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A Dielectric Measurement Technique of Thin Samples at Microwave Frequencies

(마이크로파에서 얇은 유전체의 유전상수 및 유전손실의 측정방법에 대한 연구)

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要　約

공진기의 섭동방법을 이용하여 얇은 유전체 시료의 유전특성을 결정 하였다. 마이크로파 집적회로의 기판재료는 얇은 평판으로 제조되며, 유전상수는 10이하이고, 유전손실은 10^{-3} 이하로 낮을수록 좋다. 따라서 이 연구에서는 유전상수가 10이하인 유전체의 유전상수, 유전손실의 정확한 측정방법을 제시하고저 한다. 이 방법에서는 원통형의 금속공진기 내에 얇은 유전체 시편을 넣어서 측정하는 방법으로서 측정의 정확도는 유전상수의 경우 ±1% 이내, 유전손실의 경우 3×10^{-4} 이내의 오차범위를 가지는 정확도를 가진다.

Abstract

A cavity perturbation technique is employed to determine the dielectric property of thin samples. Substrates in microwave integrated circuits are fabricated in sheet form and are expected to have a dielectric constant less than 10 and a dielectric loss better than 10^{-3}. This research aimed to determine both dielectric constant and dielectric loss with good accuracy. The technique makes use of thin circular disk samples placed in a right circular cylindrical cavity. The accuracy of measurements is within ±1% for dielectric constant and 3×10^{-4} for dielectric loss.

I. Introduction

The dielectric measurements of thin samples including thin film is important especially in the properties of integrated curcuits at microwave frequencies. Materials which are utilized as substrates in microwave integrated circuits and packaging systems are fabricated in sheet form and are expected to have a dielectric constant a lot less than 10 and a dielectric loss better than 10^{-3}.

For thin samples of this type, it is necessary to determine both dielectric constant (ϵ') and dielectric loss ($\tan\delta$) with good accuracy. To achieve this, a cavity perturbation method was chosen which is widely used in the measurement of dielectric properties of materials.[1,2,3] The main assumption of this method is that the sample

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volume is very small, so that the resonant frequency shift and the quality factor change of the cavity is very small upon sample introduction.

II. Perturbation Theory

The cavity perturbation method consists of relating the resonant frequency shift and the change in loaded quality factor of a resonant cavity to the complex dielectric constant $\epsilon' - j\epsilon''$ of the material causing the change.[4]

If the thickness of the smaple is small compared to the wavelength of the measurement frequency, and the sample surface is large enough to cover the entire cross section of the cavity and also the sample is located at the position of maximum electric field and is everywhere tangential to the electric field, then dielectric constant ϵ' is given by[4,5]

$$\epsilon' = 1 + \frac{L}{t}\ \frac{f}{f_s} \qquad (1)$$

where L is the cavity length, t is the sample thickness, Δf is the frequency shift $f_o - f_s$, here f_s and f_o are the resonant frequencies of the cavity with and without the specimen respectively.

And loss factor ϵ'' is given by

$$\epsilon'' = \frac{L}{t}\ \frac{1}{2}\ \left(\frac{1}{Q_s} - \frac{1}{Q_o}\right) \qquad (2)$$

where Q_s and Q_o are the loaded Q factors of the cavity with and without the sample respectively.

The dielectric loss is defined as

$$\tan\delta = \frac{\epsilon''}{\epsilon'} \qquad (3)$$

which is a measure of the energy lost in the form of heat when a wave is propagated through the material. The two constants ϵ' and $\tan\delta$ rather than ϵ' and ϵ'' will be used to specify any given material.

III. Experimental Technique

A right circular cylindrical transmission cavity was made of brass, which is shown in figure 1. The constructed cavity has two sections, one part being adjustible by having cylindrical rod plunger moving up and down. The total length of the cavity is made of odd integer number of resonant wavelength of the frequency used and the middle plane of the cavity is a plane of maximum electric field where the sample slot was made for placing samples for the measurement. This cavity is operating in the cylindrical TE_{013} mode, resonant at approximately 10.875 GHz.

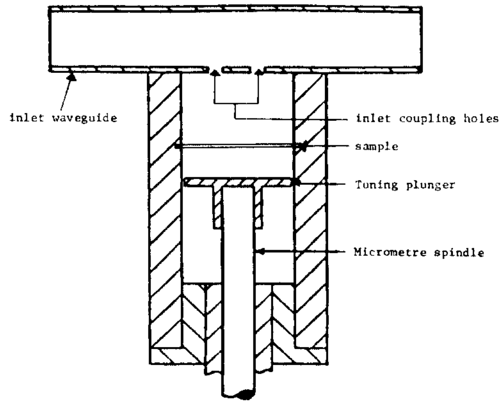

Fig.1. A right circular cylindrical cavity. (TE_{013} mode)

The measured loaded Q, Q_o was found to be greater than 10^4.

The cylindrical cavity was chosen specially because it has a very high Q,[6,7] so low loss materials can be measured. However, this type of cavity has a number of resonant modes, such as TE_{11}, TM_{01}, TE_{21}, TM_{11}, TE_{01}, TE_{31} for a few of the lower modes which can be seen in figure 2.[8] Therefore it is important to suppress all the modes except the TE_{01} mode. By careful design of the rectangular waveguide to cylindrical cavity coupling, most of these unwanted modes can be eliminated or at least greatly attenuated.

In the narrow face of a rectangular waveguide operating in the fundamental TE_{10} mode, the only field that exists is a longitudinal magnetic field which is shown in figure 3.[9]

If the narrow face of the waveguide lies along the diameter of the cylindrical cavity end wall, then only radial magnetic field will be coupled to the cavity and electric field lies on a plane perpendicular to the cavity axis. Two coupling irises are used, spaced a/4 (a being the length of a waveguide wide wall) from the center of the cavity end plate along a diameter as the input coupling and the exit coupling is placed on the

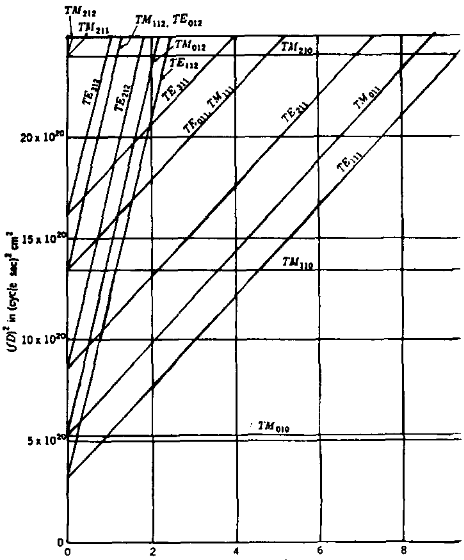

Fig.2. Mode chart for right circular cylindrical cavity.

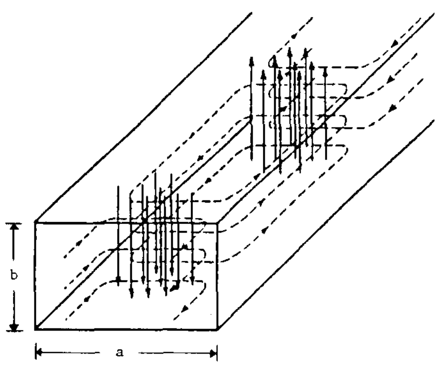

Fig.3. Schematic representation of TE_{10} mode in rectangular waveguide. Electric field represented by solid lines and magnetic field by broken lines.

curved surface of the cavity along a diameter at 45° to the line joining the inlet coupling holes. This type of cavity coupling is known as Bleaney's type coupling and is shown in figure 4.[10]

Resonant frequencies and Qs are measured by connecting the cavity to a Hewlett Packard network analyzer model 8757A with the swept frequency unit, Hewlett Packard 8350B.

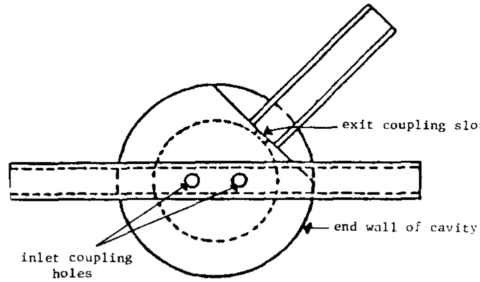

Fig.4. Waveguide to cavity coupling (Bleaney's method).

IV. Results and Discussion

Experimentally obtained values for ϵ' and tan δ of three low loss materials are given in table 1. An accuracy of ±1% for ϵ' and $\pm 3 \times 10^{-4}$ for tan δ is assigned. The accuracy is calculated from experimentally determined standard deviations of the parameters upon which ϵ' and tan δ depend.

Table 1. Values Obtained for ϵ' and tan δ.

sample	thickness (mm)	f_s (GHz)	Q_s	ϵ'	tan δ (10^{-4})
teflon	0.424	10.814	9,330	2.07	6 10^{-4}
fused Quartz	0.245	10.783	10,240	3.77	1.6 10^{-4}
Ruby mica	0.065	10.833	10,212	5.75	4.2 10^{-4}

empty cavity $f_o = 10.875$ GHz
$Q_o = 10642$

The agreement between the present values and those obtained by others may be taken as a check on the presence method of measurement.[11]

From the equation (1), it is clear that the cavity length, frequency and sample thickness measurement errors contribute to the error of ϵ' and tan δ.

Since an extremely stable signal source is being used, the main factors limiting the accuracy of ϵ' and tan δ is the accuracy of measuring the physical dimensions of the cavity length and sample thickness. Especially for non uniform thickness materials the accuracy of measuring the sample thickness has a significant effect on the overall accuracy.

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