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Effect of composition on initial permeability of $Ni_{1-x}Zn_xFe_2O_4$ prepared by flash combustion technique

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Abstract

The effect of composition on initial permeability (μ_i) and relative loss factor ($\tan\delta/\mu_i$) as the function of frequency and temperature is studied for $Ni_{1-x}Zn_xFe_2O_4$ ($x = 0.2$, 0.3, 0.4 and 0.5) prepared by flash combustion technique. The ferrite powder prepared by this technique was calcined at 900 °C. The uni-axially pressed samples were sintered at temperatures of 1150, 1250 and 1350 °C. The experimental results indicate that the initial permeability of Ni–Zn ferrites increases with increasing zinc content when measured as the function of frequency at constant room temperature. The dependence of initial permeability with respect to temperature shows the decrease in the Curie point with increase in zinc content, is the normal behaviour of ferrites. The low value of relative loss factor of the order of 10^{-2} to 10^{-4} in the frequency range from 10 kHz to 13 MHz indicates that the ferrites are relatively high purity. The microstructural features were also studied and reported. The Zn ion concentration greatly influences the initial permeability as well as relative loss factor.

Keywords: Ni–Zn ferrites; Flash combustion synthesis; Effect of composition; Initial permeability; Relative loss factor; Microstructure

1. Introduction

Polycrystalline Ni–Zn ferrites are soft magnetic materials having excellent electronic ceramic properties, which cannot be replaced by any other material because Ni–Zn ferrites are more stable, easily manufactured, inexpensive and have wide field of technological applications [1,2]. The magnetic properties of ferrites are highly dependent on chemical composition, crystal structure, grain size and porosity. Ferrites are commonly produced by the conventional ceramic method, which is not convenient to get fine particle ferrites. The wet chemical methods of preparation of ferrites offer a better alternate to overcome the drawbacks of the conventional ceramic method. These methods yield metastable products and have better control of stoichiometry, structure and phase purity [3,4]. Flash combustion technique is a modified technique reported earlier for the preparation of multi-component oxidic systems and ceramic composites [5]. Many researchers have studied the initial permeability of Ni–Zn ferrites prepared by conventional ceramic method in view of their many applications. In the present work, the authors aimed to study the effect of composition on initial permeability and relative loss factor as the function of frequency and temperature for $Ni_{1-x}Zn_xFe_2O_4$ system prepared by flash combustion technique.

2. Experimental

A series of $Ni_{1-x}Zn_xFe_2O_4$ ($x = 0.2$, 0.3, 0.4 and 0.5) powders were prepared by using flash combustion technique. The experimental details are discussed elsewhere [5,6]. The Ni–Zn ferrites precursor powders prepared by this technique were pure, chemically homogeneous and highly reactive because of the atomic level of mixing of the starting materials. The ferrites precursor powders were calcined at 900 °C and then made into cylindrical discs and toroids using uni-axial press. Poly vinyl

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alcohol (2 wt%) was used as a binder for compaction. The compacted samples were sintered at three different temperatures of 1150, 1250 and 1350 °C, for a period 3 h at a heating rate of 180 °C/h and were subsequently furnace cooled. The calcined ferrite powders were subjected to XRD analyses using Model XD-D1, Shimadzu Corporation Japan, with Cu Kα to confirm the single-phase spinel structure. The initial permeability (μ_i) and relative loss factor ($\tan \delta/\mu_i$) were calculated for sintered toroids from the inductance (L) measurements using Hewlett Packard 4192-A Impedance Analyzer in the frequency range from 1 kHz to 13 MHz (at constant room temperature) and temperature from room temperature to Curie point (at constant frequency, 10 kHz). The microstructures of the fractured surfaces of the sintered ferrite samples were recorded using Leica Stereo Scan 440 Scanning Electron Microscope (SEM). The initial permeability was calculated using the relation [3]:

$$\mu_i = \frac{(L l_e)}{n^2 \mu_0 A_e}$$

where n is the number of turns of windings; l_e and A_e are magnetic path length and cross-section of toroids, respectively.

3. Results and discussion

3.1. Initial permeability with respect to frequency

The X-ray diffraction pattern on $Ni_{1-x}Zn_xFe_2O_4$ ($x = 0.2$, 0.3, 0.4 and 0.5) prepared by flash combustion technique and calcined at 900 °C confirms the formation of cubic spinel structure and is shown in Fig. 1. The initial permeability is an important magnetic property to study the quality of soft ferrites. Initial permeability would be due to the contribution from spin rotation and from the domain-wall motion. But the contribution from spin rotation is found to be smaller than domain-wall motion [7,8]. It is mainly due to reversible motion of domain walls in the presence of weak magnetic field, and the contribution of spin rotation is negligible small [8,9]. The variation of the real part μ_i' and imaginary part of μ_i'' of initial permeability as the function of frequency in the range from 1 kHz to 13 MHz and temperature from room temperature to Curie point are studied for $Ni_{1-x}Zn_xFe_2O_4$ ($x = 0.2$, 0.3, 0.4 and 0.5) sample prepared by flash combustion technique and sintered at three different temperatures of 1150, 1250 and 1350 °C for a period 3 h. The real part of the complex initial permeability, henceforth referred to as initial permeability, which corresponds to very low applied fields can be explained by the reversible displacement of domain walls [10,11]. The walls normally remain pinned to the grain boundary and bulge when subjected to small magnetic fields [12].

The intrinsic factors such as magnetization and magnetic anisotropy influence the compositional dependence of initial permeability [13]. Magnetization increases when the number of domain walls increases which increases with grain size. It is observed that for all compositions the initial permeability is independent of frequency from 1 kHz to 13 MHz (at constant room temperature) and dependent on sintering temperature as shown in Fig. 2(i–iv). The increase in the sintering temperature

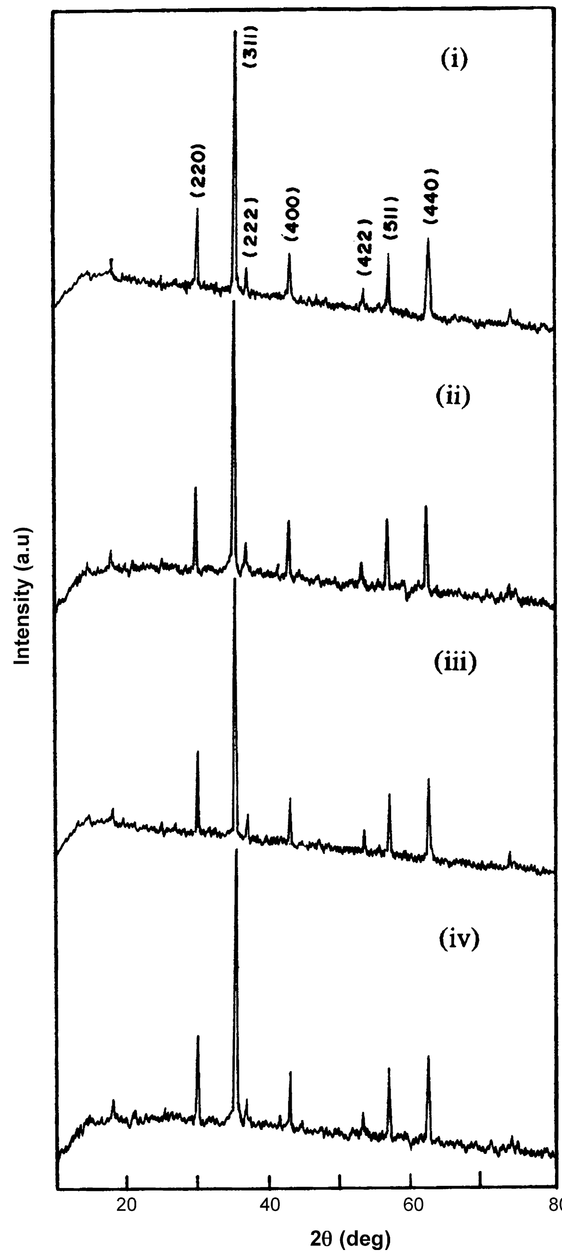

Fig. 1. XRD pattern of $Ni_{1-x}Zn_xFe_2O_4$ prepared by flash combustion and calcined at 900 °C: (i) $Ni_{0.5}Zn_{0.5}Fe_2O_4$, (ii) $Ni_{0.6}Zn_{0.4}Fe_2O_4$, (iii) $Ni_{0.7}Zn_{0.3}Fe_2O_4$ and (iv) $Ni_{0.8}Zn_{0.2}Fe_2O_4$.

results in higher grain size and density. These cause a decrease in the magnetic anisotropy by decreasing the internal stress and crystal anisotropy which reduces the hindrance to the movement of the domain walls resulting thereby in the increased value of the initial permeability [14]. Generally, domain-wall motion and domain rotation contribute to initial permeability. The contribution to the latter is negligible in polycrystalline specimens except when the grain size is so small that only a monodomain state exists and domain walls do not exist. The initial permeability contributed by domain-wall motion is expressed as [12]:

$$\mu_i^w = 1 + \left(\frac{3}{16}\right) M_s^2 \frac{D}{\gamma_w}$$