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The effects of amorphous Al_2O_3 underlayer on the microstructure and magnetic properties of $BaFe_{12}O_{19}$ thin films

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ABSTRACT

Single phase nanostructured $BaFe_{12}O_{19}$ thin films have been deposited on Si(110) substrate and Si(110) substrate with amorphous Al_2O_3 underlayer by a sol–gel method. The effects of the amorphous Al_2O_3 underlayer on the composition, microstructure and magnetic properties were explored by X-ray diffraction, scanning electron microscopy and vibrating sample magnetometery techniques. The results revealed that the amorphous Al_2O_3 underlayer promoted some perpendicular *c*-axis orientation with $\Delta Hc = Hc_{\perp} - Hc_{\parallel} = 300$ Oe.

1. Introduction

Barium hexaferrite ($BaFe_{12}O_{19}$, BaM in short) and strontium hexaferrite ($SrFe_{12}O_{19}$, SrM in short) thin films have been regarded as one of the appealing candidates in the fabrication of perpendicular magnetic recording media due to rather high magnetocrystalline anisotropy and excellent mechanical and chemical stability [1–4].

Variable substrates such as Si/SiO_2, SiC [5], GaN [6] and sapphire [7] have been used to grow oriented BaM and SrM thin films. However, the lattice mismatch produces great strains in the films, especially at the interface, which will change the growth orientation of the films, and then affect both the magnetic and microwave properties [7]. However, a proper buffer layer can also play a crucial role in moderating mismatch strains, resulting in oriented growth of M-type hexaferrite films. Over the past decade, many various crystalline and amorphous underlayers have been attempted including ZnO, AlN, AlO and Pt(111) [8–12]. Furthermore, Hylton et al. [8] have reported that the interdiffusion between film and substrate strongly affects the structural and magnetic properties of barium hexaferrite films. Their report suggests the need for an underlayer between the film and substrate to optimize the characteristics of $BaFe_{12}O_{19}$ thin films for perpendicular magnetic recording applications.

In the present work, we have investigated the effects of the amorphous Al_2O_3 underlayer on the magnetic properties and microstructure of barium hexaferrite thin films deposited by the sol–gel spin coating method.

2. Experimental procedure

An amorphous Al_2O_3 underlayer with 50 nm thickness was deposited on the Si(110) substrate by RF diode magnetron sputtering apparatus. Sputtering was carried out at room temperature and in presence of Ar gas.

The $BaFe_{12}O_{19}$ sol was prepared by dissolving barium nitrate ($Ba(NO_3)_2$), iron nitrate ($Fe(NO_3)_3 \cdot 9H_2O$) and citric acid ($C_6H_8O_7$) in ethylene glycol ($C_2H_4(OH)_2$) while stirring at 80 °C. In this solution Fe/Ba molar ratio was 8 and the pH was also adjusted to 7.0 using trimethylamine (50% solution), C_3H_9N, as the basic agent [13]. The sol was spin-coated at 2000 rpm for 20 s on the Si (110) and Al_2O_3/Si(110) substrates. The obtained samples were dried at 120 °C for 24 h to remove the organics. The process was performed three times to achieve the film thickness of around 150 nm. At the end, the films were calcined at 500, 600 and 700 °C for 1 h in air.

The crystal structure and average crystallite size of the films were determined by X-ray diffraction (XRD) in θ–2θ geometry, using CuKα radiation (Philips PW-1730). The crystallite size was calculated with Scherrer equation by applying the full width at half maximum value of the (107) diffraction peak. The morphology was determined by using a scanning electron microscope (SEM) (CamScan MV2300). A vibrating sample magnetometer (Meghnatis Daghigh kavir Co., Iran) with a maximum applied field of

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10 kOe was employed to measure magnetic properties of the samples at room temperature.

3. Results and discussion

3.1. Structural study

The XRD patterns of the $BaFe_{12}O_{19}$ films deposited on the Si(110) substrate at different calcination temperatures are shown in Fig. 1. The XRD results demonstrate that $BaFeO_{3-x}$ is the only detected phase at 500 °C and the traces of $BaFe_{12}O_{19}$, $BaFe_2O_4$ and α-Fe_2O_3 phases appeared after calcination at 600 °C. However, the single phase $BaFe_{12}O_{19}$ film was formed after calcination at 700 °C.

Fig. 2 shows the XRD pattern of the single phase BaM film deposited on the Al_2O_3/Si(110) substrate after calcination at 700 °C. The appearance of the more intense diffraction peaks of BaM (008) and (0014) planes relative to that of (107) and (114) peaks shows the BaM/Al_2O_3 film exhibits somewhat perpendicular *c*-axis orientation. The *c*-axis perpendicularly orientated growth can be attributed to the amorphous nature of the Al_2O_3 underlayer which removes lattice matching difficulties. However, the high lattice mismatches between BaM (00*l*) film and Si(110) substrate (~30%) prevents *c*-axis perpendicular orientation growth. Furthermore, the existence of the oxygen atoms in the BaM film and the amorphous Al_2O_3 underlayer also results in a lower interface energy which promotes the *c*-axis growth [14]. The mean crystallite size of the single phase BaM/Al_2O_3 film is lower than that of the BaM/Si(110) film (Table 1), probably due to the easy BaM crystallization on the amorphous Al_2O_3 underlayer.

Fig. 3 illustrates SEM micrographs of the surface morphology of the BaM films deposited on the Si(110) and Al_2O_3/Si(110) substrates. Barium hexaferrite nanodiscs can be observed clearly in the surface morphology of BaM/Si(110) film. The BaM nanodiscs are really platelet-like crystals viewed from the edge [15]. However, grains are packed more densely and showing more *c*-axis orientation by Al_2O_3 underlayer, (if the perpendicular orientation was complete, the hexagon shape of the grains should be seen clearly).

3.2. Magnetic properties

Magnetization curves of the BaM film deposited on the Si(110) and Al_2O_3/Si(110) substrates are shown in Figs. 4 and 5, respectively. The magnetic properties of the BaM films are also presented in Table 2 The superposing of the out of plane hysteresis loop with the in plane hysteresis loop for the BaM/Si(110) film indicates that there is no preferred *c*-axis orientation of BaM grains in the film. However, the comparison of the in plane and out of plane magnetization curves of the BaM/Al_2O_3 film shows that there are some *c*-axis perpendicularly orientated grains in the film, as confirmed by the XRD results (Fig. 2). Furthermore, the magnetic anisotropy ($\Delta Hc = Hc_{\perp} - Hc_{\parallel}$) for the BaM/$Al_2O_3$ film is about 300 Oe, while it is 20 Oe for the BaM/Si(110) film due to the magnetic isotropy (Fig. 1).

The lower coercivities and higher magnetization of the BaM/Al_2O_3 film than those of the BaM/Si(110) film (Table 2) are due to the larger crystallite size and more perfect film. In other words, the films are likely to contain various types of defects such as off-stoichiometric material, pores, dislocations, twin boundaries etc.; all of which can cause pinning of the domain walls and increasing

Table 1
Mean crystallite size of the BaM films deposited on the different substrates after calcination at 700 °C.

Substrate	Mean crystallite size (nm)
Si(110)	23
Al_2O_3/Si(110)	34

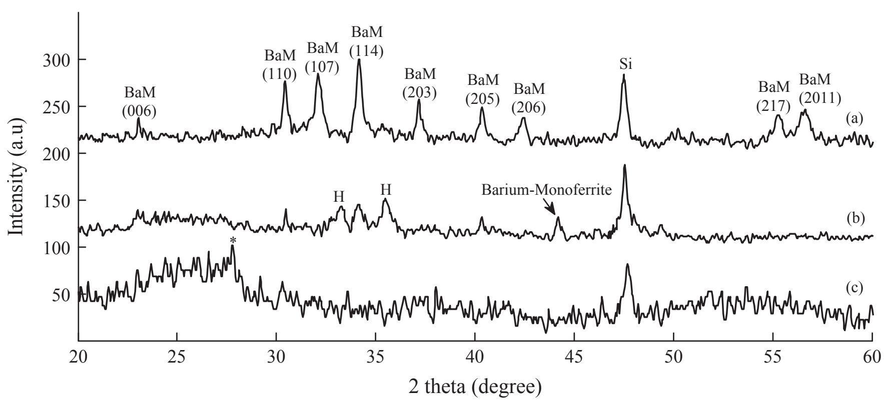

Fig. 1. XRD patterns of BaM thin films deposited on the Si(110) substrate after calcination at different temperatures: (a) 700 °C, (b) 600 °C and (c) 500 °C, (BaM: $BaFe_{12}O_{19}$, H: α-Fe_2O_3, Barium-Monoferrite: $BaFe_2O_4$, : $BaFeO_{3-x}$, Si peak in the patterns corresponds to the substrate).

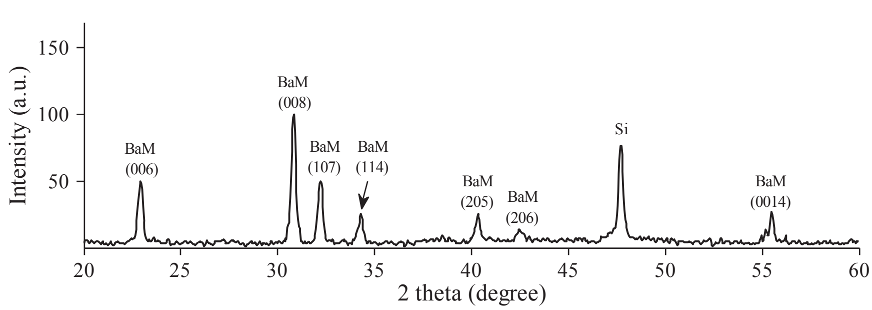

Fig. 2. XRD pattern of BaM thin film deposited on the Si(110) substrate with the amorphous Al_2O_3 underlayer after calcination at 700 °C, (BaM: $BaFe_{12}O_{19}$, Si peak in the patterns corresponds to the substrate).