

ELECTRICAL AND MAGNETIC PROPERTIES OF $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ W-TYPE HEXAFERRITES ($0 \leq x \leq 0.5$)

I. ALI^a, N. AMIN^a, A. REHMAN^a, M. AKHTAR^a, M. FATIMA^a, K. MAHMOOD^a, A. ALI^a, G. MUSTAFA^b, M. S. HASAN^c, A. BIBI^d, M. Z. IQBAL^e, F. IQBAL^f, A. ASLAM^a, K. MEHMOOD^a, Z. LATIF^a, K. HUSSAIN^a, Z. H. NAWAZ^a, S. SHARIF^a, M. JILANI^a, U. DANISH^a, I. YASEEN^a, A. DILBAR^a, N. TAHIR^a, M. BILAL, A. AMIN^g, M. I. ARSHAD^{a,*}

^aDepartment of Physics, Government College University, Faisalabad 38000, Pakistan

^bDepartment of Physics, Bahauddin, Zakariya University Multan, 60800, Pakistan

^cDepartment of Physics, The University of Lahore, 1-kM Raiwind Road, Lahore, Pakistan

^dLaboratory of NBA, Jiangsu Key Laboratory for CBFMD, Institute of FNSM and Collaborative Innovation Center of SNT, Soochow University, Suzhou, Jiangsu 215123, China

^eNanotechnology Research Laboratory, GIK Institute of Engineering Science and Technology, Topi 23640, Khyber Pakhtunkhwa, Pakistan

^fDepartment of Physics, The Islamia university of Bahawalpur, Bahawalpur, Pakistan.

^gDepartment of Physics, University of Agriculture Faisalabad, Faisalabad, Pakistan.

A series of W-type Ba-based Co-W ferrites with composition $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ($x = 0.0, 0.1, 0.2, 0.3, 0.4$ & 0.5) were fabricated by co-precipitation process at sintering 1100°C for 8 h. In order to investigate structural, optical, electrical and magnetic properties XRD, FTIR, IV and VSM tools were employed to confirm the formation of ferrites phase. Crystallite size was observed in the range of $71.79 - 27.88$ nm with the increase of cobalt contents to confirm the formation of W-type phase. FTIR investigated the existence of metal oxide (M – O). Electrical resistivity increased in the range of $0.2315 \times 10^7 - 0.5329 \times 10^7$ ohm.cm. Saturation magnetization (Ms) of the synthesized sample were observed in the range (37.36 emu/g to 87.42 emu/g) and remanance (Mr) found (2.21 emu/g to 27.81 emu/g) while coercivity (Hc) observed in the range (42.58 Oe to 346.55 Oe). Explored results revealed that such type of behavior by material is suitable for application of magnetic recording media.

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1. Introduction

W-type Ba-based ferrites with composition $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ are an interesting class of ferromagnetic oxides. In hexagonal structure Fe^{+3} are distributed in five distinct crystallographic sites, one tetrahedral ($4f_1$), three octahedral ($2a, 12k$ and $4f_2$) and one trigonal bipyramidal ($2b$) sites. In Ba-base ferrites, along crystallographic c-axis spins of three sites $12k$, $2b$ and $2a$ sites are aligned and parallel to each other when in the magnetically ordered state while spins of $4f_2$ and $4f_1$ sites point in the opposite direction [1]. Considerate the possessions of different diamagnetic and paramagnetic cations on the magnetic properties of Co^{+2} inserted ferrites is most favorite job connected with usage of these nanomaterials in range of current scientific functions [2-3]. As of huge resistivity, control and eddy current loss and decreased extremely and therefore make the designed ferrite materials more suitable in high frequency device fabrications.

* Corresponding author: miarshadgcuf@gmail.com

Several techniques have been developed and effectively employed for synthesis of ferrites such as microwave refluxing [4], citrate gel technique [5], sol-gel auto combustion process [6], spray pyrolysis [7] and co-precipitation practice [8]. Co-precipitation is an ordinary practice for the fabrication of ferrite nanomaterials. In current study, we have reported, the manipulation of Co^{+2} content on the structural and as well as magnetic possessions of $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ($x = 0.0, 0.1, 0.2, 0.3, 0.4 \& 0.5$) ferrites prepared by co-precipitation method.

2. Experimental procedure

In the present research work synthesis and characterizations of $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ with ($x = 0.0, 0.1, 0.2, 0.3, 0.4 \& 0.5$) ferrites by co-precipitation process is studied. The preferred composition $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ was acquired using stoichiometric quantity of $\text{Ba}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Cd}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ and NaOH . They were dissolved in deionized water. NaOH solution was used as precipitant. pH rate of the result was maintained 11 and it was stirred for duration of 1 hour at magnetic stirrer. Obtained precipitate was digested in a preheated water bath at 80°C for 30 min duration. Obtained precipitates were washed with deionized water to make it free of infection. The creation was dehydrated at 90°C temperatures in an oven to eradicate water stuffing. Dehydrated materials were grinded with application of mortar and pestle then sintered at 1100°C for 8 h. Again, particles were grinded until the fine powder was obtained. After preparation of fine powder XRD, FTIR, IV and VSM techniques were employed to study structural, optical, electrical and magnetic properties.

3. Result and discussion

3.1 Microstructural study

X-ray diffraction (XRD) patterns were achieved by grinded nanomaterials in an Xpert Pro PANalytical diffract meter with $\text{Cu-K}\alpha$ radiation ($\lambda = 1.54056 \text{ \AA}$) at 40 kV and 30 mA. Strength data were composed by the step counting scheme in the 2θ array from $20-70^\circ$. XRD pattern of synthesized hexaferrites sintered for 8 hrs at 1100°C is shown if Fig. 1. Correspondence of XRD pattern with JCPDS card revealed the creation of W-type Ba grounded cadmium ferrites having hexagonal crystal arrangement as shown in Fig. 1. Cobalt phases were not observed as in presented sample which approves the appearance of Cd. Most prominent peaks are also demonstrated along with miller indices (hkl) values in Fig. 1.

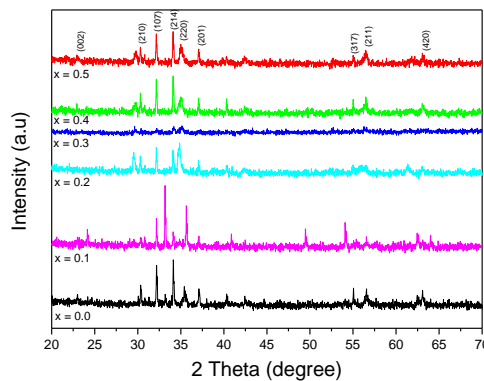


Fig. 1. XRD Patterns of $\text{Ba Co}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ with ($x = 0.0-0.5$) ferrites.

Lattice parameter a and c were investigated through interplanar spacing of hexaferrites by following relation,

$$\text{Sin}\theta^2 = A (h^2 + hk + k^2) + C l^2 \quad (1)$$

where A and C can be assumed by the following equation

$$A = \frac{\lambda^2}{3a^2} \quad (2)$$

$$C = \frac{\lambda^2}{4c^2} \quad (3)$$

In equations (2) and (3) 'a' and 'c' are lattice constant and (h k l) are Miller indices [9,10]. Fig. 2 demonstrates relation between lattice factors a and c against concentration. It can be observed that lattice constant ratio (c:a) is variable. Variations in ratios are because of difference in ionic radii of Co^{2+} (0.74\AA) and Cd^{2+} (0.97\AA). Scherrer's formula was employed to investigate crystallite size as,

$$D = \frac{k\lambda}{\beta_{hkl}\cos\theta} \quad (4)$$

where, $\lambda = 1.5406\text{\AA}$ is wavelength of X-ray diffraction, θ is Bragg's diffraction angle, k (0.9) is the shape factor and β_{hkl} is full width at half maximum (FWHM) [11]. Fig. 3 displays relation amongst crystallite size and concentration. It can be detected that initially crystallite size shows maximum value for X = 0.1 and then starts decreasing for X = 0.1 and 0.3 then again increases for X = 0.4 and then decline to X = 0.5 and increase for rest of the hexaferrite sample as in Table 1. Such increasing and decreasing trend is due to growth in cobalt and decline in cadmium contents [12].

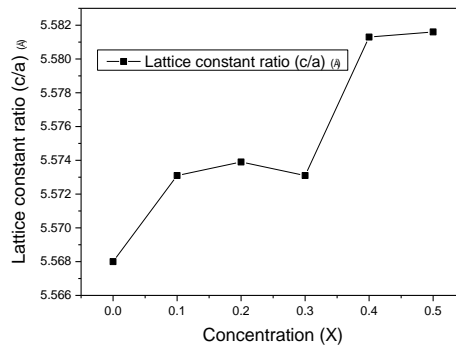


Fig. 2. Plot between Lattice constant ratio (c/a) and concentration for hexaferrite samples.

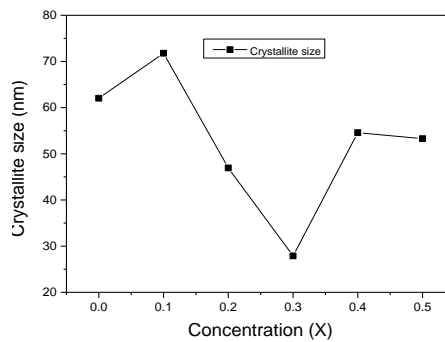


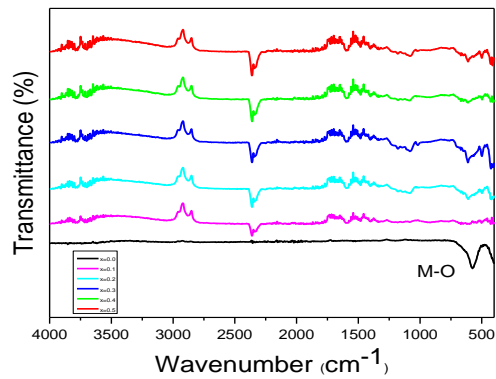
Fig. 3. Crystallite size and concentration for hexaferrite samples.

Table 1. Crystallite Size (nm), Lattice constant and Resistivity (ohm-cm).

Composition	Crystallite size (nm)	Lattice constant (c/a)(Å)	Resistivity $\times 10^7$ (ohm-cm)
BaCd ₂ Fe ₁₆ O ₂₇	62.04	5.5680	0.2315
BaCd _{1.9} Co _{0.1} Fe ₁₆ O ₂₇	71.79	5.5731	0.2708
BaCd _{1.8} Co _{0.2} Fe ₁₆ O ₂₇	46.93	5.5739	0.2713
BaCd _{1.7} Co _{0.3} Fe ₁₆ O ₂₇	27.88	5.5731	0.2810
BaCd _{1.6} Co _{0.4} Fe ₁₆ O ₂₇	54.57	5.5813	0.4378
BaCd _{1.5} Co _{0.5} Fe ₁₆ O ₂₇	53.27	5.5816	0.5329

3.2. FTIR Spectroscopy

Fig. 4 explains the FTIR spectra for hexaferrite nanomaterials of BaCo_xCd_{2-x}Fe₁₆O₂₇ (x = 0.0-0.5) ferrites witnessed in the range of 400-4000 cm⁻¹ and the widespread facial appearances of inspected ferrite spectrum display absorption peaks below 600 cm⁻¹ that symbolize metal oxygen (M-O) vibration approach. The two-absorption band Octahedral (V₁) and tetrahedral (V₂) was observed respectively. Tetrahedral band was observed in the range of 594 – 562 cm⁻¹. FTIR analysis confirmed the existence of phase identification, (M-O) metal oxide group in hexaferrite samples [13].

Fig. 4. FITR pattern BaCo_xCd_{2-x}Fe₁₆O₂₇ (x = 0.0- 0.5) ferrites.

3.3. I-V characterization

For cobalt substitution of BaCo_xCd_{2-x}Fe₁₆O₂₇ (X = 0.0 – 0.5) hexaferrites with (I-V) were examined by using Keithley electrometer model 2401. (I-V) graph gave the data curve of following samples as shown in Fig. 5. (a-c). For the measurement of resistivity following relation was used

$$\rho = \frac{RA}{L} \quad (5)$$

where R= 1/slope, L denotes thickness of prepared pellet while A represents area of electrode in contact with the sample [14]. The measured electrical resistivity for all samples with different content Co⁺² are listed in Table 1. The observed results exposed that electrical resistivity was increased with Co⁺² contents. From Fig. 5 (a) it can be observed that electrical conductivity increases initially then decreases with the rise of temperature (1000/T) for all hexaferrite samples with the increase of cobalt contents. Fig. 5 (b) illustrates the relation between resistivity and temperature of presented sample. It can be revealed that resistivity rises to 250 K temperature and then starts decreasing. Such behavior is because of increase of Co²⁺ contents. Fig. 5 (c) gives the

relation amongst resistivity and Co^{2+} contents for hexaferrites. It can be observed that resistivity boosts with the amplification of cobalt concentration. Resistivity increases in the range of $0.2315 \times 10^7 - 0.5329 \times 10^7$ ohm cm with the addition of cobalt concentration. It is because of hopping of charge carriers between iron and cobalt ions [15,16].

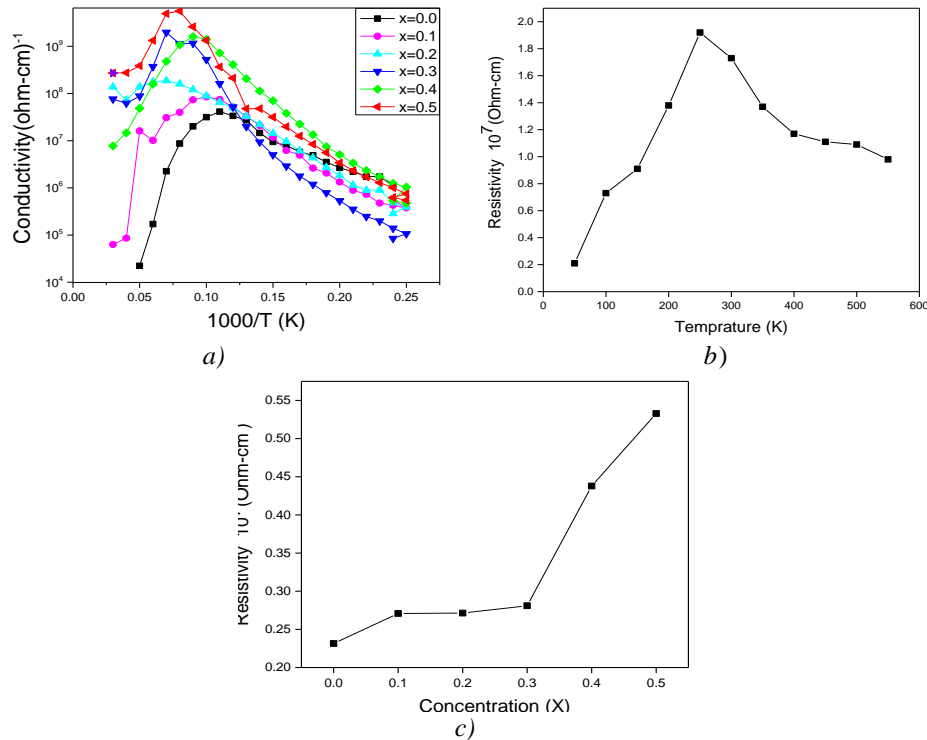


Fig. 5 a) Variation of conductivity and resistivity $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ferrites versus (a)- $1000/T$; b) temperatures, (c) Co^{+2} content (x).

3.4. Magnetic properties

Magnetic dimensions were accepted out at room temperature through application of vibrating sample magnetometer VSM, Lake Shore 735. Fig.6 shows the M-H loops of the characterized samples $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ($X = 0.0, 0.1, 0.2, 0.3, 0.4, 0.5$) ferrites prepared by co-precipitation manner. Saturation magnetization (M_s) of the synthesized sample were observed in the range (37.36 emu/g to 87.42 emu/g) and remanance (M_r) found (2.21 emu/g to 27.81 emu/g) while coercivity (H_c) observed in the range (42.58 Oe to 346.55 Oe). From the magnetic loops, measured the squareness ratio (M_r/M_s) found (0.059-0.318). The ratio M_r/M_s beyond 0.5 designates are single domain and below 0.5 is related with multi-domain structures. Another considerable factor, maximum coercivity was observed $H_c = 346.55$. Table 2 illustrates the trends of saturation magnetization (M_s), remanance (M_r), coercivity (H_c) and squareness ratio (M_r/M_s) of $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ferrites. Fig. 7 (a) and (b) explained the relation between saturation magnetization and remanance and Coercivity versus concentration (X). Coercivity shows the increasing trend with the increase of Co^{2+} concentration. Such type of material behavior is suitable for application of magnetic recording media [17].

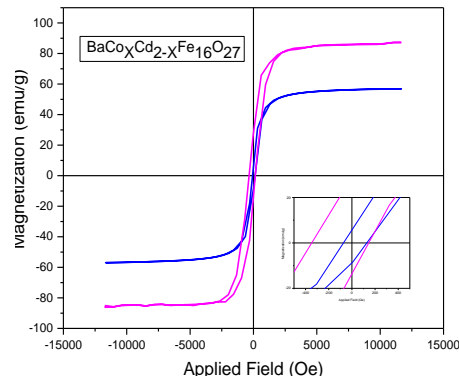


Fig. 6. M - H curves of Co^{+2} substituted $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ferrites at $x=0.2$ and $x=0.4$.

Table 2. Saturation magnetization (M_s), remanence (M_r), coercivity (H_c) and squareness ratio (M_r/M_s) of $\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ferrites.

Composition	M_s (emu/g)	M_r (emu/g)	M_r/M_s	H_c (Oe)
$\text{BaCd}_{2-x}\text{Fe}_{16}\text{O}_{27}$	41.45	3.04	0.073	48.94
$\text{BaCd}_{1.9}\text{Co}_{0.1}\text{Fe}_{16}\text{O}_{27}$	37.36	2.21	0.059	42.58
$\text{BaCd}_{1.8}\text{Co}_{0.2}\text{Fe}_{16}\text{O}_{27}$	57.21	5.32	0.092	69.46
$\text{BaCd}_{1.7}\text{Co}_{0.3}\text{Fe}_{16}\text{O}_{27}$	56.77	5.66	0.099	73.37
$\text{BaCd}_{1.6}\text{Co}_{0.4}\text{Fe}_{16}\text{O}_{27}$	87.42	27.81	0.318	346.55

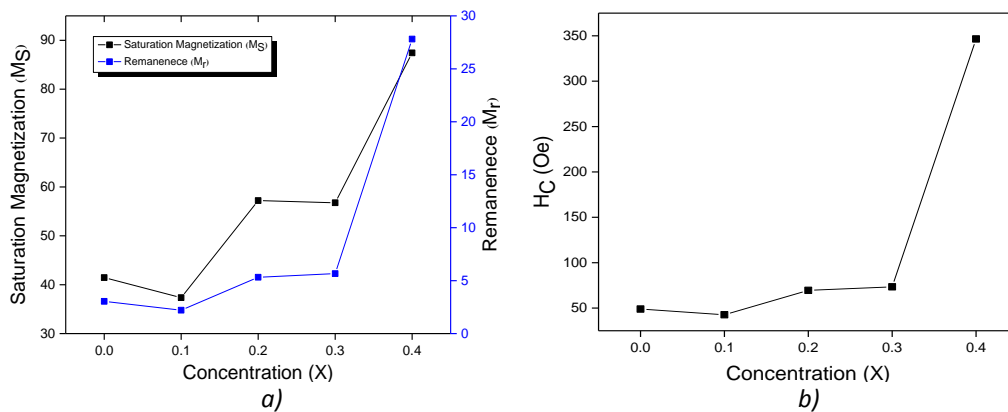


Fig. 7 a) Saturation magnetization and remanence (b) Coercivity versus content (x).

4. Conclusions

$\text{BaCo}_x\text{Cd}_{2-x}\text{Fe}_{16}\text{O}_{27}$ ($x = 0.0, 0.1, 0.2, 0.3, 0.4$ & 0.5) were fabricated by co-precipitation means sintered at 1100°C for 8 h. Crystallite size was observed in the range of $71.79 - 27.88$ nm with the increase of cobalt contents to confirm the formation of W-type phase through XRD. Existence of metal oxide (M - O) was studied by FTIR analysis. Electrical resistivity increased in the range of $0.2315 \times 10^7 - 0.5329 \times 10^7$ ohm cm. Saturation magnetization (M_s) of the synthesized sample were observed in the range (37.36 emu/g to 87.42 emu/g) and remanence (M_r) found (2.21 emu/g to 27.81 emu/g) while coercivity (H_c) observed in the range (42.58 Oe to

346.55 Oe). Explored results revealed that such type of behavior by material is appropriate for application of magnetic recording media.

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