

Study of the Structural, Electrical and Magnetic Properties of Co Ferrite

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Abstract

Bulk $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$ ($x = 1, 0.75, 0.50, 0.25$) samples were prepared by conventional solid-state reaction method and sintered at 1300K. Effects of Co substitution on lattice parameter, density, porosity, dielectric and magnetic properties of ferrite were investigated thoroughly. Single phase spinel structure of all the sintered samples are confirmed by X-ray diffraction. Lattice parameter found to be increased linearly with increasing Co substitution. Initial permeability and frequency dependence of the complex permeability measurements were carried out by LCR bridge in the frequency range 1 KHz to 13 MHz at room temperature. Permeability was observed to be decreased with the increase of content whereas magnetostriction was increased. Minimum magnetostriction gives maximum permeability due to minimum constrain on the domain wall movement. Thus a consistent relationship was found between permeability and magnetostriction.

1. Introduction

Ferrites have been used as high frequency soft magnetic materials due to their high resistivity and high permeability [1]. Of all ferrites, the Co ferrites are of the greatest practical importance today due to their higher saturation magnetization, the lower losses, and a relatively high Curie point [2,3]. Co ferrites has been widely used in electronic devices such as transformers, choke coil, thin-film read heads, and microwave acoustic devices up to 500 MHz, owing to its high magnetization, high resistivity, and low eddy-current losses. During the last few decades, there has been a growing interest in the study of the magnetic behavior and magnetic structure of mixed ferrite due to its fascinating properties and interesting technological applications [4-8]. The substitution of magnetic/nonmagnetic ions has shown a tremendous effect in controlling the magnetic, structural, and electrical properties, The magnetic oxides with spinel structure seems to be particularly attractive, as they allow a variety of magnetic disorders and frustrations to be introduced[9]. In spinel lattice AB_2O_4 , the anions (O^{2-} ions) form cubic close packing, in which the interstices are occupied by tetrahedral (form the A site) and octahedral (form the B site) coordinated cations. In such magnetic oxide materials the competition between ferromagnetic and antiferromagnetic super exchange interactions occurs between the spins of intersublattice (i.e., A-O-B, J_{AB} = intersublattices exchange interaction) and intrasublattices (i.e., B-O-B, J_{BB} , A-O-A, J_{AA} = intrasublattice exchange interaction). In general, in spinel oxide intrasublattice interactions are weaker than the intersublattice interactions. Microstructure, magnetic and electrical properties of Co ferrites depend on the method of preparation, sintering temperature and the doping concentration. Due to substitution of various cations, spinel type lattice may either compress or expand, hence there is a modification of A-B interaction, and also there is a cation redistribution in A site and B site that produce samples with various interesting properties.

2. Experimental details

The samples of $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$ ($x = 1, 0.75, 0.50, 0.25$) were prepared by solid state double sintering method. The stoichiometric amounts of highly pure powders of CoO and Fe_2O_3 mixed intimately by ball milling for about 6 hours and the mixtures were then dried in air in an oven. After drying, the mixtures were heated in alumina crucible at 900K for 6 hours following the furnace cooling in air. A small amount of polyvinyl alcohol (PVA) was added as a binder to this

dried mixture and was intimately mixed in agate mortar. The samples were then pressed into small pellets in a hydraulic press. The pellets were then heated at a temperature of 1000K in a furnace for 8 hours followed by slow cooling. After this pre-sintering operation, the pellets were further powdered. The milling, drying, pressing and pre-sintering operations were repeated once. The final sintering of the materials was done in air at 1300K for 6 hours and subsequently cooled to room temperature in a furnace at a slow rate. X-ray powder diffraction patterns for all the samples were recorded in order to check their quality and phase purity using a X-ray diffractometer with $\text{CuK}\alpha$ radiation. The frequency dependent characteristics of Co ferrite samples i.e. the initial permeability spectra were investigated using an Impedance Analyzer. The complex permeability measurements on toroid shaped specimens have been carried out at room temperature on all the samples in the frequency range 1KHz-13MHz. The relative quality factor and loss factor were calculated for all the samples. The magnetostriction of all the compositions were measured by means of strain gauge technique as a function of field.

3. Results and Discussion

Single phase spinel structure of all the sintered samples are confirmed by X-ray diffraction. The X-ray diffraction patterns for $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$ with $x = 1, 0.75, 0.50, 0.25$ are shown in figure 1. Lattice parameter was calculated for each Bragg's angle. The average value of the lattice parameter were found using Nelson-Riley function. The lattice parameter increases linearly with increasing of Co content, which is expected as Co^{2+} (0.74\AA) with

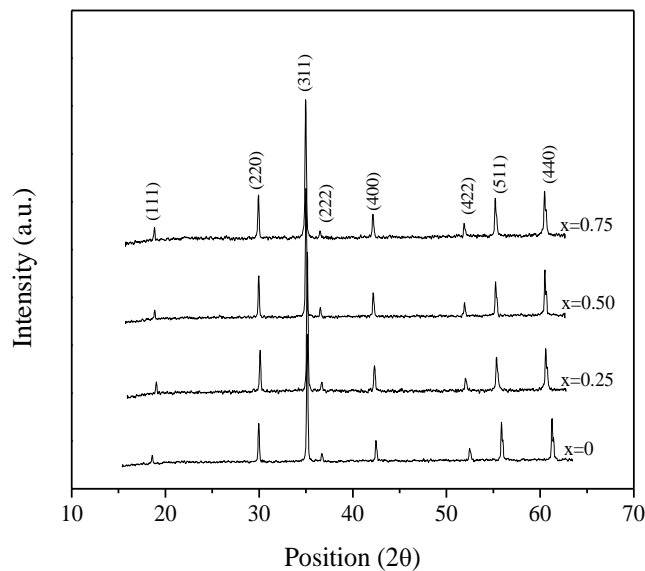


Fig. 1: X-ray diffraction patterns of $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$ ($x = 1, 0.75, 0.50, 0.25$) samples

larger ionic radius than Fe^{3+} (0.64\AA) in the octahedral sites. The tetrahedral ionic radius is constant due to unchanged Co^{2+} content in the tetrahedral sites in this series of ferrites. The lattice parameter increases linearly with increasing Co substitution as shown in figure 2 for the sample $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$. Densities for different samples were calculated using the lattice parameter and compared with the bulk density, as shown in table 1. Porosity was derived by using these lattice parameters. We observed that the value of porosity was decrease with increasing of Co content, whereas density was increased.

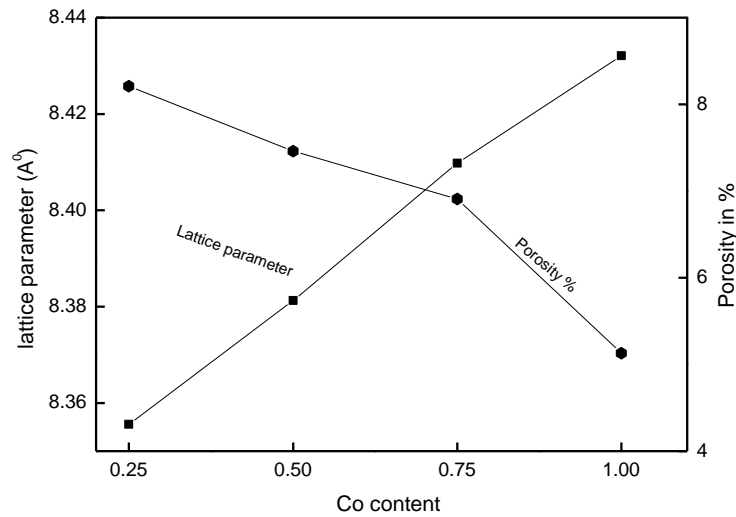


Fig. 2: Lattice parameter and porosity versus Co-content.

Table 1. The lattice parameter (a_0), theoretical density (ρ_{th}), bulk density (ρ_B) and porosity (P) of various $Co_xFe_{3-x}O_4$ samples

Compo-sition	a_0 (Å)	ρ_{th} (gm/cc)	ρ_B (gm/cc)	P %
x=1	8.3556	5.5282	4.8923	8.21
x=0.75	8.3813	5.6739	4.9072	7.46
x=0.50	8.4098	5.7911	4.9809	6.91
x=0.25	8.4321	5.8326	5.0914	5.13

The complex permeability measurements on ring shape specimens have been carried out at room temperature for $Co_xFe_{3-x}O_4$ with composition $x = 1, 0.75, 0.50$ & 0.25 in the frequency range 1KHz to 13MHz. The information obtained from complex permeability with respect to frequency dependence and composition which is

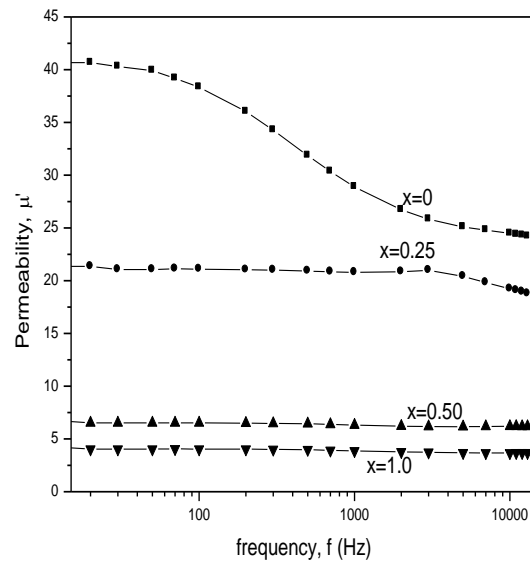


Fig. 3: Real part of permeability versus frequency of various samples

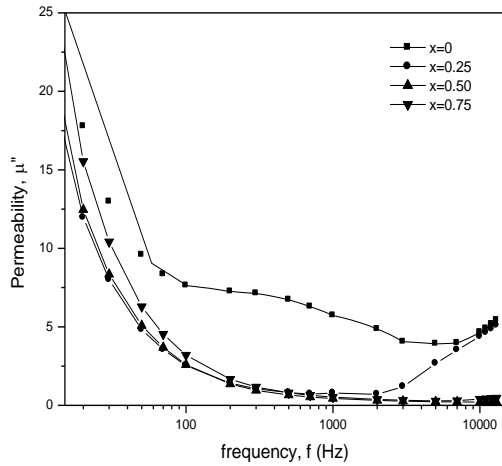


Fig. 4: Imaginary part of permeability versus frequency of various samples

useful in understanding the mechanism controlling the dynamic properties and also the applicability of these materials for high frequency uses. The frequency dependence of real

and imaginary part of complex permeability of the samples is shown in Figure 3 and Figure 4 respectively. The values of initial permeability decrease with increasing Co content as evident from the figures. It is understood that the decrease of initial permeability with increasing Mg content is due to the decrease of densification of the studied samples. Ferrites with higher density and larger average grain size possess a higher initial permeability. The calculated loss factor ($\tan\delta$) and the relative quality factor ($\mu_r/\tan\delta$) which determines the merit of the magnetic materials from the application point of view is shown in figure 5. It is observed from the Figure that the sample with $x = 0.25$ is of highest Q value which is probably due to the growth of less imperfection and defects in them than all other samples. Smaller grain size is competent for larger Q values.

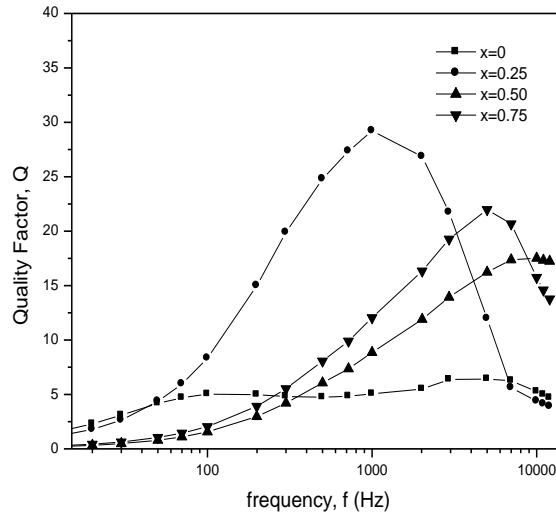


Fig. 5: Quality factor versus frequency of various samples

The magnetic or quasi magnetic forces between atoms give rise to an expansion or contraction of the lattice by opposing the purely elastic force between atoms. The equilibrium distortion or magnetostriction occurs when the sum of the two corresponding energies is a minimum. The linear magnetostriction is calculated assuming that the magnetic forces between atoms can be simulated by magnetic dipole moments alone. The values of magnetostriction thus calculated for different samples are shown in figure 6 as a

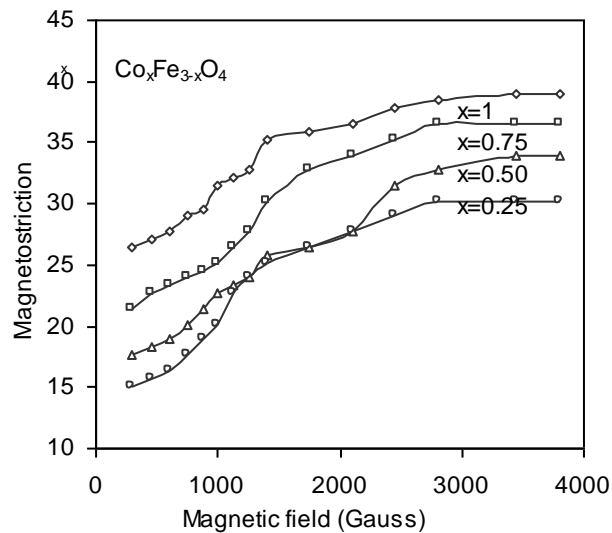


Fig. 6: Magnetostriction with variation of frequency for $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$ samples

function of applied field. The curves show that the value of the saturation magnetostriction for $\text{Co}_x\text{Fe}_{3-x}\text{O}_4$ increases with Co concentration. Since iron and Co have positive magnetostriction, it is expected by the thumb rule that in an alloy of this two elements magnetostrictive contributions from these elements will tend to cancel each other. The magnetostriction effect in Co originates from the dipolar interaction among magnetic ions, the single ion contribution of Fe^{3+} on A and B sites and the single ion contribution of Co^{2+} on B site. However, actual mechanism of magnetostriction, being a complex phenomenon of spin orbit interaction, crystal anisotropy and elastic constant, the magnetostriction of the ferrite is not likely to show any linearity with respect to the contributions from the constituent elements.

Conclusion

Addition of Co in the ferrite system causes the increase of lattice parameter, density and decrease of the porosity. Permeability decreases with Co content whereas saturation magnetostriction observed to be increased. Thus Addition of Co plays a crucial role on magnetic properties in ferrite.

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