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Magneto-optical properties $BaBi_xLa_xFe_{12-2x}O_{19}$ $(0.0 \le x \le 0.5)$ hexaferrites

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ABSTRACT

$BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$ hexaferrites were synthesized by solid state synthesis route and the effects of Bi, La substitutions on structural, magnetic and optical properties were investigated. X-ray powder diffraction, Scanning electron microscopy, Vibrating sample magnetometer, and Percent diffuse reflectance spectroscopy were used to study the physical properties. Room temperature specific magnetization (M–H) curves revealed the ferromagnetic nature of all products. The increasing Bi, La compositions increased the magnetic properties at different magnitudes with respect to undoped $BaFe_{12}O_{19}$ sample. The maximum values of remnant specific magnetization (M_r=30.3 emu/g), extrapolated specific saturation magnetization (M_s=62.12 emu/g), and magneton number (n_B=16.27) were recorded from $BaBi_{0.2}La_{0.2}Fe_{11.4}O_{19}$ hexaferrite. The average crystallite size varies in a range of (37.35–51.36) nm. The coercive field (H_c) of undoped hexaferrites is 1180 Oe and increased to maximum 2320 Oe belonging to $BaBi_{0.4}La_{0.4}Fe_{11.2}O_{19}$. Magnetic anisotropy was confirmed as uniaxial and calculated effective anisotropy constants (K_{eff}) are between 4.27×10^5 Ergs/g and 5.05×10^5 Ergs/g. The high magnitudes of magneto-crystalline anisotropy (H_a) above than 16,200 Oe revealed that all samples are magnetically hard materials. The Tauc plots were drawn to extrapolate the direct optical energy band gap (E_g) of hexaferrites. The E_g values decreased from 1.76 eV to 1.47 eV with increasing Bi, La compositions.

1. Introduction

M-type hexaferrites ($BaFe_{12}O_{19}$ and $SrFe_{12}O_{19}$ have attracted intensive attention due to their ferrimagnetic in nature and ability to absorb electromagnetic field penetration. Hence they are used as microwave absorbing materials. They also show potential application in magnetic recording and magneto-optical recording devices. The unique combine properties of chemical inertness, high mechanical hardness, large magnetic anisotropy, high coercivity and curie temperature in addition to low cost, accounts for the mentioned applications [1,2].

The facile ceramic method has advantages of synthesizing highly crystalline magnetic powder in large quantity, but its major disadvantage is high annealing temperature and longer calcination time [3–5]. Research has indicated that incorporation of Bi into hexaferrite solid solution could reduce annealing requirement and reduce particles agglomeration [6]. Yu et al. [7] found that densification of MnZn ferrite can be enhanced when the product grain boundary part contains sufficient Bi_2O_3.

Barium hexaferrite belongs has magneto plumbite structure. It unit cell constitute of one Ba^{2+}, nineteen O^{2-} and twelve Fe^{3+}, these ferric ions are dispersed into three distinctive interstial sites, octahedral (12k, 2a 4f2) tetrahedral (4f1) and trigonalbipyramidal (2b) [8]. Cation substitutions are intensively investigated to improve the magneto-optical and optical properties of transition metal substituted hexaferrites. Singh et al. [9], synthesized La^{3+} substituted BaM and observed a gradual increase in saturation magnetization (Ms) as La^{3+} content increases. The effect was ascribed due to increase in particle size, which was justified by model discussed by Lu et al. [10] in which a mathematical equation show magnetization dependency on particle size.

It is reported that the microwave absorption performance of strontium ferrite has been remarkably improved due to the grain dimension reduction and the valence change of Fe ions induced by the substitution of lanthanum [11,12]. While coercivity on the other hand has been improved by substitution of La^{3+}, and a qualitative explanation for this enhancement was given on the basis of strong magnetocrystalline anisotropy effect of Fe at 2a site [13].

In this paper, we investigated magnetic and optical behavior of Bi-La substituted Barium hexaferrite (BaM) with general formula

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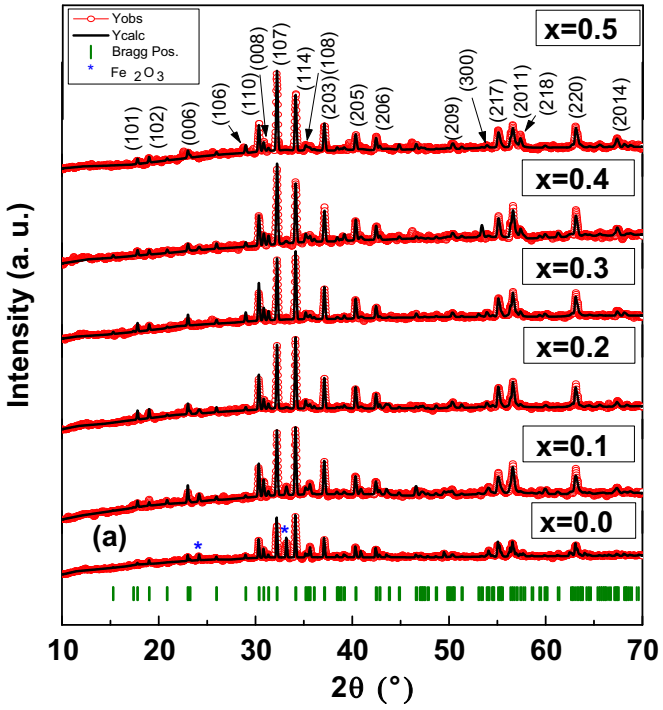

Fig. 1. XRD powder patterns of $BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$ hexaferrites.

Table 1
Bi, La content, refined structural parameters for $BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$ hexaferrites with space group $P6_3/mmc$ (No. 194).

Bi, La content (x)	$a=b$ (Å)	c (Å)	V (Å)^3	c/a	$\chi^2(chi^2)$	R_{Bragg}
0	5.891(8)	23.199(6)	805.3(3)	3.9376	1.67	19.50
0.1	5.890(9)	23.192(3)	804.8(4)	3.9370	1.17	9.63
0.2	5.889(8)	23.182(1)	804.1(8)	3.9360	1.24	10.05
0.3	5.889(3)	23.178(9)	803.9(3)	3.9358	1.26	12.94
0.4	5.887(7)	23.180(2)	803.5(4)	3.9371	1.33	17.02
0.5	5.888(1)	23.185(7)	803.8(4)	3.9377	1.16	12.07

$BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$, synthesized using conventional ceramic route.

2. Experimental

The analytical grade reagents were used for the synthesis of $BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$. The starting materials (precursors) were Fe_2O_3, $Ba(CH_3COO)_2$, Bi_2O_3, La_2O_3 and B_2O_3 which were purchased from Merck and used directly without further purification.

The phase compositions of the samples were determined using an X-ray diffractometer (XRD, DX-2700, Haoyuan Co.) with Cu K_α radiation. The surface morphology of the samples was characterized using a scanning electron microscope (SEM, JEOL JSM-6490) which is equipped with EDX, The spectral analysis of products were done by Nicolet NXR FT-Raman Spectrometer. The diffuse reflectance (DR) measurements were made by Thermo Scientific, Evolution 300 PC model spectrophotometer equipped with Praying Mantis Diffuse Reflectance accessory. Magnetization measurements were performed using a vibrating sample magnetometer (VSM) with a maximum applied magnetic field of 15 kOe.

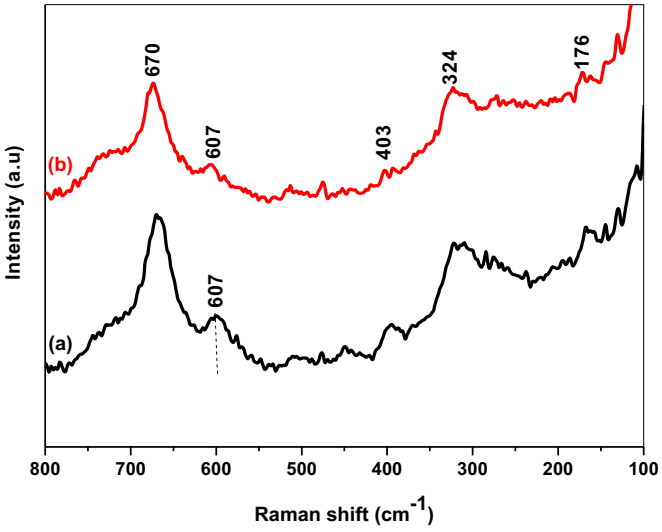

Fig. 2. FT-Raman spectra of $BaBi_{0.1}La_{0.1}Fe_{11.8}O_{19}$ and $BaBi_{0.4}La_{0.4}Fe_{11.2}O_{19}$ hexaferrites.

2.1. Procedure

$BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$, hexaferrites were synthesized by conventional solid state chemistry method [14]. For particular synthesis, the stoichiometric amounts of reactants, Fe_2O_3, $Ba(CH_3COO)_2$, Bi_2O_3, La_2O_3, and an additive B_2O_3 (1 mol%) to enhance fine crystal formation and better magnetic powder yield, were mixed and grinded in Agate mortar order [15] for 15 min and pre-calcinated at 400 °C for 3 h, finally the obtained products were ground again and calcinated at 1100 °C for 1 h.

3. Results and discussion

3.1. XRD analysis

The XRD powder patterns of $BaBi_xLa_xFe_{12-2x}O_{19}$ $(0.0 \le x \le 0.5)$ hexaferrites are given Fig. 1. All the XRD patterns were indexed and observed D-values for all diffraction peaks are compared with the standard pattern for hexagonal barium ferrite JCPDS Card No. (84-0757). All the products show a strong diffraction peak of BaM phase (Fig. 1). The detailed XRD analysis and variation of lattice parameters with "x" has been already given in our previous publications [14]. XRD profile fittings were performed using the FullProf program by employing space group $P6_3/mmc$ (No. 194). The

Table 2
Crystallite size and magnetic properties of $BaBi_xLa_xFe_{(12-2x)}O_{19}$ $(0.0 \le x \le 0.5)$ hexaferrites.

Bi, La content (x)	Crystallite size (nm) ±0.05	Molecular weight (g/mole)	H_c (Oe) ±10	M (emu/g) ±0.5	M_r (emu/g) ±0.5	M_s (emu/g) ±0.5	M_r/M_s	n_B
0.0	51.36	1415.47	1180	47.87	20.1	51.9	0.387	13.15
0.1	43.25	1439.09	1330	54.02	27.6	59.8	0.461	13.40
0.2	45.65	1462.71	2212	56.93	30.3	62.1	0.487	16.27
0.3	40.59	1486.33	1891	54.78	29.9	59.9	0.498	15.95
0.4	39.13	1509.95	2327	48.56	25.6	53.1	0.482	14.35
0.5	37.35	1533.56	1835	48.15	25.3	52.5	0.481	14.42