Study of Penetration Depth Dispersion of THz Radiation in Human Pathological Tissues

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Abstract— The dispersion of penetration depth of terahertz radiation in various human pathological tissues were obtained and analyzed for development of subcutaneous diseases diagnostics in terahertz frequency range.

1. INTRODUCTION

The terahertz (THz) radiation is an electromagnetic radiation in the wavelength range of 3 mm–30 mkm (the frequency range of 0.1–10 THz). Terahertz radiation is perspective for applications in spectroscopy and medicine. Actual use of THz radiation is to diagnose skin pathologies, such as chemical and thermal burns, mechanical damage, skin cancer and other morphological changes [1]. Diagnosis of skin cancer in the early stages becomes a complex process that requires to know how deep the radiation passes into the skin. It is necessary not to miss early cancer when examining the patient [2]. This paper is devoted to investigation of penetration depth of radiation in normal and pathological human skin tissues, for development of subcutaneous diseases diagnostics in the frequency range of 0.1–2 THz.

2. MATERIALS

We investigated in vivo several samples of human tissues: normal skin tissue, thermal burn skin tissue, chemical burn skin tissue, skin covered by ointment containing glycerin. All measurements were carried out at room temperature. Five measurements were made for each tissue sample. In one set of measurements we used an ointment in case to increase penetration depth of radiation. The ointment contained 39% of glycerin, cetearyl alcohol, stearic acid, palmitic acid, sodium cetearyl sulfate.

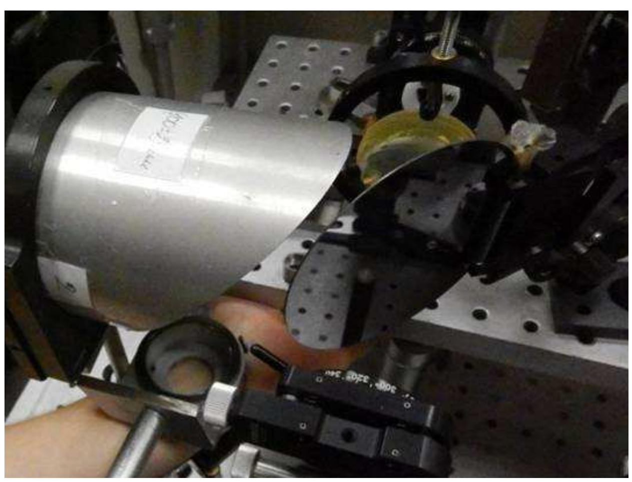

Figure 1: Sample of normal male human tissue in measurement window of terahertz time domain spectrometer.

3. EXPERIMENTAL SETUP

The reflection spectra were obtained by THz time domain reflection spectroscopy, utilizing ultra short electromagnetic pulses generated from an InAs semiconductor in magnetic system driven by femtosecond laser pulses. The THz spectrometer has the following characteristics: the average power of 30 μW; the frequency range of $0.1 \div 2.0$ THz, THz pulse duration of 3 ps, the spectral resolution about of 15 GHz [3]. The signals measured by the spectroscopy system are time domain waveforms that are directly proportional to the terahertz electric field. The frequency domain spectra were obtained from time domain waveforms using Fast Fourier Transform (FFT). Thus, it is possible to recover both phase and amplitude information, which provides a direct measure of the frequency-dependent refractive index of the tissue sample, absorption coefficient and penetration depth.

4. METHOD

In experiment we obtain THz pulses reflected from the interfaces of polystyrene window/skin sample. THz pulse reflected from the sample contains the first pulse reflected from the front of polystyrene window (reference pulse) and the second delayed pulse from the polystyrene — skin interface (sample pulse) [4]. The Happ-Genzel apodization function was applied to Fourier trans-

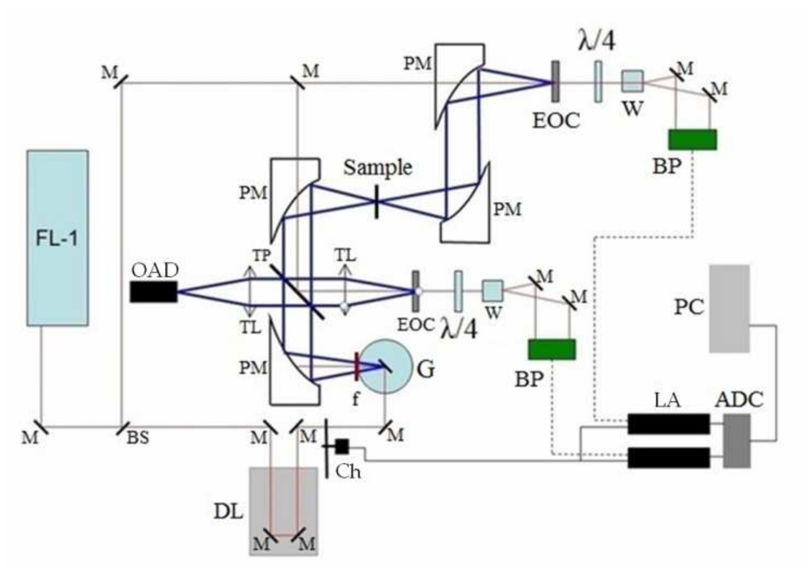

Figure 2: Scheme of the universal pulsed broadband THz spectrometer. FL-1 — laser of femtosecond pulses, M — mirrors, BS — beam splitter, DL — optical delay line, G — generator of THz radiation based on the crystal InAs, PM — parabolic mirrors, TL — lenses for THz radiation, f — teflon filter, TP — translucent silicon plate, Ch — chopper, EOC — electro optical crystal of CdTe, W — Wollaston prism, BP — balanced photodiodes, LA — lock-in amplifier, ADC — analog-to-digital converter, PC — personal computer, OAD — opto-acoustic detector (Golay cell).

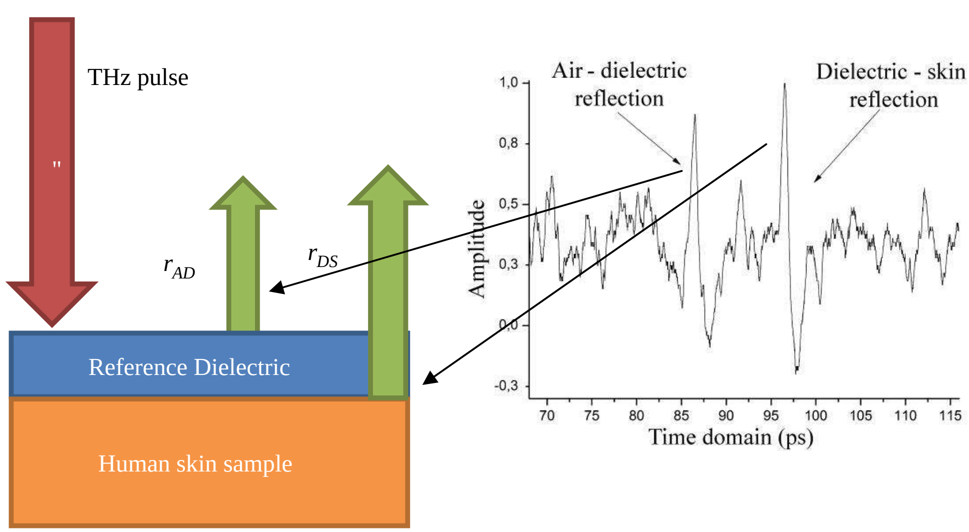

Figure 3: Scheme of the experiment. The first pulse indicates reflection from air-dielectric interface. The second pulse appears from dielectric-skin interface reflection.

form integration to reduce the ripples for each pulses (r_{AD}, r_{DS}). The Happ-Genzel function is often used to achieve a good balance between ripple size and resolution. The ratio of the Fourier transform of the reference pulse $\hat{E}_R(\upsilon)$ and the sample pulse $\hat{E}_S(\upsilon)$, is

$$\frac{\hat{E}_S(\upsilon)}{\hat{E}_R(\upsilon)} = \frac{t_{AD} r_{DS} t_{DA}}{r_{AD}} \exp\left(i \frac{4\pi n_D d_D \upsilon}{c}\right) \tag{1}$$

where t_{AD}, r_{AD}, t_{DA}, $\hat{r}_{DS}$ are Fresnel coefficients at normal incidence for the amplitude transmission t, and reflection r. The subscripts indicate the interfaces: air (A), polystyrene (D), skin (S). The Fresnel coefficients for the air-polystyrene interfaces are real because dry air and polystyrene have no absorption. The phase shift is represented in exponential factor, where n_D is the refraction index of polystyrene and d_D is the thickness of used window. From the Equation (1) we may obtain real and imaginary parts of refractive index and absorption coefficient of skin: $\hat{n}_S = n'_S - jn''_S$, where

$$n'_S = \frac{n_D\left(1 - R^2\right)}{1 + R^2 + 2R\cos\theta}, \tag{2}$$

$$n''_S = n_D \frac{-2R\sin\theta}{1 + R^2 + 2R\cos\theta}, \tag{3}$$

$$\alpha_S = \frac{4\pi\upsilon n_D}{c} \frac{-2R\sin\theta}{1 + R^2 + 2R\cos\theta}. \tag{4}$$

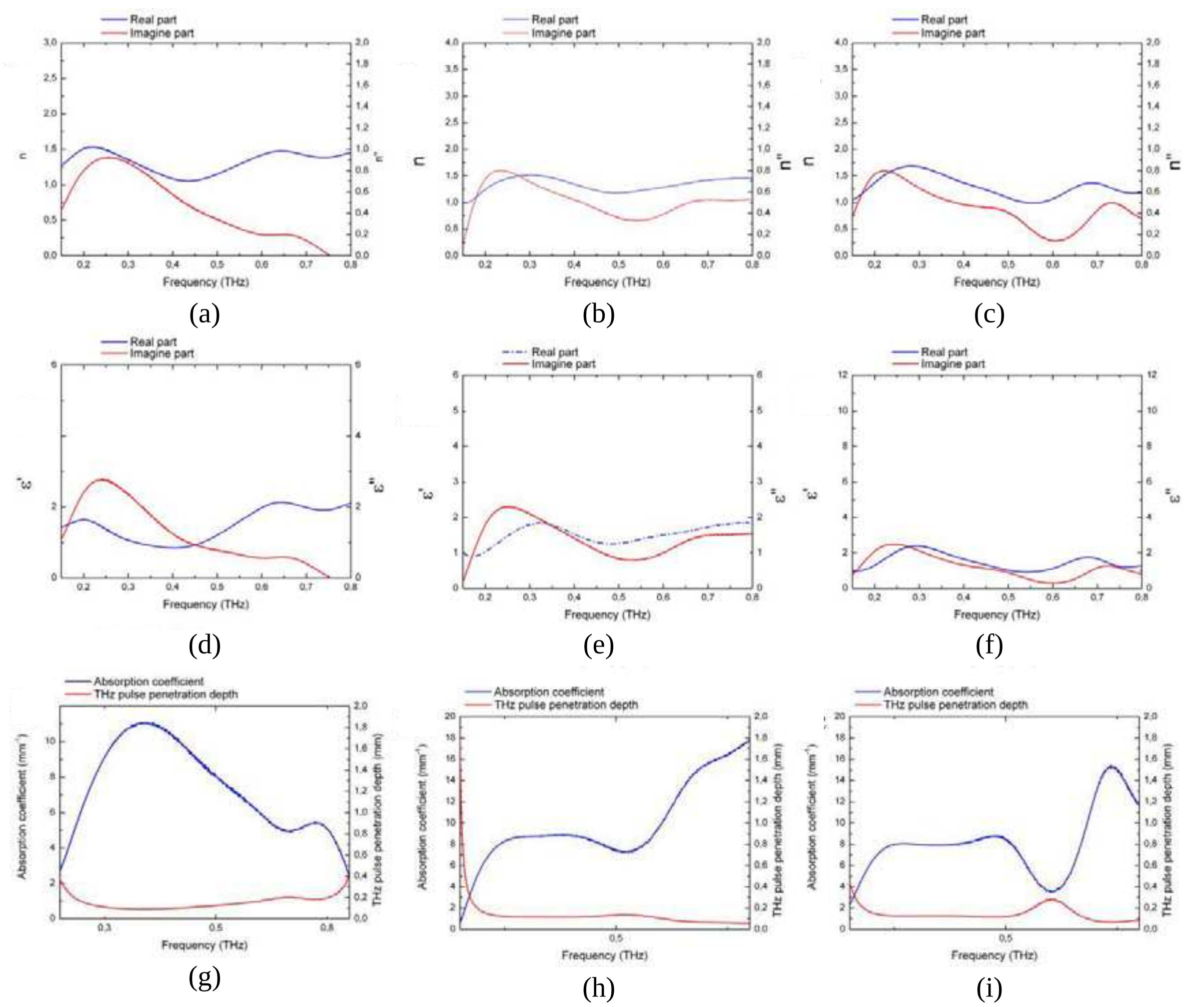

Figure 4: (a), (b), (c) Both real and imagine parts of refractive index, (d), (e), (f) dielectric permittivity, (g), (h), (i) absorption coefficient and penetration depth, (a), (d), (g) healthy skin, (b), (e), (h) skin with chemical burn, (c), (f), (i) skin with thermal burn.

If both thickness and refractive index of reference dielectric are known then amplitude R and phase angle θ can be obtained experimentally. Penetration depth can be calculated as $\sigma = \frac{1}{\alpha}$ [5]. Real and imagine parts of skin permittivity ($\hat{\varepsilon} = \varepsilon' + i\varepsilon''$) are calculated from the relation $\hat{\varepsilon} = \hat{n}^2$.

5. RESULTS

The results of the measured time domain waveforms processing are presented in Fig. 4. It is clearly seen that the explicit increase of the imaginary part of refraction index (as well as the absorption coefficient) of pathological skin (chemical burn and thermal burn) in comparison with healthy skin is observed in the frequency range of 0.6–0.8 THz (Figs. 4(a)–(c)). The effect results in the dramatically decrease of THz pulse penetration depth from 0.1 mm till 0.05 mm for skin with chemical burn and from 0.3 mm till 0.1 mm for skin with thermal burn in this frequency range (Figs. 4(g)–(i)). This fact worsens the possibility of THz diagnostics of subcutaneous diseases of burned tissue in the frequency range of 0.6–0.8 THz.

6. CONCLUSIONS

We experimentally obtained THz reflection spectra of normal human skin and human skin with thermal and chemical burns in the range 0.15–1.0 THz. Both real and imagine parts of refractive index, dielectric permittivity, absorption coefficient and penetration depth were derived by analysis of reflection spectra.

ACKNOWLEDGMENT

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