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Structural transformation and magnetic properties of copper ferrite nanoparticles prepared by sol–gel method

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Abstract
Copper ferrite nanoparticles were synthesized by sol–gel method by varying metal nitrate to citric acid (M:C) ratio as 1:1, 1:2, 1:3 and 2:1 and were subsequently annealed at different temperatures ranging from 400 to 900 °C in air for 3 h. These nanoparticle samples were characterized by X-ray diffraction, Fourier transformed infrared spectroscopy, Raman spectroscopy, field emission gun scanning electron microscopy and vibrating sample magnetometer. X-ray diffraction studies showed the as-prepared nanoparticles prepared with M:C ratio 1:1, 1:2, and 2:1 are mostly cubic Cu-ferrite. After annealing phase transformation occurred from cubic to tetragonal Cu-ferrite with increase in c/a ratio. Magnetization value decreased and coercivity increased with the increase in annealing temperature and c/a ratio for the samples prepared with M:C = 1:1 and 1:2. For the samples prepared with M:C = 1:3, the magnetization increased with the increase in annealing temperature whereas for the samples prepared with M:C = 2:1, a minimum was observed in the magnetization values for the sample annealed at 600 °C. The highest magnetization values of 45.6 and 49.5 emu/g at 300 and 60 K, respectively were observed in the present study for the as prepared sample prepared with M:C = 2:1. The highest coercivity of 1530 and 1690 Oe at 300 and 60 K, respectively were observed for the sample prepared with M:C = 1:3 and annealed at 800 °C. The observed magnetic properties can be understood on the basis of phase transformation, increase in tetragonal distortion and c/a ratio, and grain growth in these nanoparticles.

1 Introduction

Copper ferrite ($CuFe_2O_4$) attracted considerable attention in research due to its interesting magnetic, electrical [1], magneto-optical [2], gas sensing [3], electrochemical [4] and catalytic properties [5] with thermal stability [6]. In bulk at room temperature it has inverse spinel structure with 8 Cu^{2+} in the octahedral (B) sites and 16 Fe^{3+} share equally tetrahedral (A) and octahedral sites in the unit cell. The magnetic moments of Fe^{3+} cancel with each other due to the antiparallel alignment of moments in the A and B sites in the spinel structure, and the Cu^{2+} in the B-site contributes to the net magnetization. Presence of Cu^{2+} in the B-site leads to tetragonally distorted spinel structure due to Jahn–Teller distortion and c/a ratio is greater than 1 [7]. Cu-ferrite exists in two phases; tetragonal and cubic with tetragonal phase stable at room temperature. It undergoes transition from tetragonal to cubic phase around 350 °C with some Cu^{2+} migrated to the A-site replacing equal amount of Fe^{3+} to the B-site [8, 9]. Due to this changed cation distribution in the cubic phase; magnetization is enhanced in Cu-ferrite with decrease in c/a ratio. That means the magnetization increases when c/a ratio decreases and vice versa. Cation distribution and crystalline phase of Cu-ferrite can be varied depending on synthesis method. Quenching from high temperature results cubic Cu-ferrite in bulk and nanoparticles at room temperature [1, 3, 10, 11]. Cubic phase in thin film was also stabilized at room temperature by quenching it from high temperature and an enhanced magnetization was also observed [12]. Many research groups have also tried to synthesize cubic Cu-ferrite in nanoparticles by varying synthesis method with different starting materials [1, 3, 5, 10, 13–19]. Sol–gel method is one of the convenient methods to synthesize spinel ferrite nanoparticles [3, 20–22]. In the present work we synthesized Cu-ferrite nanoparticles by sol–gel method and showed that by varying metal nitrate to citric acid (M:C) ratio during synthesis it is possible to get cubic Cu-ferrite even in the as

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