Tailoring the Co substitution effect on Magnetic permeability of Ni-Zn Ferrites

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Abstract

The studies describe the influence of Cobalt inclusion on the magnetic properties of Ni-Zn ferrites. The composition with desired stoichiometry were prepared by combustion method and simultaneously sintered at 1000°C for 10hrs. The structural lattice parameter increases from 8.3849 to 8.4028Å by virtue of higher ionic radii of Co ions than Ni ions. The permeability values decrease with the increase in Co substitution and can be assigned to microstructure and increased magnetocrystalline anisotropy. Also, the saturation magnetization increases due to higher magnetic moment of Co ions than Ni ions with enhancement in hysteresis loop. The Curie temperature decreases with increase in Co content and can be attributed to weakening of A-B interaction also evident from increased lattice parameter.

Introduction

With the growing interest of magnetic materials in electromagnetic devices, it has become necessary to enhance as well as stabilize the magnetic properties of ferrites. In most of the cases, the resonance frequency of the material should be tuned to the higher frequencies. Ni-Zn ferrites are known electromagnetic material, but the limitation lies in the lower resonance frequency [1]. As cobalt is known to enhance the resonance frequency [2], the effect of Co substitution in tuning the resonance frequency and stabilizing the magnetic properties of Ni-Zn ferrites are taken under present studies.

Experimental

Co$_{0.6-x}$Ni$_x$Zn$_{0.4}$Fe$_2$O$_4$ (x=0.0, 0.3 and 0.6) were prepared by combustion method using malic acid dihydrazide. All the composition were pre-sintered at 800°C and finally sintered at 1000°C for 10hrs. The X-ray diffraction studies were carried out on all the samples for phase purity and structural analysis. The magnetization studies as a function of field were carried out on sintered powder samples and permeability studies on toroid samples. The AC susceptibility studies along with permeability studies were carried to measure the Curie temperature.

Results and discussion

Fig.1 shows the XRD patterns of all the composition, confirming monophasic nature without any impurity peaks. Also, the change in lattice parameter which increases with increase in cobalt concentration is depicted in figure and can be considered due to higher ionic radii of Co ions than Ni ions. The X-ray density also found to be decreases with increase in Co concentration.

Figure 1.XRD patterns of sintered Co$_{0.6-x}$Ni$_x$Zn$_{0.4}$Fe$_2$O$_4$ (x=0.0, 0.3 and 0.6) and Compositional variation of lattice parameter

The magnetization studies as a function of applied field at RT and 50K was depicted in Fig.2a and b. The magnetization values increase with increase in Co concentration as the magnetic moment of Co is higher than Ni ions. The saturation magnetisation(Ms) values obtained at RT were found increases from 77emu/g to 80 to 85emu/g with Co substitution and all the samples were magnetically saturated at 1Tesla with coercivity (Hc) values resembling to that of ferrimagnetic behaviour (Fig.2a). Similarly, at 50K (Fig.2b), comparatively higher values were obtained for saturation magnetization i.e., in the range of 118 to 142emu/g and the samples were saturated at around 2Tesla showing hysteresis behavior. The hysteresis behaviour of all the samples points to the fact that samples consist of domain walls with larger grains and magnetization – demagnetization occurs by
domain wall motion[3]. Moreover, the anisotropic effect becomes more predominating at lower temperature and higher concentration of Co ions.

The complex permeability studies carried out as a function of frequency are depicted in Fig.3. It is observed that the real part of permeability ($\mu'$) tend to decrease slowly up to 1MHz and start increasing above 1MHz to attain the maximum permeability corresponding to resonance frequency. Usually, at lower frequency the initial permeability in ferrite is assigned to domain wall displacement and the decrease in permeability at lower frequencies is due to phase lag between the applied field and domain wall displacement [4]. The imaginary part ($\mu''$) and loss factor in Fig.3b shows values close to zero in the high frequency region (100KHz to 10MHz) pertaining to stability of the compositions at in this region.

As a function of Co substitution, the initial permeability decreases with increase in Co ions. This is attributed higher domain wall energy and lower density of highly Co substituted Ni-Zn ferrite [5].

In order to study the thermal variation of initial permeability ($\mu'$), the permeability was plotted as a function of temperature and shown in Fig.4a. It is observed that all the composition shows slow increase in permeability with temperature and sharp fall to zero at characteristics temperature, near $T_c$. At $T_c$, the demagnetization predominates with the negligible permeability value. The slow increase and sharp fall of $T_c$ also indicates the good homogeneity and single phase formation, and thus support the XRD studies.

The AC susceptibility studies were also carried out to compare the behaviour and Curie temperature. The normalized AC susceptibility curves are shown in Fig.4b. The plot indicates multimdomain particles with Hopkinson peak and sharp fall to Curie temperature. The change in Curie temperature is concordant with the permeability studies values. It is observed that inclusion of Co ions leads to redistribution of cations among tetrahedral and octahedral sites. This results in decrease of A-B interaction and hence decreases in Curie temperature. Moreover, effects originating of grain size, microstructure and anisotropy energy results in variation of magnetic properties of the studied compositions.

**Conclusion**

Studies conclude the formation of single phase bulk ferrites throughout the substitution without any impurity. The magnetization values tend to increase with increase in Co substitution. The permeability studies shows, with increase in Co substitution, the domain wall energy increases and leads to decrease in initial permeability. The Curie temperature also decreases with increase in a cobalt substitution. Hence, although magnetization values increases with Co substitution, negligible change in resonance frequency with decrease in permeability and Curie temperature restricts the application of such highly Co substituted system in lower frequency region.
References