Structural, Electric and Dielectric Properties of Cadmium Doped Nickel-Cobalt Ferrite

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Abstract: Cadmium doped nickel-cobalt ferrite with chemical formula $Ni_{0.8-x}$ $Co_{0.2}$ Cd_x Fe_2O_4 is prepared by standard double sintering ceramic method. Electric and dielectric properties of nickel cobalt cadmium ferrite are investigated. The a.c conductivity ($\square$) of this system has been investigated in the frequency range 200 Hz – 10 kHz, and in the temperature range 300K-1073K .The D.C resistivity (ρ) is determined as a function of temperature in the range 300K-1073K by two probe method. The dielectric constant and the dielectric loss decrease as the frequency increases at constant temperature. The dielectric constant and the dielectric loss were increased as the temperature increased at a constant frequency. Dielectric constant ($\acute{\epsilon}$) is determined by measuring capacitance (C).Variations of Dielectric constant ($\acute{\epsilon}$) with frequency as well as temperature are studied. A.C. conductivity (σac) is derived from dielectric constant ($\acute{\epsilon}$) and loss tangent (tan δ) values

Keywords: Cadmium doped nickel-cobalt ferrite, Dielectric, Electric.

1. Introduction

The electrical properties of the disordered materials are dominated by the deep defect levels lying in the mobility gap of these materials. Many theoretical explanations [1, 2].Ferrites are magnetic materials with cubic spinel structure having formula AB_2O_4. In ferrite (A) is divalent metal ion and (B) is trivalent metal ion. Mostly divalent metal ions occupies octahedral site and trivalent metal ion occupies tetrahedral site with exception of cadmium ion (Cd^{2+}) and zinc ion (Zn^{2+}). In nickel cobalt ferrite divalent metal ions (Ni^{2+} and Co^{2+}) occupies octahedral site and trivalent metal ions (Fe^{3+}) occupies octahedral which forms inverse spinel structure. [3, 4] .Investigation of electrical and magnetic properties on cobalt, cadmium and zinc doped nickel ferrite have also been studied in order to improve resistivity, permeability and magnetization [5-8].Ferrite materials possess high permeability; high magnetization and low losses at higher frequencies due to these ferrites have large technological applications such as LPG gas sensor, humidity sensor, [9, 10].

Aim of the work:

The study mechanism of electrical conduction and dielectric properties we have prepared $Ni_{0.8-x}$ $Co_{0.2}$ Cd_x Fe_2O_4 where x=6, 11, and 16.

2. Experimental technique

Preparation of the samples:

Glassy samples of the system $Ni_{0.8-x}$ $Co_{0.2}$ Cd_x Fe_2O_4 (where x = 6, 11, 16, at %) were prepared using standard double sintering ceramic method. The stoichiometric amounts of AR grade powders of carbonates of nickel, cobalt and cadmium and iron oxide were weighed and thoroughly mixed in agate mortar to form homogenous mixture. These tubes were introduced into an electric furnace maintained at 950 Co for 12 hours. During the melting process, the tubes were frequently agitated in order to inter mix the constituents and ensure homogeneity of the melt. At the end of this time the tubes containing the melts were quenched in ice water [11].

Conductivity measurements

The a.c conductivity measurements were carried out by means of a complex impedance technique. A constant voltage was applied on the samples and the current passing through the samples was determined by measuring the potential difference across an ohmic resistor using a lock-in amplifier (Stanford Research System SR 510). The lock-in amplifier simultaneously measured the voltage across the resistor and the phase difference between this voltage and the applied voltage. [12].

3. Results and Discussion

The lattice parameter calculated from further analysis which is shown in Table 1. It is observed that the lattice parameter increases with the increase in Cd^{2+} concentration. Similar linear dependence results have also been observed to many researchers. [13, 14]. Table (1) shows the variation of D.C. resistivity, temperature, Dielectric const. ($\acute{\epsilon}$) at Tc (1 kHz, 10 kHz, and 100 kHz.) and Loss (tanδ). It is observed that all the samples show the decrease in resistivity with the increase in temperature, which corresponds to the semiconducting behavior of the materials. The decrease in resistivity with increase of temperature may be due to the thermally activated drift mobility of charge carriers [15].

Table (1):

Composition	Resistivity at ρT (Ω cm)	Temperature Tc (0C)	Dielectric const. ($\acute{\epsilon}$) at Tc (10 kHz)	Loss (tanδ)	Conductivity σ (s/m)	Relaxation time τ (μsec)
X= 6	7.32×10^9	730	12563	450	1.45×10^{-3}	7.4×10^{-3}
X=11	5.06×10^9	754	11542	454	8.22×10^{-3}	7.3×10^{-3}
X=16	4.33×10^9	850	10321	254	6.35×10^{-3}	7.1×10^{-3}

Temperature dependent mobility of charge carriers is characterized by activation energy. The decrease in resistivity may be due to distortion of lattice [16].The distortion of lattice may be due to replacement of Ni^{2+} (0.75Å) having smaller ionic radius by Cd^{2+} (0.98Å) of bigger ionic radius [17].

The dielectric constant decreases rapidly at low frequencies and becomes quite slow at high frequencies. The higher value of dielectric constant at lower frequencies is explained on the basis of space charge polarization. Fig.1 represents the variation of dielectric constant with temperature. The relative permittivity of the sample was calculated for each frequency using the relation:

$\acute{\epsilon} = Cd / \epsilon_o A$ (1)

Where, ϵ_o permittivity of free space, d is the inter-electrode distance in meter, A area of electrode in m^2 measured from the cell used. The loss tangent (tanδ), the dielectric loss ϵ'', the A.C conductivity σ was calculated from the relations:

$\tan\delta = 1/2\pi fRC = \epsilon'' / \acute{\epsilon}$ (2)

$\sigma = 2\pi f \epsilon'' \epsilon_o$ (3)

The value of the dielectric constant $\acute{\epsilon}$ falls from high value $\acute{\epsilon}$s to $\acute{\epsilon}$ as the frequency increases through the dispersion region where $\acute{\epsilon}$ is the real part of the complex permittivity. The dielectric dispersion ($\Delta\acute{\epsilon}$) was calculated by applying the relation:

$\Delta \acute{\epsilon} = \acute{\epsilon}$ s- $\acute{\epsilon}$ (4)

The relaxation time (T) was calculated from the equation:

$T = 1/2\pi fc$ (5)

Where fc is the critical frequency corresponding to the midpoint of the dispersion curve. Temperature dependent dielectric study shows that dielectric constant increases slowly with increase in temperature and thereafter increases rapidly up to the Curie temperature and then decreases indicating phase transition from ferromagnetic to paramagnetic state. [18].
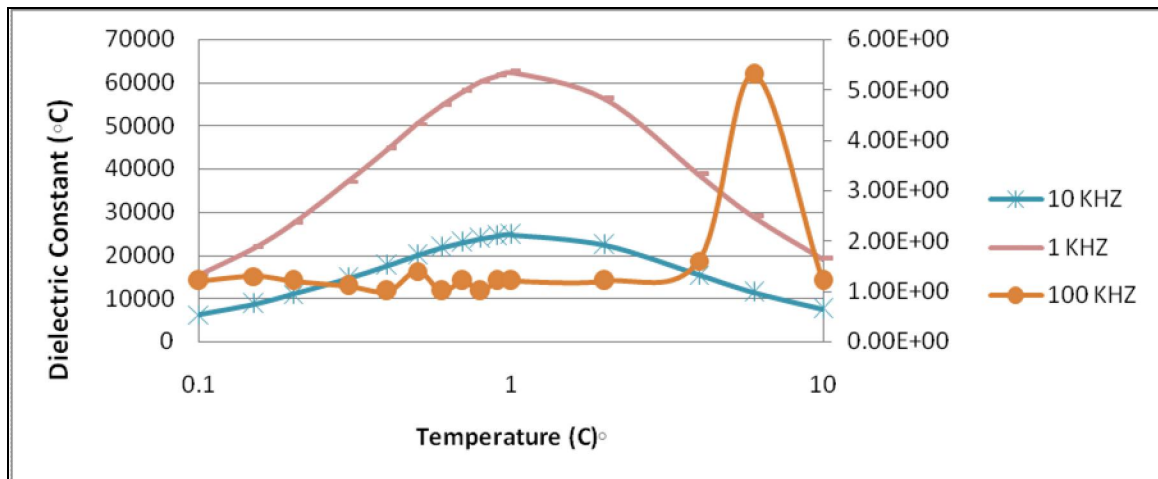
Fig(1): Comparison between dielectric constant with temperature for $Ni_{0.8-x} Co_{0.2} Cd_x Fe_2O_4$

Increase in dielectric constant with temperature is mainly due to interfacial and dipolar polarizations, which are strongly temperature dependent. The increase in polarization results accumulation of charges at grain boundary. Beyond a certain temperature the charges acquire sufficient thermal energy to overcome the resistive barrier at the grain boundary and conduction takes place resulting in decrease in polarization [19]

It is also observed that Curie temperature decreases with increase in cadmium content [Table.1].Fig.2 represents the variation of AC conductivity with frequency for x=6, 11 and 16. It is observed that AC conductivity increases with increase in frequency which is normal behavior of ferrite. Increase in AC conductivity with frequency is due to hopping of charge carriers between Fe^{2+}- Fe^{3+} on octahedral site [20].
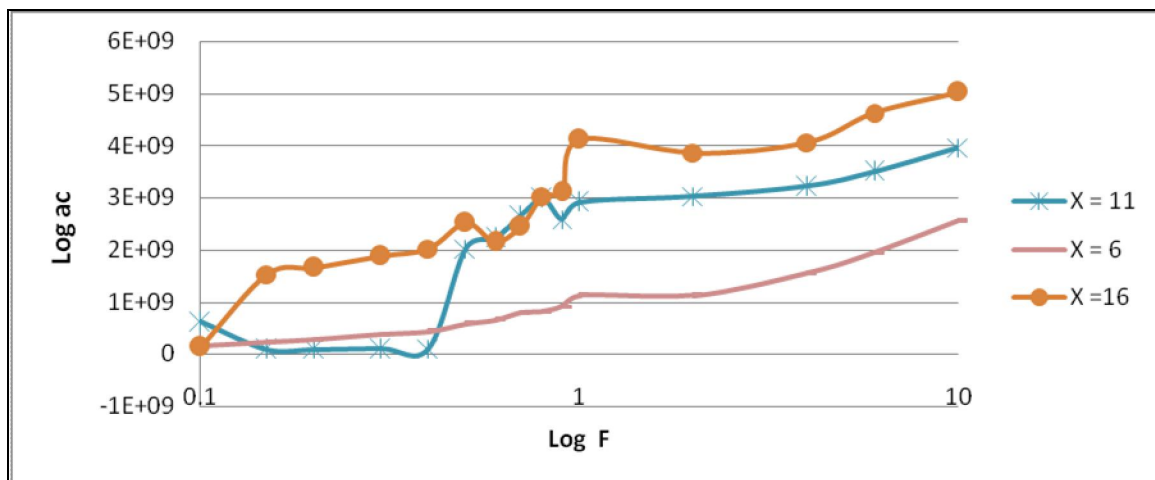
Fig (2): Comparison between AC conductivity with frequency for $Ni_{0.8-x} Co_{0.2} Cd_x Fe_2O_4$

Conclusion

All sample show decrease in resistivity with increase in temperature. In the system (Ni-Co-Cd Ferrite) where (x =6, 11, 16 at %), the a.c conductivity, increases with frequency and temperature. The increase in cadmium content causes decrease in the resistivity of the samples. The decrease in dielectric constant with increasing frequency shows dielectric dispersion is in the low frequency region. AC conductivity increases with increase in frequency which is due to small polar on hopping of charge carriers between Fe^{2+}- Fe^{3+}.The decrease in dielectric constant after Curie temperature indicates transition from ferromagnetic state to paramagnetic state.

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