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PRE-STANDARD

Withdrawn

Cavity resonator method to measure the complex permittivity of low-loss dielectric plates

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CAVITY RESONATOR METHOD TO MEASURE THE COMPLEX PERMITTIVITY OF LOW-LOSS DIELECTRIC PLATES

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CAVITY RESONATOR METHOD TO MEASURE THE COMPLEX PERMITTIVITY OF LOW-LOSS DIELECTRIC PLATES

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1 Scope

This PAS describes the measurement method of dielectric properties in the planer direction of dielectric plate at microwave frequency in order to develop new materials and to design microwave active and passive devices. This method is called a cavity resonator method.

This method has the following characteristics:

- the relative permittivity ε' and loss tangent tan δ values of a dielectric plate sample can be measured accurately and non-destructively;
- temperature dependence of complex permittivity can be measured;
- the measurement accuracy is within 0,3% for ε' and within 5×10^{-6} for tan δ;
- fringing effect is corrected using correction charts calculated on the basis of rigorous analysis.

This method is applicable for measurements in the following conditions:

- frequency : 2 GHz < f < 40 GHz;
- relative permittivity : 2 < ε' < 100;
- loss tangent : 10^{-6} < tan δ < 10^{-2}.

2 Measurement parameters

The measurement parameters are defined as follows.

$$\varepsilon_r = \varepsilon' - j\varepsilon'' = D/(\varepsilon_0 E) \quad (1)$$

$$\tan\delta = \varepsilon''/\varepsilon' \quad (2)$$

$$TC\varepsilon = \frac{1}{\varepsilon_{ref}} \frac{\varepsilon_T - \varepsilon_{ref}}{T - T_{ref}} \times 10^6 \quad (1 \times 10^{-6}/\mathrm{K}) \quad (3)$$

where

D	is the electric flux density;
E	is the electric field strength;
ε_0	is the permittivity in a vacuum;
ε' and ε''	are the real and imaginary components of the complex relative permittivity ε_r;
$TC\varepsilon$	is the temperature coefficient of relative permittivity;
ε_T and ε_{ref}	are the real parts of the complex relative permittivity at temperature T and reference temperature T_{ref} (= 20 °C to 25 °C), respectively.

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3 Theory and calculation equations

3.1 Relative permittivity and loss tangent

A resonator structure used in the non-destructive measurement of the complex permittivity is shown in Figure 1a. A cavity having diameter D and length $H = 2M$ is cut into two halves in the middle of its length. A dielectric plate sample having ε', tan δ and thickness t is placed between these two halves. The TE_{011} mode, having only the electric field component tangential to the plane of the sample, is used for the measurement, since air gaps at the plate-cavity interfaces do not affect the electromagnetic field. Taking account of fringing field in the plate-region outside diameter of the cavity on the basis of the rigorous mode matching analysis, we determine ε' and tan δ from the measured values of the resonant frequency f_0 and the unloaded Q-factor Q_u. This numerical calculation, however, is rather tedious. Therefore, we first determine approximate values ε'_a and tan δ_a from the f_0 and Q_u values by using simple formula for a resonator structure shown in Figure 1b, where the fringing effect for Figure 1a is neglected. Then, we obtain accurate values ε' and tan δ from ε'_a and tan δ_a using charts calculated from the rigorous analysis.

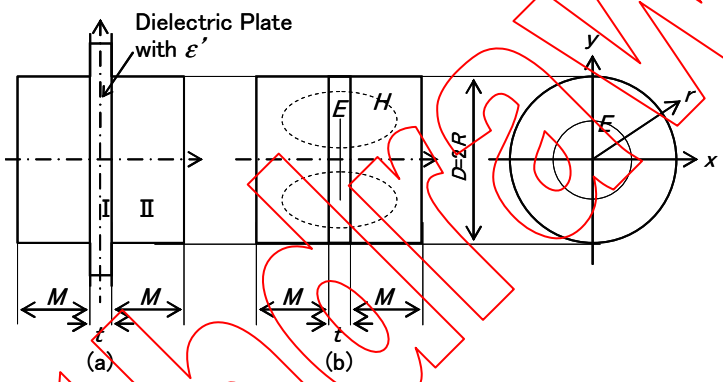

Figure 1a – Resonator used in measurement

Figure 1b – Resonator to calculate ε'_a and tan δ_a

Figure 1 – Resonator structures of two types

The value of ε'_a is given by

$$\varepsilon'_a = \left(\frac{c}{\pi t f_0}\right)^2 \left\{X^2 - Y^2\left(\frac{t}{2M}\right)^2\right\} + 1 \qquad (4)$$

where c is the velocity of light in a vacuum (c = 2,9979 × 0^8 m/s) and the first root X is calculated from a given value Y, using the following simultaneous equations:

$$X \tan X = \frac{t}{2M} Y \cot Y \qquad (5)$$

$$Y = M\sqrt{k_0^{\,2} - k_r^{\,2}} = jY' \qquad (6)$$

with $k_0 = 2\pi f_0/c$, $k_r = j'_{01}/R$, and j'_{01} = 3,83173 for the TE_{011} mode. When $k_0 - k_r < 0$, Y is replaced by jY'.

The value of tan δ_a is given by

$$\tan \delta_a = \frac{A}{Q_u} - R_s B \qquad (7)$$

where R_s is the surface resistance of the conductor of cavity, given by

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