

Spectroscopy Studies on Stream Sediments in the Terahertz Range

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Received 30 May 2016; accepted 21 August 2016; published 25 August 2016

Abstract

In order to study stream sediments in the terahertz range, we have measured six reference stream sediment samples by terahertz time-domain spectroscopy (THz-TDS). We obtained the absorption coefficients and refractive indexes. By analyzing the spectra, we got different drops in amplitude and delays in time. The absorption and refractive properties of samples changed with its components and types. In addition, we also found there was a nearly linear relationship between the absorption coefficient and the frequency. We calculated the slope value (K) of each sample by linear fitting, and find the K was corresponding to the contents of the samples. The results showed THz-TDS was an effective method to the analysis of stream sediments.

Keywords

Terahertz Time-Domain Spectroscopy, Stream Sediments, Absorption Coefficient, Refractive Index

1. Introduction

Along with the technical progress, many new technologies and methods are applied to the determination of stream sediment [1]. Terahertz time-domain spectroscopy (THz-TDS), which ranges from 0.1 to 10 THz, contains rich physical, chemical, and structural information of the materials. According to many advantages compared with classic spectroscopy, THz-TDS has been widely used in the field of analysis and testing [2]-[12].

In this paper, the application of THz-TDS in stream sediments is reported. Refractive index and absorption coefficient spectra are calculated. By analyzing the spectra, we get different drops in amplitude and delays in time. The absorption and refractive properties of samples are changed with its components and types. In addition, we also find that there is a nearly linear relationship between the absorption coefficient and the frequency. We calculate the slope value of each sample by linear fitting, and find it is corresponding to the contents of the sam-

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ples. The results show THz-TDS is an effective method to the analysis of stream sediments, and it will have a bright future in this field.

2. Experimental

2.1. Sample Preparation

Six kinds of reference stream sediment materials are in powder. They have large THz absorption, while PE (Polyethylene) powder has little absorption effect in THz range. The PE was employed to blend the stream sediment materials. The stream sediment materials were mixed by PE with the mass ratio equaling 1:1, and then were pressed to pellets. The pressure and the time length in the pressing process were 25 MPa and 2 min, respectively. Six kinds of tables with the thickness about 1.20 mm and the diameter of 13 mm were obtained for THz measurement. The information of samples is according to the given data in **Table 1**. All the samples have been using inductively coupled plasma mass spectrometry (icp-ms), inductively coupled plasma atomic emission spectrometry (icp-aes), atomic absorption spectrum (AAS), atomic fluorescence analysis method (AFS), and other methods. The composition and content of components information is already known (in **Table 2**) before the experiment.

2.2. THz-TDS Setup and Measurement Condition

The experimental setup we used is comprised of a commercial mode-locked fem to second Ti: sapphire laser and a transmission THz-TDS system. The principle and instrument parameters refer to literature [13]. The fem to second laser, producing 100 fs pulses at 800 nm with a 1000 Hz repetition rate, pumps the antennas for generating and detecting THz pulses. In order to prevent absorption by atmospheric water vapor in THz range, the setup was covered with high-purity, dry nitrogen at room temperature (294 K). The relative humidity is less than 2% during the measurement.

Table 1. The information of six samples of stream sediments.

Number	Reference materials	Thickness (mm)
1	GBW07123	1.20
2	GBW07309	1.18
3	GBW07405	1.24
4	GBW07304a	1.16
5	GBW07301a	1.18
6	GBW07408	1.26

Table 2. The component and weight ratio of six samples of stream sediments.

Number	Component and weight ratio (%)									
	Al ₂ O ₃	CaO	FeO	K ₂ O	MgO	Na ₂ O	SiO ₂	Fe ₂ O ₃	CO ₂	H ₂ O ⁺
1	13.21 ± 0.08	7.83 ± 0.13	7.24 ± 0.21	1.49 ± 0.08	5.08 ± 0.07	3.17 ± 0.10	49.88 ± 0.22	13.40 ± 0.21	(0.11)	(2.44)
2	10.58 ± 0.15	5.35 ± 0.14	1.53 ± 0.07	1.99 ± 0.08	2.39 ± 0.09	1.44 ± 0.06	64.89 ± 0.16	4.86 ± 0.11	4.20 ± 0.11	2.93 ± 0.27
3	21.58 ± 0.23	(0.095)	(0.22)	1.50 ± 0.06	0.61 ± 0.08	0.12 ± 0.03	52.57 ± 0.25	12.62 ± 0.27	(0.10)	(8.8)
4	10.94 ± 0.06	0.82 ± 0.03	(0.85)	1.51 ± 0.03	0.60 ± 0.02	0.34 ± 0.22	73.85 ± 0.35	4.55 ± 0.10	(0.4)	(4.3)
5	15.4 ± 0.1	4.0 ± 0.1	(2.4)	2.8 ± 0.1	3.30 ± 0.12	3.4 ± 0.1	59.2 ± 0.02	6.50 ± 0.12	(0.07)	(2.7)
6	11.92 ± 0.23	8.27 ± 0.18	1.22 ± 0.07	2.42 ± 0.06	2.38 ± 0.10	1.72 ± 0.06	58.61 ± 0.20	4.48 ± 0.07	5.97 ± 0.02	(3.3)

3. Results and Discussion

We obtained the optical properties of the six kinds of reference stream sediment materials in terahertz range. **Figure 1** shows the THz field signal. The reference pulse was obtained by scanning the empty cell firstly, and the waveforms of all the samples' spectra were varying from each other as shown in **Figure 1(a)**. The reference signal of free space with no sample is in the left. The other lines are the samples' spectra. Different sample causes a unique waveform, including different delay, the amplitude, and peak time, etc. It indicates that THz technique could give the amplitude and phase information of samples simultaneously.

A fast Fourier transform (FFT) was applied to obtain the THz frequency domain spectra (THz-FDS). As showed in **Figure 1(b)**, due to the strong absorption, the effective frequency range was reduced to 0.1 - 1.2 THz. The observations from the THz waveforms show the intensity decreased in a similar trend with an increase in frequency.

Using Equations (1)-(3), the absorption coefficient α and the refractive index n can be calculated: [14]-[16]

$$k(\nu) = \frac{c}{2\pi\nu d} \ln \frac{4n(\nu)}{A(1+n(\nu))^2} \quad (1)$$

$$\alpha(\nu) = \frac{4\pi\nu k(\nu)}{c} \quad (2)$$

$$n(\nu) = 1 + \frac{c\varphi}{2\pi\nu d} \quad (3)$$

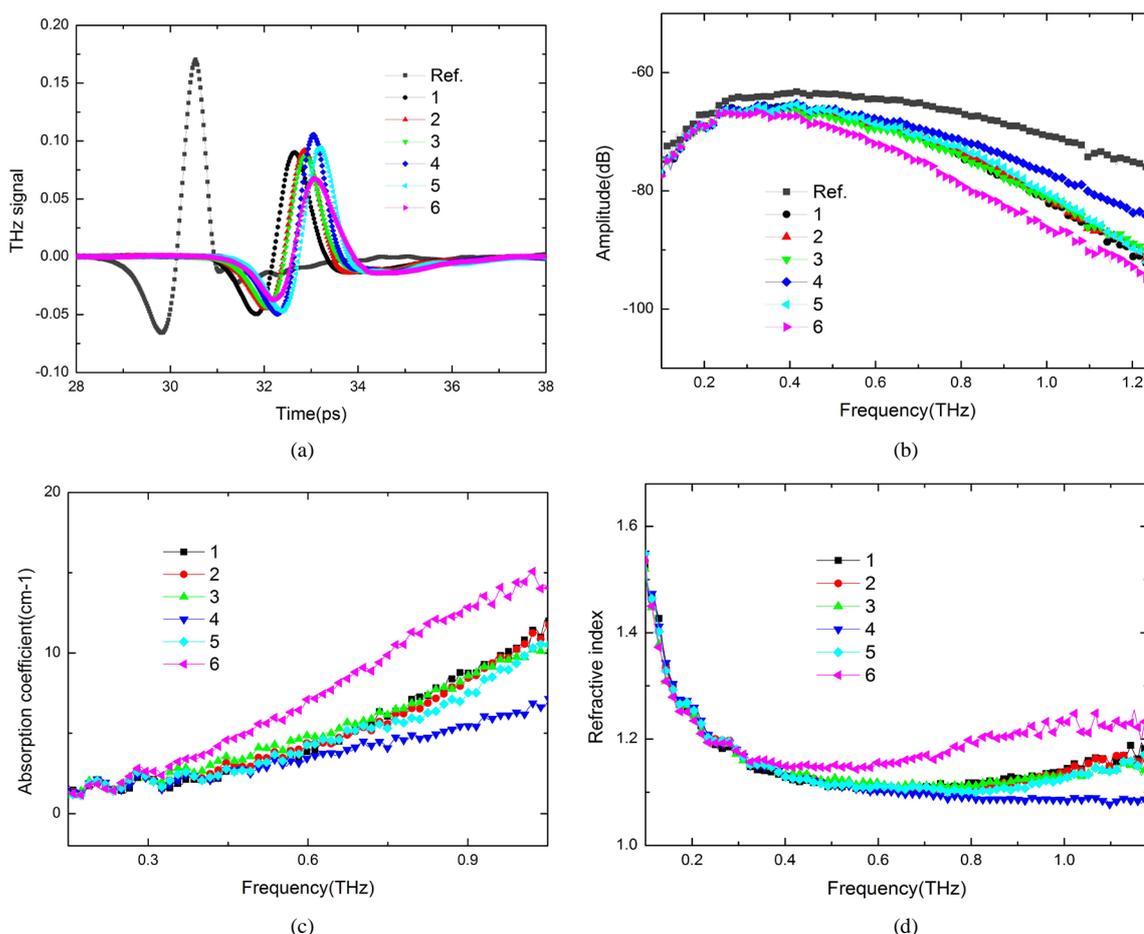


Figure 1. (a) Time dependence of THz signal spectra of reference and six samples; (b) The frequency dependent absorbance spectra in 0.1 - 1.2 THz; (c) Absorption coefficient spectra of six samples; (d) Refractive index spectra of six samples.

where d denotes sample thickness, φ represents the difference in phase shift between sample and reference, c is the speed of light, A is the frequency-dependent amplitude. The absorption coefficient spectra and the frequency-dependent refractive indices of six samples are in **Figure 1(c)** and **Figure 1(d)**, respectively. Results show that the thicker the sample is, the larger the refractive index n is. The absorption coefficient decreases with the increase of refractive index.

Figure 1(c) shows there is an approximately linear relationship between the absorption coefficient and the frequency. According to the experimental data, we calculate the slope value of each sample by linear fitting, and find it is corresponding to the contents of the samples. **Figure 2(a)** shows the slope of absorption coefficient curve. **Figure 2(b)** is the components content curve of samples according to **Table 2**. The ten main compositions were analyzed, including Al_2O_3 , CaO , FeO , K_2O , MgO , Na_2O , SiO_2 , Fe_2O_3 , CO_2 and H_2O^+ . The slope curve has a sudden change in 4#sample, while the content of SiO_2 in all the samples is the highest.

4. Conclusion

In summary, THz-TDS was used to analyze six kinds of stream sediments. The time-domain spectrum, absorption spectrum and refractive index were obtained. Through the further analysis of the spectrum, we found the spectral information was corresponding to the contents of the samples. The results show THz-TDS is a potential method to the analysis of stream sediments, and it will have a bright future in this field.

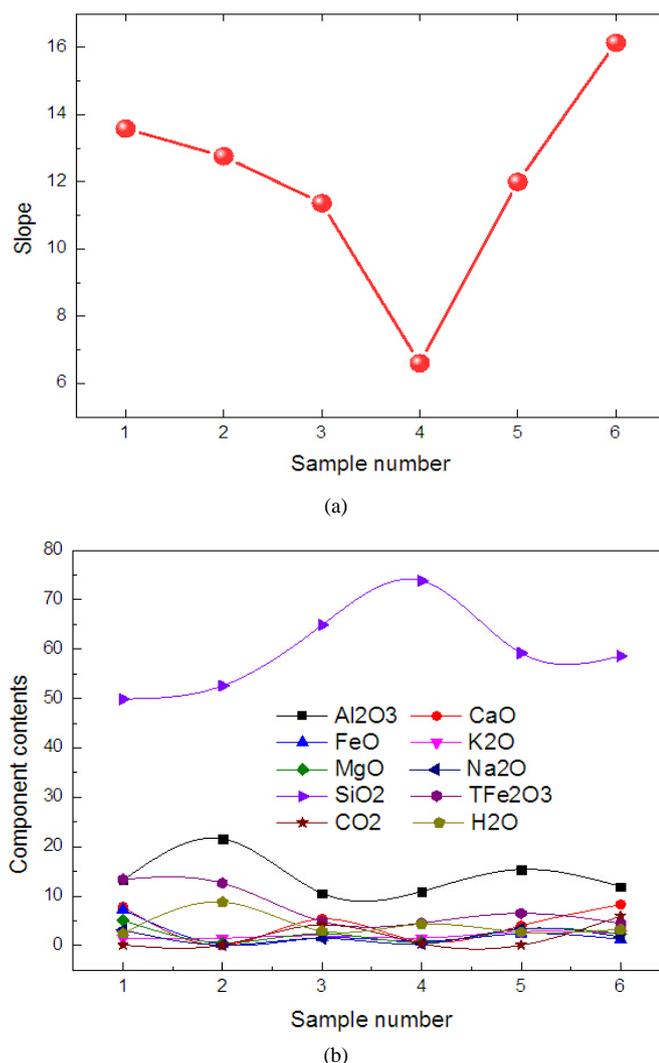


Figure 2. (a) The slope of absorption coefficient curve; (b) The components content of samples.

Acknowledgements

This research is supported by the Yangtze Youth Fund of Yangtze University (No. 2015cqn74).

The authors want to thank Prof. Kun Zhao, Honglei Zhan, Chen Jiang and Xinyang Miao at Beijing Key Laboratory of Optical Detection Technology for Oil and Gas (China University of Petroleum) for their help in experiment, and Prof. Yangen Wang, Shaolong Wang at School of Physics and Optoelectronic Engineering (Yangtze University) for their help in samples.

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