Analysis of Spectral Characteristics of the Human Cornea Obtained in the Terahertz Frequency Range

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Abstract— The spectral characteristics of the human cornea in vitro were analyzed in this work. Correct identification of the reflection spectra peaks allows using the terahertz radiation as the new diagnostics method of eye diseases.

1. INTRODUCTION

Today there is quite a number of corneal diseases that lead to impairment or loss of sight. For example, dry eye syndrome leads to drying of a cornea. Another example keratitis characterized by the so-called corneal syndrome (lacrimation, photophobia, blepharospasm), results in an irritation of sensory nerves of a cornea [1]. Last years the investigations of various degenerative processes in a cornea are of considerable interest for ophthalmic diagnostics. It is worth saying that the diagnostics of eye diseases is a very important step to carry out preventive and therapeutic measurements. Currently an eye examination with a slit lamp (biomicroscopy the eye) is used for research of a cornea state (transparency, sphericity, gloss) in low vision clinics [2]. There are most of the vibrational-rotational spectral lines of water and many organic macromolecules, such as proteins, nucleic acids, DNA, as well as the frequencies of intermolecular interactions spectral lines in the terahertz (THz) frequency range [3]. It should be noted that the characteristic feature of THz radiation is strong absorption of radiation by water, and the absorption intensity is much higher than in the millimeter wavelength range. It is well known that there are no blood vessels but many nerve endings in a cornea. Human cornea contains $75 \div 80\%$ of water [4]. Above mentioned diseases affect on a cornea composition, particularly on the quantity of water content. Therefore the visible differences in reflection spectrum of pathological cornea compared with reflection spectrum of healthy ones may be observed. At the present time the different scientific works are devoted to the research of the possible methods of parameters monitoring of a cornea state using THz radiation. In particular, the article [5] presents the application of THz technology to visualize the hydration content in ex vivo porcine corneas. In this article the pulsed reflective THz spectroscopy system was developed specifically for hydration sensing. The point of maximum reflection was found to be coincident with the center of cornea. The reflection decreased from the center to the cornea edges, suggesting that the cornea center was more hydrated than the edges.

In this work, we obtained the spectral characteristics of the human cornea using the THz pulsed spectrometer in the reflection mode.

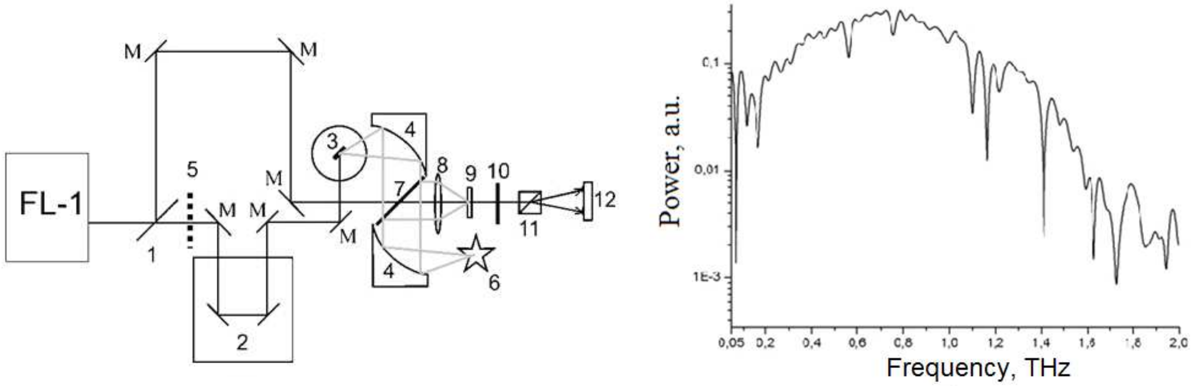
2. EXPERIMENTAL SETUP

The reflection spectra were obtained by the THz time domain (TD) spectrometer [6]. The characteristics of the spectrometer are following: the spectral resolution of 15 GHz, the sensitivity of lock-in amplifier of 1 mV, the lock-in amplifier time constant of 1 s. The THz broadband pulsed radiation had the following parameters: the spectral range of 0.1–2.0 THz, the pulse duration of 2.7 ps, the average power of 30 mW.

THz radiation was generated by femtosecond laser (Yb:KYW) irradiation of undoped indium arsenide crystal. The femtosecond laser parameters are following: the wavelength of 1040 nm, the pulse duration of 120 fs, the pulse repetition rate of 75 MHz, the power of 1 W. The spectra in frequency domain were obtained by the Fourier transform of the measured time domain waveforms of the reference sample and the biological object.

3. OBJECT UNDER THE STUDY

In this paper, two different human corneas in-vitro, respectively, were studied. Corneoscleral surgical specimens were obtained by cutting out the eyes, which were preserved in the Borzenka-Moroz medium at the temperature of +4°C. The canned samples were stored during 5 days from the



(a) (b)

Figure 1: Scheme of (a) the THz pulsed broadband spectrometer in the reflection mode and (b) the reference THz pulse frequency spectrum. FL-1 — infrared laser; M — mirrors; 1 — beam splitter; 2 — optical delay line; 3 — THz radiation generator: crystal of InAs in a magnetic system; 4 — parabolic mirrors; 5 — chopper; 6 — biological object; 7 — THz radiation beam splitter on the basis of high-resistivity silicon wafer; 8 — TPX polymer lens; 9 — electro optical crystal of CdTe; 10 — achromatic quarter-wave plate; 11 — Wollaston prism; 12 — balanced photodiodes.

operation moment until the experiment. The corneoscleral discs were cut out of the eyes in vitro. The sparing technique based on microsurgical approach allows preserving native, architectonic and endothelial cell density of corneas in-vitro during their hypothermic preservation in the cultural environment. The domestic environment for hypothermic preservation of the viable corneas in vitro had high barrier properties and it stabilized cell membranes, safety and stability of endothelial cell density during the cold storage process. The typical microphotography of human cornea is presented in the Figure 2.

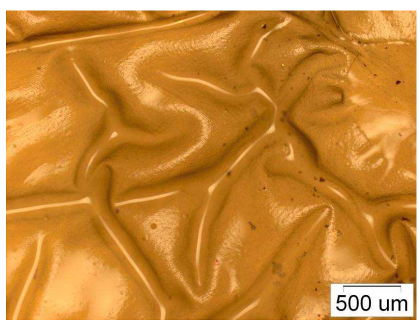


Figure 2: Microphotography of object under study (microscope OLYMPUS STM6).

The location of the sample in the THz spectrometer scheme is shown in the Figure 3. The reflection time domain waveforms were recorded sequentially for the following structures: mirror, object + mirror, dielectric, dielectric + object.

4. RESULTS AND DISCUSSION

In our work, we obtained the spectral characteristics of two different human corneas in vitro. Averaging was made by five measurements of each sample of cornea. The average reflection spectrum of the first sample of the normal human cornea in vitro is shown in the Figure 4. The pronounced peak in the reflection spectrum at the frequency of 0.9 THz and the faint peak at 1 THz are observed.

The average reflection spectrum of the second sample of the normal human cornea in vitro is shown in the Figure 5. The pronounced peak in the reflection spectrum at the frequency of 0.9 THz and the faint peaks near 1.3, 1.8 THz are observed.

The visible differences in the characteristic spectral lines in the reflection spectra of two samples of the normal human corneas can be explained by various composition and water content.

THz absorption spectrum of water is illustrated in the Figure 6 [7]. Comparing the our results with the absorption spectrum of water, it can be assumed that in our spectra the reflection peaks

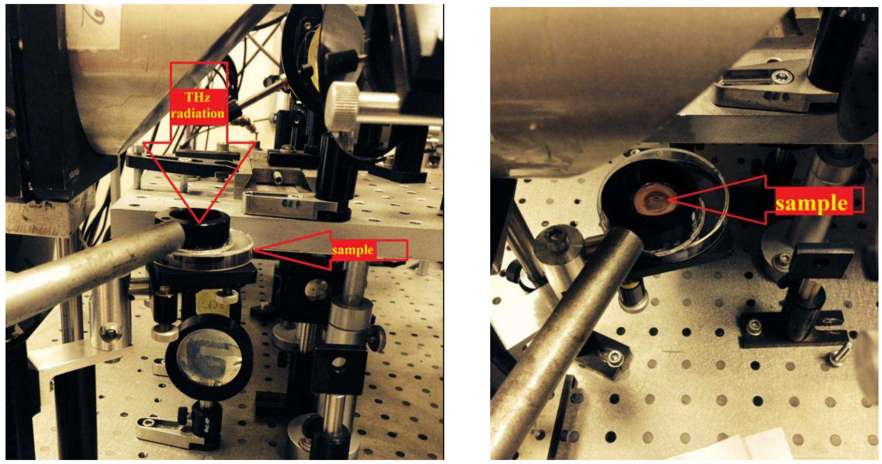


Figure 3: Photo of the irradiation human cornea using the pulsed THz spectrometer in the reflection mode.

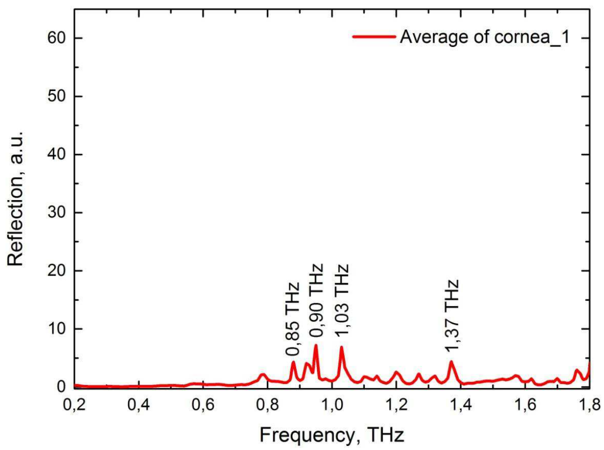


Figure 4: The average reflection spectrum of the first sample of the normal human cornea in vitro.

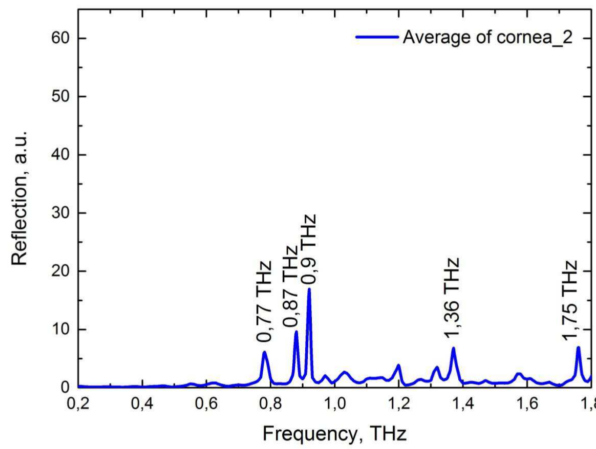


Figure 5: The average reflection spectrum of the second sample of normal human cornea in-vitro.

near 1.00 THz and 1.70 THz are associated with the absorption of radiation by water.

The manifestation and correct identification of the characteristic peaks of the reflection spectra, which are specific to the certain diseases (such as different types of keratitis) in the reflection spectra of the human cornea, it can be seen as new non-invasive diagnostics method of the human cornea state.

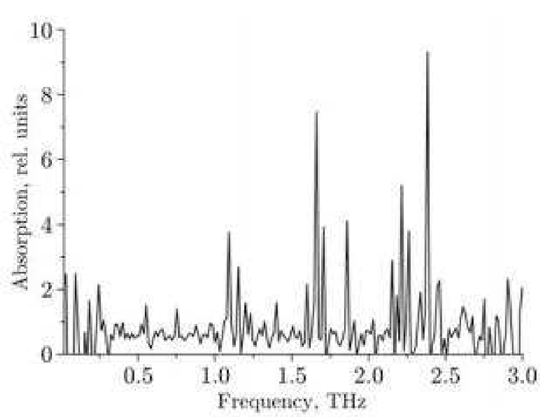


Figure 6: The absorption spectrum of water [7].

Finally, in this paper we proposed the possible option of development of the new non-invasive diagnostics of the cornea state by the identification of the reflection spectrum peaks.

5. CONCLUSIONS

The spectral characteristics of the human cornea were analyzed for the development of the non-invasive methods of cornea diagnostics for the frequency range of 0.1–2.0 THz.

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