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# Structural and magnetic properties of $Zn_XCo_{1-X}Fe_2O_4$ nanoparticles: Nonsaturation of magnetization

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ABSTRACT

$Zn_XCo_{1-X}Fe_2O_4$ nanoparticles were synthesized by sol-gel method and were annealed at two different temperatures; 500 °C and 900 °C in air for 2 h. Structural studies were carried out by X-ray diffraction and Fourier transformed infrared spectroscopy. The crystallite size didn't show any variation with the increase in $Zn^{2+}$ concentration and was increased after annealing. The magnetization value at 300 K for the as-prepared samples increased from 53 emu/g to 60 emu/g when $Zn^{2+}$ concentration increased from x=0 to 0.2 and then it decreased to 11 emu/g for x=1. Similar magnetic behavior was also observed for the annealed samples with a peak at x=0.2. A very high magnetization value of 116 emu/g at 60 K was observed for the 900 °C annealed sample with x=0.4. The coercivity decreased monotonically with the increase in the $Zn^{2+}$ concentration for both the as- prepared and the annealed samples. The magnetization and coercivity values were observed to be enhanced with the decrease in measurement temperature. The nonsaturation behavior of the magnetic hysteresis loops of these nanoparticle samples observed for all compositions and temperatures was studied by the method of approach to saturation by fitting $M(H)=M(\infty)\,[1-(H^*/H)^{1/2}]$ to the high field data of the initial curve from 20 kOe to 30 kOe. It was observed that $H^*$ value which is the measure of the nonsaturation increased with the increase in the $Zn^{2+}$ concentration. The observed magnetic properties in these nanoparticle samples can be ascribed to the changed cation distribution in the spinel structure and to the decrease of $Co^{2+}$ concentration.

## 1. Introduction

Spinel ferrites due to their unique physical properties and their potential industrial applications have been studied extensively. In nanoparticles, physical properties of these ferrites strongly depend on many factors like grain size and their distribution, packing density, composition, cation distribution, coating and doping by a magnetic or nonmagnetic material.

Co-ferrite ($CoFe_2O_4$) has very interesting physical properties like high coercivity [1], anisotropy [2] and magnetostriction [3], and moderate saturation magnetization [4]compared to other spinel ferrites. Zn-ferrite ($ZnFe_2O_4$) is also a very interesting magnetic material in nanoscale. It is antiferromagnetic in bulk and show ferrimagnetic behavior in nanoparticle and thin film form [5,6]. In bulk Co-ferrite has inverse spinel structure with 8 $Fe^{3+}$ in the tetrahedral (A) sites and 8 $Co^{2+}$ along with 8 $Fe^{3+}$in the octahedral (B) sites in the unit cell. Zn-ferrite has normal spinel structure with 8 $Zn^{2+}$ in the A-sites and 16 $Fe^{3+}$ in the B-sites [7]. The super exchange interactions between the cations in the A- and B-sites explain the magnetic behavior of these materials. The strength of the exchange interaction depends on the distances between the cations and the oxygen anion that is mediating the exchange interaction as well as on the angle between these ions [8]. $Co^{2+}$is highly magnetic with 3 unpaired electrons compared to $Zn^{2+}$ which is non-magnetic due to no unpaired electron. $Co^{2+}$ has preference towards B-site where as $Zn^{2+}$ prefers A-site. In the Co-ferrite the A-B interaction is the strongest compared to A-A and B-B interactions. In the Zn-ferrite B-B interaction is the strongest one compared to the others which explains its magnetic behavior [9]. So, the substitution of nonmagnetic $Zn^{2+}$ in Co-ferrite lattice is expected to certainly modify the exchange interactions and its magnetic properties.

Several studies have been reported on the influence of $Zn^{2+}$ concentration on the magnetic properties of $Zn_XCo_{1-X}Fe_2O_4$ nanoparticles. It has been reported that with the substitution of small concentration of $Zn^{2+}$ in $Zn_XCo_{1-X}Fe_2O_4$ nanoparticles enhances the magnetization [10,11] and for higher $Zn^{2+}$ concentration magnetization decreases [12]. Some researchers observed a maximum in magnetization with the variation of $Zn^{2+}$ concentration in $Zn_XCo_{1-X}Fe_2O_4$ nanoparticles [13–15]. However, other groups ob-

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