Microwave Effect on Zirconia Ceramics at High Temperature

Thoria A. Baeraky

Faculty of Science, Physics Department, King Abdulaziz University, Jeddah, Saudi Arabia

Abstract: ***The project of this work is to study the microwave effect on zirconia ceramics at high temperature. Three samples of zirconia ceramics, pure zirconia (ZrO_2), zirconia stabilized with yattria (Y_2O_3), and zirconia stabilized with magnesia (MgO), are chosen for this work. A full computerized cavity perturbation technique working in frequency ranges, 615 MHz, 1412 MHz, 2214 MHz, and 3017 MHz at temperature ranging from 25 ^oC to 2000 ^oC, are using to measure the microwave dielectric properties of the three samples. The microwave effect on these samples can be determined due to the variation in the real and the imaginary parts, ε' and ε'', of the dielectric properties in microwave frequency range at high temperature.***

Keywords: Micrwaves, cavity perturbation, Ceramics. Zirconia, permmtivity

1. Introduction

Microwave processing has a clear industrial perspective in such areas as the joining , sintering and production of advanced ceramic engineering, the science and technology of creating objects from inorganic, non-metallic materials. High performance ceramics, which are excellent in resistance to heat and corrosion, are promising candidates for replacing metals under high temperature environment. These ceramics have been developed for various applications including aeronautical, automotive, and electronic material. Microwave heating generates inside the material due to the microwave material interaction, it depends on the nature of the material characteristic. It is more volumetric and very rapid leads to time, and temperature saving as well as improving the homogeneity of heating.Microwave processing of ceramics demonstrate the necessity to understand both the materials and electromagnetic field aspects of successful microwave processing [1-3]. Microwave dielectric properties, the complex permittivity, $\square^*$, is the macroscopic parameter which provides direct data about the microwave interaction with materials and the ability of these materials to absorb and store electromagnetic energy [4].Cavity perturbation technique is the best method for dielectric properties measurements. It is distinguished by its higher measuring precision and simple calculations and does not have a special requirement for one geometry, size and kind of the sample such as solid, powder, and liquid [5].

Zirconia (ZrO_2) is the most commonly investigated oxide ceramics for researchers aiming possibilities of industrial applications when joined with other materials. It is produced from natural minerals such as Baddeleyite (zirconium oxide) or zirconium silicate sand. Transforming in its crystal structure from monoclinic to, tetragonal, and cubic structures depends on the temperature. Additions of some oxides (MgO, CaO,Y_2O_3) to pure zirconia depress allotropic transformations (crystal structure changes). With sufficient amounts added, the high temperature cubic structure can be maintained to room temperature. Cubic stabilized zirconia is a useful refractory and technical ceramic material because it does not go through destructive phase transitions during heating and cooling[6,7]. The microwave effect on three samples of zirconia, pure zirconia (ZrO_2), zirconia stabilized with yattria (Y_2O_3), and zirconia stabilized with magnesia (MgO), well be investigated in this work by measuring their dielectric properties in term of the two part of the complex permittivity, $\square^*$.

2. Experimental

Cavity perturbation technique was used to measure the complex permittivity of the three samples of zrconia,pure zirconia (ZrO_2), zirconia stabilized with 2.8 % magnesia, (MgO), and zirconia stabilized with 5.4% yattria, (Y_2O_3), in microwave frequency ranging, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz.Measurementsare taken at approximately 50°C intervals from room temperature to 1700°C. The details of this technique have been reported in [8] and will not be discussed further. Measurements are performed by measuring the resonant frequencies of the cavity without and with the sample, $f_o$and f, respectively, and the quality factors of the cavity without and with the sample, $Q_o$and Q, respectively. The simple perturbation formula derived by Nakamura and Furuichi [9] is based on the shift of frequency, Δf, and on the shift of the reciprocal quality factor, $\Delta(1/Q)$. The real, ε,' and the imaginary, ε'', parts of the complex permittivity can be calculated by using Eqs. (1), (2).

$$\varepsilon' = 2 j^2 (\chi_{on}) \frac{a^2}{b^2} \frac{\Delta f}{f} + 1 \quad (1)$$

$$\varepsilon'' = j^2 (\chi_{on}) \frac{a^2}{b^2} \Delta\left(\frac{1}{Q}\right) \quad (2)$$

where$\chi_{on}$is the root of the zero order Bessel function, j, of the first kind. $a$and b are the sample and the cavity volumes, respectively.

3. Results and Discussion

Three kinds of zrconia,pure zirconia (ZrO_2), zirconia stabilized with 2.8 % magnesia, (MgO), and zirconia stabilized with 5.4% yattria, (Y_2O_3), of densities; 1.23 g cm^{-3}, 1.43 g cm^{-3}, and **1.31 g cm^{-3}**, respectively are selectedto observe the microwave effect on their dielectric properties in microwave frequency ranging, 615 MHz, 1412 MHz, 2214 MHz, 3017 MHz, and 3820 MHz.and at high temperature up to 2000 °C.Holder sample is a special silica tube, stand totemperature up to 2000 °C. The tube of 5 mm in diameter is used for the three samples and filled by the samples to hold them during the measurementsbetween the cavity and the furnace.Figures 1-5 show the variation of the two parts of the complex permittivity, ε' and ε'', of the three samples with temperature increasing at the five frequency ranges.The real and imaginary parts, ε' and ε'', of pure zirconia and zirconia stabilized with magnesia, seem to be constant during the measurements at the five microwave frequency ranges with the temperature increasing. The increasing in ε' and ε'' of pure zirconia when the temperature reaches 1500 °C is very small which can be neglected. The signals of these samples disappeared when temperature reached 1700 °C, that the system could not catch them. The real and imaginary parts, ε' and ε'', of zirconia stabilized with yattria have the same behaviour as pure zirconia and zirconia stabilized with magnesia at the five frequency ranges with the temperature increasing up to 700°C . A significant increase of,ε' and ε'', appeared when temperature reached 700 °C. The values of,ε' and ε'',ofzirconia stabilized yattria reach the maximum at 1400 °C, and at this degree of temperature the signals disappeared that the system could not catch them. It has been noted that the values of ε' and ε'',ofzirconia stabilized with yattria decrease with increasing frequency when temperature reach 700 °C as shown in Fig. 1 – 5.

4. Conclusion

Microwave high temperature effect on,pure zirconia (ZrO_2), zirconia stabilized with 2.8 % magnesia, (MgO), and zirconia stabilized with 5.4% yattria, (Y_2O_3) are investigated in term of microwave permittivity. The measurements show that there is no microwave high temperature effect on pure zirconia (ZrO_2) and on zirconia stabilized with 2.8 % magnesia, (MgO). The microwave high temperature effect appears only on zirconia stabilized with 5.4% yattria, (Y_2O_3). The two parts of its microwave permittivity, ε' and ε'', increase suddenly when temperature reached 700 °C but the values of this increasing decrease with frequency increasing as shown in Fig. 1-5. At 700 °C microwave absorption occurred in zirconia stabilized with yattria, (Y2O3) while it didn't occur in pure zirconia (ZrO_2) and zirconia stabilized with magnesia, (MgO),

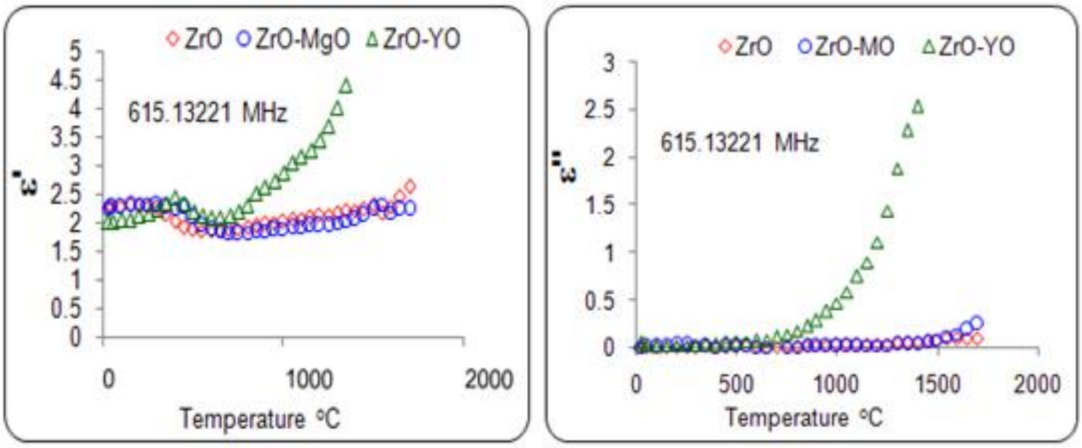

Figure 1: The variation of the real and the imaginary parts of the three kinds of zrconia at high temperature in frequency 615.13221MHz.

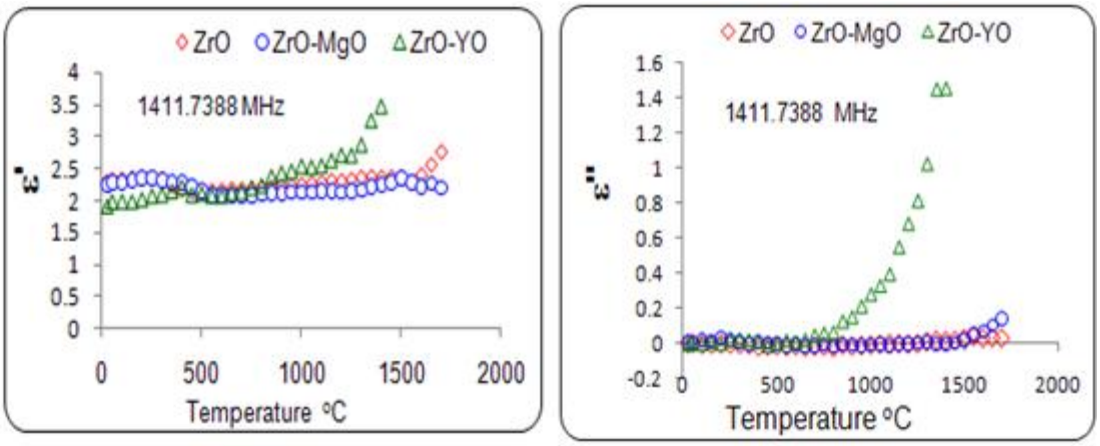

Figure 2: The variation of the real and the imaginary parts of the three kinds of zrconia at high temperature in frequency 1411.7388MHz.

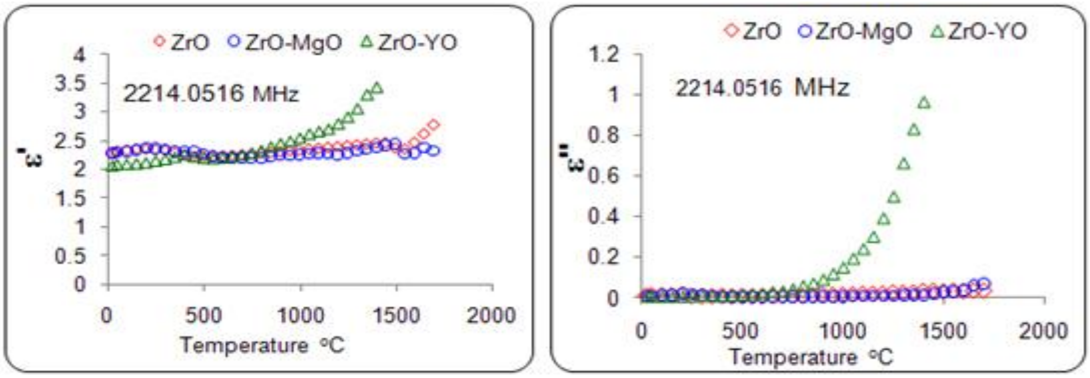

Figure 3: The variation of the real and the imaginary parts of the three kinds of zrconia at high temperature in frequency 2214.0516 MHz.

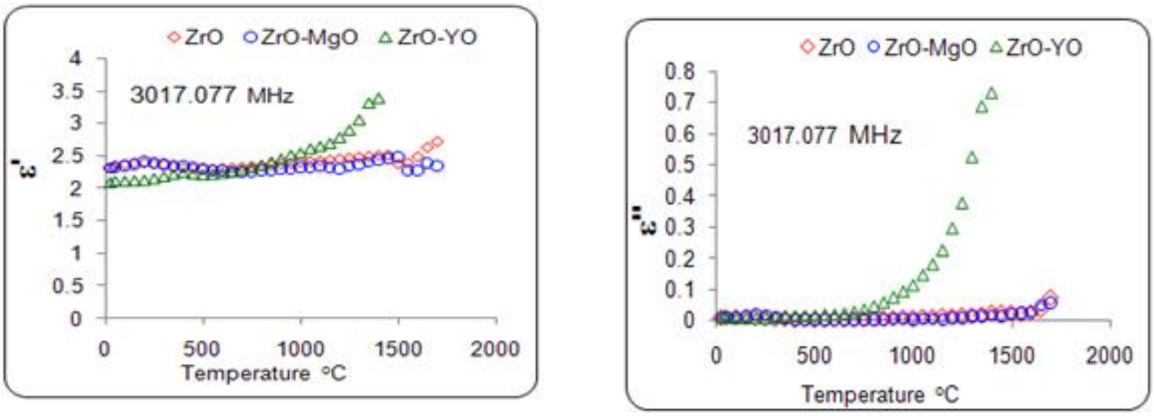

Figure 4: The variation of the real and the imaginary parts of the three kinds of zrconia at high temperature in frequency 3017.077 MHz.

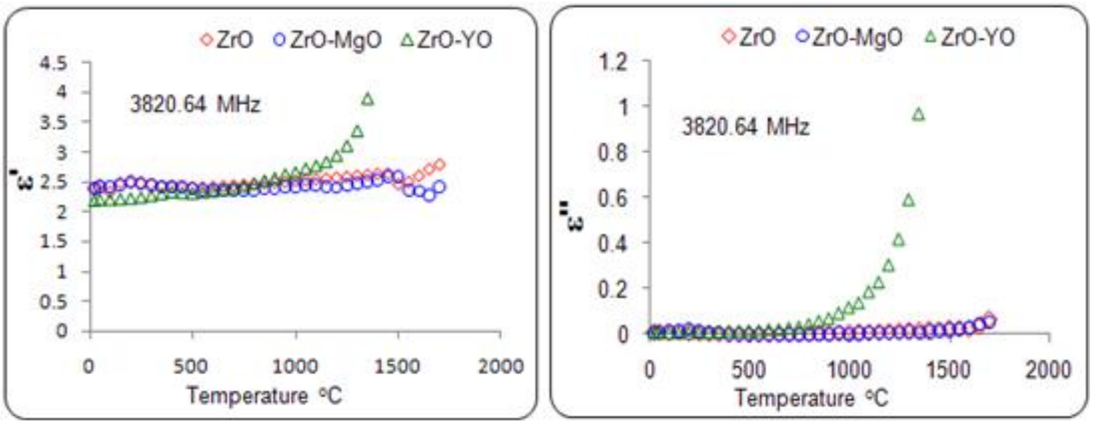

Figure 5: The variation of the real and the imaginary parts of the three kinds of zrconia at high temperature in frequency 3820.64 MHz.

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