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Compositional dependence of magnetization reversal mechanism, magnetic interaction and Curie temperature of $Co_{1-x}Sr_xFe_2O_4$ spinel thin film

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ABSTRACT

$Co_{1-x}Sr_xFe_2O_4$, (x varies from 0 to 0.5 in a step of 0.1) nanoparticles were formed by means of sol–gel processing method. The morphological and structural features of nanoparticles were evaluated by Fourier transform infrared spectroscopy, field emission scanning electron microscopy (FE-SEM) equipped by EDS analysis, Mössbauer spectroscopy and vibrating sample magnetometer. It was found that almost narrow size distribution of nanoparticles with cation distribution occupancy preference in octahedral site was synthesized. The nanoparticles were used for addition in subsequent solution for fabricating ferrite thin films with similar mentioned chemical composition. Several techniques including FE-SEM, atomic force microscopy and vibrating sample magnetometer were employed to find the role of strontium cation distribution on the structural and magnetic properties of films. The Curie temperature, coercivity and magnetic interaction which was evaluated by Henkel plot were reduced by an increase in substitution contents. Coercivity of thin films reduced from 0.65 MA/m to 0.39 MA/m and Curie temperature declined from 690 to 455 °C. The value of strength of interaction was enhanced from −0.23 for $x = 0$ to −0.75 for $x = 0.5$. Angular dependence of coercivity proved that the magnetization reversal process was accompanied by the combination of domain wall motion and Stoner–Wohlfarth rotation, however for thin film with $x = 0.2$–0.5, the reversal mechanism obey the Stoner–Wohlfarth rule.

1. Introduction

With the miniaturization and integration of high frequency microelectronic devices, such as thin film inductors, micro-transformers and core materials of writing head, the high frequency spinel ferrite have been the focus of intensive research [1–5]. The most common type is cubic spinel ferrites with formula AB_2O_4 which contains tetrahedral (A site) and octahedral (B site) crystalline sites. The magnetic and electrical properties of ferrite could be easily tuned by incorporation and suitable distribution of additional cations (divalent or trivalent) in the spinel structure. Among all ferrites, cobalt ferrite $CoFe_2O_4$ (CFO), well known hard magnetic material, has a special place due to its unique properties like high Curie temperature, high coercivity, high magneto-crystalline anisotropy, and moderate saturation magnetization, as well as its excellent chemical stability, large Kerr effect and Faraday rotation [4–9]. Beside unique magnetic properties, cobalt ferrite has cubic spinel structure and is widely used in many electronic devices because of high electrical resistivity, hard mechanical properties, and environmental stability [10–12]. Cobalt ferrite could be prepared by several techniques including thermal decomposition method [1], sol–gel [2,3], co-precipitation [4] and hot injection thermolysis methods [5]. In current research, sol–gel technique was employed due to the high homogeneities of final product, low cost of precursor, low sintering temperature and simplicity of the process. Cobalt ferrite is a suitable candidate for practical application such as biomedical in human pancreatic and ovarian cancer cells [6,7], catalyst for oxidation of alkenes [8] adsorbent for the efficient removal of arsenic [9], catalyst for methanol decomposition [10] and even microwave absorption media [11]. The role of several substitutions on the structural features and magnetic consequences of cobalt ferrite was evaluated. Based on the site occupancy of incorporated cations and amount of them, magnetic properties could be encountered by different magnetic states. Typically addition of terbium cation, nickel, various rare earth elements, zinc, copper, manganese and several transition cations were deeply studied and published in previous literatures [11–17]. Dielectric, magnetic relaxation and magnetic anisotropy of cobalt ferrite were also investigated by several researchers [18–20]. The

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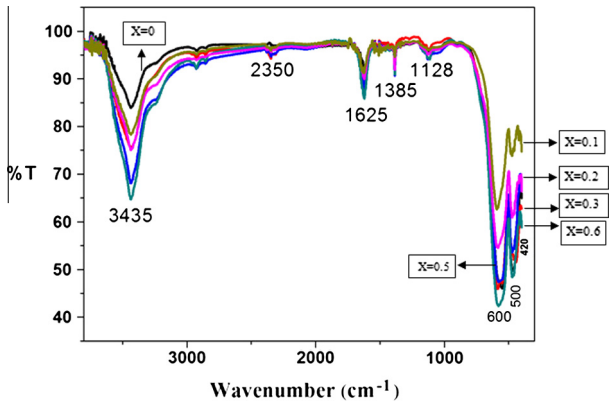

Fig. 1. FTIR spectrums for the whole series of synthesized nanoparticles.

cobalt ferrites in bulk configuration exhibit inverse spinal structure with one half of Fe^{3+} ions in the A sites and the remaining half of Fe^{3+} ions occupying the B sites along with Co^{2+} ions [20].

The sol–gel method has been employed in the preparation of cobalt ferrite thin film. It usually involves dissolving solutions containing iron and cobalt cations in solvents such as an organic acid (e.g. citric acid) in appropriate proportions. The solution is vigorously heated to bring about a chemical reaction and spin-coated or dip coated onto wafers [21,22]. Several effective processing parameters including pH, drying temperature, sintering temperature, viscosity of solution and time of dipping process can affected on the magnetic properties of final fabricated cobalt ferrite thin films. The coated substrates are further heated to a high temperature to remove the organic solvent and to form amorphous thin films of cobalt ferrite. The chosen temperature depends on the type of organic solvent. The amorphous films are then crystallized at higher temperatures. To achieve homogeneity, samples should be annealed at temperature above 450 °C [23].

In current research the strontium substituted cobalt ferrite nanoparticles was synthesized by a sol–gel process. The substitution of strontium in cobalt ferrite, make the materials very suitable for practical application in electromagnetic wave absorption media and angle sensing. Structural features and site occupancy for

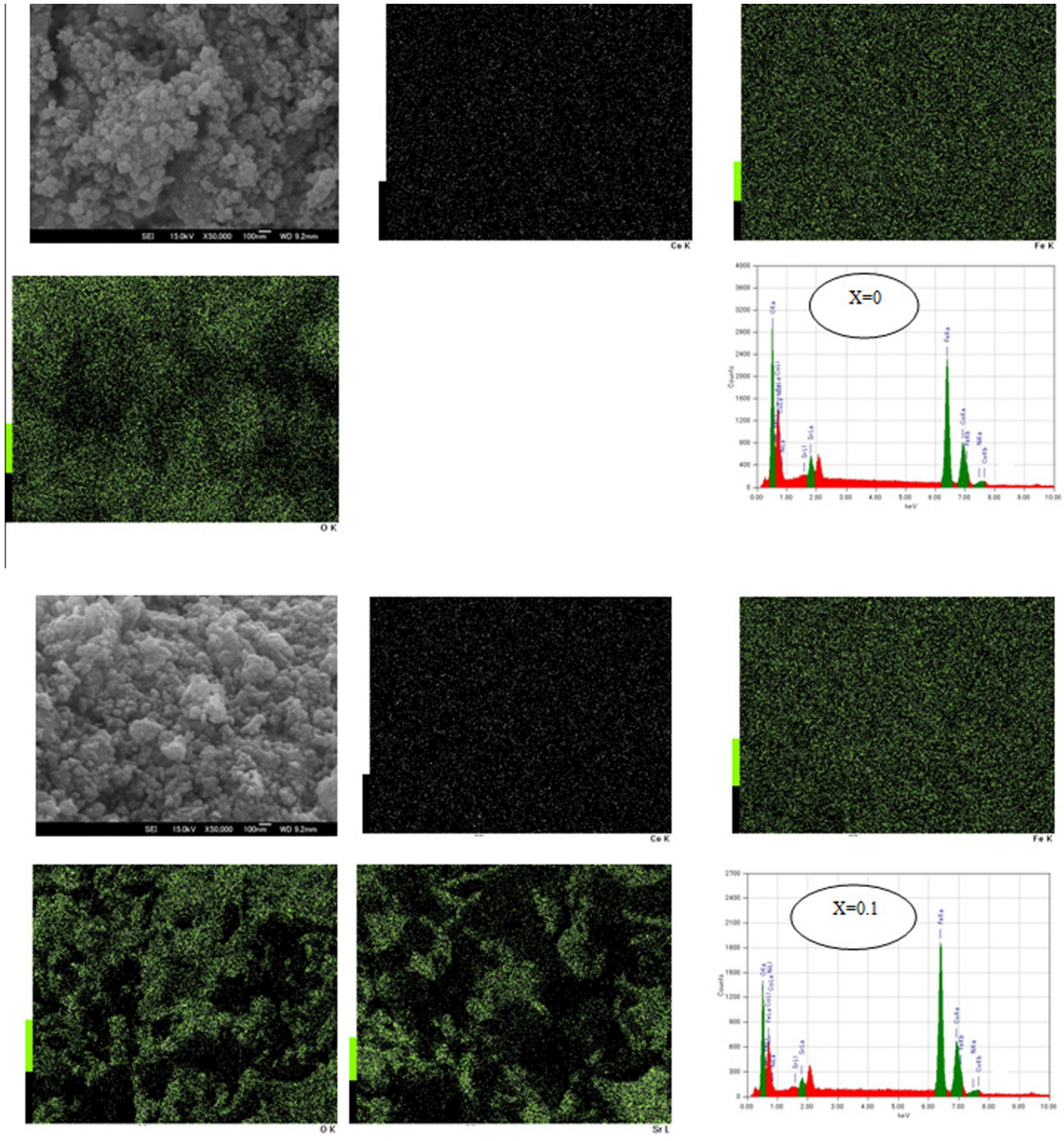

Fig. 2. FE-SEM micrographs coupled with EDS map analysis of ferrite nanoparticles.