Measurement of Reflection and Transmission Characteristics of Glasses at 300 GHz

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***Abstract*- We evaluated the reflection and transmission characteristics of 7 types of glasses used as building materials at a frequency of 220-320 GHz. In case the incident angle is 0 degree, reflection characteristics is almost the same regardless of the types of the glasses. Transmission characteristics depends only on the thickness of glasses except for heat absorbing plate glass. We measured the dependence of reflection characteristics on the incident angle, and used it as a parameter of materials in the propagation simulation. The indoor propagation simulation results using the measured reflection characteristics of glasses indicates that the reflection at high incident angle in our model is larger than that of ITU-R model.**

I. INTRODUCTION

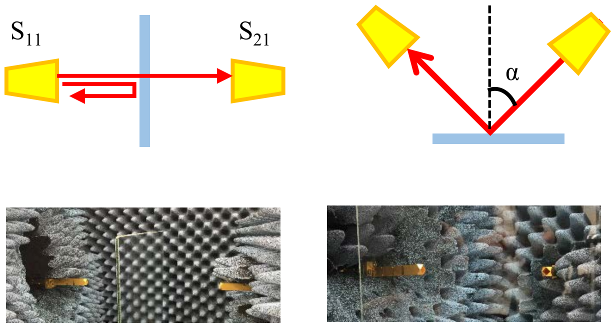
Recently, terahertz (THz) wireless systems whose frequency range is 100 GHz to 3 THz is attracting a great deal of interest for the use of backhaul/fronthaul of “beyond 5G network” or ultra-high-speed short range wireless links. For example, ThoR (TeraHertz end-to-end wireless systems supporting ultra high data Rate applications) project started in 2018 [1]. ThoR is a joint EU-Japan project to provide technical solutions for the data networks beyond 5G based on 300 GHz RF wireless links. Precise radio wave propagation simulations are necessary for the prediction of data transmission characteristics of wireless link system at 300 GHz. To increase the accuracy of radio wave propagation simulation, accurate material property model, such as transmission/reflection coefficient, should be used. Material property models described in Recommendations of IUT-R are usually used for the propagation simulations [2,3]. However, these recommendations cover at a frequency of up to 100 GHz, and there is no recommendation that can be used for the 300-GHz-band THz wave propagations. There are some experimental reports that measured the permittivity of glasses at over 300 GHz [4,5], however, they measured only one glass, and had not shown that their measurement results can be generally applied for material property model that can cover various glasses used as building materials.

In this paper, we measured the reflection/transmission characteristics of 7 types of glasses used for building materials. Moreover, we measured the dependence of reflection characteristics of glasses on the incident angle, and measurement results are used for the radio wave propagation simulation. The simulation results are compared with the simulation results that employed material property model of Recommendation ITU-R that covers a frequency range of below 100 GHz.

II. REFLECTION/TRANSMISSION CHARACTERISTICS OF GLASSES AT 300 GHZ

We measured the reflection/transmission characteristics of 7 types of glasses that are used as building materials. These glasses were supplied from two glass companies, Central Glass Co. and Nippon Sheet Glass Co. The reflection/transmission characteristics of glasses are measured by a vector network analyzer (VNA). The experimental setups and the photographs are shown in Figs. 1. We used two diagonal horn antennas with a gain of 25 dBi, and they are attached with the frequency extenders for the VNA. The experimental setup shown in Fig. 1(a) is used for the evaluation of reflection/transmission characteristics of the glasses, and that in Fig. 1(b) is used to measure the dependence of reflection characteristics on the incident angle (α).

Figure 2 shows the reflection characteristics of glasses. In order to calibrate the free space transmission loss and the loss at the antennas, we measured S_{11} when a metal plate is set instead of the glasses, and we subtracted the S_{11} of the metal plate from that of the glasses. S_{11} is between -5 dB to -10 dB for all types of glasses, and periodic fluctuations are observed. These periodic fluctuations come from the superposition of reflection wave at the glass surface and that at the glass bottom.



(a) (b)

Fig. 1. (a) Experimental setup for measuring the reflection/transmission characteristics of glasses. (b) Experimental setup for measuring the dependence of reflection characteristics of glasses on the incident angle.

Figure 3 shows the reflection characteristics of a frosted glass. S_{11} reflected at the frosted plane is larger than that at the non-frosted plane by 1.3 dB. The periods of fluctuation are same for both of S_{11}. The roughness of the frosted glass is generally several tens of μm, which corresponds to below 1/10 of the wavelength at 300 GHz. There is a possibility that the roughness of the frosted glass could scatter the 300-GHz THz waves.

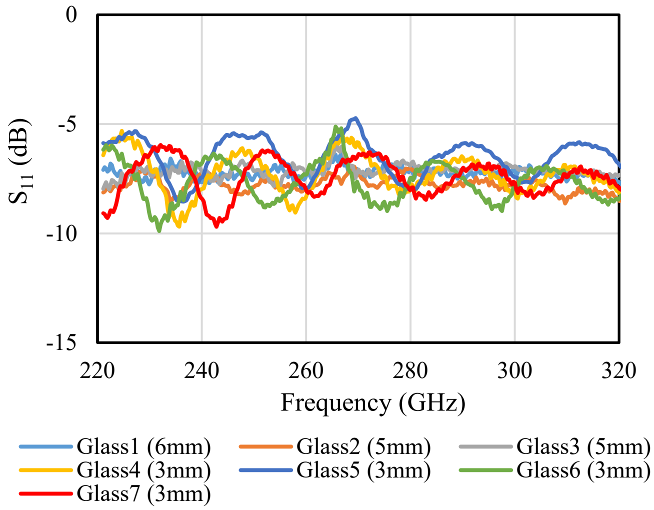


Fig. 2. Measurement results of reflection characteristics of glasses.

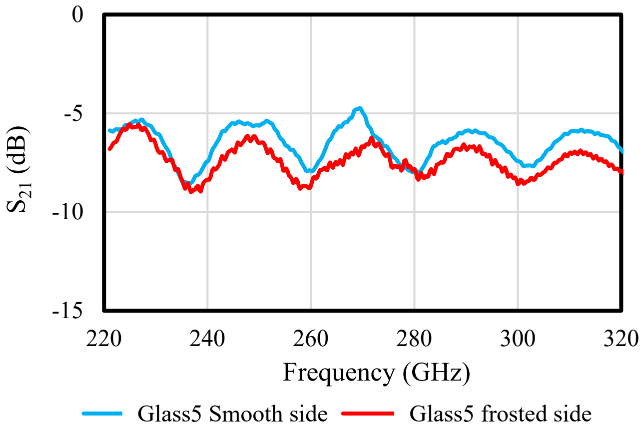


Fig. 3. Measurement results of reflection characteristics of the frosted glass.

Figure 4 shows the transmission characteristics of glasses. In case the glass thickness is 3 mm, their transmission characteristics are almost same. S_{21} decreases as the frequency increases, and S_{21} at 320 GHz is about 2.3 dB smaller than that at 220 GHz. In case the glass thickness is 5 mm, there is a large difference between two types of glass. S_{21} of Glass 2 is about 3 dB larger than that of Glass 3. Glass 3 is heat absorbing plate glass, and it is colored by adding a small amount of metal component in the plate glass composition, which prevents the transmission of THz waves. S_{21} of the glass (Glass 1) with a thickness of 6 mm is almost equal to the square of S_{21} of the glasses with a thickness of 3 mm. This result indicates that the transmission loss coincides with the general properties of transmission loss.

Figure 5 shows the dependence of reflection characteristics of 3-mm-thick glass (Glass7) on the incident angle. As the incident angle increases, S_{21} increases. The period of the fluctuations becomes shorter as the incident angle decreases.

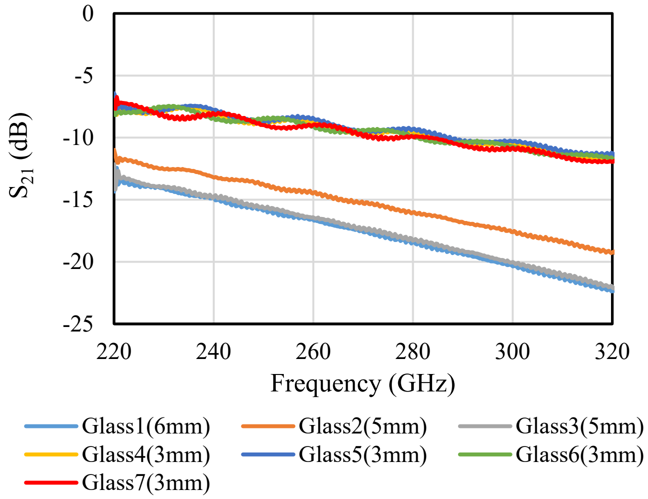


Fig. 4. Measurement results of transmission characteristics of glasses.

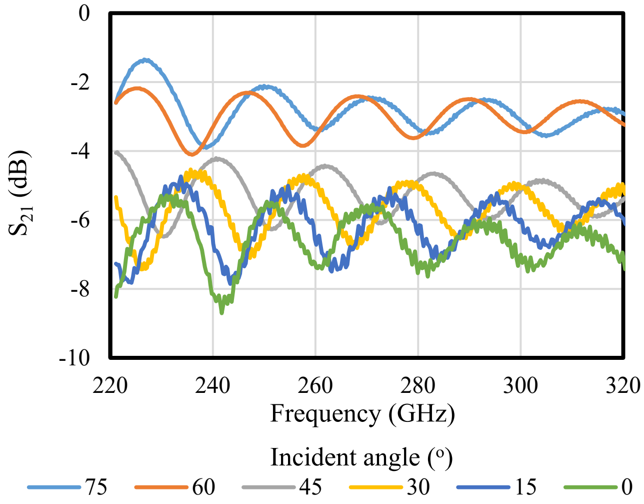


Fig. 5. Dependence of reflection characteristics of Glass7 on the incident angle.

III. INDOOR PROPAGATION SIMULATION

We conducted indoor propagation simulations using the measured reflection characteristics shown in Fig. 5. We employed Wireless Insite [6] for radio wave propagation simulator. Wireless Insite has several built-in material property models for the simulation of reflection/transmission characteristics. We can make new material property model using the measurement results of dependence of reflection characteristics on the incident angle, and can use it in the radio wave propagation simulations. We employed the material property model of Glass7 using the experimental results shown in Fig. 5.

Figure 6 shows the indoor propagation model and the simulation results of propagation path loss. The size of the room is 20 m x 60 m x 3 m. Tx and Rx are set 20 m apart from each other. The height of Tx and Rx is 2 m, and omni-directional antenna with an E-plane half power beamwidth of 10° are used for Tx and Rx. The carrier frequency is 300 GHz and Tx output power is 10 dBm. The walls of the room are set to be concrete, and we set a glass (40 m x 1 m) that employs our material property model on the wall. We employed the built-in ITU-R glass model [3] for comparison. The received power of the path that THz wave reflects at the glass one time is -76.5 dBm for the ITU-R model, and -79.3 dBm for our model. The received power of the path that THz wave reflects at the glass one time and at the concrete wall one time is -88.4 dBm for the ITU-R model, and -87.7 dBm for our model.

Figure 7 shows the map of the received power simulated by changing the Rx position. Received power is almost the same near Tx. Compared with the ITU-R model, the received power of our model is higher in many areas at the left side of the room. These results indicate that the reflection at high incident angle in our model is larger than that of ITU-R model.

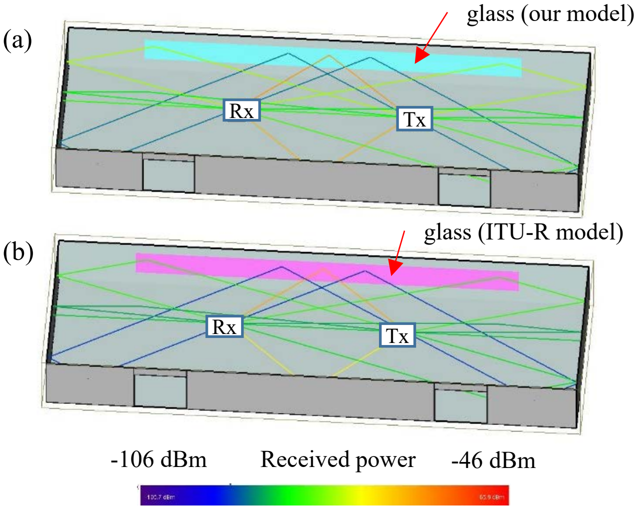


Fig. 6. Simulation results of propagation paths using (a) our model and (b) ITU-R model.

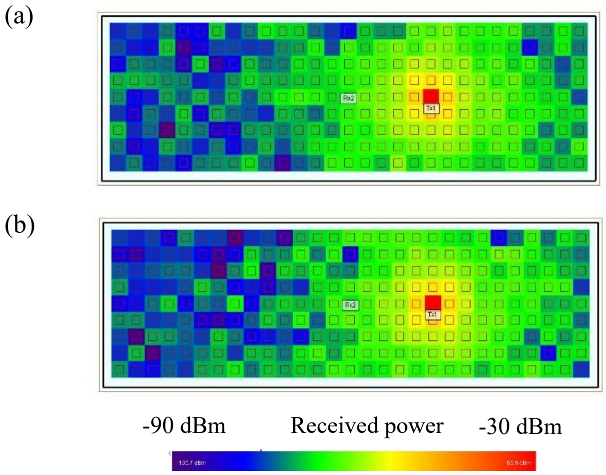


Fig. 7. Simulation results of received power maps using (a) our model and (b) ITU-R model.

IV. CONCLUSION

We evaluated the reflection and transmission characteristics of 7 types of glasses used as building materials at a frequency of 220-320 GHz. In case the incident angle is 0 degree, S_{11} is between -5 dB to -10 dB for all types of glasses, and periodic fluctuations are observed. Transmission characteristics depends only on the thickness of glasses except for heat absorbing plate glass, and the difference of the transmission loss between the normal plate glass and heat absorbing plate glass is about 3 dB at 300 GHz. We measured the dependence of reflection characteristics on the incident angle, and used it as a parameter of materials in the propagation simulation. The simulation results of indoor propagation using the measured reflection characteristics of glasses indicate that the reflection at high incident angle in our model is larger than that of ITU-R model.

ACKNOWLEDGMENT

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