Sensitive measurement of water content in dry material using low-frequency terahertz time-domain spectroscopy system equipped with micro-structured photoconductive antennas

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Summary

We proposed sensitive measurement of water content in dry material using low-frequency THz time-domain spectroscopy. Simultaneous use of micro-structured bowtie-type photoconductive antennas for generation and detection of THz pulse enables to achieve water content measurement in dry materials.

Introduction

Terahertz time-domain spectroscopy (THz-TDS) has emerged as a new mode for sensing, non-destructive inspection, and material characterization. One of most important applications is a non-contact, remote determination of water content in a dry material because THz pulse possesses unique charactertics, such as free-space propagation, excellent transmittance to nonmetal material, low scattering, low invasion, and most importantly, strong absorption due to rotational transition of polar water molecules [1, 2]. For example, ultimate sensitivity to liquid water was effectively applied to monitor moisture level of a leaf from a common houseplant [3]. However, too strong absorption in a higher frequency in THz region (≈ 230 cm^{-1} at 1THz) [2] often limits samples to thin and/or considerably dry materials.

In this paper, we developed a low-frequency THz-TDS system equipped with micro-ctructured bowtie-type photoconductive antenna (PCA) to reduce restrictions on the sample in sensitive measurement of water content. The developed system is applied for sensitive measurement of water content in coffee powder in a glass bottle.

Experimental setup

Figure 1 shows experimental setup for low-frequency THz-TDS system based on a transmission configuration. A mode-locked Ti:Sapphire laser (pulse duration = 80 fs, average power = 300 mW, center wavelength = 808 nm) is used for generation and detection of THz pulse. The bowtie-type PCAs were fabricated on low-temperature GaAs with bowtie length of 1 mm and a gap of 5 μm. The laser beam is split into two ways with a beam splitter (BS) for a pump beam and a probe beam. After passing through an optical chopper, the pump beam is focused onto a PCA with a lens. The radiated THz beam from the PCA emitter is collimated with a diameter of 25 mm by a hemispherical silicon lens (Si-L) and an off-axis parabolic mirror (OAP-M), and then is incident to a sample. The THz beam passing through a sample is focused onto a PCA detector by another Si-L and another OAP-M. On the other hand, the probe beam via an optical delay line is incident to the PCA detector and induces free photocarriers at a gap between two electrodes in PCA detector. When the THz pulse and the probe pulse are incident to the PCA detector simultaneously, the electric field of the THz pulse accelerates the photocarriers and hence causes transient photocurrent between in the PCA detector. The resulting current signal is converted into a voltage signal by a current preamplifier, and then the voltage signal is measured with a lock-in amplifier referring to the chopper. The temporal waveform of the THz electric field is obtained by sampling measurement using the optical delay line. Finally, Fourier

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transform of the measured temporal waveform gives frequency spectra of amplitude and phase in the THz radiation, directly.

Result

We performed a non-contact, remote measurement of water content in instant coffee powder in a glass bottle. Figure 2(a) shows comparison of the THz transmittance spectra without sample, with an empty glass bottle, and with a glass bottle including instant coffee powder. In general, usual glass strongly absorbs the THz pulse because it contains the water. However, the low-frequency THz pulse can pass through a thick glass bottle even though higher frequency components are considerably absorbed as shown in Fig. 2(a). On the other hand, the coffee powder hardly attenuates the THz pulse because of low scattering characteristic. Hence, it enables us to monitor the water content in the coffee powder in the glass bottle using lower frequency THz region. Figure 2(b) shows comparison of THz transmittance spectra before and 3.5 hours after forced humidifying (> 90 %RH). From absorption of water at 0.07 THz, increase of water content caused by the 3.5hours forced humidifying is estimated to be 7.5 mg/cm^3.

Conclusion

We demonstrated sensitive measurement of water content in dry material using low-frequency THz-TDS method. The proposed method will be a powerful tool for quality control of water content in dry materials.

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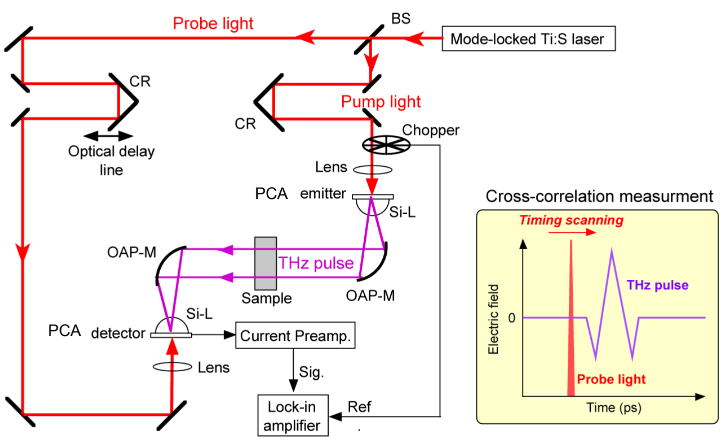

Fig. 1. Experimental setup. BS: beam splitter, CRs: corner reflectors, PCA: photoconductive antenna, Si-L: silicon lens, OAP-M: off-axis parabolic mirror.

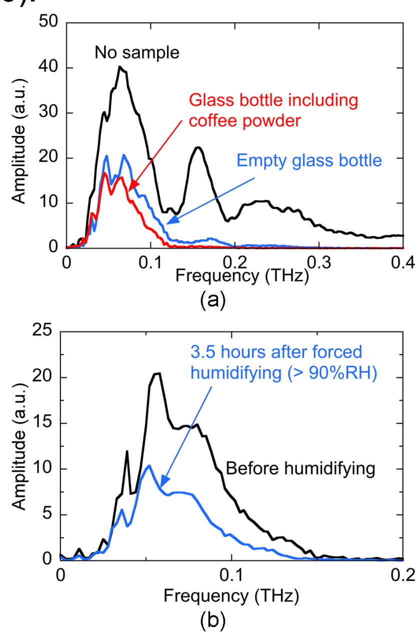

Fig. 2. (a) Comparison of THz transmission spectra without sample, with an empty glass bottle, and with a glass bottle including coffee powder, (b) change of THz transmission spectra by 3.5hours forced humidifying.

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