Investigation on substitution of transition metal ion (Nickel) on structural and magnetic properties of rare earth doped cobalt ferrite nanoparticles

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Abstract

Co1−xNixDy0.05Fe1.95O4 and Co1−xNixDy0.1Fe1.9O4 (where x = 0.1, 0.2) polycrystalline samples were prepared by sol gel auto combustion method. The effect of nickel substitution on structural and magnetic properties of Co1−xNixDy0.05Fe1.95O4 and Co1−xNixDy0.1Fe1.9O4 (where x = 0.1, 0.2) ferrite nanoparticles was investigated. Powder X-ray diffraction (XRD) and vibrating sample magnetometer (VSM) were used to study the structural and magnetic properties of these ferrite nanoparticles. XRD pattern shown the formation of cubic inverse spinel structure. VSM study obtained hysteresis curve at room temperature shows ferromagnetic behavior of the sample. It was observed that due to substitution of nickel in rare earth (Dy) doped cobalt ferrite structural and magnetic properties of nanoparticles varied. Saturation magnetization (Ms), retentivity (Mr) and coercivity (Hc) increases with increase in nickel content.

Key words: Anisotropy, Coercivity, Retentivity, Spinel, Saturation magnetization.

Introduction

Cobalt ferrite (CoFe2O4), Nickel ferrite (NiFe2O4) and Ferric oxide (Fe2O3) showing inverse spinel structure with general formula B(AB)O4 having two sites tetrahedral and octahedral. Half of the B3+ ions occupy tetrahedral site and remaining half of B3+ and A2+ ions occupy octahedral site [1]. In cobalt ferrite Fe3+ ion presence in tetrahedral site while Co2+ and remaining Fe3+ ions presence in octahedral site. Properties of spinel ferrite depends on kind of cations present as well as their distribution in lattice sites [2]. Inversion parameter δ decides the structure whether it is normal spinel ferrite, inverse spinel ferrite or mixed spinel ferrite. In normal spinel ferrite δ = 0 all the divalent cations presence in tetrahedral site. In case of inverse spinel ferrite δ = 1 all the divalent cations occupied in octahedral site. In mixed ferrite 0<δ<1 divalent ions presence in both tetrahedral and octahedral sites [3,4].

Cobalt ferrite is most of the important material because of its moderate saturation magnetisation (Mσ), high coercivity (Hc), low eddy current loss and chemical stability. There are wide range of applications of cobalt ferrite used in magnetic storage devices, transformer core, In filters, magnetic sensor etc. [5,6]. Cobalt ferrite have high anisotropy constant (K1). For bulk cobalt ferrite which is in the range of 2.1-3.9×106 ergs/cm³ and for Nano materials is in the order of 6.5×106 ergs/cm³ which is increases with decrease in temperature [7,8].
Experimental

Co$_{1-x}$Ni$_x$Dy$_{0.05}$Fe$_{1.95}$O$_4$ and Co$_{1-x}$Ni$_x$Dy$_{0.1}$Fe$_{1.9}$O$_4$ (where $x=0.1, 0.2$) polycrystalline samples were prepared by the sol-gel auto-combustion method [9] using stoichiometric proportions of 99.9% pure AR grade ferric nitrate (Fe(NO$_3$)$_3$·9H$_2$O), cobalt nitrate (Co(NO$_3$)$_2$·6H$_2$O), nickel nitrate (Ni(NO$_3$)$_2$·6H$_2$O) and dysprosium nitrate Dy(NO$_3$)$_3$·xH$_2$O]. Citric acid (C$_6$H$_8$O$_7$) was used as an ignition agent. Citrate-Nitrate ratio was 1:1 maintained throughout the experiment. To maintain particle size reaction was performed in a constant pH=7 environment. Reaction was performed by using a magnetic stirrer with a heater. The synthesized sample by the sol-gel auto-combustion method sintering at 700°C temperature to obtain pure phase.

Result and Discussion

Structural Analysis

The x-ray diffraction (XRD) patterns of synthesized power (12,13) are shown in Figure 1. Given below.

![Figure 1. Intensity against 2Theta](image_url)

Figure 1. shown diffracted patterns of perfect crystals. XRD patterns obtained indicate pure inverse spinel structure. By using Scherer formula crystallite size $= \frac{0.9 \lambda}{\beta \cos \theta}$, where $\lambda = 0.15406$ nm (wavelength for Cu K-alpha), $\beta =$ Full width at half maxima, $\theta =$ Diffracted Angle corresponding to maximum intensity. From Scherer formula crystallite size obtained was 12-14 nm. The crystallite size maintained at nanometre scale because we had pH = 7 throughout the reaction.
Magnetic Analysis

Figure 2. given below shown hysteresis curves of synthesized power obtained by using Vibrating sample magnetometer (VSM) (12,13).

Table given below shown Retentivity ($M_r$), Saturation magnetisation ($M_s$) and Coercive field ($H_c$) for $\text{Co}_{1-x}\text{Ni}_x\text{Dy}_{0.05}\text{Fe}_{1.95}\text{O}_4$ and $\text{Co}_{1-x}\text{Ni}_x\text{Dy}_{0.1}\text{Fe}_{1.9}\text{O}_4$ (where $x = 0.1, 0.2$) polycrystalline powders.

<table>
<thead>
<tr>
<th>Dy</th>
<th>Ni</th>
<th>$M_r$ (emu/g)</th>
<th>$M_s$ (emu/g)</th>
<th>$H_c$ (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.1</td>
<td>19.26</td>
<td>47.63</td>
<td>951.01</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>21.76</td>
<td>48.81</td>
<td>967.80</td>
</tr>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>15.04</td>
<td>42.23</td>
<td>795.25</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>18.23</td>
<td>44.74</td>
<td>894.96</td>
</tr>
</tbody>
</table>

From table Retentivity ($M_r$), Saturation magnetisation ($M_s$) and Coercive field ($H_c$) increases in rare earth (Dy) doped cobalt ferrite with increase in nickel content. The $M_r$, $M_s$ and $H_c$ increase with increase in nickel content because of super paramagnetic characteristics of nickel. Due this characteristics nanoparticles need to overcome the thermal behaviour to align themselves with the direction of magnetic field [10,11].

Conclusion

$\text{Co}_{1-x}\text{Ni}_x\text{Dy}_{0.05}\text{Fe}_{1.95}\text{O}_4$ and $\text{Co}_{1-x}\text{Ni}_x\text{Dy}_{0.1}\text{Fe}_{1.9}\text{O}_4$ (where $x = 0.1, 0.2$) nanoparticles were synthesized by sol gel auto combustion method obtained pure phase at low sintering temperature $700^\circ\text{C}$. XRD patterns obtained reveals pure inverse spinel structure. By Scherer formula crystallite size obtained was $12-14$ nm for given ferrite powers. Particle size maintained at Nanometre scale due to reaction perform in $pH = 7$ controlled environments. Due to nickel substitution in rare earth (Dy) doped cobalt ferrite $M_r$, $M_s$ and $H_c$ values increases with increase in nickel content because of superparamagnetic behaviour of nickel nanoparticles.
References