Curie Temperature and Initial Permeability Studies of Nickel-Copper Spinel Ferrite

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***ABSTRACT**: Polycrystalline soft spinel ferrite samples having the chemical formula $Ni_{1-x}Cu_xFe_2O_4$ with varying x (x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0) were prepared by standard ceramic technique. The formation of single phase cubic spinel structure of all the samples was characterized by X-ray diffraction technique. X-ray diffractograms did not show any impurity phases. The values of lattice constant increases as Copper (Cu^{2+}) percentage increases. The initial permeability μ_i was measured by measuring inductance (L) using LCR-Q meter. It is found that $\mu_i$increases with Cu substitution .Curie temperature measured through permeability versus temperature plot.*

***Keywords:** Ferrite, Initial Permeability, Curie Temperature.*

I. INTRODUCTION

The magnetic oxides, namely ferrites, having the formula MFe_2O_4 have been investigated extensively by many workers because of their interesting combined property of magnetic conductor and electrical insulator. They are of great importance to the technologists and academicians owing to their remarkable electrical and magnetic properties. The high electrical resistivity, low eddy current and dielectric loss, high saturation magnetization, chemical stability etc. are the important aspects of ferrite material which make them useful in many applications. These aspects are highly sensitive to the preparation methodology [1], amount of constituent metal oxide [2], sintering condition [3] etc. Usually, ferrites are prepared by ceramic technique. It is well-known that the properties of ferrite materials are influenced by the material composition and microstructure. The sintering temperature, sintering time, sintering atmosphere etc. also plays an important role in governing the properties of ferrites [4].

Spinel ferrites are important in several applications, hence studies of structural, electrical, magnetic and other properties of spinel ferrites is very essential [5-6]. The interest in these materials is sustained till date because of their applications in the field of drug delivery, multilayer chips, magnetic recording, sensors, catalysts, etc. The substitution of divalent, trivalent and tetravalent ions in spinel ferrites leads to diversification in various properties. The properties of spinel ferrites can be modified by substituting the various kinds of cations. In the literature, many reports are available on the structural, electrical and magnetic properties of Zn, Cd, Al, Cr, Ti,Mn substituted spinel ferrites [7-8].

In the present work, the properties of Nickel ferrites were modified by substituting Cu^{2+} ion in place of Ni^{2+} ions with a view to improve the permeability properties. We report the structural and initial permeability studies of $Ni_{1-x}Cu_xFe_2O_4$with $x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0$.

II. MATERIALS AND METHODS:

NiCu spinel ferrites of the chemical composition $Ni_{1-x}Cu_xFe_2O_4$ with x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 were prepared by using the standard ceramic method. A.R. grade NiO, CuO and Fe_2O_3 were used for the preparation of ferrite as a raw material. The compositions of these ferrites are shown in Table 1. The oxides were mixed thoroughly and ground in stoichiometry proportion. First pre-sintering of powder was carried out at 1225K for 12 hr. The sintered powder is again reground and sintered at 1375K for 12 hr. To measure the initial permeability toroids of outer diameter 2 cm and inner diameter 1 cm are prepared. The prepared samples were characterized by X-ray powder diffractometer (Phillips X-ray diffractometer, Model PW 3710) using Cu-Kα radiation (λ = 1.5406Å) in the 2θ range 200-800.

Table 1: Chemical composition of various components of $Ni_{1-x}Cu_xFe_2O_4$

system in mole percentage.

Composition X	NiO	CuO	Fe_2O_4
0.0	50	0	50
0.2	40	10	50
0.4	30	20	50
0.6	20	30	50
0.8	10	40	50
1.0	0	50	50

III. RESULTS AND DISCUSSION:

The structural characterization of all the samples of spinel ferrite system $Ni_{1-x}Cu_xFe_2O_4$ with x = 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 was carried out using X-ray diffraction technique. Results indicate that these oxides crystalline with a single spinel cubic structure. Fig.1 shows the typical X-ray diffraction (XRD) pattern of $Ni_{1-x}Cu_xFe_2O_4$(for x = 0.4) spinel ferrite system.The XRD patterns indicates that all the composition exhibits single phase cubic spinel structure and exclude the presence of any secondary phase. The Braggs reflection observed in XRD pattern are intense and sharp. The XRD pattern shows the reflections (220), (311), (222), (400), (422), (511), (440) and (533) belonging to cubic spinel structure. The analysis of XRD pattern reveals the formation of single phase cubic spinel structure. No extra peak has been detected in the XRD pattern.

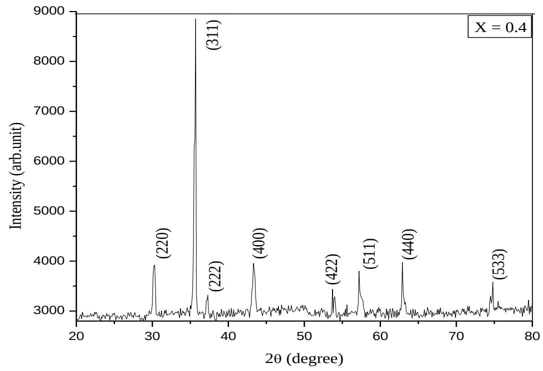

Fig. 1: XRD patterns of $Ni_{1-x}Cu_xFe_2O_4$ for x = 0.4

Using XRD data the interplaner spacing (d) was calculated using Bragg's law and the values of lattice constant (a) of all the samples was calculated by the relation

$a = d_{hkl}(h^2+ k^2 + l^2)^{1/2}$-------------------------1

where, a is the lattice constant,

d is inter planer spacing and

(h k l) is the Miller indices.

The values of lattice constants are given in the Table 2. The variation of lattice constant awith composition x is shown in Fig. 2. From Fig. 2 it is observed that lattice constant increases with Cu substitution. The increase in lattice constant is related to the difference in ionic radii of copper and nickel. In the present case, nickel ions with ionic radii 0.69 Ǻ are replaced by copperions of ionic radii 0.72 Ǻ, and hence lattice constant of the NiCu system increases with increasing copper content x.

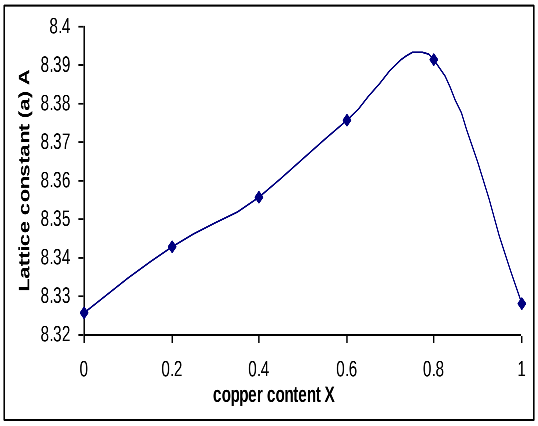

Fig.2:Variation of lattice constant a with copper content x for the system

$Ni_{1-x}Cu_xFe_2O_4$.

The variation of permeability μ_i was measured as a function of temperature. The initial permeability μ_i was calculated using the following relation.

$$L = 0.0046 N^2 h \mu_i Log_{10}\left(\frac{d_2}{d_1}\right) \quad \text{..........2}$$

where, d_2 is the outer diameter,

d_1 is the inner diameter,

L is inductance in micro-Henry,

h is the height in inches,

μ_i is initial permeability and

N is number of turns of wire.

The plot of permeability versus temperature of typical sample (x=0.4) is shown in Fig. 3. It is observed from permeability versus temperature plot that permeability decreases slowly as temperature increases. Thereafter, permeability suddenly falls down near to Curie temperature. The curve exhibits tailing effect.

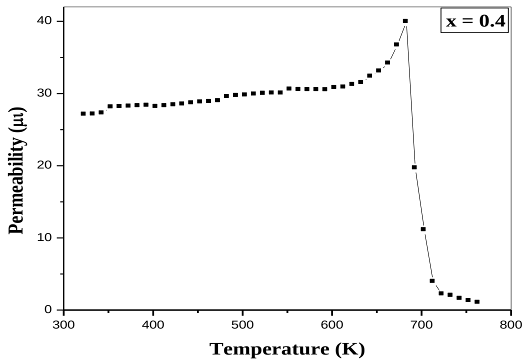

Figure 3: Permeability versus Temperature plot of $Ni_{1-x}Cu_xFe_2O_4$ system at x = 0.4

Table 2

Initial permeability (μ_i) at room temperature and Curie temperature (T_C)

for $Ni_{1-x}Cu_xFe_2O_4$ system

Composition x	Lattice Constant a(Å)	Permeability μ_i	Curie Temperature T_C (K)
0.0	8.3259	24.38	550
0.2	8.3429	23.19	530
0.4	8.3555	23.55	480
0.6	8.3755	40.96	430
0.8	8.3912	42.86	420
1.0	8.3279	46.90	417

Using these plots Curie temperature of all the samples was also obtained. The values of initial permeability for all the samples were calculated and the values are presented in Table 2. It can be seen from Table 2 that initial permeability increases with copper substitution. Similar variation in permeability with composition was observed in other well-known spinel ferrite.

IV. CONCLUSIONS

The single phase nature of all the samples of Ni-Cu spinel ferrite was confirmed by X-ray diffraction analysis. Lattice constant increases with increasing Cu concentration x. Curie temperature decreases as copper content increases. The permeability values are affected much by copper substitution.

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