THz techniques using metal mesh sensor for human skin measurement

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Abstract: Metal meshes work as band-pass filters in the terahertz (THz) region with their transmission spectra acutely being affected by the refractive index of the material inside and above the metal mesh openings. We used a metal mesh for high-sensitivity observations by focusing on the "dip", i. e. a sudden change in transmittance that only appeared when the THz wave was obliquely incident onto the metal mesh. Here we report a measurement of stratum corneum to inspect the feasibility of applying the metal mesh sensor to observations of human skin.

Keywords: Terahertz wave, Metal mesh sensor, Stratum corneum, Transmission spectra

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1. Introduction

The photoconductivity and charge transport properties of semiconductor nanoparticles (NPs) are critically important with regard to their use in electro-optic devices [1]. Similarly, understanding the microscopic details of carrier transport in nanocrystalline colloidal thin films is required for complete understanding of a variety of photochemical and photoelectrochemical cells utilizing interpenetrating networks. Measuring the photoconductivity in these materials, however, is a challenging problem because of the inherent difficulty in attaching wires to nanometer-sized objects. Furthermore, picosecond (ps) carrier dynamics play an important role in efficient charge separation and transport, but the low temporal resolution of traditional methods used to determine their photoconductivity precludes their use in studying sub-ps to ps dynamics.

Over the past two decades, terahertz (THz) waves have been found with an increasing number of applications in various fields of research. Terahertz waves are electromagnetic waves of around 0.3–3 *THz* frequency, which can travel through materials such as paper, plastic, ceramics, and wood. They are used for spectroscopic measurements, with a view to practical applications such as the nondestructive inspection of illicit drugs in an envelope, the detection of complex antigen-antibody reactions, and DNA hybridization detection. The intermediate and collective vibration modes of many protein and DNA molecules are predicted to occur in the THz range [1-3]. In addition, because THz devices can have spatial resolution of around several hundreds of microns, and the waves are easily guided by lenses or mirrors, they may be used to capture two-dimensional (2D) images of the state of a material [4, 5]. We are developing a high-sensitivity sensing method that combines the unique properties of THz waves with a 2D photonic-crystal "metal mesh" [6]. Previously, we successfully used this technique to detect minute differences in protein density and thickness between very thin dielectrics, which were too difficult to detect using THz waves alone [6, 7].

The metal mesh used for our sensing method in the THz region had an opening ratio of approximately 50%. This is far greater than the ratios used in the visible light region. The metal mesh used in our study had a 2D square lattice with square apertures, as shown in Fig. 1(a). The structure was determined by the thickness t, the aperture size in the X direction a_1, the aperture size in the Y direction a_2, the grating period in the X direction g_1, and the grating period in the Y direction g_2. In our measurements, the grid constant g ($g_1 = g_2$.), apertures size a ($a_1 = a_2$), and the thickness t were 260 μm, 183 μm, and 63 μm, respectively. The metal mesh behaved as a band-pass filter, as shown in Fig. 1(b), with a high-efficiency transmission peak in the wavelength region greater than the grating period. This high-efficiency transmittance was believed to be due to the Pendry's Spoof SPP (Surface Plasmon Polariton), which was excited by perforating periodic holes in the metal film [8]. The dip in transmittance appeared only when the THz wave was obliquely incident to the metal mesh.

Here we report a measurement of stratum corneum to inspect the feasibility of applying the metal mesh sensor to observations of compositional variation of human skin.

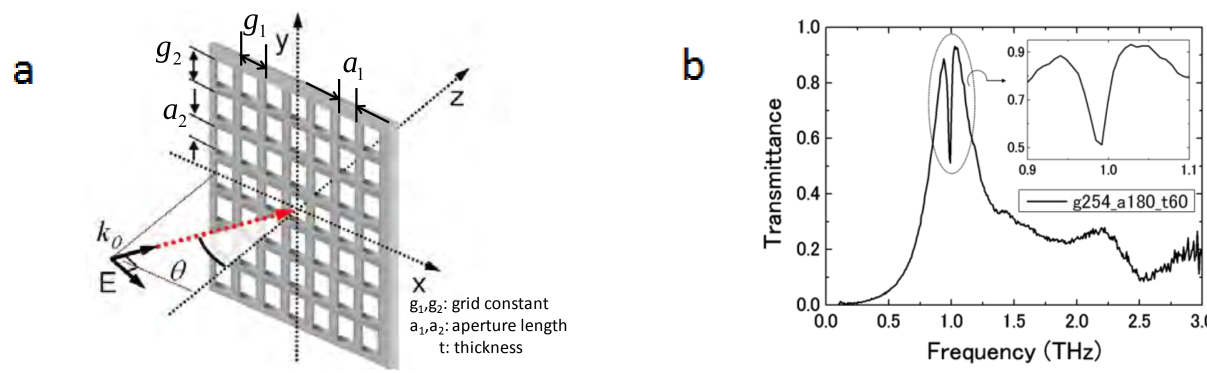

Fig. 1 Schematic and transmission spectrum of the metal mesh

2. EXPERIMENTAL SETUP

We used a terahertz time domain spectroscopy (TDS) system to measure the stratum corneum sample. The experimental setup is shown in Fig. 2-1. Conventional THz-TDS was performed to obtain the transmittance in the frequency range 0.2 to 2 *THz*. Transmission spectra can be acquired using the reference and the sample time domain waveform by the fast-Fourier transform method.

In the human skin measurements, the frequency resolution of the THz-TDS system was 1.1 *GHz*. A parallel THz beam was incident onto the surface of the metal mesh at angle θ as shown in Fig. 2-2. We performed the stratum corneum measurements with an incident angle of five degrees.

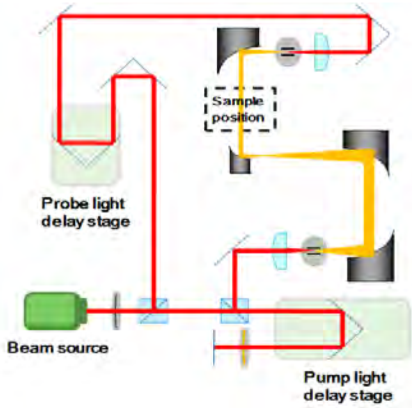

Fig. 2-1 Schematic of the THz-TDS system

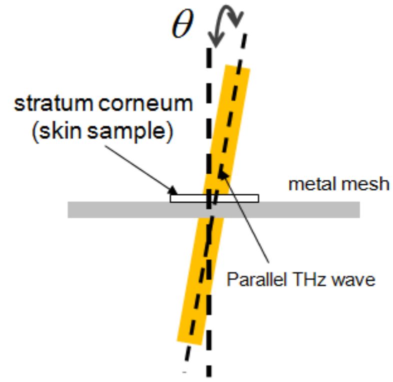

Fig. 2-2 Pattern diagram of the metal mesh sensor

3. EXPERIMENTAL RESULTS

By slowly aspirating pure water in a container with metal mesh at the bottom, the floating stratum corneum sheet sank smoothly onto the mesh. Thus we measured the spectrum of the stratum corneum attached to the metal mesh sensor. Then we dropped 1 *mL* chloroform methanol onto the stratum corneum to dissolve the lipid between cells. We waited for about 15 min to volatilize the chloroform methanol completely, and then measured the spectrum again. After that, we resupplyed mixed solution which had same composition as the human lipid (mixed with ceramide, cholesterol and palmitic acid) back to sample twice to observe the change of spectrum, first time of 10μL and then 25μL. At last, the sample was treated by chloroform methanol once more. The results are shown in Fig. 3.

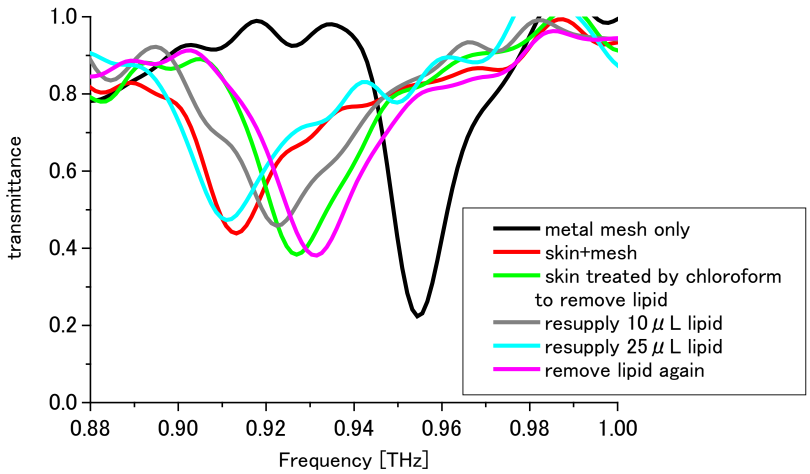

Fig. 3 Shift in the frequency of the dip under different conditions

4. CONCLUSION

We measured the transmission spectra of stratum corneum adhered to a metal mesh. The dips in the frequency of the transmission spectra shifted as the sample conditions were changed. The results demonstrated that the dielectric constant of the metal mesh surface changed after the stratum corneum was attached. After the lipid among the skin cells was dissolved by chloroform methanol, the change was confirmed in the transmission spectra. Thus, these indicated that the metal mesh sensor was sensitive to the lipid content change and could be used to measure compositional variation of human skin by observing its transmission property.

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