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## Growth and characterization of ferrite film prepared by pulsed laser deposition

S. N. Kane<sup>a,1</sup>, M. Satalkar<sup>a</sup>, A. Ghosh<sup>a</sup>, D. M. Phase<sup>b</sup>, R. J. Chaudhary<sup>b</sup>,  
A. Pasko<sup>c</sup>, M. LoBue<sup>c</sup>, and F. Mazaleyrat<sup>c</sup>

<sup>a</sup>School of Physics, D. A. University, Khandwa road Campus, Indore – 452001, India

<sup>b</sup>UGC-DAE CSR, University Campus, Khandwa Road, Indore – 452 001, India

<sup>c</sup>SATIE, UMR CNRS 8029, ENS de Cachan, 61, Avenue du President Wilson,  
94235 Cachan, France

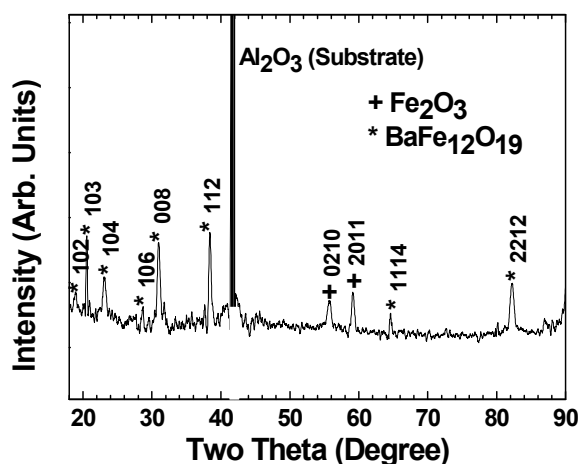
E-mail: kane\_sn@yahoo.com (S. N. Kane)

**Abstract.** Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> (BaO.6Fe<sub>2</sub>O<sub>3</sub>) films have been grown on (0001) sapphire substrate using pulsed laser deposition (PLD) technique. Prepared films were characterized by X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), X-ray reflectivity (XRR), atomic force microscopy (AFM) and magnetic measurements. XRD confirms the formation of Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> phase, whereas presence of Fe<sub>2</sub>O<sub>3</sub> was also identified. X-ray photoelectron spectroscopy (XPS) shows the signature of all the elements present in the barium ferrite. XRR data show the thickness of the film is ~ 24.2 nm with top layer roughness of ~ 3.7 nm. AFM measurement suggests the formation of clusters with average roughness of ~ 3.9 nm. Magnetic measurements of the target reveal its anisotropic nature with coercivity values: 0.23 and 0.24 T, obtained along two orthogonal directions. For the prepared thin film, the obtained coercivity ~80 mT and saturation induction 0.13 T are lower than the usual values obtained for Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> compound (coercivity and saturation induction values are 0.19 Tesla and 0.48 T respectively), can be ascribed to the presence of Fe<sub>2</sub>O<sub>3</sub> phase.

### 1. Introduction

Prominent feature of M-type hexaferrites is their chemical inertness, large uniaxial anisotropy inherent in the hexagonal crystal structure where the crystallographic c-axis is the magnetic easy axis, and high coercivity [1-2]. Hexaferrites have been the subject of intensive studies due to an appealing combination of good magnetic properties and low cost. This large family of oxides with hexagonal crystal structure contains ferrimagnetic compounds with easy axis of magnetization (*e.g.* M-type ferrites) and easy plane of magnetization (*e.g.* Y-type ferrites). Hence, hexaferrites have been widely adopted in two distinct fields: permanent magnets and microwave technology components [3]. In exchange spring media, two magnetically hard layers and a magnetically softer layer are strongly exchange coupled. The technological realization of such materials shows that they should be crystallographically coherent and consequently they are magnetically exchange coupled [4]. Objective of the present work is to obtain proper preparation conditions for growing Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> films using pulsed laser deposition (PLD), a pre-requisite in realizing exchange-spring magnets, for various applications. Although, we have grown Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> phase in our films, but our film also shows the

<sup>1</sup> To whom any correspondence should be addressed.



**Figure 1.** X-ray diffraction pattern of the prepared film.

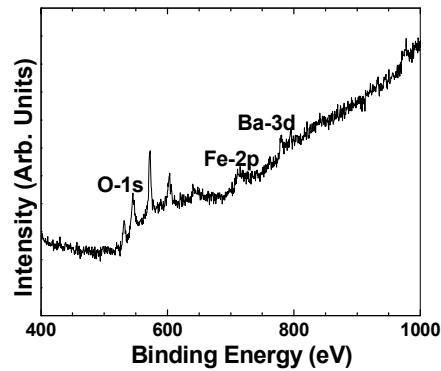
presence of Fe<sub>2</sub>O<sub>3</sub> phase. Further studies are under way, in order to grow single phase Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> films.

## 2. Experimental details

Thin film was deposited using a commercial barium hexaferrite target mounted on a rotating axel, and deposition was done for 30 min on (0001) sapphire (Al<sub>2</sub>O<sub>3</sub>) substrate. PLD set-up uses a KrF excimer laser (Lambda Physik model COMPEX-201) of wavelength 248 nm and pulse duration of 20 ns. During deposition the laser energy was kept 200 mJ/pulse, with pulse repetition rate of 10 Hz. The substrate temperature and oxygen pressure were maintained respectively at 800 °C and ~ 50 Pa (base pressure ~ 0.001 Pa). Focussed laser beam was made incident on the target surface at an angle of 45°. The substrate was mounted opposite to the target at a distance of 4 cm on a heater plate. After deposition, the sample was cooled slowly to room temperature. During cooling, the oxygen pressure was raised to 101325 Pa. It is of value to note that similar experimental conditions as well as same substrate (sapphire) was used to deposit barium hexaferrite thin films as reported in [5]. X-ray reflectivity and X-ray diffraction (θ-2θ configuration) measurements were done using a Bruker D8 Advance diffractometer, with Cu-K<sub>α</sub> radiation ( $\lambda = 0.154$  nm). The X-ray photoelectron spectroscopy (XPS) study was carried out using an Omicron EA-125 photoelectron spectrometer at a base pressure better than  $6.7 \times 10^{-8}$  Pa. Al K<sub>α</sub> radiation was employed for recording the spectra. Au 4f<sub>7/2</sub> at 84.7 eV served as an external reference. The sample surface was cleaned using 1 keV Ar ions before performing measurements to remove surface contamination. Atomic force microscope (AFM) image of sample was taken by Nanoscope-E using a pyramidal silicon nitride tip in contact mode. Magnetization measurements on target and deposited thin film were done using LakeShore Model 7410 VSM with a maximum applied field of  $\pm 1.7$  Tesla.

## 3. Results and discussions

Figure 1 depicts the X-ray diffraction pattern of Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> thin film. XRD of the substrate (Al<sub>2</sub>O<sub>3</sub>) was also done and the contribution of the substrate was subtracted from the diffraction pattern of the film. But, still a strong peak corresponding to substrate is seen in figure 1. Analysis of XRD pattern reveals the formation of Ba<sup>2+</sup>Fe<sub>12</sub>O<sub>19</sub> phase with lattice parameters:  $a = 0.5936$  nm,  $c = 2.3297$  nm, matches well as reported in [3]. XRD pattern also shows the presence of Fe<sub>2</sub>O<sub>3</sub> phase (Lattice parameters:  $a = 0.5572$  nm,  $c = 2.2506$  nm), also agrees well with the values given in JCPDS database.



**Figure 2.** XPS spectrum of the prepared film.

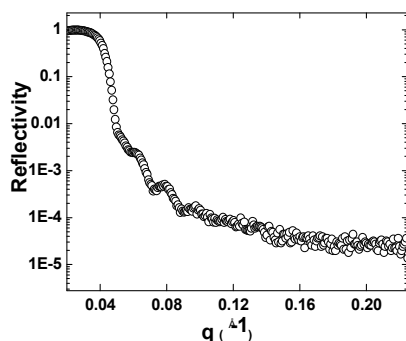
Figure 2 depicts the XPS spectrum corresponding to the pulsed laser deposited thin film prepared from barium ferrite target on sapphire ( $\text{Al}_2\text{O}_3$ ) substrate. Perusal of figure 2 shows the signature of all the elements present in barium ferrite.

Figure 3 shows the X-ray reflectivity pattern of the prepared film. Experimentally obtained XRR data were fitted using software based on the formalism developed by Parratt [6]. The thickness value obtained by fitting the X ray reflectivity pattern is  $\sim 24.2 \pm 0.5$  nm with top layer roughness  $\sim 3.7$  nm.

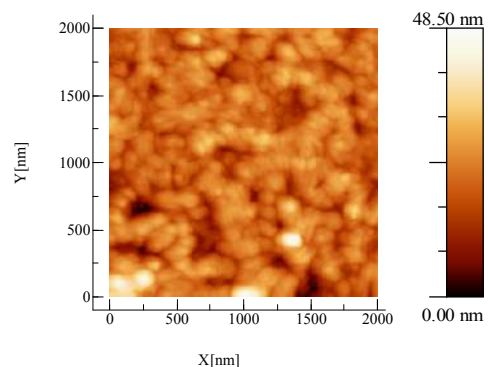
Figure 4 shows the AFM image of the prepared film. AFM image shows cluster formation with average roughness  $\sim 3.9$  nm, matches well with reflectivity measurements. Observed surface roughness ( $\sim 3.9$  nm) can be attributed to the higher substrate temperature during deposition.

Figure 5 shows the hysteresis loops of the target in two orthogonal directions, suggests the presence of in-plane anisotropy, with coercivity values 0.23 and 0.24 T respectively.

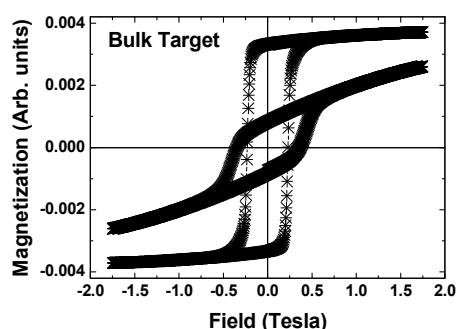
Figure 6 depicts the hysteresis loops of the prepared thin film. The obtained coercivity  $\sim 80$  mT and saturation induction 0.13 T are lower than the usual values obtained for  $\text{Ba}^{2+}\text{Fe}_{12}\text{O}_{19}$  compound



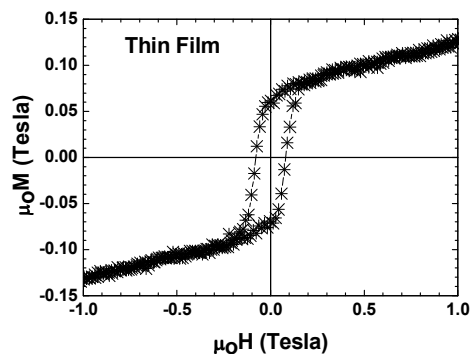
**Figure 3.** X-ray reflectivity of the prepared film.



**Figure 4.** AFM image of the prepared film.



**Figure 5.** Hysteresis loops of the target in two orthogonal directions, showing anisotropic nature.



**Figure 6.** Hysteresis loop of the prepared film.

(coercivity and saturation induction values are 0.19 T and 0.48 T respectively), can be ascribed to the presence of  $\text{Fe}_2\text{O}_3$  phase. Observed positive slope in the M-H curve shown in figure 6 could be due the contribution from the  $\text{Al}_2\text{O}_3$  substrate.

#### 4. Summary

Pulsed laser deposition technique was used to grow  $\text{Ba}^{2+}\text{Fe}_{12}\text{O}_{19}$  film on (0001) sapphire substrate. Formation of  $\text{Ba}^{2+}\text{Fe}_{12}\text{O}_{19}$  phase was confirmed by XRD. Presence of  $\text{Fe}_2\text{O}_3$  phase in the film was also confirmed by XRD. XPS measurements show signatures of all the elements present in the barium ferrite. XRR data give the thickness of the film to be  $\sim 24.2$  nm with roughness of the layer  $\sim 3.7$  nm. AFM images suggest the formation of clusters with average roughness of  $\sim 3.9$  nm. Hysteresis loops of the target reveal its anisotropic nature with coercivity values 0.23 and 0.24 T. Hysteresis loop of the prepared thin film reveals its coercivity to be  $\sim 80$  mT and saturation induction 0.13 T. These values are lower than the usual values obtained for  $\text{Ba}^{2+}\text{Fe}_{12}\text{O}_{19}$  compound (coercivity and saturation induction values are 0.19 T and 0.48 T respectively). This behaviour can be ascribed to the presence of  $\text{Fe}_2\text{O}_3$  phase, confirmed by XRD measurements.

#### Acknowledgments

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