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Journal of the European Ceramic Society 26 (2006) 1817–1820
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Novel evaluation method for complex high permittivity of $BaTiO_3$ families at microwave frequency

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Available online 2 November 2005

Abstract

A simple but practically accurate evaluation technique is proposed for the complex dielectric constant of high permittivity materials in microwave region using the discontinuity structure in coaxial line. The test fixture is designed using the accurate theoretical analysis, i.e., the extended spectral domain approach and mode matching method (ESDMM). The complex permittivity is estimated by inversely fitting the measured *S*-parameters of test fixture loaded with specimen to the most probable permittivity values of specimen using ESDMM simulation. The new method provides an easy way to evaluate the high complex permittivity exceeding 10,000, which is difficult to be measured by currently used measurement techniques.

Keywords: Dielectric properties; $BaTiO_3$ and titanates; Microwave property; Spectroscopy

1. Introduction

The demand on the miniaturization and high performance of mobile communication equipment has increased the use of high permittivity materials such as BST ((Ba,Sr)TiO_3). It is required to develop the accurate evaluation methods for high permittivity materials at microwave frequencies. A number of measuring methods have been proposed for the evaluation of relatively lower permittivity materials, including waveguide or coaxial line methods,[1] resonant cavity and parallel plate methods.[2,3] These methods, however, are not suitable for the measurement of high permittivity materials, due to the inevitable disturbance which comes from the higher order modes caused by high permittivity of sample. In this paper, we report a practically accurate evaluation method for the high permittivity materials with either low or high losses, free from the effect of higher order modes. The measurement technique is based on the accurate electromagnetic field analysis, the extended spectral domain approach combined with the mode matching method (ESDMM).[4,5] The computational procedure based on electromagnetic (EM) field theory is numerically efficient and suitable for heavy iterative calculation to estimate the characteristics of the high permittivity materials.

1.1. Theory and procedure of new measurement technique

The schematic structure and coordinate system of the 1 port test fixture is shown in Fig. 1. The cylindrical sample is inserted at the end gap between the center conductor of the coaxial line and the metal plate terminating this test fixture. The sample may be lossless and/or lossy dielectric with low or high permittivity. This structure is suitable for heating or cooling of the sample, which is important for the characterization of ferroelectric materials, compared to 2 port fixture.[4,5] When the other side of the coaxial line is terminated with metal plate, the structure becomes the re-entrant cavity and it can be analyzed as an eigenvalue problem by the mode matching method.[6] However, the test fixture considered here is analyzed as a deterministic problem with the input port, by using a novel theoretical method, i.e., ESDMM.

The dominant TEM wave is incident upon the sample. The reflected wave is measured to identify the dielectric characteristics of the sample by using the accurate electromagnetic field analysis, i.e., the extended spectral domain approach and mode matching method (ESDMM). In ESDMM, the aperture electric field are introduced at the boundary between the region I: $z < 0$ and region II (sample): $0 < z < t$ as shown in Fig. 2. The whole region to be analyzed is divided into two regions, region I and region II. Each region is treated separately. Region I is homogeneous and the EM field is expressed by simple eigen functions

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0955-2219/$ – see front matter
doi:10.1016/j.jeurceramsoc.2005.09.006

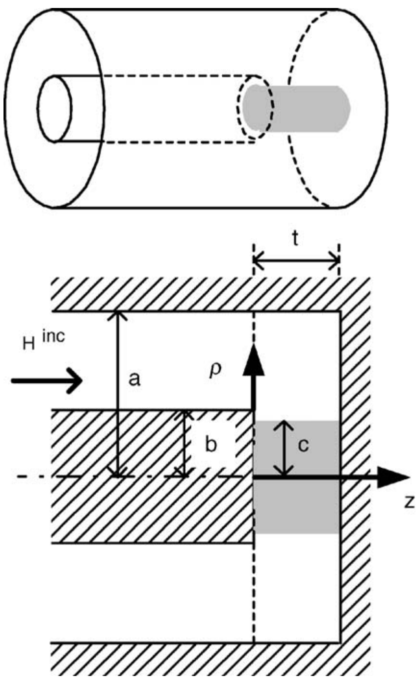

Fig. 1. The schematic structure and coordinate system for coaxial line test fixture with lossless and/or lossy dielectric sample.

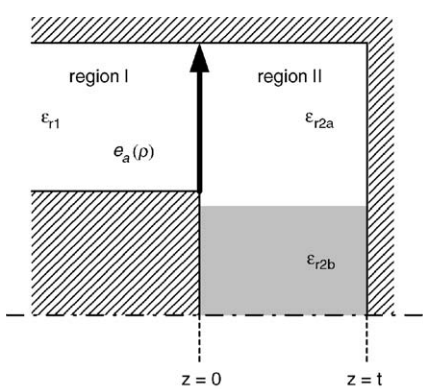

Fig. 2. Introduction of aperture field.

as shown in Fig. 3 I. Region II, on the contrary, is loaded with the sample and inhomogeneous, so that EM field is not expressed by simple eigen functions. In ESDMM, the mode-matching procedure is applied to combine two localized eigen functions series

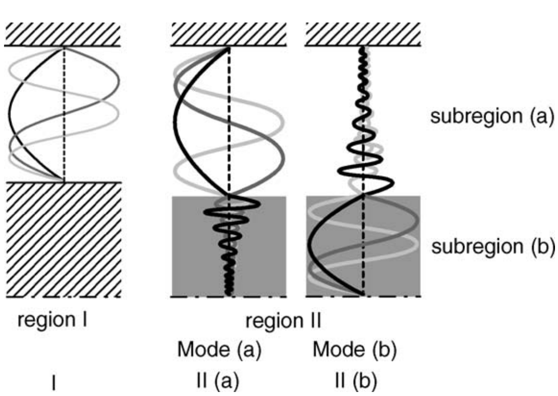

Fig. 3. I, II(a) and II(b). Eigen functions in each region.

in regions II-a and II-b into unified expression of EM fields in region II, Fig. 3 II(a and b).[4,5] Finally, applying the continuity condition at the boundary between the regions I and II, the scattering parameters (the complex reflection constant) can be obtained.

The numerical procedure is based on Galerkin's method. In this procedure, the unknown aperture electric fields, $e_p(\rho)$ is expressed in terms of the basis functions

$$f_k(\rho) \quad (k = 1,\ 2,\ \ldots,\ N).$$

$$e_p(\rho) = \sum_{k=1}^{N} p_k f_k(\rho) \tag{1}$$

where N is an integer, p_k $(k = 1, 2, \ldots, N)$ are unknown constants.

When the basis functions $f_k(\rho)$ are chosen so as to express properly the continuity condition between regions I and II, the series of Eq. (1) converge rapidly.[4,5] It should be noted that the matrix size in this method is the order of the number of basis functions N and far smaller than that of the conventional mode matching methods and other numerical analyses by simulators, in which order of matrix size is equal to the number of eigen functions.

2. Results and discussions

Preliminary calculation are carried out to confirm the validity of the present method and to design the test fixture. Fig. 4 shows the numerical results of the frequency dependence of the scattering parameter S_{11} for the test fixture loaded with a disk of

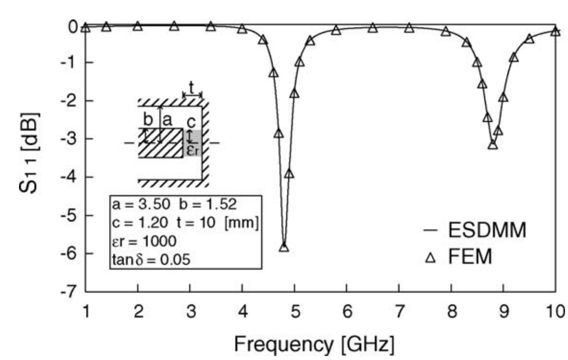

Fig. 4. Comparison of S_{11} values simulated by ESDMM and FEM.

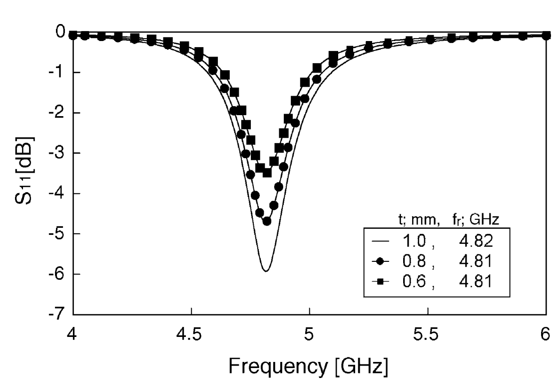

Fig. 5. Dependence of the resonance frequency on the sample height.