様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Human sweat duct as a helical antenna: experimental investigation

研究課題名（英文）Human sweat duct as a helical antenna: experimental investigation

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研究成果の概要（和文）：ヒトの皮膚内に存在する汗腺はらせん構造を持つため，ヘリカルアンテナとして動作し，テラヘルツ領域で共振することが報告されている。本研究では汗腺のノーマルモードでの共振周波数を推定し、その共振を実験的に検証するためにテラヘルツ時間領域分光器を構築した。本実験では指からの反射率を測定し、反射スペクトルにおいて280GHz付近で反射率の減少が観測された。これは汗腺の共振が原因と考えられるが、共振を正確に確認するために実験結果の再現性の検証が必要である。

研究成果の学術的意義や社会的意義
We investigated the potential biomedical applications of terahertz wave where we studied whether the human sweat ducts act like a helical antenna in THz region. Our preliminary finding suggests that this research has a potential to create a method of remote sensing of mental stress using THz wave.

研究成果の概要（英文）：It was reported that the human sweat duct could acts a helical antenna in sub-terahertz frequency region. In this project, we estimated the frequency of resonance of sweat duct in normal mode of operation. We experimentally investigated the sweat duct resonance using terahertz time domain spectroscopy, where we measured the terahertz wave reflection from the finger. We observed the reduction in reflectance at around 280 GHz and we believe that this is due to the sweat duct resonance. However, the repeatability of the results needs to be investigated further to confirm the resonance.

研究分野：テラヘルツ光学

キーワード：テラヘルツ波　汗腺　アンテナ

様　式　C－１９、F－１９－１、Z－１９、CK－１９（共通）

１．研究開始当初の背景

The morphological structure of the human sweat ducts embedded in the epidermis resembles a helix. Their topology coupled with the dielectric properties of skin led to the concept that these coiled structures would have an electromagnetic response in the millimeter and terahertz (THz) frequency range and it presents the intriguing possibility that it could act as a helical antenna in the terahertz frequency band. According to the antenna theory, a helical antenna resonates in two different modes of operation known as normal mode and axial mode and the dimension of the helix such as diameter, number of turns and length plays a key role to determine the frequency of resonance.

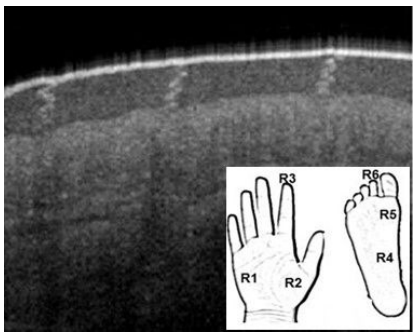

Fig. 1: A typical OCT image showing the stratum corneum and the helical sweat duct. Inset shows the various measurement regions. R1: the base of the little finger; R2: between thumb and wrist; R3: the right index finger tip; R4: the inner arch; R5: mound of the big toe; and R6: the right second toe on the foot.

Therefore, it is important to study the morphological structures of the sweat duct to obtain the frequency of resonance in two different modes and to experimentally investigate the resonating behavior of sweat duct. This study allows us to understand the terahertz wave interaction with human skin and to explore the possibility of remote sensing of mental stress and other biomedical applications using terahertz waves.

２．研究の目的

When the helical structured sweat ducts are filled with sweat consisting of conducting electrolyte, the duct could respond at the certain frequency in terahertz wave region as determined by the diameter of duct and dielectric properties of the skin. Therefore, our first objective was to obtain the morphological features of skin and sweat duct and to compute the frequency of resonance. Another objective was to develop terahertz time domain spectrometer in attenuated total reflection mode in order to investigate the resonating frequency.

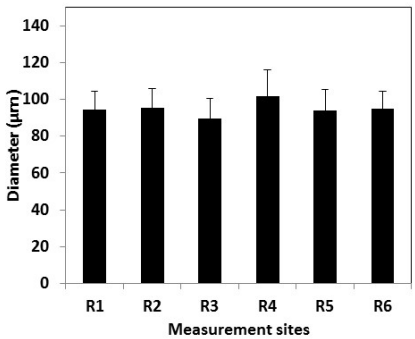

Fig. 2: Diameter of sweat duct in different measurement regions.

３．研究の方法

In this study, we used commercially available OCT system to study the structural parameters of sweat duct. The OCT system consists of a fiber laser with a wavelength of 1310 nm. We obtained a 3D data set consisting of (x = 255, y = 255, z = 849) pixels covering a volume 2.5 mm × 2.5 mm × 8.49 mm was recorded for each measurement. We recruited several subjects and performed OCT measurements in vivo on different regions of the palm (R1 = the base of the little finger; R2 = between thumb and wrist; R3 = the right index finger tip) and foot (R4 = the inner arch; R5 = mound of the big toe; R6 = the right second toe on the foot). Fig. 1 shows the typical OCT image showing the stratum corneum, the helical structured sweat duct in the stratum corneum and dermis. From the images obtained from different human subjects, we obtained the diameter, length and number of turns in sweat duct. Fig. 2 shows the diameter of the helical portion of the sweat duct in all the measurement regions. We observe that the diameter of the duct, regardless of the subject, is almost equal for all measurement regions. The average duct diameter was 95μm. Based upon duct diameter and dielectric properties of skin, the frequency of the resonance of sweat duct in normal mode of operation was estimated to be 228 GHz when the axial ratio is unity as shown in Fig 3.

In the next step, we developed terahertz time domain spectrometer in attenuated total reflection mode. In this system, the THz wave emitted by photoconductive antenna was guided by parabolic mirrors and incident on the silicon prism as shown in the Fig. 4. The THz wave undergoes total internal reflection at the boundary between silicon and air and finally THz wave is detected by another photoconductive antenna.

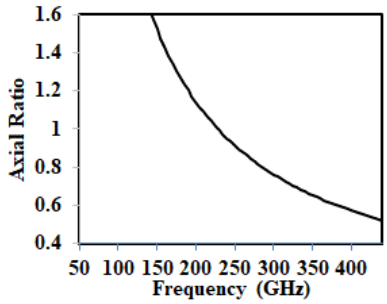

Fig. 3: Axial ratio of helix. The frequency of resonance is about 228 GHz when the axial ratio is 1.

In our experiment, we performed in vivo measurement of the finger using the attenuated total reflection (ATR) terahertz time domain spectroscopy (THz-TDS). Here we choose to measure the reflection from the tip of the finger due to the high density of sweat ducts in this region.

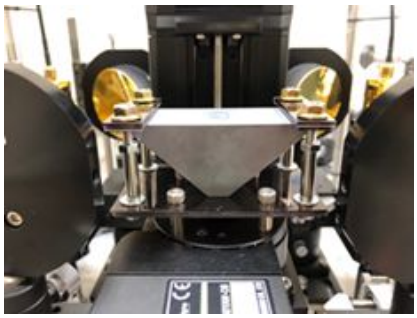

Fig. 4: Attenuated total reflection terahertz time domain (ATR THz-TDS) measurement setup.

Since the sweat glands are typically activated by sympathetic nervous system, we measured the THz wave reflection from the finger when the subject is under stress. In order to evoke sweating due to the mental stress, the subject was asked a sets of math questions. During this process, we simultaneously measured the THz reflection from the finger and computed the attenuated total reflectance. We observed the ATR spectra was almost flat without any spectral feature when the subject was in calm state.
In contrast to this, we observed the reduction of reflection in the terahertz spectra at around 280 GHz when the subject was under emotional stress. We believe such reduction in reflection intensity spectra is due to the sweat duct resonance. However, further investigation is necessary to confirm the resonating behavior of sweat duct.

４．研究成果

The study on interaction of THz wave with human skin with the consideration of helical structured sweat duct as an antenna is relatively new. Since the helix has two modes of operation, in this project we studied the frequency of resonance of human sweat duct in normal mode of operation by investigating the various morphological features of sweat duct such as their diameter, length and number of turns. We numerically estimated that the sweat duct in normal mode of operation resonates at 228 GHz. In the next step, we developed attenuated total reflection terahertz time domain spectroscopy to investigate frequency of resonance. Our experimental result shows the possible sweat duct resonance. However, the repeatability of the results needs to be investigated further in order to confirm the sweat duct resonance and further explore the biomedical applications.

５．主な発表論文等

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〔図書〕（計　0　件）

〔産業財産権〕
○出願状況（計　0　件）

名称：
発明者：
権利者：
種類：
番号：
出願年：
国内外の別：

○取得状況（計　0　件）

名称：
発明者：
権利者：
種類：
番号：
取得年：
国内外の別：

〔その他〕
ホームページ等

６．研究組織

(1)研究分担者
なし

(2)研究協力者
なし