Saturation magnetization and susceptibility study of Cr^{3+} substituted Mg-Cd ferrites

S. A. Masti[a*], A. K. Sharma[b], P. N. Vasambekar[c],

[a]Department of Physics, Dr. Ghali College Gadhinglaj - 416 502 INDIA

[b]Department of Physics, Shivaji University Kolhapur - 416 004 INDIA

[c]Department of Electronics, Shivaji University Kolhapur - 416 004 INDIA

Abstract

Saturation magnetization and susceptibility properties of polycrystalline ferrites with general formula $Cd_x\ Mg_{1-x}\ Fe_{2-y}\ Cr_y\ O_4$ (x = 0, 0.2, 0.4, 0.6, 0.8, 1.0; y = 0, 0.05 and 0.10) were studied. Saturation magnetization study reveals that the Neels two sublattice model exists up to x = 0.4, for y = 0, 0.05 and 0.1 and a three sublattice model (Y-K-model) is predominant for x > 0.4, y = 0, 0.05 and 0.10. The saturation magnetization and magnetic moment were found to decrease with the increase of Cr^{3+} contents, which is attributed to the dilution of B-B site interaction. Temperature dependence normalized AC susceptibility study reveals that $MgFe_2O_4$ exibits single domain(SD) structure. On substitution of Cd^{2+} , single to multi domain transition takes place. Curie temperature decreases with Cd^{2+},was attributed to decrease in A-B intraction. On substitution of Cr^{3+} , peak obtained in $MgFe_2O_4$ was supressed which is attributed to decrease in grain size and further decrease in Curie temperature is attributed to the decrease in B-B interaction.This is because Fe-Fe interaction is greater than Cr-Fe interaction at B-site.

Keywords: magnetization, Susceptibility, chromium substitution, magnesium ferrites.

* Corresponding author
Thin Film and Material science Division,
Department of Physics,
Dr. Ghali College, Gadhinglaj- 416502
(MS) India. Tel: +91 2327 222119

ISSN: 2278 – 7798

1. Introduction

Magnetization in spinel ferrites is due to the interaction between A-sites and B-sites. Square loops with large Mr / Ms ratio are the prime requirement in recording and memory cores [1]. The magnetic properties of mixed ferrites Mg-Zn [2], Mg-Cd [3] Mg-Mn [4] and Mg-Cu-Zn [5] have been already studied. Trivalent substitution of Nd^{3+} ions causes a decrease in the magnetic moment of Mg-Zn ferrites [2]. Structural and magnetic studies of magnesium doped ferrites have also been made by Widatallah et al [6]. Other researchers have also investigated the effect of Cr^{3+} in different ferrite system [7]-[8]. The substitution of Mg^{2+} ions in Co-Cr ferrite yields a decrease of the saturation magnetization.

Soft ferrites consists of Multimomain (MD), single domain(SD) and superparamagnetic(SP) particle, which mainly depends on substituation [9]. These domain states can be distingushed by the technique of low field AC sussceptibility [10]. The MD particles have domain walls [11] and magnetic changes takes place due to domain wall(DW) motion. As particle size decreases, formation of domain walls becomes energitcally unfavorable, then it is said to be single domain (SD) particle. In these mañgnetic changes do not takes place through DW motion but require the rotation of spins resulting in larger coersivity. As the particle size further decreases, spins are affected by thermal fluctuations and the system becomes SP particle. SP particle nature reduces magnetic character of the material. Cd^{2+} substitution is interesting substitutioin in the spinels [12]. Addition of Cr^{3+} in $NiFe_2O_4$ the domain structure changes from MD to SD [13]. Substitued mixed Cu-Cd ferrites exhibit mixture of SD and MD partices [14].

ISSN: 2278 – 7798

2 Experimental

Spinel ferrites with general formula $Cd_x Mg_{1-x} Fe_{2-y} Cr_y O_4$ (x = 0, 0.2, 0.4, 0.6, 0.8, 1.0; y = 0, 0.05 and 0.10) were prepared by standard ceramic method. The oxides in their weight proportion were mixed thoroughly and wet milled using acetone. The mixed powder was pre-sintered at 700^0C for 12 h and sintered at 1050^0C for 24 h. Sintered powder was again wet milled using acetone and then pellets of 1cm in diameter were prepared by using hydraulic press, applying pressure of 7 tons/cm^2. The pellets were finally sintered at 1050^0C for 24 h. The furnace was slowly cooled.

The powder of each composition under investigation was characterized by X-ray diffraction using powder diffractometer PW 3710. CuKα radiations of wavelength λ=1.54 A^0 were employed.

The saturation magnetization of pelletized samples were studied at room temperature using an AC current electromagnet type-high field hysteresis loop tracer

3 Results and Discussion

3.1 Characterization

A typical X-ray diffractogram is presented in Fig. 1 corresponding to the sample x = 0.6 and y = 0. From the X-ray diffraction study, it is seen that all the compositions have face centered cubic spinel structure. The lattice constant plotted against Cd^{2+} content is presented in Figure 2. The lattice constant was found to increase with the increase of Cd^{2+} content and decreases with the increase of Cr^{3+}. The X-ray density was also found to increase with Cd^{2+} and decrease with Cr^{3+}content. These changes are attributed to the differences in the ionic radii of Fe^{2+}(0.67A^0), Cd^{2+}(0.99A^0), Cr^{3+}(0.63A^0).

ISSN: 2278 – 7798

3.2 Magnetization

The magnetic parameters like saturation magnetization (Ms), magnetic moment [n_β] were calculated and presented in Fig. 4 and Fig. 5. From these figures it is seen that Ms and n_β increase with the increase of Cd^{2+} contents up to x = 0.4, for y = 0, 0.05 and 0.10. The substituted Cd^{2+} ion invariably occupies A-site and displaces the proportional amount of Fe^{3+} ions from A-site to B-site. The net magnetization is resulting from the magnetization at A-sites and B-sites; hence as the amount of non-magnetic Cd^{2+} ion increases on A-sites, the magnetization at A-site decreases. This results in an increase of the net magnetization.

The increase in magnetization should be linear with Cd^{2+} content but it is practically true up to x = 0.4 and deviates thereafter. This is because of canted spins at B-site, this suggest that Neel's two sublattice model is applicable up to x = 0.4 and thereafter Yafet-Kittle model is applicable. The composition with x = 0.8 and 1.0 have no magnetization suggesting that they are of paramagnetic nature at and above room temperature.

If a small amount of Cr^{3+} ions substitute Fe^{3+} ions, then Ms and n_β are found to decrease. The substituting Cr^{3+} ions enter into B-sites [13], therefore the magnetization on B-site decreases. This is because the magnetic moment of Cr^{3+} is 3 μ_B and that of Fe^{3+} is 5 μ_B. This results in the dilution of the magnetization on B-sites causing a reduction in Ms and n_β.

3.3 Normalized susceptiblity

The typical plots of normalized susceptiblity (χ/ χ_{RT}) verses temperature with y =0.05 is presented in the Figure 6. From the study it can be seen that for magnesium ferrite, the susceptibility slowly increases and reaches peak value with temperature and susddenly drops to zero. The sudden drop of χ/ χ_{RT} curve shows the formation of single phase cubic spinel [15].The

ISSN: 2278 – 7798

incresase in sussceptibility with peak values suggests there is existance of multidomain(MD)particles in the material [16]. The peak is found to suppresed with substitution of Cr^{3+} in $MgFe_2O_4$. The values of Curie tempratures obtained from the study of susceptebility is plotted against Cd^{2+} and is presented in Figure 7. Curie temparature (Tc) decreases with Cr^{3+} content. For the composition x=0.2; y=0, 0.05 and 0.1, susceptiblity is found to be independent on temperature upto Tc and after Tc it suddenly drops to zero. Such nature of curve indicates that the presence of SD particles in the materials [17]. Joshi et al [18] also reported similar behaviour in Mg-Zn ferrite system. The compositions with x=0.4 and x=0.6 for y=0, 0.05 and 0.1 shows exponential decrease in susceptibility indicating SD to SP transition. The composition with x=0.8 and x=1 y=0 , 0.05 and 0.1 shows paramagnetic behaviour at and above room temperature. On substitutiion of Cd^{2+} in $MgFe_2O_4$ Curie temperature found to decrease. This is because substituted Cd^{2+} ion invariably occupies tetrahedal (A) site, resulting into decrease in A-B intereaction [19]. The composition with x= 0.8 and 1.00 shows paramagnetic behaviour at room temparature, their Curie temperature lies below room tempetature. Substitution of Cr^{3+} ion, Curie temperature of each composition is found to decrease. This is attrbuted to dilution of B-B interaction[19]. On substitution Cr^{3+} ion occupies B-site replacing equivalent Fe^{3+} ions and so also decrease in magnetization at B-site.

4. Conclusions

Magnetic parameters like Ms and n_β were found to increase with the increase of Cd^{2+} contents up to x = 0.4, for y = 0, 0.05 and 0.10 and deviates thereafter. this suggest that Neel's two sublattice model is applicable up to x = 0.4 and thereafter Yafet-Kittle model is applicable.

Temperature dependent normalized susceptibility measurements reveals that $MgFe_2O_4$ exhibit MD particle and on substitution of Cd^{2+},domain structure changes from MD to SD and

ISSN: 2278 – 7798

for higher concentration SD to SP. Curie temperature was found to decrease on substitution of Cd^{2+}, which is attributed to the dilution of A-B interaction. On substution of Cr^{3+}, peak obtained in the graph of normalized susceptibility of $MgFe_2O_4$ is suppresed may be attributed to the decrease in grain size. Further decrease in Curie temperature in Mg-Cd ferrite system due to substitution of Cr^{3+} is attributed to the dilution of B-B site.

References

[1] C.T. Birajdara, T. Suresh, R.H. Kadam, K.M. Jadhav, "D.C. Electrical Resistivity and A. C. "Susceptibility study of Mg-Cr spinel ferrites prepared by chemical synthesis route", Indian Streams Research journal, Vol. 2(9)63, October 2012.

[2] S. S. Khot, N. S. Shinde, B. P. Ladgaonkar, B. B. Kale and S. C. Watawe, "Magnetic and structural properties of Magnesium Zinc Ferrites synthesized at different temperature" *Advances in Applied Science Research*, 2 (4) pp 460-471 , 2011.

[3] A. B. Gadkari, T.J. Shinde,P.N. Vasambekar "Structural and magnetic properties of Nanocrystalline Mg–Cd ferrites prepared by oxalate co-precipitation method",Journal of Mater. Sci.: Mater. in Electronics Vol 21 (1) pp 96-103, January 2010.

[4] A. Lakshman, K.H. Rao, R.G. Mendiratta, " Magnetic properties of In3 + and Cr3 + Substituted Mg-Mn ferrites", Journal of Mag. and Mag. Mater., Vol. 250 ,pp 92-97, (2002)

[5] J. Park, J. Kim and S. Cho, "Effect of Additives on the Magnetic Properties in Mg-Cu-Zn Ferrite" *J. PHYS. IV FRANCE* , 7 pp 193-194, 1997.

[6] H . M . Widatallalh , C . Johnson , F . Berry , M . Pejaka ."Systhesis, Structural and mimetic characterization of magnesium doped lithium ferrite of composition $Li_{0.5}Fe_{2.5}O_4$," *Solid*

ISSN: 2278 – 7798

State Comun. 120 (4) pp 171-175, 2001.

[7] P . N . Vasambekar , R . G . Kulkarni , A . S . Vaingankar ," Cation distribution and susceptibility study of Cd-Co and Cr^{3+} ferrites" *J . Mag . and .Mag .Mater ,Vol. 186 pp 333=341, 1998* .

[8] U .V . Chhaya , R . G . Kulkarni , "Metal-insulator type transition in aluminium and chromium co-substituted nickel ferrites" *Mater . Letters* , Vol. 39 (2) pp 91-96 April 1999.

[9] G.B. Kadam, S.B. Shelke and K.M. Jadhav "Effect of Zinc on A. C. Susceptibility and D. C. "Resistivity of $Ni_{1-x} Zn_x Fe_{2-y}Eu_yO_4$" Journal of Electronic and Electrical Engineering, Vol. 1, Issue 1, PP-03-11, 2010.

[10] A. Wiechec, R. Zach, Z. Kakol, Z. Tarnawski,, A. Koz"owski, J.M. Honig "Magnetic susceptibility studies of single-crystalline zinc ferrites under pressure", Physica B 359–361 pp 1342–1344,2005.

[11] Murthy V.R.K. , Chitra S. And Reddy K.V.S., Indian J.Pure and Appl. Phy, 16(1978)79.

[12] A Y Lipare, P N Vasambekar and A S Vaingankar, "A.c. susceptibility study of CaCl2 doped copper– zinc ferrite system" *Bull. Mater. Sci.,* Vol. 26, No. 5, pp. 493–497 August 2003.

[13] R. M. More, T.J. Shinde, N.D. Choudhari,P.N. Vasambekar "Effect of temperature on X-ray, IR and magnetic properties of nickel ferrite prepared by oxalate co-precipitation method" J. Mater. Sci. Volume 16,pp 721-724 2005.

[14] R.G. Kulkarni, R.V. Upadhay "Magnetic properties of Cu-Cd ferrite investigated by Mössbauer spectroscopy" Journal Mater. Sci. Vol. 19,(5),pp1622-1628,May 1984.

[15] A.M Sankpal, S.S Suryavanshi, S.V Kakatkar, G.G Tengshe, R.S Patil, N.D Chaudhari, S.R Sawant., "Magnetization studies on aluminium and chromium substituted Ni-Zn ferrites",

ISSN: 2278 – 7798

J. Mag. Mag. Mater.,Vol 186pp 349-356,July 1998.

[16] S. Basu, M. Pal, D. Chakravorty, "Magnetic properties of hydrothermally synthesized $BiFeO_3$ nanoparticles", J. Mag. Mag Mater., Vol. 320 (24) pp 3347-33349, December 2008.

[17] G. Kumar, J. Chand, S. Verma and M Singh "Mixed Mg–Mn ferrites for high frequency applications processed by citrate precursor technique" *J. Phys. D: Appl. Phys.* 42 pp 1-6, 2009.

[18] Feng Wang, Wei-Wei Huang, Shan-Yu Li, A-Qiang Lian, Xiao-Ting Zhang, Wei Cao, "The magnetic properties of FexZn1-xO4 synthesized via the solid state reaction route: Experiment and theory", J. Mag. Mag Mater., Vol. 340, pp 5-9, August 2013

[19] P.A Mariño-Castellanos, J Anglada-Rivera, A Cruz-Fuentes, R Lora-Serrano "Magnetic and microstructural properties of the Ti^{4+} doped Barium hexaferrites", J. Mag. Mag Mater.,Vol 280, (2–3), pp 214-220, September 2004.

ISSN: 2278 – 7798

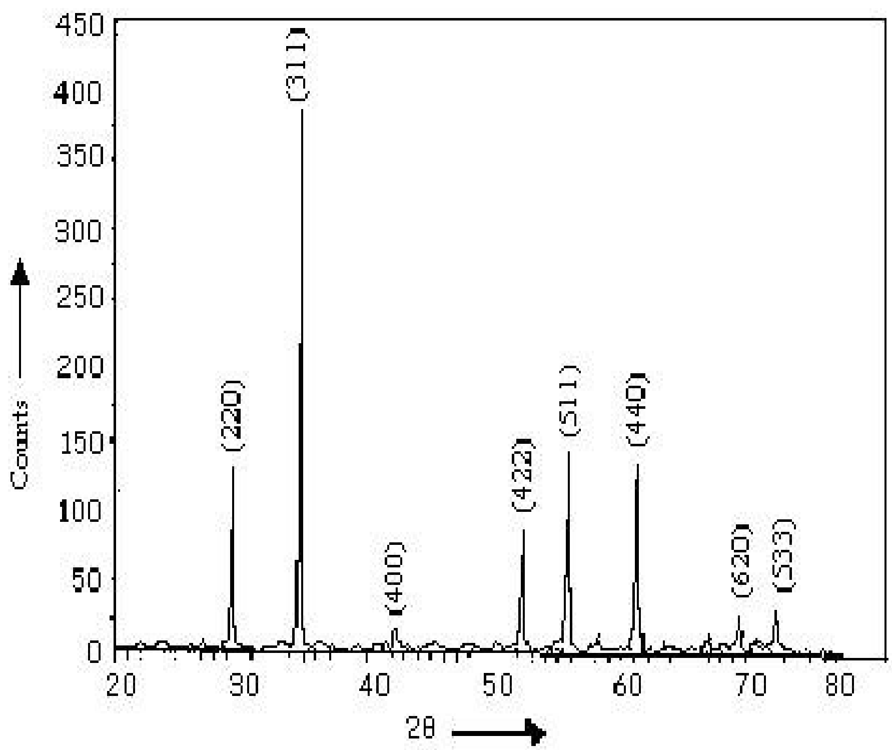

Fig. 1 Typical XRD Pattern of $Cd_x Mg_{1-x} Fe_{2-y} Cr_y O_4$ Ferrite System with x=0.6, y=0

ISSN: 2278 – 7798

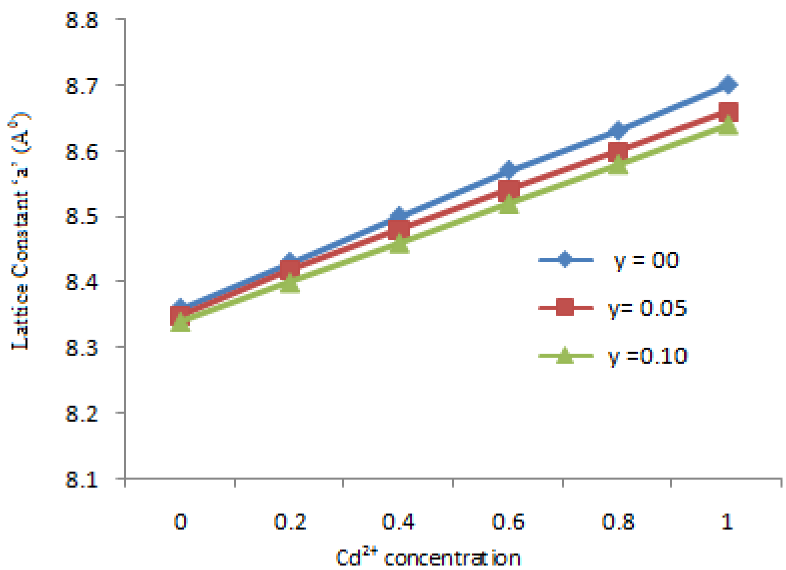

Figure 2. Variation of Lattice constant with Cd^{2+} content

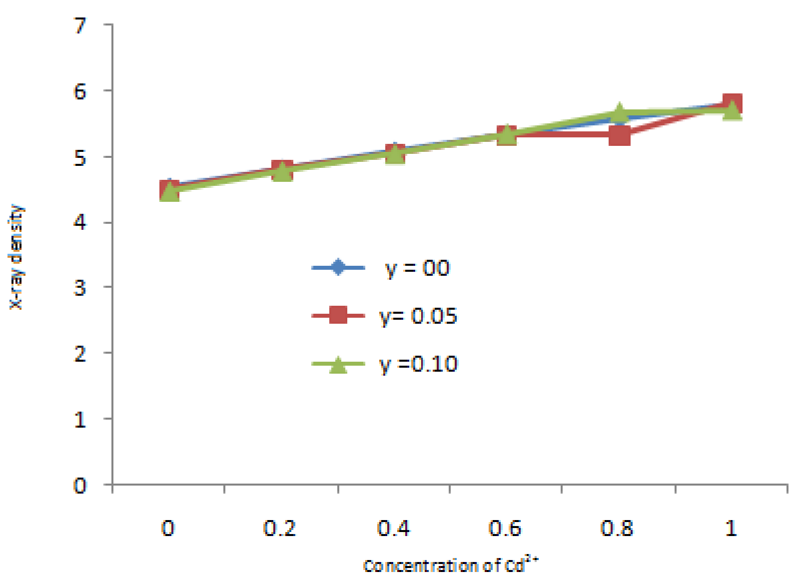

Figure 3. Varioation of X-ray density with Cd^{2+} concentration

ISSN: 2278 – 7798

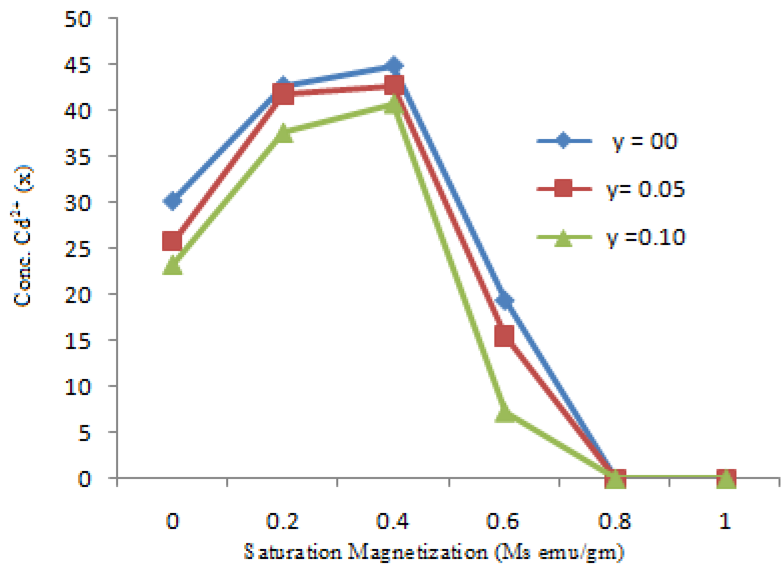

Figure 4. Variation saturation magnetization with Cd^{2+} content

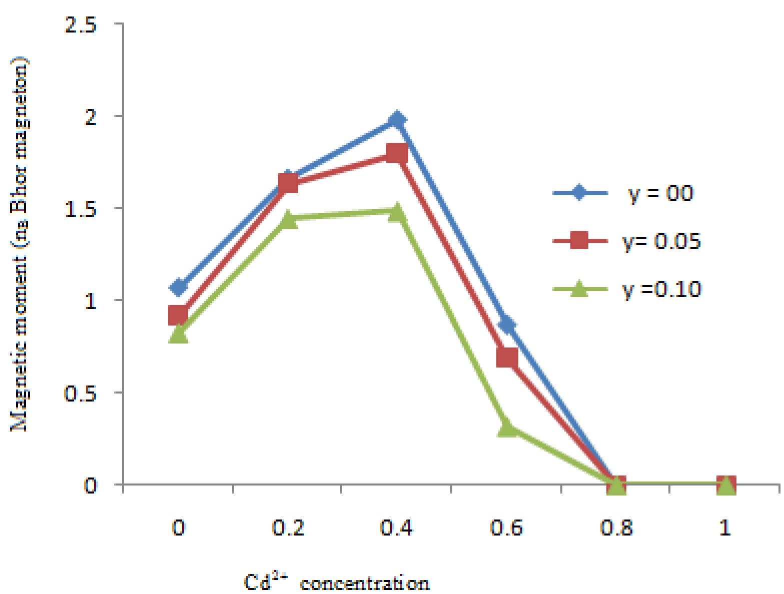

Figure 5. Variation of Magnetic moment with Cd^{2+} concentration

ISSN: 2278 – 7798

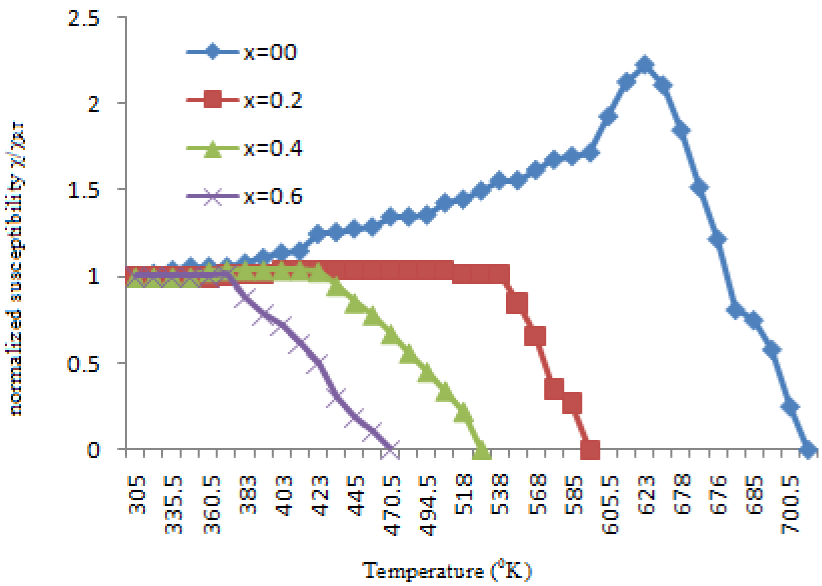

Figure 6. Variation of normalized susceptibility χ/χ_{RT} with Temperature (^{0}K) (with y=0.05)

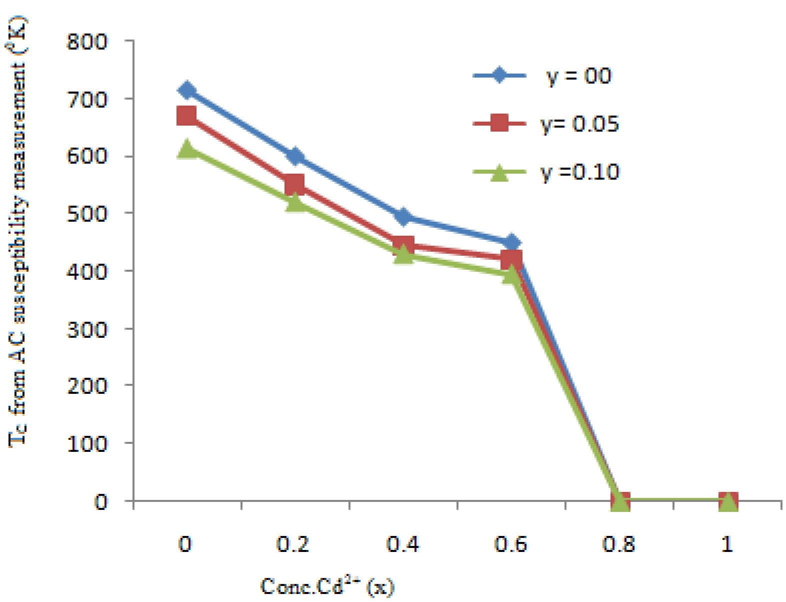

Figure 7. Variation of Curie temprature from susceptibilty with Cd^{2+} content

ISSN: 2278 – 7798