Structural and Magnetic Properties of Zn-Ni Ferrite Synthesized by Precursor Method

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Abstract: In this work nickel zinc ferrite with general formula Zn<sub>x</sub>Ni<sub>1-x</sub>Fe<sub>2</sub>O<sub>4</sub> (x = 0.3, 0.4, 0.5, 0.6 and 0.7) were synthesized by precursor decomposition method starting from metal nitrates. X-ray analysis indicated the formation of well crystallized Zn-Ni ferrite. The change in the particle size with increasing Zn content was confirmed by scanning electron microscopy which revealed that the powders prepared by precursor method resulted in nano sized particles with a particle size of 19–42 nm. The crystallite size and lattice parameter increased and Curie temperature decreased as the concentration of Zn increased. Saturation magnetization and remnant magnetization, both, continuously increase up to x=0.5, and then decreased for more Zn content. The influence of the grain size on saturation magnetization and of Zn on Curie temperature was investigated for the Zn-Ni ferrite samples.

Keywords: decomposition, nano sized, lattice parameter, electron microscopy, Curie temperature.

1. Introduction

In recent times lot of interest is generated in the study of several soft spinel ferrites in the development of nano sized particles at low temperatures by different chemical synthesis techniques, as they are commercially very important materials. Among them Ni–Zn ferrites is one of the most sought after material for use in both lower and higher frequency devices due their high resistivity, low dielectric losses, and high Curie temperature [1, 2]. They have applications, such as gas sensors, as a catalyst, electromagnetic interference (EMI) suppression, multi layer chip inductor, and telecommunication devices.[3, 4]. These ferrites are also used in biomedical applications [5]. The most important properties of these ferrites are saturation magnetization, Curie temperature, resistivity, dielectric constant etc [6]. These properties are highly sensitive and are dependent on the following factors like the method of preparation, sintering temperatures and the presence of impurities. These properties can be altered as per the requirement for the specific application by controlling the preparation and sintering conditions, by changing the composition, and or by introducing required amount of additives. There are several methods of preparation of ferrites; the most common and simplest is the ceramic technique that is used to identify the crystal structure as it is reliable for material identification. As inter atomic spacing in the crystal is of the order of 10<sup>-8</sup> cm, therefore a ray with wavelength of similar order will give rise to diffraction phenomena. The structural characterization of the prepared Zn-Ni ferrite nanoparticles was carried out using Rigaku, X-ray advance Power diffractometer using Cu Kα radiation (λ = 1·54183 Å). The step size employed was 0-02°, in the range of 20<sup>0</sup> – 80<sup>0</sup>.

The average crystallite size was calculated by Debye–Scherer's equation using data obtained from X-ray diffractograms, for the most intense peak (311). The particle size and structural morphology studies were carried out using Scanning Electron Microscope Model JEOL 5800LV. The saturation magnetization measurements of all the samples were carried out at room temperature using Pulse Field Magnetic Hysteresis Loop Tracer, of Magneta India Model PFMHT-1. The Curie temperature measurements of the Zn-

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Ni ferrite samples were done by using Dual Channel Data Acquisition System supplied by Magneta India Model pfm-2.

3. Results and Discussion:

Figure 1: XRD pattern of Ni$_{x}$Zn$_{1-x}$Fe$_2$O$_4$ samples

Formation of single phase cubic spinel structure of Zn$_x$Ni$_{1-x}$Fe$_2$O$_4$ samples (with X= 0.3, 0.4, 0.5, 0.6, and 0.7) synthesized by precursor decomposition method are illustrated in fig. 1. It was confirmed with help of XRD patterns obtained for all the samples.

Table 1: Variation of lattice constant of Zn$_x$Ni$_{1-x}$Fe$_2$O$_4$ samples

| Samples           | Lattice constant “a” in cm. |
|-------------------|-----------------------------|
| Zn$_{0.3}$Ni$_{0.7}$Fe$_2$O$_4$ | 8.3510 X 10$^{-8}$ |
| Zn$_{0.4}$Ni$_{0.6}$Fe$_2$O$_4$ | 8.3687 X 10$^{-8}$ |
| Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ | 8.3963 X 10$^{-8}$ |
| Zn$_{0.6}$Ni$_{0.4}$Fe$_2$O$_4$ | 8.4021 X 10$^{-8}$ |
| Zn$_{0.7}$Ni$_{0.3}$Fe$_2$O$_4$ | 8.4271 X 10$^{-8}$ |

Figure 2: Variation of lattice constant

As shown in the table 1 the values of lattice constants “a” calculated from XRD data were found to increase with increase in Zn concentration. This increase is attributed to replacement of the smaller ionic radii of Ni (0.78Å) with higher Zn content and with larger ionic radii (0.82Å) [17], and are in agreement with reported values.

Table 2: Variation of particle size in nm of Zn$_x$Ni$_{1-x}$Fe$_2$O$_4$ samples

| Concentration of Zinc | Particle size in nm |
|-----------------------|---------------------|
| 0.3                   | 19.2                |
| 0.4                   | 25.6                |
| 0.5                   | 29.5                |
| 0.6                   | 37.7                |
| 0.7                   | 42.6                |

The particle size of samples is calculated using the Scherer formula, indicated in table 2 is in the range from 19.2 nm to 42.6 nm. This shows that the method gives nano size ferrite particles, which is also confirmed by the SEM micrograph.

Table 3: Variation of saturation magnetization of Zn$_x$Ni$_{1-x}$Fe$_2$O$_4$ samples

| Concentration | Saturation Magnetization (emu/g) |
|---------------|----------------------------------|
| Zn$_{0.3}$Ni$_{0.7}$Fe$_2$O$_4$ | 31.64                           |
| Zn$_{0.4}$Ni$_{0.6}$Fe$_2$O$_4$ | 39.28                           |
| Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ | 47.86                           |
| Zn$_{0.6}$Ni$_{0.4}$Fe$_2$O$_4$ | 41.16                           |
| Zn$_{0.7}$Ni$_{0.3}$Fe$_2$O$_4$ | 36.31                           |

Figure 4: Variation of Saturation magnetization
The variation of the saturation magnetization with Zn contents for the Zn-Ni ferrite samples of various compositions is given in Table 3. It can be observed that the value for saturation magnetization increases with increasing Zn content up to x=0.5. A marked reduction was observed for the values of x= 0.6 and 0.7. Based on the particle sizes, which increased with increasing Zn concentrations, and the theoretical magnetization foreseen for the spinel lattice, the magnetization was expected to increase. However, this increase was observed only at Zn concentrations of up to 0.5. Costa [18] has attributed this behavior to the spin canting effect that occurs when B-B interactions are comparable to A-B interactions. Bercoff et al. [19] explain this phenomenon as follows: In mixed Ni–Zn ferrites, the Zn ions concentrate preferentially in the A -sites and the Ni ions in the B- sites in the cubic spinel lattice. When the concentration of Fe\textsuperscript{3+} ions in the A- sublattice is diluted by low concentrations of diamagnetic substitutions by Zn\textsuperscript{2+}, the net magnetization increases. However, magnetization decreases at higher levels of doping. The reason for this is that low Zn concentrations reduce the number of spins occupying the A -sublattices, causing the magnetization to increase. As the Zn content increases, the exchange interactions are weakened and the B-spins are no longer held rigidly parallel to the few remaining A- spins. The decrease in the B-sublattice moment, interpreted as a spin departure from colinearity, causes the effect known as canting. This effect is also seen in other ferrites [20].

Table 4: Variation of Curie temperature of Zn\textsubscript{x}Ni\textsubscript{1-x}Fe\textsubscript{2}O\textsubscript{4} samples

| Samples          | Curie temperature (°C) |
|------------------|------------------------|
| Zn\textsubscript{0.3}Ni\textsubscript{0.7}Fe\textsubscript{2}O\textsubscript{4} | 392                   |
| Zn\textsubscript{0.4}Ni\textsubscript{0.6}Fe\textsubscript{2}O\textsubscript{4} | 368                   |
| Zn\textsubscript{0.5}Ni\textsubscript{0.5}Fe\textsubscript{2}O\textsubscript{4} | 311                   |
| Zn\textsubscript{0.6}Ni\textsubscript{0.4}Fe\textsubscript{2}O\textsubscript{4} | 247                   |
| Zn\textsubscript{0.7}Ni\textsubscript{0.3}Fe\textsubscript{2}O\textsubscript{4} | 204                   |

4. Conclusion

Zn- Ni ferrite with general formula Zn\textsubscript{x}Ni\textsubscript{1-x}Fe\textsubscript{2}O\textsubscript{4} where x= 0.3, 0.4, 0.5, 0.6, and 0.7 were prepared by precursor decomposition method. The single phase formation was confirmed by XRD. SEM analysis indicated a high level of powder agglomeration. The size of the crystallites increases when more Ni ions were replaced by Zn ions. Magnetic measurements showed that magnetization was rising with increasing of Zn content up to x=0.5 and followed by a decrease for higher Zn concentration. It was observed that, there is a systematic decrease in the value of the Curie temperature (T\textsubscript{c}) as the zinc amount is increased in these ferrites. This is due to the substitution of non-magnetic Zn\textsuperscript{2+} ions for the magnetic Ni\textsuperscript{2+} ions in the samples.

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