第76回応用物理学会秋季学術講演会 講演予稿集 (2015 名古屋国際会議場)

Role of human sweat ducts in interaction of terahertz wave with human skin

Saroj R. Tripathi, Eisuke Miyata and Kodo Kawase

Nagoya University, Furo-cho, Chikusa Ku, Nagoya 464-8603, Japan

E-mail: tripathi@nuee.nagoya-u.ac.jp

1. Introduction

Rapid development of optoelectronics and ultrafast technology has enable the emission and detection of broadband terahertz (THz) waves and the applications of THz waves have expanded into diverse fields such as homeland security, information and communication technology, material characterization, biomedicine and so on. Due to such applications, encounters between THz radiation and humans are expected to become common. Therefore, knowledge of the fundamental principles of THz wave interaction with human beings is crucial for understanding the health consequences.

Recently, some studies have demonstrated that sweat glands present in the human skin play a critical role in THz wave interaction with human beings [1,2]. It was reported that the sweat ducts act as a low-Q-factor helical antenna due to their helical structure, and resonate in the terahertz frequency range according to their structural parameters, such as helix diameter and helix length. According to the antenna theory, when the duct works as a helical antenna, the dimension of the helix plays a key role to determine the frequency of resonance. Therefore, the accurate determination of structural parameters of sweat duct is crucially important to obtain the reliable frequency of resonance and modes of operations. Therefore, here we performed the optical coherence tomography (OCT) of human subjects on their palm and foot to investigate the density, distribution and morphological features of sweat ducts. Moreover, we calculated the dielectric properties of human skin using terahertz time domain spectroscopy and based upon this information, we determined the frequency of resonance.

2. Results

In our experiment, we recruited 32 subjects for the measurement and investigated the intersubect and intrasubject variation in density and structural parameters of the sweat ducts using OCT. As shown in figure 1(a), we observed that the density of ducts was highest at the tip of the index finger (633 ± 252 ducts/cm^2) whereas the inner arch has the lowest (384 ± 165 ducts/cm^2). Here, it is important to note that the variation in duct density was relatively high. In contrast to this, the sweat ducts h similar diameters regardless of measurement location .The average duct diameter was 95±11μm. Based upon this information on diameter of duct and THz dielectric properties of stratum corneum (ε=5.1±1.3), we have calculated the frequency of resonance of sweat duct using the mathematical expression: $3C_0/4C\sqrt{\varepsilon} < f < 4C_0/3C\sqrt{\varepsilon}$, where C_0 is velocity of light, C (= πD) is circumference of the duct, D is the duct diameter and ε is the dielectric constant of stratum corneum. Finally, we determined that the center frequency of resonance was 442±76 GHz [3]. We believe that these findings will facilitate further investigation of the THz-skin interaction and provide guidelines for safety levels with respect to human exposure to electromagnetic waves at these frequencies.

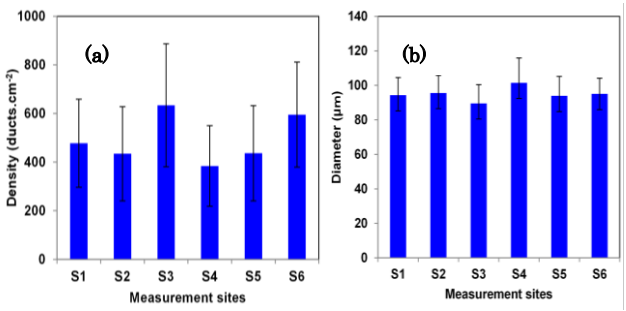

Figure: (a) Density and (b) diameter of human sweat ducts. Here, S1: Base of little finger; S2: Between thumb and wrist; S3: Index finger tip; S4: Inner arch; S5: Mound of big toe; S6: Right second toe

3. Conclusion

We analyzed the density and dimension of the ducts based on 3D images obtained with optical coherence tomography. We observed that the average diameter of the human sweat ducts was approximately 95 μm. Based on the sweat duct dimensions and THz dielectric properties of skin measured using terahertz time-domain spectroscopy, we calculated the resonating frequency of the sweat duct under the assumption of it functioning as a helical antenna. Here, we found that the resonance frequency of human sweat ducts in the axial mode of operation lies in the THz wave region with a center frequency of 0.44 ± 0.07 THz.

Acknowledgements

We thank all volunteers for the OCT measurements. S. R. Tripathi gratefully acknowledges the Japan Society for Promotion of Science (JSPS) for the postdoctoral fellowship. Part of this work was financially supported by a Grant-in-Aid for Scientific Research (Tokubetsu Kenkyin Shore-hi Grant No: 25.03356).

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