Estimating Permittivity of a material using Waveguide

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***Abstract*— In this paper a simple method to determine the dielectric constant of dielectric sheets using waveguide at microwave frequencies is presented. The electric field inside the waveguide gets modified by the inclusion of dielectric and based on the reflection coefficient the dielectric constant of the material is identified. The frequency dependence of dielectric constant is also studied in detail. The results obtained are verified experimentally. The studies are carried out in X-band and the predicted and experimental results are found to be in good agreement.**

Keywords—waveguide, dielectric constant, X-band,

I. INTRODUCTION

Over the past fifty years, there have been numerous attempts to measure the permittivity of semiconductors at microwave frequencies employing waveguides, resonators, and broadband dispersive Fourier transform spectroscopic technique. For the most accurate measurement of the permittivity or conductivity of semiconductor at microwave frequencies, it is essential that the sample under test has no electrical contact with any metal part of the fixture that is used for measurements [1]. Some microwave techniques offer the possibility of contactless measurements, e.g., cylindrical resonant cavities and waveguides operating in one of the modes (usually the dominant one) [2]. For such structures, currents have only circumferential component and, thus, do not flow through the metal–semiconductor interface. The permittivity is defined for a particular temperature and frequency range [3, 4]. The same is the case with temperature. For simplicity sake, X band is considered in this paper.

II. MEASUREMENT TECHNIQUES

The dielectric constant of the material was determined experimentally and by FEM analysis. For simplicity sake, waveguide was used as it offers contactless measurements. The geometry for the analysis is shown in Figure.1. For FEM analysis, an X-band waveguide, dimensions represented as a×b in the figure.1, was considered with a perfect metallic boundary. The sample whose dielectric constant has to be determined is placed inside the waveguide. The reflection coefficient corresponding to that was noted. From the reflection coefficient, the reflection coefficient of the material can be found out considering the material one to be air or vacuum.

From the equation,

$$\Gamma = S_{11} = \frac{\sqrt{\varepsilon_{r2}} - \sqrt{\varepsilon_{r1}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}$$

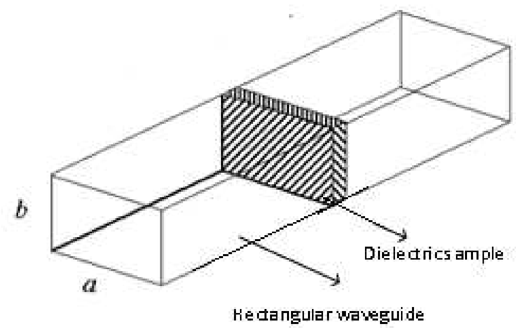

Fig.1. Rectangular waveguide with dielectric sample

The unknown permittivity can be easily calculated as the value of reflection coefficient Γ and ε_{r1} are known.

For experimental analysis, a rectangular waveguide with a matched termination is used as the sample holder. The thin dielectric slab under test is placed at the input flange of the waveguide. Figure.2. shows the block diagram of the experimental set up. A solid sample or length $l\varepsilon$ is loaded in rectangular waveguide against short circuit that touches it well. D & DR - the positions or first voltage minima of the sanding wave pattern when waveguide is unloaded & loaded with the dielectric is noted. The respective distance from the short circuit will be ($l + l\varepsilon$) & ($lR + l\varepsilon$). The impedance are equal so Z_0 and Z_ε are respectively the characteristic impedance of empty & dielectric filled waveguide β and β_ε are respective propagation constant. Assuming dominant mode was propagating through the rectangular waveguide, the dielectric constant ε_r is given by:

$$\frac{\tan\beta(D_R - D + l_\epsilon)}{\beta l_\epsilon} = \frac{\tan\beta_\epsilon l_\epsilon}{\beta_\epsilon l_\epsilon}$$

$$\epsilon_r = \frac{\left(\frac{a}{\pi}\right)^2\left(\frac{\beta_\epsilon l_\epsilon}{l\epsilon}\right)^2 + 1}{\left(\frac{2a}{\lambda_g}\right)^2 + 1}$$

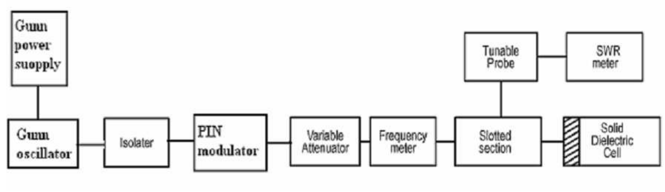

Figure.2. Experimental setup

The dielectric constant of the samples measured experimentally and from FEM analysis is presented in Table.1. The present method of analysis can predict the dielectric constant with less error.

Estimated Permittivity		
Material (permittivity)	***FEM***	***Experiment***
Teflon (2.1)	2.15	2.032
Ebonite (2.5)	2.554	2.55
Epoxy (4.4)	4.5	4.35

Table.1.

We were able to predict the dielectric constant of the materials understudy by FEM analysis as close to experimental values. So the method can be used to find the permittivity of unknown materials. The material thicknesses were varied to find the variation of dielectric constant with thickness. The observed results are plotted in Figure.3.

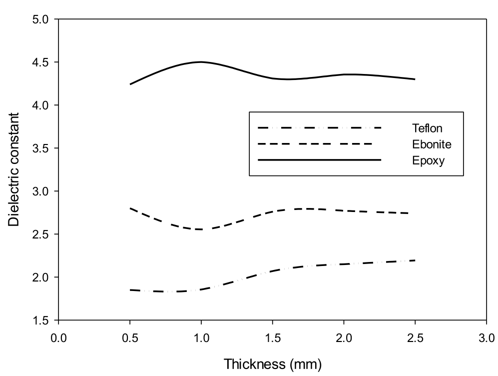

Figure.3. Variation of dielectric constant with thickness

Thickness of the substrate is found to have only slight variation in permittivity. The values can be more accurate if transmission characteristics are also included.

III. CONCLUSIONS

The permittivity of an unknown dielectric can be calculated both experimentally and using FEM analysis using reflection method. Here the sample must be placed exactly at the waveguide flange.The analysis is found to give an accurate measure of dielectric constant. This method is used to verify dielectric constant of three materials and is found to give good results. The dependence of dielectric constant on thickness is also studied.

V. REFERENCES

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