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Dielectric properties of alumina ceramics in the microwave frequency at high temperature

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Abstract. The dielectric properties of alumina ceramics have been measured using a free-space time-domain technique from room temperature to 1400 ^{o}C in the frequency range 8.2 – 12.4 GHz. The effects of thickness and lateral size of specimen were investigated with comparing the measured values to the calculated ones based on the half-wavelength and the Gaussian beam focusing. From these results the optimum specimen dimension for the high temperature dielectric measurement was suggested with experimental verification.

Introduction

Dielectric measuring techniques at radio and microwave frequencies have been an important subject within a wide range of scientific and engineering applications. Traditionally, such measurements have been made in the frequency domain using cavity, waveguide, stripline or coaxial transmission line.[1 – 3] They are basically destructive in nature and tedious sample preparations are required. More recently, non-destructive measurement techniques, such as open-ended transmission line, have been developed and used in basic research, industrial and medical applications. There is, however, some limitations in the maximum temperature, necessity of accurate specimen dimension, and the difficulties in inhomogeneous materials. ,.

In recent years, there has been increasing interest in using free-space techniques for measurement of electrical properties of materials.[4–6] Althogh the temperature and frequency dependence of the dielectric properties have been studied in the ferroelectric materials which have high dielectric constant in general. there is a limited number of report in dielectric properties of low dielectric ceramic materials, which have a potential applications in microwave window..

In this study, a novel free-space time-domain measurement technique had been conducted for *in-situ* measurement of the complex permittivity of low dielectric material at elevated temperature. Dielectric constant and tangent loss of alumina ceramics up to 1400 ^{o}C were measured by the free-space technique. The effect of thickness of specimens on dielectric properties was also discussed.

Experimental procedure

A schematic illustration of the experimental measurement configuration is shown in Fig. 1. High temperature box furnace was located in between two horn X-band (8.2 – 12.4 GHz) antennas, of which focal length is 30.5 cm. The planar alumina specimen with size of 120 X 120 mm was placed inside the furnace and was finely adjusted position to fit in the focal region.

Scattering parameters were measured from the vector network analyzer(HP 8510C) for specimens. The density of alumina specimen was about 97% of theoretical density. Dielectric constant and tangent loss at microwave frequency were calculated by the material characterization package program(Agilent 85071E).

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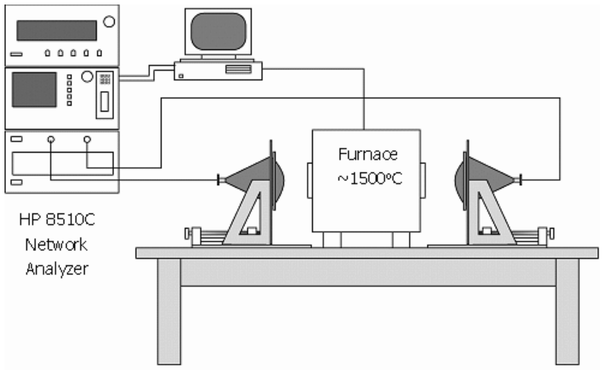
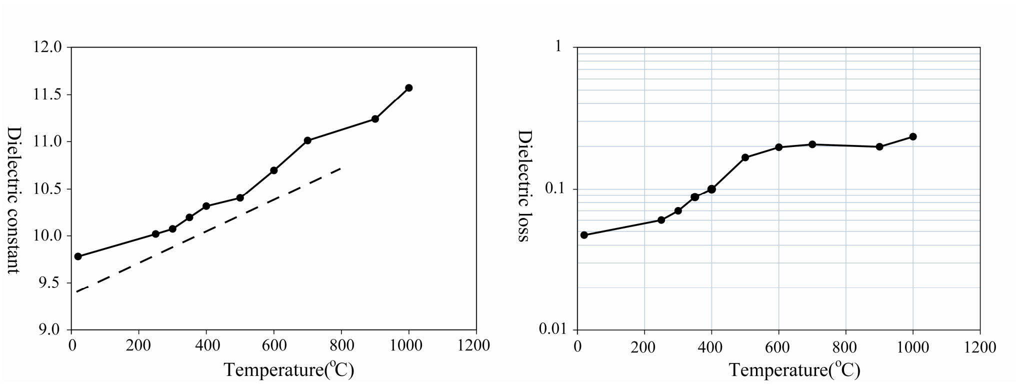


Fig. 1. Schematic of high temperature measurement system

Results and discussion

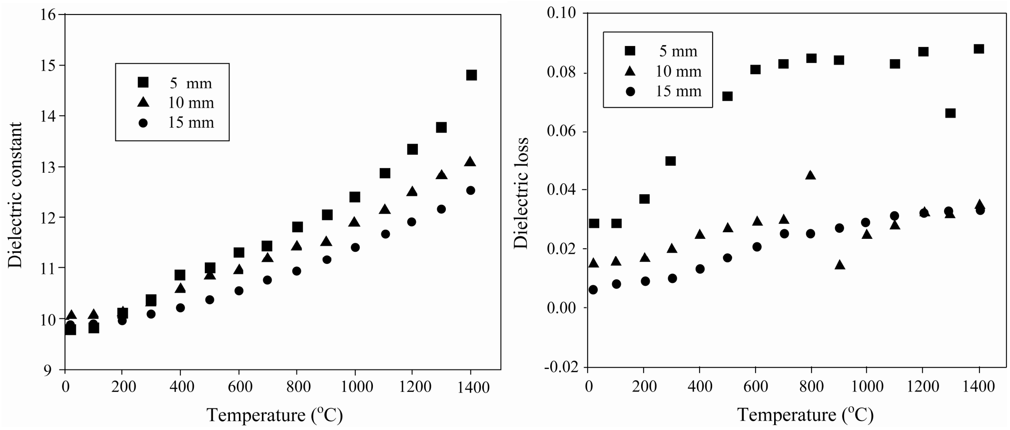
Figure 2 shows the dielectric constant and tangent loss for alumina with sample thickness of 5 mm from room temperature to 1000 ^{o}C. The dielectric constant varied from 9.78 at 25 ^{o}C to 11.61 at 1000 ^{o}C while the tangent loss varied from about 0.05 at 25 ^{o}C to 0.23 at 1000 ^{o}C. The previous result of dielectric constant reported by Hollinger et al.[7] is shown as dashed line in Fig. 2(a). As shown in the graph, the dielectric constant and tangent loss increased with the temperature. The temperature dependency of dielectric constant was coincided well with the reference value. But the measured value of tangent loss of alumina ceramics was higher than previous result. The discrepancy is considered due to the relative high microwave adsorption by the furnace insulation materials compare to specimen under testing.



(a) (b)

Fig. 2 (a) Temperature dependence of dielectric constant (b) Temperature dependence of dielectric loss at X-band(8.2 – 12.4 GHz) measured for alumina specimen using free-space method.

To investigate the relation of the thickness and tangent loss, the dielectric properties of alumina specimens with the thickness of 5, 10, and 15 mm were measured with increasing temperature up to 1400 ^{o}C. Figure 3 shows the dielectric constant and tangent loss of three different thickness specimens. As shown in Fig. 3, the dielectric constant and tangent loss increased with increasing temperature, and the temperature dependencies of the dielectric constant and the tangent loss were measured in the thinner specimen,.



(a) (b)

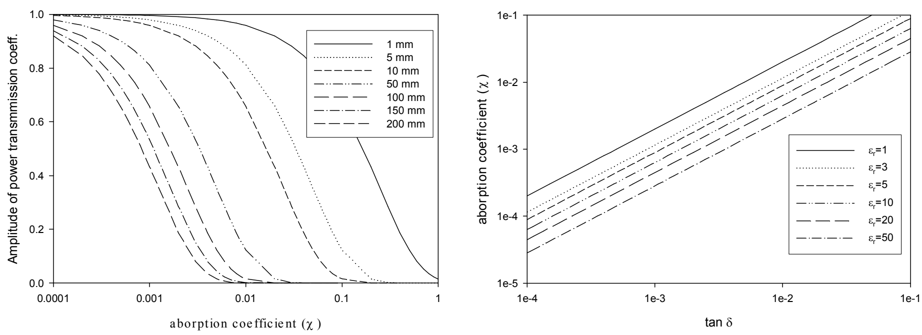
Fig. 3 (a) Temperature dependence of dielectric constant (b) temperature dependence of dielectric loss at X-band (8.2 – 12.4 GHz) measured for alumina specimen using free-space method

Equation (1) and (2) show the relation among the dielectric constant, tangent loss, and specimen thickness, where d is the thickness of a specimen, s is integer, λ_0 is wavelength of incident beam, ε_r is dielectric constant of a specimen, χ is absorption coefficient, and tan δ is tangent loss. [8]

$$d = s\frac{\lambda_0}{2\sqrt{\varepsilon_r}} \tag{1}$$

$$\chi = \frac{1}{2}\sqrt{\varepsilon_r}\tan\delta \tag{2}$$

Figure 4 (a) shows the relations between the thickness of specimen and absorption coefficient (χ). When the thickness becomes thicker, and the absorption coefficient decreases more quickly. According to eq. (2) and Fig. 4, the tangent loss can be related with the thickness of the specimen. The absorption coefficient becomes smaller with the thickness of a specimen thicker, accordingly the tangent loss will be also lowered. From the experimental results, the thickness of specimen is revealed one of important parameters for the accurate measurement of dielectric properties in low loss materials. .It is suggested that the thicker specimen would provide the more accurate dielectric properties with the integer times of half wavelength, especially in low dielectric constant and low tanget loss ceramics.



(a) (b)

Fig. 4 (a) Dependence of the amplitude of the power transmission coefficient on the absorption coefficient (χ) for various specimen thickness (b) the absorption coefficient as a function of loss tangent

Summary

In this study, dielectric properties of ceramic alumina were measured with increasing temperature using the free-space measurement method. For the high temperature measurement, the measurement devices were designed and the dielectric properties of alumina were measured. Measured dielectric constant was coincided with the reference value, but tangent loss was not.

To investigate the relation of the thickness and tangent loss, the dielectric properties of alumina specimens with different thickness were measured from room temperature to 1400 ^{o}C. It is suggested that the thicker specimen would provide the more accurate dielectric properties with the integer times of half wavelength, especially in low dielectric constant and low tanget loss ceramics. These results of dielectric properties can provide useful information on optimum design criteria and parameters to give the best performance in terms of electromagnetic properties.

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