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EVALUATION OF a.c. CONDUCTIVITY BEHAVIOR OF SiC FILLED MgO COMPOSITE

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ABSTRACT

Composite of MgO having different amounts of SiC particles has been prepared using powder technology technique. Temperature dependence of dielectric constant, dielectric loss, and volume resistivity was measured in the frequency range 40 Hz-5MHz and sintering temperatures 800,1000, and 1450 °C for 2,4,6,8 wt% SiC. It was observed that the increase in temperature leads to increasing in dielectric constant and decreasing in dielectric loss and volume resistivity. Addition of 8wt% of SiC produces an increased in dielectric constant, dielectric loss, and volume resistivity respectively comparing to the same sintering temperature and frequency that uses with less addition.
The addition of SiC particles enhanced the value of dielectric constant of MgO/SiC composite and the enhancement was found to be a function of the concentration of SiC powder.

Keywords: MgO/SiC Composite, dielectric constant, dielectric loss, volume resistivity.

I. INTRODUCTION

Microwave Lossy Ceramics is a class of particulate composites that fire micron size, microwave dissipative particles into a ceramic matrix. These materials selectively absorb unwanted frequencies. There are several formulations to select from, making it possible to design narrow band and broadband absorbers. There are several formulations to select from, making it possible to design narrow band and broadband absorbers. Common types of these ceramic materials are Al_2O_3-SiC, MgO-SiC, AIN-SiC and AIN Composites falls into this category [1, 2, 3]. Silicon carbide is an important engineering ceramic for structural and electrical applications because of its excellent mechanical properties at high temperature. Silicon carbide (SiC) is a wide band gap semiconductor suitable for high-voltage, high-power, and high-temperature devices from dc to microwave frequencies. Therefore, alternative dielectrics having a dielectric constant higher than or of the same order as that of SiC ($\varepsilon_r \approx 10$) should be used to reduce the electrical field in the insulator. Among alternative dielectrics to silicon dioxide (SiO_2), magnesium oxide (MgO) seems to be a good candidate regarding its bulk properties: large band gap, high thermal conductivity and stability, and a suitable dielectric constant ($\varepsilon'' \approx 10$). MgO films could be obtained under various crystallization states; the sol–gel process appears to be a convenient route to elaborate this kind of coatings [4]. Gates Jr et. Studies the lossy dielectric composition of disclosure consists essentially of critically prepared MgO dielectric matrix and silicon carbide mixtures to provide a lightweight lossy dielectric of uniformly reproducible strength and properties. The disclosure consists essentially of the method for providing a matrix of selective materials whereby the dielectric properties are adjusted within certain limits to obtain improved operating characteristics for microwave attenuators or high power loads. They have obtained that the dielectric constant of the resulting material is within the range 9 to 20 and the loss tangents within the range 0.005 to 0.600, thus providing a range of property values capable of accommodating a wide spectrum of high power microwave energy absorption. This providing an improved in lossy dielectric material by dissipate a continuous power wattage on the order of 100 to 1,800 W without requiring external water cooling and can be operated under conditions up to 1,200 °C without undergoing physical damage, in comparison to any known commercially available material not having this ability [5].

Determination of a.c conductivity behavior of SiC filled MgO composite is very necessary for finding its suitable application. In this paper, SiC particles have been incorporated into MgO matrix. Dielectric constant, dielectric loss, and a volume resistivity have been determined at different sintering temperature and frequencies and analyzed.

II. FUNDAMENTAL OF POLAM-ARIZATION BEHAVIORS

The dielectric response of solid is a complex function of frequency, temperature, and type of solid especially in ceramic. Various charged entities are capable of polarization such as electrons, protons, cations, anions, and charge defects. Under d.c conditions, all mechanisms are operative, and the dielectric constant is at its maximum and is given by the sum of all. When the sinusoidal electric field of frequency "f" is applied to a dielectric, some of the bound charges will move with the applied field and will contribute to $\acute{\varepsilon}$ .another set of bounds charges, however, will oscillate out of phase with the applied field, will result in energy dissipation, and will contribute to the dielectric loss factor ε''. In addition to those bound charges, there will always be a d.c component to the total conductivity of the sample and is a loss current. As the frequency of the applied electric field increases, various mechanisms will be unable to follow the field and will drop off. Temperature, however, will influence only the polarization mechanisms that depend on long-range ionic displacement such as dipolar polarization [6, 7].

III. EXPERIMENTAL WORK

The batches are prepared by weighing the constituents of MgO/SiC composite which contain 2wt%, 4wt%, 6wt%, and 8wt% of SiC powder using an analytical balance type (AD GF-300, precision of 0.001 g, Japan). Batches were crashed and milled by ball milling (FRITSCH Puluerisette, Germany) then mixed in a porcelain jar laboratory blender for about 10 min to achieve homogeneity. Two gram units of each batch were pressed to disks of 1.5cm diameter using a stainless steel cylindrical die and press (type iCL international – Crystal Laboratories– U.S.A.). The pressing time was 3 min and the pressure was 3 tons. The samples were sintered at three different temperatures 800C, 1000 C, AND 1450 C for 3hrs.

Precision Impedance Analyzer type Agilen technologies 42942 A made in U.S.A. was used for dielectric measurements. The device was first calibrated using a standard capacitor. Dielectric constant (relative permittivity ε′), and loss index (Loss factor ε″), have been measured. The frequency range extends from 40Hz to 5MHz.The results are directly read on the monitor and recorded on computer data sheet file. Real part of the dielectric constant (ε′) and imaginary part (ε″) were obtained.

Electrical resistivity may be defined as the electrical resistance of material of unit volume and constant cross section in which current is continuously and uniformly distributed. Electrical resistivity ρ_e has obtained directly using LCR device. The unit of ρ_e can be derived to be (Ohm.cm) [8]. An electrical insulator such as a ceramic or glass will have a very high resistivity, typically of the order of (10^{10}Ohm.cm) or higher.

IV. RESULTS AND DISCUSSION

Figures 1a and 1b show the dielectric constant (έ) for MgO/SiC composite with the different content of SiC powders (4wt% and 8wt %) as a function of frequency. It has been shown that the έ was constant regardless of the applied frequency especially for samples sintered at 1000 °C, and 1450 °C. It is known that the dielectric response of solids is complex function of frequency, temperature, and type of solids [9]. In contrast to electronic polarization and ionic polarization, which occurs at high frequencies ($w>10^{10}$ Hz), dipolar polarization and space charge polarization occurs at out lower frequencies and is thus important because it can greatly affect the capacitive and insulative properties of glasses and ceramic [10]. At low frequencies, all polarization mechanisms can follow the applied field and the dielectric constant is ≈ α static (d.c) which includes the space interfacial, dipolar, ionic, and electronic contributions. At higher applied frequencies> 10^{10} Hz, the interfacial and dipolar polarization component to α static drops out and only the ionic and electronic contributions remain

Samples that have sintered at 1000°C and 1450 °C show unaffecting behavior with the variation frequency, this reveled that all mechanisms of polarization (α) deal with applied frequency as the same way. The increasing of sintering temperature from 1000 C to 1450 C leads to great increase in έ. This can be due to the increase in space charge (also called the interfacial polarization) which is develops when there is a local conduction within a dielectric and dipolar polarization [11]. Electric and ionic polarizations were quite insensitive to temperature [10]. For dipolar polarization, the preferential occupancy of one site relative to the other result of the application of an electric field result in solids that can have quite large έ values. That’s mean; the resultant έ was produced by the sum of $\alpha_e+\alpha_i$ plus the increasing in $\alpha_{space}+\alpha_{dip}$. This explanation was true for the tow figures with attention that the increasing of SiC leads to increases in έ for all prepared samples. The increase in έ on addition SiC is due to the conducting nature of SiC [10]. The special attention was reveled in sample sintered at 800 C. It could be noted from figures 1a and 1b that this sample have a large έ than the sample sintered at 1000 C and it have a different behavior than the other samples. This figures show that at low frequency the έ decreases sharply and then it remains constant with respect to increasing in frequency variation. The explanation was that, initially, the space charge polarization can follow the applied field and contribute to increase the dielectric constant values, with the increases of applied frequency, the space charge component to έ drops out and can not follow the applied field. Latter, only the ionic and electronic contributions remains [11].

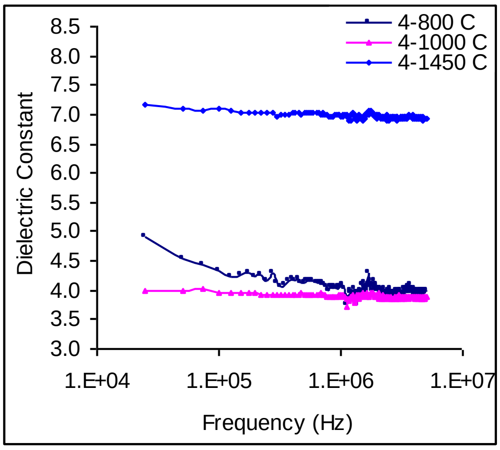

Fig.1 (a): Variation of dielectric constant with frequency for samples contains 4wt% SiC and different sintering temperatures.

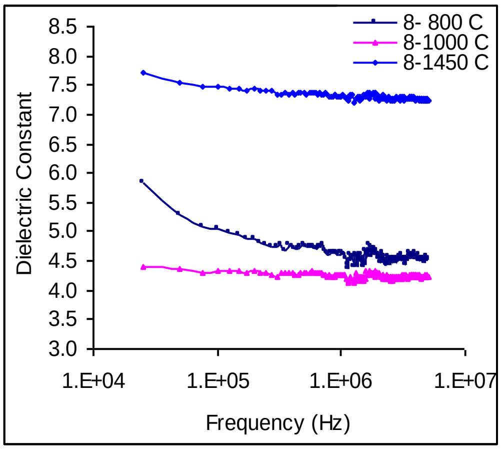

Fig.1 (b): Variation of dielectric constant with frequency for samples contains 8wt% SiC and different sintering temperatures.

Increasing the temperature will reduce α_{dip} as a result of thermal randomization. This functionality on temperature is known as Curie's law

$$\alpha_{dip} -1=N_{dip}\,\mu_{dip}/KT\varepsilon_0 \qquad (1)$$

Now α_{dip} is a function of the total number of dipoles per unit volume (N_{dip}), and the charge on the ions that are jumping, and the distance of the jump. Note here that neither ΔHm nor the frequency of the applied field plays a role [7]. These results reflect that only the space charge polarization is only the polarization remain.

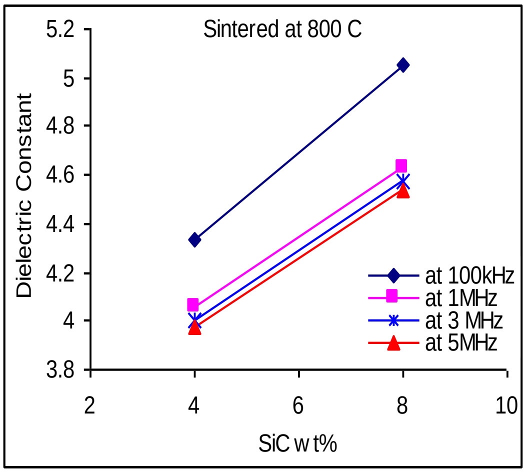

Fig.2 (a): Variation of dielectric constant with SiC content for samples sintered at 800 C at different frequencies.

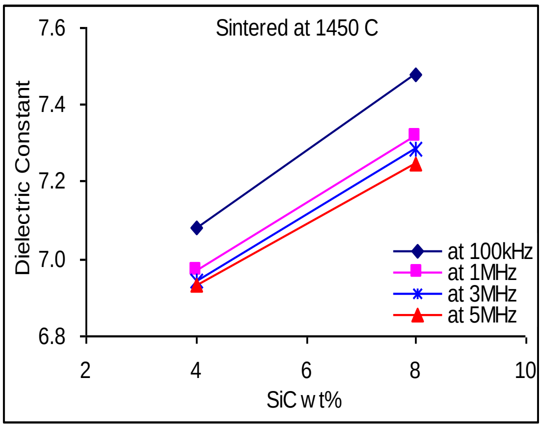

Fig.2 (b): Variation of dielectric constant with SiC content for samples sintered at 1450 C at different frequencies.

The variation of dielectric constant for sample sintered at 800 C versus SiC wt% content at specific frequencies 100Hz, 1, 3, 5 MHz was shown in figure 2(a). This figure reveled that the dielectric constants increase with increases of SiC content and decreases with the applied frequency. The increase of ε˝ with increases of SiC content was due to increasing of conducting regions and the decreases of it with increases of frequency is due to decreasing in space charge polarization to contribute in ε˝ with increasing frequency. This behavior is similar when the sintering temperature is 1450 °C with attention it possess greater values of ε˝, fig. 2(b).

The dielectric loss is a measured of energy dissipated in the dielectric in unite time when an electric field acts on it.

Since temperature usually tends to increase the conductivity of ceramic exponentially. Its effect on ε˝ can be substantial. The increased mobility of the cations results in an increase in the dielectric loss. The effect of impurities, in as much as they increase the conductivity of a ceramic, can also result in large increases in the dielectric loss.

The variation of dielectric loss ε˝ versus frequency was shown in fig.3 (a,b). It can be seen that in the small frequencies the ε˝ for samples sintered at 1000 °C and 1450 C were approximately ~0.04, the increases in frequency beyond ~$1.8E10^4$ Hz leads this property to remain constant with respect to frequency variation. That's means that these sintered temperatures were perfect to obtained MgO/SiC composite with small loss factor.

Sample sintered at 800 °C shows a high ε˝ values over the frequency range. It has noted that the power dissipation in dielectric depends on the energy dissipation create from the bound charges that oscillate out of phase with the applied field. In addition to these bound charges, there will always be a d.c component to the total current which contributes to the total conductivity of the sample and is a loss current [7], which means that these two components have a significant effect on loss in this sample and this effect was reduce linearly with increasing frequency but in any way, this sample have a higher ε˝ in contrast with other prepared samples over all frequency range.

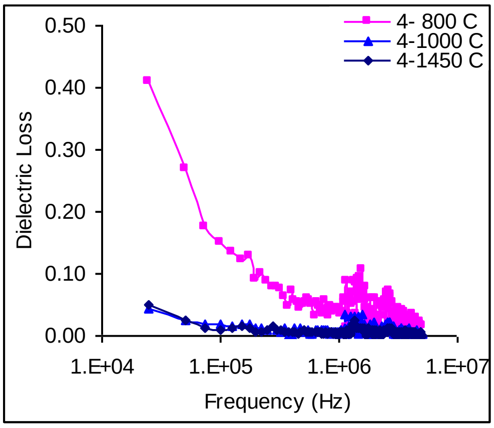

Fig.3 (a): Variation of dielectric loss with frequency for samples contains 4wt% SiC and different sintering temperatures.

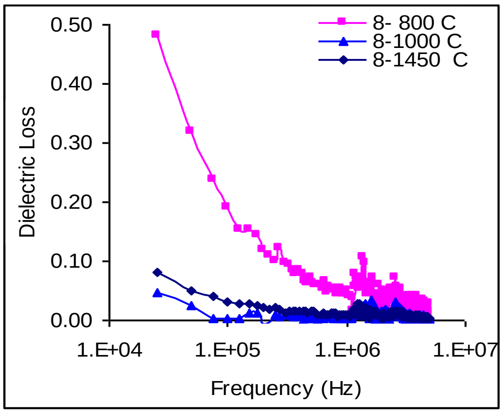

Fig.3 (b): Variation of dielectric loss with frequency for samples contains 8wt% SiC and different sintering temperatures.

The increasing of SiC addition leads to increasing in loss factor for all prepared samples, figure 3(b). The influence of SiC content on loss factor has been explained by considering the increasing of the mobility of charge carriers.

Since temperature usually tends to increase the conductivity of ceramic exponentially. Its effect on ε˝ can be substantial. The increased mobility of the cations results in an increase in the dielectric loss. The effect of impurities, in as much as they increase the conductivity of a ceramic, can also result in large increases in the dielectric loss.

Figure 3b shows that, as temperature increases, the thermal expansion effect of the constituents take place which reduces the a.c conductivity and consequently reduce the ε˝ [12].

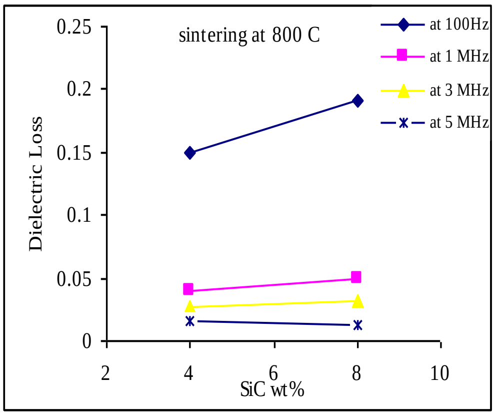

Fig.4 (a): Variation of dielectric constant with SiC content for samples sintered at 800 C at different frequencies.

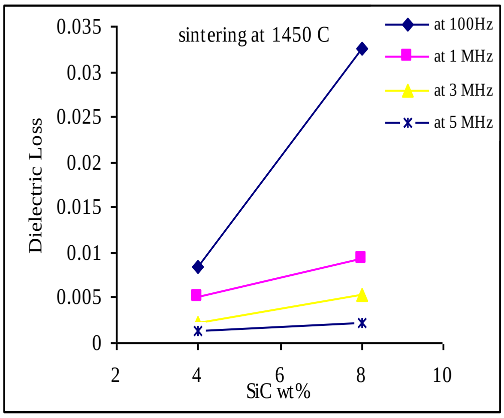

Fig.4 (b): Variation of dielectric loss with SiC content for samples sintered at 1450 C at different frequencies.

The dielectric loss for sample sintered at 800 °C as a function of SiCwt% content at specific frequencies 100Hz, 1, 3, 5 MHz was shown in figure 4(a). This figure reveled that the dielectric losses increase with increases of SiC content and decreases with the applied frequency. The larger values of ε´ was shown at 100 Hz, however, ε´=0.15 for sample content 4wt%SiC and ε´=0.191 for sample content 8wt%SiC. The lower value was obtained at 5 MHz. This can explain by the small dissipation energy of composite at this definite frequency and content. Figure 4(b) shows the dielectric loss as a function of SiC content sintered at terming temperature 1450 °C. in contrast with ε´ values for sample sintered at 800 °C, the increases of sintering temperature leads to highly decreasing in ε´. The best composition that can withstand the highest applied field with out faller was obtained for 8wt% SiC and 5MHz. This composite have ε´=0.0022, fig. 4(b).

Fig. 5 (a) shows the effect of sintering temperatures on the volume resistivity with respect to frequency variation for samples contain 4wt% SiC filled MgO composite. Similar trends were observed for prepared samples sintered at 800, 1000, and 1450 °C respectively. It can see clearly that the increase of sintering temperature decreases the volume resistivity over all the frequency range. This result was very expected because MgO is an insulator and SiC is a semiconductor, thus, the increase of temperature leads increases the conductivity of prepared composite. These samples show gradually or continuous decreasing in resistivity values over the entire plotted curve. Sample sintered at 800 C reveled higher resistivity than the other samples that sintered at 1000 and 1450 °C, this may be due to the exist insulating phases inside the composite that inhibiting the conducting properties with a variation frequency. At low frequencies, volume resistivity values for sample sintered at 1000 and 1450 °C were merged. The increase of applied filed lead to distinguish between their resistive values. Sample sintered at 1000 °C has higher values than the sample sintered at 1450 °C, which mean, the increases of sintering temperature leads to formation of conducting phases at the interfaces that enhance the conducting properties. The addition of SiC particles in MgO composites which sintered at 800, 1000, and 1450 °C with respect to frequency was shown in fig. 5(b). It was noted that the increase of SiC addition leads to increases in volume resistivity with increasing of sintered temperature in contrast with sample content 4wt% SiC. In spite of MgO/SiC composite was consisted of insulator and semiconductor materials respectively and the increasing of SiC addition must leads to increasing the conductance of composite (in contrast with sample content 4wt%) but the results show the inverse. This behavior can explain that at this specific addition (8wt% SiC) formation of oxides layer take place and covered the prepared samples especially sample sintered at 1000 °C and 1450 °C because SiC reveled an oxides layer at 1200 °C [10, 11].Volume resistivity of samples content 4wt% and 8wt% SiC were found to be strongly dependent on the frequency of the applied filed and temperatures, fig. 5(a,b).

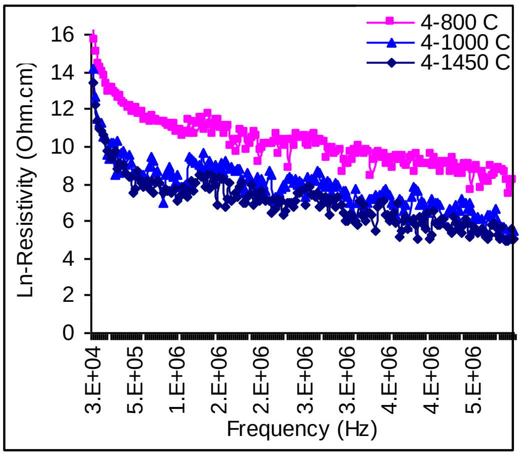

Fig 5(a): Resistivity of MgO/4wt%SiC composite samples have sintered at different temperature as a function of frequency.

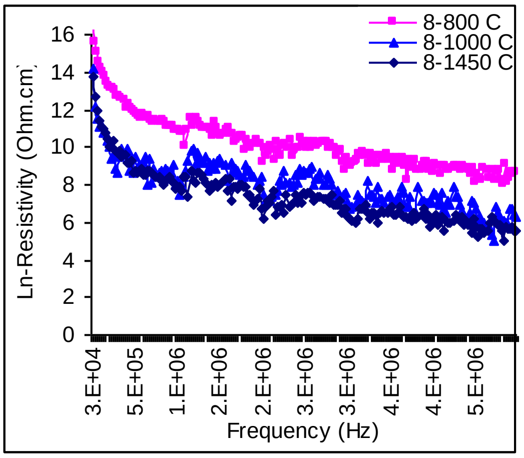

Fig 5(b): Resistivity of MgO/8wt%SiC composite samples have sintered at different temperature as a function of frequency.

V. CONCLUSION

Composite of MgO having different amounts of SiC particles has been prepared. Temperature dependence of dielectric properties and volume resistivity at different temperatures and concentration od SiC wt%. It was observed that the increase in temperature leads to increasing in dielectric constant and decreasing in dielectric loss and volume resistivity. Addition of 8wt% of SiC produces an increased in dielectric constant, dielectric loss, and volume resistivity respectively comparing to the same sintering temperature and frequency that uses with less addition.

REFERENCES

[1] CiDRA® Precision Services, "Machining / Grinding Microwave Lossy Ceramics", (2008)

[2] E Campisi, K Summers, E Finger, M.Johnson,"Micowave Absorption by Lossy Ceramic Materials", J. Materials Research Society, 258 – 278, (1992).

[3] X. Li Yong, F. T. Qiu ,"Study on microwave attenuation performance of MgO-Mg2SiO4 lossy ceramics", Microwave and Millimeter Wave Technology, 4 , 2066 – 2068, (2008).

[4] C. Bondoux, P. Prené, P. Belleville, F. Guillet, S. Lambert, B. Minot, and R. Jérisian.," MgO insulating films prepared by sol–gel route for SiC substrate", Journal of the European Ceramic Society, 25, Issue 12, 2795-2798, (2005).

[5] Jr. Gates, L. E. Lent, E. William, " MgO-SiC Lossy Delectric for High Power Elelectric Microwave Energy" ,United States Patent 3765912,(1973).

[6] F. A .m. Ali ,"Study the dielectric properties for ceramic bodies at the low frequency", MSc. thesis, University of Mustansiryah, (1979).

[7] M.W. Barsoum, "Fundamentals of ceramics", McGraw-Hill Companies, Inc.(1997).

[8] B. Tareev, "Physics of dielectric materials ", Mir Publisher. Moscow, (1979).

[9] C. Kittel, "Introduction to solid state physics", Wiley eastern private limited, New Delhi, fourth edition, (1974).

[10] D. W. Budworth, "An introduction to ceramics science ", Pregamon Press Ltd., First edition, (1970).

[11] L. H. Van Vlack, "Elements of materials science and engineering", Addiso - wesley Publishing Company, Inc., Six edition, 1989.

[12] J. Luo, and R. Stevens , "Residual stress and microcracking in SiC-MgO composites", J.European Ceramic Society, Vol.12, Issue 5, 1993, P.P 369-375.