



Magnetic Ordering and Enhancement of Magnetization in Zinc-Substituted Copper Ferrite Nanoparticles

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Abstract

$Zn_xCu_{1-x}Fe_2O_4$ ($0.05 \leq x \leq 0.85$) nanoparticles were synthesized by sol-gel method and were annealed at 500 and 900 °C in air for 3 h. Characterization techniques like XRD, Raman spectroscopy, and vibrating sample magnetometer were used to investigate phase, cation distribution, and magnetic properties. XRD studies showed that all the as-prepared samples are of cubic spinel phase. Tetragonal phase was observed in the samples with $x < 0.15$ after annealing, whereas all other samples retained cubic phase. Raman spectroscopy showed increase of Zn^{2+} ions in the tetrahedral site with the increase in Zn^{2+} concentration in the nanoparticle samples. Cation distribution and magnetic ordering enhanced the magnetization value with increasing x value, and a maximum was observed in the as-prepared and annealed samples. The coercivity decreased with the increase in Zn^{2+} concentration. The highest magnetization value of 110 emu/g with coercivity of 25 Oe was observed in the present study at 60 K for the sample annealed at 900 °C with $x = 0.5$. Law of approach to saturation method was adopted to study the magnetic ordering in the nanoparticle samples. The blocking temperature decreased with increase in Zn^{2+} concentration and annealing temperature. Cation distribution associated magnetic ordering and anisotropy variation with the increasing Zn^{2+} concentration explains the observed magnetic behavior in these nanoparticle samples.

Keywords Cu-ferrite · Substitution · XRD · Raman spectroscopy · Cation distribution · Magnetization

1 Introduction

Spinel ferrite nanoparticles have attracted attention in research for their use in different fields of science, technology, biomedical, and environmental applications due to their excellent physical, chemical, electrical, magnetic, and biocompatible properties [1–10]. Due to the reduced size in nanoscale, they show magnetic behavior different from their bulk counterpart [11–14]. Properties of these nanomaterials can be tailored by substitution of diamagnetic or paramagnetic cations and their distribution in the spinel structure, grain sizes and their distribution, and surface morphology.

Magnetic properties of Cu-ferrite ($CuFe_2O_4$) have attracted much interest due to its different magnetic behavior in two different phases. It crystallizes either in tetragonal or in cubic phase. It has inverse spinel structure with 16 Fe^{3+} ions equally distributed among tetrahedral (A) and octahedral (B) sites and all the 8 Cu^{2+} ions in the B site in the unit cell. In bulk, it is stable with tetragonal (T) phase at room temperature and changes to cubic phase (C) around 360 °C [15]. In cubic phase, some Cu^{2+} ions occupy the A site, and a mixed spinel structure is formed. The cation distribution among the interstitial sites affects the super exchange interaction and plays important role in deciding its magnetic properties. The A-B interaction is antiferromagnetic and is the strongest interaction than the ferromagnetic A-A and B-B interactions in Cu-ferrite. The strong antiferromagnetic interaction between A and B sites depends on the strength of individual magnetic moments, the distance between cations, and angle between them via oxygen anions [16]. The cubic Cu-ferrite shows higher magnetization and lower coercivity, whereas tetragonal phase shows lower magnetization and higher coercivity [17]. Zn-ferrite ($ZnFe_2O_4$) is another interesting spinel ferrite which is antiferromagnetic below 10 K [18]. In this case, the A-A and

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