Study of Dielectric Properties of Magnesium Ferrite Synthesized by Chemical Method

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Abstract: **Nanocrystalline $MgFe_2O_4$ ferrite sample was synthesized by sol–gel auto-combustion method. Analysis of X-ray diffraction patterns reveals the formation of single phase cubic spinel structure. The crystalline size was calculated from XRD data using Debye Scherrer equation, which reveals the formation of nanocrystalline ferrites. The dielectric constant (∈') and loss tangent (tan δ) were determined in a frequency range 100 Hz to 120 MHz. The dielectric constant decreases rapidly with increasing frequency, and then reaches a constant value. This shows the usual dielectric dispersion which is due to the Maxwell–Wagner type interfacial polarization and explained by Verway-de-Boer hopping mechanism. The loss tangent tan δ exhibits a peak which is explained by resonance phenomena.**

Keywords: **Nanocrystalline, ditlectric constant, loss tangent.**

1. INTRODUCTION

Ferrites are the ferromagnetic oxides having the general formula $M^{2+}Fe_3O_4$ where M is a divalent metallic ion such as Fe^{2+}, Ni^{2+}, Mg^{2+}, Zn^{2+}, Co^{2+} or mixture of these ions [1]. Ferrites are the important group of materials because of their broad range of applications in electric and magnetic fields [2]. Among them spinel ferrites play a significant role in technology and microwave area such as circulators, isolators and phase shifters. Magnesium ferrite ($MgFe_2O_4$) has found wide applications in microwave devices because of their low dielectric and magnetic losses and high resistivity. Magnesium ferrite is also used in high-density recording media, heterogeneous catalysis and sensors, it is also known for its good photoelectric effect [3]. $MgFe_2O_4$ has a mixed spinel structure consists of a face-centered cubic close-packed oxygen sublattice in which a fraction of the tetrahedral and octahedral sites are filled by Mg ions. This paper reports the structural characterization and dielectric measurements with frequency at room temperature of $MgFe_2O_4$ synthesized by sol-gel auto combustion technique

2. EXPERIMENTAL

Synthesis Technique-

Magnesium ferrite powder is synthesized by sol-gel auto combustion method [4]. The analytical grade of magnesium nitrate, iron nitrate and citric acid were first dissolved into distilled water to form a mixed solution. The molar ratio of metal nitrates to citric acid was taken as 1:1. The pH value is maintained at about 7 by using ammonia solution. The solution is continuously stirred during this process. Then the mixed solution was poured into a dish and kept onto a hot plate at 70˚C with constant stirring. During evaporation, the solution became viscous and finally transformed in a xerogel. After a few time, the gel automatically ignited and burnt until all the gels were burnt out completely to form loose powdered sample [5].

3. CHARACTERIZATION STUDIES

The structural characterization and phase identification of $MgFe_2O_4$ powder is done by using X - ray diffraction (XRD) measurements using Panalytical make X'Pert PRO MPD PW 3040 diffractometer using CuKα (1.5413 Å) radiation in 2θ range of 25˚ to 70˚. This confirms the formation of single phase spinel ferrites. The average grain size D, was determined from line broadening of (311) reflection peak using Debye Scherrer formula [6].

$$D=0.9\lambda/\beta\cos\theta \quad (1)$$

Where β is full width at half maximum of the highly intence peak (311) and θ is the Bragg angle for the peak.

4. DIELECTRIC MEASUREMENTS

The ferrite powder was pressed into pellets of 13mm diameter at a presser of 5 tons. The pellets were then coated with silver on both surfaces for dielectric measurements. The dielectric measurements were done using an impedance analyzer (Wayn Kerr 6500B precision impedance analyzer) at room temperature in the frequency range from 100Hz to 120MHz.

Capacitance of the sample was determined and the dielectric constant of prepared sample was calculated using the formula

$$\varepsilon' = C\,d/\varepsilon_0 A \quad (2)$$

Here 'C' is the capacitance of the pellet in farad,'d' is the thickness of the pellet in meters, 'A' is the cross-sectional area of the flat surface of the pellet and ε_o is the constant of permittivity of free space

5. RESULTS AND DISCUSSION

X-ray diffraction

The X-ray diffractogram of the $MgFe_2O_4$ is shown in figure 1. The X-ray powder diffraction peaks confirm the single phase cubic spinel structure with no impurity phase [7]. The lattice parameter 'a' has the values 8.39Å as calculated from the diffraction data. The crystallite size of the sample is 21.118 nm which is calculated by Scherrer equation.

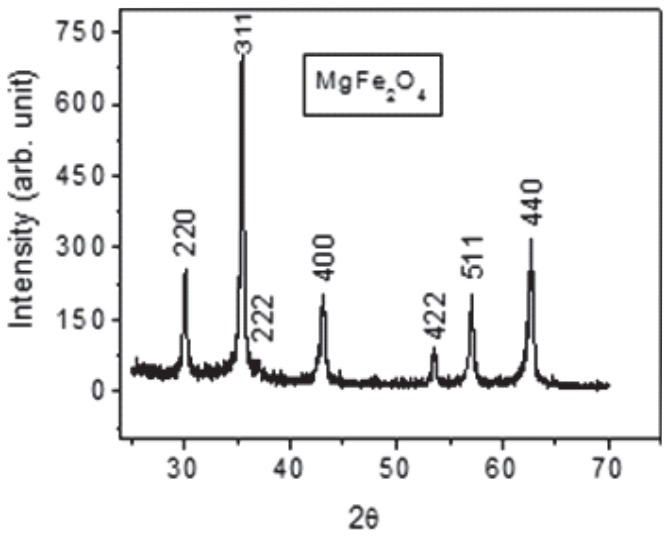

Fig. 1: X-ray diffraction of nanocrystalline $MgFe_2O_4$ ferrite sample

6. DIELECTRIC MEASUREMENTS

Fig. 2(a) shows the variation of the dielectric constant (ε′) of the ferrite $MgFe_2O_4$ as a function of frequency at room temperature from 100 Hz to 120 MHz. It is observed that dielectric constant decreases with increasing frequency [8, 9]. The dielectric behaviour of ferrites may be explained on the basis of dielectric polarization process which is due to the Maxwell–Wagner type interfacial polarization, is similar to that of the conduction mechanism. Electrical conduction in ferrites can be explained by Verway-de-Boer hopping mechanism [10]. According to Verway, the electronic conduction in ferrites is mainly due to hopping of electrons between ions of the same element existing in more than one valence state and distributed randomly over crystallographically equivalent lattice sites The electronic exchange between Fe^{3+} and Fe^{2+} ions present at octahedral site (B-site) [8], results the local displacement of charges in the direction of applied electric field, which is responsible for the polarization in ferrites. The magnitude of exchange depends on the concentration of Fe^{2+}/Fe^{3+} ion pairs present on B-site. The dielectric constant decreases with increasing frequency and then reaches a constant value due to the fact that beyond a certain frequency of external AC field, the electron exchange between Fe^{2+} and Fe^{3+} cannot follow the alternating field.

Fig. 2(b) shows the variation of dielectric loss tangent (tan δ) with frequency. The occurrence of the peak in tan δ is explained qualitatively. There is a strong correlation between the conduction mechanism and dielectric behavior. The conduction is considered as due to the hopping of electrons between Fe^{2+} and Fe^{3+} over the octahedral site. Therefore, a maximum can be observed when the jumping or hopping frequency of electrons between Fe^{2+} and Fe^{3+} ions at adjacent B-sites becomes approximately equal to that of the applied AC field and the phenomenon is termed as ferromagnetic resonance. The sharp peak can be observed when both the frequencies exactly match with each other [9]

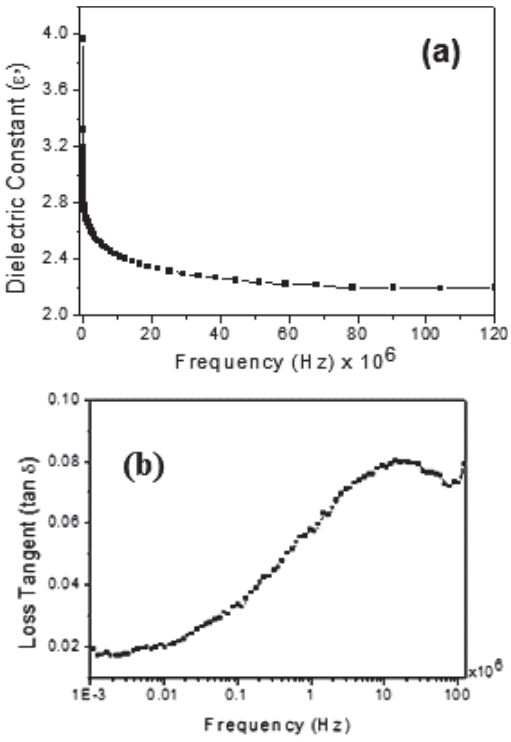

Fig. 2: Variation of (a) dielectric constant (ε′) and (b) dielectric loss tangent (tan δ) with frequency at room temperature

7. CONCLUSION

The $MgFe_2O_4$ ferrite was synthesized by sol-gel auto combustion method. The XRD study confirms the formation of cubic spinel structure with all the characteristic reflections. The lattice constant 'a' is found 8.39Å and the calculated crystallite size is 21.118 nm. Decrease in dielectric constant with frequency can be explained through the mechanism of polarization process. According to Verway the electronic hopping between Fe^{3+} and Fe^{2+} ions at octahedral site is responsible for polarization in ferrites. A peak in tanδ is occurred when the hopping frequency between Fe^{2+} and Fe^{3+} is nearly equal to that of the external applied field frequency.

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