Physical and Magnetic Properties of Si doped Co-Zn ferrite

Shinde S.S.
Department of Physics, A.S.C.College, Naldurg, 413602, sureshshinde186@gmail.com

Abstract – Five samples of Si doped Co – Zn ferrite with general formula $Co_{0.7+x}$ $Zn_{0.3}$ Si_x Fe_{2-2x} O_4 (x = 0.0 to 0.4) were prepared by double sintering ceramic technique. The physical and magnetic properties of these samples were studied by X-ray diffraction, high field hysteresis loop technique and a.c. susceptibility measurements. Lattice constant 'a' is found to decrease with increase in Si content from x=0.1 to 0.4. X-ray density dx decreases with increase in Si content. The particle size of the samples is found to vary in the range of 70 nm to 78.8 nm. Magnetic moment n_B is found to increase with increase in Si concentration upto $x \leq 0.2$ and then it decreases for $x \geq 0.3$. A.C. susceptibility increases slowly with increase in temperature then decreases sharply and finally becomes zero near the curie temperature Tc.

Keywords: Ceramic, Lattice constant, a.c. susceptibility.

1. Introduction

Ferrites are the most widely used magnetic materials due to their high performance and low cost [1]. These are ferrimagnetic oxide materials with good magnetic properties and large number of technological applications. The physical and other properties of ferrites arise from their ability to distribute the captions among the tetrahedral [A] and octahedral [B] sites.

Cobalt ferrite is one of the most important ferrite to be used in several applications. It possesses inverse spinel structure and degree of inversion depends upon heat treatment [2]. Many workers [3,4] have studied the structural and magnetic properties of cobalt and cobalt – substituted ferrites. Substitution of tetravalent ions in cobalt ferrite influences the physical electrical and magnetic properties. So far no investigation of Si doped Co-Zn ferrite have been reported in the literature. In the present study, a systematic investigation of physical and magnetic properties of ferrite system $Co_{0.7+x}$ $Zn_{0.3}$ Si_x Fe_{2-2x} O_4 prepared by ceramic method have be carried out.

2. Experimental

Five samples of the spinal system $Co_{0.7+x}$ $Zn_{0.3}$ Si_x Fe_{2-2x} O_4 (x = 0.0 to 0.4) were prepared by standard double sintering ceramic technique using AR grade oxides CoO, ZnO, SiO_2 and Fe_zO_3. The physical properties of the prepared samples were determined by X-ray powder diffraction technique. The X-ray diffraction (XRD) patterns of all the samples were recorded on a PW710 diffractometer using CuKα radiation in the range of $2\theta = 10^0$ to 90^0 and scanning rate of one degree per minute.

The magnetization measurements were carried out by using high field hysteresis loop technique [5] at 300K. the a.c. susceptibility measurements were carried out from room temperature up to 650K using double coil set up operating at a frequency of 110 Hz and in r.m.s. field of 0.5 Oe.

3. Results and Discussion

3.1 XRD Analysis

Fig.1 shows the XRD patterns of the two sumples of the present system for Si content X=0.0 and 0.1. These XRD patterns show sharp lines corresponding to single phase cubic spinel structure. The values of lattice constant 'a' were determined from XRD date and are listed in Table 1. It is evident that the lattice constant initially increases with increase in Si content from x = 0.0 to 0.1 and then starts decreaseing with increasing Si contant for $x \geq 0.2$. The initial increase in lattice constant may be due to the fact that the substitution of Si upto x = 0.1 does not affect the lattice. The decrease in lattice constant above Si content $x \geq 0.2$ may be due to the fact that larger Fe^{3+} ions (0.64 A^0) are replaced by smaller Si^{4+} ions (0.42 A^0) on tetrahedral [A] site.

By comparing the calculated and observed x-ray intensity ration I_{220}/I_{400} and I400/I422 and using site preference of various ions, the cation distribution of the present system can be written as

For x=0.0 $(Zn_{0.3}\ Fe_{0.7})^{A}\ [Co_{0.7}\ Fe_{1.3}]^{B}$

For x=0.1 to 0.4

$(Co_{0.05}\ Zn_{0.3}\ Si_{0.05+y}\ Fe_{0.6-y})^{A}\ [Co_{0.75+y}\ Si_{0.05}\ Fe_{1.5-y}]^{B}$

Where x = 0.1 +y , y = 0.0, 0.1, 0.2, 0.3

The x – ray density for each sample was calculated using the relation dx = ZM/NV

Where Z is the number of molecules per unit cell (Z=8), M is molecular weight, N is Avogadro's number and V is volume of unit cell. The values of X-ray density listed in Table 1 are found to decrease with increase in Si content similar to lattice constant. This shows that the decrease in mass overtakes the decrease in volume of unit cell in the present system.

The values of particle size t of all the samples estimated by using Scherre's formula [6] are listed in Table 1. It is evident that the particles size is found to vary in the range of 70 to 78.8 nm which is consistent with the particle size of ceramically prepared ferrites.

3.2 Magnetization

The values of saturation magnetization (σ_s) and magneton number n_B (saturation magnetization per formula unit in Bohr magneton) at 300K for all the samples of the present system are listed in Table 2. It is evident that the magnetion number increases with increase in Si content up to $x \leq 0.2$ and there after it decreases for $x \geq 0.3$.

According to the Neel's two sublattice model of ferrimagnetisms [7], the magnetic moment per formula unit in μ_B [n_B^N] is

$n_B^N = M_B(x) - M_A(x)$

Where M_A and M_B are the A and B sublattice magnetic moments in μ_B. The calculated values of n_B^N using the cation distribution and Neel's equation are listed in Table 2. Comparing the observed values and calculated values (Necl model) of n_B, the magnetic structure of present system is collinear up to Si content $x \leq 0.2$. The decrease in observed values of n_B for Si content $x > 0.2$ indicates that significant canting exists on B – site suggesting that the magnetic structure is non – collinear. This could be related to the fact that with increase in Si content beyond 0.2 there is decrease of Fe^{3+} ions on A-site giving rise to the reduction of A-B interaction. The ionic spins on B-site are not parallel to one another and their angular orientation results in reducing the magnetic moment.

3.3 A.C. Susceptibility

Fig. 2 shows variation of a.c. susceptibility with temperature for Si content x = 0.0 and 0.1. It is evident that normalized a.c. susceptibility increases slowly with temperature, then decreases sharply and finally becomes zero near the Curie temperature Tc. The values of Curie temperature determined from susceptibility plots are listed in Table 2.

Depending upon the particle size, a polycrystalline magnetic crystal may consist of three types of magnetic states viz. Multidomain (MD), single domain (SD) and superparamagnetic (SP) [8,9]. For a MD sample, susceptibility does not change appreciably with temperature and drops sharply at Curie point [10]. In the present case the susceptibility slightly increases with temperature which is characteristics of SD+MD particles.

From Table 2. it is observed that the Curie temperature obtained from susceptibility plots decreases with increase in Si content x. This is attributed to decreasing AB interaction resulting from the replacement of Fe^{3+} ions by Si^{4+} ions on A-site.

Conclusion

1. Lattice parameter initially increases from Si content x = 0.0 to 0.1 and then decreases.
2. X-ray density decreases with increase in Si content.
3. Particle size is found to be in the range of 70 to 78.8 nm.
4. Variation of magneton number n_B indicates that magnetic structure is collinear for Si content up to x = 0.2 and it is non – collinear beyond x = 0.2.

5. Decrease in Curie temperature shows that there is reduction of AB interaction with increase in Si content.

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Table 1-Lattice constant (a), X-ray density (dx) and particle size for $Co_{0.7+x}\ Zn_{0.3}\ Si_x\ Fe_{2-2x}\ O_4$

Composition x	Lateice constant a (A^0)	X-ray density dx (gm/cm^3)	Particle size t (nm)
0.0	8.410	5.283	70.9
0.1	8.426	5.199	78.8
0.2	8.421	5.153	77.2
0.3	8.412	5.114	75.3
0.4	8.439	5.103	72.0

Table 2-Saturation magnetization (σ_s), Magnetron number (n_B), Curie temperature (Tc) for $Co_{0.7+x}\ Zn_{0.3}\ Si_x\ Fe_{2-2x}\ O_4$.

Composition x	Saturation magnetization σ_s (emu/gm)	Magneton number $n_B(\mu_B)$		Curie Temp. Tc(K)
		Observed	Neel Model	
0.0	51.23	3.11	5.1	623
0.1	49.92	3.41	5.1	585
0.2	43.37	3.44	5.4	568
0.3	35.86	2.75	5.7	558
0.4	31.93	2.10	6.0	538

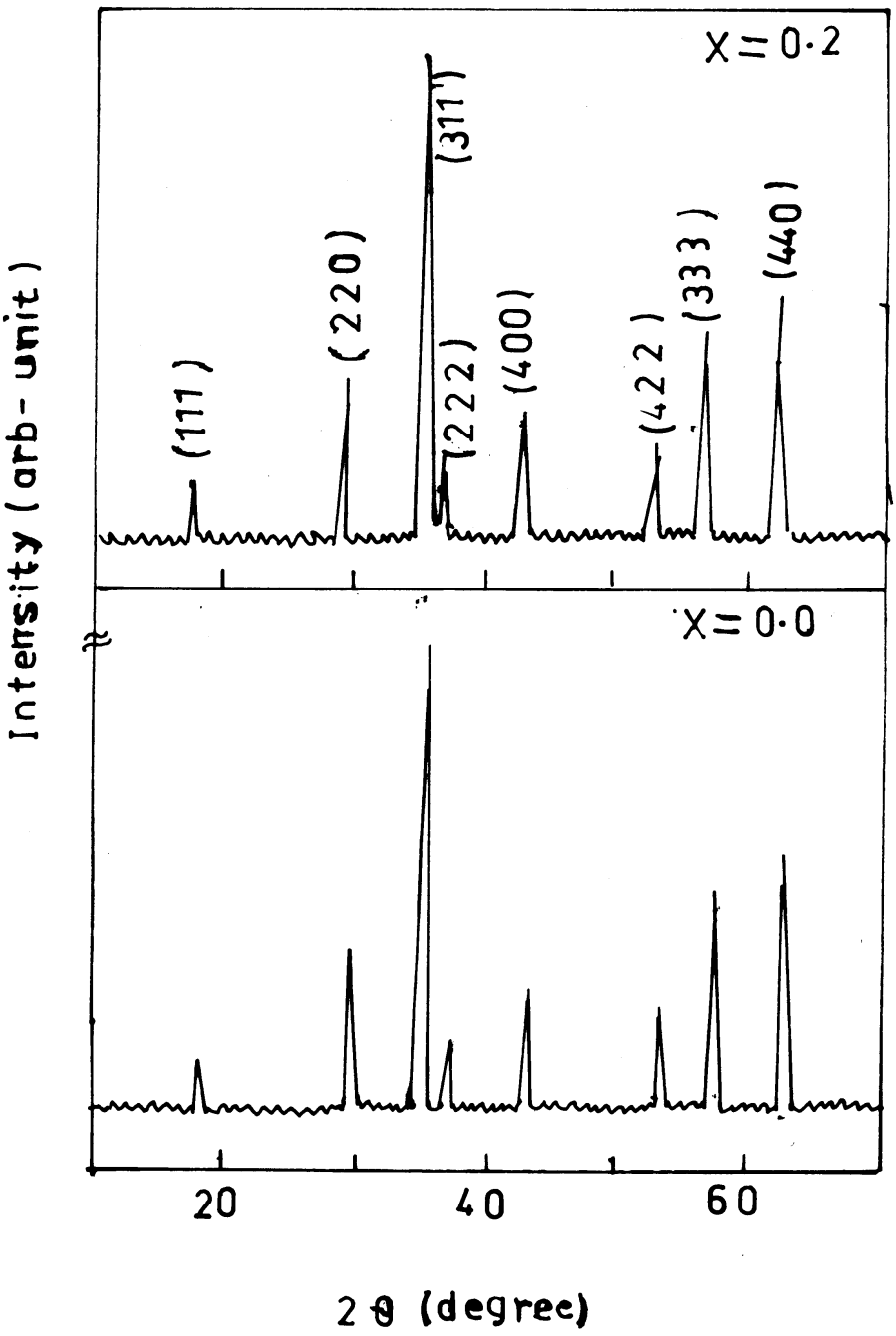

Fig. 1-Typical X-ray diffraction patterns of $Co_{0.7+x}\ Zn_{0.3}\ Si_x\ Fe_{2-2x}\ O_4$ for x = 0.0 and 0.1.

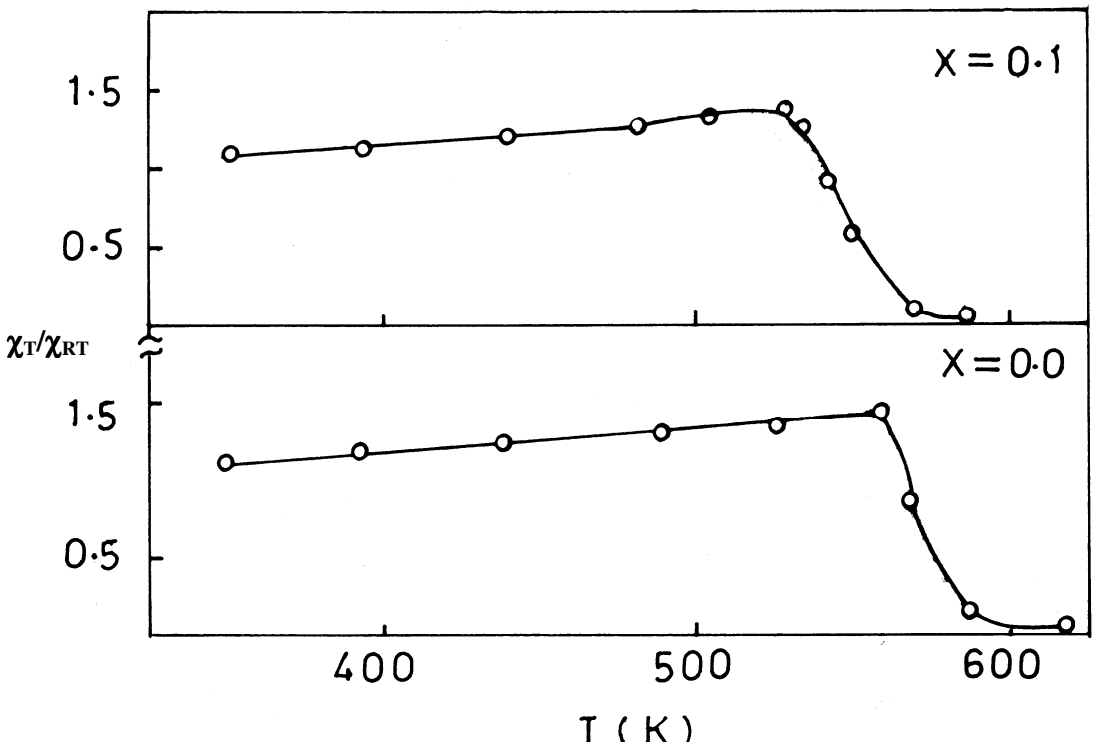

Fig. 2-Thermal variation of a.c. susceptibility for x = 0.0 and 0.1.