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AC Susceptibility Studies of Lithium Cdmium Ferrite

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Abstract:
Lithium-cadmium ferrite samples with composition $Li_{0.5-x/2}Fe_{2.5-x/2}Cd_xO_4$ (x =0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7) were synthesized by the conventional ceramic method. The variation of normalized ac susceptibility with temperature and Cd content were studied. Samples with x = 0.2, 0.3, 0.4 and 0.5 show a clear blocking temperature, indicating single-domain behaviour at low temperature and superparamagnetic behaviour above it, and this blocking temperature decreases with increasing Cd^{2+} content. A reduction in Curie temperature with Cd^{2+} substitution is also observed, consistent with weakening magnetic interactions due to non-magnetic ion substitution. For $x \geq 0.6$, the a.c. susceptibility decreases continuously with temperature, confirming dominant superparamagnetic behaviour, showing that higher Cd^{2+} content weakens magnetic ordering and favours the superparamagnetic state.
Keywords: *Ferrite, AC susceptibility, Temperature, Cd content, Superparamagnetic state.*

I. INTRODUCTION

For ferrimagnetic materials with zero magnetocrystalline anisotropy, the exchange interaction between spins favors their parallel arrangement, resulting into uniform magnetization. This state of uniform magnetization produces high demagnetizing field energies, which are reduced to non-uniform state of magnetization. The domain wall between two oppositely oriented domains has a width of about 1000 A°. Obviously, ferromagnetic particles of size less than 1000 A° cannot contain a wall and hence are single domain. The magnetostatic energy of a single domain particle is given by vJsHc, where v is the volume of the particle, Js is the spontaneous magnetization and Hc is the coercive force of the particle corresponding to the overall anisotropy field. If the volume of the particle is small enough or its thermal energy is equal to its magnetic energy, the magnetization direction fluctuates in the two long easy axis of particle and the grain superparamagnetism (SP). Hence the magnetic state of single domain and superparamagnetism are interchangeable by temperature. The grains which have domain walls in them are known as multi domains (MD). Thus, ferromagnetic grains can be of three distinct types viz. large grains with domain walls and net zero magnetic moment, termed as multi domains (MD); uniformly magnetized optimum single domain (SD) and superparamagnetic (SP) grains. For the materials with zero magnetoorystalline anisotropy the single domain particles are formed for minimum dimensions, approximately equal to $A^{1/2}M^{-1}$ cm where $A = 2JS^2/a$ ergs/cm and a is the lattice constant. In case of highly anisotropic materials ($K > M_S^2$) the critical dimension Ro can be written as

$$Ro = AK / M_S^2 \qquad ... 1$$

Hence one can say that the high magnetocrystalline anisotropic materials may still remain in a single domain state for larger particle size. In ferro and ferrimagnetic materials the variation of normalized a.c susceptibility (χ_T/ χ_{RT}) temperature curves exhibit three peaks viz. (i) Hopkinson's peak which occurs just below the curie temperature (Tc). (ii) Single domain peak which could be obtained if the material under study has SD particles and it occurs at blocking temperature (Tb). (iii) Isotropic peak which is observed when magnetic material is in the MD state and at this temperature magnetocrystalline anisotropy vanishes. At blocking temperature the particles turn into superparamagnetic state. Superparamagnetism has all the characteristics of paramagnetism, the difference is that it deals with groups of about 10^8 coupled spins whereas paramagnetism deals with single spins. The a.c susceptibility studies for mixed ferrites have been used by number of workers to identify MD, SD and SP particles [2,3,4,5,6]. Naik et al [4] have showed that in case of pure copper ferrite, particles with single domain state are easily formed and this tendency is inhibited by the addition of Li in the system. Secondly, it has been pointed out that normalized a.c. susceptibility for MD particles does not change appreciably with temperature and drops out sharply at the Curie temperature (Tc). In case of ferrite containing SD particles, there occurs a broad hump below Tc or a sharp cusp near Tc depending upon the temperature at which the single domains becomes superparamagnetic.

II. MATERIALS AND METHODS

Lithium cadmium ferrite were prepared by standard ceramic method having general formula $Li_{0.5-x/2}Fe_{2.5-x/2}Cd_xO_4$ where x= 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 using high purity A.R. grade Li_2Co_3, CdO and Fe_2O_3.These powders were weighted in the required mole proportions on a semi microbalance having least count of 0.001 mg and were mixed thoroughly is an agate mortar in acetone medium. This powder was presintered at 700ºC for 10 hours, in a glowbar furnace in air. Then the furnace was cooled slowly. Calibrated chromel-alumel thermocouple was used to measure the temperature of furnace. The presintered powder was then ground in an agate mortar in acetone medium. The fine powders of the resultant ferrites were obtained by sieving them through a 100-micron mesh. The mixture was compressed in the form of pellets by using a die of 1 cm. diameter and by applying a pressure of about 7 to 8 tonnes per square inch for 2 minutes. To reduce the lithium loss the sample were fired at 950^{O}c for 20 hours in air medium. The samples were cooled in the furnace atmosphere. XRD, FTIR and SEM studies has already been published elsewhere [12].

III. EXPERIMENTAL TECHNIQUES

The measurement of normalized a.c susceptibility (χ_T/χ_{RT}) of the samples as a function of temperature was carried out in powder form, employing the experimental set up developed by Tata Institute of Fundamental 'Research, Bombay [7] (Fig. 1). The block diagram of the experimental set up is shown in Fig. - 1 The apparatus essentially consists of a double coil set up. One of the coil produces a magnetic field of 7 Oe operating at 263 Hz and another coil produces a emf directly proportional to the susceptibility of magnetic material at different temperatures (χ_t) and at room temperature (χ_{RT}). The measured emf (χ_t) is related to real susceptibility (χ) by the relation

$$\chi t = \frac{\chi}{1+N\chi} \qquad \ldots 2$$

where N is the demagnetization factor.

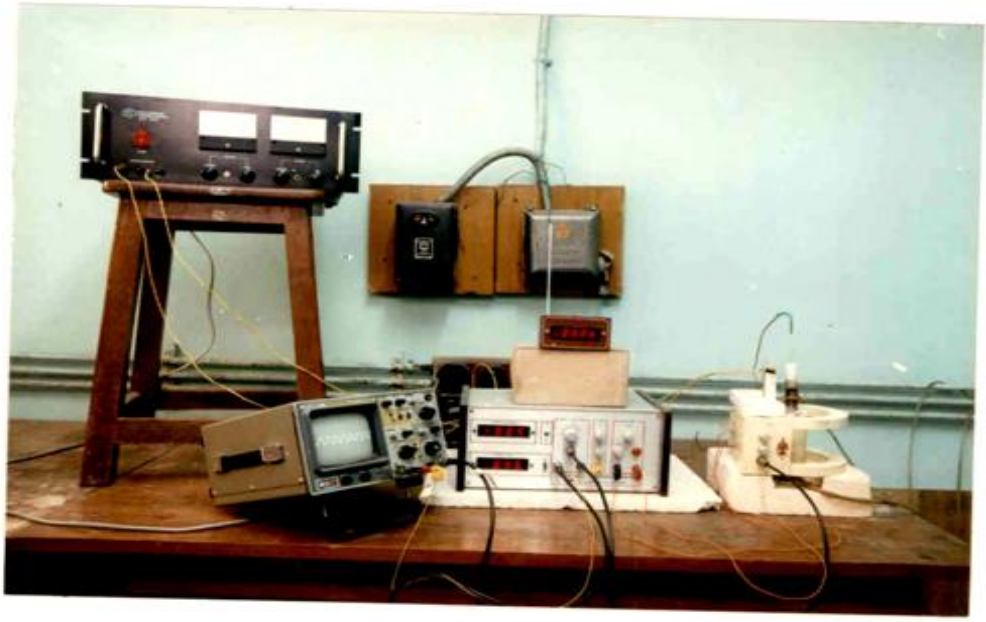

Fig.1 Experimental Set-up of A.C. Susceptibility Measurement

IV. RESULTS AND DISCUSSION

The variation of normalized a.c. susceptibility with temperature for the system $Li_{0.5-x/2}Fe_{2.5-x/2}Cd_xO_4$ with x = 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 is shown in Fig.2. The Curie temperatures determined from high temperature susceptibility data are shown in Table 1. From the table it can be observed that there is a decreasing trend for Curie temperature with the addition of $Cd^{2+.}$ From the variation of normalized a.c. susceptibility with temperature it can be observed that the samples with x = 0.2, 0.3, 0.4 and 0.5 show peaking behaviour before the Curie temperature (Tc) and χ_{ac} drops sharply to zero at curie temperature (Tc) for these samples and the sample with x = 0.6 and 0.7 show continuous decreasing trend with increasing temperature.The shapes of hysteresis loops and χ_{ac}-T curves provide information regarding the domain state of sample [8] viz. multi domain (MD), single domain (SD) or superparamagnetic (Sp). High temperature susceptibility measurement were first carried out by Hopkinson on iron [9]. He observed a peak just before the curie temperature. Domain structure in ferrites have been studied by number of other workers [1,2,3,7,10,11].

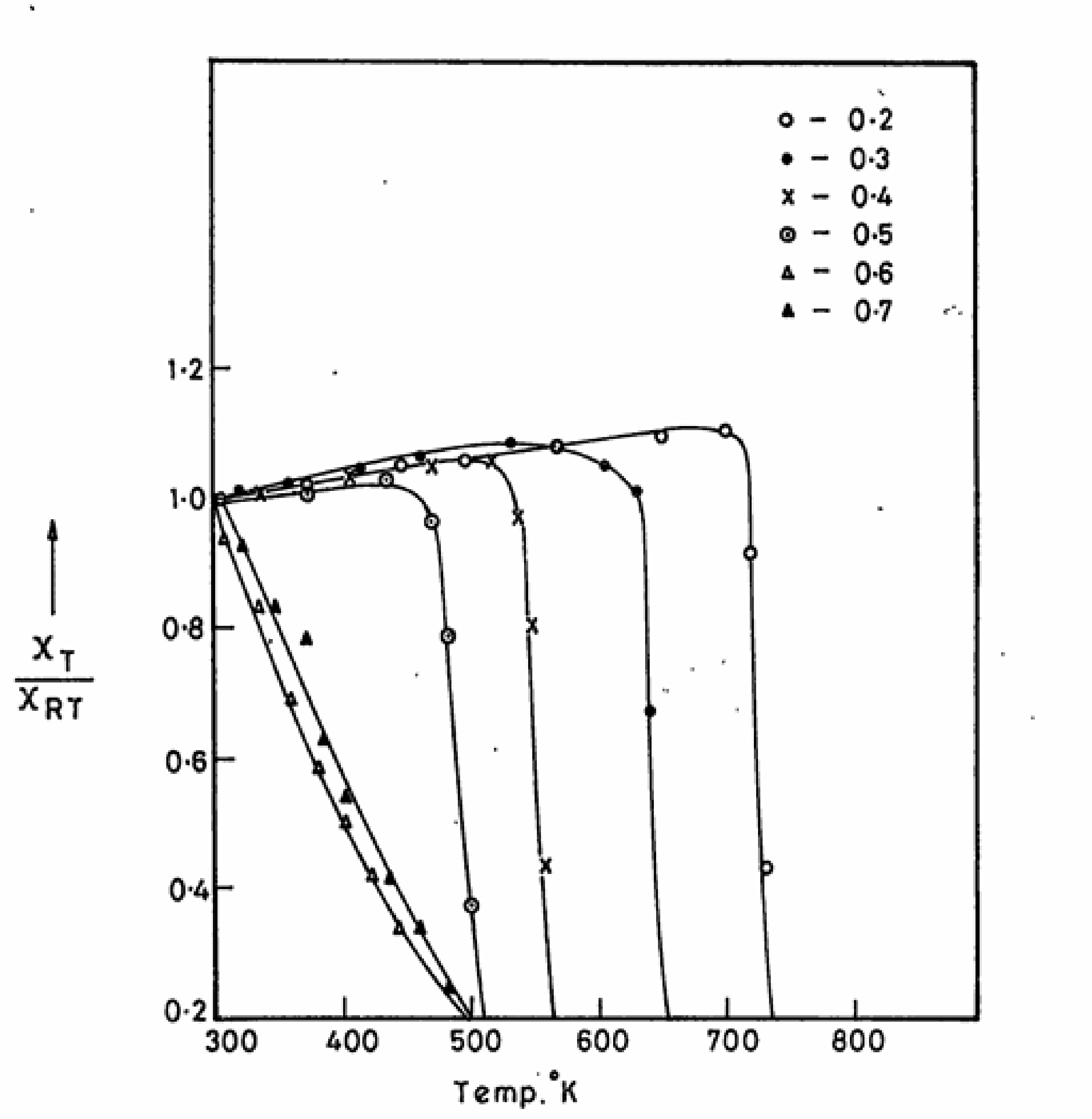

Fig.2 VARIATION OF χ_T / χ_{RT} WITH TEMPERATURE

Table no 1: Curie temperature, Blocking temperature and Mr/Ms of $Li_{0.5-x/2}Fe_{2.5-x/2}Cd_xO_4$ ferrites

Cd content	Tc K	Tb K	MR/MS
0.0	-	-	0.83
0.1	-	-	0.92
0.2	740	650	0.88
0.3	650	560	0.4
0.4	580	500	0.43
0.5	510	480	0.5
0.6	-	-	0.5
0.7	-	-	-

A peak at blocking temperature (Tb) has been exhibited by the sample with x = 0.2, 0.3, 0.4, 0.5. It indicates that below the blocking temperature (Tb) all the samples are in the single domain (SD) state while above Tb they are in superparamagnetic (SP) state. From Table no 1 it is seen that increasing Cd^{2+} content results in the decrease of

Tb , which suggests that the formation of SD particles is gradually suppressed by the addition of Cd^{2+}. These samples also show high values of Mr/Ms. A continuous decrease in a.c. susceptibility with temperature shows that the samples are superparamagnetic (SP) state. Thus it is clear that the addition of Cd^{2+} beyond 0.5 favours SP state .

V. Conclusion

The temperature dependent a.c. susceptibility study of ferrite shows strong influence of Cd^{2+} substitution on magnetic behaviour. The curie temperature decreases with increasing Cd content, indicating weakening of magnetic interactions. Sample with x=0.2, 0.3, 0.4 and 0.5 exhibit a distinct blocking temperature, confirming single domain behaviour below Tb and superparamagnetic behaviour above it. A continuous decrease in a.c. susceptibility for $x \geq 0.6$ conforms dominant superparamagnetic behaviour. Thus higher Cd^{2+} concentration favours the superparamagnetic state.

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