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Investigation of Nerve Fiber Network in THz Spectrum Range

T. Hovhannisyan*, A. Makaryan**

Institute of Physics, Yerevan State University, 1 Alex Manoogian, 0025, Yerevan, Armenia

*E-mail: tigran.hovhannisyan@ysu.am
**E-mail: armenm@ysu.am

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Abstract. The behavior of the nerve fiber system of the spinal cord of animals in the THz wavelength range (0.1-3 THz) was experimentally studied using a time domain spectrometer. Terahertz wave transmittance of nerve tissue is investigated, when DC voltage is applied to the sample. It has been shown that when a constant voltage is applied along the nerve fibers (also in the absence of voltage), no noticeable changes occur in the transmitted THz wave, regardless of the orientation of the sample relative to the THz E-field vector. Significant changes in the electrodynamic properties of the sample were observed when the nerve fibers were parallel to the THz E-field vector and the applied voltage was perpendicular to the nerve fibers, particularly, resonant absorption was observed at frequencies of 0.6 THz and 2 THz.

Keywords: THz, resonance, neuroscience, nerve fiber, axon, excitation, neural network

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1. Introduction

The principle of neural signal generation and propagation are the most fundamental but still not fully revealed problems in neuroscience. In the early 20th century, it was discovered that electrical impulses (action potentials) propagate along nerve fibers [1], which formed the basis for the assumption that information spreads in the nervous system of living organisms through these electrical impulses. A number of models have been created by different researchers to explain the mechanism of information transmission in living organisms, and based on the most common models, equivalent electrical circuits have been proposed for the propagation of electrical signals through nerve fibers [2].

According to studies the duration of electrical impulses propagating through nerve fibers are of order of miliseconds, and the maximum speed of their propagation does not exceed ~120 m/s. However, numerous processes happening in central nervous system, such as memory, logical reasoning, information processing, learning and so on, require significantly larger speeds of information exchange.

Researches about recording high frequency processes in central nervous system have been carried out during last decades [3-6]. According to [7], microwave radiation (from 1.5 to 4.5 GHz) has been detected from human brain. Radio frequency (MHz range) signals have also been recorded experimentally [8], where some of the signal components were correlated with each other. Based on the structural features, dimensions and electrodynamic parameters of myelinated nerve fibers, a number of works have suggested that nerve fibers can serve as waveguides for electromagnetic waves in the infrared, THz and microwave ranges, some models for information exchange mechanisms are proposed [9-13].

Nevertheless we have not yet met any published paper on experimental studies of the properties of nerve fibers in the THz range, which could help clarify the mechanisms of generation, storage, exchange and transformation of the information signals, as well as test the truthfulness of the above-mentioned models.

In present research the behaviour of nerve fibers system of animal spinal cord is experimentally studied in THz waves range.

2. Expermients and results

Research samples are selected from the thoracic vertebrae section of the spinal cords of the animals (pigs and sheep) taken from the slaughterhouse. 70 micrometer thick samples are cut from white matter, which consists of vertically arranged axons (see Fig.1a).

Samples are placed inside a cuvette made from polytetrafluoroethylene (PTFE) plates with a thickness of 1.2 mm. Two pairs of tungsten electrodes 18 mm far from each other are attached to the edges of the sample maintaining electrical contact with it (see Fig.1b). 1-2 electrodes pair is parallel and 3-4 pair is perpendicular to nerve fibers.

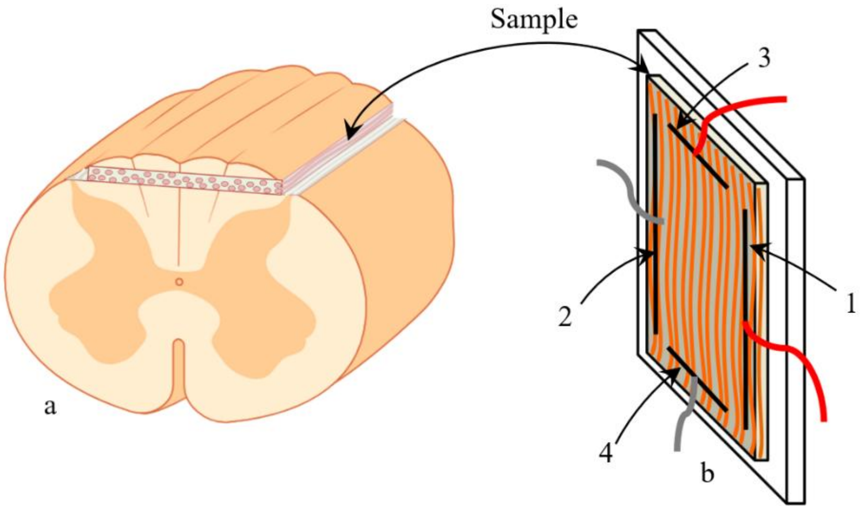

Fig. 1. a) Spinal cord piece, b) sample on 1.2mm thick PTFE substrate, 1, 2, 3, 4 – tungsten electrodes.

Researches are done with Menlo Systems LAC 1550 time domain terahertz spectrometer, which generates and detects linearly polarized THz pulse with duration of around 2 ps and spectral range of roughly 0.2-4 THz.

Terahertz wave transmittance of nerve tissue is investigated, when DC voltage is applied to the sample. PTFE cuvette is placed between the THz transmitter and receiver of the spectrometer, where the THz beam diameter is around 5 mm. During experiments the sample is always in a plane perpendicular to the THz pulse propagation direction. The block diagram of experimental system is presented in Fig.2.

Fig.3a presents time domain waveforms of THz pulse transmitted through empty cuvette (1) and cuvette which contains the sample (2), when no voltage is applied to the sample. Corresponding frequency domain waveforms are shown in Fig.3b. It is notable, that when no DC voltage is applied to the sample, the results do not depend on the angle between nerve fibers and E field vector of THz pulse - same results when nerve fibers are parallel and when they are perpendicular to the THz E field vector. When DC voltage is applied to the 3-4 electrodes, there are no noticeable changes in transmitted THz wave, regardless of the sample's orientation with the respect to THz E field vector.

There are noticable results, when nerve fibers are parallel to the THz wave E field vector and at the same time a DC voltage is applied to 1-2 electrodes – DC field is perpendicular to nerve fibers. Fig.4a and Fig.4b correspondingly represent the time domain and frequency domain waveforms of transmitted THz waves, when 100V DC voltage is applied to 1-2 electrodes for

30 seconds - waveform (2) and for 4 minutes – waveform (3). For comparison, waveform (1) – no voltage, is also provided in graphs.

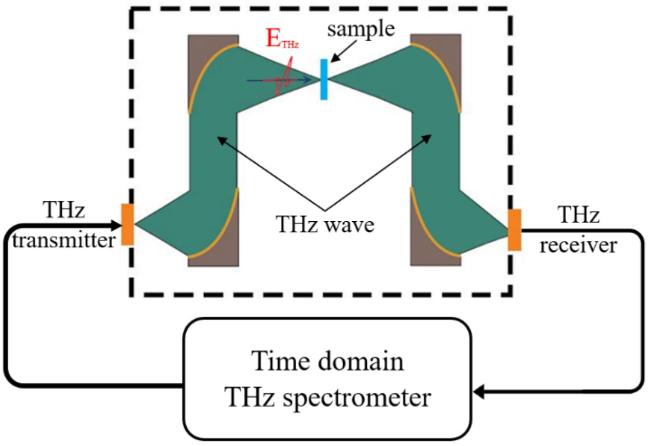

Fig. 2. Block diagram of experimental system consisting of THz spectrometer and test sample.

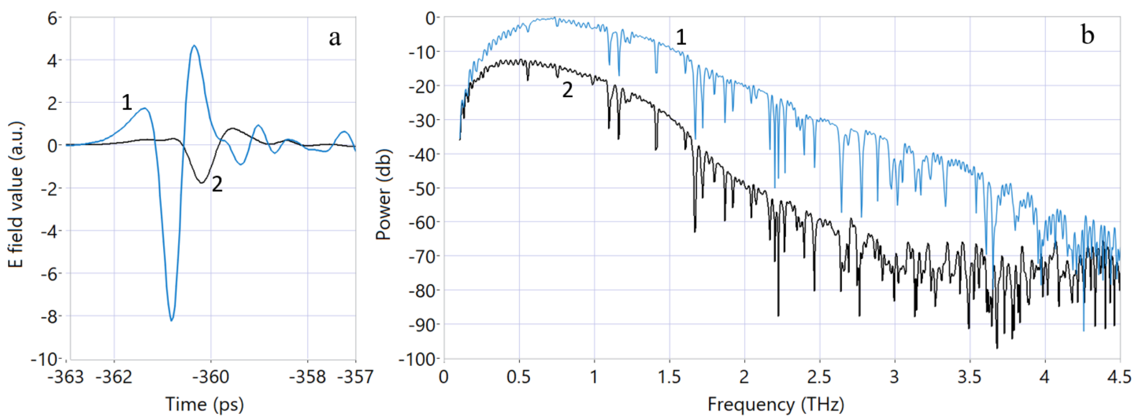

Fig. 3. a) Time domain waveforms, b) spectra of THz pulse transmitted through empty cuvette (1) and cuvette which contains the sample (2).

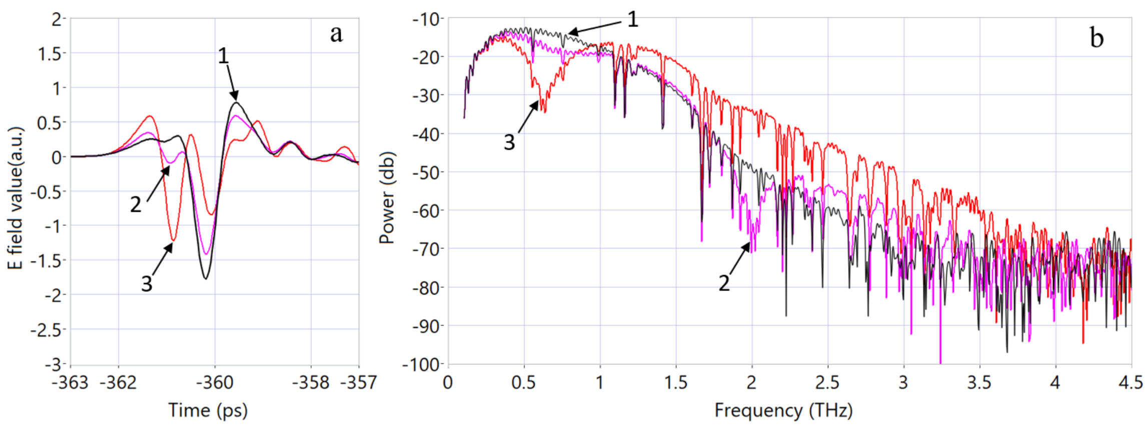

Fig. 4. a) Time domain waveforms, b) spectra of THz pulse transmitted through the sample without external DC voltage (1), with external DC voltage for 30 seconds (2), with external DC voltage for 4 minutes (3).

After one hour of turning off the DC voltage the THz transmittance of the sample returns its initial values.

3. Discussion and conclusions

Performed measurements show, that the electrodynamical properties of the sample taken from animal spinal cord can thoroughly be changed by applying DC voltage perpendicular to nerve fibers. Moreover, when nerve fibers are parallel to THz E field vector and when DC voltage is applied, we can see resonances on different frequencies. Resonances change during time – 2 THz resonance disappears during time, and the resonance on 0.7 THz smoothly moves to 0.5 THz. After some time (in this case 6 minutes) applied DC voltage makes no noticeable changes and after turning off the DC voltage, in around 1 hour the electrodynamical properties of the sample smoothly return to their initial values.

It is remarkable, that the occurrence of resonances is accompanied by an increase in the amplitudes of the spectral components away from the resonances – especially high frequencies.

The analysis of the results allows us to assume that when the voltage is applied to the nerve fibers, the ion channels of Ranvier nodes are opened, making nerve fibers unique conducting wires, which turns the entire sample into a specific diffraction grating. According to our estimations, the nuber of nerve fibers in the sample can be around 10^2 -10^4. Therefore, assuming that the nerve fibers are uniformly distributed across the sample, when 100 V is applied to the sample, the voltage applied to one neuron can reach up to 1 V, which is sufficient to open the ion channels.

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