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Magnetic properties of zinc-substituted cobalt ferric oxide nanoparticles: Correlation with annealing temperature and particle size

S.J. Azhagushanmugam [a,*], N. Suriyanarayanan [b], R. Jayaprakash [c]

[a] Department of Physics, Muthayammal Engineering College, Rasipuram 637408, Tamil Nadu, India
[b] Department of Physics, Government College of Technology, Coimbatore 641013, Tamil Nadu, India
[c] Department of Physics, Nanotechnology Laboratory, Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore 641020, Tamil Nadu, India

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ABSTRACT

Nanocrystalline zinc (Zn)-substituted cobalt ferric oxide ($CoFe_2O_4$) was prepared through chemical co-precipitation; the prepared samples were annealed at 600 °C, 750 °C and 900 °C. The crystallite size, microstructure and magnetic properties of the prepared and annealed samples were studied by using X-ray powder diffraction (XRD), Transmission Electron Microscopy (TEM), Fourier Transform Infrared Spectroscopy (FTIR), Energy Dispersive Spectroscopy (EDS) and Vibrating Sample Magnetometry. The structural investigations carried out by XRD reveal that the particle size and lattice constant of single phase spinal structured Zn substituted $CoFe_2O_4$ increase with the increase of annealing temperature. The FTIR spectra for the samples measured in the range of 4000–400 cm^{-1} exhibit symmetric stretching mode of vibration of tetrahedral and octahedral sites. Furthermore, Zn substituted $CoFe_2O_4$ nanoparticles have the crystallite size in the range ~13–65 nm, as confirmed by TEM. The elemental analysis was obtained from EDS. Finally, increased annealing temperature resulting in increased particle size and the impact on magnetic properties of $CoFe_2O_4$ nanoparticles is a significant finding of this study.

1. Introduction

Spinel ferrites have received a great interest in technologically anchored modern society due to their promising application in electrode materials [1], microwave adsorption [2,3], environmental remediation [4,5] and drug-loading materials [6]. Generally, the physical and chemical properties of magnetic materials show a close relation with their surface morphologies [7]. The methods of synthesizing ferrites with different morphologies had been widely studied [8]. There are several methods for synthesizing nanosized magnetic spinel ferrite particles with different morphologies, such as seed–hydrothermal route [9], sol–gel template approach [10], electrospinning method [11], PEG-assisted hydrothermal route [12], co-precipitation [13], polyol route [14], auto-combustion and evaporation methods [15–18], etc. Among them chemical coprecipitaion method seems to be the most convenient method for the synthesis of nanomagnetic particles with large yield rate. It is very simple and has better control over crystalline size and other properties of the materials. In this paper, the effects of particle with impact of annealing temperature on the structural and magnetic properties of Zn substituted $CoFe_2O_4$ prepared by co-precipitation method have been investigated. The investigation was done by using X-ray powder diffraction (XRD), Transmission Electron Microscopy (TEM), Fourier Transform Infrared Spectroscopy (FTIR), Energy Dispersive Spectroscopy (EDS) and Vibrating Sample Magnetometry (VSM).

* Corresponding author.
E-mail address: azhagushanmugam@yahoo.co.in (S.J. Azhagushanmugam).

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2. Experimental details

2.1. Method of preparation

Ferrite nanoparticles were prepared by chemical coprecipitation route using metal chlorides such as $CoCl_2 \cdot 6H_2O$, $ZnCl_2 \cdot 2H_2O$ and $FeCl_3 \cdot 6H_2O$. Metal chlorides were dissolved in minimum volume of distilled water with constant stirring by a magnetic stirrer, until a clear solution was obtained. The precipitating reagent is prepared in distilled water and NaOH by taking their appropriate weights depending upon the amount of metal chlorides taken for coprecipitation of ferrite precursor. The precipitating reagent is added dropwise into the metal solutions contained in a beaker with constant mixing until co-precipitation occurs. The precipitates were thoroughly washed several times with distilled water to remove salt residues and other impurities. The product was dried in a muffle furnace at a temperature of 100 °C overnight to remove water contents. The resultant dried product is powdered by using an agate mortar and a pestle to have very fine particles. The powder was annealed at 600 °C, 750 °C and 900 °C.

2.2. Equipment used for characterization

The crystallite size was determined from the X-ray diffraction (XRD) data. XRD data were taken at room temperature using CuKα (λ = 1.5406 Å) radiation. TEM micrographs were recorded by using Transmission Electron Microscopy (Philips make CM 200 model) to investigate powder morphology as well as grain size. Energy Dispersive Spectroscopy (EDS) was used to examine the elemental analysis of the samples, using a JEOL 5600LV microscope at an accelerating voltage of 10 kV. Infrared spectroscopic analysis using KBr pellets were carried out in the range of 4000–400 cm^{-1} in a Perkin-Elmer FTIR RXI spectrometer. The magnetic properties of the samples

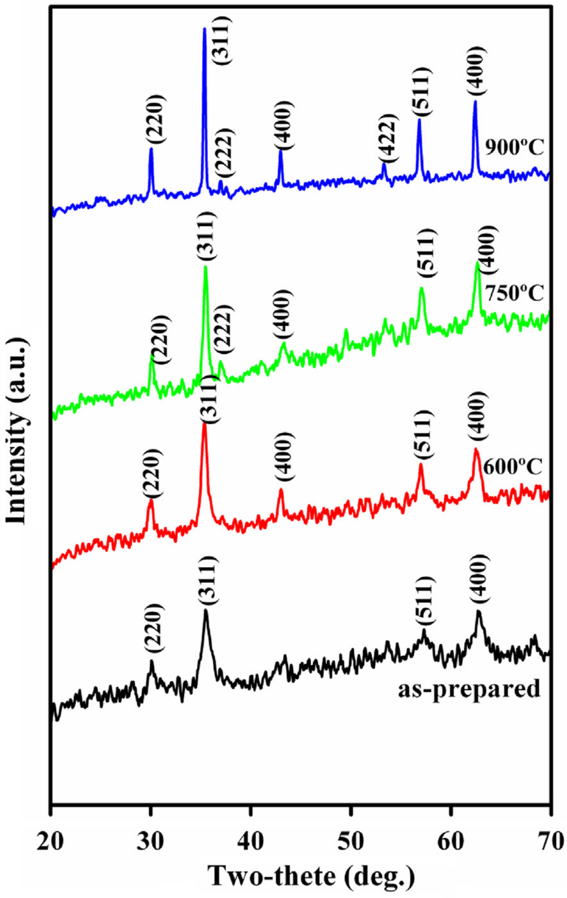

Fig. 1. Indexed XRD pattern of Co–Zn Fe_2O_4 nanoparticles.

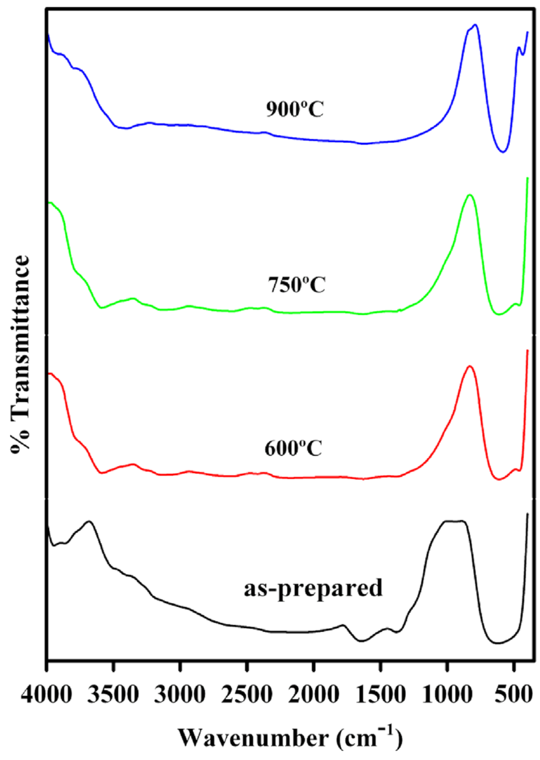

Fig. 2. FT-IR spectrum of Co–Zn Fe_2O_4 nanoparticles.

Table 1

Parameters	Zn substituted $CoFe_2O_4$ ferrite nanoparticles			
	As-prepared	600 °C	750 °C	900 °C
Particle size t (nm)	13.45	15.16	29.40	59.58
Lattice constant a (Å)	8. 380	8.390	8.406	59.58
Saturation magnetization M_s (emu/g)	29.58	41.06	49.168	67.04
Coercivity H_c (G)	369.31	397.35	408.77	529.55