Terahertz spectroscopic investigation of magnetic materials

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Abstract. The absorption spectra of three kinds of magnetic materials in the frequency range of 0~2.0THz has been measured with terahertz time-domain spectroscopy at room temperature in nitrogen atmosphere. Simultaneously, the terahertz refraction, transmission and absorption spectrum of the three kinds of magnetic material are obtained through the experiment. Comparing the spectroscopic characteristics of the samples of the three kinds of magnetic materials, the difference can be obviously observed. The results provided in this paper will help us to study the terahertz application to magnetic materials quality evaluation and the development of rare earth resources.

1. Introduction
Terahertz wave is usually refers to the frequency of 0.1~10THz of the electromagnetic wave, of which the photon energy is about 1~10 meV, coinciding with the energy between the molecular rotation vibration and energy transition. THz radiation can penetrate through dielectric and non-polar substances such as ceramic, fat, carbon board, plastic, cloth, etc. Globus and Shen have made terahertz spectrum identification on various categories of biological molecules such as nucleotide, carbohydrate and protein [1-2]. There is high correlation between biological molecules and the overall structure of the macromolecules and their terahertz spectrum properties. In recent years, terahertz spectrum technology attracts more and more attentions [3-4].

In this paper, terahertz time domain spectroscopy (THz-TDS) technique is introduced to test the spectrum of three kinds of magnetic materials at room temperature in nitrogen atmosphere. And the terahertz refraction spectrum and absorption spectrum of the three samples are obtained in the 0.1~2.0THz-band. Through the spectroscopic characteristics, the difference can be obviously observed and which can be used to distinguish the three kinds of samples magnetic materials. The results show that the THz-TDS detection technique has an important meaning on magnetic materials quality evaluation.

2. Theory analysis
The schematic diagram of the THz-TDS setup used in this experiment is shown in figure 1. A repetition rate of 80MHz, diode-pump mode-locked Ti:sapphire laser (MaiTai, Spectra Physics) provided the femtosecond pulses with duration of 100fs and center wavelength of 810nm. A p-type InAs wafer with <100> orientation was used as the THz emitter and a 2.8 mm-thick <110> ZnTe was employed as the sensor. A standard lock-in technology was used in this system. A femtosecond laser pulse was split into two beams. The pump beam was used to generate THz radiation and the probe
beam acted as a gated detector to monitor the temporal waveform of THz field. A silicon lens and parabolic mirrors were used to collimate and focus the THz beam through free space onto the detector. A balanced photodiode detector detected the probe beam, and the signal was amplified by a lock-in amplifier and sent to the computer for processing. The THz beam path was purged with dry nitrogen to minimize the absorption of water vapor and enhance the signal to noise ratio (SNR). The humidity was kept less than 1% and the temperature was kept at 298K. The dynamic range was about 4000:1, and the spectral resolution was better than 60 GHz in the 0.2–1.8THz region.

The THz-TDS can be used to extract optical parameters such as the absorption coefficient and refractive index of the sample. The transmitted field, \( H = \frac{E_{\text{sam}}(\nu)}{E_{\text{ref}}(\nu)} \) is related to the complex refractive index \( N = n + ik \) by

\[
H = \frac{4N}{(1+N)^2} e^{i(2\pi(N-1)\omega d/c)} = A e^{-i\phi}
\]

where \( \omega \) is the frequency of the THz wave, \( A \) the amplitude of the THz wave, \( \phi \) the phase difference between the sample and reference waveforms, and \( d \) the thickness of the sample. The multiple internal reflection is ignored in this equation under the condition \( K \ll n \), where \( K \) is the extinction coefficient. Hence the Fabry–Perot effect can be neglected. Thus, we can obtain the refractive index \( n \), absorption coefficient \( \alpha \), respectively:

\[
n = \frac{c\phi}{2\pi d\omega} - 1
\]

\[
\alpha = \frac{4\pi k\omega}{c} = \frac{2}{d} \ln \left[ \frac{4n}{A(n+1)^2} \right]
\]

3. Experiment results

The measured THz time-domain spectroscopy of the three magnetic materials is shown in figure 2. The experimental results were redone more than 3 times, the results provided here are repeatable and credible. Compared to the first peak of the reference signal, one sees that the time delays of the magnetic materials are 2.61ps, 2.60ps, and 2.49ps, respectively.

Figure 3 indicates the absorption coefficient of three magnetic materials. It can be noted that the three magnetic materials have some obvious characteristic absorption peaks around 1THz. The absorption coefficient for the first sample is 52.68cm\(^{-1}\) at 0.72THz, 51.75cm\(^{-1}\) at 0.91THz, 50.43cm\(^{-1}\) at 1.07THz and 89.72cm\(^{-1}\) at 1.29THz and for the second sample is 31.99cm\(^{-1}\) at 0.68THz, 47.46cm\(^{-1}\) at 1.02THz, and 68.68cm\(^{-1}\) at 1.31THz. The absorption coefficient for the third sample is a little weak, and is about 26.24cm\(^{-1}\) at 0.69THz, 32.57cm\(^{-1}\) at 1.01THz, and 40.19cm\(^{-1}\) at 1.32THz.

![Figure 1. A schematical THz-TDS system](image-url)
Figure 2. Measured terahertz time-domain spectra of reference and samples

Figure 3. The absorption coefficient of three magnetic materials

The refractive index of three magnetic materials is illustrated by figure 4. In the frequency band from 0.2 to 1.8THz, the refractive index decline with the increased frequency. The refractive index of three magnetic materials is 1.066, 1.060 and 1.054 at 1THz respectively. There are large refractive index differences between the three samples, which can obviously identify the three magnetic materials.
4. Conclusion
The THz spectral transmission of three kinds of magnetic materials in 0.1~2.0THz range has been measured and analyzed. Simultaneously, the terahertz refraction, transmission and absorption spectrum of the three kinds of magnetic material are obtained through the experiment. Differences between refractive index are obvious enough to identify the three magnetic materials. The results provided that the THz-TDS detection technique has an important meaning on magnetic materials quality evaluation and the development of rare earth resources.

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