

Effect of neodymium ions on preparation and structural properties of strontium hexaferrite

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Abstract

Nd³⁺ doped strontium hexaferrite nanoparticles have been successfully synthesized using citrate precursor technique. The effect of doping elements on structural properties has been examined by using X-ray diffraction (XRD) and fourier transform infrared spectroscopy (FTIR). The structural results showed the formation of hexaferrite phase of M-type crystal with well defined diffraction peaks without forming any secondary phases. The crystallite size has been calculated by using Scherrer's formula and found to be in the single domain particle size range (22–43 nm). The incorporation of rare earth element for iron site hinders the grain growth. The lattice vibration and bond stretching of prepared nanoparticles has been deliberated through fourier transform infrared spectroscopy in Mid-IR frequency range to investigate the vibration of metal–oxygen bond.

Keywords: Magnetic materials, X-ray diffraction, FTIR, Nd³⁺–substitution

1. Introduction

Hexagonal ferrites have widely attracted the attention as permanent magnets due to large saturation magnetization, high coercivity and uniaxial magnetocrystalline anisotropy. Ferrites are extensively used in different fields of technology and have drawn attention over the years and have now become an important material commercially and technologically such as magnetic memories, electronic components, sensor and integrated circuits. Hexagonal hard magnetic materials cover the 57% share of world market of permanent magnetic materials. With the advancement in field of telecommunication, industries are opting small scale integrated circuits and demand for electronic technology has increased rapidly in recent years. This demand has led to the development of many inductive devices in very high frequency. The development of electronic industry and information technology in gigahertz has led to so many electromagnetic interference problems that are not only harmful for health of human beings but also influences the electronic devices functioning and creating malfunction. There are wide varieties of absorbing materials depending upon their applications in low or high frequency. The conventional ferrites are irresponsible at GHz frequency. Thus, the focus has been drawn in the development of materials that have high microwave absorbing properties over a broadband frequency range so that the radiation pollution is reduced [1]. Hexaferrites are considered to be the best suitable candidate for making materials which can absorb microwave radiations as they are highly stable and affordable to fulfill all market demand because of high curie temperature, high resonance frequency and corrosion resistivity [2]. Multi-layer chip inductors (MLCIs) and chip electromagnetic interference filters are in demand due to operation of information and communication industry in hyperfrequency. Multi-layer chip inductors become the one of the

most important component in various electronic gadgets. Also, high electric resistive ferrite materials become the part of present research work at point where there is a requirement of high resistivity of the order of $10^9 \Omega \text{ cm}$ to overcome the eddy current losses. In order to obtain well organized microstructure of high quality hexaferrite variety of techniques have been developed to prepare single domain ultrafine nanoparticles i.e. solid state reaction, sol-gel method, hydrothermal and co-precipitation [3–6]. Along with the above mentioned techniques, cation substitution can also be very useful technique to improve the magnetic properties of hexaferrite [7–10]. In this manuscript, the effort has been made to study the structural properties of prepared ultrafine nanoparticles by cationic substitution of Fe^{3+} ions by trivalent ions.

2. Experimental technique

$\text{Sr}(\text{NO}_3)_2$, $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, $\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$, $\text{C}_6\text{H}_8\text{O}_7 \cdot \text{H}_2\text{O}$ and NH_3OH were used as purchased without any purification for the preparation of neodymium doped strontium hexaferrite. $\text{SrNd}_x\text{Fe}_{12-x}\text{O}_{19}$ ($0.0 \leq x \leq 0.2$) nanoparticles were synthesized through citrate precursor technique using metal nitrate followed by citric acid as a chelating agent. The ammonia solution was added drop wise in stoichiometric mixture of metal nitrates in proportion to maintain $\text{pH} = 6-7$. The homogeneous solution was obtained with help of magnetic stirrer at $60-70^\circ\text{C}$ after continuous stirring and till formation of precursor powder. The residues are finally heat treated at 1000°C (5h) to obtained ultrafine hard magnetic nanoparticles. Physical properties were measured with the help of X-ray diffraction $\text{Cu-K}\alpha$ radiation (X'Pert Pro diffractometer, operating at 45 kV and 40 mA). Shimadzu Corporation designed FTIR-8400S was used to measure characteristic absorption bands of potassium bromated mixed calcinated nanoparticles in the range $4000-400 \text{ cm}^{-1}$.

3. Results and discussion

Fig.1a–c shows the X-ray diffraction pattern of prepared $\text{SrNd}_x\text{Fe}_{12-x}\text{O}_{19}$ ($0.0 \leq x \leq 0.2$) nanoparticles. XRD results confirms that magnetoplumbite phase with hexagonal structure has been formed at 1000°C (5h). The XRD peak are well indexed with standard ICSD data 080–1198. Structural parameters such as crystallite size, lattice constant, lattice volume have determined for most dominating peak position (107), (110) and (114) using Scherrer's formula and interplanar equation [11]. The crystallites size was calculated as 22–43 nm that makes these materials suitable for high density recording media. The crystallite size and lattice constant 'c' ($23.03 \text{ \AA} - 22.92 \text{ \AA}$) found to be decrease with an increase dopant concentration. The decrease in physical parameters has been explained on the basis of substitution of different ionic radii element in crystal lattice. This decrement can be attributed to (i) dopant rearrange themselves in host lattice and (ii) lattice distortion. This is because difference in ionic radii that causes displacement in peaks. The ionic radii of Nd^{3+} is greater than Fe^{3+} ($0.64 \text{ \AA}$) ions that may results in expansion of crystal which directly effects the Braggs angle (decreases) due to increase in distance between crystal plains [12]. But in present research work, the substitution of Nd^{3+} ions for Fe^{3+} ions highlights c-axis compactness and shifting of peak position towards higher Bragg's angle which is directly consistent with compactness of lattice, decrease of distance between crystal plains reflection

towards higher Bragg's angle during the incorporation of Nd^{3+} ions at Fe^{3+} site. Moreover, the substitution of rare earth elements causes distortion at octahedral and tetrahedral site due to creation of iron vacancies in host lattice. This distortion sturdily affects the bond length, bond angle and lattice dimension become plausible reason for decrement of lattice constant as well as possibility of rare earth elements near to grain boundary restrict the grain growth and exert a pressure on the grain [13–15]. As a result, the grain size and lattice constant decreases with increase in doping concentration of rare earth element. The formation of hexaferrites in single domain size range contributes towards the number of grains in bit area that directly help in the improvement of signal to noise ratio for high density recording media.

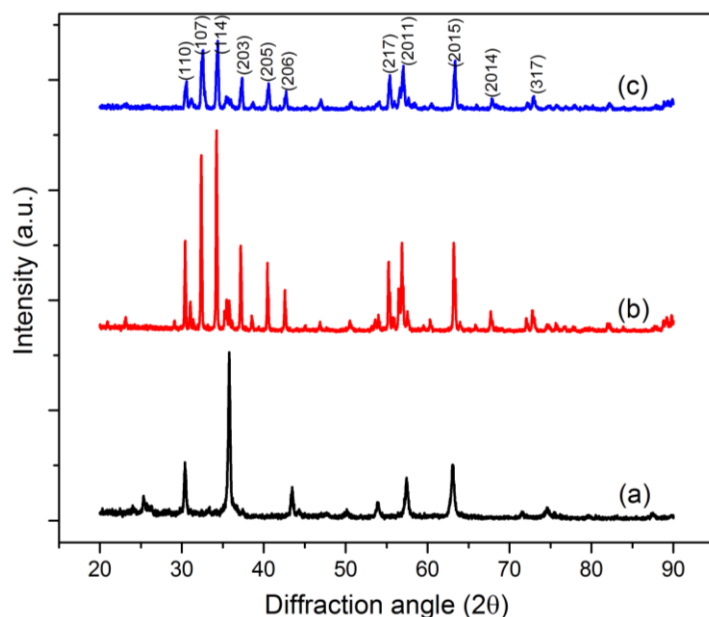


Fig.1: XRD diffraction pattern of (a) precursor powder and calcinated $\text{SrNd}_x\text{Fe}_{12-x}\text{O}_{19}$ nanoparticles at 1000°C (b) $x = 0.0$, (c) $x = 0.2$.

Absorption frequency of as prepared and heat treated hexaferrite nanoparticles have been investigated by using FT-IR (Fig.2a–c). FT-IR is non-destructive employed to detect the presence of functional group and impurities in compound. Fig.2a represent the characteristic band absorption of as prepared nanoparticles which shows the strong absorption of iron oxides near $400\text{--}600\text{ cm}^{-1}$, vibrations of nitrate, carboxyl group were obtained between $1300\text{--}1600\text{ cm}^{-1}$ and asymmetric stretching modes of carbon dioxide are appeared near 2350 cm^{-1} in Fig.2a. Fig.2b,c. present informational spectrum as a function of Nd^{3+} . FT-IR spectra show the characteristics absorption band at 589 cm^{-1} , 547 cm^{-1} and 432 cm^{-1} for heat treated sample. The frequency absorptions in characteristic range are attributed to the lattice vibration of ferrite phase [16,17]. The lattice vibration of characteristic bands in the frequency range $430\text{--}470\text{ cm}^{-1}$ and $550\text{--}590\text{ cm}^{-1}$ correspond to octahedral and tetrahedral site for metal–oxygen bonds. The substitutional spectrum is consistent with intrinsic compound which confirms the rearrangement of metal ions in host lattice. The difference in bond length of $\text{Fe}^{3+}\text{--O}^{2-}$ for octahedral and tetrahedral site is considered the plausible reason for difference in absorption peak position in hexaphase. Moreover, substitution of rare earth

ions result in shift of octahedrate site to higher wavenumber confirmation the inclusion in host lattice [18,19].

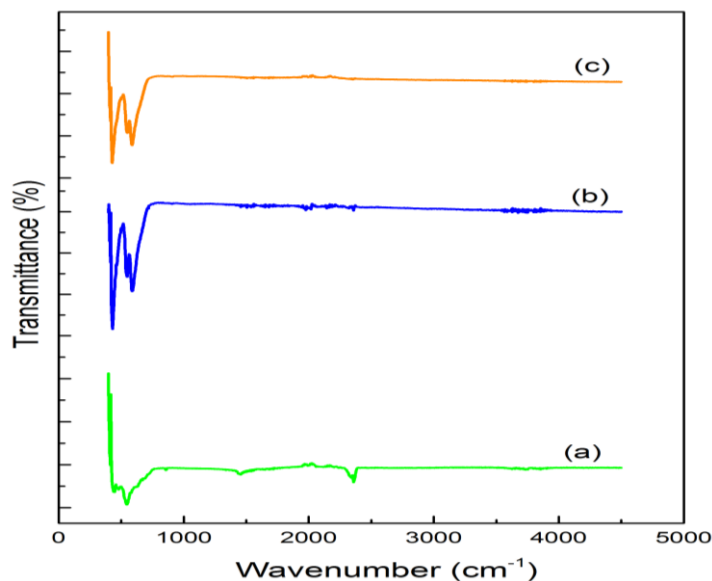


Fig.2: FT–IR spectra of (a) precursor powder and calcinated $\text{SrNd}_x\text{Fe}_{12-x}\text{O}_{19}$ nanoparticles 1000°C (b) $x = 0.0$, (c) $x = 0.2$.

4. Conclusion

Neodymium doped strontium hexaferrite nanoparticles have been successfully synthesized by versatile and economical technique. Synthesized nanoparticles are characterized by using XRD and FT–IR. X-ray diffraction pattern confirms the formation of magnetoplumbite phase and calculated crystallite size through Scherrer's formula found to be in nanoscale. The decrease in crystallite size and lattice constant with an increase in doping concentration of Nd^{3+} ions for Fe^{3+} site has been explained on the basis of substitution of large ionic radii rare earth element that causes lattice disorder and occurrence of rare earth element at grain boundary hinders the grain growth by exerting pressure on the grain. The lattice vibration of metal–oxygen bond near characteristic frequency $430\text{--}470\text{ cm}^{-1}$ and $550\text{--}590\text{ cm}^{-1}$ attributes the formation of hexaferrite phase.

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