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**Test Method for Complex Permittivity of Solid Dielectric
Materials at Microwave Frequencies**

固体电介质微波复介电常数的测试方法

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Test Method for Complex Permittivity of Solid Dielectric Materials at Microwave Frequencies

1 Scope

This Standard specifies the test method for the microwave complex permittivity of homogeneous and isotropic solid dielectric materials.

This Standard applies to the determination of the complex dielectric constant within the frequency range of 2 GHz ~ 18 GHz. The recommended test frequency is 9.5 GHz. Its measurement range: the real part of the relative permittivity ϵ' is 2 ~ 20, and the dielectric loss tangent $\tan\delta_\epsilon$ is $1 \times 10^{-4} \sim 5 \times 10^{-3}$.

2 Definition

The complex permittivity $\dot{\epsilon}$ is as follows:

$$\dot{\epsilon} = \epsilon_0 \cdot \epsilon_r = \epsilon_0 (\epsilon' - j\epsilon'') \quad \dots\dots\dots (1)$$

Where:

ϵ_r - complex relative permittivity;

ϵ_0 - vacuum permittivity, its value is $8.854 \times 10^{-12} \text{F/m}$.

The complex permittivity mentioned in this Standard actually refers to the relative permittivity, and is characterized by the real part of the relative permittivity ϵ' and the dielectric loss tangent $\tan\delta_\epsilon = \epsilon''/\epsilon'$.

3 Principle of Test

At a certain frequency, the resonant length of the cylindrical TE_{01n}^0 mode high-quality factor test cavity is l_0 , and the inherent quality factor is Q_{0e} , as shown in Figure 1(a). When a disk-shaped sample with a thickness d is placed in the test cavity, as shown in Figure 1(b), two changes will occur: (1) since the dielectric constant ϵ of the dielectric sample is greater than 1, the phase constant of the section of the waveguide filled with the sample medium will increase; and the length of the resonant cavity at the original frequency will be shortened to l_s ; (2) since the dielectric sample will introduce additional dielectric loss, the inherent quality factor of the test

Voltage resolution is $1\mu\text{V}$, $4\frac{1}{2}$ digits of reading.

5.6 Crystal detector

Non-modulated broadband crystal detector.

5.7 Isolator

The isolation ratio is superior than 20 dB; and the forward and reverse standing-wave-ratio coefficients are less than 1.20.

6 Specimen Sizes and Requirements

6.1 Sample diameter D_s

$$D_s = (2R - \delta) \pm 0.1 \text{ mm} \quad \dots\dots\dots (2)$$

Where:

R – radius of test cavity, in mm;

δ – The amount related to the size of the test cavity is recommended to be 1.5 mm in the test cavity with the recommended test frequency.

6.2 Sample thickness d

The principle of selecting the sample thickness d is to take its electrical length at about 85° to improve the test sensitivity and reduce the test error. When the dielectric constant ϵ of the material to be tested is roughly known, the sample thickness can be calculated according to the following Formula.

$$d = 0.236 \left[\left(\frac{f_o}{300} \right)^2 \cdot \epsilon' - \left(\frac{1}{1.64 R} \right)^2 \right]^{-\frac{1}{2}} \quad \dots\dots\dots (3)$$

Where:

f_o – test frequency, namely, the resonant frequency of the test cavity, in GHz;

R - radius of test cavity, in mm;

d – sample thickness, in mm.

Selection of sample thickness can refer to Appendix B (prompted).

6.3 Sample requirements

The non-parallelism of the two main planes of the disc-shaped sample is no more than 0.01 mm; and the non-straightness of the two main planes is no more than 0.01 mm.

There shall be no abnormal spots and scratches on the surface of the sample, and no abnormal impurities and pores inside; it shall be strictly cleaned and dried before testing.

7 Test Procedure

7.1 Measurement of empty test cavity

7.1.1 Turn on the machine and warm up for 15 minutes to make the system work normally.

7.1.2 Set the signal source to output the continuous wave frequency at the test frequency f_0 , adjust the precision graduated attenuator within the range of 9.0 dB~9.8 dB; adjust the output level of the signal source; and make the crystal detector output can read the indication number α_0 of about 10 mV on the digital voltmeter; and record the attenuation amount A_1 of the precision graduated attenuator at this time.

7.1.3 Adjust the medium test chamber. The test cavity has been adjusted to the resonance point determined by the digital voltmeter indicating that has dropped to the lowest point. The frequency of the resonance point is f_0 . Record the piston position scale l_0 and resonance frequency f_0 of the dielectric test cavity. At this time, the reading on the digital voltmeter is α_r .

7.1.4 Adjust the precision graduated attenuator (decrease the attenuation), so that the reading on the digital voltmeter rises from α_r to return and rise to α_0 ; record the attenuation A_2 of the precision graduated attenuator at this time, then the attenuation introduced by the dielectric test cavity introduced at the resonance point is $A_{oc}=A_1-A_2$ in decibels.

$$A_{he} = 10 \lg \left(1 + 10^{\frac{A_{oc}}{10}} \right) - 3.01 \quad \dots\dots\dots (4)$$

7.1.5 Calculate the attenuation A_{he} at the "half power point" of the resonance curve according to Formula (4); and set the precision graduated attenuator at $A_{he}+A_2$. At this time, the reading on the digital voltmeter is α'_r , $\alpha'_r < \alpha_0$.

7.1.6 Fine-tune the frequency of the signal source. On both sides of the resonant frequency f_0 , adjust the reading of the digital voltmeter to return to α_0 , and record the two frequencies f_1 and f_2 . Calculate $\Delta f_c = f_2 - f_1$.

7.2 Measurement of the test cavity after placing the sample

7.2.1 Use the same exact procedure as in 7.1 to measure the piston position scale l_s at the original frequency f_0 , the resonance point attenuation A_{os} , the half power point attenuation A_{hs} and the

Where:

Δf_o - resonant frequency test error;

ΔR - machining accuracy of test cavity radius;

ΔS_1 - the error introduced by the micrometer precision of the cavity when measuring S ;

$\Delta f'_o$ - the deviation of the tuning of the test cavity between two tests before and after being placed in the dielectric. It is determined by experimental statistics;

Δd - the measurement error of the thickness of the dielectric sample;

$\Delta(\Delta f)_s$ - after the sample is loaded into the test cavity, measure the error of the bandwidth at the “half power” point of the test cavity. Determined by experimental statistics;

$\Delta(\Delta f)_e$ - measure the error in frequency width of the “half power” point of the test cavity without a sample, determined by experimental statistics;

ΔA_{11} - measure the error of attenuation A_1 introduced by the accuracy of the attenuator;

ΔA_{21s} - after the sample is loaded into the test cavity, measure the error of the attenuation A_2 introduced by the accuracy of the attenuator;

ΔA_{21e} - when no sample is loaded in the test cavity, the error of the attenuation A_2 introduced by the accuracy of the attenuator;

In order to achieve:

$$\frac{\Delta \epsilon'}{\epsilon'} \leq 1.0\%$$

$$\Delta \tan \delta_e = 3\% \tan \delta_e + 3 \times 10^{-5}$$

The above accuracy, the following requirements shall be met in the test:

$$\Delta f_o = \Delta f'_o \leq 1 \times 10^{-6} f_o$$

$$\Delta D = 2\Delta R \leq 0.02\% D$$

$$\Delta S_1 \leq 0.01 \text{ mm}$$

$$\Delta d \leq 0.01 \text{ mm}$$

$$\Delta(\Delta f)_s = \Delta(\Delta f)_e \leq 5 \times 10^{-7} f_o$$

$$\Delta A_{11} = \Delta A_{21s} = \Delta A_{21e} \leq 0.02 \text{ dB}$$

$$Q_{oe} \geq 40000$$

$$9 \text{ dB} > A_{oe} > 7 \text{ dB}$$

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