Dielectric and Electrical Properties of Ni and Zn Doped Fe₃O₄ Nanoparticles

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Abstract
We have presented the dielectric and electrical properties of NiFe₂O₄, ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles. Dielectric constant (ε) is found to increase with increase in temperature and decrease with increase in frequency. It has been observed that ε is not change with doping elements and doping levels for all the nanoparticles. Interestingly, dielectric loss (tan δ) is found to exhibit a strong dependence on doping element and doping level for all the nanoparticles. The detailed electrical properties has been studied for ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles by using complex impedance spectroscopy technique. The value of impedance decreases with increase in temperature and merges at high frequency for all the nanoparticles indicating relaxation type behaviour for both the nanoparticles. Activation energy (E_a) is estimated from Nyquist plots using Arrhenius relation. The thermal conductivity is obtained for ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles. It is observed that Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles show maximum ac conductivity as compared to ZnFe₂O₄ nanoparticles.

Keywords: Ferrite, Dielectric, Electrical properties, Nanoparticle.

I. INTRODUCTION
Ferrite also known as “magnetic ceramic” has attracted many researchers due to its special magnetic behaviour. It is widely used in multilayer chip inductor, gas sensors, medical diagnosis technology, magnetic warming and cooling technology. In order to achieve improved dielectric and electric properties, many research groups have doped different transition metals and rare earth metals in ferrite nanoparticles [1-3].

In the present work, we have performed detailed dielectric and electrical properties of ferrites in nano dimension. For this purpose, we have chosen NiFe₂O₄, ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles. ε is found to be increased with increase in temperature and is maximum at low frequency range for all the ferrite nanoparticles. ε is nearly similar for all the nanoparticles and does not vary with doping elements and doping levels. But tan δ shows a strong dependence on doping levels and doping elements. The impedance value of ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles is found to be decreased with increase in temperature and merged at high frequency. Also, ac conductivity is found to be maximum for Zn₀.₅Ni₀.₅Fe₂O₄ as compared to ZnFe₂O₄ nanoparticles.

II. EXPERIMENTAL DETAILS
The NiFe₂O₄, ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles were prepared through “pyrophoric chemical process” [4]. Structural characterisations of NiFe₂O₄, ZnFe₂O₄ and Zn₀.₅Ni₀.₅Fe₂O₄ nanoparticles have been done by x-ray diffraction technique (XRD) with monochromatic Cu-Kα radiation, and high resolution field emission scanning electron microscopy (FE-SEM) and energy
III. RESULTS AND DISCUSSIONS

(a) Structural characterisation

Structural characterisation is analysed by XRD pattern of NiFe$_2$O$_4$, ZnFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles, which reveals the formation of single phase nanoparticles. FE-SEM micrograph and EDAX spectra correspond to absence of any phase segregation and good chemical homogeneity of Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles (not shown here).

(b) Dielectric study

$\varepsilon$ as a function of temperature for NiFe$_2$O$_4$, ZnFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles with frequency ranging from 1 kHz to 1 MHz (not shown here). $\varepsilon$ increases with increase in temperature attaining maxima followed by sudden decrease with further increase in temperature. The $\varepsilon$ remain constant for all the nanometric samples whereas tan (δ) shows a significant dependence with doping element. The temperature dependent behaviour of $\varepsilon$ can be explained on the basis of interfacial and dipolar type of polarisation [5]. We have also performed $\varepsilon$ and tan (δ) as a function of frequency for NiFe$_2$O$_4$, ZnFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles at room temperature as shown Figs. 1 (a) and (b).

The value of $\varepsilon$ for all the nanometric samples remain almost same but tan (δ) for ZnFe$_2$O$_4$ is less as compared to Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ and is nearly equal to NiFe$_2$O$_4$ nanoparticles. So, in both the cases the...
tan (δ) for ZnFe$_2$O$_4$ is found to less as compared to other nanometric samples. Such type of behaviour can be explained on the light of electrical resistivity in the system. In our case the resistivity of ZnFe$_2$O$_4$ is high as compared to Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ and NiFe$_2$O$_4$ nanoparticles. As a result there is no leakage current in the system, which consequently reduces the electric loss in the system.

(c) Complex Impedance

Real (Z’) and imaginary (Z’’) part of impedance as a function of frequency for ZnFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles (not shown here) is found to be decrease with increase in temperature. The value of Z’ merges at higher frequency for all temperatures and become independent on frequency. Such behaviour at high frequency can be explained on the basis of space charge polarisation, which remains active during lower frequency. Nyquist plots of ZnFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles are shown in Fig. 2 (a) and (b), respectively indicating relaxation type behaviour of the samples.

(d) AC Conductivity (σ$_{ac}$)

The temperature dependence of σ$_{ac}$ at different frequencies for ZnFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles (not shown here) is calculated using the relation: σ$_{ac}$ = ωε$_r$ε$_o$ tanδ, where ω is the angular frequency, tanδ is the tangent loss of the material, ε$_r$ is the dielectric constant, ε$_o$ is the dielectric constant of vacuum. In both the nanometric samples the σ$_{ac}$ increases with increase in temperature and merges at high frequency. The Ea is estimated using the relation: σ$_{ac}$ = σ$_o$ exp (Ea/kBT), where σ$_o$ is the pre-exponential factor, k is Boltzmann constant and T is absolute temperature. It has been observed that the Ea decreases with increase in frequency. This is due to the combination of hopping, mobility and transportation of charge carriers over a large distance at low frequency conduction mechanism [6]. The frequency dependence σ$_{ac}$ follows universal power law and is fitted by relation: σ(ω) = σ$_{dc}$ + Aω$^n$, where σ(ω) is the total electrical conductivity, σ$_{dc}$ is the dc conductivity, A is temperature dependent pre-exponential factor and n is frequency exponent (0 < n < 1).

IV. CONCLUSIONS

At low frequency, ε is found to be increased with increase in temperature and is found to be independent of doping elements and doping levels. But tan (δ) shows a strong dependence on both doping elements and doping levels. The high ε at low frequency can be explained on the basis of interfacial polarisation. Also, low tan (δ) in case of ZnFe$_2$O$_4$ nanoparticles is due to presence of high resistive behaviour as compared to other nanometric samples. Complex impedance is found to exhibit a relaxation process in the nanometric system with no broadening of peak. The σ$_{ac}$ is found to increase with increase in temperature and is maximum at low frequency, which attributes the conduction process taking place through hopping, mobility and transportation of charge carrier over a large distance.

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REFERENCES


