Analysis of Terahertz Spectral Variations in Porcine Dermis

Maya Mizuno, Kensuke Sasaki, Soichi Watanabe, and Kaori Fukunaga
National Institute of Information and Communications Technology, Koganei, Tokyo 184-8795, Japan

***Abstract*— The absorption spectra of dried porcine dermis were measured under different sample handling conditions in a terahertz band from 0.3 to 12 THz. The spectral shapes and polarization properties depended on the drying and impurity conditions at approximately 3 THz. We inferred that the configuration changes of collagen fibers inside the dermis caused the spectral variations.**

I. INTRODUCTION

TERAHERTZ waves from 0.1 to 10 THz are frequently used in various research fields such as wireless communication, biology and medicine. For the health and safety of terahertz users who develop or apply terahertz technologies, it is necessary to study the interactions between terahertz waves and tissues such as the skin (dermis) and cornea. To understand these interactions caused by thermal or non-thermal effects, many exposure measurements using physical or chemical parameters and modeling are required. In addition, the terahertz absorption properties of the tissues must be analyzed as the fundamental data of exposure measurement and modeling. It is known that dermis includes collagen fibers, whose absorption properties are significantly affected by the sample handling conditions, whereas the tissues have similar characteristics regardless of the handling conditions. In this study, we therefore measured the terahertz absorption spectra of the dermis prepared under different drying and impurity conditions and investigated whether the shapes of the absorption spectra differ with the configuration of the collagen fibers, which changes with the variation of the tissue conditions. Furthermore, we considered the terahertz absorption properties of non-dried dermis.

II. RESULTS

A terahertz time-domain spectrometer (Rayfact SpecTera RS-01020, Tochigi Nikon) (from 0.3 to 4 THz) with linear polarization and a Fourier transform terahertz spectrometer (VIR-F, JASCO) (from 4 to 12 THz) with random polarization were used to obtain the absorption spectra of porcine dermis. The dermis samples were made of frozen porcine dermis. One was a vacuum-freeze-dried sample of approximately 3 mm diameter. The others were thawed once and then naturally dried or used as non-dried samples. We also prepared a sample naturally dried after adding 3 ml of phosphate-buffered saline (PBS) to a vacuum-freeze-dried sample.

Firstly, we obtained the spectra of three dried samples to determine the absorption properties without the effect of hydration. In Figure 1, spectral data indicating similar values between the terahertz time-domain spectrometer and the Fourier transform terahertz spectrometer at 3 THz were selected and then showed as an example for each sample condition. As shown in Figure 1, absorption peaks at approximately 3 and 10 THz were observed for all the samples, and a new absorption peak at 5 THz appeared only when PBS (mainly including sodium chloride) was added to a vacuum-freeze-dried sample and then naturally dried. These characteristics were similar to the absorption properties corresponding to the collective vibrations of functional groups in collagen [1] because approximately 70% of the dry weight of the dermis consists of collagen fibers. At approximately 3 THz, we found that the absorption bandwidth broadened by natural drying and salt addition. To determine the reason for the broad absorption bandwidth, we measured the polarization properties of the dermis samples using a terahertz time-domain spectrometer with linearly polarized waves. Figure 2 shows the

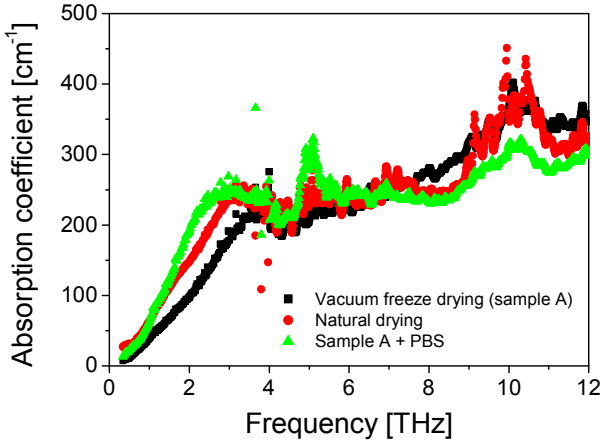


Fig. 1. Example of absorption spectra of dermis samples dried under different sample handling conditions. Black squares, red circles and green triangles show the absorptions of the samples that were vacuum-freeze-dried and naturally-dried without and with PBS, respectively. PBS was added to the vacuum-freeze-dried sample.

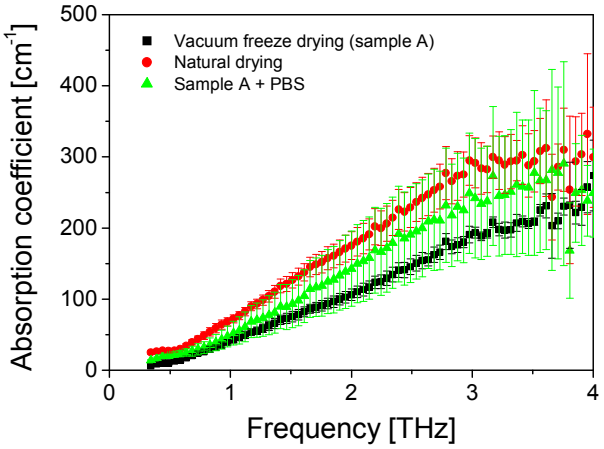
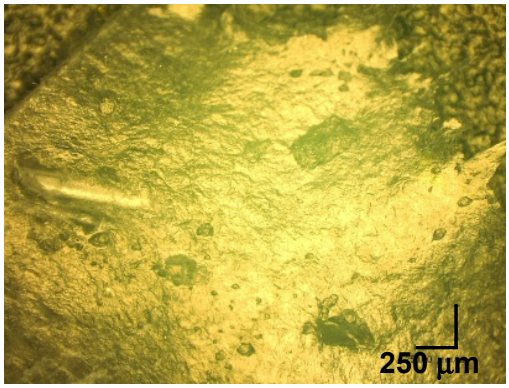
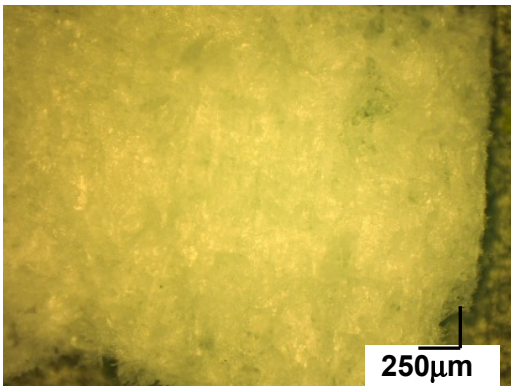


Fig. 2. Variation of absorption spectra of dried porcine dermis samples. Black squares, red circles and green triangles show average values of four measurements: the error bars indicate standard deviations.



(a)



(b)

Fig. 3. Microscopy images (100-fold magnification) of surfaces of (a) naturally dried and (b) vacuum-freeze-dried dermis.

average absorption coefficients at four angles of 0 (arbitrary), 45, 90 and 135º; the error bars indicate standard deviations (1σ). The standard deviation was larger for the sample with added salts than for that without salts. Thus, anisotropy of the dried dermis appeared and became large after a natural drying treatment and salt addition. We inferred that the natural drying treatment and impurity addition affected the configuration of the collagen fibers, and as a result, the absorption bandwidth broadened because the molecular vibrations of functional groups were damped. Such anisotropic changes were hardly observed at frequencies below approximately 0.7 THz, owing to the edge of resonance absorption at 3 THz. The anisotropy of vacuum-freeze-dried porcine dermis was small. One of the reasons considered for this was that the arrangement of collagen fibers was mostly random at the macro level. We therefore observed the surfaces of the dried samples using a microscope. When the dermis was naturally dried, the collagen fibers aggregated by self-organization and the sample configuration was similar to a collagen sheet (Figure 3 (a)). The vacuum-dried sample had a random structure similar to that of a cotton plant, as shown in Figure 3 (b); the non-dried dermis could be in a similar state [2].

Furthermore, we obtained the absorption spectrum of the non-dried dermis using a terahertz time-domain spectrometer, and we compared the spectrum of the dermis and the merged

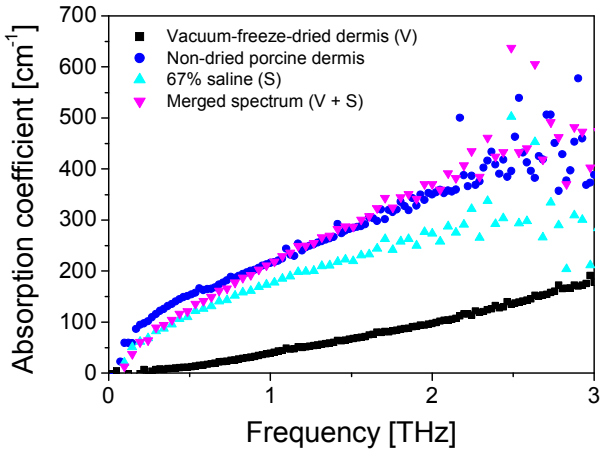


Fig. 4. Absorption spectra of vacuum-freeze-dried dermis (black squares), non-dried porcine dermis (blue circles) and 67% saline (light blue triangles), and merged spectrum of vacuum-freeze-dried dermis and 67% saline (pink inverted triangles).

spectrum of the vacuum-freeze-dried dermis and saline. The water content of the dermis sample was approximately 67%. A merged absorption coefficient was therefore derived from the values of the vacuum-dried sample and 67% saline. The absorption spectrum of the non-dried dermis showed agreement with the merged spectrum of the saline and vacuum-freeze-dried dermis as shown in Figure 4. This result indicated that collagen molecules were free from water as a result of hydrophobic bonding. When the non-dried anisotropic sample was measured, the spectrum of the dermis was different from the merged spectrum owing to polarization and hydration. These results suggest the possibility of analysis of the non-dried dermis by terahertz spectroscopy.

III. Summary

Absorption spectra of dried porcine dermis were obtained in the terahertz band. The spectra showed that the shapes of absorption spectra of the dried dermis depended on the sample handling conditions. We inferred that configuration changes in collagen fibers affected the spectral shapes. On the basis of the above consideration, the spectra of the non-dried dermis could reflect the differences in the polarization and hydration caused by configuration changes in collagen fibers. We intend to use these results to evaluate the dermis conditions for reducing the variation of dielectric property measurement and for detecting exposure effects.

References

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[2] Masahiro Ito, Takeshi Yasui, Syuichirou Fukushima, Tsutomu Araki, Toyonobu Yamashita, Naomi Kunizawa, and Motoji Takahashi, "Observation of dermal collagen fiber with second harmonic generation imaging (in Japanese)" Kogaku Vol. 36, pp. 35—40, 2007.