Magnetic properties of sputtered IrMn/CoFeB nanometric bilayers for exchange biased magnetic tunnel junctions

Himanshu Fulara, M. Raju, Sujeet Chaudhary, Subhash C. Kashyap and D. K. Pandya

Thin Film Laboratory, Indian institute of Technology Delhi, New Delhi-110016 (India)

ABSTRACT

In the present work, magnetic properties of sputtered IrMn (y nm)/CoFeB (x nm) bilayers were studied systematically as a function of annealing temperature, applied magnetic field and thickness of individual layers. The MOKE loops of the A- and B-series bilayers with x =7, 10, 15 and 20nm and y =5, 10, 15 and 20nm were obtained for both, as-deposited as well as magnetically-annealed films. The coercivity, as inferred from these loops, was found to increase by nearly three times with magnetic annealing. The coercivity values estimated from current in plane AMR measurements at room temperature match with the MOKE results.

Keywords: IrMn, MOKE, Thin Films, Exchange bias, MTJ

1 INTRODUCTION

Ultrathin magnetic multilayers find application in spintronic devices including spin valves and magnetic tunnel junctions (MTJs). In a spin valve [1], typically two ferromagnetic (FM) layers are separated by a metallic layer, while in an MTJ [2] the metallic layer is replaced by an insulator film also called as barrier. The electrical resistance of MTJs depends on the relative orientation of the magnetization of the FM layers. In order to obtain well separated magnetic states, an antiferromagnetic (AF) layer is deposited juxtaposed to one of the FM layers. Due to the exchange interaction at the AF/FM interface, the FM layer is pinned and the reversal of the magnetization (M) in this layer will occur at a high applied magnetic field, and hence the name pinned FM layer. The magnetization of the other so-called free layer FM layer can be reversed with a small applied magnetic field [3]. The exchange bias (EB) is manifested by a shift in magnetic hysteresis loop, enhanced coercivity, and asymmetry in the magnetization reversal process. Reported high interfacial exchange energy (J_k or H_{ex}), low coercivity (H_c), high blocking temperature (T_B), and good thermal stability of $Ir_{20}Mn_{80}$ thin films make it most suitable AF layer [1]. Magneto-Optical Kerr Effect (MOKE) is an effective technique to characterize such magnetic structures.

The aim of the present research is to study the effect of thickness of FM and AF layers on the coercivity of IrMn/CoFeB,and hence to pin the bottom FM layer in CoFeB/MgO/CoFeB magnetic tunnel junctions (MTJs). In this paper, we report systematic study of magnetic properties such as coercivity (H_C) and magnetoresistance (MR) of the $Ir_{22}Mn_{78}$(IrMn)/ $Co_{20}Fe_{60}B_{20}$ (CoFeB) bottom-configuration system (i.e., AF layer below the FM layered) as a function of annealing temperature, direction of applied magnetic field and thicknesses of individual layers.

2 EXPERIMENTAL DETAILS

The bottom configuration $Ir_{22}Mn_{78}$/ $Co_{20}Fe_{60}B_{20}$ bilayer system was sputter deposited at room temperature onto an oxidised Si(100) substrate. Two sets of bilayers: (A) IrMn(10 nm)/CoFeB(x nm), where x = 7, 10, 15 and 20 nm and (B) Si(100)/IrMn(y nm)/CoFeB(10 nm), where y = 5, 10, 15 and 20 nm, were prepared. The IrMn layers were deposited by DC magnetron sputtering at a working pressure of 1×10^{-2} Torr, and the CoFeB layers were deposited by ion-beam sputtering at a working pressure of 1.3×10^{-4} Torr. The layer thicknesses were estimated by using X-ray reflectivity (XRR) measurements. For each set of bilayers, we have three different sample type, namely (a) as-grown samples deposited at substrate temperature (T_S) of 25°C (RT); (b) Magnetically annealed samples, i.e., which are subjected to post-deposition annealing in presence of magnetic field of 3 kOe at a temperature (T_A) of 350°C for 30 min in a vacuum of 4×10^{-6} torr, followed by field cooling to RT; (c) the same procedure as in (b) except that T_A was 420°C.

The magnetic properties of the IrMn/CoFeB system were investigated at room temperature by Magneto-Optical Kerr Effect (MOKE). MOKE M-H hysteretic loops were obtained in the transverse geometry, with H in the film plane and perpendicular to the laser-beam incident plane. The magneto resistance (MR) of few samples was measured at room temperature in a four terminal geometry.

3 RESULTS AND DISCUSSION

The MOKE M-H loops obtained for both, as-deposited as well as magnetically-annealed IrMn (10 nm)/CoFeB (x nm) bilayers are presented in Fig. 1 for selected thicknesses (x=7, 10, 15 and 20 nm). We observe a smooth and relatively less sharp magnetization reversal in M(H) for as-deposited as compared that observed in magnetically annealed bilayers. The loops in latter cases were almost of square shape. The H_C obtained from these MOKE loops shows a peak and then decreases to its value as x increases above 10 nm (i.e., greater than AF layer thickness) in as-deposited as well as magnetic annealed samples.

This may be interpreted by considering the random field model [4] as described below.

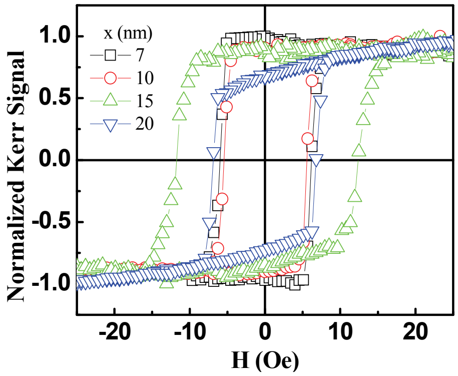

Fig. 1a: MOKE loops obtained for IrMn(10 nm)/CoFeB(x nm) as deposited bilayers.

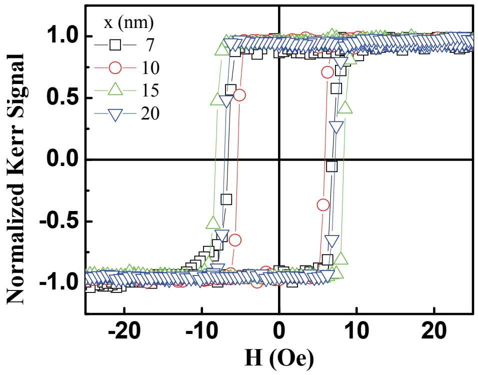

Fig. 1b: MOKE loops obtained for IrMn(10 nm)/CoFeB(x nm) bilayers magnetic annealed at 350°C

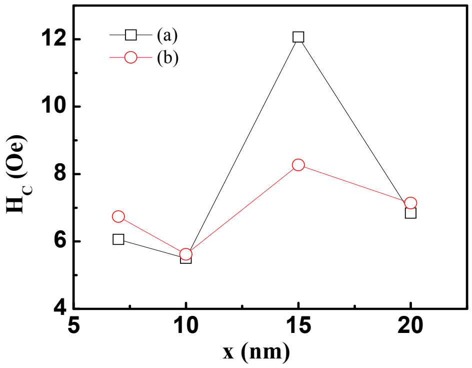

Fig. 1c: Dependence of H_C on the FM layer thickness for Si/IrMn(10 nm)/CoFeB(x nm) (a) as deposited, and (b) magnetic annealed (350°C).

At lower film thickness, the FM layer is expected to break into large number of domains, possibly of size much smaller than grain size. The random field arising due to inhomogeneities present in the AF grains can better act upon the FM layer and can delay the magnetisation reversal of the FM layer resulting in higher H_C. We believe that this is the case at an optimum thickness of 15 nm for the present CoFeB/IrMn system, where the additive grain boundary pinning contributions causing further increase in H_C are at maximum. Since the ferromagnetic coupling between two neighbouring ferromagnetic blocks is proportional to the thickness of the FM layer, thicker FM layer produce larger domain sizes in the FM layer. For larger domains, the net coercive force (random fields from the underlying AF grains) acting on the FM layer is averaged out. Understandably, this would lead to small H_C as observed in the present case.

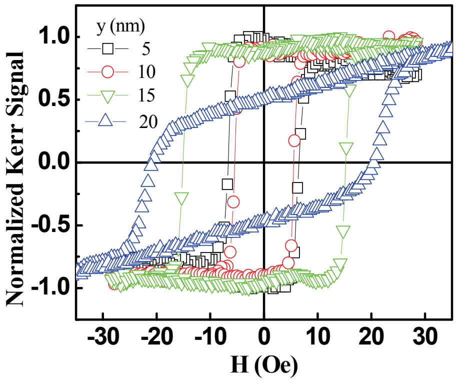

Fig. 2a: MOKE loops obtained for IrMn(y nm)/CoFeB(10 nm) as deposited bilayers

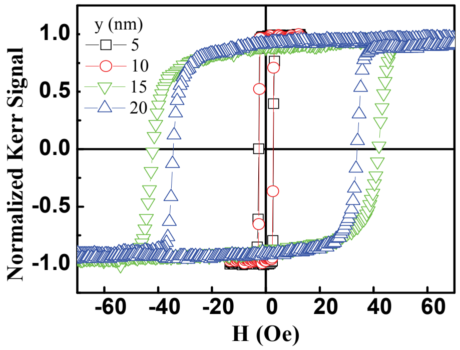

Fig. 2b: MOKE loops obtained for IrMn(y nm)/CoFeB(10 nm) bilayers magnetic annealed at 350°C

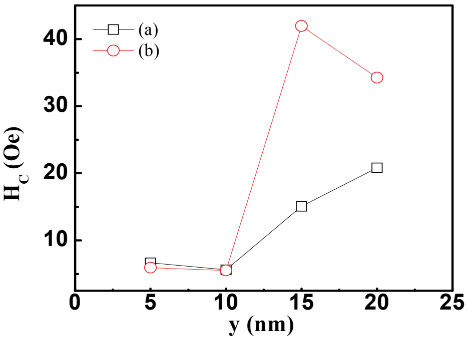

Fig. 2c: Dependence of H_C on the FM layer thickness for Si/IrMn(y nm)/CoFeB(10 nm) (a) as deposited, and (b) magnetic annealed (350°C).

Figure 2 shows the y-dependence of H_C for the IrMn(y nm)/CoFeB(10 nm) system. The higher H_C observed CoFeB film deposited on for thicker AF layer (i.e., y=15 and 20) in both as deposited and magnetically annealed samples can be attributed to the effective interaction of the random field in the thicker AF layer with the FM domains, since on increasing the AF film thickness the number of bulk inhomogeneities in the AF layer is increased leading to more effective pinning/biasing of the FM spins. The precise nature of the inhomogeneities in the AF layer (e.g., structural, thickness or compositional randomness), is unclear [5].

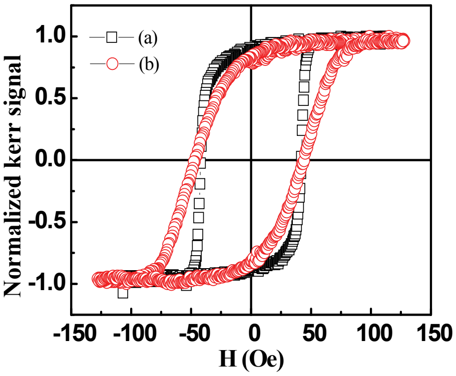

Fig. 3: MOKE MH loops for magnetic annealed Si/IrMn(15 nm)/CoFeB(10 nm), H applied in film plane but (a) parallel (b) perpendicular to the direction of annealing field (3kOe).

Figure 3 Shows the MOKE MH-loops recorded on the same magnetically annealed Si/IrMn(15 nm)/CoFeB(10 nm) sample by applying magnetic field (in film-plane) in a direction parallel (Fig 3a) and perpendicular (Fig 3b) to the direction along which 3 kOe field was aligned during magnetic annealing. It was observed that M-H loop measured along hard axis (normal to the direction of annealing field) deviates from the loop measured along the easy axis (in the direction of annealing field). This clearly shows that magnetic annealing conditions have induced anisotropy in these bilayers.

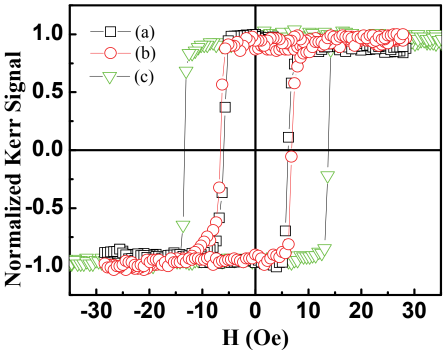

Fig. 4a: MOKE loops obtained for Si/IrMn(10 nm)/CoFeB(7 nm) under three different conditions: as-deposited at RT (a), magnetic annealed at 350°C (b) and 420°C (c).

Subsequently, the effect of varying the annealing temperature in presence of magnetic field was also investigated in both the series, i.e., Si(100)/IrMn(y nm)/CoFeB(x nm), and Si(100)/IrMn(10 nm)/CoFeB(x nm). It was found that higher annealing temperature always resulted in increase of H_C (See Figs. 4a, 4b and Figs. 4c & 4d). Also, the increase was found to be more when thickness of IrMn layer was increased further to 20 nm.

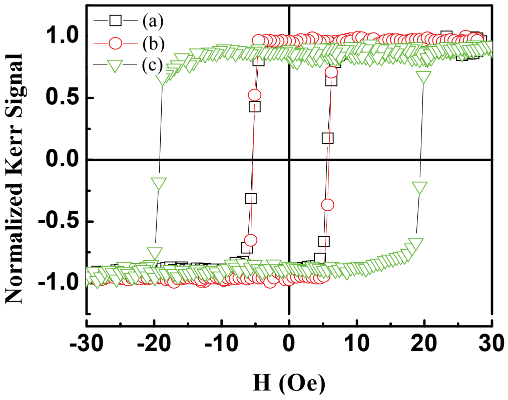

Fig. 4b: MOKE loops obtained for Si/IrMn(10 nm)/CoFeB(10 nm) under three different conditions: as-deposited (a), magnetic annealed at 350°C (b) and 420°C (c).

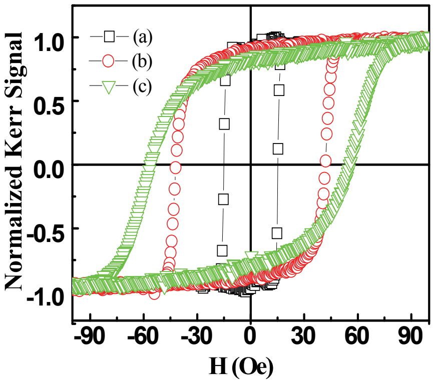

Fig. 4c: MOKE loops obtained for Si/IrMn(15 nm)/CoFeB(10 nm) under three different conditions: as-deposited at RT (a), magnetic annealed at 350°C (b) and 420°C (c).

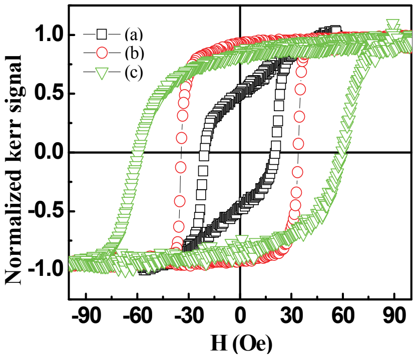

Fig. 4d: MOKE loops obtained for Si/IrMn(20 nm)/CoFeB(10 m) under three different conditions: as-deposited at RT (a), magnetic annealed at 350°C (b) and 420°C (c).

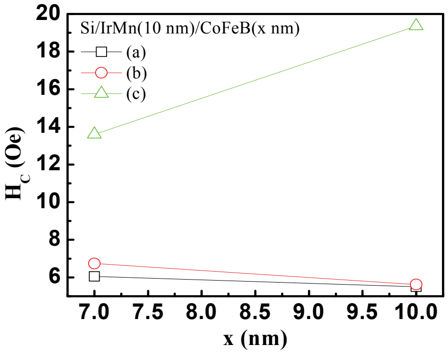

Fig. 5a: Variation in H_C with the FM layer thickness x under different annealing temperatures as-deposited at RT (a), magnetic annealed at 350°C (b) and 420°C (c).

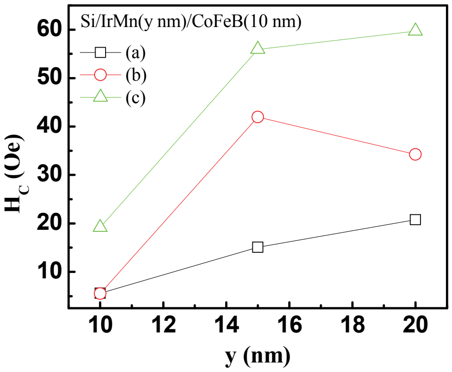

Fig. 5b: Variation in H_C with the AFM layer thickness y under different annealing temperatures as-deposited at RT (a), magnetic annealed at 350°C (b) and 420°C (c).

Figures 5a and 5b summarises the results of magnetic annealing temperature for two series samples. The substantial increase in H_C, irresepective of the thickness of the FM/AF layer, with increase in annealing temperature from 350°C to 420°C is likely to be due to the fact that the exchange bias effects get more pronounced as the magnetic annealing temperature is increased across the Neil temperature (T_N) of the underlying AF layer. In the present case, T_N of the IrMn layer is ~410-420°C, and hence magnetic annealing at 420°C shifted the magnetisation-reversal to higher field resulting in higher H_C~60Oe. We further stress here that other pinning mechanisms such as in homogeneities in the AFM-FM coupling or thermal fluctuations may also in part account for the observed higher H_C [1].

Figure 6 show the current-in-plane magnetoresistance (MR) measurements recorded at room temperature for the magnetically annealed (350°C) IrMn(5nm)/CoFeB(10nm) bilayer sample. The MR data has been recorded by applying magnetic field normal to the measuring current. The H_C values obtained from these measurements on different samples agree with that obtained by MOKE M-H results.

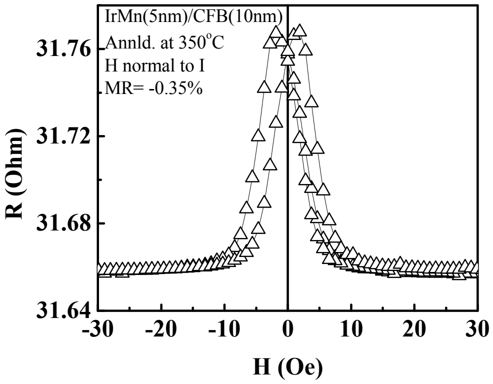

Fig. 6: MR curve (RT) of the magnetic annealed sample IrMn(5 nm)/CoFeB(10 nm).

4 CONCLUSIONS

We performed MOKE studies on IrMn/CoFeB bottom configuration systems with variable CoFeB or IrMn thickness, as a function of annealing temperature and applied magnetic field. The study reveales that higher IrMn thicknesses are needed to increase the coercivity of CoFeB films. Tunability H_C of FM electrode in IrMn/CoFeB exchanged bias systems can be realized by IrMn thickness. Further higher annealing temperature helps in increasing the coercivity by nearly three times compared to as deposited case. Coercivity values obtained from the MR measurements agrees with the coercivity obtained from MOKE measurements. The study promised that compared to Fe/MgO/Fe system, the coercivity values of top and bottom FM electrodes can be easily independently tuned to widely different H_C values in Si/IrMn(y nm)/CoFeB(x nm)/MgO(t nm)/CoFeB(z nm) TMR structures.

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