Study on the transmission characteristic of terahertz pulse through packing materials

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Terrorism has become an international problem in recent years as evidenced by toxins mailed through the post, liquid explosives planted in airplanes, and so on. Clearly, the security screening of packing materials is highly required. We conduct nondestructive and contactless detection of some packing materials used in daily life by terahertz time-domain spectroscopy. The THz time-domain spectra of five typical kinds of packing materials are measured in the frequency range of 0.3–2.5 THz. THz absorption spectra and transmittance are also analyzed.

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In the last two decades, terahertz (THz) technology has advanced rapidly and been applied widely, such as in gas detection, medical diagnosis, security screening, and defect analysis in complex materials[1−5].

Recently, terrorism has become an international problem, such as toxins mailed through the post, detonation of liquid explosives, harboring of illegal drugs, etc. Clearly, the security screening of packing materials is required. THz waves can partly penetrate through popular packing materials, such as paper, plastic, and wood. Unlike X-ray detection, which can only identify the shape of the sample, THz wave is suitable for detection purposes and can acquire the characteristic absorption spectrum that helps identify the type of sample. In this letter, we examined five typical kinds of packing materials used in daily life. The terahertz time-domain spectra were measured in the frequency range of 0.3–2.5 THz. The absorption spectrum and transmittance were also analyzed.

In the experiment, five different containers were used: beverage bottle (polyethylene terephthalate (PET)), paper cup (paper and polyethylene film), medicine bottle (high density polyethylene (HDPE)), chinaware (ceramic), and glass cup (glass). In order to weaken the influence of the shape (radian of the wall) and size of bottles (thickness of the wall), highly similar samples were measured by terahertz time-domain spectroscopy (THz-TDS).

The THz-TDS system used is shown in Fig. 1. A diode-pumped Ti: Sapphire laser provids the ultra-short pulse at a central wavelength of 790 nm with a repetition rate of 76 MHz. The output beam is split into two beams by a beam splitter: one for exciting the emitter antenna and the other for overlapping the THz signal in the detector crystal. Four off-axis parabolic mirrors are used to collect and collimate the THz radiation. A standard electro-optics sampling setup is used for THz signal acquisition. The output signals from the balanced photodiodes are monitored by a lock-in amplifier and a computer.

The samples chosen for the experiment are: beverage bottle (sample 1), paper cup (sample 2), medicine bottle (sample 3), chinaware (sample 4), and glass bottle (sample 5). The time-domain spectra and frequency-domain spectra of the THz pulses traveling through air (reference) and the samples are shown in Figs. 2 and 3, respectively. The measured pulses are delayed due to the refractive index of the samples being different from that of air. The amplitude of the measured pulses decreases due to absorption and scattering of the samples. In Fig. 2, the THz pulses clearly have better penetration in the samples made by plastic (e.g., PET and HDPE) and paper with PE film, whereas the THz pulses have feeble penetration in the ceramic sample and glass sample. The ratio of signal intensity is about 30:1 for the plastic sample and glass sample. In Fig. 3, the spectrum of the HDPE sample is clearly the closest one to the reference; the samples made by PET and paper with PE film have narrower spectra compared with the sample made by HDPE, whereas the samples made by ceramic and glass almost lose their spectra in the THz frequency region.

Figure 4 shows the THz transmittance spectra of the five samples. The periodic modulations of the spectra are due to the multiple reflections of the THz waves inside the walls of the bottle. The transmittance of the HDPE bottle in the THz region is larger than that of the PET bottle, although the wall of the former is thicker than that of the latter. The increase

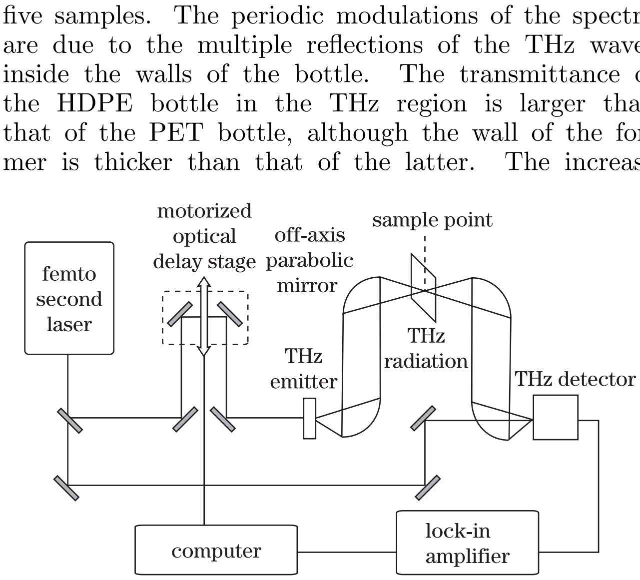

Fig. 1. Schematic of the transmittance-mode THz system.

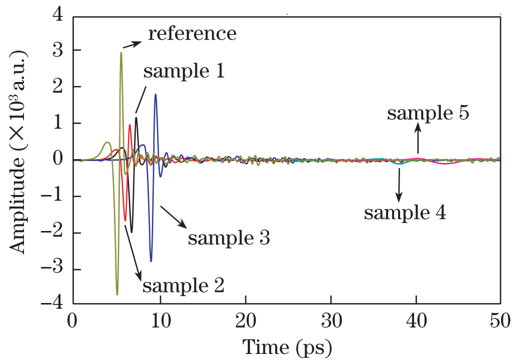

Fig. 2. THz time-domain spectral of the five samples.

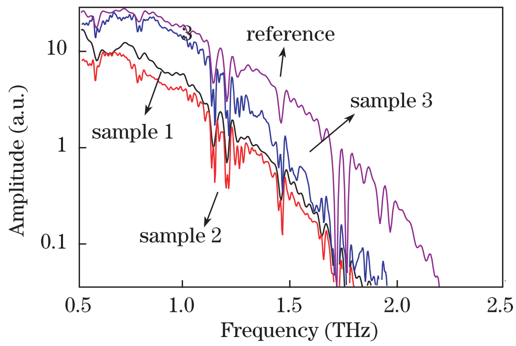

Fig. 3. THz frequency-domain spectral of the samples.

in polar groups in polymers suggests the increase in the absorption intensity in the THz region[6]. Due to high absorption and scattering, the pulses can hardly pass through the ceramic and glass materials in the THz frequency region of 0.3–2.5 THz.

Figure 5 shows the absorption of the samples in the THz frequency region. The absorption coefficient of the glass or ceramic sample used in our experiments increases monotonically with frequency and is much higher than the absorption of PET, HDPE, and paper. Note that the optical properties of PET are not too different from those of commercial glass studied by Naftaly *et al.*[7] A more significant difference between PET and glass bottle is the thicker wall, which is required to ensure the mechanical strength of a glass bottle compared with a PET bottle.

In conclusion, the nondestructive and contactless detection of several common containers, i.e., beverage bottle, paper cup, medicine bottle, chinaware, and glass used in daily life, is examined by THz-TDS. Clearly, plastic and paper materials have better penetration in the THz region, whereas ceramic and glass do not. Although both of them have strong absorption, we can still obtain a signal after passing through these samples. In the future, THz-TDS could become

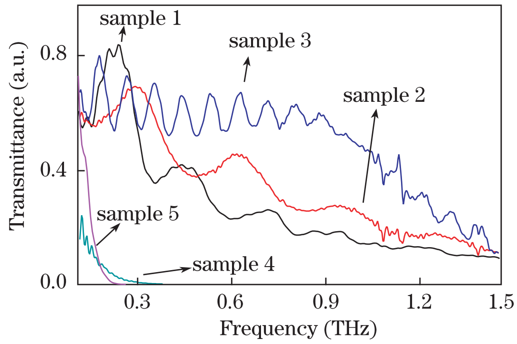

Fig. 4. THz transmittance of the five samples.

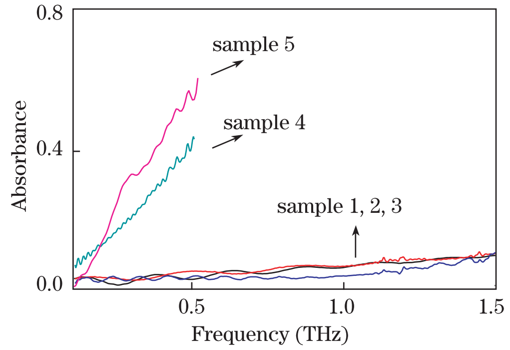

Fig. 5. Absorption of five samples in the THz region.

the fastest and most effective detective technology to prevent terrorist activities that employ the use of containers.

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