MEASUREMENT OF TEMPERATURE DEPENDENCE OF RELATIVE PERMITTIVITY BY THE CAVITY PERTURBATION METHOD

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ABSTRACT

A new cavity perturbation method has been proposed as a technique for evaluating the temperature dependence of relative permittivity, τ_ε, in the pseudo-microwave range. In order to increase the accuracy of this method, an automatic measuring apparatus, satisfying the perturbation principle, was constructed and improvements in data processing were employed, such as the periodic least square method. Results for some microwave dielectrics demonstrated that measured τ_ε values for this method conform to those of the dielectric rod resonator method.

1.INTRODUCTION

With the increasing spread of mobile communication, and the proliferation of pagers, cellular phones and wireless-LANs, dielectric materials used in RF devices have been evolving from bulky microwave dielectrics to multilayered substrate materials, so as to aid the miniaturization of these devices. Polymer materials have also partially begun to be utilized in these devices, due to their lighter weight.

The dielectric rod resonator (DRR) method[1-2] is generally used for measurements of complex permittivity. However, it is difficult to prepare specimens for the pseudo-microwave range which is the primary frequency band for mobile communications, because of the requirements for larger sample sizes, due to the dependence of resonant frequency on both the relative permittivity and size of the measured dielectric cylinder. Relative permittivity and Q-factor of multilayered substrate materials and polymer materials, in particular, are considerably lower than those of bulky microwave dielectrics, and hence it is very difficult to evaluate the complex permittivity of these materials in the pseudo-microwave range by this method.

Furthermore, the "Qf-constant rule" which signifies that the product of Q-factor and frequency, Qf, is constant, cannot always be applied, due to the frequency dependence of the properties of some RF materials[3]. Hence, the need for a reliable technique for the evaluation of complex permittivity at actual material operating frequencies has increased. Although the time domain network analysis method[4] can evaluate frequency dependence of complex permittivity, results of measurements demonstrates unreasonable ripple at specific frequency.

The authors have proposed the advanced cavity perturbation method, which is highly suitable for the evaluation of complex permittivity in the pseudo-microwave range[5-6]. However, the conventional cavity perturbation method[7-8] possess difficulty in the evaluation of temperature dependence. A new cavity perturbation method will be presented in this paper, as a technique for evaluating the temperature coefficient of relative permittivity, τ_ε, in the pseudo-microwave range. In order to increase the accuracy of this method, an automatic measuring apparatus has been constructed which satisfies the perturbation principle and some improvements in data processing have been employed. The accuracy of this new cavity perturbation method is also discussed, as compared with the DRR method.

2.PRINCIPLES

When a thin rectangular dielectric rod is inserted into the strongest electric field region of a cavity, perturbations of the cavity's resonant properties are created, depending on the dielectric permittivity of the inserted material. This perturbation method is used to calculate the complex permittivity of the dielectric material using the resonant frequency, fc, and the Q-factor, Qc, for the initial cavity, and fs and Qs for the sample-charged cavity, as follows:

$$\varepsilon' = 1 + \frac{V_C}{\alpha_\varepsilon V_S} \times \frac{f_S - f_C}{f_C} \quad \text{(Eq.1)}$$

$$\varepsilon'' = \frac{V_C}{2\alpha_\varepsilon V_S} \times \left(\frac{1}{Q_S} - \frac{1}{Q_C} \right) \quad \text{(Eq.2)}$$

where Vc and Vs are the volumes of the cavity and sample, respectively, taking thermal expansion in consideration. α_ε is a geometrical constant dependent upon the cavity mode and is 1.855 for the circular TM010 mode[8].

3. EXPERIMENTAL PROCEDURES

3.1. Apparatus for measuring temperature dependence

To evaluate the temperature dependence of sample, an automatic measuring apparatus, including a cavity as summarized in Table I, is used, as presented in Fig.1. A thin rectangular

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Table I. Specifications of cavity.

Resonant mode	Resonant freq. (GHz)	Unloaded Q
Circular TM010	1.913	13600

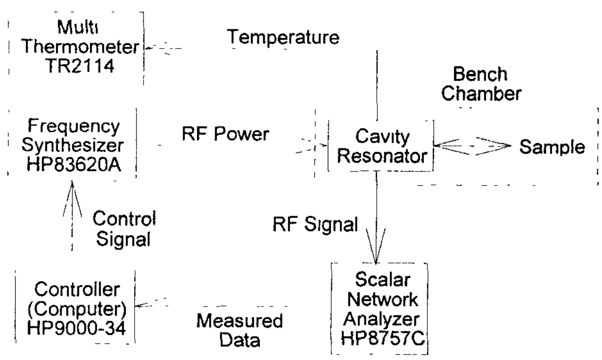

Fig.1. Measuring apparatus.

specimen is inserted into or pulled out the cavity by the flow of dry nitrogen, the temperature of which is controlled by a heat-exchanger. The position of the sample inside or outside the cavity is determined by the direction of nitrogen flow, as illustrated in Fig.2(a) and Fig.2(b). Using dry nitrogen prevents the deterioration of sample properties due to high humidity and avoids dew condensation at low temperature. It also protects the structure of the cavity against oxidation at high temperature.

3.2. Improvements in data processing

Based on Eq.1 and Eq.2, the measurement accuracy of cavity resonant properties directly determines the accuracy of the material evaluation. Since the accuracy of the conventional perturbation method is low, especially with regard to Q-factor measurements, this method has not been widely adopted. In order to rectify this problem, some improvements[5-6] have been employed, such as the resonance curve area (RCA) method for Q evaluation, the comparative RCA method for the evaluation of resonant frequency, and the periodic least square (PLS) method for data processing.

The RCA method is based on the fact that the power resonance curve area, which signifies the square of voltage curve area, is inversely proportional to the Q-factor in the frequency domain. This method calculates the Q-factor from the ratio of the resonance curve area in the frequency domain S, to the resonant frequency fr, as follows:

$$Q = \frac{P_0}{S} f_r \tan^{-1}\left(\sqrt{\frac{P_0}{\left(\frac{P_0}{1+x^2}\right)} - 1}\right) \qquad \text{(Eq.3)}$$

$$x = \frac{2Q(f - f_r)}{f_r} \qquad \text{(Eq.4)}$$

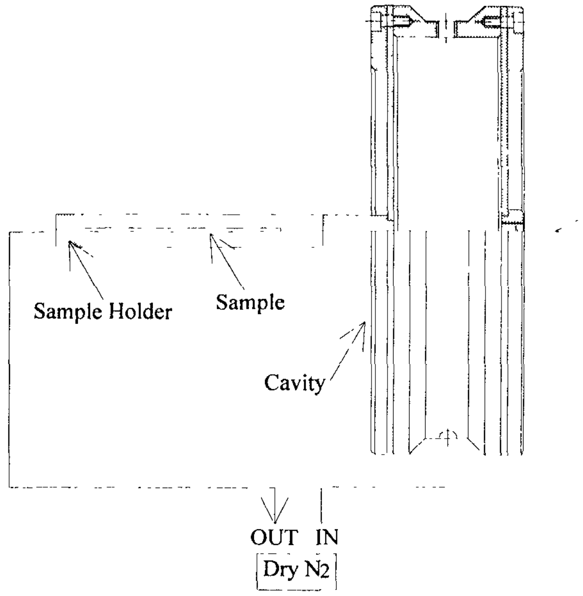

Fig.2(a). Cross section of initial cavity.

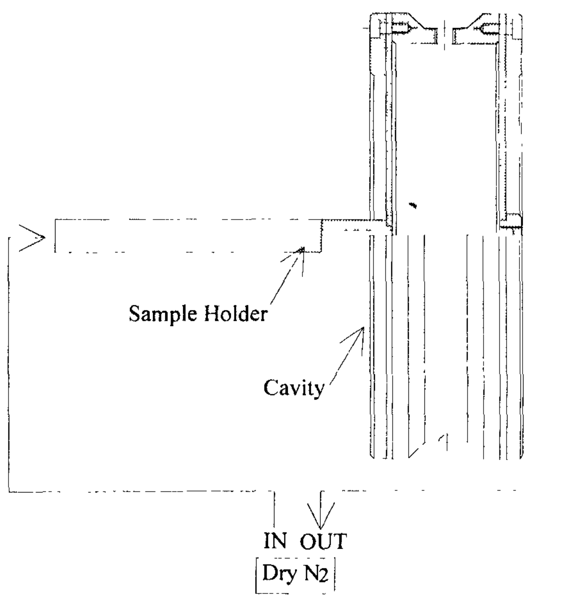

Fig.2(b). Cross section of sample charged cavity.

where P0 is the peak output power of a resonator and f is the driving frequency. Compared with the half bandwidth method which is generally used and which is based only on point data, the RCA method is more accurate since it uses plane data.

In the case of the comparative RCA method, resonant frequency is determined considering an area of the difference between measured resonance data and a corresponding best-fit theoretical resonance curve. This method uses characteristics such as the equivalency of an area of lower frequency to that of higher frequency with resonant frequency as a boundary frequency.

The PLS method is employed to reduce spurious variations

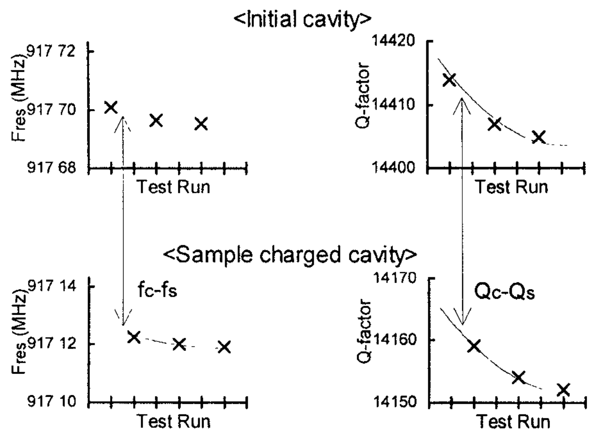

Fig.3. Changes with the passage of the time.

in acquired data with the passage of time. Such variations are common in both the initial and sample-charged cavities as shown in Fig.3. Using the PLS method, measured data are approximated by quadratic curves, the coefficients of which are determined in such a way that the parabolic curve for the initial cavity is parallel to that of the sample-charged cavity. Such spurious changes are due in part to environmental temperature drifts, and the PLS method is very effective in improving the accuracy of measurements of $\tau\varepsilon$ with removing the time dependent factor.

3.3. Measured samples

In order to compare this method with the DRR method, the reliability of which has been widely recognized, two kinds of samples were simultaneously prepared from identical materials, as illustrated in Fig.4, thereby eliminating variations in dielectric property, due to ceramic processing. From identical dry-pressed rectangular blocks, with dimensions of 10×10×100mm, thin rectangular rods, with dimensions of 1×1×80mm, were sliced for the cavity perturbation method and cylinders, with dimensions of ϕ9×4.5mm, were produced for the DRR method. Four materials were investigated, namely, Forsterite(εr~8), Al_2O_3(εr~9), $MgTiO_3$-$CaTiO_3$(εr~19), Ba(Mg,Co,Nb)O_3(εr~32).

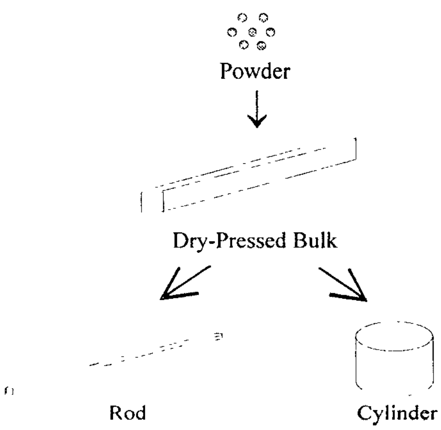

Fig.4. Sample preparation procedure.

All materials measured for in this paper are microwave dielectrics produced from dry-pressed bulks, for the purpose of comparison with the DRR method. In practice, this new cavity perturbation method has been applied to multilayered substrate materials, produced from laminated ceramic sheets and polymer materials produced by the processing of dried solutions.

4. RESULTS AND DISCUSSION

The reproducibility of $\tau\varepsilon$ measurements was evaluated by the repetitive measurement of samples using the new cavity perturbation method, enhanced by the improvements discussed above. Repetitious measurements of $\tau\varepsilon$ (n=10) and the reproducibility of such measurements are presented in Fig.5 and Fig.6 for Ba(Mg,Co,Nb)O_3 materials with measured temperature ranging from -40 to 80°C. From these results, the reproducibility of $\tau\varepsilon$ measurements was found to be satisfactory with a statistical average of -41.47±0.85 (ppm/°C).

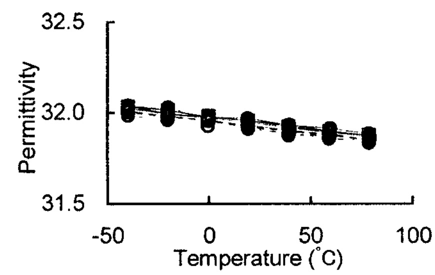

Fig.5. Repetitious measurements of temperture dependence of relative permittivity.

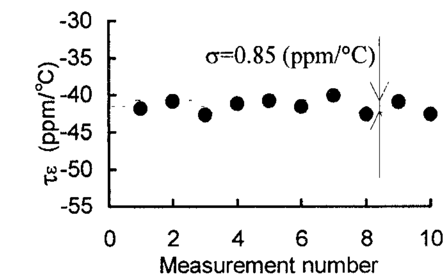

Fig.6. Reproducibility of $\tau\varepsilon$ measurements.

In order to make comparison with the temperature coefficient of resonant frequency, τf, measured by the DRR method, $\tau\varepsilon$ measured by the cavity perturbation method is converted to τf as follows:

$$\tau_f = -\left(\frac{1}{2}\tau_\varepsilon + \alpha\right) \quad \text{(Eq. 5)}$$

where α is the coefficient of thermal expansion. Comparison of both methods for various materials is shown in Fig.7, where □ and P represent the cavity perturbation method, and × and D signify the DRR method. Fig.7 shows that there is good agreement between both methods for the measurement of temperature coefficients.

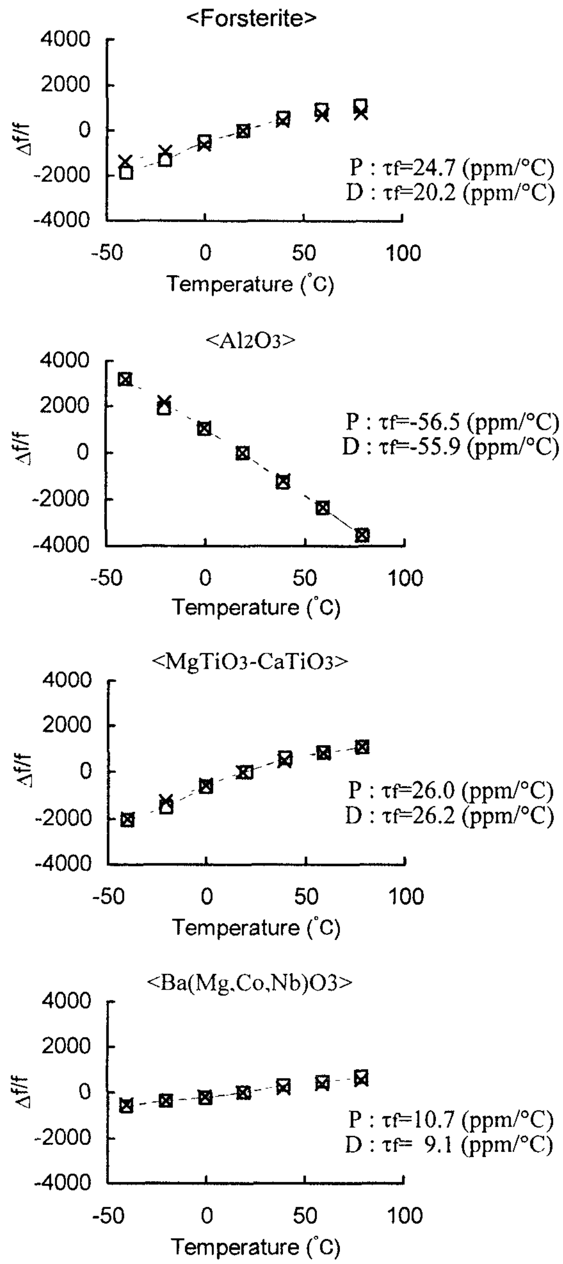

Fig.7. Comparison of measurement methods.

5.CONCLUSION

A new cavity perturbation method has been proposed as a technique for evaluating the temperature dependence of relative permittivity in the pseudo-microwave range. In order to increase the accuracy of this method, an automatic measuring apparatus which satisfied the perturbation principle was constructed and some improvements in data processing were employed, such as the resonance curve area method, the comparative resonance curve area method and the periodic least square method. The accuracy of this method was thus enhanced, reducing the deviation in temperature coefficient of relative permittivity, τ_ε, for the investigated materials to less than ±0.9ppm/°C. Results for some microwave dielectrics demonstrated that measured τ_ε values for this method agree with those measured by the dielectric rod resonator method.

The development of the advanced cavity perturbation method is a significant step forward, as a technique for the evaluation of temperature and frequency dependence of complex permittivity for materials operating in the pseudo-microwave range. This method also eliminate the necessity for larger sample sizes. It is anticipated that this method will be of extensive practical use, such as confirming dielectric properties measured by the S-parameter method and the time domain network analysis method, and comparing the consistency of measurements by several other methods.

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