS-THz-TDS. In the THz-TDS system, the THz pulse radiated from a bowtie-type photoconductive antenna (THz-EM) propagates in free space via two hemispherical silicon lenses (Si-L) and a THz lens, and then is incident into another bowtie-type photoconductive antenna (THz-DT). Using the two laser lights as a pump light and a probe light in THz-TDS, rapid scanning of time delay is achieved without necessity of the mechanical stage. Since the resulting temporal waveform of a pulsed THz electric field is temporally expanded by a scaling factor of f_1/Δ (= 82,800,000 / 108 = 766,667) based on the principal of the AOS method [1], it can be directly observed by a digital oscilloscope.

Figure 2 (a) shows temporal profiles of the THz electric field in the AOS-THz-TDS, in which signal averaging of 1-sweep, 10-sweep, 100-sweep and 1000-sweep is carried out in the digital oscilloscope (required time = 10 ms, 100 ms, 1 s and 10 sec). Upper and lower horizontal scales indicate the time scale on the oscilloscope and the real time scale translated from the above scaling factor, respectively. One can confirm that the temporal waveform of the pulsed THz electric field is directly measured within a temporal window of 500 ps. In contrast to the conventional THz-TDS, the AOS-THz-TDS can acquire a temporal waveform of the THz electric field at a fixed scan rate of Δ (= 108 Hz) regardless of size of overall temporal window, resulting in a substantial decrease of measurement time in long time delay scanning. Figure 2 (b) shows THz amplitude spectrum calculated from the Fourier transform of the temporal waveform (not shown) of THz electric field measured with a temporal window of the pulse period (= 12.1 ns). The frequency resolution is estimated to be 82.8MHz (= mode-locked frequency). Fine structure of the THz spectrum in 0.1-THz region is clearly visualized as a result of ultrahigh frequency resolution in AOS-THz-TDS.

In conclusion, we demonstrated AOS-THz-TDS with frequency resolution of 82.8 MHz at a date acquisition time of 10 sec.

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Reference

[1] Y. Takagi and S. Adachi, Rev. Sci. Instrum. 70, 2218(1999)

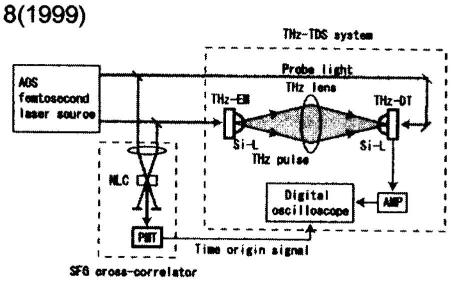
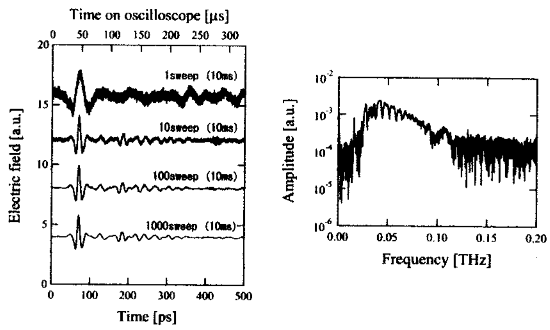


Fig. 1 Experimental setup.



(a) (b)

Fig. 2 Results of AOS-THz-TDS. (a) Temporal waveform of a THz electric field, and (b) THz amplitude spectrum measured with a temporal window of the pulse period.