J Mater Sci: Mater Electron (2018) 29:813–822
DOI 10.1007/s10854-017-7976-1

Tailoring magnetic properties of cobalt ferrite nanoparticles by different divalent cation substitution

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Received: 8 August 2017 / Accepted: 3 October 2017 / Published online: 10 October 2017

Abstract Different divalent cation substituted Co-ferrite ($M_XCo_{1-X}Fe_2O_4$, where $M = Mg^{2+}$, Ni^{2+}, Cu^{2+}, Zn^{2+}, with $x = 0.20$ and 0.75) nanoparticles were synthesized by sol–gel method and were annealed at 900 °C in air. After annealing, grain growth was observed for all the samples. With the substitution of Mg^{2+}, Ni^{2+} and Cu^{2+} with $x = 0.20$, the magnetization of the as-prepared and the annealed samples was decreased from that of the Co-ferrite whereas Zn^{2+} substitution enhanced the magnetization. The highest magnetization values of 79.9 and 92.9 emu/g at 300 and 60 K respectively were observed for the Zn^{2+} substituted annealed sample with $x = 0.20$. For higher concentration of $x = 0.75$, the magnetization value was further decreased in all the samples and the lowest magnetization value of 5.1 emu/g was observed in the Zn^{2+} substituted annealed sample with $x = 0.75$ at 300 K. The coercivity was reduced in the samples except for the Cu^{2+} substituted sample. In the Cu^{2+} substituted sample with $x = 0.75$, the highest coercivity of 1.43 kOe at 300 K was observed after annealing. The changed cation distribution in the spinel structure, ionic magnetic moment and anisotropy compared to the Co^{2+} in these nanomaterials can explain the observed magnetic properties.

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1 Introduction

Magnetic properties of the spinel ferrite nanoparticles are modified relevant to their applications by controlling the grain size and their distribution, composition, packing density, cation distribution, substitution and/or coating by a magnetic or a nonmagnetic material [1–9]. These ferrite nanoparticles find applications in different fields like data storage, magneto-optical devices, sensors, catalysis [10–13], biomedical applications like drug delivery, magnetic resonance imaging, biosensors and hyperthermia [14–17]. Co-ferrite ($CoFe_2O_4$) is one of the interesting spinel compounds having high anisotropy, coercivity, magnetostriction and saturation magnetization [5, 18–20]. In bulk Co-ferrite has inverse spinel structure with 8 formula units per unit cell. The 8 Fe^{3+} occupy the tetrahedral (A) site, and 8 Co^{2+} along with the other 8 Fe^{3+} occupy the octahedral (B) sites. The super exchange interactions between the cations in the A- and B-sites control the magnetic properties of these materials. The number of unpaired electrons and size of the cation, and their occupancy in different sites in the spinel structure strongly affects the superexchange interactions [5, 6, 21]. Therefore, the effect of different divalent cation substitution in Co-ferrite nanoparticles, is not only interesting for the basic understanding of their fundamental magnetic properties but also for their different applications. In the present study we have tailored the magnetic properties of Co-ferrite nanoparticles by substituting different divalent cations like Mg^{2+}, Ni^{2+}, Cu^{2+} and Zn^{2+} in place of Co^{2+} in the spinel structure. Different methods are adopted to synthesize spinel ferrite nanoparticles and to control their magnetic properties [2, 22–25]. In this work we have synthesized substituted Co-ferrite nanoparticles by sol–gel method and studied their magnetic properties.