

# On The Nature Of Electrical Resistivity In Co-Mg Ferrites.

S.M.Kadam.\* B.M.Kulkarni \* and B.K.Chougule\*\*

*\*Asso.Prof, Physics Dept, Shivraj College, Gadhinglaj. 416502 (India)*

*bandopantkulkarni@yahoo.com*

*\*\*Ex HOD, Physics Dept, Shivaji University, Kolhapur. 416004 (India)*

**Abstract:** The electrical resistivity of mixed single-phase spinel structure  $\text{Co}_x\text{Mg}_{1-x}\text{Fe}_2\text{O}_4$  ferrites with  $x=0, 0.2, 0.4, 0.6, 0.8$  and  $1.0$  was studied as a function of temperature between  $300$  to  $1000\text{K}$  and composition. Plots of the logarithm of the resistivity versus the reciprocal of temperature show a transition temperature usually known as Curie temperature. The Curie temperature increases linearly as concentration of cobalt is increased. The conduction in these ferrites is explained on the basis of hopping mechanism. The activation energy in the paramagnetic region is higher than that in the ferri magnetic region. The resistivity of all the samples is found to be decreases as temperature is increased upto  $x=0.4$ . A break in the decreasing trend of resistivity occurs in the range  $0.4 < x < 0.6$ .

**Keywords:** Ferrites, resistivity, Curie temperature

## Introduction

$\text{MFe}_2\text{O}_4$  ferros spinels ( Where  $\text{M} = \text{Mg}^{2+}, \text{Co}^{2+}, \text{Ni}^{2+}$  etc ) constitute a very important group of magnetic materials as they show interesting structural, electric and magnetic properties, which vary with nature of ions, their charge and site distribution amongst tetrahedral and octahedral sites<sup>1</sup>. Among different kinds of ferros spinels, cobalt ferrite ( $\text{CoFe}_2\text{O}_4$ ) has attracted much attention because of its promising applications in the fields of high density data storage, ferrofluid technology, heterogeneous catalysis, magnetic resonance imaging and drug delivery<sup>2</sup>. The Cobalt ferrite ( $\text{CoFe}_2\text{O}_4$ ) possesses excellent chemical stability, good mechanical hardness and a large positive magneto crytalline anisotropy and a promising material for magneto- optical recording media<sup>3</sup>. A three dimensional ordered macroporus  $\text{CoFe}_2\text{O}_4$  ferrite is a kind of promising anode material for lithium ion batteries<sup>4</sup>. On the other hand, the magnesium ferrite ( $\text{MgFe}_2\text{O}_4$ ) is widely used in

microwave devices, latching type phase shifter elements, radio engineering and refractory industries<sup>[5,6]</sup>. The magnesium ferrite ( $\text{MgFe}_2\text{O}_4$ ) is typical spinel in which cation distribution in the crystal lattice is very much sensitive to heat treatment while the cobalt ferrite ( $\text{CoFe}_2\text{O}_4$ ) is not so much prone to heat treatment<sup>7</sup>.

Thus in  $\text{Co}_x\text{Mg}_{1-x}\text{Fe}_2\text{O}_4$  ferrite system, the competition between  $\text{Mg}^{2+}$  and  $\text{Co}^{2+}$  ions for particular site in the spinel lattice is expected to give interesting electrical property. The electrical property of these ferrites is not yet studied so far. With this view in mind, we report here the electrical resistivity in Co- Mg ferrites.

## EXPERIMENT

Ferrite samples having general formula  $\text{Co}_x\text{Mg}_{1-x}\text{Fe}_2\text{O}_4$  (with  $x=0, 0.2, 0.4, 0.6, 0.8$  and  $1.0$ ) were prepared by standard ceramic technique starting with AR grade oxides of cobalt, magnesium and iron. Presintering was carried out at  $800^\circ\text{C}$  for  $10\text{h}$ . Pellets of composition

x=0,0.2,0.4,0.6,0.8 and 1.0 were prepared by pressing the powders in hydraulic press and finally sintered at 1250 °C for 40h and cooled at the rate of 80 °C/h. The completion of solid state reaction was confirmed by x-ray diffraction studies on computerized x-ray diffractometer (Philips PW 1820) using filtered FeK $\alpha$  ( $\lambda=1.9360$  Å) radiation. The electrical resistivity measurements in the temperature range 300 to 1000K were carried out on pellets using two probe method<sup>8</sup>.

**RESULTS AND DISCUSSION:**

The values of electrical resistivity ( $\rho$ ) at room temperature and at higher temperatures upto 1000K for Co<sub>x</sub> Mg<sub>1-x</sub> Fe<sub>2</sub>O<sub>4</sub> ferrites obey the exponential relation,

$$\rho = \rho_0 \exp ( \Delta E /KT) \text{-----(1)}$$

Where  $\Delta E$  is the activation energy, K is Boltzmann constant and  $\rho_0$  is resistivity at 0K. The plots of logarithm of the resistivity versus reciprocal of temperature for all the samples are shown in FIGURE 1.

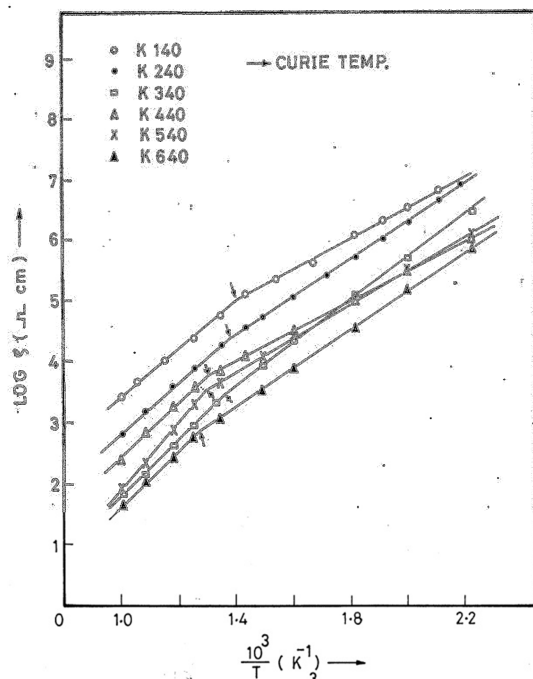


FIG. 1: Plots of Logarithm of the resistivity versus reciprocal of temperature.

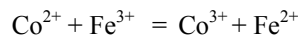
There is a perceptible kink or break in the plots at temperature which is equal to the Curie temperature<sup>[9,10]</sup>. Irkhin and Turov<sup>11</sup> have proposed a theoretical explanation of kinks at Curie temperature. They have concluded that the activation energy and effective mass of the current carrying electrons in ferrites depend on the spontaneous magnetization because of the exchange interaction between the outer and inner electrons. This lead to an additional temperature dependence of the electrical conductance which is particularly strong near the Curie temperature. The kink will be most marked for those cases in which there is a strong exchange interaction between the outer and inner electrons. It is the interesting to note that the transition temperature (Curie temperature) increases continuously and linearly as cobalt content is increased (TABLE 1).

TABLE-1 Activation energy ( $\Delta E$ ) and Curie temperatures (Tc) for Co<sub>x</sub>Mg<sub>1-x</sub> Fe<sub>2</sub>O<sub>4</sub> ferrites

composition	$\Delta E$ (eV) in		Tc(°C) from	
	Para region	Ferri-region	Resistivity Expt.	Susceptibility Expt.
0.0	0.79	0.51	439	437
0.2	0.86	0.60	452	450
0.4	0.87	0.71	468	469
0.6	0.83	0.50	479	482
0.8	1.13	0.57	496	495
1.0	0.82	0.62	521	520

Secondly, the Mg-ferrite contains multi-domain (MD) particles whereas Co-ferrite contains single-domain (SD) particles<sup>[3,12]</sup>. The presence of cobalt ions (Co<sup>2+</sup>) hinders the formation of MD particles and hence the Curie temperature increases as cobalt content is increased. Davale and Kulkarni<sup>13</sup> have investigated the d.c. resistivity of FeCoCrO<sub>4</sub> and concluded that the presence of Co<sup>2+</sup>

ions on the B site lowers the resistivity. The presence of  $\text{Co}^{2+}$  ions on octahedral site of spinel structure results in the conduction mechanism<sup>14</sup>.



This is the predominate conduction mechanism in Co-Mg ferrites.

Jonkar<sup>15</sup> studied the electrical conductivity of a series of ferrites with a formula  $\text{Co}_{1-x}\text{Fe}_{2+x}\text{O}_4$  and observed two regions of conductivity. One region of lower conductivity containing  $\text{Co}^{2+}$  and  $\text{Co}^{3+}$  ions and the other regions of high conductivity containing  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  ions. Hence in our logarithm of resistivity versus reciprocal temperature curves (fig 1), the ferri-region is of high resistivity containing two valance states of cobalt ( $\text{Co}^{2+}$  and  $\text{Co}^{3+}$ ) ions while para region is of low resistivity containing two valance states of ions ( $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ ) ions.

Broese van Groenou<sup>16</sup> have pointed out earlier that in the ferrites the presence of  $\text{Fe}^{2+}$  amidst the  $\text{Fe}^{3+}$  ions give rise to n-type conductivity if the temperature is high enough for the extra electron on the  $\text{Fe}^{2+}$  ion to move through the lattice. A similar situation exists for  $\text{Co}^{3+}$  in  $\text{CoFe}_2\text{O}_4$ . In these cases the deviating valance is higher than that originally present ( $\text{Co}^{2+}$ ) which results in p-type conductivity. Mg-ferrite is an n-type conductor and Co-ferrite is p-type conductor. The low conductivity (high resistivity) of the Co-Mg mixed system may be due to the electron-hole compensation.

The activation energies calculated from figure 1 and using relation (1) are given in table 1. The activation energy in the paramagnetic region is found to be higher than that in the ferrimagnetic region. This is in agreement with the theory development by Irkhin and Turoy<sup>11</sup>. The results are also in accordance with the conclusion of Smith and Wijn<sup>17</sup> who collected the data for a number of

ferrites. According to Otatri<sup>18</sup>, the fact that the activation energy in the para-region is higher than in the ferri-region can be attributed to magnetic ordering. One of the difference between  $\text{MgFe}_2\text{O}_4$  and  $\text{CoFe}_2\text{O}_4$  is that the disorder in Mg-ferrite is caused by the random replacement of  $\text{Fe}^{3+}$  ions by non-magnetic  $\text{Mg}^{2+}$  ions while the disorder in Co-ferrite results from the random replacement of magnetic  $\text{Fe}^{3+}$  ions by magnetic  $\text{Co}^{2+}$  ions<sup>19</sup>.

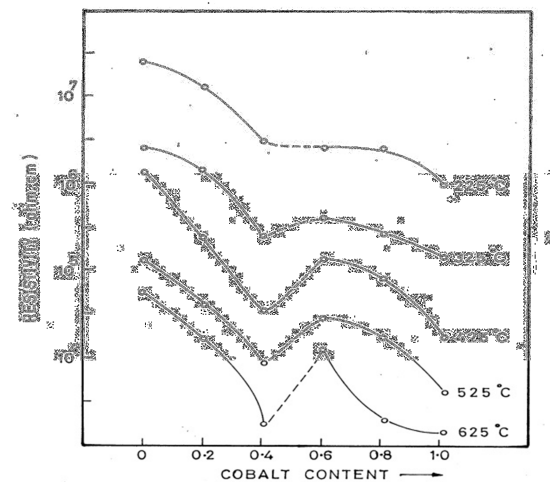


FIG. 2: VARIATION OF RESISTIVITY WITH COBALT CONTENT AT DIFFERENT TEMPERATURES.

In FIGURE 2 variations of resistivity ( $\rho$ ) as a function of composition is shown at different temperatures (225,325,425,525, and 625 °C). It is observed that the resistivity shows a decreasing trend with cobalt content except for  $0.4 < x < 0.6$ . The break in the decreasing trend of resistivity which occurs for  $x$  in the range  $0.4 < x < 0.6$  is mainly due to the formation of  $\text{Co}_3\text{O}_4$  phase<sup>13</sup>. The phase is somewhat more dominant in this region of concentration. The decreasing trend of the resistivity is further attributed to the presence of high amount of cobalt ions which can show  $\text{Co}^{2+}$  to  $\text{Co}^{3+}$  transition. It is interesting to note here that the nature of variation of resistivity as a function of cobalt content is similar at different temperatures studied (figure 2).

#### ACKNOWLEDGEMENT

The authors are thankful to Prof. R.N. Patil for encouragement.

#### REFERENCES

1. P.P. Hankare, V.T. Vader, N.M.Patil, S.D.Jadhav, U.B.Sankpal, M.R. Kadam, B.K. Chougule, N.S. Gajbhiye *Materials Chemistry and Physics* **113** (2009) 223-228.
2. Yonglian Qi, Yinsheng Yang, Xiqofei Zhao, Xilan Liu, Peng Wu, Fazhi Zhang, Sailong Xu. *Particology* **8** (2010) 207-2011
3. Y cedeno- mattei, O. Perales – Perez. *Microelectronics journal* **40** (2009) 673-676.
4. Z.H.Li, T.P. Zhao, X.Y.Zhan, D.S.Gao, Q.Z. Xiao, G.T. Lei. *Electrochemical Acto* **55** (2010) 4594-4598
5. E.Melagiriappa, H.S. Jayanna, B.K. Chougule. *Materials Chemistry and Physics* **112** (2008) 68-73.
6. S.S. Bellad, S.C. Watawe and B.K. Chougule. *Materials Research Bulletin* **34** (1999) 1099-1106.
7. Venkatesh Rao *Ph. D Thesis, IIT Bombay* (1975)
8. R.S. Devan, C.M. Kanamadi, S.A. Lokare, B.K. Chougule. *Smart Materials Sturct.* **15** (2006) 1877-1881.
9. P. J. B. Clarricoals *Microwave Ferrites, Chapman and Hall, London* (1961)
10. S. Raman Murthy, *Ph. D. Thesis, Osmania University, Hyderabad* (1978)
11. Yu P. Irkhin and E. A. Turov *Sov. Phys. JETP*, **33**, (1957) 673.
12. S. M. Kadam *Ph. D. Thesis, Shivaji University, Kolhapur.* (1992)
13. A. B. Devale and D. K. Kulkarni, *Indian J. Pure and Applied Phys.* **16** (1978) 697.
14. R. Parkakr, B. A. Griffiths and D Elwell *Brit. J. Appl. Phys.* **17**,(1966) 1269
15. G. H. Jonker *J. Phys. Chem. Solids* **9**, (1959) 165
16. A. Broese Van Groenov *Mater. Sci and Engng.* **3**, (1958/69) 317
17. J. Smith and H. P. J. Wijn *Ferites, Philips Tech. Library series, Cleaver Home, London* (1959)
18. S. M. Otari, V. B. Kadam, S. R. Sawant, And S. A. Patil, *Indian J. Pure and Appl. Phys.*, **28**,(1990) 2488
19. T. Methasiri, K. Yoodee, I. M. Tang, *Physica* **101B**, (1980) 243