DIELECTRIC MEASUREMENTS ON LOW-LOSS MATERIALS

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ABSTRACT

Resonant techniques that allow achieving the highest sensitivity of the loss dielectric loss tangent measurements are described. For isotropic materials the TE_{0np} dielectric resonator technique enables to measure real permittivity with accuracy about 0.2% and obtain loss tangent resolution down to $1x10^{-7}$ on high permittivity samples. Whispering gallery mode technique can be employed for the complex permittivity measurements of uniaxially anisotropic dielectrics having arbitrary low lossess. For measurements of laminar dilectric materials split post dilectric resonators can be used at frequency range from 1 to 30 GHz.

INTRODUCTION

Resonant techniques employing cavities and dielectric resonators [1]-[6] provide the highest measurement accuracy for determining the complex permittivity of low-loss dielectric materials at microwave frequencies. The most important criteria for choice of a specific measurement fixture are measurement uncertainty of real permittivity and measurement sensitivity of the dielectric loss tangent. Real permittivity measurement uncertainty depends on several factors namely: uncertainties in physical dimensions of the sample under test and resonant structure, computational inaccuracies, and in some cases presence of air gaps between the sample and cavity walls. For the most accurate measurement techniques uncertainty of the physical dimensions of the sample under test should constitute the dominant part of the uncertainty of real permittivity. Sensitivity of the dielectric loss measurements is always related to the presence of parasitic losses like conductor losses and/or radiation losses. The highest sensitivity of dielectric loss measurements can be achieved if parasitic losses are minimized.

MEASUREMENTS EMPLOYING TE0mn MODE CAVITIES AND WHISPERING GALLERY MODE DIELECTRIC RESONATORS

When the electric field for specific modes is continuous across a sample boundary, such as for quasi-TE_{0np} modes in cylindrical samples shielded by cylindrical metal cavity, high measurement accuracy of real permittivity and high resolution of the dielectric loss tangent are generally achieved. Using quasi-TE_{0np} dielectric resonator technique it is possible to measure real permittivity with accuracy about 0.2% and obtain loss tangent resolution down to $1x10^{-7}$ on high permittivty samples. This technique can be also used with slightly lower resolution for measurements of low permittivity materials like plastics [2]. The most effective way to decrease radiation or conductor losses is to employ higher-order azimuthal modes, called whispering gallery modes, that can be excited in spherical or cylindrical specimens (dielectric resonators) made of material under test. For open dielectric resonators radiation losses decrease very rapidly when the order of modes and permittivity increase as it is shown in Fig. 1 where Q-factor due to radiation are presented for an open spherical resonator As it is seen for moderate permittivity values it is possible to choose elevation angle mode index n such that radiation losses become negligible (to compare to dielectric losses in the sample) for all modes having indices $\geq$ n. For shielded cylindrical or spherical whispering gallery mode resonators parasitic losses are associated with conductors. Again conductor losses can be made arbitrary low for all the modes having azimuthal indices $\geq$ m, if dielectric resonator is situated at a certain distance from all walls of the metal shield. It is possible to choose mode index and size of metal shield such that conductor losses can be neglected even for dielectrics having as low dielectric loss tangent as 10^{-10} (sapphire at 10 GHz and liquid helium temperature). Whispering gallery mode technique has the highest resolution for dielectric loss tangent measurements. It is also very accurate for permittivity determination providing that the modes are identified properly. Several extremely low loss dielectrics have been measured employing WGMR technique including uniaxially anisotropic materials [6]. Loss tangent measurement results on sapphire sample at 21.3 GHz are shown in Fig.3.

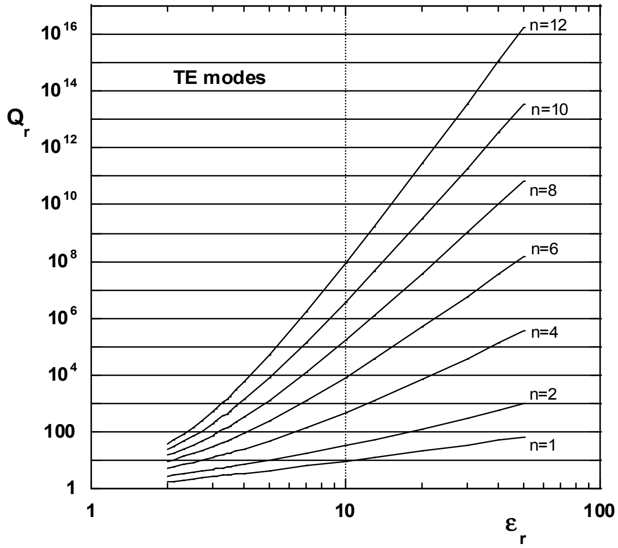

Fig.1 Q-factors due to radiation of TE_{n01} modes versus permittivity for an open spherical resonator

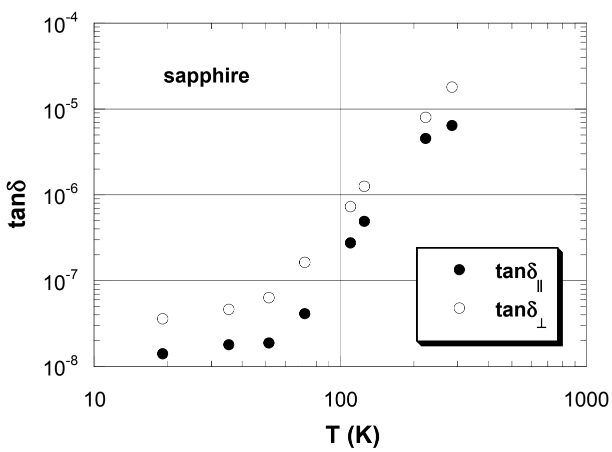

Fig.3 Dielectrc lossess of sapphire at 21.3 GHz

SPLIT POST DIELECTRIC RESONATORS

Fig.2 Photograph of dissasembled 3.2 GHz split post dielctric resonator

Split post dielectric resonator (SPDR) technique is very convenient for measurements of dielectric materials at frequencies from 1 to 30 GHz. The main advantage of SPDR technique is that it can be applied for arbitrary shaped, laminar specimens. It was shown in earlier papers [5]-[6] that this technique permits measurements of permittivity with accuracy 0.3% and dielectric loss tangent with resolution down to $2x10^{-5}$. Result of measurements of standard reference quartz samples are presented in Table.1. As it is seen agreement between SPDR results and reference data is excellent. SPDR technique can be also optimized for measurements of specific materials (e.g. ferroelectrics or low permittivity materials) by appropriate choice of permittivity and dimensions of the dielectric resonators.

TABLE 1. COMPLEX PERMITTIVITY MEASUREMENTS OF SINGLE CRYSTAL QUARTZ USING SPLIT POST DIELECTRIC RESONATORS

	SPDR data		Reference data			
f(GHz)	ε_r'	tanδ	ε_{rr}'	tanδ	$\frac{\varepsilon_{rr}' - \varepsilon_r'}{\varepsilon_{rr}'}(\%)$	Material
1.4	4.448±0.3%	1.15E-05±2E-05	4.443±0.1%	1.5E-05±5%	0.11	Quartz
2.0	4.454±0.3%	1.82E-05±2E-05	4.443±0.1%	1.5E-05±5%	0.25	Quartz
3.9	4.443±0.3%	2.58E-05±2E-05	4.443±0.1%	1.5E-05±5%	0	Quartz
5.5	4.439±0.3%	3.40E-05±2E-05	4.443±0.1%	1.5E-05±5%	0.09	Quartz

The split-post dielectric resonator offers accurate measurements with quantifiable uncertainties for wide ranges of permittivity and loss in frequency range 1-30 GHz that plugs a gap in the frequency coverage of existing methods. The method is especially useful for measurements of flat laminar specimens without any need for machining of their shape.

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