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Investigation of structural and magnetic properties of nanoscale Fe/Co bilayers

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ABSTRACT

To understand the effects of deposition order and ion implantation on magnetic films, we have prepared Fe/Co and Co/Fe nanoscale bilayers by ion beam sputtering technique on Si(100) substrates. Implantation of 35 keV nitrogen ions in the presence of an in-plane magnetic field was done to modify the magnetic anisotropy at the nanoscale. The resulting microstructure and magnetic properties have been studied by X-ray diffraction and Magneto-Optical Kerr Effect. X-ray diffraction patterns of both the films give strong structural texture. The two films exhibit very different magnetic properties in terms of coercivity, anisotropy and domain structure. Two-fold uniaxial anisotropy has been observed in case of Sub./Co/Fe film while Sub./Fe/Co gives isotropic behaviour. Ion irradiation does not change the anisotropy in the film up to the ion fluence of 2×10^{16} ions/cm^2. Reduction in the coercivity up to 2×10^{16} ions/cm^2 has been observed in Sub./Fe/Co bilayers.

1. Introduction

Magnetic recording devices require soft magnetic materials with precisely defined uniaxial magnetic anisotropy and high saturation magnetization. Among the known soft magnetic materials, $Fe_{1-x}Co_x$ alloys have the highest saturation magnetization (~2.45 T), but their large coercivity does not make them suitable for magnetic write heads [1]. Magnetic properties of multilayer thin films are strongly influenced by microstructure such as film thickness, interface roughness and crystallinity [2–4]. In the case of Co/Fe bilayers, the microstructure and magnetic properties of the underlayer play an important role during the cooperatively coupled domain-wall movement [5]. Magnetic structure and anisotropy can easily be changed either by ion beam irradiation or by thermal annealing [6,7]. Zhang et al. showed that Xe-ion irradiation induces different effects as a function of ion fluence on the magnetic properties of Co/Fe bilayers. In the present paper, we study the effect of change of deposition order (Co-on-Fe and Fe-on-Co) and of nitrogen ion implantation on the magnetic properties Co/Fe bilayer films.

2. Experimental procedure

Bilayer films of Fe/Co were deposited on Si(100) substrates(Sub.) by ion beam sputtering deposition. Substrates were cleaned by ultrasonic cleaning with acetone. An argon ion beam was used for sputtering, and a base pressure of the order of 10^{-6} Torr was achieved. The sputtering rates of Fe and Co were initially measured by X-ray reflectivity and found to be 3.0 nm/min and 2.6 nm/min for Fe and Co respectively. All the deposition parameters were kept constant in the two cases of Sub./Fe/Co and Sub./Co/Fe films so as to compare only sample dependent properties. The thickness of each Fe and Co layer in both cases was 37 nm with the sample dimensions of 8×12 mm. 35 keV nitrogen ion implantation was performed at an IGCAR low energy accelerator having an RF ion source. An in-plane magnetic field of 100 Oe was applied so as to align the direction of magnetization in the film plane. Beam sweeping arrangement was used, with the beam collimator diameter of 12.5 mm, so as to cover the maximum sample area. According to SRIM simulations, the ion energy was selected so that the N-ion profile covered only the Fe/Co films, and ion beam mixing at the film/substrate interface was avoided. Phase analysis of the samples was done by X-ray diffraction using Cu–Kα radiations in θ–2θ geometry. Magnetic hysteresis loops were measured at room temperature by means of the magneto-optical Kerr effect (MOKE) with the linearly polarized beam of a He–Ne laser ($\lambda=632$ nm) in the longitudinal configuration, which probes the in-plane magnetization. Angular dependence of coercivity and M_r/M_s was measured by rotating the sample at fixed angles, where M_r represents magnetic remanence and M_s represents saturation magnetization. The long axis of each specimen was considered as the reference line for the MOKE angular scans. The irradiated areas and surroundings were characterized simultaneously by atomic force microscopy (AFM) and magnetic force microscopy (MFM) at room temperature, operating in

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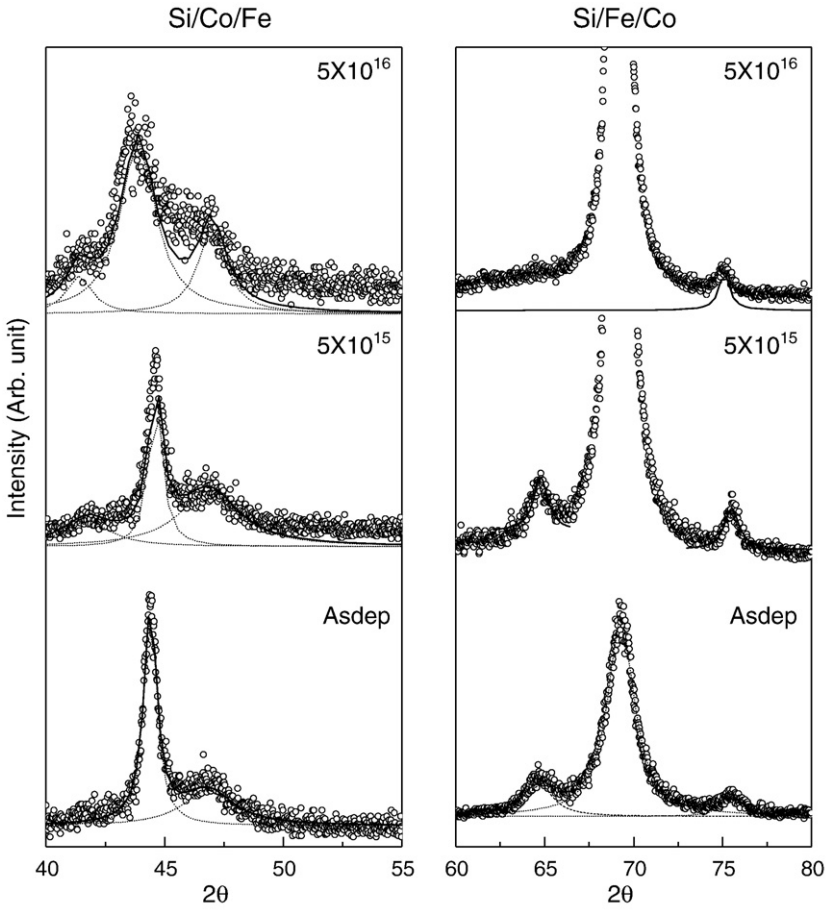

Fig. 1. X-ray diffraction patterns of Sub./Fe/Co films and Sub./Co/Fe, before and after ion implantation of different nitrogen ion fluence.

the "tapping/lift™" scanning mode, to separate short-range topographic effects from long-range magnetic signal. Thin film pyramidal MFM tips [type magnetic etched silicon probe] coated with a magnetic CoCr alloy magnetized perpendicular to the sample surface have been used as a scanning probe. The images were collected in the remanence state. In-plane fields were applied up to 500 Oe to saturate the film.

In order to monitor the film thickness, sputtering and interface mixing effects, Rutherford backscattering spectrometry (RBS) with 1.8 MeV He^{2+} ions was performed, using a Si surface barrier detector with about 18 keV energy resolution, positioned at a scattering angle of 165° relative to the beam axis.

3. Results and discussion

3.1. As-deposited

Fig. 1 shows the X-ray diffraction pattern of as-deposited films of Sub./Co/Fe and Sub./Fe/Co. From the XRD pattern, one may observe that the Sub./Co/Fe gives the peaks at 44.05 degree corresponding to bcc Fe(110), fcc Co(111) and hcp Co(002) and 46.82 degree corresponding to hcp Co (101), while the Sub./Fe/Co gives the peak at 64.82 degrees which corresponds to Fe(200) and at 75.45 degrees, which is attributed to fcc Co (220) and hcp Co(110), besides the peak of Si substrate. From the XRD pattern, one can conclude that a strong texture due to substrate effect or order of deposition is present in the film. Earlier Zhang et al. showed that the Sub./Fe/Co film deposited by electron beam evaporation gives an XRD pattern similar to the pattern obtained in the case of Sub./Co/Fe bilayer thin film [8]. The different orientation of the film in our case may be due to the ion beam sputtering method. Similar strong texture has been observed by Gupta et al. [9] also, when they deposited the bcc FeCo film by pulsed laser deposition method. They found that the structural texture in the film is due to columnar growth of FeCo [10]. Yu et al. [11] also demonstrated that for deposition of NiFe layer by RF sputtering, grains are randomly oriented, while columnar grains of Co are present when Co is deposited on NiFe. However, due to the columnar grain growth of Co, an induced columnar grain structure has been observed for NiFe layer deposited on Co. Thus, one can obtain different crystal textures in the film. From the energy dispersive X-ray diffraction measurements, Gupta et al. showed that the texture in the Fe/Co Film is out-of-plane [12].

Fig. 2 shows the magnetic hysteresis loops for both of the bilayer films. The average coercivity of the film is quite different in the two cases; it is 76 ± 3 Oe and 34 ± 2 Oe in case of Sub./Fe/Co and Sub./Co/Fe,

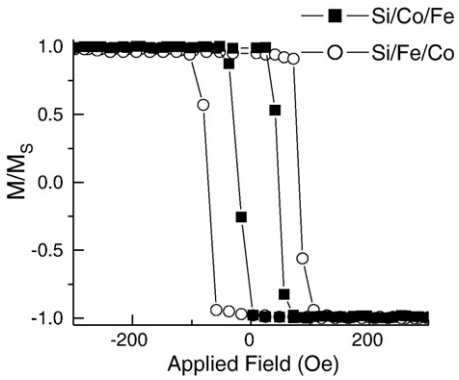

Fig. 2. In-plane hysteresis curves of Sub./Fe/Co and Sub./Co/Fe in the case of as-deposited specimens.