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Dielectric Studies Of Cr^{+3} Doped Ni Ferrite

S. P. Pareek [1], Rajesh Jain[2]
[1]Department of Physics
S. S. Jain Subodh P. G. College
Jaipur
[2]Department of Physics
Government College
Jamwa Ramgarh
Jaipur
(*Corresponding Author:shyamsubodh2006@yahoo.co.in)
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Abstract

Dielectric behavior of nanosized $NiCr_xFe_{2-x}O_4$ particles with x = 0.2, 0.4, 0.6 and 0.8, synthesized using sol-gel method have been studied. The XRD patterns confirm formation of single phase cubic spinel structure of the specimens. The dielectric behavior of all the samples has been studied at 300 K as a function of frequency in the range 75 kHz to 10 MHz. Both the real value of dielectric constant (ε') and the dielectric loss factor ($tan\delta$) decreases with frequency respectively for all the samples. This decrease in the values could be explained on the basis of available ferrous, i.e. Fe^{2+}, ions on octahedral sites such that beyond a certain frequency of applied electric field the electronic exchange between the ferrous and ferric ions i.e. $Fe^{2+}\leftrightarrow Fe^{3+}$ cannot follow the applied alternating electric field. Also, a gradual reduction in both ε' and $tan\delta$ is observed as Cr concentration increases.

Keywords: Nanoparticles, Dielectric Measurements, Spinel Ferrites.
PACS: 75.50.Gg, 75.60.Ej, 78.67.Bf

Introduction

The spinel Ni-Cr ferrites find wide applications in microwave devices, computer memories magnetic recording and refrigeration[1] due to their unique magnetic and dielectric behavior. These are important as core materials over a wide range of frequencies starting from a few hundred hertz to several Mega hertz. The low permittivity and high electrical resistivity in this frequency range make them particularly useful for inductor and transformer cores and in switch mode power supplies. Several reports are available in the literature on the dielectric properties of bulk Ni-Cr ferrite. One of the main considerations of high frequency performance of ferrites is the high eddy current losses, which prevent the interaction of the magnetic field with the ferrite component and hence impair the device performance. These loses can be reduced by having a material of high resistivity. The electrical conductivity of Ni-Cr ferrite has been attributed to electron hopping [2] between the two valance states of iron, $Fe2+\leftrightarrow Fe3+$, on octahedral sites. Maintaining the +3 valance state of octahedral Fe ion is thus the prerequisite for achieving high resistivity. Studies in this field have been revealing that these materials in their nanocrystalline form exhibit remarkable physical properties that can be predominantly controlled over by the grain boundaries than by the grains [3]. In this context, an attempt has been made here to compare the dielectric properties of nanosized NiCrxFe2-xO4 particles with x = 0.2, 0.4, 0.6 and 0.8, synthesized using sol-gel method. The effects of Cr concentration in Ni-Cr ferrites on the dielectric constant and dielectric loss factor have been studied to comprehend their suitability for high frequency applications.

Experimental

The nanocrystalline NiCrxFe2-xO4 ferrite, where x varies in steps of 0.2 were prepared by the sol-gel method, in which the analytical grade Ni(NO3)2. 6H2O, Cr(NO3)3.9H2O, Fe(NO3)2.9H2O and citric acid were used as raw materials. The molar ratio of nitrates to citric acid is kept 1:1. All the nitrates and citric acid solutions were mixed together with continuous stirring. A small amount of ammonia is added to the solution to adjust the pH to about 7. The mixed solution was slowly heated to 90 °C with stirring constantly to transform it into a Xero-gel. Further heating resulted in burning of the gel in a self propagating combustion manner until all the gel gets burnt out completely to form a loose powder. The synthesis conditions were kept steady for the preparation of each samples (having different x values) to get a narrow size distribution more or less identical for all the samples.

The XRD measurements have been performed using Cu Kα radiation (λ=1.54 Å). The dielectric measurements have been performed at room temperature using Model 4285 A LCR meter in the frequency range 75 kHz-10 MHz.

Results And Discussions

Figure 1 shows the typical XRD patterns obtained for the NiCrxFe2-xO4 with x = 0.2, 0.4, 0.6 and 0.8 which confirm that the samples are formed in single phase cubic spinel structure.

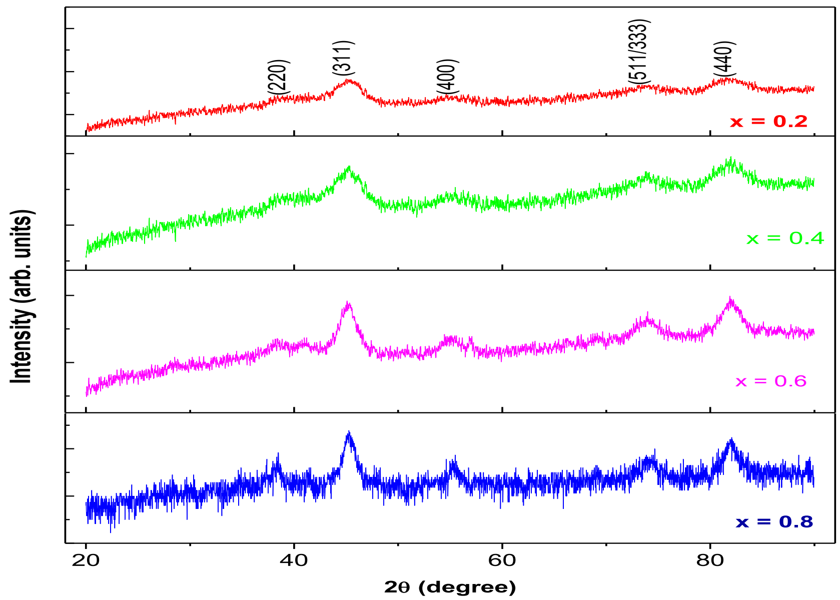

Figure1. The XRD Pattern Obtained For The Samples

Considerably broadened lines in the XRD pattern are indicative of the presence of nano-size particles. The maximum intensity peak (311) of all the samples were fitted with a Gaussian shape to determine the exact peak position as well as the full width half the maximum (FWHM).

The average particle sizes were estimated with the help of the Debye-Scherrer [4] equation

$$t = \frac{0.9\lambda}{B\cos\theta_B} \quad ; \qquad B = \left(B_M^2 - B_S^2\right)^{1/2}$$

where t is the thickness (diameter) of the particle, λ is the X-ray wavelength (1.54 Å), BM and BS are the measured peak broadening and instrumental broadening in radian respectively and θB in the Bragg angle of the reflection. The estimated average particle size for all the samples is ~10 nm.

Figure 2 shows the variation of the real part of dielectric constant as a function of the frequency of applied electric field for all the samples. It has been found that as frequency increases the value of ε' decreases as observed by Rezlescu and Rezlescu [5], which suggests the normal dielectric behavior. The decrease in the value could be explained on the basis of available ferrous, i.e. Fe2+, ions on octahedral sites such that beyond a certain frequency of applied electric field the electronic exchange between the ferrous and ferric ions i.e. $Fe2+\leftrightarrow Fe3+$ cannot follow the applied alternating electric field. Further as the Cr concentration increases, the values decrease for each frequency. This is attributed to the least possibility of occurrence of Fe2+ ions in the octahedral site, on increase in Cr concentration, as oxygen moves faster in smaller grains, thus keeping iron mostly in the Fe3+ state only [6]. For x=0.2 sample maximum value of ε' is observed at 75 kHz which is equal to 550. At 10 MHz the value reduces to 240. For x=0.8 sample the value reduces from 250 to 140 as frequency varies from 75 kHz to 10 MHz. The similar trend can be observed for other concentrations which are understood from figure 2.

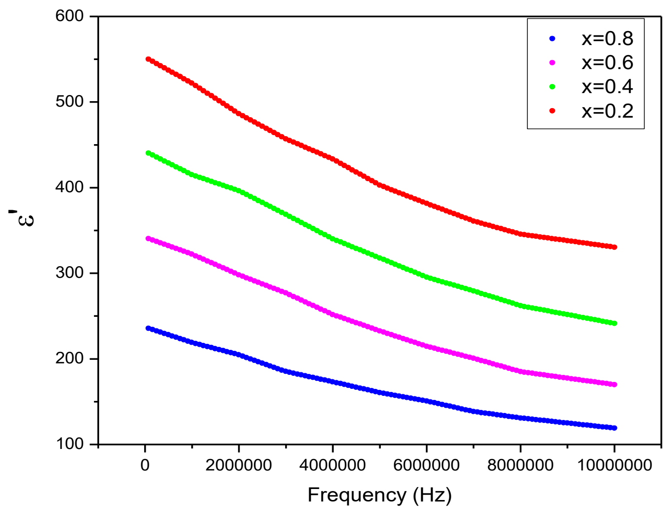

Figure2. Variation Of ε′ As A Function Of frequency

The variation of dielectric loss factor (tan δ) as a function of frequency for all samples is shown in figure 3. It can be seen that the dielectric loss factor decreases with increasing frequency which is in accordance with the Koop's Phenomenological model [7]. At 75 kHz the value varies as 25, 21, 18 and 13 respectively for x=0.2, 0.4, 0.6 and0.8. The reduction in the value of tan δ as Cr concentration increases is again attributed to the diminution in the availability of Fe2+ ions at the octahedral site. There is a strong relation between the conduction mechanism and the dielectric behavior of ferrites through the equation $\sigma ac=2\pi f\varepsilon 0\varepsilon' \tan\delta$. The conduction in ferrites is considered as due to hopping of electrons between Fe2+ and Fe3+. Thus the reduction in the value of tanδ ultimately reduces the hopping frequency leading to higher resistivity for samples having higher Cr concentration.

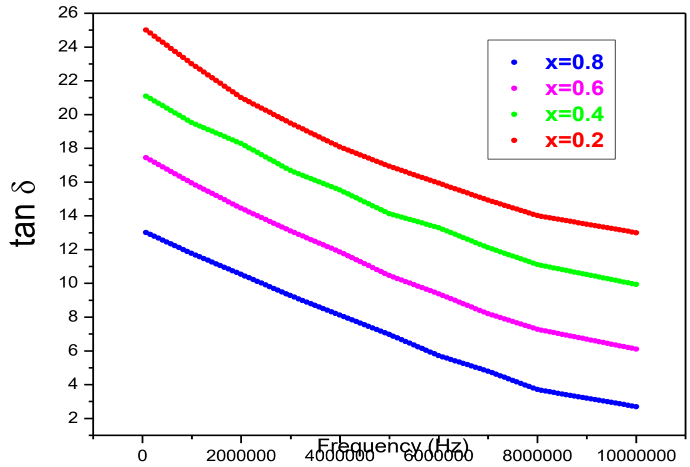

Figure3. Variation of tanδ as a function of frequency

Conclusion

Nanocrystalline samples of NixCr2-xFe2O4 ferrites are synthesized by sol-gel method. The single phase cubic spinel structure and average crystallite sizes are estimated through XRD patterns. All the samples show normal dielectric behavior with applied frequency. Also the gradual reduction in the values of ε' and $\tan\delta$ as Cr concentration varies from 0.2 to 0.8 suggest the enrichment of resistivity of the samples.

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