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MEASUREMENT OF DIELECTRIC LOSS AT MILLIMETER RANGE IN THE LOW LOSS MATERIALS WITH ARBITRARY RATIO OF WAVELENGTH AND SAMPLE THICKNESS

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Abstract. For the first time the measurement technique is developed for dielectric loss in the low loss materials at the long-wave part of the millimeter range of electromagnetic waves on the basis of compact open semi-symmetric confocal resonator for the samples with arbitrary ratio of the sample thickness and wavelength in the dielectric material. The loss in the aluminum oxide ceramics (Al_2O_3) of the brand VK-99 was measured at room temperature at the frequency 69.4 GHz: $\tan\delta = 3.1\cdot10^{-4}$. This value is close to the corresponding value in the aluminium oxide ceramics Al_2O_3 of the Russian production of the brand VK100M, and it is lower than in the corresponding ceramics of the Chinese production [5]. In addition, this value is close to the loss in the single crystal of Al_2O_3 (sapphire). This indicates a very high quality of the modern Russian ceramics of aluminum oxide.

Key words: open resonator, millimeter range of electromagnetic waves, dielectric loss, low loss materials.

1. Introduction

In the works [1, 2] the features of the measurement for dielectric loss in the films and a thin plane-parallel plates (whose thickness is less than half of wavelength in the dielectric material) were considered. These measurements were carried out by a compact open semi-symmetric confocal resonator in which a sample is placed on a flat mirror, or at some distance from the mirror to increase the activity of the interaction of the sample with the electric field of the electromagnetic wave. The length of the resonator may change, and the resonator is adjusted for resonance at the selected frequency. The operating range of the resonator is 50–80 GHz.

In [2] the dielectric loss was measured by this setup and technique in thin sample (the thickness of which was less than a half of wavelength in the material) of the silicon carbide SiC of polytype 6H (6H-SiC) at the frequency of 69.4 GHz.

In many cases, the samples of low loss materials, particularly ceramics, have a thickness that is more than half of wavelength in the dielectric sample [3–5]. In this work the measurement technique is upgraded to measure the dielectric loss in the samples whose thickness is of the order or greater than a half of the wavelength in the material.

The dielectric loss was measured in the sample of aluminum oxide ceramic Al_2O_3 of the brand VK-99.

2. A technique of measuring the dielectric loss

The measurement technique for the dielectric loss tangent $\tan\delta$ includes the measurement of the Q-factors of empty resonator without of a dielectric plate Q_0 and of the resonator with included dielectric plate in it Q_1.

For the measurement the open semi-symmetrical confocal resonator was used, similar to that which was used in [2]. In the Figure 1 such a resonator with the sample of dielectric plate is shown in a longitudinal section. The plate is placed on the end face of the annular absorber and covered with a copper mirror.

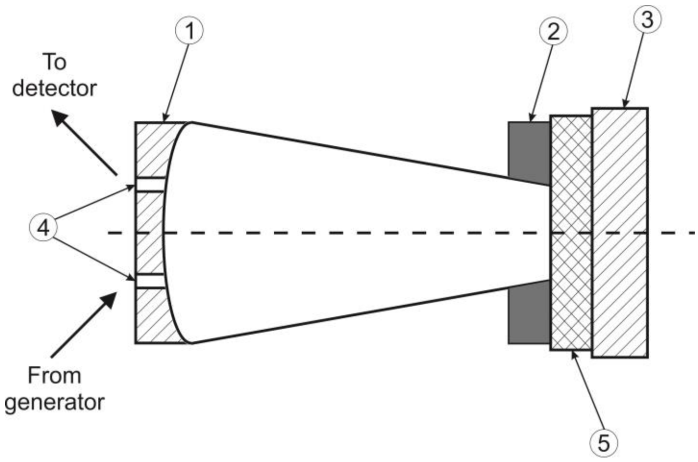

Figure 1. The resonator with a sample: 1 – spherical metal mirror; 2 – flat ring absorber of the parasitic electromagnetic waves; 3 – flat metal mirror, 4 – connection holes; 5 – a sample of the dielectric plate.

The resonator consists of a spherical metal copper mirror with two coupling holes and a plane mirror.

The ring absorber from the micarta provides a suppression of spurious microwaves in the resonator. The coupling of the source and detector with the resonator is performed by circular coupling holes with diameter of 1.25 mm. The diameter of the spherical mirror is 40 mm, the radius of curvature is 40 mm, and the aperture diameter of the diaphragm with ring absorber is 25 mm. The distance between the mirrors is varied by the differential screw mechanism from 17 to 25 mm.

The samples are placed outside the diaphragm. The setup allows measurements of plane-parallel dielectric plates with arbitrary transverse shape and size allowing to cover fully the aperture of the diaphragm.

The complex reflection coefficient *r* from the plate located on the copper mirror, is described by the expression [2]:

$$r = \frac{\frac{1-n^*}{1+n^*} - r_2 \cdot e^{2ikhn^*}}{1 - \left(\frac{1-n^*}{1+n^*}\right) \cdot r_2 \cdot e^{2ikhn^*}} \qquad (1)$$

Here $n^* = n \cdot [1 + i \cdot (\tan\delta)/2]$ is the complex refraction index in the dielectric plate, $k = 2\pi f/c$; f is the frequency of electromagnetic field, c is the speed of light; h is the plate thickness, n is the real part of the refractive index, $\tan\delta = \varepsilon''/\varepsilon'$ is the tangent of the dielectric, where ε' and ε'' are the real and imaginary parts of complex permittivity, r_2 is the coefficient of reflection from a flat metal copper mirror.

According to [6], r_2 is described by the expression:

$$r_2 = \sqrt{1 - 2\left(\frac{f}{\sigma}\right)^{1/2}} \quad , \qquad (2)$$

where σ is the specific conductivity of the mirrors.

The quality factor of the empty resonator without dielectric plate is described by the expression:

$$Q_0 = \frac{kL}{\alpha_0} \quad , \qquad (3)$$

where L is the length of the resonator; α_0 is the loss of the electromagnetic wave in a single pass through the empty cavity.

When the thickness of the sample is about or more than the half the wavelength in the dielectric, there is a need to consider an additional increase in the electrical length of the resonator (taking into account the double passage of the wave through the dielectric plate) on the value of $\Delta = 2n\cdot h$, where n is the refractive index, h is the thickness of the sample. After placing the sample in the resonator, its quality factor Q_1 is described by expression (4):

$$Q_1 = \frac{k(L+\Delta)}{\alpha_0 + \alpha_1} \quad , \tag{4}$$

where α_1 is the additional loss in the resonator, which is described by expression (5):

$$\alpha_1 = \left(\frac{Q_0}{Q_1}\cdot\left(\frac{L+\Delta}{h}\right) - 1\right)\cdot\frac{kL}{Q_0} \tag{5}$$

Dielectric losses $\tan\delta$ are calculated from the solution of the equation (6) [2]:

$$\alpha(\tan\delta) - \alpha_2 - \alpha_1 = 0 \quad , \tag{6}$$

Here the function $a(\tan\delta)$ is given by the expression: $\alpha(\tan\delta) \equiv 1 - |r(\tan\delta)|^2$; α_2 is the loss in the reflection from the copper mirror.

Note that in another technique, also based on open resonators [7–11], the measurement of dielectric loss is only possible when thickness of the sample equal to or a multiple of half the wavelength (i.e., only on the so-called "resonance" frequencies of the sample).

The method described in the present work, in contrast to the above, allows measuring the loss at an arbitrary ratio of wavelength and sample thickness.

3. Dielectric loss in ceramics VK-99

On the base of the technique developed in the present work, and by using the above-described resonator, the dielectric loss was measured in the sample of the ceramics of aluminum oxide Al_2O_3 of the brand VK-99, produced by the Open Public Company "Plant Magneton" (St. Petersburg). As a source of microwaves the Gunn's diode was used as monochromatic generator with the frequency of 69.4 GHz.

The ceramic sample had a thickness of 4 mm, i.e. its thickness exceeded several times the half-wavelength in this material. It was located in front of the flat copper mirror and completely covered the entrance aperture of the resonator.

Earlier we measured the refractive index in this ceramics using the technique described in [2], based on the values of the "resonant" frequency of the sample: n = 3.123. From the experimental data [12] the value of loss at reflection from the copper mirror α_2 at the frequency of 69.4 GHz is $7.8 \cdot 10^{-4}$. From the solution of equation (6) the obtained value of dielectric loss in this material at this frequency at room temperature: $\tan\delta = 3.1 \cdot 10^{-4}$. This value is close to the corresponding value in the aluminium oxide ceramics Al_2O_3 of the brand VK100M produced by the Company "Plant Magneton" [5]. In addition, these values are close to the losses in the single crystal of Al_2O_3 (sapphire). It should also be noted that the relevant Chinese ceramics production losses are higher [5]. This indicates a very high quality of the modern Russian ceramics of aluminum oxide.

4. Conclusion

The technique is developed of the measurement of dielectric loss in the low loss materials in the millimeter range on the basis of compact open semi-symmetric confocal resonator with arbitrary ratio of the sample thickness and wavelength, including the cases when the sample thickness is of the order or more than the half-wavelength in the material.

The loss is measured in ceramics Al_2O_3 of the brand VK-99 at the frequency of 64.9 GHz at room temperature. It is close to the loss in the single crystal Al_2O_3 (sapphire).

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