Structural and magnetic characterization of $CoFe_{2-x}RE_xO_4$ (RE=Dy,Yb,Gd) nanoparticles for magnetic hyperthermia applications

Abstract

Cobalt ferrite materials ($CoFe_2O_4$) have attracted a great interest over recent years due to their special properties such as their thermal stability, mechanical hardness, high magnetocrytalline anisotropy constant and large coercive fields in combination with a moderate saturation magnetization. All these features make them candidate materials for use in a wide range of applications from medicine to electronics. Many research groups are investigating the influence of Fe^{3+} substitution by RE cations on $CoFe_2O_4$ magnetic performance in order to synthesize materials with properties suitable to the intended application. Magnetic hyperthermia is an under-investigation application of treating cancer by supplying heat to tumor cells using magnetic nanoparticles (MNPs) and an alternative magnetic field. Magnetic nanoparticles act as heating centers due to the interaction of their magnetic moments with the alternating magnetic field. However, the heating efficiency of the magnetic nanoparticles is influenced by several factors such as their size, structure and stoichiometry which can induce changes to their magnetic parameters and can be fine-tuned in order to obtain MNPs with optimum heating performance. In this work, the effect of the partial substitution of iron cations in cobalt ferrite with rare earth cations such as dysprosium (Dy), ytterbium (Yb) and gadolinium (Gd) on their magnetic performance was studied. Cobalt ferrite nanoparticles doped with rare earth metals with general formula $CoFe_{2-x}RE_xO_4$ (where RE=Yb, Dy, Gd and x= 0.01;0.03; 0.05; 0.1; 0.2; 0.3) were synthesized by Virlan et al. [30]. The nanoparticles were prepared by co-precipitation method while a part of obtained powders were annealed at 1250ºC for 12 hours in air, in order to investigate if the annealing process may lead to greater solubility of rare earth cations in the spinel lattice of these ferrites. In this thesis the structural and magnetic characterization of both the annealed and non-annealed samples is demonstrated, to determine if annealing leads to a better structural relaxation and entrance of the rare earth element into the spinel structure, while maintaining or improving magnetic properties. Heating efficiency is estimated for all samples using an alternating magnetic field (25 mT, 765 kHz), evaluating the effect of annealing on the specific loss power (SLP). Solutions of the samples were taken (10 mg/ml, distilled water) to estimate SLP using calorimetric method. With the purpose of investigating the effect of different field magnitude and frequency on heating efficiency, SLP values were obtained for Dy doped samples, before and after annealing, in two different magnetic field conditions (25 mT- 765 kHz, 70 mT- 375 kHz). SLP was also calculated through magnetometric method for some of the samples and a comparison between the two methods is given along with some likely reasons of energy loss mechanisms. The purpose of these experiments was the investigation of the influence of annealing and doping with RE elements on the properties (structural, magnetic and thermal) of cobalt ferrites. The use of different magnetic fields as well as SLP calculation methods, underline the multiparametric dependence of MNP's' heating efficiency and the need of their properly tuned properties. Proper parameters are also required in order to achieve stability and repeatable SLP results towards the final goal of utilizing magnetic hyperthermia as a safe clinical practice in cancer treatment.