PERMITTIVITY MEASUREMENT BY CAVITY PERTURBATION METHOD

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Abstract:

Measurement of the permittivity of wide range of materials of different cylindrical sizes was performed using the method of perturbing the fields inside microwave specially designed rectangular cavities. Resonable results were obtained in consistence with calculated ones.

Introductiore

According to [1]-[3], the standard perturbation theory was developed to measure the complex permittivity using microwave cavities with suitable holes in them to allow sample insertion.

In this paper the previous technique [1] is presented. Gunn diodes (type Mullard CXY11C) are inserted in a designed Gunn flange to perform a principal part of a cavity controlled oscillator. Experimental measurements for a wide range of materials were carried out using designed cavities. Comparison with obtained theoretical results together with limitations on the different used cavities were represented.

Cavity Perturbation Method

In order to monitor the resonant frequency shift Δf of a cavity disturbed by the insertion of a rod-shaped sample when the microwave electric field is either parallel or perpendicular to the axis of the sample; the volume of the sample V_s is selected small compared with the volume of the air-filed cavity V_o. Then, according to the standard perturbation theory [1], the frequency shift Δf for nonmagnetic will be formuated as:

$$\frac{\Delta f}{f_o} = \frac{\epsilon_o(\epsilon'-1)\int_{V_S}\vec{E}_o\,\vec{E}_p\,dv}{\int_{V_c}(\epsilon_o\vec{E}_o\vec{E}_o - \mu_o\vec{H}_o\vec{H}_o)\,dv} \qquad (1)$$

where ϵ_o and μ_o are the permittivity and permiability of free space respectively; $\vec{E}$ and $\vec{H}$ are the electric and magnetic field vectors with subscripts "o" and "p" density unperturbed and perturbed values.

For a rectangular cavity resonating in the TE_{101} mode, a cylindrical sample can be inserted into the centre of the cavity through small holes, so that it is parallel or perpendicular to the maximum electric field as shown in Fig. 1.

The frequency shift for both cases can be deduced from eqn. (1) and represented by

$$(\Delta f/f_o)_{//} = 2\ (\epsilon'-1)\ A_s b/V_c \quad \text{parallel case} \tag{2}$$

and $$(\Delta f/f_o)_{\perp} = 2\ (\epsilon'-1)\ A_s a/V_c \quad \text{perpendicular case} \tag{3}$$

where a and b are the width and height of the cavity respectively, and A_s is the cross-sectional area of the sample. Also, $V_s = A_s b$.

Solving eqs. (2) and (3) to separate the variable ϵ' and A_s from measured frequency shift Δf values we get:

$$\epsilon' = (a/b)\ [V_c(\Delta f/f_o)]_{//}/[V_c(\Delta f/f_o)] - 1 \tag{4}$$

where the subscripts // and $\perp$ refer to parallel and perpendicular cases respectively.

Design Procedure:

Two rectangular cavities were designed to enable parallel and perpendicular insertion of dielectric samples. The proposed dimensions to excite the TE_{101} mode are ($a \times b \times L = 22.86 \times 10.16 \times 22.86\ mm^3$) resulting in a resonant frequency 9.2796 GHz. The drilled holes have 3.1 mm in diameter.

Also, a Gunn-diode flange was designed to replace one of the end walls (lying in the x-y plane) of the cavity. The x-band flange is shown in Fig. 2 where a GaAs Gunn-diode (type Mullard CXY11C) is mounted in it. The iris slot (22.86 mm length and 3.175 mm width) is centered at the cavity end.

In order to investigate the characteristics of these cavities, they are mounted with the Gunn-diode flange to realize the TE_{101} mode. The combination was connected in a microwave line containing a dc power source, an attenuator, a frequency meter, a slide screw tuner, a thermistor mount and a powermeter. Their resonant frequencies are measured and found to be 9.125 GHz and 9.014 GHz for // and $\perp$ respectively. The cavities characteristics are shown in Fig. 3 at measured resonant frequencies 9.125 GHz for parallel case and 9.014 GHz for perpendicular case. The output power is found to be maximum at an optimum bias voltage 7.25 volts. Although hole diameters are the same the maximum output power is less in the perpendicular case due to differences in hole radiation. The frequency shifts between the calculated and the measured for the two cases were found to be

$$(\Delta f)_{//} = 0.153 \text{ GHz} \quad \text{and} \quad (\Delta f/f_o)_{//} = 0.0165$$

$$(\Delta f)_{\perp} = 0.264 \text{ GHz} \quad \text{and} \quad (\Delta f/f_o) = 0.0285$$

Where it is clear that it is minimum in the parallel case.

Permittipity Measurements and Discussions:

In order to determine the validity and to compare the theoretical and experimental results of the method used a known material (Teflon rods) with known $\epsilon' = 2.03$ is used. The frequency shift, eqs. (2) and (3), are calcualted for different cross-sectional areas (0.5-3.0 mm diameter). Also, samples of diameters ranging from 0.8 to 2.9 mm were inserted in the rectangular cavity to measure the change in frequency Δf using the frequency meter in the line. Then, ϵ' and $\epsilon'(V_s/V_c)$ were determined from eqs. (2) and (3).

Figure 4 shows the experimentally measured values for the two cases (parallel and perpendicular). The solid lines represent the theoretically calculated values. It is clear that the deviation between theoretical and experimental curves are very small and the solid lines are nearly the mean value of the measured points. At the same time, the relative dielectric constant is calculated from the experimental data and the variation of ϵ' with the specimen diameter is represented in Fig. 5. The frequency shfit against $\epsilon' V_s/V_c$ is also shown in Fig. 6. From the measured experimental frequency shift Δf, ϵ' was calculated. The mean value was found to be 1.95, which shows that this method is adequate and is precise for measuring ϵ'.

Wide range of materials were measured ad tested using the previously developed method. The limits of ϵ' to be measured by the designed rectangular cavity was determined since the greater the value of ϵ' the more the frequency shift we get. Thus, the oscillations in the cavity cannot be excited due to the shift of the resonant frequency beyond the limits of the cavity and Gunn-diode oscillation conditions. It was found suitable to limit $\Delta f/f_o$ to its maximum value which does not alter the conditions of excitation due to the high values of ϵ' or layer diameters. The case of horizontal sample hole was found more suitable to measure ϵ' since a wider range of sample diameters can be used.

As an example of the materials measured is TROLITUL. Rods of diameters ranging from 0.8 to 2.9 mm were used. The relation between the frequency shift and specimen cross-sectional area is shown in Fig. 7. Also, variation of f with $\epsilon' V_s/V_c$ is represented in Fig. 8. The measured frequency shift was used to get ϵ' and found to have a mean value of 2.63, showing that this method is adequate and precise in measuring '.

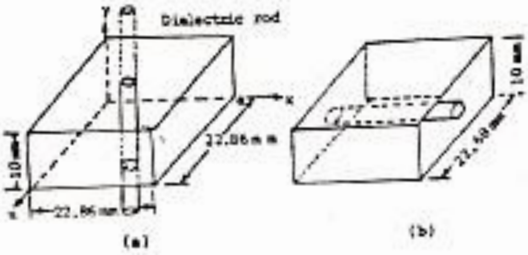

Fig. 1. Inner diameter of the TE_{101} mode rectangular cavity with vertical and horizontal sample holes (a) and (b) respectively.

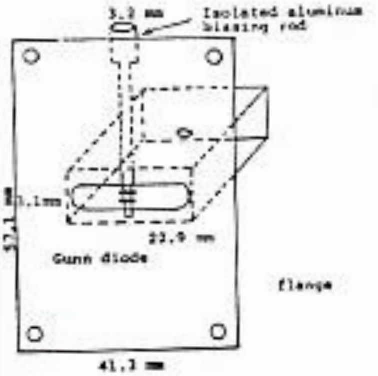

Fig. 2. Diode flange with rectangular cavity, vertical sample hole f_o = 9.279 GHz.

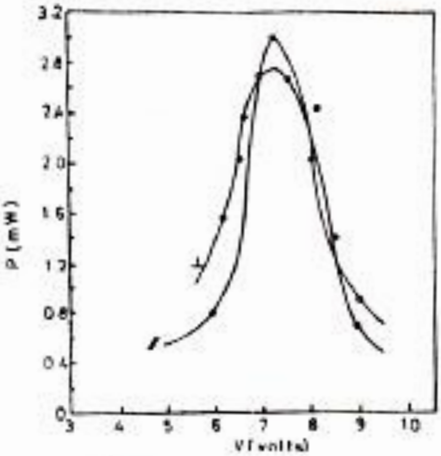

Fig. 3. The output power as a function of the bias voltage for the rectangular (TE_{101} mode), (a) hole vertical position f_o = 9.125 GHz and (b) hole horizontal f_o = 9.014 GHz.

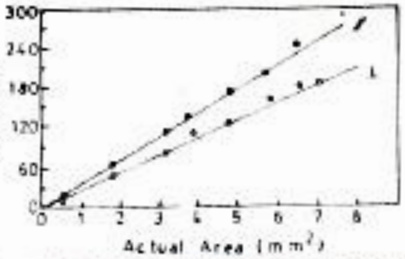

Fig. 4. Relation between frequency shift Δ f and the actual areas A_s in mm^2 for the parallel and perpendicular cases for Teflon rods.

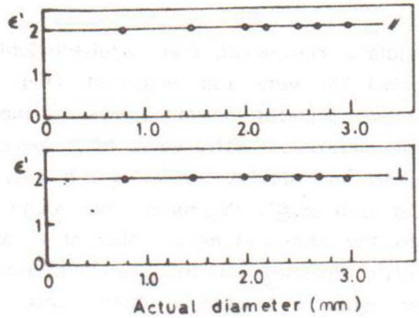

Fig. 5. Calculated relative dielectric constant again actual Diameter for Teflon rods in TE_{101} mode-rectangular cavities.

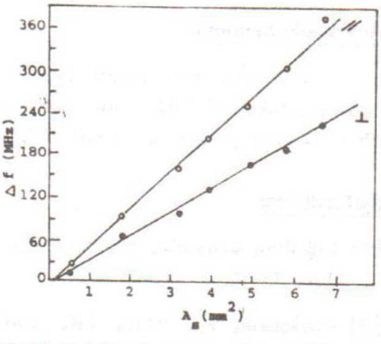

Fig. 7. Relation between frequency shift Δ f and the actual Areas A_s in mm^2 for TROLITUL rods.

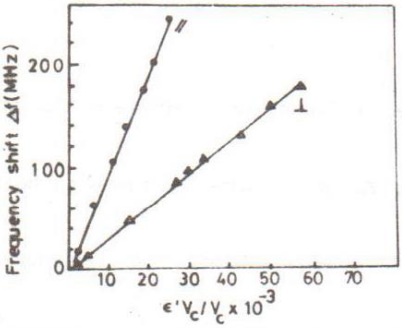

Fig. 6. Frequency shift Δf against $\epsilon' V_s/V_c$ for Teflon rods in rectangular cavities.

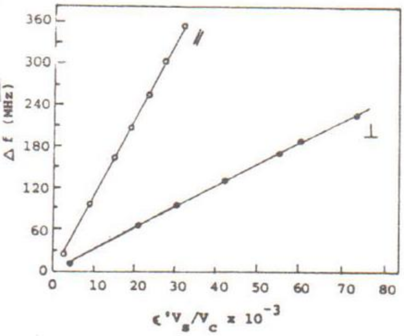

Fig. 8. Frequency shift Δ f against $\epsilon' V_s/V_c$ for TROLITUL rods in rectangular and cylindrical cavities.

Other materials; such as Holz, Plexiglass, Hargummi, PVC (Polyvinylchloride), Hartgewebe, Hartpapier, Stycast 6, and Stycast 15; were also measured. Their results emphasize that the developed cavity controlled oscillator method allows the measurement of the permittivity for wide range of materials - (the value of ϵ' determines the type of cavity and sample position used). For small values of ϵ', it was found that the relations between Δf and the actual area or $\epsilon' V_s/V_c$ have the same trend and differ in shape for large ϵ' values. Also, the measured mean value of ϵ' approaches the actual true value of the dielectric constant of the used material since from statistical point of view such mean value is calculated from nearly almost 28 measured experimental values.

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