In vivo measurement of dielectric properties of human skin using attenuated total reflection terahertz time domain spectroscopy

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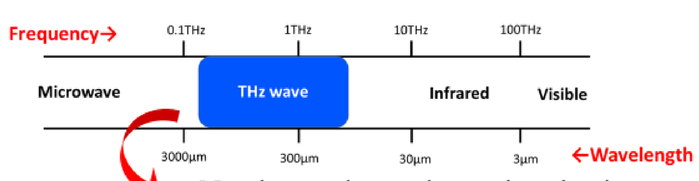
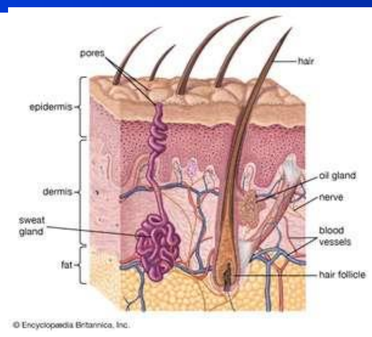
Abstract

The applications of terahertz waves have been increasing rapidly in different fields. With the rapid development of such applications, encounters between THz waves and humans are expected to become common. Therefore, it is important to have the knowledge of terahertz properties of human skin in order to understand the interaction of THz wave with human skin. In this study, we developed attenuated total reflection THz time domain spectroscopy and measured the refractive index and absorption coefficient of skin in the frequency range of 200GHz to 2THz. This information help understand the terahertz wave interaction with human skin and other possible biomedical application of THz wave.

Introduction



- Nondestructive testing and evaluation
- High speed data communication
- Medical applications such as cancer detection, burn assessment and so on



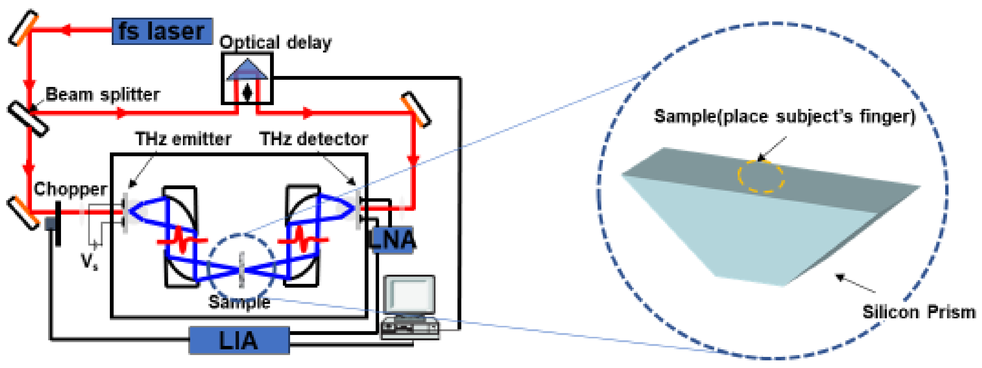
Ebling, F. John G. and Montagna, William. "human skin". Encyclopedia Britannica, 30 Jul. 2021, https://www.britannica.com/science/human-skin. Accessed 18 October 2021.

Importance of skin measurement in THz frequency region :

① Analysis of moisture content in skin
②Understand the THz wave interaction with human skin

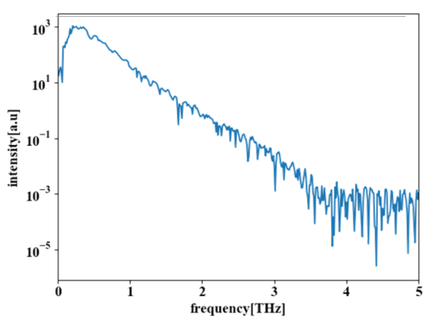
In vivo measurement of dielectric properties of human skin

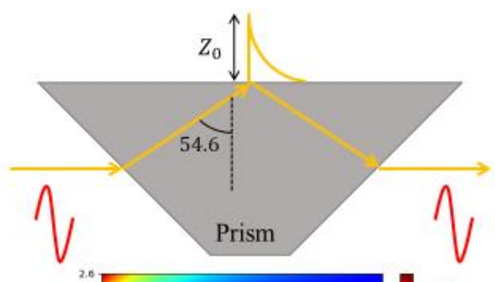
Experiment Method

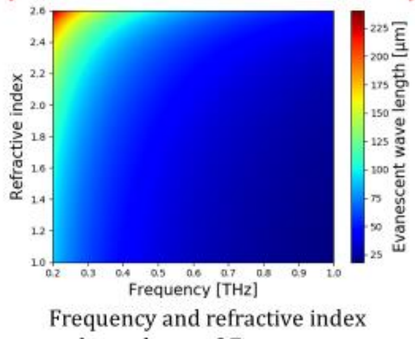


THz time domain spectroscopy

- Frequency range = 100 GHz to 3.5 THz
- Dynamic range = 6 orders of Magnitude
- Frequency resolution = 12 GHz
- Emitter : photoconductive antenna
- Laser = (λ = 780 nm, pulse width < 100fs , average power = 20mW)





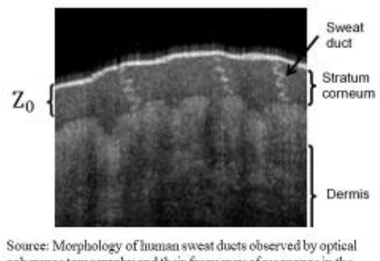


Frequency and refractive index dependence of Z_0

Z_0 : Distance where the amplitude becomes 1 / e

$$Z_0 = \frac{\lambda}{2\pi\sqrt{(n_1 sin\theta)^2 - {n_2}^2}}$$

n_1 : Refractive index of silicon prism 3.41
n_2 : Refractive index of sample
θ : Incident angle(54.6°)



Source: Morphology of human sweat ducts observed by optical coherence tomography and their frequency of resonance in the terahertz frequency region

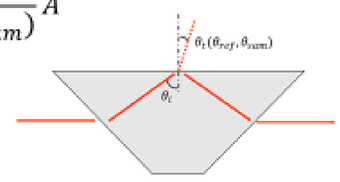
Calculation

Complex reflectance of p-polarized light $R = \frac{tan(\theta_i - \theta_t)}{tan(\theta_i + \theta_t)} A$

Complex reflectance of reference and sample R_{ref} and R_{sam} is expressed by following formula

$$R_{ref} = \frac{tan(\theta_i - \theta_{ref})}{tan(\theta_i + \theta_{ref})} A \qquad R_{sam} = \frac{tan(\theta_i - \theta_{sam})}{tan(\theta_i + \theta_{sam})} A$$

$$\frac{R_{sam}}{R_{ref}} = \frac{tan(\theta_i - \theta_{sam})}{tan(\theta_i + \theta_{sam})} \cdot \frac{tan(\theta_i + \theta_{ref})}{tan(\theta_i - \theta_{ref})}$$

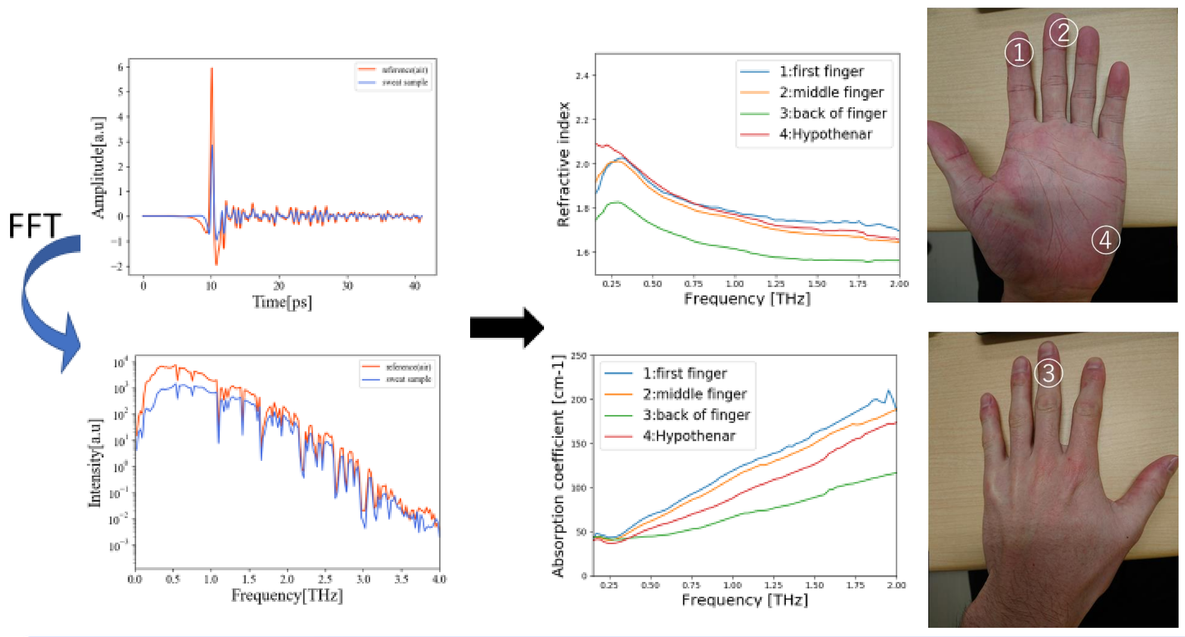


By using Snell's law, the complex refractive index $\tilde{n}(\tilde{n} = n + i\kappa)$ is expressed by following formula

$$\tilde{n} = \underbrace{\sqrt{\frac{n_{Si}^2 \cdot \sin^2\theta_i}{2 \cdot (\sin\theta_{sam} \cdot \cos\theta_{sam})^2}}}_{\mathbf{n}} + i \underbrace{\sqrt{\frac{\sqrt{1 - 4 \cdot (\sin\theta_{sam} \cdot \cos\theta_{sam})^2}}{2 \cdot (\sin\theta_{sam} \cdot \cos\theta_{sam})^2}}}_{\kappa}$$

θ_i : Incidence angle
n_{si} : Refraction ratio of silicon prism

Result



Summary

- We measured the dielectric properties of different parts of human skin by using terahertz time domain spectroscopy in attenuated total reflection mode(ATR THz-TDS) in the frequency range of 200 GHz to 2 THz.
- We observed that the index of refraction decreases with frequency, whereas the absorption coefficient increase with frequency.
- Different parts of finger have different dielectric properties. Especially, back and front of finger shows the biggest difference in absorption coefficient, which is possibly due to the difference in moisture content.

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