Journal of Physics: Conference Series

The versatile terahertz reflection and transmission spectrometer with the location of objects of researches in the horizontal plane

To cite this article: N S Balbekin *et al* 2015 *J. Phys.: Conf. Ser.* **584** 012010

The versatile terahertz reflection and transmission spectrometer with the location of objects of researches in the horizontal plane

N S Balbekin, Ya V Grachev, S V Smirnov and V G Bespalov
ITMO University, St. Petersburg 197101, Russia
E-mail: Godnikolay@yandex.ru

Abstract. The experimental setup of versatile pulse terahertz reflection and transmission spectrometer and operation concept were described. Using this setup the temporary forms of THz signal reflected from and transmitted through the samples like amino acids, dental tissue and normal were obtained. The possibility of structural determination of powdered media was demonstrated using this method.

1. Introduction

Terahertz (THz) optics and spectroscopy, and also technologies using the most long-wave optical frequency range are gaining interest because of the common use for scientific purposes, as well as for applications in the civil and military applications. The emergence of this trend is primarily due to the appearance of sources and receivers of coherent THz radiation in the 80 years of XX century [1, 2]. During the following years, due to the development of femtosecond lasers and microelectronics, there has been considerable progress in THz region studies. New methods for the generation, distribution control and detecting of THz radiation appeared, first monographs were written [3, 4].

At present, methods of generation and detection of THz radiation using pulsed lasers in the near IR range spectrum with femtosecond duration are the most developed [5]. Such detection methods allow registering directly temporal form of the electric field of THz pulse. Complex spectrum of radiation, spectra of the transmission or reflection substances and permittivities in this frequency range is obtained using the Fourier transform [6].

Huge number of spectral singularities of substances is observed in THz frequency range, energy of THz quanta corresponds to the rotational transitions of the molecules, the vibrational modes of organic compounds, the lattice vibrations in solids, intraband transitions in semiconductors and energy gaps in superconductors. Pulsed THz time-domain spectroscopy allows to investigate all of these spectral features. Broadband THz radiation reflected from the object / transmitted through the object carries a lot of information about its internal structure and spectral properties. However, standard configurations of THz spectrometers require that the sample is placed in a vertical plane. It makes difficulties when dealing with powdered samples or liquid media. The proposed scheme of the spectrometer allows solving such problems like these. This technique of researches can be considered as an ideal (non-contact, non-ionizing, safe) non-destructive testing technology that provides high spatial resolution both in coatings, and in depth of the investigated sample.

2. The experimental setup

For the present paper we erected the experimental setup generating broadband pulsed THz radiation by means of photoconductive antenna (undoped InAs) [7, 8] placed in a constant magnetic field of 2.4 T [9] , which was exposed to radiation of femtosecond laser pulses FL-1 (the active medium - Yb: KYW; λ = 1040nm, t_p = 46 fs, ν = 70 MHz, P = 1,2W). The parameters of THz radiation were: spectral range from 0.05 to 1.6 THz, average power 30 mW, pulse power 755 mW, pulse duration 2.7 ps. The main power was distributed between 0.12 and 1.10 THz. The scheme of general-purpose THz spectrometer is shown on figure 1.

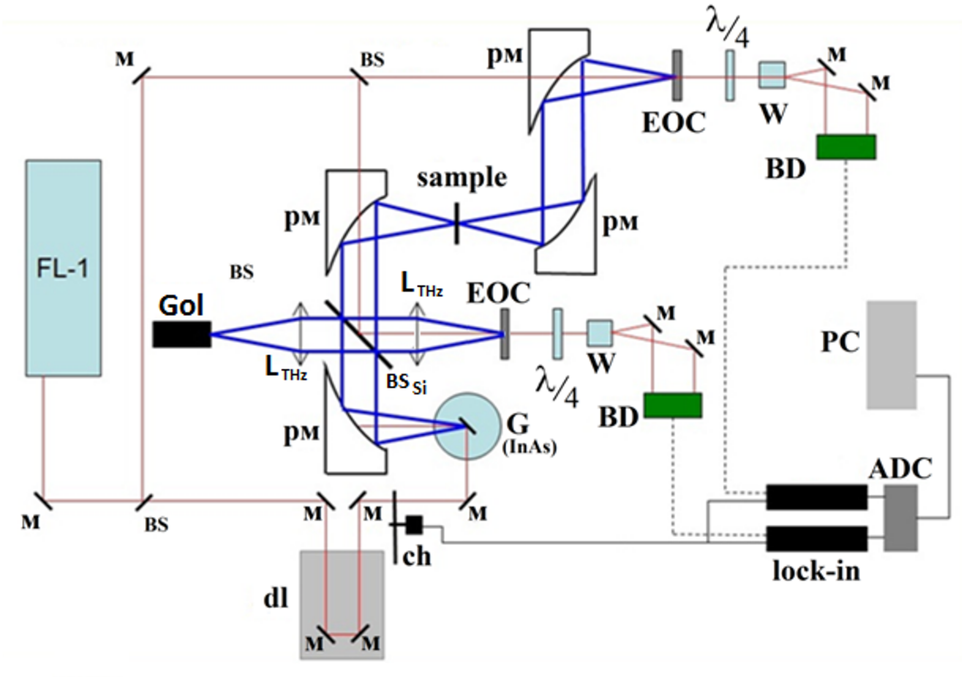


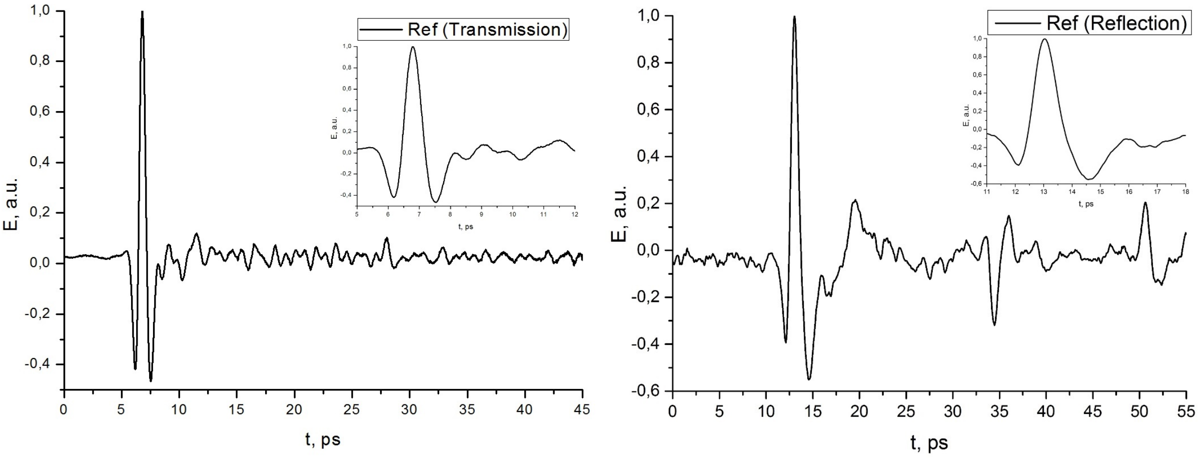
Figure 1. The scheme of general-purpose THz spectrometer. FL-1 - femtosecond laser; M - mirrors; BS - beam spleater; dl - optic delay line; G - THz radiation generator in InAs; pm - parabolic mirrors; ch - modulator; L_{THz} - lenses for THz radiation; EOC - electro-optical crystal CdTe; W - Wollaston prism; BD - balanced photodetector; lock-in - lock-in amplifier; ADC - analog-digital converter; PC - personal computer, Gol - Goley cell receiver.

Generated radiation passed through the teflon filter to cut off the wavelength range less than 50 microns, and then through the sample having a certain amplitude and phase transmittance. Passed THz radiation was focused on the EOC using two parabolic mirrors PM. Reflected from the object THz radiation is also collimated by an off-axis parabolic mirror PM, and after reflection from the beam splitter BS it was focused by THz lens LTHz with a focal length of 5 cm to electro-optical detector - CdTe crystal, that is cut in the direction of |100|. The sample was fixed perpendicularly to the optical axis in the focal plane using two axis motorized translation stage. EO detection was carried out using [10] quarter-wave plate, Wollaston prism, balanced photodetector and lock-in amplifier. Filtered and amplified signal was transmitted to a computer via a digital voltmeter. The magnitude of the error in determining the frequency during measurements was about 10 GHz [11]. Operation of the setup was realized by means of software environment NI LabVIEW.

When detecting terahertz radiation, we obtain the time dependence of the electric field E(t) of THz pulse at each point of the plane, so we can calculate the reference complex spectrum of the radiation incident on the sample $E_{ref}(\omega)$, by calculating the Fourier transform of the corresponding time sequence. By placing the required object in the path of THz radiation, it is possible to measure changed temporal form of THz pulse and complex spectrum of radiation transmitted through (reflected from) it $E_{obj}(\omega)$. The refractive index, the absorption coefficient and the dispersion of the investigated medium can be calculated using two obtained complex spectra [3, 6].

3. Experimental results

Using a laboratory setup (figure 1) reference THz pulses were obtained at the first stage of the researches. Air transmission for transmission mode (figure 2(a)) and the reflection from the golden mirror - for reflection mode (figure 2(b)) are presented. The generated THz pulse has single-period structure at the leading edge with a time width of the positive pulse peak at the half-amplitude about 1 ps. Oscillations with significantly smaller amplitude follow after the main single-period structure. They represent the dispersion properties of the medium. This is mainly due to the presence of water vapors in the air and their absorption lines in the THz frequency range.



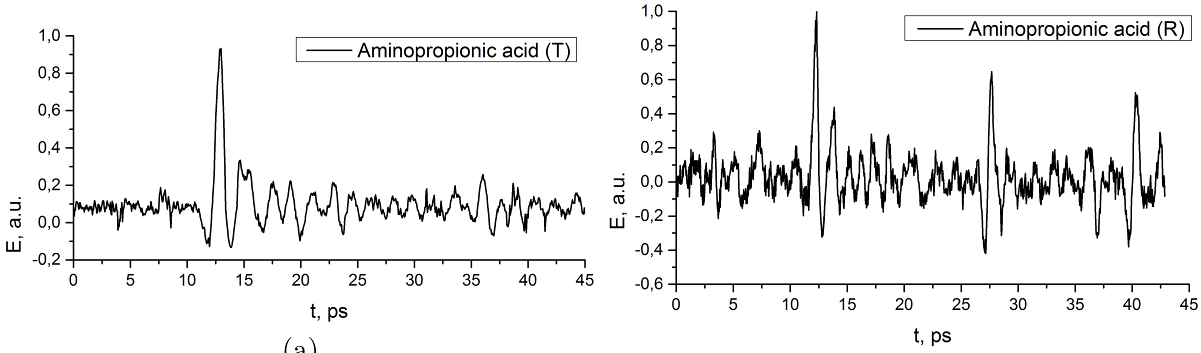
(a) (b)

Figure 2. Dependence of THz pulse electric field intensity passed through air(a), reflected from gold mirror(b).

Single-period structure is observed in 34-36 ps (figure 2(b)), it corresponds exactly to the shape of the first one, but in antiphase and with a peak pulse amplitude about 0.3 from the first. This structure, which is delayed by 23 ps, is caused by the reflection of THz pulse from the second surface of the THz beamsplitter based on plate made of high-resistance silicon with a thickness of 1 mm (figure 1, BS_{Si}). The following temporary structures, in-phase with the first single-period structure, 27-29 ps (figure 2(a)) and 49-52 ps (figure 2(b)), correspond to the double reflection in CdTe crystal with a thickness of 3 mm. It is used as a detector of THz field (figure 1, EOC).

At the second stage transmission and reflection of THz radiation from the experimental objects for problems of biomedicine were investigated. Powdered amino acid Alanine, a human tooth and normal fibroblasts were used as objects. Dependence of THz pulse electric field intensity passed through and reflected from the samples is shown in figure 3 and figure 4.

Journal of Physics: Conference Series **584** (2015) 012010 doi:10.1088/1742-6596/584/1/012010



(a) (b)

Figure 3. Dependence of THz pulse electric field intensity passed through amino acid (a), reflected from amino acid (b).

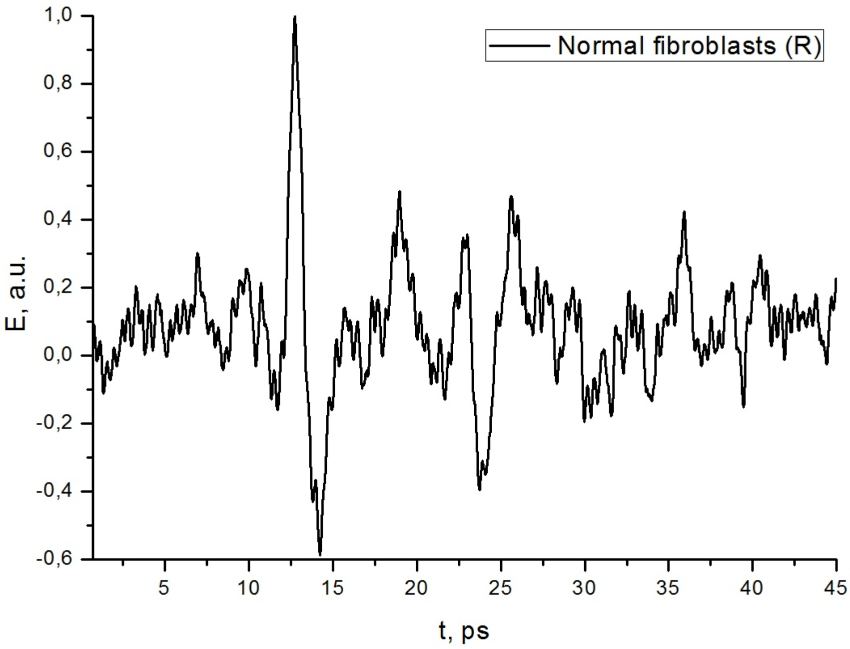


Figure 4. Dependence of THz pulse electric field intensity reflected from normal fibroblasts.

Experiments showed the opportunity to work with the powdered and liquid medias for carrying out their structural analysis without any extra preparations, tools and iterations. Using a laboratory setup experiments with the reflection of THz radiation on the human tooth were carried out.

In recent years, using of THz radiation for non-invasive determination of the state of teeth is rather perspective. Figure 5 shows tomographic image of human tooth obtained by raster scanning. It is clearly seen from the figure that the reflection from the front layer of enamel which has two interfaces - external layer and an inside layer. On the basis of graph, it is possible to determine the optical thickness of the enamel by measuring the time interval between pulse peaks. The reflection from dentin is observed on the back front of the reflected pulse, after reflection from the structure of tooth enamel.

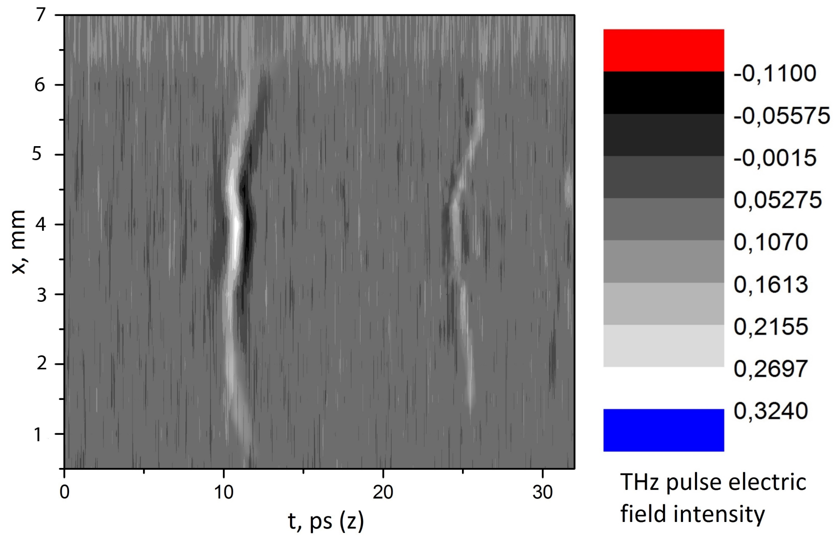


Figure 5. Tomographic image of human tooth obtained by raster scanning.

4. Conclusion

Laboratory setup is designed and developed for the measurements of transmission and reflection of THz radiation from a variety of media for biomedical problems. Dependences of THz pulse electric field intensity passed through / reflected from amino acid Alanine, dental tissue and normal fibroblasts were obtained using a laboratory setup. The possibility of studying the structure of powdered and liquid medias was demonstrated using this method.

Acknowledgments

This work was partially financially supported by Government of Russian Federation (Grant 074-U01). Nikolay Balbekin acknowledges financial support from Russian Ministry of Education and Science project within the state mission for institutions of higher education (Agreement No 2014/190).

References

[1] Auston D 1975 *Appl.Phys.Lett.* **26** 101-03
[2] Mourou G, Stancampiano C, Antonetti A and Orszag A 1981 *Appl. Phys. Lett.*. **39** 295-365
[3] Zhang X and Xu J 2009 (NY: Springer) 34-246
[4] Lee Yun-Shik 2007 (NY: Springer Science+Business Media) **LLC** 340
[5] Bespalov V, Gorodetsky A, Denysiuk I, Kozlov S, Krylov V, Lukomskii G, Petrov N and Putilin S 2008 *J. of Optical Technology* **75** 34-41
[6] Grischkowsky D, Keiding S, van-Exter M and Fattinger C 1990 *J. Opt. Society Am.* **7** 2006-15
[7] Gurtler A, Winnewisser C, Helm H and Jepsen P 2000 *J. Opt. Soc. Am.* **17** 74-83
[8] Izumida S, Ono S, Liu Z, Ohatake H and Sarukura N 1999 *Appl. Phys. Lett.* **72** 451-53
[9] Mittleman D, Cunningham J, Nuss M and Geva M 1997 *Appl. Phys. Lett.* **71** 16-18
[10] Lee Yun-Shik 2009 (NY: Springer) **XII** 340
[11] Chan W, Deibel J and Mittleman D 2007 *Prog. Phys.* **70** 1325-79