Terahertz time-domain ellipsometry method for cancer diagnostics

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***Abstract*—The methods of terahertz time-domain ellipsometry and polarimetry were developed to obtain the complex permittivity tensors gyrotropic and anisotropic non-gyrotropic materials. The components of the complex permittivity tensor of a composite - a bismuth-antimony film deposited on a mica substrate were experimentally obtained.**

***Index Terms*—terahertz frequency range, ellipsometry, polarimetry, permittivity tensor**

I. INTRODUCTION

TERAHERTZ radiation has some advantages as extreme water absorption THz radiation. It allows using water content as an effective contrast mechanism for biological applications. In addition, many molecules exhibit strong absorption in the THz frequency range. Due to low photon energy THz radiation is harmless for biological objects.

Terahertz time-domain spectroscopy is unique among spectroscopic techniques in that it employs coherent detection to measure directly the amplitude and phase of the electromagnetic wave. Cancer often causes an increased blood supply to affected tissues and a local increase in tissue water content was observed. This fact is a natural contrast mechanism for terahertz spectroscopy of cancer [1].

Furthermore, the structural changes that occur in affected tissues cause a difference between the normal and cancer tissues. The THz techniques provide information about biological tissues in the broadband frequency range and make it possible to distinguish tissue regions with different optical characteristics (normal and tumor tissues).

Ellipsometry and polarimetry allow characterizing the optical properties of a material in the broadband frequency range using the measurement of the two orthogonal polarization components of the electromagnetic waves after the interaction with the material

Terahertz time-domain ellipsometry and polarimetry methods provide phase-sensitive information about the interaction of THz radiation with the material and it enables to the determination of complex dielectric functions of materials. The diagonal and off-diagonal components of the complex permittivity tensor gyrotropic and anisotropic non-gyrotropic materials can be obtained using these methods. Ellipsometry and polarimetry have found its application in such areas: magneto-optical measurements for non-contact Hall mobility measurements, detection of chiral molecules, and sensing for biological applications. Currently, the terahertz time-domain ellipsometry and polarimetry methods haven't been used in medical applications yet [2].

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II. TERAHERTZ ELLIPSOMETRY AND POLARIMETRY

The goal was to develop a method for the determination of the polarization properties for the diagnosis of cancer using the THz time-domain ellipsometry. But due to the situation with the pandemic in the world (inability to obtain biological tissue), the goal of the work has been adjusted. Therefore, the goal of this study is to develop methods for terahertz time-domain ellipsometry and polarimetry to obtain the permittivity tensor of anisotropic materials. Biotissues are anisotropic media.

A. *THz time-domain ellipsometry*

The improved algorithm to obtain the permittivity tensor of gyrotropic (examples of gyrotropic media are sugar molecules, amino acids, DNA) materials based on MOKE was presented. In this case, there is no need to set the condition on the relation of off-diagonal to diagonal components permittivity tensor. For this purpose, it is necessary to measure the reflection coefficients at the normal and oblique incidence without magnetic field and the reflection coefficients of *s*- and *p*-components of the electromagnetic wave at some non-zero angle of incidence and at the two different polarizer rotation angles with and without of external magnetic field. From this data, the diagonal and off-diagonal components of the permittivity tensor of gyrotropic materials, the ellipticity angle, and the azimuth rotation angle can be obtained [3].

B. *THz time-domain polarimetry*

A method terahertz time-domain polarimetry was developed for obtaining the permittivity tensor of gyrotropic and anisotropic non-gyrotropic materials from the complex amplitudes of the electromagnetic field. The algorithm for obtaining the permittivity tensor of materials: it is necessary to measure the complex amplitude of two reference amplitudes and two objects with two polarizer rotation angles. Next, the values of these amplitudes are counted prior to interaction with polarizers. From these amplitudes, the components of the transmission matrix in the Cartesian coordinate system are calculated, from this data the transmission coefficients for the right and left circular polarization waves are calculated. After

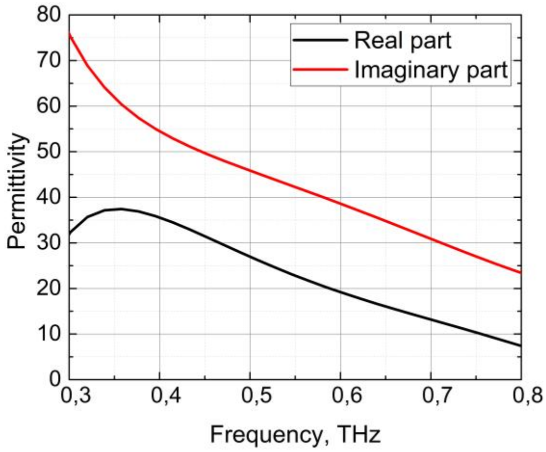

Fig. 1. Dispersion of the real and imaginary parts of the diagonal component of the complex permittivity tensor $\tilde{\varepsilon}_{xx}$ of the composite - bismuth-antimony film (the percentage of antimony is 5%) 70 nm thick, deposited on a 21 μm mica substrate.

that, the components of the permittivity tensor are calculated from the refractive index for the right and left circular polarization waves [4].

C. THz time-domain polarimetry - experiment

The terahertz time-domain polarimeter was based on the THz time-domain spectrometer with the addition of three polarizers. The sample was placed in an experimental cell with a magnetic field. The algorithm for obtaining the permittivity tensor and the schematic diagram of polarimetry are described in [4].

In this work, we experimentally obtained the components of the complex permittivity tensor of a composite - a bismuth-antimony film deposited on a mica substrate. The percentage of antimony is 5%, the film thickness is 70 nm, the mica substrate is 21 μm. The sample was in a constant magnetic field of 0.2 T. The components of the complex permittivity tensor were obtained using the terahertz time-domain polarimetry [5].

Dispersion of the real and imaginary parts of the diagonal component $\tilde{\varepsilon}_{xx}$ of the complex permittivity tensor of the material under study has the form according to the Drude model. The imaginary part of the off-diagonal component $\tilde{\varepsilon}_{xy}$ of the complex permittivity tensor of the material under study decreases with increasing frequency.

III. CONCLUSION AND FUTURE WORK

As a result of this project, the methods of terahertz time-domain ellipsometry and polarimetry were developed to obtain the permittivity tensors gyrotropic and anisotropic non-gyrotropic materials. The setup of the terahertz time-domain polarimetry was modified and an experiment was carried out to obtain the permittivity tensor of a gyrotropic material. A program for data processing was written in Matlab. The components of the complex permittivity tensor of a composite - a bismuth-antimony film deposited on a mica substrate was experimentally obtained. The results were presented at three

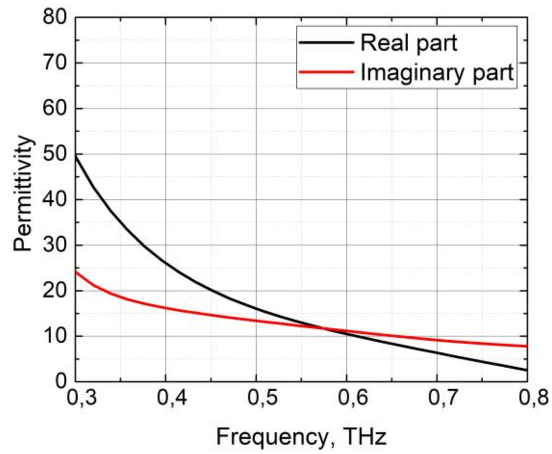

Fig. 2. Dispersion of the real and imaginary parts of the diagonal component of the complex permittivity tensor $\tilde{\varepsilon}_{xy}$ of the composite - bismuth-antimony film (the percentage of antimony is 5%) 70 nm thick, deposited on a 21 μm mica substrate.

conferences (SPIE Photonics Asia 2020, SPIE Photonics Europe 2020, TERA-2020 conference).

Since the main goal was to develop the terahertz time-domain ellipsometry method for cancer diagnostics, the next step will be to assemble the THz time-domain ellipsometer in an inclined incidence configuration. After the epidemic situation in the world improves, the dielectric constant tensors of healthy and cancer stomach tissues will be obtained using this method.

ACKNOWLEDGMENT

I would like to thank the IEEE MTT-s Society for the given opportunities which allow highly-motivated students to do research at a high level. The IEEE MTT-S Undergraduate/Pregraduate Scholarship motivated and supported me to continue research in the terahertz technics. Due to the current pandemic situation, I hadn't been able to participate in the IEEE conference. Currently, I'm a Ph.D. student at ITMO University.

Also, I want to thank Dr. Anna Vozianova and the laboratory head Dr. Mikhail Khodzitsky for the help.

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