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Investigation of structural, thermal and magnetic properties of cadmium substituted cobalt ferrite nanoparticles

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ABSTRACT

Cd substituted Cobalt ferrite nano particles are synthesis using co-precipitation method. The as prepared samples are calcinated at 300 and 600 °C respectively. The existence of single phase spinal cubic structure of the prepared ferrite material is confirmed by the powder XRD measurement. The surface morphology images, compositional features are studied by SEM with EDX, and TEM. From the FT-IR spectra the absorption bands observed at 595 and 402 cm^{-1} are attributed to vibrations of tetrahedral and octahedral complexes respectively. From the VSM data, parameters like magnetization, coercivity, remanent magnetization and remanent squareness are measured. The saturation magnetization value is increases with increasing calcination temperature. The DSC and TG–DTA curves reveal that the thermal stability of the prepared ferrite nanoparticles. The calcination temperature affects the crystallite size, morphology and magnetic properties of the samples.

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1. Introduction

In the recent years, the synthesis of composite magnetic nanoparticles has been received increasing attention due to their properties [1–4]. Spinel structure ferrites are a very significant group of magnetic materials due to their chemical, thermal strengths, cubic magneto crystalline anisotropy [3], moderate saturation magnetization, electrical insulation and wear resistance [5–7]. Ferrite has attracted considerable attention in the field of technological application as well in a wide range of frequencies.

An inverse spinel structure of $CoFe_2O_4$ is one of the most significant ferrite, where oxygen atoms make up an FCC lattice and one half of Fe^{3+} ions occupies the tetrahedral A sites and the other half, together with Co^{2+} ions locate at the octahedral B sites. It is a ferromagnetic material with a Curie temperature (T_C) around 793 K which distinguishes it from other spinel ferrites. Moreover, cobalt ferrite nanoparticles are known to be a photo magnetic material it shows an interesting light-induced coercivity change [8,9] and as active material for lithium ion battery [10,11]. The physical properties of the ferrites depend strongly on the shape and size of the nanoparticles [9,12,13].

To the best of our knowledge, very few research groups were reported on the Cd substituted cobalt ferrite$_4$ materials. In details, Farea et al. studied the electrical properties of cadmium cobalt ferrite and their results implies Cd atoms are plays an important role in enhancement of the dielectric constants ε' and ε'', the loss tangent $\tan\delta$, and the AC conductivity σ_{ac} [14–16]. Narendra et al. reported on cadmium-substituted $CoFe_2O_4$ nanoparticles exhibits the super paramagnetic behavior [17]. Therefore, this observation is attracting to widely focus on these materials. In addition, Gabr et al. investigated the conductance properties and the catalytic decomposition of 2-propanol of CdCoFe materials [18]. Nikumbh et al. reported on cadmium cobalt ferrite with compositional changes of cadmium and cobalt; the magnetic coupling strengthens A–B interactions takes place at dopant concentration above $x \geqslant 0.6$ [19]. The properties of ferrites strongly depend on the chemical composition, the electronic structure of the magnetic ions, preparation conditions, and the crystal structure of the lattice [15,20–22].

In fact, preparation methods of cobalt ferrite nanoparticles are diverse, such as microemulsions [23], a microwave hydrothermal flash method [24] and polymerized complex method [25]. However, these methods have low yield rate and they require a long processing time. In contrast, the chemical synthesis from aqueous solutions is a relatively simple method that is suitable for mass production. Moreover, the preparation parameters such as the concentration, pH, and complexing agent are easily controllable [26].

In the present work, we report the preparation of $Cd_{0.5}Co_{0.5}Fe_2O_4$ nanostructures (in the forms of nanoparticles) by co-precipitation method using a solution that contained NaOH, Oleic acid is used for coated samples. In order to find the temperature effect on structural, morphology, thermal and magnetic properties, the prepared $Co_{0.5}Cd_{0.5}Fe_2O_4$ nanoparticles are analyzed using X-ray diffraction, SEM with EDX, TEM, FT-IR, DSC,TG–DTA and VSM techniques.

2. Experimental procedure

The chemical co-precipitation method is used for the preparation of $Cd_{0.5}Co_{0.5}Fe_2O_4$ nanoparticles. Stoichiometric amounts of aqueous solutions containing $CoCl_2$, $CdCl_2$, and $FeCl_3$ (100 mL of 0.5 M CoCl2, 100 mL of 0.5 M $CdCl_2$, and 100 mL of 2 M $FeCl_3$) are mixed and kept at 60 °C. This mixture is added to a boiling solution of NaOH (0.63 M dissolved in 1200 mL of distilled water). The solutions are maintained at 85 °C for 1 h to adjust the pH to around 12. The pH of the solution is reduced to 10.5 for surfactant coating, for which oleic acid ($C_{18}H_{34}O_2$) is used. The oleic acid is heated with the NaOH solution to convert the oleic acid to sodium oleate. The sodium oleate solution is transfer to a glass beaker and stirred for 3 h. Surfactant coating is carried out at a temperature of about 100 °C for 1 h. Dilute HCl is added to coagulate the oleic-acid-coated particles. After decantation, the product is washed with distilled water to remove soluble impurities. The coated particles were collected after removing the excess water by washing with acetone. The as-prepared samples are then sintered at 300 °C and 600 °C respectively for 1 h hereafter samples named as S1 and S2.

The cadmium cobalt ferrite nano particles are characterized using the Powder X-ray diffraction (XRD) pattern using Cu Kα radiation on PANalytical X'Pert PRO diffractometer. The Microstructural