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Structural, morphological, electrical and magnetic properties of Dy doped Ni–Co substitutional spinel ferrite

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ABSTRACT

Dysprosium doped $Ni_{0.8}Co_{0.2}Fe_{2-x}Dy_xO_4$ ferrite is prepared by simple ceramic method with x varied from 0 to 0.1 in step of 0.025. The influence of Dy doping on structural, morphological, electrical and magnetic properties were studied. The formation of ferrite phase was confirmed by X-ray diffraction, which is a characteristic of the spinel ferrite. Increase in average crystallite and grain size has been observed with increase in Dy doping. Prepared samples show the usual dielectric dispersion having Maxwell–Wagner-type interfacial polarization. Reduction in dielectric constant, loss tangent and ac conductivity has been observed with frequency. Room temperature complex impedance analysis shows semicircles attributed to the high resistance values at lower frequencies. Magnetic properties have been studied by measuring M–H plots.

1. Introduction

Ferrites play an important role in modern industrial society. They are used in advanced electronics because of their multifunctional features and potential applications in transducers, actuators, sensors, microwave and computer technology etc [1,2]. Modifying the chemical composition of the spinel ferrite nanoparticles one can possibly control the magnetic properties. The ions of lanthanide series {Ln=Ce, Sm, Eu, Gd, Dy, or Er} possess a variety of magnetic properties [3]. The magnetic moment among lanthanide ions can vary from 0 (diamagnetic ion such as La^{3+}) to 10.5 μ_B (Dy^{3+} ion) [4]. Moreover, lanthanide ions can be isotropic or anisotropic due to the great variation in the ‘ f ’ electron orbital contribution to magnetic interactions. The magnetic anisotropy is a key parameter that controls the magnetic transition temperature between superparamagnetic and ferromagnetic phases in nanoparticles [5].

To achieve the desired electric, dielectric and magnetic properties nickel ferrite is substituted by different divalent metal ions (Co^{2+}, Cu^{2+}, Mn^{2+} etc.) Ni–Co ferrite is highly resistive and magnetostrictive [6]. Incorporation of various substitutions and different molar ratios in Ni–Co ferrite was studied [7,8]. Partial substitution of Fe^{3+} by Tb^{3+} and Dy^{3+} in the cobalt ferrite has been reported to cause an increase in the coercive field to about 2 kOe [9], due to the contribution of single ion anisotropy from the rare earth sublattice. Substitution of rare earth ion into the spinel structure shows structural distortion [9–11] inducing strain in the sample with significant change in the electrical and magnetic properties. The structural, dielectric and transport properties of rare earth doped Ni ferrite were reported by Dwevedi et al. [12].

The elements of lanthanide series have different magnetic properties. Therefore, it is of great interest to investigate the effect of rare earth element substitution in Ni–Co substitutional ferrite. Due to the large diversity in lanthanide elements, we have chosen a representative subset of Dy, to illustrate significant effect on the magnetostrictive properties of substituted Ni–Co ferrites. In the present work the structural, morphological, electrical, dielectrical and magnetic properties of Dy doped Ni–Co ferrite system have been investigated.

2. Experimental

The $Ni_{0.8}Co_{0.2}Fe_{2-x}Dy_xO_4$ (where, x=0.0, 0.025, 0.05, 0.075 and 0.1) ferrites of stoichiometric composition were prepared using Nickel carbonate ($Ni_4CO_3(OH)_6.(H_2O)_4$), Ferric oxide (Fe_2O_3), Dysprosium oxide (Dy_2O_3) and Cobalt carbonate ($Co_2(CO_3)_3$) as starting materials. All the starting materials were milled for 2–3 h in agate mortar. Then milled mixtures were presintered at 1000 °C for 5 h to decompose carbonates and higher oxides. Resulting powder were again milled for 2 h and pelletized using

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polyvinyl alcohol as a binder and hydraulic press by applying pressure of 5 tones for 15 min. These pellets were sintered at 1100 °C for 11 h to reduce porosity and increase density. Finally, silver paint was employed on both sides of pellet to obtain good ohmic contact.

Thermo gravimetric analysis (TGA) of as prepared powder was carried for determination of decomposition temperature using TA Instruments model SDT Q600. The powders were characterized by X-ray diffractometer (Philips, Model PW-3710) using CuK$_\alpha$ radiation (λ=1.5406 Å) for structural properties. The surface morphology was observed using a JEOL JSM- 6360 scanning electron microscope (SEM). The frequency dependent dielectric permittivity (ε'), dissipation factor ($\tan\delta$) and impedance in the range from 20 Hz to 1 MHz were studied using a precision LCR meter bridge (HP 4284 A). The dc resistivity with respect to temperature was measured using Keithly electrometer (6514). The hysteresis loops were obtained by using high field hysteresis loop tracer (Magneta B–H loops tracer).

3. Results and discussion

3.1. Thermogravimetric analysis

Fig. 1 shows the typical TGA curve of $Ni_{0.8}Co_{0.2}Fe_2O_4$ ferrite system. Total weight loss of about 25% occurs below 350 °C which can be ascribed to the decomposition of higher oxides and carbonates. It can be inferred that the fine particles of complex ferrite can be obtained up to 600 °C. After 600 °C negligible weight loss up to 800 °C is observed. No weight loss occurs above 800 °C which confirms formation of stable phase of $Ni_{0.8}Co_{0.2}Fe_2O_4$ ferrite. Accordingly, prepared samples are pre-sintered at 1000 °C for 5 h in ambient atmosphere.

3.2. X-ray diffraction

X-ray diffraction patterns of $Ni_{0.8}Co_{0.2}Fe_{2-x}Dy_xO_4$ ferrite system are shown in Fig. 2. The patterns correspond well-defined crystalline FCC phase and confirm the spinel structure. The peaks are indexed by using JCPDS data card No. 80-0072. The intensity of (311) peak decreases with increase in Dy content. The crystallite size is estimated by using the Scherrer's formula [13],

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

where D is the crystallite size, λ the wavelength of x-ray (1.5406 Å), β the full-width at half-maximum, and θ the angle of diffraction. The average crystallite size (Table 1) increases with Dy content.

The x- ray density of the samples is calculated by relation,

$$\rho_x = \frac{8M}{Na^3} \quad (2)$$

where M is the molecular weight of the sample, N the Avogadro's number and a^3 the volume of the cubic unit cell. The measured density is calculated by using relation,

$$\rho_m = \frac{M}{V} = \frac{M}{\pi r^2 t} \quad (3)$$

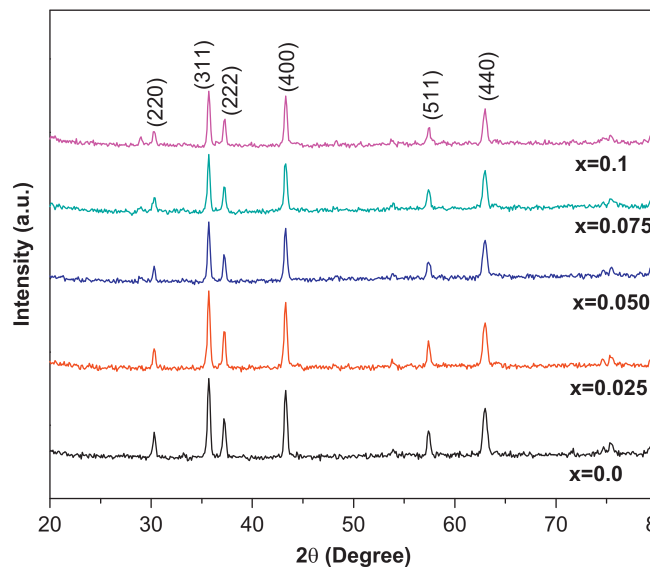

Fig. 2. X-ray diffraction patterns of $Ni_{0.8}Co_{0.2}Fe_{2-x}Dy_xO_4$ ferrite.

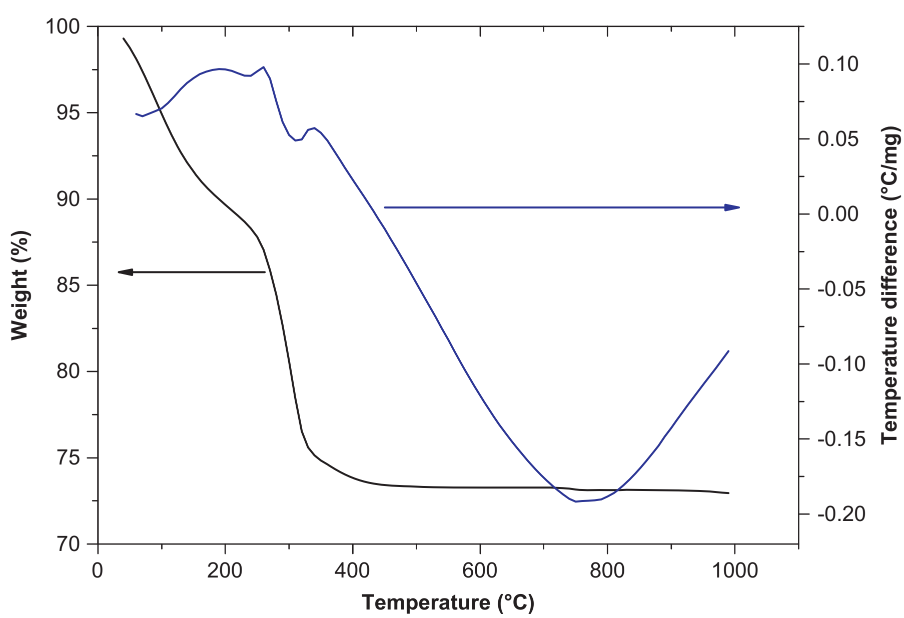

Fig. 1. TGA-DTA thermogram of $Ni_{0.8}Co_{0.2}Fe_{2-x}Dy_xO_4$ ferrite.