Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.550-551

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High frequency dielectric mapping using un-contact probe for dielectric materials

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1.Introduction

Nowadays, dielectric devices, such as multi-layered ceramics capacitors (MLCCs), were miniaturized and used at high frequency region. Recently, the local dipole moment behavior in miniaturized MLCCs has been reported about their core-shell structure.[1] The uneven dipole moment behavior in dielectric materials is well known, and local dipole moment behavior should be also investigated in high frequency region. The local dipole moment behaviors were difficult to be investigated from total dielectric properties. Therefore a high frequency measurement method for the local dielectric properties should be developed.

Identically, a high frequency measurement method for the local dielectric properties is desired as follows below, i) measurable local dipole moment behavior, ii) prevent resonance effect, and iii) frequency free. Therefore, un-contact probe is useful as the high frequency measurement method, however the impedance (Z) in measurement system is changed as a function of phase in input electric (*E*) field. In this report, we propose a measurement method for high frequency region. The reflection intensity (*r*) using un-contact probe was measured in high frequency, and *r* was successfully transformed to dielectric permittivity (ε_r).

2.Experimental

Figure 1 shows the measurement system and simulation model. The measurement system was, as shown in Fig.1(a), constructed from an oscillator generated by a gun diode (8.5-11GHz), phase shifter (0-360^o), directional coupler, detector (diode), test-probe (0.99mmϕ, Micro Denshi Co. Ltd.) and micro-probe (6μmϕ, KEYCOM Corp.). The frequency was ranged from 8.5GHz to 11GHz. The test-probe was formed from semi-rigid coaxial cable. The test-probe was sized 8mm for length. The micro-probe was sized also 8mm, and it was attached to top of coaxial cable. The *XYZ*-stage was moved by d.c. servomotors (Chuo precision industrial Co.Ltd.) for setting to each axes, and they are controlled by a personal computer using GP-IB interface. The sample was selected for Cu-plate (reference, size: 40x40x2.0mm^3), Al_2O_3(1000) (ALO) and $SrTiO_3$(100) (STO) substrates (Shinko-sha Co.Inc., size: 10x10x0.5mm^3). The reflection intensity (*r*) was measured at room temperature as a function of distance (*d*) between probe and sample. In additon, the scanning for *XY*-plane was carried out for samples.

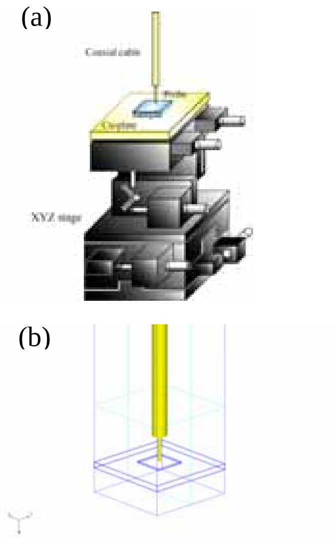
Fig.1 The measurement system (a) and simulation model for electromagnetic analysis (b).

The electromagnetic (EM) analysis was carried out using finite differential time domain (FDTD) method using MAGNA/TDM software (CRC solutions Corp.). Figure 1(b) shows the simulation model. The size and physical quantities were input to the simulation model, and then Gaussian pulse was loaded to simulation model. The reflection coefficient (Γ) and Z were calculated using results of EM field distribution.

3.Results and Discussion

3.1 Reflection intensity for Cu-plate

Figure 2 shows the *r* intensity for Cu-plate as a function of distance between probe and Cu-plate at 9.4GHz. The *r* intensity showed minimum value at *d*=0.2mm only at 9.4GHz, and *r* at other frequencies was increased with decreasing *d* in Fig.1(a). Figure 3 shows the *r* intensity for ALO and STO as a function of *d*. The *r* was increased with increasing ε_r of sample (ALO:ε_r=10, STO:ε_r =310). In order to investigate *r* property, the EM analysis was carried out using simulation model in Fig. 1(b).

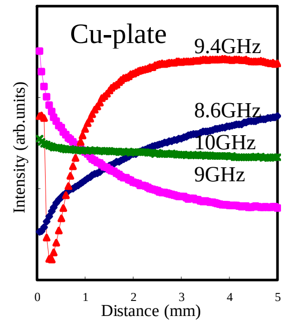

Fig.2 Reflection intensity for Cu-plate as a function of distance.

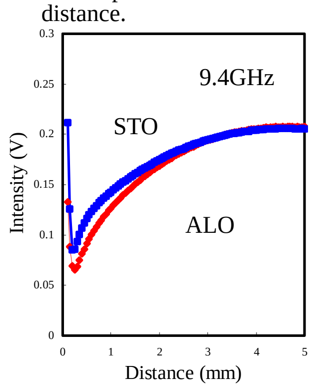

Fig.3 Reflection intensity of Al_2O_3 and $SrTiO_3$.

3.2 Results of electromagnetic analysis

The E field distribution of ALO (ε_r=10) was calculated by EM analysis. The E field distributes to space and sample surface, and obtained E distribution presents a dipole antenna. From E field distribution, Γ, Z and θ of Γ were calculated. Figure 4 shows Γ as a function of d. Γ is also presents minimum value at d=0.2mm. The Γ and Z were calculated 0.34 and 98.7Ω at d=0.2mm, respectively. The relationship between Γ and Z is expressed in eq.(1)

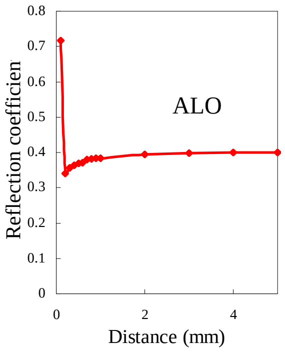

Fig.4 Reflection intensity of Al_2O_3 calculated by electromagnetic analysis.

$$\Gamma=(Z-Z_o)/(Z+Z_o), \qquad (1)$$

where Z_o is the characteristic Z defined as 50Ω. The Γ and Z at d=0.2mm in Fig.4 are well accordance with eq.(1).[2]

3.3 Reflection intensity and reflection coefficient of ALO and STO

Figure 5 shows the r (Fig.3) and Γ (Fig.4) properties of ALO and STO. (The open circle is calculated value of EM analysis.) At d=0.2mm, Γ of ALO and STO is 0.34 and 0.36. From results in section 3.2, impedance matching was found at d=0.2mm. Hence, the d presents minimum r can be considered as the electrical length (l).

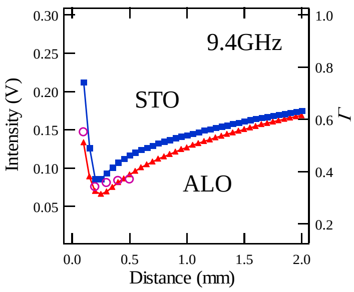

Fig.5 Plots of reflection intensities (experimental) and coefficient (analysis) of Al_2O_3 and $SrTiO_3$.

3.4 Transform to dielectric permittivity

From the result in section 3.3, Z in eq.(1) indicates Z of sample ($Z_l=1/j\omega C$, where C is capacitance of sample). The C of sample is $C=\varepsilon_r\varepsilon_o S/d_o$, where S is effective EM wave irradiated to sample. The S was calculated from eq.(1) as $Z=Z_l$.

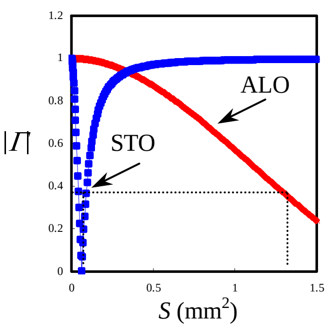

Fig.6 Reflection coefficient versus effective area.

Figure 6 shows the Γ as a function of S. The S was decided to be 1.33mm^2 (ALO) and 0.06mm^2 (STO) in Fig.6. As shown in Fig.6, S was decreased with increasing ε_r. From above discussion, the ε_r at d=0.2mm was estimated using eq.(2)

$$\varepsilon_r = 2|\Gamma|\sin\theta/[\omega C_o Z_o(|\Gamma|^2+2|\Gamma|\cos\theta+1)], \qquad (2)$$

where θ=90°, $\omega=2\pi f$, $C_o=\varepsilon_o S/(0.5\text{mm})$ and Z_o=50Ω.[3] Figure 7 shows the ε_r versus l. The ε_r of ALO and STO is estimated to be 8.9 and 290. The ε_r in Fig.7 is accordance with the ε_r of samples. Figure 8 shows the r mapping of ALO at 9.4GHz. The obtained mapping shows the homogeneous distribution of r reflecting ε_r of ALO.

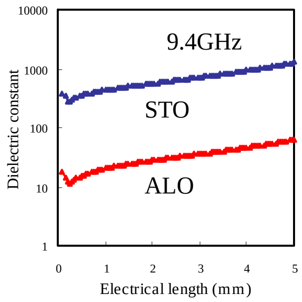

Fig.7 Dielectric permittivity of samples versus electrical length.

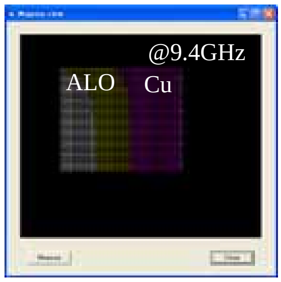

Fig.8 Reflection intensity mapping of Al_2O_3/Cu-plate.

4.Conclusion

Using un-contact probe, the reflection intensity measurement at high frequency was carried out for dielectric materials. The reflection intensity showed the minimum value at distance of 0.2mm. The reflection intensity minimum point presented an impedance matching one. The dielectric permittivity of samples was calculated by using reflection intensity minimum point value and result of electromagnetic analysis. In addition to dielectric permittivity calculation, in-plane reflection intensity mapping was also obtained.

Acknowledgment

The author would like to thank Y.Suzuki (KEYCOM Corp.) for designing micro-probe, and M.Saruhasi (CRC solution Corp.) for useful discussions of electromagnetic analysis. This work was supported by Japan Society Promotion of Science (Project No.16760542).

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