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# Exchange spring like magnetic behavior in cobalt ferrite nanoparticles

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ABSTRACT

Cobalt ferrite nanoparticles were prepared by sol–gel technique and were annealed at 900 °C in air for 2 h. Structural properties were studied by X-ray diffraction, Raman spectroscopy and Fourier transformed infrared spectroscopy. Scanning electron microscopy and transmission electron microscopy studies show presence of mostly two different sizes of grains in these samples. Magnetization value of 58.36 emu/g was observed at 300 K for the as prepared sample and an enhanced magnetization close to the bulk value of 80.59 emu/g was observed for the annealed sample. At 10 K a two stepped hysteresis loop showing exchange spring magnetic behavior was observed accompanied by very high values of coercivity and remanence. Two clear peaks were observed in the derivative of demagnetization curve in the as prepared sample where as two partially overlapped peaks were observed in the annealed sample. The observed magnetic properties can be understood on the basis of the grain size and their distribution leading to the different types of intergranular interactions in these nanoparticles.



## 1. Introduction

Magnetic nanoparticles have attracted much attentions in research because of their wide range of applications in data storage [1–3], magneto-optical devices [4], catalysis [5], biomedical applications like drug delivery [6], magnetic resonance imaging [6,7], biosensors [8] and hyperthermia [9–12]. These nanoparticles show very interesting physical properties due to their reduced size compared to their bulk counterpart. The physical properties of these nanoparticles can also be easily tailored by controlling its microstructure and enabling them for many applications [13–15]. The sizes of the nanoparticles [14,16], morphology [7,13], size distribution [17–19], packing density [20], intergranular exchange interaction [21–23], and cation distribution [24,25] are some of the factors which are responsible for the modified magnetic properties in the nanomaterials. Among these, grain/particle size and their distributions are most of the important factors governing the magnetic properties in the nanomaterials. Nlebedim et al. [17] observed that the particle size distribution of $CoFe_2O_4$ (Co-ferrite) is an important factor in controlling the magnetostictive properties. Malik et al. [18] observed double peaks in the zero field cooled and field cooled magnetic measurements performed at low field due to bimodal particle size distribution in Ni-ferrite nanoparticles. Chinnasamy et al. [26] found that nanostructured Zn-ferrite shows ferrimagnetic behavior and the magnetization increases with the decrease in grain size though it is antiferromagnatic in the bulk. In Zn-ferrite thin film also, it is possible to get high magnetization and a very low ferromagnetic resonance line width depending on the grain size and their distribution without going through high temperature processing [19,27]. Co-ferrite nanoparticles also show some interesting features like super-paramagnetism [28], increased/decreased saturation magnetization [29,30], low/high coercivity [31,32], and spin glasses [29] depending on the grain size. Song et al [28] observed that Co-ferrite nanocrystals show superparamgnetic behavior at 300 K and ferrimagnetic behavior at 5 K. They have also observed coercivity ($H_C$) of 10.8 kOe at 5 K in 5 nm Co-ferrite nanocrystals. They suggested on the basis of their experimental observations that the superparamagnetic properties can be controlled through magnetic coupling at atomic level in spinel ferrite nanocrystals. Peddis et al. [29] observed an enhanced saturation magnetization of 109 emu/g at 5 K for ultra-small (3 nm) Co-ferrite nanoparticles compared to the bulk value of 90 emu/g at 0 K [33]. Their study showed that localized spin canting and cation distribution in the spinel structure are responsible for such high value of magnetization. However, Lopez et al. [30] observed a reduced saturation magnetization of 27.3 emu/g and $H_C$ of 14.7 kOe at 4.2 K in Co-ferrite nanoparticles of average diameter of 7.2 nm. Toksha et al. [34] studied magnetic properties of Co-ferrite nanoparticles as a function of grain size after annealing. However, the effects of grain size and their distribution as well as the intergranular interactions on the magnetic properties of the Co-ferrite nanoparticles need to be studied thoroughly. In the present study we show that depending on the grain size and their distribution, exchange spring magnetic

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