Terahertz time-domain spectroscopy system for deflected and reflected metasurface

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***Abstract*—Among the proposed methods for efficient next generation communication, the Intelligent Reflecting Surface (IRS) can be applied as an active or passive type and consists of a metasurface. In order to use the metasurface as a communication device, it is essential to verify the transmitted, deflected and reflected THz properties. However, most of the measurements used so far have been of the continuous wave (CW) type, which means they can only measure at a single frequency. To overcome this, we have constructed a transmissive setup that allows observations from 0.3 to 2.5 THz in a single measurement using generic terahertz time-domain spectroscopy (THz-TDS). Furthermore, we designed experimental setup that could measure transmission, reflection, and deflection by the metasurface.**

Keywords—6G communication, metasurface, terahertz

I. Introduction

Current commercial fifth generation (5G) communications have bandwidths of several GHz and data-rate of up to 20 Gbps with 1 ms latency, but as network-based services such as the Internet of Things (IoT), cloud services, virtual reality (VR), and autonomous vehicles expand and mobile devices become more diverse, it is essential to secure frequency areas with wide bandwidths to handle exponentially increasing data traffic.[1, 2] To improve these, terahertz frequency was suggested for next generation wireless communications with bandwidths of tens of GHz, data-rate of Tbps, and latencies of 0.1 ms. In general, the terahertz band refers to the area of 0.1-10 THz between mm-wave and infra-red, and is applied to various fields such as sensing, imaging, and spectroscopy, and various studies for communication are also actively underway.[3, 4]

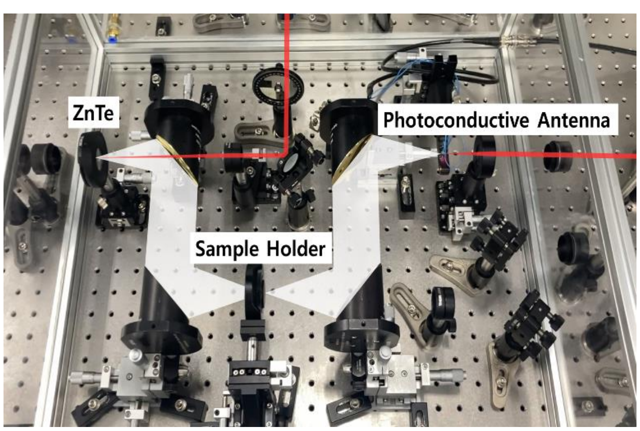

Fig. 1. Picture of THz time-domain spectroscopy system. The photoconductive antenna and ZnTe was used for THz generation and detection, respectivley.

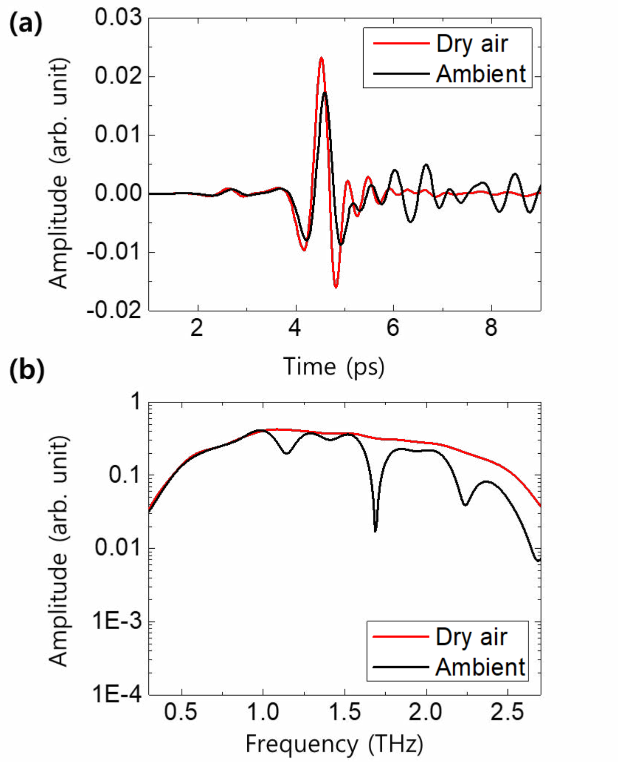

Fig. 2. The time trace (a) and frequency-domain (b) amplitde of ambient (balck line) and dry air (red line). The ambient has a relative humidity of 19%, and the dry air is almost dehumidified.

Metasurfaces are typically used to control these terahertz frequencies. A metasurface is an artificial structure with a sub-wavelength thickness that can be adjusted to the desired frequency depending on the material, shape, and size of the artificial structure, and various studies are currently being conducted on sensing, imaging, and antenna using it.[5-7] Among them, intelligent reflecting surface (IRS) is a technology that plays a relay role between the transmitting and receiving ends to use terahertz as an efficient communication frequency.[8, 9]

Here, we construct THz-TDS setup by using pulse laser for transmitted measurement at normal axis. With this setup, we measured ambient condition and dry air to see the fingerprint of moisture, confirming that observations in the 0.3-2.5 THz region are possible. Based on this spectroscopy system, we designed measurement setup that could measure transmission reflection, and deflection by the metasurface.

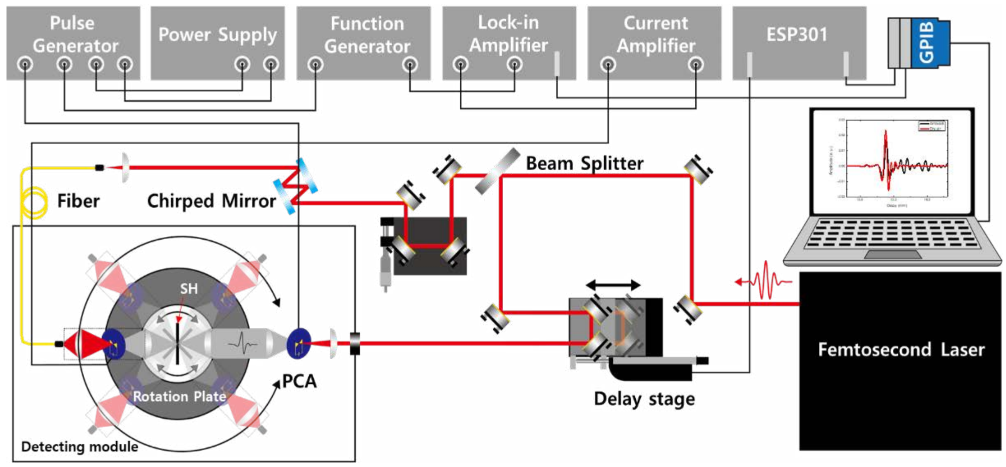

Fig. 3. Schematic of angle dependence THz-TDS setup. The roational base plate was used to enable measurement according to the angle of the transmitted or reflected beam. Furthermore rotational mount was used to enable measurement according to the polarization of the incident beam.

II. Terahertz Time-Domain Spectroscopy

The figure 1. is an image of a typical type of THz-TDS setup as it is set up. In this setup, we use ultrashort pulse laser (80MHz repetition rate, 800 nm center wavelength, 150 femto-second pulse width) and it was divided for pump and probe beam line by using beam splitter. Each beam line was used for THz generation and detection by applying to a photoconductive antenna (PCA) and nonlinear crystal (ZnTe), respectively. Four parabolic mirrors were used to guiding terahertz wave, and sample located between second and third parabolic mirror. This setup can measured transmitted terahertz waves.

It is well known that certain frequencies in the terahertz are absorbed by the vibration and rotation of water. We measured THz transmission under the ambient condition and dry air condition. For the dry air condition, The THz-TDS system is shielded by closed system and a dry air generator was installed so that dry air could be supplied. The measured ambient condition is at 19% relative humidity.

Figure 2. shows the effect of humidity in terahertz range, intuitively. In the time trace (figure 2. (a)) THz amplitude is decrease due to the water molecules in ambient condition. And through the Fourier-transform, frequency-domain (figure 2. (b)) spectrum can be extracted. From the figure 2.(b) the strongest absorption by water is at 1.69 THz, followed by absorption at 2.23 THz, 1.15 THz, and 1.4 THz.[10, 11] This result can give information for selecting a wireless communication frequency.

III. Angle-Dependence THz-TDS

To allow for angle-dependent measurement, we designed THz-TDS setup as shown in figure 3. In the previous setup, a nonlinear crystal (ZnTe) was used to construct the THz detection system through electro-optic sampling (EO-sampling). However for the angle dependent THz measurement, fiber-coupled PCA is used. The PCA can be used as a detector because the current is generated by THz wave after carrier excitation by the pulsed laser. By adopting optical fiber to the PCA, we can have same optical path as the change of the THz detection position.

Unlike conventional THz-TDS, where the laser beam is guided in free-space, fiber-coupled PCA causes significant changes in the laser pulse width because of the dispersion. Therefore, to compensate the fiber dispersion of 800 nm pulse laser, a pair of chirped mirrors is used before the fiber transmission of the laser.

To facilitate rotation, detecting module consisted of a THz lens, PCA and fiber, and was fixed to a rotational base plate that could be rotated. The base plate itself can be rotated 360 degrees, but due to structural issues with the optics, the angle that can actually be moved is limited to the emitter part. This could be improved by moving the emitter and detector farther away from the sample holder using optics with sufficiently long focal lengths, but it is difficult to see a significant change in utility, so the design was made to minimize the reduction in amplitude of the signal measured by tight focusing.

Finally, a rotatable base plate and rotatable mount were considered to change the direction with incident beam and polarization. And then, detection module was also considered to rotate for polarization. These two rotatable setups allow the observation of transmission and reflection of the beam at different angles.

IV. Conclusion

We built a THz-TDS setup based on a pulsed laser. Unlike typical CW sources, we were able to observe the 0.3-2.5 THz region with a single measurement, and we confirmed that the previously reported fingerprints of moisture in the ambient were well measured by measuring the ambient condition. Furthermore, to characterize the metasurface for next-generation wireless communication, we designed a experimental setup that can measure transmission, reflection, and deflection . The angle dependence THz-TDS setup can adjust the angle and polarization of the THz beam incident on the sample with a rotatable base plate with a rotatable mount, and is expected to observe angle-dependent transmission, reflection, and deflection by combining the detector and the rotational base plate. The suggested setup can be expected to enable efficient observation of IRS and beamforming, which are important technologies for next-generation wireless communications.

ACKNOWLEGEMENT

This work was supported by supported by the MSIT (Ministry of Science and ICT), Korea, under the ITRC (Information Technology Research Center) support program (No. IITP-2023-RS-2022-00156353) supervised by the IITP (Institute for In-formation & Communications Technology Planning & Evaluation).

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