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Effect of Magnesium Substitution on the Structural and Magnetic properties of M-type Strontium Hexaferrite

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Abstract

A systematic investigation on the structure and magnetic properties of strontium hexaferrites doped Mg was performed. All ferrite samples were prepared by the citrate-precursor method and characterized with a combination of X-ray diffraction, FTIR, and Vibrating sample magnetometer. XRD analysis confirms the magnetoplumbite structure with space group $p63/mmc$. Average grain size has been seen increasing with Mg substitution. The presence of peaks near $500-600\text{ cm}^{-1}$ in Fourier transform infrared spectroscopy spectra indicates the formation of M-type hexaferrites. An increase in coercivity and magnetization were observed for all the samples. Large value of coercivity suggests that these materials are useful in longitudinal recording media.

Keywords: Magnetization, XRD, FTIR.

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1. Introduction

The hexaferrite with M-type structure have been the interest of continuous research due to their various remarkable properties.[1-2] and industrial applications such as computer memory chip , high density recording media, transformer, microwave devices, plastic and permanent magnets[3-4] from last few decades. To date, several experiments have been carried out to examine the influence of various dopants on modifying the structural and magnetic properties of strontium hexaferrites to make them desirable for different applications [5 ,6]. Strontium hexaferrites have been synthesized by different techniques like hydrothermal process [7], the self-propagating high-temperature synthesis [8], the microwave-assisted calcinations route [9], and the citrate precursor [10]. Among these, the Sol-Gel method is well-known as a simple and low cost route for the preparation of hexaferrite nanoparticles [11]. Alam. et al [12] studied Magnetic and microwave absorption properties of $\text{BaMg}_{x/2}\text{Mn}_{x/2}\text{Co}_x\text{Ti}_{2x}\text{Fe}_{12-4x}\text{O}_{19}$ hexaferrite nanoparticles.

The present study presents the effect of Magnesium substitution on the structural and magnetic properties of strontium hexaferrites. In this context, novel strontium hexaferrite with nominal composition $\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$) were synthesized by Sol-gel method.

2. Experimental Details

$\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$) have been prepared by citrate-precursor method using analytical grade chemicals namely ferric nitrate nona-hydrate, strontium nitrate anhydrous, magnesium nitrate hexa-hydrate, citric acid anhydrous. Metal salts and citric acid were dissolved in a triply deionised water separately and then mixed together at room temperature with continuously constant stirring. Citric acid anhydrous acts as a fuel. The pH of the solution was adjusted at 6.5 by using ammonia (25%). The obtained solution was heated at $90\text{ }^\circ\text{C}$ till a gel solution was obtained. The so obtained gel was heated till combustion, ultimately leaving only loose ashes. These ashes were grinded by a motor pestle arrangement for about 30 min. The whole powder was then heated at $500\text{ }^\circ\text{C}$

to remove the organic moiety. Finally the powder was calcinated at 950 °C for 3 h.

The phase of the synthesised samples were determined by the D8 Advance Bruker X-ray diffractometer with CuK α ($\lambda=1.5406$ Å) radiation. Attached functional groups with samples have been analysed with Fourier transform infrared spectra [FT-IR interferometer IR prestige-21 FT-IR (model-8400S)] in the range of 400–4000 cm^{-1} . Magnetization measurements of samples, major hysteresis loops, were obtained using a vibrating sample magnetometer (MicroSense EZ9 VSM) with maximum field strength of 20 kOe.

3. Results and Discussions

3.1 XRD ANALYSIS

The X-Ray diffraction patterns of $\text{Sr}_{1-x}\text{Mg}_x\text{La}_x\text{Fe}_{12-x}\text{O}_{19}$ demonstrate that all the samples of the series have magnetoplumbite structure space group p63/mmc (PDF No. 41#1373) and only a small trace of Fe_2O_3 was detected. The presence of the Fe_2O_3 is related to an incomplete calcinations reaction [13]. Various lattice parameters are listed in Table 1. From table 1 lattice constant a, c and volume cell agree with the reported literature. A small change in the lattice parameters were observed by the substitution of Mg dopants. The volume cell was calculated by using the following relation [14];

$$V_{\text{cell}} = 0.8666a^2c$$

Where V_{cell} is the volume of the unit cell and 'a' and 'c' are the lattice constant.

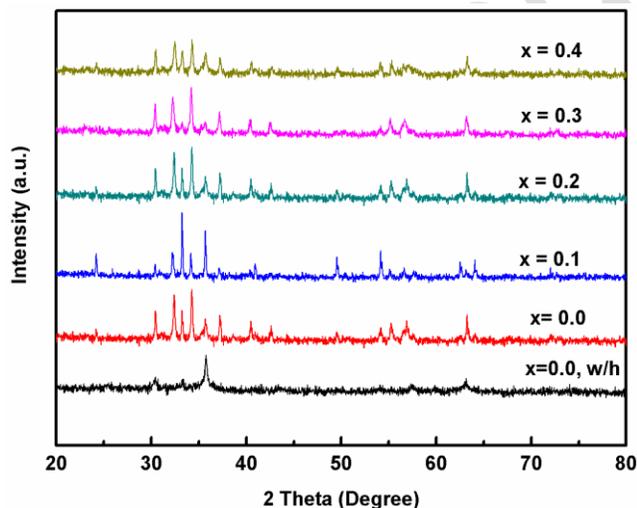


Fig 1. XRD pattern of $\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$) at room temperature.

X-ray density and crystallite size (D) are calculated by using the following formula:

$$\rho = \frac{2M}{N_A V}$$

$$D = \frac{K\lambda}{\beta \cos \theta}$$

Where λ is the X-ray wavelength, β is the half peak width, $K = 0.96$, the constant, Z the number of formula units in a unit cell, M the molecular mass of the sample and N_A Avogadro's number. The values of X-ray density and crystallite size are listed in table 1. It is observed that the average grain size is in between 6nm to 25nm which is smaller than that reported earlier i.e. 14-30nm for the M-type hexaferrites [15]. The value of X-ray density shows slight variation with increase in concentration of the doped ion, Mg. Also the average grain size D increases with Mg concentration.

3.2 Fourier transform infrared spectroscopy (FTIR) Analysis:

The FT-IR spectra for the un-annealed $\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$) hexaferrite powders are depicted in Fig. 2. FTIR provides the information regarding attached molecular bands or presence of functional groups, which are remains of chemicals use in the synthesis process. The band near 500–600 cm^{-1} attribute to the vibration of the ferric crystallographic site (octahedral and tetrahedral) [16]. The band appearing around 2000 cm^{-1} -2500 cm^{-1} is related to antisymmetric stretching of carbon dioxide in the atmosphere. One can notice a gradual red shift of both bands with the increase of dopants content.

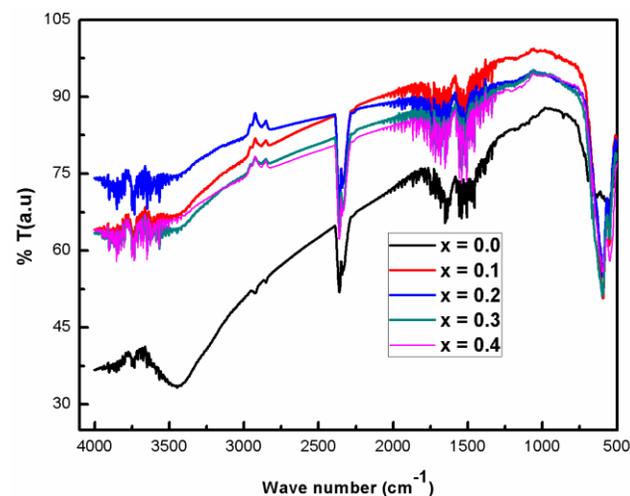


Fig.2. FTIR spectrum of $\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$) at room temperature.

Table 1. Table showing various parameters of $\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$).

Variation $x=0.0$ to 0.4	Average Grain Size D (nm)	Lattice Constant		$V_{CELL} =$ $0.866a^2c$ \AA^3	X_{ray} Density g/cm^3	M_r	coercivity	M_s
		$a(\text{\AA})$	$c(\text{\AA})$					
0.0 before heating	10.55nm	5.88	23.02	686.29	5.11	*	*	*
0.0 heated	12.57nm	5.88	23.02	685.25	5.11	*	*	*
0.1	13.37nm	5.86	22.96	681.25	5.17	11	2300	23
0.2	23.17nm	5.87	23.00	688.46	5.12	*	*	*
0.3	24.98nm	5.86	22.99	684.88	5.17	14	4496	27
0.4	17.73nm	5.86	22.95	683.29	5.19	*	*	*

This shift is related to the substitution of Mg^{2+} cations that affects the distribution of Fe^{3+} in the lattice. The peak in the area between $1100\text{--}1600\text{ cm}^{-1}$ is related to (metal–oxygen–metal) band vibration such as $\text{Fe}\text{--O}\text{--Fe}$ [17].

3.3 Magnetic Measurements:

Fig.3. shows magnetic hysteresis loops for 0.1 and 0.3 Mg doped $\text{SrFe}_{12}\text{O}_{19}$ at 300 K. The prepared materials show the behaviour of a hard magnetic material with high coercivity and magnetization. Various magnetic parameters of all samples are listed in table. It is evident from the table that saturation magnetization, coercivity and M_r increase with the substitution of Mg.

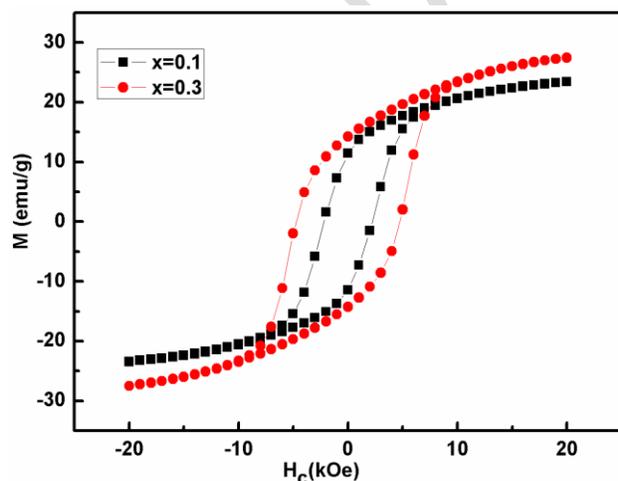


Fig.3. Magnetic hysteresis loops of the $\text{SrFe}_{12}\text{O}_{19}$ substituted with 0.1 and 0.3 Mg concentration

It is observed in the present investigation that Mg substituted strontium hexaferrite possess largest coercivity. It can be generalized that the increase of coercivity is attributed to enhancement in crystalline anisotropy field due to substitution of Mg. In other word, the substitution of Mg exerts intrinsic effects on the enhancement of coercive field. In the present study, the coercivity is more than $M_r/2$, thus the present material are hard magnets and are useful for high frequency applications [18].

4. Conclusions

The M-type hexaferrites $\text{Sr}_{1-x}\text{Mg}_x\text{Fe}_{12}\text{O}_{19}$ ($x = 0.0, 0.1, 0.3, 0.4$) hexaferrites were successfully synthesized employing citrate-precursor method. Phase formation was confirmed by X-ray diffraction. The XRD patterns exhibits that the prepared material were single phase of M-type hexagonal ferrite. The presence of peaks near $500\text{--}600\text{ cm}^{-1}$ in Fourier transform infrared spectroscopy spectra indicates the formation of M-type hexaferrites. The incorporation of Mg cations increases the saturation magnetization and increase in coercivity. The good magnetic properties of the prepared materials may be useful for high density magnetic recording media and permanent magnets.

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