SPLIT POST DIELECTRIC RESONATORS FOR MEASUREMENTS OF THE COMPLEX PERMITTIVITY OF LAMINAR DIELECTRIC MATERIALS AT MICROWAVE FREQUENCIES

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ABSTRACT

Split-post dielectric resonators operating at frequencies 1.4-30 GHz were used to measure complex permittivity of standard reference dielectric materials with known dielectric properties previously measured by other techniques. It was proved experimentally that using split post resonators it is possible to measure permittivity with uncertainty of 0.3% and dielectric loss tangent with resolution of $2x10^{-5}$ for well-machined laminar specimens. Applications of split post dielectric resonators for measurements of ferroelectrics and thin film materials were highlighted

INTRODUCTION

The split-post dielectric resonator (SPDR) described in [1]-[7], and shown in Fig.1 and Fig.2., is already well-established technique for measurements of the complex permittivity of dielectric and ferrite laminar specimens at frequency range 1-10 GHz [1]-[7]. Recently new split post dielectric resonators have been constructed that operate at frequencies up to 33 GHz. Theoretical error analysis presented in former papers [5]-[6] has shown that SPDR technique enables measurements of permittivity with accuracy 0.3% and dielectric loss tangent with resolution down to $2x10^{-5}$. In this paper results of measurements of standard reference materials are presented to verify experimentally those uncertainties.

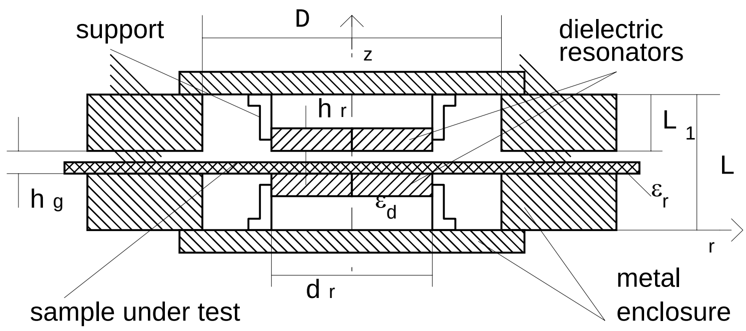

Fig.1. Schematic diagram of a split post dielectric resonator fixture.

Fig.2 Photograph of disassembled 3.2 GHz split post dielectric resonator

SPLIT-POST DIELECTRIC RESONATORS OPTIMISED FOR SPECIFIC APPLICATIONS

Appropriate choice of permittivity and dimensions of their dielectric resonators can optimize split post dielectric resonator technique for measurements of specific materials. One SPDR operating at frequency 1.45 GHz was designed for measurements of ferroelectrics. Its posts were made of low loss dielectrics having permittivity equal to 80. This resonator can be used for measurements of materials having large permittivity values and medium losses. In Fig. 2 quasi-TE_{011} mode resonant frequencies of 1.45 GHz resonator versus permittivity and thickness of samples under test are presented. It is seen that for thin samples (0.1 mm - 0.2 mm) resonant frequency shifts does not exceed 20% that allows measuring materials having permittivity larger then 1000.

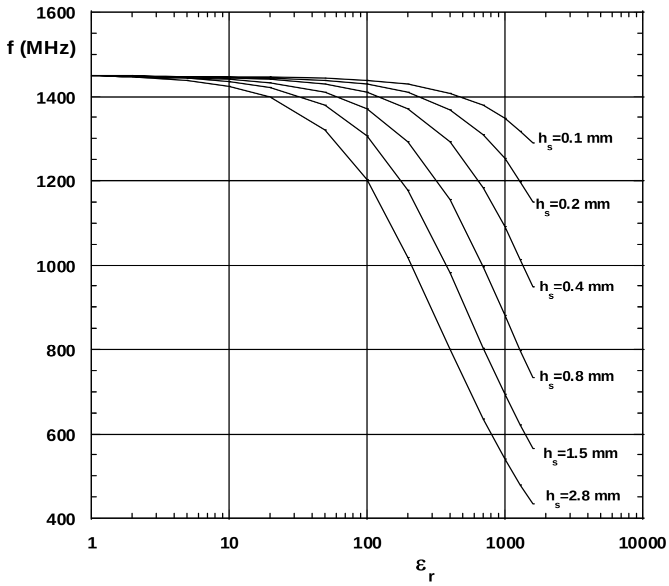

Fig.3. Quasi-TE_{011} mode resonant frequency of 1.45 GHz SPDR resonator, optimized for measurements of ferroelectrics, versus permittivity and thickness of samples.

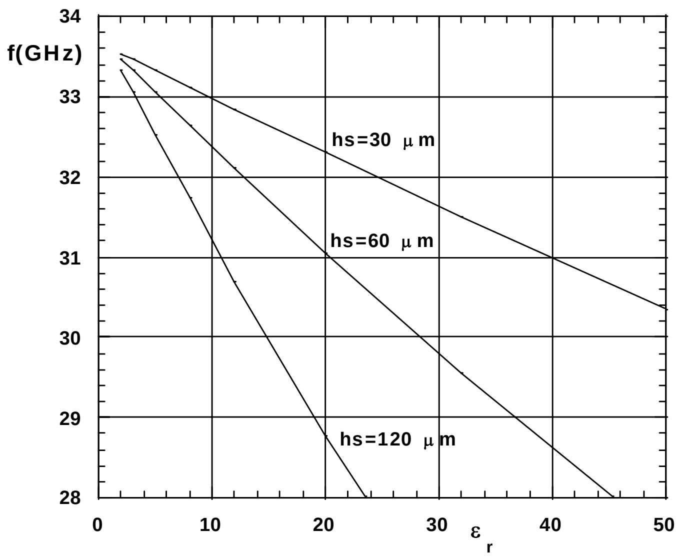

Fig.4. Quasi-TE_{011} mode resonant frequency of 33 GHz SPDR resonator, optimized for measurements of thin dielectric films, versus permittivity and thickness of samples.

Another resonator was designed for measurements of thin film materials. Its dielectric resonators were made of sapphire. In Fig. 4 quasi-TE_{011} mode resonant frequencies of this resonator versus permittivity of samples under test are presented. One can observe that even very thin samples produce significant resonant frequency shifts that allows to measure materials having thickness smaller then 1 μm

MEASUREMENTS OF STANDARD REFERENCE MATERIALS

Measurements have been performed using six different split post dielectric resonators constructed by the author, and optimized for measurements of low loss dielectrics. We choose single crystals as standard reference materials since they have precisely determined permittivity and very low dielectric losses. The first property enables to assess experimentally measurement uncertainty of permittivity in SPDR's and the second enables to assess loss tangent resolution. In Table 1 there are results of complex permittivity measurements of sapphire and quartz samples Results of measurements are compared to the reference values [8-13]. It is seen that all permittivities agree within specified measurement uncertainties. Loss tangent data versus frequency for single crystal quartz are not given in literature with satisfactory precision. Measurements using whispering gallery mode technique at frequency about 17 GHz gave loss tangent value of 1.5E-05 at room temperature [8]. Comparing this value with results shown in Table 1 one can conclude that tangent values agree with reference data within specified loss tangent resolution. It should be mentioned that loss tangent resolution is predominantly limited by Q-factor uncertainties, and Q-factor values of empty SPDR's.

Table 1. Complex permittivity measurements of standard reference materials using split post dielectric resonators

	SPDR data		Reference data [8]		
f(GHz)	ε_r'	tanδ	ε_{rr}'	$\frac{\varepsilon_{rr}' - \varepsilon_r'}{\varepsilon_{rr}'}(\%)$	Material
3.9	9.420±0.3%	2.40E-05±2E-05	9.400±0.1%	0.21	Sapphire
1.4	4.448±0.3%	1.15E-05±2E-05	4.443±0.1%	0.11	Quartz
2.0	4.454±0.3%	1.82E-05±2E-05	4.443±0.1%	0.25	Quartz
3.9	4.443±0.3%	2.58E-05±2E-05	4.443±0.1%	0	Quartz
5.5	4.439±0.3%	3.40E-05±2E-05	4.443±0.1%	0.09	Quartz
9.7	4.430±0.3%	3.80E-05±2E-05	4.443±0.1%	0.29	Quartz
30.8	4.440±0.3%	3.42E-05±2E-05	4.443±0.1%	0.07	Quartz

Measurements of the dielectric loss tangent of materials having larger losses are always more accurate then low loss materials. It can be seen in Table 2 where permittivity and loss tangent values are shown for stacked kepton films. One can observe that measurement results are very consistent and independent on the number of films.

Table 2 - Results of measurements of stacked kepton films

h (mm)	ε_r'	tanδ	Number of stacked films
0.100	3.19	49E-04	1
0.201	3.20	50E-04	2
0.406	3.20	49E-04	4
0.616	3.18	50E-04	6

CONCLUSIONS

The split-post dielectric resonator has been shown to make a useful, accurate and convenient tool for complex permittivity measurements of various dielectric materials. It offers accurate measurements with quantifiable uncertainties for wide ranges of permittivity and loss in frequency range 1-30 GHz. The method is especially useful for measurements of flat laminar specimens without any need for machining of their shape.

REFERENCES

[1] J. DelaBalle, P.Guillon, and Y. Garault, "Local complex permittivity measurements of MIC substrates", AEU Electronics and Communication, vol.35, pp.80-83, Feb. 1981.
[2] J. Krupka J. and Maj S., "Application of the $TE_{01\delta}$ mode dielectric resonator for the complex permittivity measurements of semiconductors", CPEM '86 , pp.154-155, 1986.
[3] Nishikawa T. et al, "Precise measurement method for complex permittivity of microwave substrate", CPEM '88, pp. 154-155, 1988.
[4] J. Krupka, R.G. Geyer, J. Baker-Jarvis, and J. Ceremuga, "Measurements of the complex permittivity of microwave circuit board substrates using split dielectric resonator and reentrant cavity techniques", pp.21-24, DMMA'96 Conference, Bath, U.K. 23-26 Sept. 1996.
[5] J. Krupka, A. P. Gregory, O. C. Rochard, and R. N. Clarke, Le split resoantor et d'aautres techniques de mesures", Int. Conf. 6-emes Journees de Caracterisation Mico-ondes et Materiaux (JCMM'2000), Paris 22-24 Mars, 2000.
[6] J. Krupka, R. N. Clarke O. C. Rochard, and A. P. Gregory, „Split Post Dielectric Resonator technique for precise measurements of laminar dielectric specimens – measurement uncertainities", XIII Int. Conference MIKON'2000, Wrocław, Poland, pp.305-308, May 22 - 24, 2000.
[7] J Krupka, S A Gabelich, K Derzakowski, and B M Pierce,"Comparison of split post dielectric resonator and ferrite disc resonator techniques for microwave permittivity measurements of polycrystalline yttrium iron garnet", Meas. Sci. Technol. pp. 1004-1008, Vol. 10, 1999.
[8] J. Krupka, K. Derzakowski, M.E. Tobar, J. Hartnett, and R.G. Geyer, "Complex permittivity of some ultralow loss dielectric crystals at cryogenic temperatures", Measurement Science and Technology, vol.10, pp.387-392, Oct.1999.
[9] R. Shelby J. Fontanella and C. Andeen, "The low temperature electrical properties of some anisotropic crystals", J. Phys. Chem. Solids, vol. 41 , pp. 69-74, 1980.
[10] E.V. Lowenstein, D.R. Smith, and R.L. Morgan, "Optical constants for far infrared materials. I. Crystalline solids", Applied Optics, vol.12, No.2, pp.398-406, February 1973.
[11] R.G. Jones, "The measurement of dielectric anisotropy using open microwave resonator", Journal of Physics D-Applied Physics, vol.9, No.5, pp.819-827, April 1976.
[12] J. Fontanella, C. Andeen, and D Schuele, "Low-frequency dielectric constant of alpha – quartz, sapphire, MgF2 and MgO", Journal of Applied Physics, vol.45, No.7, pp.2852-2854, July 1974.
[13] I. Wolf and N. Schwab, "Messung der Dielektrizitatszahl anisotroper dielektrischer Materialien im Mikrowellenbereich", Westdeutscher Verlag GmbH, Opladen, 1980.