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THICKNESS DEPENDENT COERCIVE FIELD AND MAGNETIC ANISOTROPY IN COFEB THIN FILMS

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ABSTRACT

Transition metal–metalloid (TM–M) alloy CoFeB is an amorphous soft ferromagnetic material. The structural and magnetic properties of as-grown 6–24 nm thin magnetron sputtering deposited $Co_{20}Fe_{60}B_{20}$*films are reported in this communication. We report the magnetization behavior of the as-deposited sputtered CoFeB films synthesized at 300 K. The longitudinal Magneto-Optic Kerr Effect measurements achieved at 300 K in these as-grown films clearly established increase in the coercivity with the increase of the film thickness. The coercivity is increasing due to the annealing of thin films at 300*$^{\circ}$*C. The X-ray measurement of as-deposited Si/CoFeB thin films indications that the as-deposited film is amorphous whereas after 300*$^{\circ}$ *anneal it become crystalline bcc CoFeB as it obvious from the clear presence of the diffraction peak at* $2\theta \sim 44.8^{\circ}$ *attribute to (110) plane.Study of their magnetization behaviour by MOKE measurement for examinations of anisotropy measured at different angles between the applied field H and the uniaxial anisotropy axis (*0°*) of the film and find easy axis (*0°*) & hard axis (*90°*). We have estimated the magnetic anisotropy by evaluating the anisotropy field* H_k *(*θ*) is found to increase from* $\theta = 0^{\circ}$ *to* 90° *thus magnetization behavior in this film is telling of certain existence of in plane uniaxial anisotropy (*K_u*).*

Keyword; Magnetization, MOKE, CoFeB thin film, uniaxial anisotropy and As-deposited.

1. Introduction:-

Ultrathin ferromagnetic (FM) thin films are the basic key of the Spintronic devices due to the fact that the direction of magnetic easy-axis and strength of magnetic anisotropy in these films can be manipulated by underlying buffer layer, external magnetic field for the period of growth, deposition and magnetic annealing[1–3]. The magnetic properties of these materials are the result of the competition between the ferromagnetic exchange interaction and the magnetocrystalline anisotropy of each site. The magneto-crystalline anisotropy will try to rotate the spin moment to the direction of anisotropy of each particular site whereas the exchange coupling will try to align the spins from site to site. As aoutcome, the spins will be spatially interconnected (aligned) over a characteristic length that will be longer the stronger is the exchange interaction compared to the magneto-crystalline anisotropy. The magnetization behavior of such films is likely to add to the appreciative of the complex participation of domains in the magnetization procedure.[4]

The ferromagnetic CoFeB alloy is an amorphous soft material. It steadily recrystalline at annealing above a temperature which depends on its composition.The CoFeB is a strongly utilizable material in spintronics devices such as in magnetic tunnel junctions (MTJs), sensor applications, magnetic random access memories (MRAMs) and other novel devices [5-6].CoFeB in concurrence with AlO[7-8] and recently with MgOhas been shown to reveal a record high tunnel magnetoresistance (TMR) values at room temperature. In such devices, the in-plane magnetic anisotropy of the CoFeB films is a required property for their process.Long-range nature is not necessary for a material to demonstrate ferromagnetic propertiesbecause of the nature of the exchange interaction, short-range nature is far more momentous. The structural and magnetic properties of as-grown 6–24 nm thin magnetron sputtering deposited transition metal–metalloid $Co_{20}Fe_{60}B_{20}$ (CFB) films are reported in this paper.CoFeB films can be either amorphous or crystalline, depending on the boron content, seed layers, film thicknesses and magnetic thermal treatment. This was investigated by Cardoso *et.al* [9].In the current report, the structural and magnetic properties of the as deposited single layer softferromagnet *CoFeB* of different thicknesses is investigated by using MOKE SET UP (to investigate magnetic properties) and GAXRD (to investigate the structural properties).

2. Experimental details

Single layer $Co_{20}Fe_{60}B_{20}$(x) films (where x = 6nm, 14nm, 20nm and 24 nm) are deposited bydc-magnetron sputtering system on Si (100) substrate. Before the deposition, substrates were cleaned first with acetone and then propane in ultrasonic bath. Deposition was carried out at 1×10^{-3}torr pressure and 50 watts DC power in argon gas environment (30 sccm) at room temperature. The deposition rate is estimated (~ 0.034 nm / sec) by knowledge of film thickness and depositiontime. The grown films were further annealed at 300 °C for 60 min in 4×10^{-6}torr vacuum.*As-deposited* and annealed samples were characterized for structural and magnetic properties using versatile techniques. Structural characterization is carried out with glancing angle X-ray diffraction (GAXRD). Hysteresis loop and hence magnetic properties of *as-deposited* and annealed samples were characterized at room temperature using magneto optical Kerr effect (MOKE). MOKE measurement was recorded in longitudinal geometry where direction of magnetic field is both in plane and perpendicular to laser incident beam (where laser beam is in s-polarized state).

3. Result and discussion

3.1 X-Ray Diffraction Analysis

Fig.1 (a & b) shows GAXRD measurement of as-deposited and 300 °C annealed CoFeB thin film (24nm). The featureless XRD pattern observed for *as-deposited* thin film shows amorphous nature of the film[10-11]. The presence of diffraction peak at 44.7°for the films annealed at 300 °C is attributed to (110) plane with bcc structure[12-13]. This is clear evidence of the fact that annealing leads to conversion in amorphous to crystalline nature. Furthermore, increase in films thickness results in the enhancement in crystalline nature due to increase in peak intensity (or reduction in FWHM). The reduction in FWHM indicates an increase in grain size which is estimated using Scherer's formula

$$D = \frac{0.89\ \lambda}{\beta cos\theta}$$

Where D is crystallite size,λ wavelength of X-ray used (1.54 Å) and β is FWHM and θ is Bragg's angle.

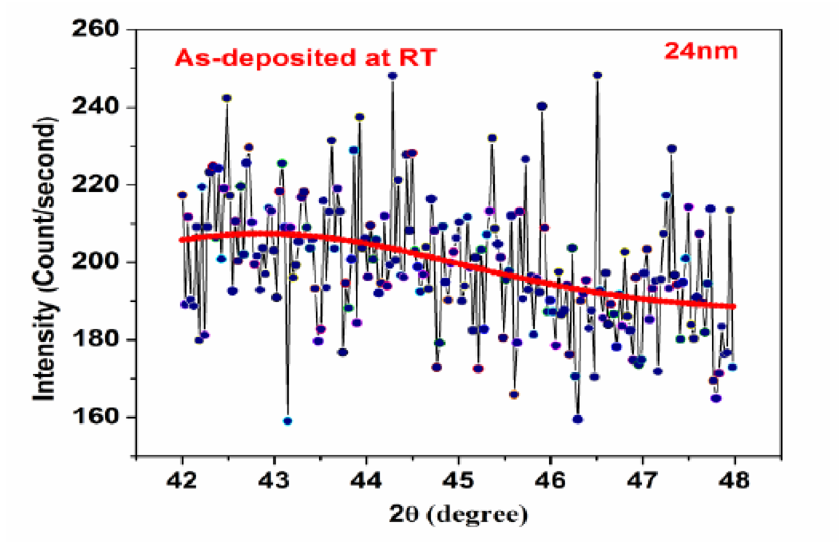

Fig. 1 (a) XRD scan of *as-deposited* CoFeB thin film (24 nm) exhibiting amorphous nature

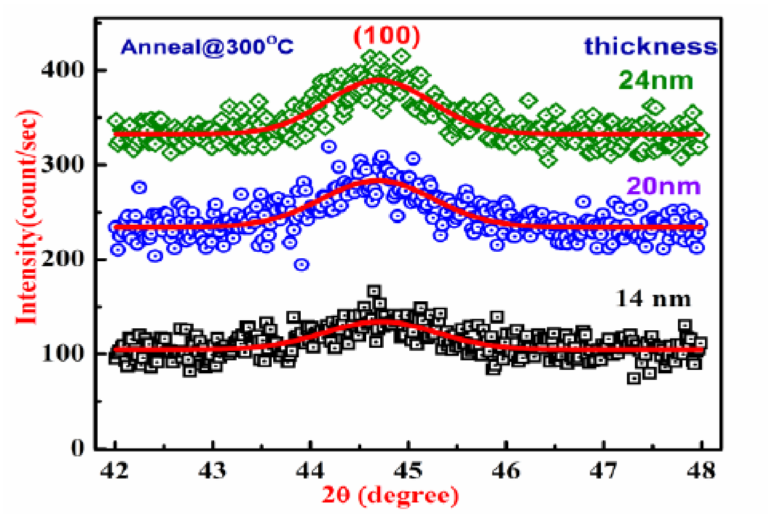

Fig.1 (b) XRD pattern of CoFeB thin films (14 nm, 20 nm and 24 nm) annealed at 300°C.

3.2 Magneto-Optic Kerr effect

Magnetic characterization (M–H loop) was carried out at room temperature using longitudinal magneto-optic Kerr effect (L-MOKE) magnetometer (Fig. 2). MOKE works on the principle that the interaction of polarized light with a magnetic sample governs the change in polarization of light. In L-MOKE system, magnetic field orientation is perpendicular to the plane of incidence and parallel to the surface of sample.

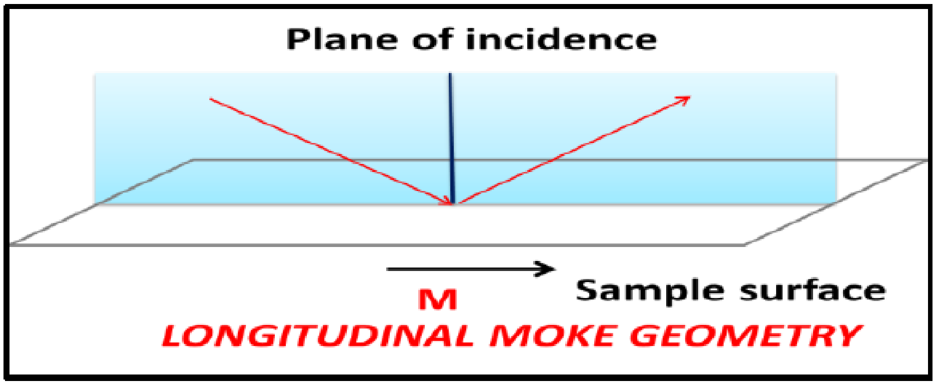

Fig.2 Schematic representation of Longitudinal MOKE (L-MOKE) Geometry

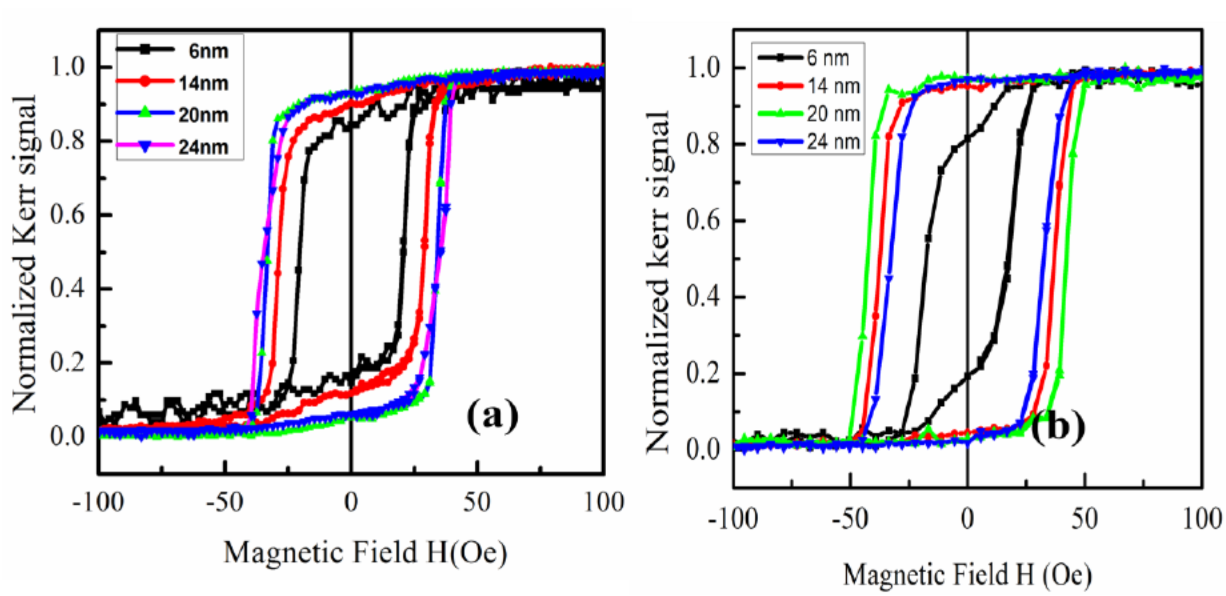

Fig. 3 MOKE M-H loops of CoFeB thin films having thickness 6 nm, 14 nm, 20 nm& 24 nm(a)*as-deposited*& (b) annealed at 300 °C.

3.2.1Thickness dependence magnetization study

The magnetic loops for $Co_{20}Fe_{60}B_{20}$ thin films (*as-deposited* and annealed) obtained using L-MOKE technique are presented in Fig. 3**.** Well-defined coercive (Hc) behaviour in magnetization loop shows transition from one saturated magnetic state to oppositely saturated magnetized state. The coercivity(H_c) values for *as-deposited* films having thickness 6 nm, 14 nm, 20 nm and 24 nm are found to be ~ 20 Oe, ~ 28 Oe, ~33 Oe and ~34 Oe respectively.

Magnetic measurements were again carried out on these samples after vacuum annealing at 300 °C. In this case, coercivity(H_c)value for 6 nm film annealed at 300 °C is ~17 Oe. The increase in thickness i.e. for 14 nm & 20 nm leads to boost in coercive values (~ 37 Oe and ~ 42 Oe) respectively. Further, increase in film thickness is expected to cause increase in grain size and hence reduction of grain boundaries. Generally in thin films, grain size is proportional to film thickness.The observed XRD patterns, as discussed earlier (Fig. 1) indicate that *as-deposited* CoFeB film is amorphous, whereas annealed CoFeB films are crystalline in nature. It can be concluded there is an enhancement in film-crystallinity and coercivitydue to annealing in comparison to as-deposited CoFeB thin films. However for 24 nm thick film annealed at 300 °C shows reduction in H_c value (~32 Oe) as can be seen from (Fig. 4). This may be attributed to multi-domain behavior of thin films at higher thicknesses.

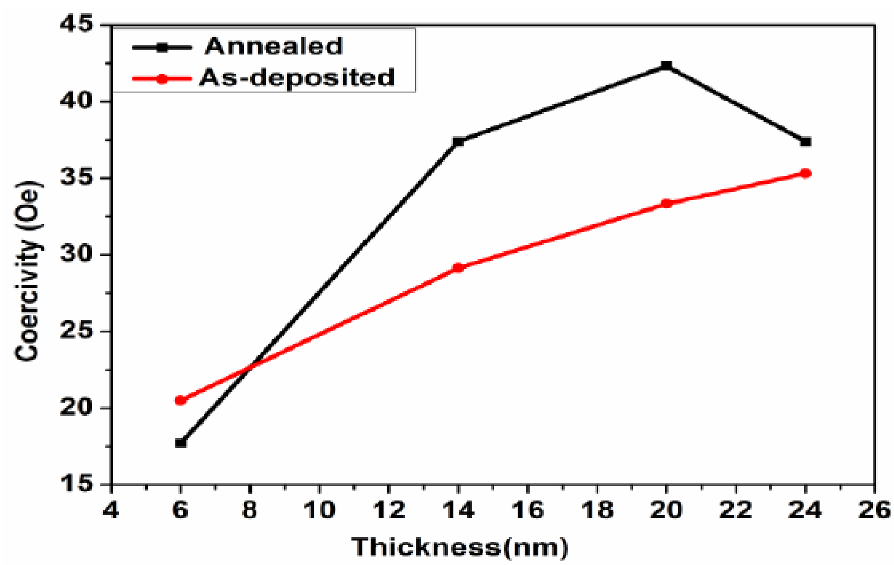

Fig. 4 Variation of coercivity (H_c) with film thicknesses (t) for *as-deposited* and 300°C annealed CoFeB thin films.

3.2.2Angular dependence of magnetization reversal mechanism

To further study the nature of magnetic anisotropy, MOKE measurements were carried out at different angles lying between θ=0° to90°[14]. Fig. 5(a) shows such a data for 24nm CoFeB thin film. The growth of magnetization in hysteresis loop is attributed to systematical change from the sharp reversal. The gradual change in saturation with increasing angle from θ=0° to θ=90°essentially involves the rotation of domain walls.

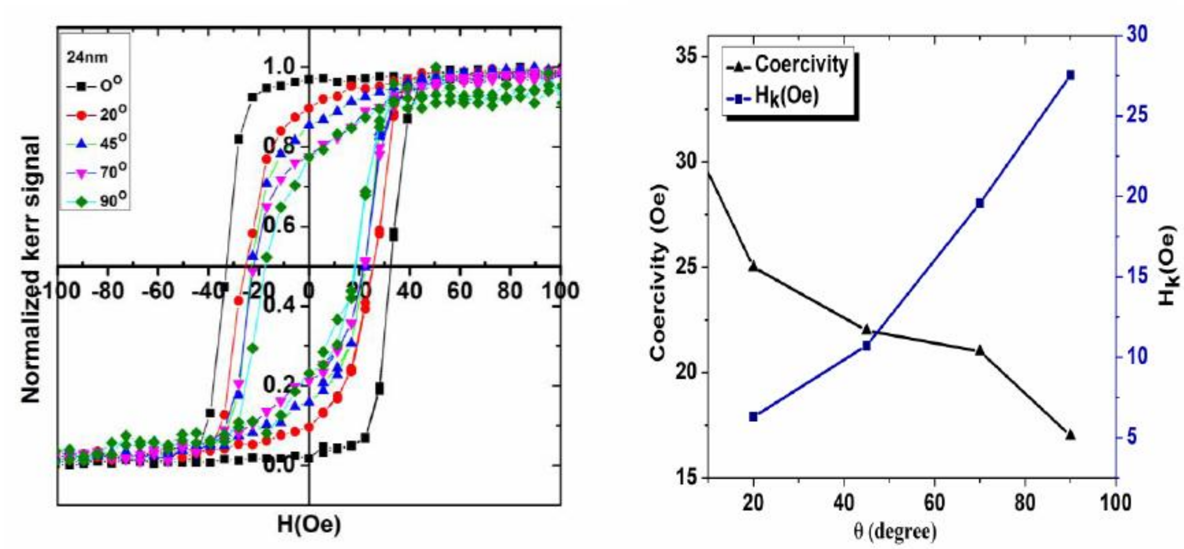

Fig. 5(a) MOKE M-H loops of Si/CoFeB (24nm) film, measured at different angles between applied magnetic field direction and the easy axis.(b) Variation of anisotropy field $H_k(\theta)$ and coercivity with angle (θ) between easy and hard axis for 300°C annealed CoFeB film (24 nm).

Reports have shown thatmagnetic anisotropy is calculated by knowing the anisotropy field (H_k) which is given by difference between saturation field at angle θand easy axis θ=0°[15-17].

$$H_k(\theta) = H_{sat}(0^0) - H_{sat}(\theta) \quad (1)$$

Fig. 5(b) shows the variation in anisotropy field $H_k(\theta)$for 300°C annealed CoFeB film (24 nm). $H_k(\theta)$ is found to increase with the increase in angle from θ=0° to 90°. The existence of magnetic behaviour in 300°C annealed CoFeB film reveals the presence of in-plane uniaxial magnetic anisotropy (K_u) estimated using following equation

$$K_u = H_k M_s/2 \quad (2)$$

Here, $H_k$and M_s are the anisotropy field and saturation magnetization respectively. The magnetization curve follows Stoner-Wolfarthsingle domain magnetization reversal mechanism. It shows a complete or near complete alignment of ferromagnetic spins along the direction of applied field. Further, the coercivity of 300°C annealed CoFeB film (24 nm) is found to be maximum when the applied field is aligned parallel to the direction of easy axis (θ=0°) and reduces along the hard axis (θ=90°). The magnetization reversal starts as early as the angle between easy axis and field is gradually increasedresulting in reduced coercivity with increasing angle (see Fig.5b). This indicates that for$\theta = 90°$,low field are required to reduce the net magnetization of film to zero. Thus, the coercivity essentially measures the resistance by theferromagnetic film from becoming demagnetized.

4. Conclusion:-

Structural and magnetic properties of *as-deposited* and annealed CoFeB films of four different thicknesses (6nm, 14nm, 20nm and 24nm) were studied by GAXRD and MOKE respectively. After vacuum annealing at 300°C, the films exhibited poly-crystalline nature with bcc structure of CoFeB, as was evident from the clear presence of the diffraction peak at 2θ~44.7° The grain size was found to increases with the increase in film thickness.It was observed that the coercivity increases with the increase in thicknesses of the as-deposited films. The coercivity exhibited noticeable decrease on annealing for film thickness greater than 20nm. This was attributed to multi-domain behavior of thin films at higher thicknesses.The MOKE M-H measurements showed the presence of magnetic anisotropy in the measured sample. The anisotropic field $H_k(\theta)$ is found to increase as the field was oriented away from the easy direction, i.e., from θ=0° to 90°. This behavior of the magnetization in the annealed film is reveal of the existence of in plane uniaxial anisotropy (UMA).

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