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Zinc Composition and its Effect on Magnetic Properties of Nickel-Zinc Ferrite Prepared Via Sol-gel Technique

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Abstract: Nickel-Zinc (Ni-Zn) ferrite ($Ni_{1-x}Zn_xFe_2O_4$) with different Zinc composition (x = 0, 0.25, 0.50, 0.75 and 1.0) were prepared and synthesized by applying sol-gel technique and the morphological characterization is done by X-Ray Diffraction (XRD) and Field Emission Scanning Electron Microscope (FESEM) to confirm the formation of Ni-Zn ferrite nanoparticle and estimate the particle sizes. Magnetic study was also performed using Vibrating Sample Magnetometer (VSM). Results showed that Zn composition when x = 0.5 possesses the highest magnetization which is 52.6 emu/g.

Keywords: Sol-Gel, Nanoparticles, Magnetization

Introduction

Rapid growth in nanotechnology has forced the Research and Development (R&D) to pay more attention on it as it provide alternatives to solve current problems in the industry. The range of nanotechnology which is 1-100 nm and very close to dimension of molecules has changed many viewpoints in science and provide another pathway to solve old problems of previous technologies (Yavarina *et al*., 2013). It has endless potential to contribute to the human society.

Researchers had tried many methods in order to change or minimize the NPs sizes. One of the method is to change the heating rate from 2 to 4°C per hour of a furnace (KSL 1600× MTI) in air (Hong *et al*., 2008). On the other hand, Patil and team used surfactant-assisted method to yield homogeneous sol-gel films (Patil *et al*., 2011). The films were crack-free and contained only anatase phase. The grain size of the films was small with increased BET surface area.

Improved sol-gel method has proved to be an alternative to prepare highly concentrated Ni-Zn ferrite (Chatterjee *et al*., 1993). The sol concentration can be achieved by using water as a modifier while increased the temperature and stirring velocity at the same time. This speeded up the particle formation (Chiang *et al*., 2013). Higher temperature assists the nucleation process and it is not affected by stirring velocity and can be used to alter the NP sizes. Average size of the NPs greatly depends on capping, temperature, stirring velocity and concentration of reactant (Chiang *et al*., 2013). It has shown that increase in temperature, reactant concentration and stirring velocity will result in increase of NP size.

In this study, we prepared the Ni-Zn ferrite NPs by using sol-gel technique by changing the Zn composition. The influence of the Zn content on the magnetization was investigated by using VSM. Based on the magnetization measurements we can optimize the Zn composition to achieve maximum magnetization.

Methodology

The Ni-Zn ferrite NPs were synthesized by using sol-gel method. The staring materials which consist of Nickel Nitrate Hexahydrate ($Ni(NO_3)_2.6H_2O$), Zinc Nitrate Hexahydrate ($Zn(NO_3)_2.6H_2O$) and Iron Nitrate Nonahydrate ($Fe(NO_3)_2.9H_2O$), which certain ratio were dissolved in nitric acid and stirred with constant rate at room temperature. The solution temperature was then increased to 70°C and the stirring continued until gel is formed. The gel was then dried at 110°C and further annealed at 900°C for 4 h. XRD method is used to determine the crystallography of the Ni-Zn ferrite NPs with different Zn composition such as crystallite size, phase and structure. The morphology and the particle size were investigated using FESEM. The magnetic properties of the prepared NPs were then carried out by performing VSM measurements.

Results and Discussion

Figure 1 illustrates the XRD patterns for the samples with different Zn composition annealed at 900°C. Despite of different Zn composition, all matched well with the typical Ni-Zn ferrite pattern (Zahi *et al*., 2007) which show the crystalline cubic spinel structure. The sharp peaks at about 2θ = 35° indicate that only single phase (311) appears which is spinel ferrite (Krishna *et al*., 2012). Crystallite size for each sample was calculated by choosing the most intense peak (311) using the Scherrer formula (Gul *et al*., 2008). The calculation showed that the crystallite size decreases when the Zn^{2+} composition increases. The crystallite sizes for x = 0, 0.25. 0.5, 0.75 are 4.5, 4.1, 3.4 and 3.6 nm, respectively. Here we can observe that inclusion of Zn obstructs the crystal formation. This is because the formation of Zn-ferrite is more exothermic compared to Ni-ferrite (Navrotsky and Kleppa, 1968) due to the increase in surface temperature affects the concentration of molecules at the surface of the crystal. In other words, the crystal surface temperature increases when concentration of Zn^{2+} increases and this will decrease the concentration of molecule at the crystal surface.

The Ni-Zn ferrite NP sizes are estimated using FESEM images that are illustrated in Fig. 2. The estimated sizes of the Ni-Zn ferrite NPs by referring to FESEM images are about 110, 125, 100, 85 and 70 nm, respectively. Generally, increase in Zn concentration will result in decrease in particle size. This is consistent with the decrease in crystallite size when Zn concentration increases determined from XRD results.

Table 1 and Fig. 3 depict the magnetic saturation versus different Zn concentration. The magnetic saturation reaches maximum when Zn concentration is x = 0.5. However when the concentration further increases, the magnetic saturation eventually decreases. This is because Zn ions are nonmagnetic, it will increase the magnetic moment at certain extent and weakens the super-exchange interaction between the magnetic ions when the concentration further increases (Liu *et al*., 2012). Here we can conclude that magnetic ions from "A" sites has been replaced by Zn ions which decreases the magnitude of moment of "A" sites. However, because the difference in moment between the A site and B site increases, the magnetic moment increases. After x = 0.75, the magnetic moment decreases probably due to the canted spin (noncollinear) structure. When Zn^{2+} composition increases, the magnetic moment decreases, this indicates the ferromagnetic behavior vanishes when x is more than 0.5 (Singhal and Chandra, 2007).

Table 1: Magnetic saturation Vs Zinc composition

Zinc composition, x	Magnetic saturation (emu/g)
0	29.7
0.25	49.8
0.5	52.6
0.75	23.4
1	17.7

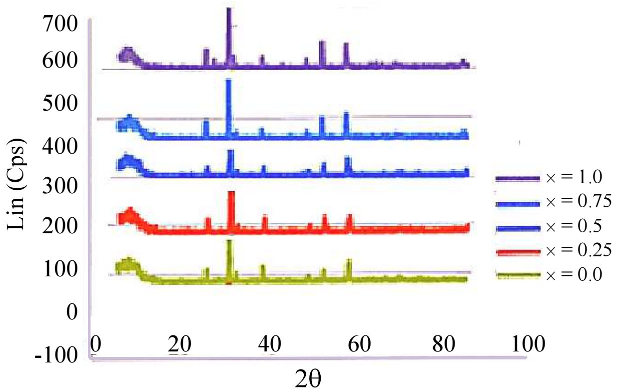

Fig. 1: XRD of Ni-Zn ferrites with different Zn composition annealed at 900°C

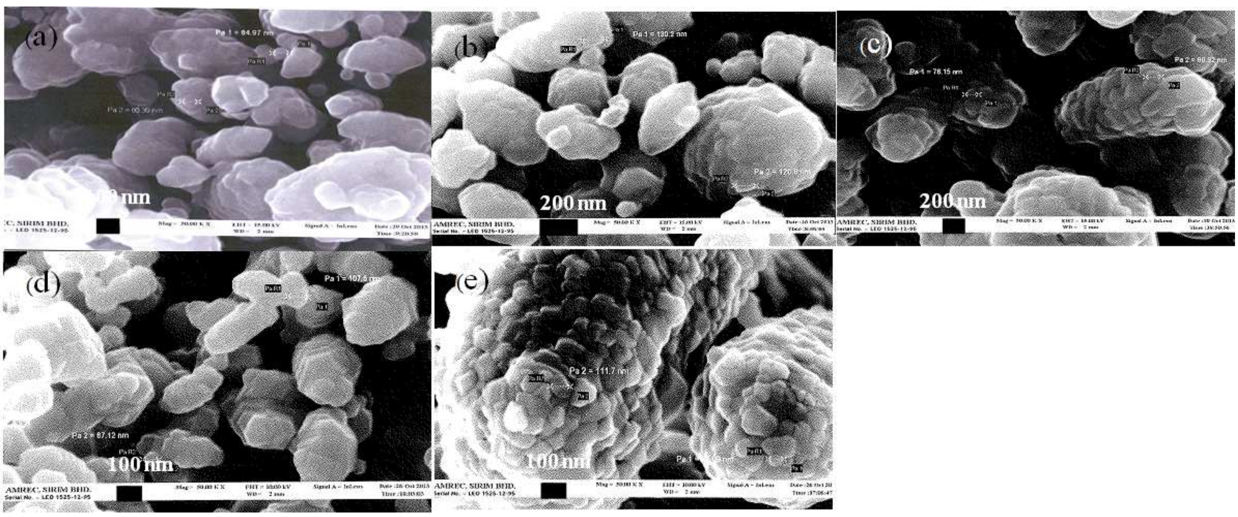

Fig. 2: FESEM images for samples with (a) x = 0, (b) x = 0.25, (c) x = 0.5, (d) x = 0.75 and (e) x = 1.0

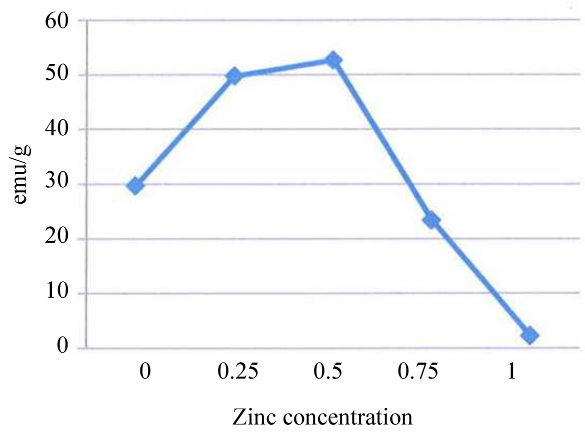

Fig. 3: Magnetic Saturation Vs Zn concentration

Conclusion

The synthesis and characterization of Ni-Zn ferrites with different Zn concentration has been demonstrated. The XRD and FESEM results both showed the crystallite and particle size decreases when the Zn ion concentration increases. This is due to the increase in Zn concentration will lead to increase in crystal temperature which will impede the crystal formation. Magnetic characterization showed the maximum magnetization when x = 0.5 which indicates the replacement of magnetic ions by Zn^{2+} at A site which results in increase in total moment of both A and B sites.

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Author's Contributions

Both authors equally contributed in this work.

Ethics

The authors declare no competing financial interest.

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