DC Electrical and Mobility Studies of Indium Substituted Cobalt Ferrite

A. B. Shinde

Department of Physics,
Abasaheb Garware College, Pune

Abstract: *Indium substituted Cobalt ferrite with generic formula $CoIn_xFe_{2-x}O_4$ was synthesized through nitrate-citrate sol-gel auto-combustion method using citric acid as a fuel. The obtained powders were calcined, compacted and sintered at 600 °C for 4 h. X-ray analysis confirmed the nano crystalline nature and single phase cubic spinel structure formation. Further, the DC electrical resistivity and mobility of Cobalt ferrite by In^{3+} substitution were studied.*

Introduction:

Recently, nano-magnetic materials have attained great interest because of their potential applications in many fields like high density data storage, ferro-fluid, magneto-optical recording, magneto-caloric refrigeration, magnetic resonance imaging, drug delivery. Among the different spinel type ferrite material, cobalt ferrites are of great importance because of their excellent chemical stability, good mechanical hardness, high electrical resistivity, low eddy current and dielectric losses, high coercivity, moderate saturation magnetization, positive anisotropy constant and high magneto-striction [1-6]. Owing to their important properties cobalt ferrite are widely used magnetic materials in high frequency applications. They belong to inverse spinel structure category. The crystal structure allows incorporating different metallic ions which can considerable influence the magnetic and electrical properties. The important magnetic properties originate mainly from the magnetic interaction between cations that are present in the tetrahedral (A) and octahedral [B] site. Cobalt and substituted cobalt ferrite has been studied intensively due to their versatile properties and numerous applications [7-12]. Cobalt ferrite in pure and substituted form has been synthesized in nano-metric size by using several methods. In most of the studies, the characterization of the nanoparticles was carried out by X-ray diffraction and scanning electron microscopy technique and the structural and magnetic properties of ferrite were investigated. Less attention is paid on the characterization by infrared spectroscopy, cation distribution studies, electrical and dielectric properties of cobalt and indium substituted cobalt ferrite ($CoIn_xFe_{2-x}O_4$).

Experimental:

Indium doped Cobalt ferrite ($CoIn_xFe_{2-x}O_4$) nanoparticles were synthesized by a sol-gel auto combustion technique. The precursors used in the synthesis were cobalt nitrate, indium nitrate and ferric nitrate, citric acid was added as the fuel. All the reagents used for the synthesis were of an analytical grade and used as received without further purification. The detailed procedure followed in the synthesis is reported by [13].

DC Electrical Resistivity

The dc electrical resistivity of all the samples for $CoIn_xFe_{2-x}O_4$ system ($0.0 \le x \le 0.5$, with the step of 0.1) were measured at different temperature using two probe technique. The resistance R, of each sample was measured at regular interval of 10 K. The resistivity ρ was calculated using the values of resistance and pellet dimensions. DC electrical resistivity of indium substituted cobalt ferrite samples measured as a function of reciprocal of temperature is shown in Fig. 1.

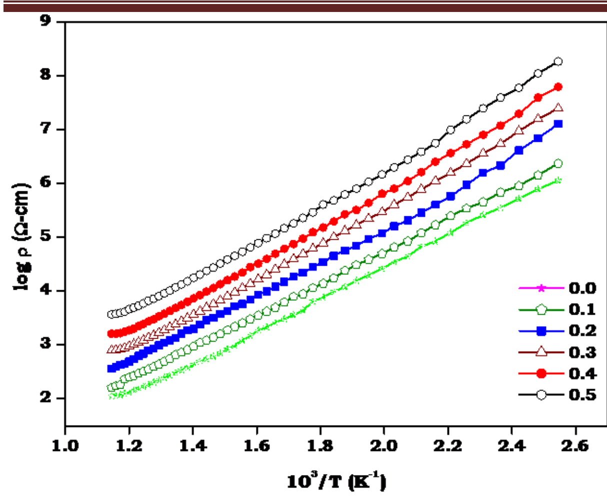

Figure 1: Variation of dc electrical resistivity with reciprocal of temperature for $CoIn_xFe_{2-x}O_4$ nanoparticles

The plots of log ρ vs. $10^3/T$ showed nearly linear nature without any break; obeying the Wilson's law, $\rho=\rho_0 \exp \Delta E/KT$. From these plots it is seen that all the samples show the decrease in resistivity with increase of temperature which shows semiconducting nature of the samples.

The decrease in resistivity with increase in temperature may be due to increase in drift mobility of thermally activated charge carriers [14]. The conduction in ferrites is attributed to the hopping of electrons from Fe^{3+} to Fe^{2+} ions. The number of such ion pairs depends upon the method of preparation and preparative conditions. In general the resistivity of ferrites is controlled by the Fe^{2+} concentration on octahedral B site.

The activation energies (ΔE) involved in the conduction process are calculated from the slope of the log ρ versus reciprocal of temperature plots. The values of activation energies are given Table 1.

Table 1: Activation energy in paramagnetic (E_p) and ferrimagnetic (E_f) region for $CoIn_xFe_{2-x}O_4$ nanoparticles

x	Ep	E_f	ΔE
0.0	0.08	0.04	0.04
0.1	0.11	0.03	0.08
0.2	0.71	0.59	0.12
0.3	0.66	0.49	0.17
0.4	0.79	0.59	0.20
0.5	0.83	0.67	0.16

The resistivity (ρ) of each composition of Co-In spinel ferrite nanoparticles was deduced at room temperature and the values are listed in Table 2. It was found from Table 2 that electrical resistivity increases with indium concentration from 4.005×10^7 to 11.382×10^7 Ω-cm. The change in the resistivity may be attributed to the concentration of Fe^{2+} ions at -octahedral site, difference in the ionic size of the cations and distribution of cations. The concentration of Fe^{3+} ions gradually decreases at octahedral [B] site when indium is substituted in place of iron. The hopping rate of electron transfer decreases with decrease of Fe^{3+} ion concentration. As a result, the dc resistivity increases with increase in indium concentration. The increase in resistivity with indium substitution may also attributed to the fact that the occupancy of indium ions at octahedral [B] site will result in decrease in Fe^{3+} ions at octahedral sites and therefore enhances the separation between Fe^{3+} and Fe^{2+} ions in proportion to their ionic radii. This causes the obstruction in the movement of electron transfer between Fe^{2+} and Fe^{3+}. Our results are consistent with those reported by other authors [14]. Increase in resistivity for the present samples may also be contributed to nano-sized ferrite particles obtained by sol-gel method. The small particle size of the samples may have more number of grain boundaries which act barrier to the flow of electron. Therefore, a partial substitution of the Fe^{3+} ion on the octahedral site by other ions is expected to result in change in the electric properties of the ferrite materials. Another advantage for smaller size is that it helps in reducing Fe^{2+} ion concentration as oxygen moves faster in small grains keeping iron in Fe^{3+} ion concentration as oxygen moves faster in small grains keeping iron in Fe^{3+} state.

Table 2: Resistance (R), Resistivity (ρ) and Drift mobility (μ_d) for $CoIn_xFe_{2-x}O_4$ (0 < x < 0.5) nanoparticles

x	R×10^7 (Ω)	ρ×10^7 (Ω - cm)	Log ρ	μ_d ×10^{-13} (cm^2/Vs)
0.0	2.15	4.005	0.603	2.452
0.1	3.78	7.042	0.848	1.395
0.2	4.64	8.644	0.937	1.136
0.3	5.61	10.451	1.019	0.941
0.4	5.66	10.544	1.023	0.934
0.5	6.11	11.382	1.056	0.861

Conclusion:

A series of substituted indium ferrites with composition $CoIn_xFe_{2-x}O_4$ with x = 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5 were prepared by sol gel auto combustion method. The effect of substitution of indium on cation distribution, electrical and mobility of cobalt ferrite has been studied. DC electrical resistivity increases with increase in indium substitution x and decreases with increase in temperature obeying Arrhenius relation.

References:

[1]. Muhammad Yasir Rafique, Liqing Pan, Qurat-ul-ain Javed, Muhammad Zubair Iqbal, Lihong Yang J. Nanopart. Res. (2012) 14:1189.

[2]. B. Parvatheeswara Rao, G.S.N. Rao, A Mahesh Kumar and K.H.Rao. V. N. Murthy, S.M. Hong, Chong-oh Kim and Cheol Gi Kim J. Appl. Phys. 101 (2007)123902.

[3]. S.D. Shenoy, P.A Joy, M.R Anantharaman J. Magn. Magn. Mater. 269 (2004) 217

[4]. X.S. Niu, W.P. Du, W.M. Du Sensors Actuators B 99 (2004) 405.

[5]. P. Brown, L.J. Hope-Weeks J. Sol–Gel Sci. Tech. 51 (2009) 238.

[6]. R. Sato Turtello, Giap V. Duong, W Nunes, R Grpssinger, M. Knobel J. Magn. Magn. Mater 320 (2008) 339.

[7]. J.Zheng, J.S.Reed, J.Am.Ceram.Soc. 72 (1989) 810.

[8]. M.A. Ahmed, E. Ateia, F.M. Salem Physica B 381 (2006)144 – 155.

[9]. A.A. Sattar, Egypt J. Sol. 26 (2) (2003) 113 – 121.

[10]. S. Somiya, R. Roy, Bulletin of Mater. Sci. 23 (2000), 453.

[11]. J.Zhou Ma, J. F Sun, C. Xie, L. J. Zhao, Z. Q. Tian, H. Wang, Y. G. Tao, J. T. Zhu,. J. Am. Ceram. Soc.88 (2005) 3535.

[12]. J.Wang, Y. J. Zhu, Modern Physics Letters B 20 (2006) 359.

[13]. T.J. Shinde, A.B.Gadkari , P.N.Vasambekar J. Magn. Magn. Mater. 322 (2010) 2777.

[14]. S.A. Patil, V.C. Mahajan, A.K. Gatge, S.D. Lotake Mater. Chem. Phys. 57 (1998)86.