P-11-1
Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp669-670

Terahertz spectroscopic technology for safety and security

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1. Introduction

In recent years, Terahertz (THz) waves have been expected to potential applications to telecommunication and sensing fields for safety and security. THz waves are in the region of the electromagnetic spectrum between 0.3 terahertz and 3 terahertz, corresponding of the submillimeter wavelength range between 1millimeter (high-frequency edge of microwave band) and 100 micrometer (long-wavelength edge of the far-infrared light). The properties of this THz radiation are high-spatial resolution, unique spectral fingerprints, penetration of materials, so it can be surveillance, such as security screening, non-destructive examination for tissues and DNA, unlike X-rays, and so on. Figure 1 shows the wavelength and frequency of electromagnetic.

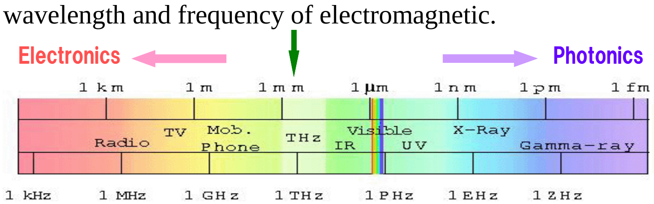

Figure 1 Wavelength and frequency of electromagnetic

Our project is "The research and development of information and communications technology based on the THz wave technology for safety and security", which is the adopted research and development by National Institute of Information and Communications Technology (NICT). And the role of our research in this project is to provide some basic information for gas-detection and life-saving systems under some specific circumstances such as fire. Therefore we first constructed a THz time-domain spectroscopy (THz-TDS) system based on a conventional pump-and-probe setup, then we fabricated heating-gas cell and simulated circumstances system in cases of fire and last, these gas cell and simulated circumstances system were combined with the THz-TDS setup. We performed the measurements of gas-phase spectroscopy in various conditions using this system. Furthermore, we measured a variety of biological materials such as polymer and protein.

In this paper, we will report on results of THz transmission spectra of water vapor, smoke and soot. Soot is a general term that refers to impure carbon particles resulting from the incomplete combustion of a hydrocarbon with THz-TDS setup for gas-phase spectroscopy. And also we will show the results of THz absorption spectra of biological and polymer materials. In addition, we will introduce the results of THz imaging of a mouse and biomolecules (e.g., antigen-antibody binding, DNA hybridization, and biotin-streptavidin binding) using imaging device which was fabricated by NEC Corporation in this project.

2. Experimental procedures

2.1 THz-TDS setup for gas-phase spectroscopy

Figure 2 shows the schematic diagram of THz-TDS setup for gas-phase spectroscopy. The femtosecond laser pulses are split into a pump and a probe beam which hit the THz emitter and receiver, respectively. Emitter and receiver are dipole antennas on low-temperature GaAs. THz radiation from the emitter antenna is focused with off-axis parabolic mirrors onto the sample. The transmitted radiation is again focused onto the receiver. The receiver signal is recorded using lock-in amplifier and fed into a computer. A signal at the receiver is generated by the THz electric field during the lifetime of the carriers which are generated by the laser probe pulse. There is a time-delay line in the probe beam, so that time-resolved reconstructions of the THz pulse can be recorded. A window material of the heating gas cell is used non-doped silicon and the thickness is 3mm. The heating gas-cell, which has a diameter of 20mm and a length of 80mm, is placed at the center of the off-axis parabolic mirrors in place of sample.

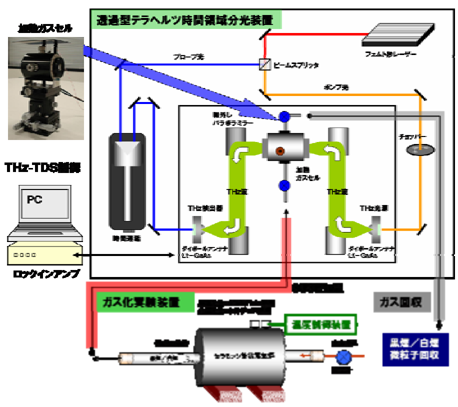

Figure 2 Schematic diagram of THz-TDS setup for gas-phase spectroscopy

2.2 The gas sample

The reference spectrum was measured after repetitions of vacuum and replacement by nitrogen gas in order to remove water vapor. During the measurement, relative humidity (RH) was kept about 6%. And then the measurements of water vapor were performed in conditions of 20% and 80% RH mixed with dry nitrogen. The temperature and RH were continuously monitored during measurement.

Next we reproduced simulated circumstances in cases of fire and measured smoke and soot with THz-TDS setup for gas-phase spectroscopy. These smoke and soot are constituted of volatile elements of hydrocarbon and carbon particles resulting from the smoldering and the combustion of materials (e.g. wood and polymer).

2.3 The biological samples and THz imaging

The biological materials are albumin, hemoglobin, and collagen type I. And the polymer materials are cotton, polyester, polyester/nylon, polyurethane, and cellulose.

For the evaluation of the bio-sensing, we are planning to measure a mouse and biomolecules (e.g., antigen-antibody binding, DNA hybridization, biotin-streptavidin binding) using THz imaging device which was fabricated by NEC Corporation in this project.

3. Results and discussion

Figure 3 shows water vapor transmission spectra mixed with dry nitrogen obtained using THz spectrometer. Shown in Figure 3, as the solid line (black), is 20% RH of THz transmission spectrum and the red line is 80% RH of it. Compared to that calculated using the HITRAN database, the obtained results showed in good agreement with the calculated one. And with increasing RH concentration, the transmission peak was increased.

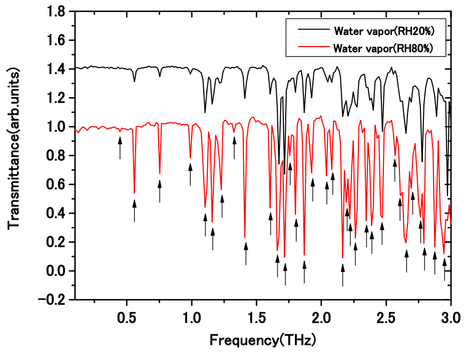

Figure 3 THz transmission spectra of water vapor

In Figure 4, we show smoke transmission spectra mixed with dry nitrogen obtained using THz-TDS setup for gas-phase spectroscopy. Smoke is resulting from the smoldering of woods. The result of smoke transmission spectra corresponds to water vapor transmission spectra. Therefore the present result implies that when woods burn slowly without a flame, smoke is nearly constituted of water vapor. The black line is smoke spectrum and the red line is measured as a reference which is non-smoke spectra after smoldering. The transmittance reduction of reference is due to contaminant of the window materials.

Finally, we report on THz absorption spectra of the biological and the polymer materials. Figure 5 shows the

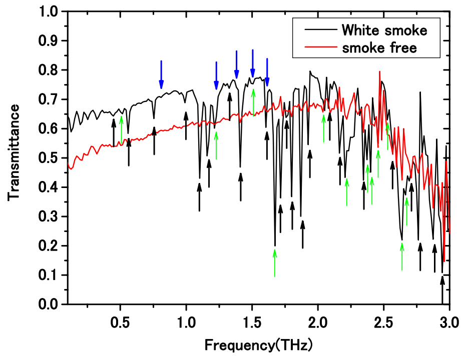

Figure 4 THz transmission spectra of smoke

results of the biological and polymer materials absorption spectra obtained using THz-TDS. The biological samples are shown in figure 5 (a) and the polymer samples are shown in figure 5 (b). All spectral shape reflected a fairly smooth increase with frequency, and the spectrum lacks any identifiable absorption structures that can be assigned to intrinsic vibrational or rotational modes. This is common feature of the THz spectra of most protein molecules and so on. And the results of THz imaging for evaluation of bio-sensing will be shown in presentation.

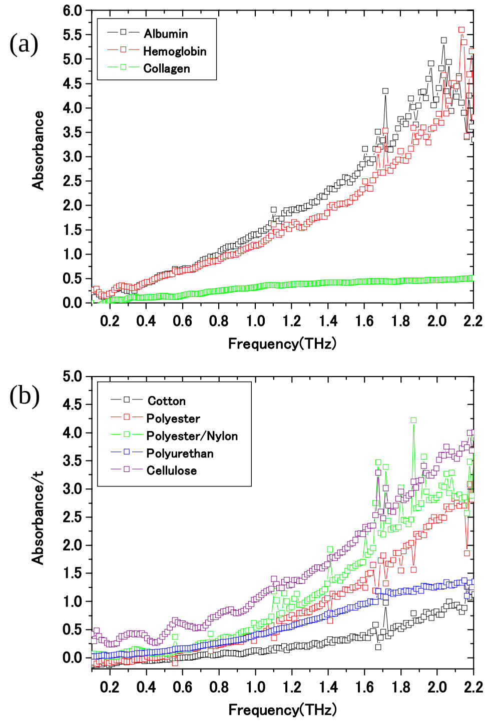

Figure 5 THz absorption spectrum of the biological and polymer materials (a) biological samples (b)polymer samples

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Acknowledgements

This work was supported by Grant-in-Aid for the adopted research and development by National Institute of Information and Communications Technology (NICT).