Influence of Magnetic Layer Thickness on Magnetic, Microstructural and Electrical Properties of CoFeB sandwiched in Ta Layers

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Abstract. Ta [RT]/ CoFeB (2-50nm) [Ts=500°C] /Ta [RT] films were grown on Silicon dioxide substrates by UHV magnetron sputtering system. The magnetic, microstructural and electrical properties were investigated as a function of CoFeB thickness (tCoFeB) at suitable substrate temperature (Ts). Further, we identify that, the strength of perpendicular coercivity (Hc┴)of the stacks mainly depends on the tCoFeB. Higher Hc┴ value of ~ 564 Oe is observed for the thicker CoFeB film. The enhancement in the Hc┴ on increasing the film thickness upto 50 nm is due to the crystallization of CoFeB film at Ts=500 °C. The morphological studies show larger grain size for thicker CoFeB film. A high value of electrical resistivity (ρ) is obtained by employing the standard four probe method, which further proves the amorphous nature of the CoFeB films. This Ta/CoFeB/Ta at Ts= 500 °C structures having high Hc┴, large spin polarization (P) and low damping constant (α) values could be a capable candidate in the fabrication of novel spintronic devices.

Keywords : DC magnetron sputtering, Co₄₀Fe₄₀B₂₀, perpendicular coercivity, spintronics

INTRODUCTION

Recently, CoFeB film has gained a great deal of interest from the scientists and researchers. Especially, in magnetic tunnel junctions (MTJs), CoFeB films can be used as a free layer and/or reference layer due to the requirement of the fundamental properties like high Tunneling magneto resistance (TMR), strong perpendicular magnetic anisotropy (PMA), large perpendicular coercivity (Hc┴), low gilbert damping constant (α), large spin polarization (P),and high Curie temperature (Tc), etc. Varying the CoFeB film thickness and temperature could play a major role in tuning the above mentioned properties during the fabrication of novel spintronic devices such as Read/Write head in hard disc drive (HDD), magnetic random access memories (MRAM), spin-torque oscillators, spin logic devices and so on [1].

Achieving Hc┴ in CoFeB films is highly needed for the modern spintronic devices to overcome the demagnetization field. Hence, recent research work is focused on fabricating the films with the Hc┴ [2-5]. From our previous study on CoFeB films deposited at Ts = 475 °C on SiO₂, the film deposited at 475 °C was found to have lowest perpendicular coercivity [5]. In this work, we concentrate on CoFeB films sputtered at Ts= 500°C to obtain large Hc┴ with different thicknesses. Additionally, the magnetic, surface morphology and electrical resistivity properties have been studied.
EXPERIMENTAL DETAILS

Experiments were conducted on Co$_{40}$Fe$_{40}$B$_{20}$ (CoFeB) sandwiched between buffer and capping layers of Ta deposited on thermally oxidized Si (100) substrates at RT by ultra-high vacuum (UHV) magnetron sputtering system using the power source of Direct Current (DC) [LJUHV SP5]. The base pressure was maintained at 7.6 x 10$^{-5}$ Torr with Argon gas flow rate of 10 sccm. CoFeB and Ta were sputtered at 100 W and 25 W sputtering powers respectively at a sputtering pressure of 5 x 10$^{-3}$ Torr. Here, Tantalum (Ta) is deposited at RT and acts as both the buffer and capping layers; Whereas, CoFeB of different film thicknesses was deposited at suitable Ts of 500 °C. The thickness of CoFeB layer was tuned in order to optimize the condition of strong perpendicular coercivity in the same stack of Ta (5 nm)/ CoFeB (t$_{CFB}$) / Ta (3 nm) trilayer at Ts = 500 °C, where t$_{CFB}$ = 2, 5, 10, 25, 50 nm. The substrates were rotated (15 RPM) during the deposition to attain a homogeneous film formation.

The magnetic properties were taken from the Vibrating Sample Magnetometer (VSM) at RT [Microsense Inc. USA- EZ9]. The surface morphology of the samples was analyzed by Field Emission Scanning Electron Microscopy (FE-SEM) [FEI Quanta 200 FE] and Atomic Force Microscopy (AFM) [Agilent technologies SPM 500 Pico LE]. The electrical resistivity was studied by four probe method using Van der Pauw technique at RT [Ecopia HMS-3000].

RESULTS AND DISCUSSION

To understand the influence of t$_{CoFeB}$ on perpendicular coercivity in the Ta/CoFeB/Ta structures, magnetization studies have been taken first. Fig. 1 shows the out-of-plane hysteresis curves of CoFeB at Ts = 500°C films of varying thickness from 2 nm to 50 nm. While, reducing the thickness of CoFeB films (2 nm and 5 nm) no M-H loops in the out-of-plane direction was observed. Whereas, Hc⊥ is only observed for certain trilayer films with 10, 25 and 50 nm CoFeB, suggesting that, Hc⊥ essentially depends on a combination of appropriate film thickness and Ts. Hence, when the CoFeB thickness was increased from 10 to 50 nm, the Hc⊥ also increased gradually. However, a large Hc⊥ value of ≈ 564 Oe was obtained for the 50 nm CoFeB film. The presence of Hc⊥ in the thicker CoFeB films could arise due to two main reasons. First, the formation of nanocrystallites (CoFe) in the CoFeB amorphous phase improved at adequate Ts (i.e. 500°C), resulting in crystallization of CoFeB films [6,7]. Secondarily, the changes in the microstructure at Ta/CoFeB/Ta interfaces [4] occurred.

![FIGURE 1](image.png)

FIGURE 1. Room Temperature out-of-plane M-H curves for samples with t$_{CoFeB}$= 2 nm, 5 nm, 10 nm, 25 nm and 50 nm sputtered at 500°C Ts.

In order to obtain the detailed inference of at Ta/CoFeB/Ta trilayer, in-plane and out-of-plane M-H has been studied for 50 nm CoFeB film with large Hc⊥ and is displayed in Fig. 2. For in-plane direction, all the trilayer films obviously showed low coercivity (Hc∥) and high saturation magnetization (Ms∥) and exhibited the easy axis of magnetization. However, the maximum Hc∥ of ≈ 240 Oe and Ms∥ ≈ 1134 emu/cc are observed for the 50 nm CoFeB film.
The surface morphology of the selected CoFeB (50 nm) trilayer film was studied by AFM and FESEM as shown in fig. 3. Microstructure of the sample acquired from AFM (in contact mode) matches well with the FESEM image. For 50 nm CoFeB sample, well separated and spherically shaped grains with the size of approximately 60 nm was clearly observed. The higher grain sizes relates with the larger coercivity of the CoFeB films [8,9]. The surface roughness ($R_{rms}$) was measured to be with the value of $\approx 1.5103$ nm. Moreover, these results were in good agreement with the earlier reports [4,5].

Fig. 4 shows the $\rho$ values for Ta/($t_{CoFeB}$ = 2 to 50 nm)/Ta trilayer at suitable $T_s$. The $\rho$ values gradually decreased with increase in the thickness of CoFeB films. The $\rho$ values obtained lies between $\approx 639 \, \mu\Omega\cdot\text{cm}$ and $\approx 161 \, \mu\Omega\cdot\text{cm}$ as $t_{CoFeB}$ increases from 2 to 50 nm. In general, amorphous CoFeB film has the $\rho$ value of $\approx > 100 \, \mu\Omega\cdot\text{cm}$ [10].

However, in this study the highest values of $\rho$ have been observed for all the trilayer samples owing to the majority phase of amorphous phase which was still present in the CoFeB film. Further, this has been recently supported by Yamanouchi et al. [7]. Hence, a sharp increase in the $\rho$ values would be due to the existence of large sized amorphous phase grain boundaries.
SUMMARY AND CONCLUSION

The magnetic, microstructural and electrical resistivity properties were studied as a function of $t_{\text{CoFeB}}$ at suitable $T_s$ of 500 °C and the following has been concluded:

1. The perpendicular coercivity in Ta/CoFeB/Ta trilayer mainly depends on the different film thickness of CoFeB.
2. The maximum perpendicular coercivity observed for 50 nm thick CoFeB film might be due to the presence of improvement in the crystallization of CoFeB and microstructural changes at their interfaces.
3. Surface morphology studies displayed higher grain size of $\approx$ 60 nm and lower electrical $\rho$ values of $\approx$ 161 $\mu\Omega$-cm observed for the optimum 50 nm of CoFeB thickness suggested that, still amorphous phase existed in CoFeB film.

This optimum Ta/CoFeB (50nm)/Ta trilayer sputtered at $T_s$=500 °C could be a promising candidate for modern spintronic devices.

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