Measurement of Glass Complex Permittivity at 200-500 GHz for THz Propagation Simulation

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***Abstract* – Terahertz (THz) band wireless link is promising candidate for the 6G mobile communication standard. However, there are a few experimental data on the reflectance and transmittance characteristics of building materials, such as glass, at the 300GHz band, which is necessary for THz-band radio wave propagation simulation. In this paper, we measured the complex permittivity of glasses at 200-500 GHz by using terahertz time-domain spectroscopy (THz-TDS) and vector network analyzer (VNA), and compared these results. We conducted 300-GHz-band outdoor radio wave propagation simulation by using the measured complex permittivity of the glass.**

***Keywords* —material property, terahertz, propagation**

I. INTRODUCTION

6G, next generation mobile wireless system, research is already underway in industry and academia. In 6G system, the use of terahertz (THz) band has been investigated in order to achieve the data rate of over 100 Gbit/s, because wide contiguous frequency blocks can only be found at THz bands [1]. The propagation model at THz band is important for the practical use of THz wireless system. Reflection and transmission characteristics of building materials are described in Recommendations ITU-R P.527, P.1238, and P.2040 [2]. However, there is no Recommendations that covers the building material properties at over 100 GHz.

In this paper, we measured the reflection or transmission characteristics of glass by using terahertz time-domain spectroscopy (THz-TDS) and vector network analyzer (VNA), and calculated the complex permittivity of the glass from the measured reflection or transmission characteristics. THz-TDS measurement system has advantages of ultra-broad bandwidth, and it can easily eliminate the effects of multiple reflection, because its probe signal is ultra-narrow (>1ps) pulse signal. In case of VNA, the magnitude and phase of the probe signal is very stable. We compared the complex permittivity of the glass with different measurement methods and examined the certainty of the results. We also conducted the radio wave propagation simulation using the measured complex permittivity of the glass.

II. MEASUREMENT OF COMPLEX PERMITTIVITY BY THz-TDS AND VNA

Figures 1 show the diagrams of the complex permittivity measurement systems. Figure 1(a) employs THz ellipsometry technique by using THz-TDS. The complex permittivity of the sample can be obtained by injecting the s-polarized wave and p-polarized wave into the sample and by calculating the ratio of reflectance of p-polarized signal (r_p) over that of s-polarized signal (r_s) [3]. The polarization of the THz pulse signal can be changed by rotating the wire grid placed before Tx and Rx. The complex permittivity of the sample ($\varepsilon_1 - i\varepsilon_2$) was obtained by Eq. (1)

$$\varepsilon_1 - i\varepsilon_2 = \sin^2\theta + \frac{\sin^4\theta}{\cos^2\theta}\left(\frac{1-\frac{r_p}{r_s}}{1+\frac{r_p}{r_s}}\right)^2 \qquad (1)$$

where θ is the incident angle. The incident angle was 60°.

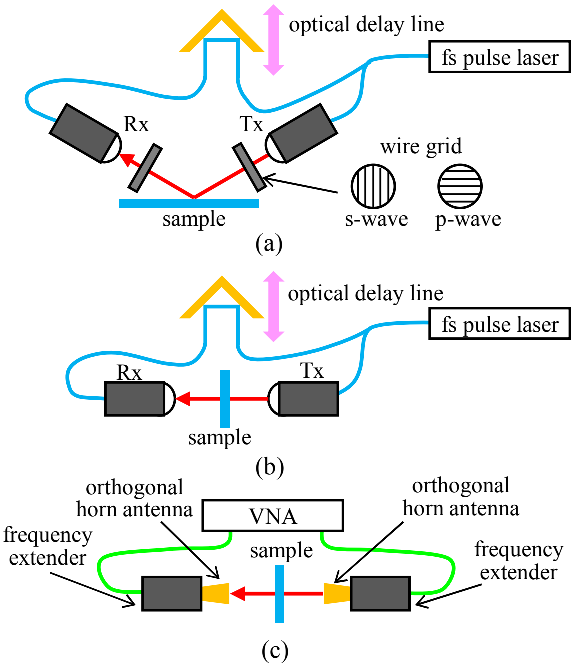


Fig. 1 Experimental setup for complex permittivity measurement of. (a) THz ellipsometry using THz-TDS, (b) Transmission measurement by THz-TDS, (c) Transmission measurement by VNA

Figure 2 shows the complex permittivity of the heat ray absorbing plate glass with a thickness of 3.0 mm. The complex permittivity was obtained by the method shown in Fig. 1(a). Heat ray absorbing plate glass is a float plate glass in which metal ions are doped. The reflected pulse signal was time-gated with a width of 10 ps in order to eliminate the reflection signal at the backside of the glass. The real part of the permittivity decreases from 6.3 to 5.0 at 200-500 GHz, and the imaginary part of the glass is found to be between 0.35 and 0.50 at 200-500 GHz.

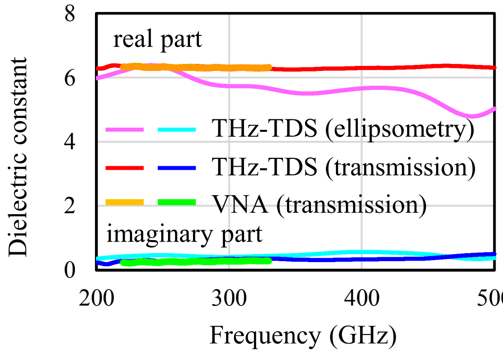


Fig. 2 Complex permittivity of the heat ray absorbing plate glass measured by THz-TDS and VNA.

We can calculate the complex permittivity from the transmission characteristics of the sample by using Eq. (2).

$$\left(x+\frac{1}{x}\right)\sinh(xP)+2\cosh(xP)-\frac{2}{S_{21}}=0 \qquad (2)$$

where $x=\sqrt{\varepsilon_1-i\varepsilon_2}$, $P=\mathrm{j}\beta_0 d$, $\beta_0=2\pi f/c$ with d being the glass thickness, and c being the speed of light [4]. The experimental setup of the transmission characteristics measurement by THz-TDS and VNA was shown in Fig 1(b) and 1(c), respectively. The measurement bandwidth of VNA was 220-330 GHz. Figure 2 also shows the complex permittivity of the same heat ray absorbing plate glass calculated from the transmission characteristics measured by THz-TDS and VNA. The glass permittivity measured by THz-TDS and VNA was almost the same, and both of the real part and the imaginary part of the complex permittivity was almost constant at 200-500 GHz. The real part and imaginary part of the permittivity was about 6.3 and 0.3, respectively. Figure 3 shows the complex permittivity of the float plate glass and frosted float plate glass that are measured by THz-TDS shown in Fig. 1(b). The surface roughness of the frosted glass was 3-10 µm. The complex permittivity is smaller than that of the heat ray absorbing plate glass (real part: 5.8, imaginary part: 0.28 @300 GHz). The complex dielectric constant of the glass and the frosted glass is almost the same at 200-500 GHz. These results indicate that the glass surface roughness of 3-10 µm does not affect the complex permittivity measurement.

We conducted outdoor radio wave propagation simulations using the measured glass complex permittivity shown in Fig. 2. We employed the building data at Shinjuku area. In 6G system, remote antenna units (RAUs) are considered to be mounted on lamp poles and traffic lights at height ranging from 2.5 m to 5 m in order to achieve ultra-high data rate and ultra-high density. Therefore, we set the Tx and Rx height to be 5 m and 1.2 m, respectively. Tx and Rx antenna employs a directional antenna with a half power beam width was 60º. Output power of Tx is 30 dBm. Figure 4(a) and 4(b) shows the received power map and propagation path, respectively. Judging from the relationship between the receiver sensitivity and the date of the 300-GHz-band wireless link [5], 33-Gbit/s data transmission can be achieved within a diameter of 4 m.

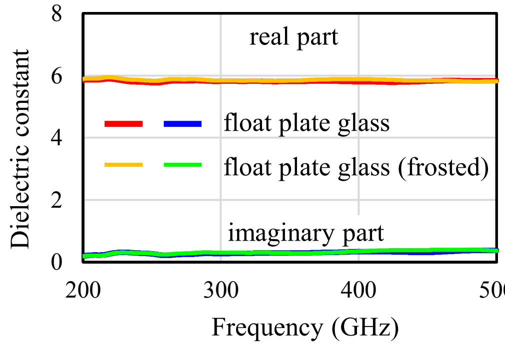
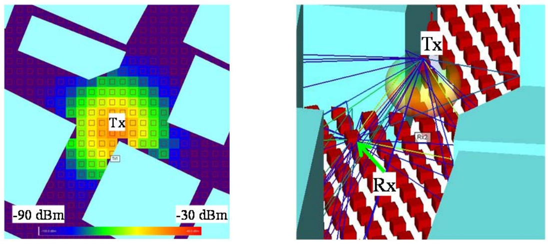


Fig. 3 Complex permittivity of the float plate glass and the frosted float plate glass calculated from the transmission characteristics measured by THz-TDS.



(a) (b)

Fig. 4 (a) Received power map, (b) propagation path.

III. CONCLUSION

We employed terahertz time-domain spectroscopy (THz-TDS) spectroscopy and vector network analyzer (VNA) to obtain the complex permittivity of the float plate glasses at 200-500 GHz. The complex permittivity of the float plate glass is 5.8-0.28i and the measured complex permittivity does not change even though the surface of the float plate glass was frosted. We conducted indoor radio wave propagation simulations using the measured complex permittivity of concrete and glass at 300 GHz.

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