Measurement of Water Concentration in Biological Samples by Terahertz Time Domain Spectroscopy

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Abstract—**The noninvasive measurement of water concentration in biological tissues using terahertz (THz) waves is a promising tool in bio and medical applications. Due to the strong water attenuation of THz radiation, a device based on THz Time-Domain-Spectroscopy (TDS) would be a noninvasive, sensitive and precise sensor of the water concentration. The project is devoted to the development of the methods for non-invasive measurement of water concentrations in biological tissues by THz time-domain-spectroscopy.**

Index Terms—**biophotonics, terahertz biomedicine, terahertz time-domain spectroscopy**

I. INTRODUCTION

In recent years, different techniques using terahertz (THz) radiation have been applied in a variety of scopes due to unique properties of this type of emission. One of the most significant areas of interest is the diagnosis of different diseases or stresses through examination of biological tissues and objects. Sensitive and precise tool for non-invasive water concentration measurement would help in such areas as cancer diagnosis, products quality control or the plants' stress responses monitoring [1-3]. THz radiation is characterized by the strong water absorption, which means that this frequency range can be used as a sensitive non-invasive hydration probe.

My project is devoted to the development and testing of the methods for non-invasive measurement of water concentrations in biological tissues by THz TDS. Leaves and fruits from different plants were used as the objects of investigation. The measurement of water concentration in botanic tissues and objects is significant due to the steadily worsening ecological situation in the world. Giving that plants and trees are essential for humanity living, there is a need for non-invasive tools to measure and evaluate stress responses of different types of plants, including response for drought.

Currently, water content in plants is monitored mostly by destructive methods (gravimetric, pressure chamber). Besides, there also are some non-destructive methods which are used for water content measurement (chlorophyll fluorescence, visual estimate), however, they are usually not very precise. Moreover, there have already been reported some methods for water concentration measurement using THz TDS or continuous THz setups, based on correlation between water content level and attenuation of transmitted through the sample THz signal [3]. These methods work only in transmission mode, which significantly limits their application. Due to strong water absorption, only thin tissues can be used for the investigation. In order to examine thicker biological objects, the reflection geometry should be applied.

My aim is to develop and test the methods for non-invasive water concentration measurement in biological tissues using THz TDS in transmission and reflection modes.

II. THEORETICAL BACKGROUND

The method of water concentrations determination is based on the extended Landau-Looyenga-Lifshitz model [4]. Equation (1) shows the relation between effective permittivity of a water-containing sample and the dielectric function of its components:

$$\sqrt[3]{\varepsilon_{mix}(f)} = a_w\sqrt[3]{\varepsilon_w(f)} + a_1\sqrt[3]{\varepsilon_1(f)} + a_2\sqrt[3]{\varepsilon_2(f)}, \quad (1) \quad [3]$$

where ε_{mix} – permittivity of the sample, ε_w, ε_1 and ε_2 – permittivity of water, the 1st and 2nd components, a_w, a_1 and a_2 – water, 1st and 2nd component volume fractions.

III. EXPERIMENTS DESCRIPTION

For this investigation, a series of experiments were performed both in transmission and in reflection modes. In a transmission mode, the examined samples were leaves from different plants. For the experiments in reflection mode, some thicker biological objects were used: skin of orange, pieces of carrot, slices of pork.

The first stage of the experimental series was calculation of the dispersion of the water dielectric function in the frequency region of 0.1-0.9 THz. The data obtained experimentally was consistent to what was published before.

The second stage was performance of an experiment with a number of stages: at each stage, the sample was being dried up using a special heater for a certain time. Therefore, a number of different water content levels were obtained within each experiment in order to test the methods sensitivity and precision. By the end of each experiment, the sample was completely dried up and used as a solid component in the calculations. Simultaneously, the water concentrations were measured gravimetrically at each stage in order to verify the THz data.

For the convenient water concentrations calculation in

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transmission and reflection modes, two programs in Matlab with Graphical User Interface (GUI) were developed. In the programs, the user has to upload the waveforms of dehydrated sample and investigated sample obtained experimentally. In order to control the water status in the leaves or fruits from the same plant, it is enough to use the same dehydrated sample as a solid component for testing other samples from the same species.

IV. RESULTS

During the series of experiments, optical properties of different samples in relation to their water concentration were studied. The experiments demonstrated how the optical properties of the samples move from near water dispersion towards the dispersion of absolutely dry tissue.

The Fig. 1 shows dispersion of complex refractive indices of the *Carpinus caroliniana* tree leaf in 5 different stages of dryness obtained in the experiment using the mini-Z spectrometer by Zomega corp. in transmission mode.

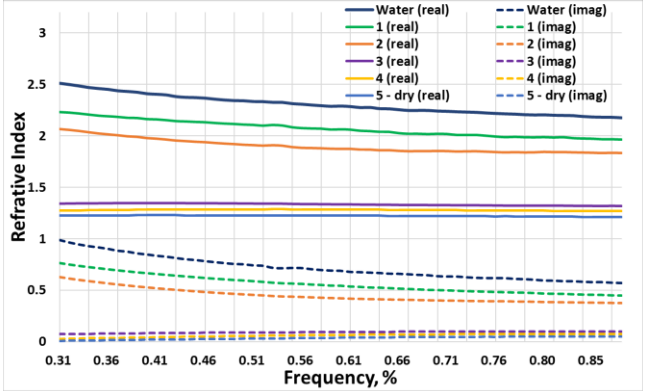

Fig. 1. Dispersion of complex refractive index of a leaf in 5 different stages of dryness in the experiment in transmission mode.

The figure demonstrates that while the leaf was still hydrated, its optical properties was similar to water dispersion. By the 3rd, 4th and final stages of dryness the refractive index dispersion of the sample was completely flat.

Fig. 2 shows the results obtained in the experiment. The results obtained by THz method correspond to the gravimetrical data very well.

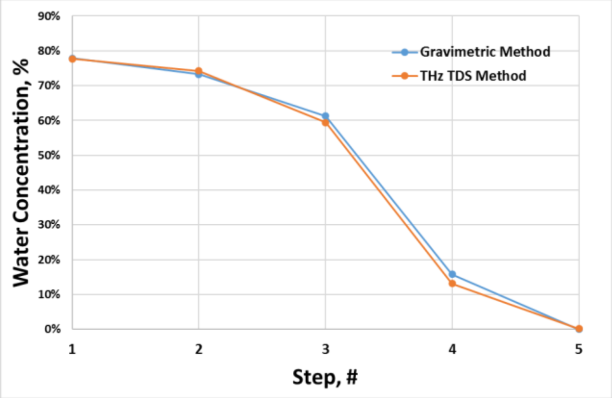

Fig. 2. Results of the experiment in transmission mode (and comparison with gravimetrical measurements)

For the reflection mode, experiments were conducted using the piece of the orange skin (*Cītrus sinēnsis*) at the THz TD spectrometer in the THz Biomedicine lab of the ITMO University.

Fig. 3 shows the results obtained in the experiment. THz data corresponds to the gravimetrical method, but with less accuracy then in the transmission experiment. This can be explained by the fact that gravimetrical measurement corresponds to the whole thick sample (2-3 mm thick) overall water content, whereas THz data in related only to the surface layer of a sample. Therefore, the methods accuracy cannot be judged by the gravimetrical data.

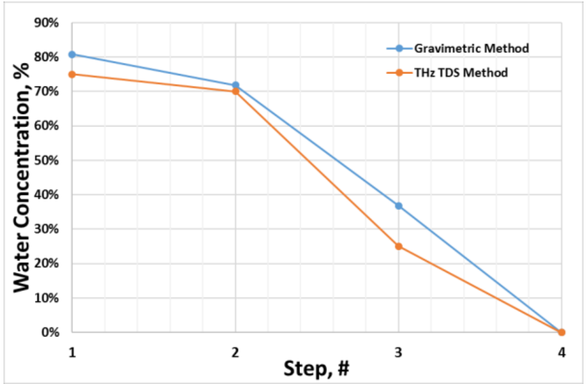

Fig. 3. Results of the experiment in reflection mode (and comparison with gravimetrical measurements)

V. CONCLUSIONS

It is shown that the THz time-domain spectroscopy systems can be used as a tool for in-vivo water level measurement in the biological tissues or objects in transmission and in reflection modes. Described methods allow quite precise nondestructive measurements, which can be used in such areas as the plants stress respond estimation, indication of anomalies of human skin, or products quality control.

ACKNOWLEDGEMENTS & FUTURE PLAN

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