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Al_2O_3 crystal의 유전손실계수 측정에 관한 연구

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A study on dielectric loss tangent measurement with Al_2O_3 crystal

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Abstract

The standards of the capacitance are measured and analyzed by the dry nitrogen or mica film as a dielectric. In this paper, respectively the standard capacitors of 10 pF and 100 pF for the establishment of the dielectric loss tangent are made by Al_2O_3 crystal disc with the low dielectric loss tangent, and then measured the dielectric loss tangent with precision. To regard for the existence of capacitances just in the dielectric, 3-terminal configuration electrode is used. With using the 2D electric field simulator, precise design values are derived in addition to stray capacitance. As stated above method, respectively the standards of the capacitances with 10 pF and 100 pF are made with the low dielectric loss tangent less than 10^{-4}.

I. Introduction

The capacitor, which is simply defined two conductors embedded in a dielectric, has function of the energy stored. The stored energy of the capacitor is proportioned to an area of the dielectric, but has inverse proportion to the thickness of the dielectric [1][2]. The study of the capacitor has been focused on dielectric properties which are a dielectric constant, loss tangent and stability with variety dielectric. The dry nitrogen or mica film as a dielectric, are generally used the standards of the capacitance at 1000 Hz. In the reforming of the capacitances, the dielectric loss tangent ($\tan\delta$) must be also reformed. Practically, for lack of the standard dielectric loss tangent, the basic property of the variable air capacitor is employed the primary standard of the dielectric loss tangent. Futhermore, the processes of the complicated measurements are needed at any standards of each ranges.

Al_2O_3 crystal is corundum structure, which show the hexagonal closest packing with the oxygen and the stratiform structure -ABABA. Al^{3+} ion is located on interstice with 6 oxygen between layers. In the paper, with using the Al_2O_3 crystal with low loss tangent and almost stability to frequency, the standard capacitors for the establishment of the dielectric loss tangent is designed and produced. As using the high quality Al_2O_3 crystal disc with parallel structure and protecting the electromagnetic effects, the standard capacitors with low loss electrode are produced with 3-terminal structure in the metal construction.

II. Electrode property and design

The electrode is designed as a 3-terminal configuration to obtain the measurement with the trustworthy. To produce the precise 10 pF and 100 pF capacitors, the dependences of the dielectric constant, the electrode dimension, the thickness of dielectric and the stray capacitance are existed respectively.

The basic equation for a capacitance is expressed as follow;

$$C = \frac{\varepsilon_0 \varepsilon_r S}{d} = \frac{8.854\times10^{-12}\varepsilon_r S}{d} \quad [F]$$

In the above equation, S and d are respectively the surface area of the electrode and the thickness of the dielectric. ε_0 and ε_r are the dielectric constant of air and dielectric material.

As the electrode, the silver, which is solderable conductor, is suitable for screen printing ,contains the 75 % silver and is dried during 5 ~ 10 min. at 150 ~ 200 ℃, is used.

And to reduce the loss in the electrode, the thickness of the electrode is limited by below 0.02 mmt.

Ⅲ. Experiment and result

Before the prototype fabricating, the design values of prototype are simulated in R-Z coordinate system with the electric field simulator. The simulated results are respectively 9.967 pF and 99.83 pF in 10 pF and 100 pF when 10 V is biased. Practically, the considering about an augmentation of the capacitance must be caused by the stray capacitance. So, the simulated values of needed capacitances must not the above quantity.

In the Fig. 1. and Fig. 2., respectively the equipotential line and the mesh-plot with using the simulated values in the metal construction are shown. From the equipotential line, the stray capacitance, which are located on the gap, between main and guard electrode, and the edge of electrode, are known.

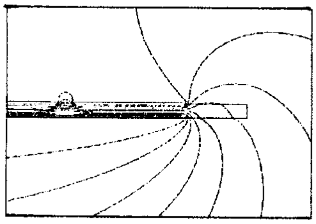

Fig. 1. Equipotential line in electric field simulator

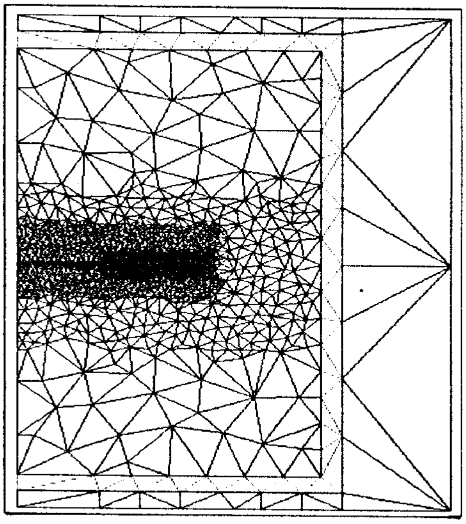

Fig. 2. The mesh-plot in metal construction

In the metal construction, the lead line, which is flexible, coated with Ag and shielded the teflon with low loss tangent from Al_2O_3 crystal disc to output port is used. The connection method to a measuring instrument is 4-terminal pair, being the potential sensing cable separated from the current signal path and being reduced the related errors from inductance, resistance and stray capacitance in BPO coaxial cable. Simultaneously, the capacitance and loss tangent are measured in 100 ~ 5000 Hz and 1000 Hz with HP 4194A Impedance/Gain-Phase Analyzer. The capacitance of 10 pF and 100 pF Al_2O_3 crystal disc capacitor is shown as follow table. The accurate values are obtained by clipping main electrode. In this progress, capacitance is reduced but loss tangent still is fixed.

In the Fig. 3. and Fig. 4. respectively, capacitances of Al_2O_3 crystal for 10 pF are measured at 1000 Hz and from 100 to 5000 Hz. With the same configuration, capacitances of Al_2O_3 crystal for 100 pF are measured in Fig. 5. and Fig. 6.

	10 pF		100 pF	
	C [pF]	tan δ	C [pF]	tan δ
1	11.5	3.6751×10^{-4}	101.27	3.6521×10^{-4}
2	11.3	3.6603×10^{-4}	100.98	3.6587×10^{-4}
3	10.9	3.6684×10^{-4}	100.12	3.6524×10^{-4}
4	10.05	3.6650×10^{-4}	100.004	3.6555×10^{-4}

Table 1. Results of 10 pF and 100 pF at 1000 Hz

Ⅳ. Conclusion

In this paper, respectively the standard capacitors of 10 pF and 100 pF for the establishment of the dielectric loss tangent are made by Al_2O_3 crystal disc with the low dielectric loss tangent, and then measured the dielectric loss tangent with precision.

1) Al_2O_3 crystal is difficult to process but is given to lower dielectric loss tangent than general dielectric material and has stable frequency of 10^{-4} and less.

2) In electrode design on Al_2O_3 crystal disc, 2D electric field simulator is determined most suitable electrode values.

3) The quality of material and manufacture of electrode using silver, also dried as being made to high temperature hardening are ascertained to be superior to mechanical property or soldering.

4) The connection method to a measuring instrument is 4-terminal pair, being reduced the related errors from inductance, resistance and stray capacitance in BPO coaxial cable.

5) Through above methods, the results is gained that dielectric loss tangents of 3.6650×10^{-4} and 3.6555×10^{-4} are showed in 10.05 pF and 100.004 pF respectively. So, Al_2O_3 crystal disc capacitors can be used for dielectric property measurement and evaluation.

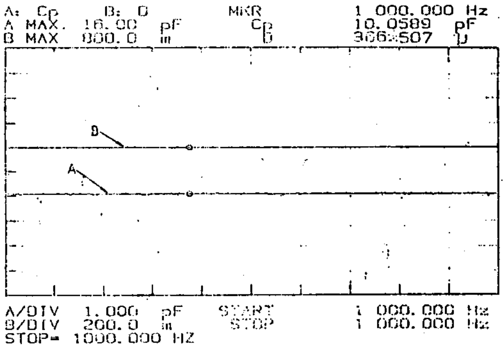

Fig. 3. The capacitance and loss tangent of Al_2O_3 crystal capacitor for 10 pF at 1000 Hz

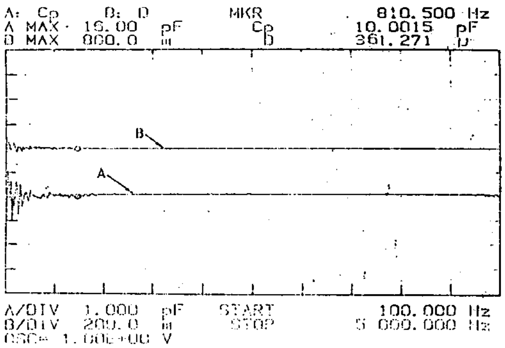

Fig. 4. The capacitance and loss tangent of Al_2O_3 crystal capacitor for 10 pF from 100 to 5000 Hz

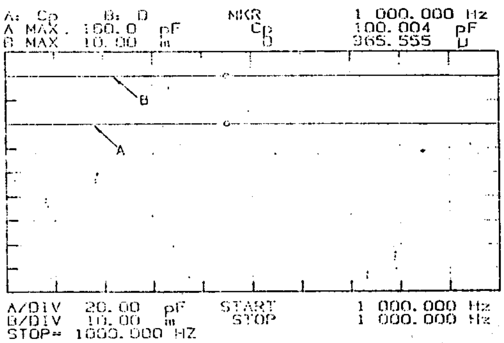

Fig. 5. The capacitance and loss tangent of Al_2O_3 crystal capacitor for 100 pF at 1000 Hz

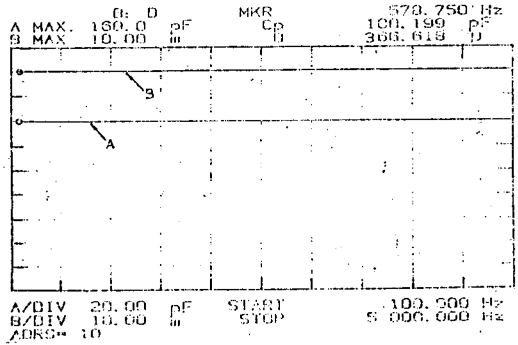

Fig. 6. The capacitance and loss tangent of Al_2O_3 crystal capacitor for 100 pF from 100 to 5000 Hz

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