Investigation of induced parallel magnetic anisotropy at low deposition temperature in Ba-hexaferrites thin films


Abstract

In this paper we present the effect of low substrate temperature on structural, morphological, magnetic and optical properties of Ba-hexaferrite thin films. Films were deposited on single crystal Silicon (1 0 0) substrate employing the Pulsed Laser Deposition (PLD) technique. The structural, morphological, magnetic and optical properties are found to be strongly dependent on substrate temperature. The low substrate temperatures (room temperature to 200 °C) restrict the formation of larger grains. For the higher substrate temperature i.e., 400 °C, the grain size of the deposited thin film are much larger. The film grown at low substrate temperature do not show any anisotropy. As the substrate temperature is increased, the easy axis of the films aligned itself in the direction parallel to the film plane whereas the hard axis remained in the perpendicular direction. The higher substrate temperature caused the uniaxial magnetic anisotropy, which is very important in magnetic recording devices. The saturation magnetization and optical band gap energy values of 62 emu/cc and 1.75 eV, respectively, were achieved for the film of thickness 500 nm deposited at 400 °C. Higher values of coercivity, squareness and films thickness are associated with the growth of larger grains at higher substrate temperature.

1. Introduction

Hexagonal ferrites are important magnetic oxides in thin film technology due to their high resistivity, high uniaxial magnetic anisotropy field and moderate saturation magnetization values [1]. Unlike magnetic metals, ferrites are transparent to RF and microwave frequencies, therefore they have the potential of being used in monolithic microwave integrated circuitry (MMIC), in magnetic wave frequencies, therefore they have the potential of being used in

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stoichiometry of the target material on the film after deposition. In our previous work single crystal c-axis Ba-hexaferrites thin films on sapphire substrate was deposited using Nd: YAG laser [16].

A long sought goal of the ferrite community has been the integration of ferrite-based microwave passive devices with semiconductor electronics. This requires the growth of ferrites on semiconductor substrates. Oriented hexaferrite films to be deposited on semiconductor substrates have the requirement of temperatures to grow a ferrite having low microwave loss. There is a great interest in fabricating the thin films of Ba-hexaferrites with either out of plane or in plane magnetic anisotropy using both amorphous or crystalline substrate for magnetic recording devices [17]. In the previous work, thin film deposition is performed usually at higher substrate temperatures, ranging from 500 to 920 °C [14,18,19]. In this paper, we present the work on the barium hexa ferrite films deposition using KrF Excimer laser comparatively at lower substrate temperature, i.e., RT to 400 °C on Si (1 0 0) substrate.

Aim of this work is to investigate the effect of lower (<500 °C) substrate temperature on the induced parallel magnetic anisotropy, structural, morphological and optical properties of thin films.

2. Experimental setup

The Ba-hexaferrites thin films have been fabricated on Si (1 0 0) substrates using PLD technique at different substrate temperatures i.e., RT, 100, 200, 300 and 400 °C. The experimental setup is shown in Fig. 2. Prior to the deposition, the native Si oxide was removed by a standard HF etching. KrF excimer laser (λ=248 nm, 50 mJ) operated at the repetition rate of 20 Hz was focused on the target with the help of a 20 cm focal length lens. The sintered target was mounted at an angle of 45° with respect to the laser beam. The target was rotated with the help of stepper motor at 6 rpms for the uniform film deposition. Substrate was placed parallel to the target at an optimized distance of 1.5 cm. The substrate temperature was measured with a thermocouple positioned in the middle of the substrate holder. The base pressure of the chamber was attained up to 10⁻⁵ Torr with a turbomolecular pump.

Crystal structure of these films was investigated by X-ray diffractometer (XRD), PANalytic Xpert in θ-2θ configuration (CuKα line λ =1.54 Å). The surface morphology and composition of thin films was explored by the Scanning Electron Microscope (SEM), S-3400N Hitachi equipped with Energy Dispersive X-ray (EDX) spectroscope. In order to characterize the magnetic behavior of the thin films, the measurements were performed using 7400 Lake Shore Vibrating Sample Magnetometer (VSM). Film thickness and optical band gap energies were evaluated by the Ellipsometric Spectroscopy (SE).

3. Results and discussions

The deposited Barium hexaferrite thin films on Si (1 0 0) were characterized by XRD, SEM, VSM and Spectroscopic Ellipsometry. The obtained data are discussed in detail.
The behavior of these films is due to an increase in substrate temperature, following the creation of new planes as already reported in [14,18].

Due to the higher substrate temperature, the mobility of the adsorbed molecules is formed due to the lattice mismatch between target and substrate [24]. The Ba-hexaferrite molecules will stack-up in certain nucleation sites, which will be arranged in nanorods-like structures (for film at 300 °C) and then in circular grains (at 400 °C). The relative spacing between the particles of the film decreases as a result the thickness of the thin films increases, which is observed from the cross-sectional views in Fig. 5.

3.3. Magnetic properties

The in-plane and out-plane hysteresis loops were measured at room temperature by applying the magnetic field parallel and perpendicular to the film plane. Due to the extremely low value of magnetic moment, the hysteresis loops were obtained after subtracting the offset background signals as a function of field. The magnetic curves of the thin films deposited at different substrate temperatures are shown in Fig. 4(f–j). The applied magnetic field was swept from −10 to +10 kOe. The coercive force ($H_c$), remnant magnetization ($M_r$) and magnetic moment ($M$), as well as the hysteresis squareness ($S_q=M_r/M_s$) for in-plane measurements are listed in Table 1.

The loops in Fig. 4 shows that the thin film deposited at RT, 100 and 200 °C exhibits paramagnetic behavior it may be due to the amorphous nature of the thin films. Whereas, the films prepared at 300 and 400 °C show the ferromagnetic behavior with the in-plane saturation magnetization. The saturation magnetization increases with the increasing thickness of the films. In the loops, one observes a uni-axial anisotropy with the magnetic easy axis aligned parallel to the film plane where the hard axis remained in the perpendicular direction of the film plane. The film deposited at 400 °C has small in-plane saturation magnetization i.e., 62 emu/cc and high coercivity value due to the higher thickness and larger grain shown in FESEM results. The lower value of $M_s$ is possibly due to the insufficient crystallization of the thin films.

A simple comparison between microstructures allows us to conclude that the origin of the higher in-plane magnetization in Ba-hexaferrites with the increasing substrate temperature is associated with the texturing of the films such that the crystallographic c-axis of the individual grains lies in the film plane considering large magnitude of the magnetocrystalline anisotropy field rather than the shape anisotropy. Such confirmation is supported by the analyses of [25,26].

3.4. Optical properties

Optical band gap energy ($E_g$) and thickness of these thin films were determined by employing the Ellipsometry Spectroscopy using Cauchy Uruck model [27]. The optical band gap is estimated from absorption coefficient,

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\alpha = \frac{4\pi k}{\lambda}
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where $k$ is an extinction coefficient and $\lambda$ is a wavelength of incident beam. According to the Tauc relation [28],

$$zhv = A(hv-E_g)$$

where $h$ is Planck’s constant, $v$ is frequency of incident light, $A$ is constant, and $E_g$ is optical band gap.
where $A$ is a constant, which is different for different material, $h\nu$ is energy of incident photon, $E_g$ is the band gap energy, and $m$ is theoretically equal to 2 (1/2) and 3 (3/2) for allowed indirect (direct) and forbidden indirect (direct) electronic transition, respectively. $(\chi h^2)^2$ is plotted versus $h\nu$ as shown in Fig. 6 (for films deposited at RT and 400 °C). The extrapolation of straight
line to \((\alpha h\nu)^2 = 0\) gives the value of direct band gap. The estimated value of optical band gaps are 2.32 and 1.75 eV for the films deposited at RT and at 400 °C, respectively. The optical band gap energies of these films decrease as the substrate temperature increases. The thin films thickness increases from 112 to 500 nm with the increase in the substrate temperature from RT to 400 °C, respectively. This is because of the increased adhesion between hot substrate and deposited material [29]. The increase in thickness and grain size with the increasing temperature is responsible for the reduction in optical band gap energy [30].

### 4. Conclusions

The thin films of Ba-hexaferrites were deposited on silicon (1 0 0) substrates using the pulsed laser deposition technique at different substrate temperatures. The film deposited at 400 °C is polycrystalline, but has the insufficient film crystallization. The thickness of the film increases with the increase in the substrate temperature, which in turn is responsible for the growth of bigger grains. The in-plane anisotropy is observed at lower substrate temperature (< 500 °C). The growth temperature of 400 °C resulted in better film crystallization.
in larger grain size and thicker films, as well as relatively high coercivity and saturation magnetization. The decrease in the band gap energy at this substrate temperature is due to the growth of larger grain and more defects inside the film.

References