

Structural and magnetic evaluation of substituted $\text{NiZnFe}_2\text{O}_4$ particles synthesized by conventional sol–gel method

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Abstract

The aim of this study is to evaluate the structural and magnetic properties of Ni–Zn doped ferrite with trivalent Al^{3+} and Cr^{3+} cations substitution in $\text{Ni}_{0.6}\text{Zn}_{0.4}\text{Fe}_{2-x}\text{Cr}_{x/2}\text{Al}_{x/2}\text{O}_4$ ($x=0, 0.1, 0.2, 0.3, 0.4$ and 0.5) synthesized by employing conventional sol–gel method. X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, field emission scanning electron microscopy (FE-SEM), Mössbauer spectroscopy (MS) and vibrating sample magnetometer (VSM) analysis were carried out in order to characterize the structural and magnetic properties of particles. The XRD results confirmed the formation of single phase of spinel ferrite particles for a whole series of samples. The results of FTIR analysis indicated that the functional groups of Ni–Zn spinel ferrite were formed during the sol–gel process. Furthermore, FE-SEM micrographs revealed that the distribution of particles size is narrow. According to Mössbauer spectra, the doped cations are replaced in iron site occupancy of octahedral sites. It was found that with an increase in substitution contents magnetization decreased due to occupation of Al and Cr cations at low level substitutions in octahedral sites.

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1. Introduction

In case of magnetic ceramic materials, ferrites are exceptional magnetic materials widely used in microwave and electrical industries. They exhibit high electrical resistivity combined with useful ferromagnetic behavior [1]. There are several different synthesis methods used to fabricate ferrites as reported in literatures including sol–gel [2], coprecipitation [3], hydrothermal [4], mechano-chemical [5], refluxing [6], precursor [7], and auto-combustion [8] methods. The spinel ferrites belong to an important group of magnetic materials, because of their significant magnetic properties particularly in radio frequency region, physical flexibility, high electrical resistivity, mechanical hardness and chemical stability [9]. Among spinel ferrites, Ni–Zn ferrites are one of the most versatile soft magnetic materials. Recently, the synthesis process, characteristics and technological application of these materials have been studied extensively [10] due to their potential applications in many electronic devices owing to their

high permeability at high frequency, remarkably high electrical resistivity, low eddy-current loss and reasonable cost [11–14]. The spinel structure of soft magnetic materials possesses the chemical formula of $(\text{A})[\text{B}_2]\text{O}_4$, where A expresses the cations in tetrahedral sublattice sites and B represents the cations in octahedral positions in a cubic structure. However, in case of spinel ferrites the chemical formula $(\text{A}_{1-i}\text{B}_i)[\text{A}_i\text{B}_{2-i}]\text{O}_4$ represents many possible intermediary cation distributions that denote considerable cation disorder, indicating that spinel structure requires special attention in terms of magnetic characterization [15]. Spinel ferrites crystallize in the face-centered cubic (FCC) structure. The spinel crystal structures are usually categorized by inverse and normal structures. In the normal spinel structure A is a divalent element atom, occupying tetrahedral A sites, while B is a trivalent element sitting on the octahedral B sites. When A is a trivalent element which occupies tetrahedral site and B consists of equal numbers of trivalent and divalent elements, distributed over octahedral sites, the spinel structure is referred to as the inverse kind. The schematic picture of spinel structure is shown in Fig. 1. The Ni–Zn ferrite is a well-known mixed inverse spinel [16] whose unit cell is represented by the formula $(\text{Zn}_x\text{Fe}_{1-x})[\text{Ni}_{1-x}\text{Fe}_{1+x}]\text{O}_4$ [17],

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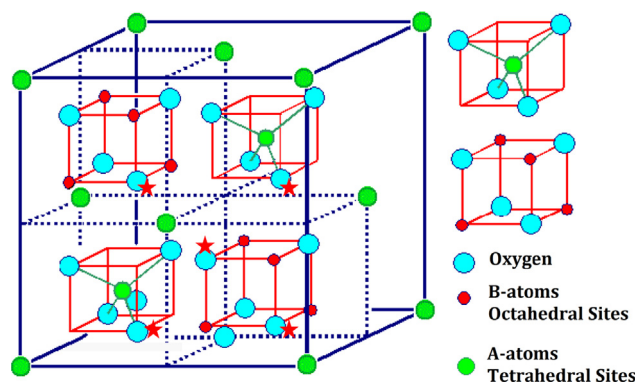


Fig. 1. Schematic picture of spinel structure; star means the intermediary cation sites that denote considerable cation disorder.

whereas the intrinsic magnetization (magnetic moment or total theoretical Bohr magneton of the lattice spinel) results from the inverse and normal phase, i.e., the distribution of cations in the spinel lattice. Based on these facts, the intrinsic magnetization of Ni–Zn ferrite can be calculated with and without the addition of 0.1 mol of chromium ions. Based on Hund's Rules [18], the magnetic moments of Fe^{3+} , Cr^{3+} , Al^{3+} , Ni^{2+} and Zn^{2+} are 5, 3, 0, 2 and $0\mu_B$, respectively. The addition of impurities induces changes in the defect structure and texture of the crystal [19], creating significant modifications in the magnetic and electrical properties of these materials. Several researchers have studied the effects of Cr^{3+} substitution in the spinel structure of ferrites [19–21]. However, the effect of Cr–Al cations simultaneously, has not been studied extensively yet.

In this research, the effect of Cr–Al cations simultaneous substitution was evaluated on the structural and magnetic properties of NiZn ferrite in order to correlate magnetic analysis and reflection loss characteristic in MHz band for near future literatures in the field. With this view in mind, the present paper is intended to clarify the characteristic magnetic properties of this ferrite. For obtaining this goal, the prepared samples were characterized using X-ray diffraction (XRD), Fourier transformed spectroscopy (FTIR), field emission scanning electron microscopy (FE-SEM), Mössbauer spectroscopy (MS), and vibrating sample magnetometer (VSM).

2. Experimental

2.1. Synthesis process

The Cr–Al doped ferrite $\text{Ni}_{0.6}\text{Zn}_{0.4}\text{Fe}_{2-x}\text{Cr}_{x/2}\text{Al}_{x/2}\text{O}_4$ with $x=0, 0.1, 0.2, 0.3, 0.4$, and 0.5 powders was synthesized by use of conventional sol–gel method. Consequently, the stoichiometric amounts of precursors including citric acid ($\text{C}_6\text{H}_8\text{O}_7$), $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Zn}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, and $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ were employed to synthesize the soft magnetic powders. At first, an amount of citric acid was dissolved in distilled water. Citric acid helps in the homogenous distribution and segregation of metal ions. The metal nitrates were added to the solution. The solution was circulated and heated using magnetic stirrer at a temperature of

80 °C. The viscous gel was obtained after evaporation of water from solution and the occurring polymerization reactions during sol–gel process. Consequently, the dried gel was placed in an oven at a temperature of 200 °C. Finally, the powders were calcined at a temperature of 1300 °C for 3 h.

2.2. Measurements

X-ray diffraction measurements (XRD) were performed for phase evaluation of the synthesized samples using a Philips diffractometer (MPD-XPET model) with $\text{Cu } k_\alpha$ radiation operated at 40 kV and 30 mA. FTIR spectroscopy was carried out to evaluate the functional groups which were formed during sol–gel process using a 680PLUS JESCO spectrometer. In order to evaluate the microstructure of the powders, FE-SEM micrographs were taken using a JEOL scanning electron microscope with an accelerating voltage of 15 kV. ^{57}Fe Mössbauer spectroscopic measurements were performed in transmission geometry at 293 K. $^{57}\text{Co}/\text{Rh}$ was used as gamma ray and quantitative investigations were carried out using software. A vibrating sample magnetometer was used to measure the magnetic properties of the calcined ferrite powders at ambient temperature. The magnetic hysteresis loops were measured at room temperature with maximum applied magnetic field of 10 kOe. The magnetic field sweep rate was 5 Oe/s for all measurements.

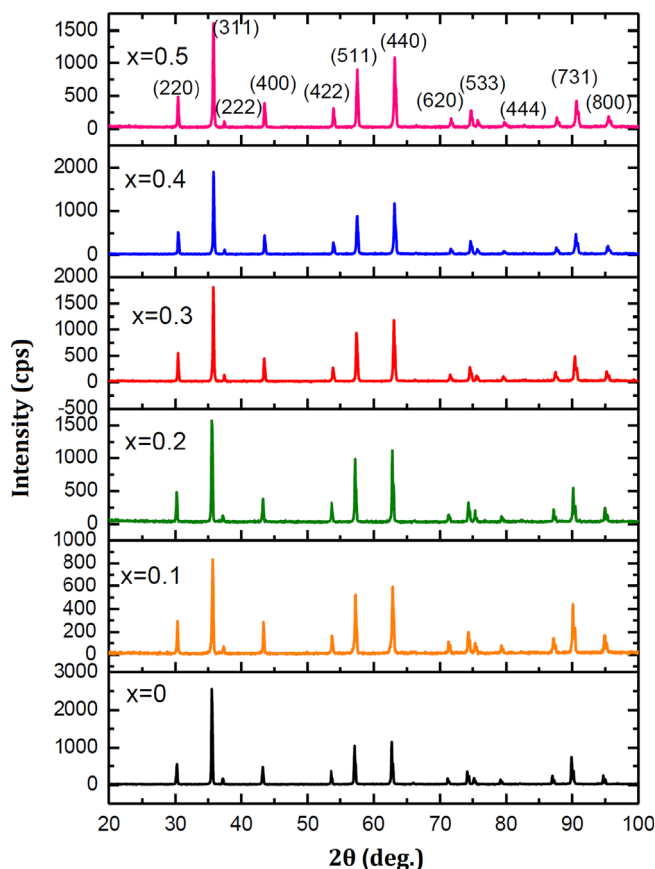


Fig. 2. X-ray diffraction (XRD) patterns of the synthesized powders.

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