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Microwave reflection intensity measurement for dielectric material using a single probe

Hirofumi Kakemoto *, Satoshi Wada, Takaaki Tsurumi

Department of Metallurgy and Ceramics Science, Graduate School of Engineering, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8552, Japan

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Abstract

Microwave reflection intensity for microwave absorber, Cu-plate and Al_2O_3 (1 0 0 0) single crystal substrate was measured from 8 to 11 GHz as a function of distance between single probe and sample at room temperature. The minimum reflection intensity was observed in the distance of 0.2 mm between single probe and sample at 9.4 GHz, although the reflection intensity was decreased with increasing distance in other measurement frequencies. The electromagnetic field analysis was hence carried out for simulation model that is defined with coaxial cable, probe and sample using finite differential time domain method. The reflection coefficient and impedance for simulation model were calculated, and compared to the experimental data. The results of electromagnetic analysis shows that the minimum point of reflection intensity was caused from an impedance matching.

Keywords: Al_2O_3; Impedance; Single

1. Introduction

The resonance method is widely used for high frequency measurement of dielectric materials. Although the resonance method shows the accurate data for dielectric materials, the measurement frequency is however limited by the resonator size.[1,2] The impedance (Z) method on the other hand measures the continuous dielectric spectrum in frequency domain. Commonly, in the dielectric measurement, the electrodes were deposited on surface of sample in order to load the voltage. Hence, the obtained data present total dipole moment behaviors of sample between the both electrodes.[3] The dielectric and ferroelectric materials have however uneven dipole moment behaviors that form the domain structure. Hence, the domain structure need to investigated in the microwave frequency region. Although the free space method is useful for high frequency dielectric measurement technique without electrodes, the horn antenna and dielectric-lens that are equipped with the measurement apparatus have a limit to investigate for domain structure of sample.

In order to spread the frequency range and to remove electrode limitation, we try to measure the microwave reflection (r) intensity using a single probe without electrode, contact and resonance phenomena.[4–6] In addition, due to comparing the experimental data, the electromagnetic analysis was also carried out using the finite differential time domain (FDTD) method, and reflection coefficient (Γ) and Z were also calculated in the view of Z matching.

2. Experimental

Fig. 1 shows schematic illustration of the measurement system. The measurement system was assembled from the microwave oscillator that is equipped with the gun diode, directional coupler, detector and single probe. The measurement frequency was controlled using mechanical tuner for wide range (from 8 to 11 GHz) and electronic tuner for narrow range (up to 40 MHz) region.

The probe was prepared using a semi-rigid coaxial cable. The inner and outer radii of coaxial cable were sized about 0.99 and 3.0 mm, respectively. The probe was formed from a coaxial cable removed outer conductor and sealing material, and probe length was fixed to 8.0 mm. The r was measured automatically using GPIB interface (Agilent 82357A). The measured r was calibrated by immersing probe into ethanol bath (dielectric permittivity: $\varepsilon_r = 24.5$) as open state and using a microwave absorber as short state.

* Corresponding author. Fax: +81 3 5734 2829.
E-mail address: hkakemot@ceram.titech.ac.jp (H. Kakemoto).

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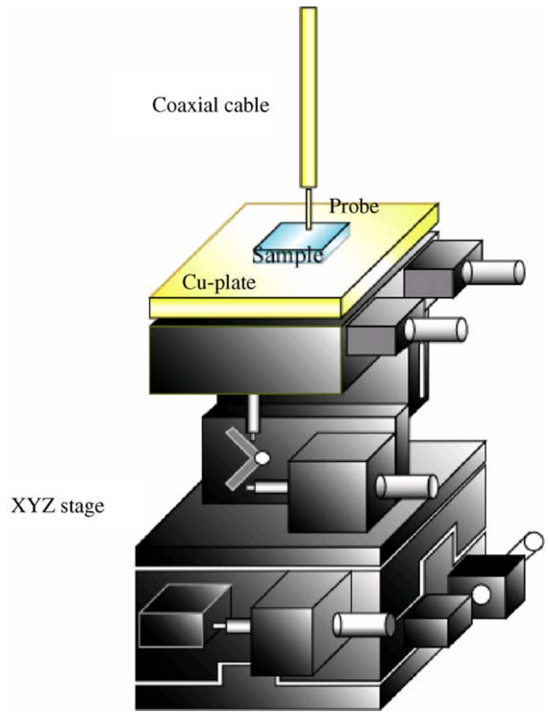

Fig. 1. Schematic illustration of measurement equipment.

The Cu-plate (60 mm × 60 mm × 2 mm) and Al_2O_3 (0 0 0 1) single crystal substrate (ALO, $\varepsilon_r = 10$, size: 10 mm × 10 mm × 0.5 mm) were selected for reference and the sample, respectively. They were put to the XYZ stage, as shown in Fig. 1. The measurement was carried out from 8 to 11 GHz as a function of distance (d) between probe and sample at room temperature.

The electromagnetic field analysis was carried for simulation model that was defined with coaxial cable, probe, Cu-plate and sample using finite differential time domain (FDTD) method. The FDTD analysis was performed using Magna TDM software (CRC solutions). Using electromagnetic field analysis, the electric field distribution was visualized, and then Γ and Z were also calculated using FDTD method.

3. Results and discussion

3.1. Reflection intensity measurement for Cu-plate

The r intensity measurement was firstly carried out for Cu-plate as reference from 8 to 11 GHz. The r intensities decreased with increasing d between probe and Cu-plate in the almost measurement frequency region.

Fig. 2 shows, for example, the r intensities versus d of Cu-plate at 8.6 and 9.4 GHz. At 8.6 GHz, the r was decreased with increasing d from $d = 0$ point. On the other hand, at 9.4 GHz, the minimum r intensity was appeared at $d = 0.2$ mm. The r scale was different at 8.6 GHz and at 9.4 GHz in Fig. 2. The probe length was fixed to 8 mm, that is λ/4 of electromagnetic wave at 9.4 GHz. The r scale in Fig. 2 was compared with calibration values for both measurement frequencies. As the result, this intensity difference was caused from frequency dependence of oscillator power and probe length. The probe was hence act as a λ/4 dipole antenna.

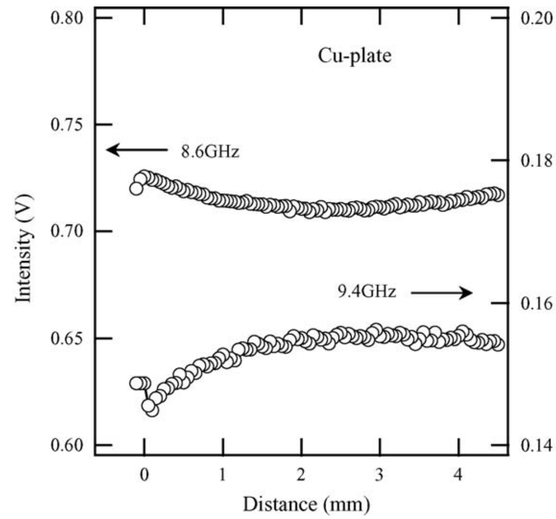

Fig. 2. Reflection intensities of Cu-plate at 8.6 and 9.4 GHz.

3.2. Reflection intensity measurement for Al_2O_3

Fig. 3 shows the r intensities of Cu-plate (dashed line) and ALO (solid line) at 9.4 GHz. The r intensities of Cu-plate and ALO present the minimum values at $d = 0.2$ mm. The r intensities of Cu-plate and ALO showed values very close to each other in near minimum r intensity point. In addition, minimum value of Cu-plate and ALO is different. This is caused from the difference between impedance value of Cu-plate and ALO, i.e. dielectric permittivity (ε_r) if Z matching was done at $d =$ 0.2 mm.

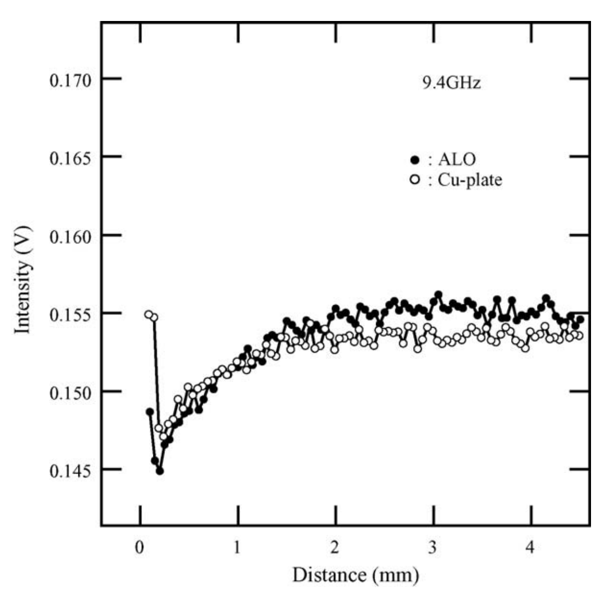

Fig. 3. Reflection intensities of Cu-plate and Al_2O_3 single crystal substrate.

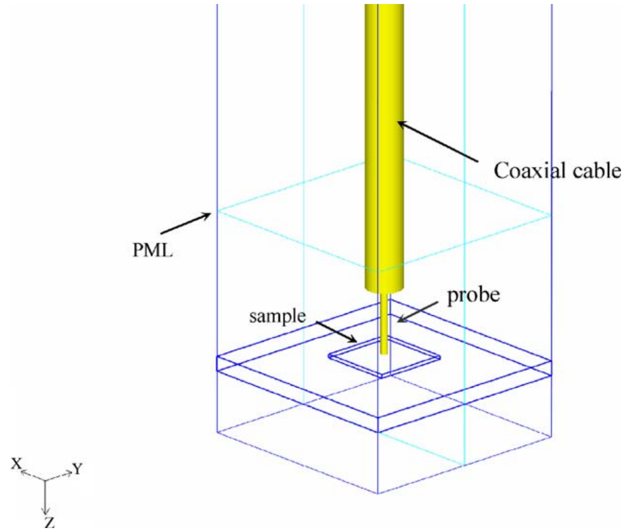

Fig. 4. Simulated model using FDTD software.

3.3. Electromagnetic field analysis

In order to analyze electric field distribution around sample (ALO), probe and obtained r intensity in Fig. 3, the electromagnetic field analysis was carried out using FDTD method (software: Magna TDM software).

The sizes of sample, probe and a part of coaxial cable were used as input in Magna TDM software. These parts were defined in perfect multi-layer (PML), which absorbs electromagnetic wave. Fig. 4 shows the simulation model for the measurement system with sample, probe and coaxial cable as input for software. The input parts were meshed within λ/10, where λ is wavelength of electromagnetic wave. The electromagnetic analysis was made using Maxwell-equation in differential form. The input voltage function to simulation model was selected for Gaussian-pulse. The time domain response of simulation model was analyzed, and then frequency domain Z and Γ for simulation model were calculated using Fourier transformation of time domain data.

In order to understand the minimum r intensity in Fig. 3, the electromagnetic analysis was carried out for simulation model in Fig. 4. Fig. 5 shows the result of electromagnetic field analysis at 9.4 GHz and $d = 0.2$ mm. The analyzed result showed the electric field around a probe and sample, and the transmission of electromagnetic wave in to the sample was observed in Fig. 5. The electric field toward sample and reflection to probe were clearly observed in Fig. 5(a). In addition, the electric field is spread to x-axis as observed in Fig. 5(b). As shown in Fig. 1 and discussed in the above section, the electric field distribution in Fig. 5(b) is similar like that of dipole antenna.

3.4. Impedance matching

The obtained Γ in above electromagnetic analysis was shown in Fig. 6. The Γ was presented with a minimum value at $d = 0.2$ mm, and Γ was estimated to be 0.34 at $d = 0.2$ mm. In addition, Γ is defined as follows, $\Gamma = (Z - Z_0)/(Z + Z_0)$, where

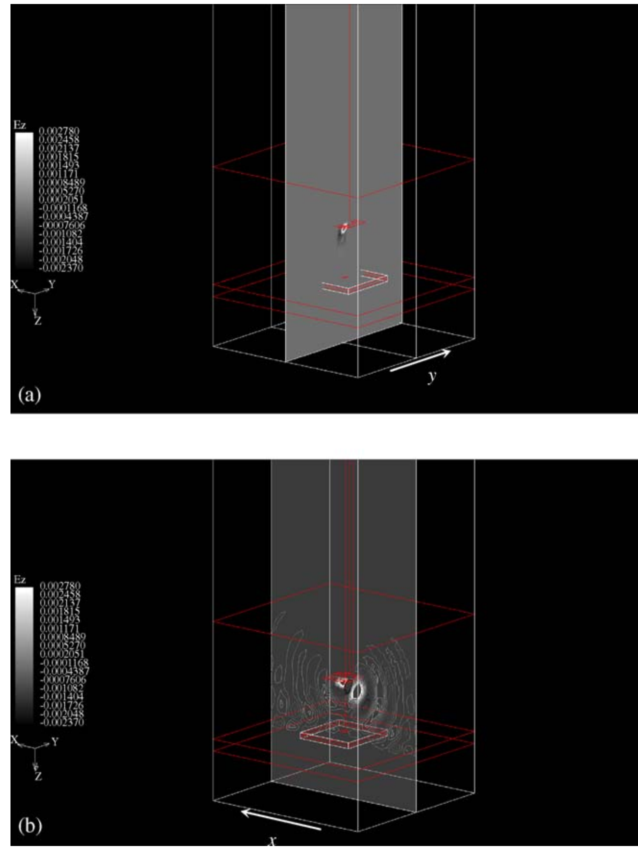

Fig. 5. Electric field distributions obtained by electromagnetic analysis, cross-section of (a) y-direction and (b) x-direction.

Z_0 is characteristic impedance (50 Ω). Z was also calculated to be 98.7 Ω from electromagnetic field analysis. The Γ and Z at $d = 0.2$ mm in Fig. 6 are satisfied by the above relation ship. Hence, the obtained simulation results shows that the minimum

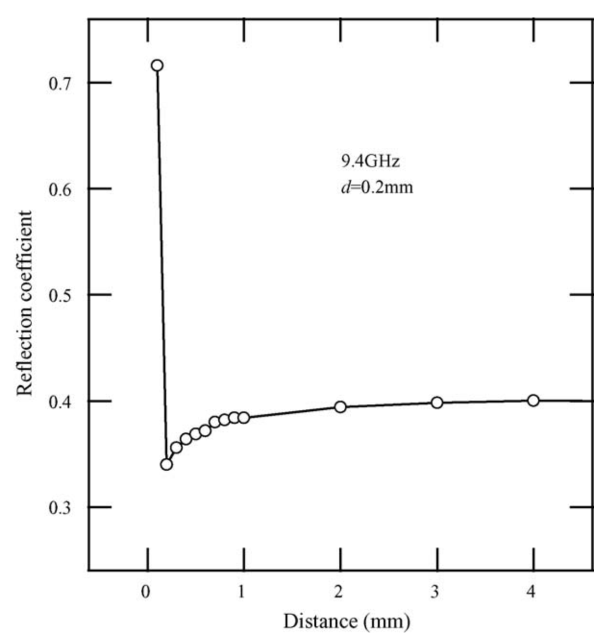

Fig. 6. Reflection coefficient obtained from electromagnetic analysis.

point of r intensity indicates Z matching. Therefore, r intensity in minimum point is caused from ε_r of samples.

4. Conclusion

In conclusion, the reflection intensity measurement was performed using a single probe as a function of distance between probe and samples at room temperature. The minimum reflection intensity was presented at distance of 0.2 mm at measurement frequency of 9.4 GHz. In order to analyze this minimum reflection intensity, electromagnetic field analysis was demonstrated. The experimental reflection intensity spectrum at 9.4 GHz was compared with results of electromagnetic field analysis. As a result, this minimum reflection intensity was caused by an impedance matching.

The possibility of dielectric measurement without electrodes and contact was shown by obtained experimental result and electromagnetic field analysis. If reflection coefficient and phase would be estimated, dielectric permittivity of sample in microscopic region can be calculated. However, the calibration is not fully carried out for measured reflection intensity in order to transform reflection coefficient. Therefore, dielectric permittivity cannot be estimated from the obtained reflection intensity. Hence, dielectric permittivity transformation from reflection intensity is the future investigation.

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