THE IRON SPIN TEXTURE IN ANNEALED AMORPHOUS FE/TB MULTILAYERS

M. Sajieddine[1], M. Sahlaoui[1], E. Agouriane[1], H. Lasri[2], Ph. Bauer[3] and J. Ghanbaja[4]

[1]LPM, Université Cadi Ayyad, F.S.T., BP 523, 23000 Béni-Mellal (Maroc)
E-mail : sajieddinem@yahoo.fr
[2] LPMM, Faculté des Sciences, Aïn Chock, Casablanca (Maroc)
[3] LSGS, Ecole Nationale des Mines, Parc de Saurupt, F-54514 Nancy (France)
[4] LCMS, UHP, Nancy-I, BP 239, F-54042 Nancy (France)

Fe/Tb multilayers have been obtained by vacuum evaporation with Tb-layer thickness fixed to 40Å and amorphous Fe-layer thickness fixed to 19Å. ^{57}Fe-Mössbauer spectrometry was used to obtain information on the structure and the spin texture of the multilayers before and after annealing at 530K for different durations of the annealing. The Mössbauer results indicate that the Perpendicular Magnetic Anisotropy (PMA) was stabilised and reinforced after annealing.
Keywords : magnetic multilayers, magnetic anisotropy, Mössbauer spectrometry

I. Introduction

Transition metal (TM)/rare-earth (RE) multilayers have been attracting much attention both from technological and physical interest and are being actively investigated by several laboratories. Iron/rare-earth (Fe/RE) multilayers are studied for their magnetic properties, in particular for the general interest of coupling between magnetic layers and for the possibility of using them in perpendicular devices. The variety of magnetic properties in Fe/RE multilayers depends on the sort of RE metals. Perpendicular magnetic anisotropy (PMA) has been observed for Fe/Nd [1], Fe/Tb [2-5] and Fe/Dy [6] multilayers when the Fe and RE layer thicknesses are properly controlled. In Fe/Tb multilayers, it has been established that magnetic properties depend strongly on the individual layer thicknesses and on the temperature substrate (T_s) during the deposition process [2, 3].
This study is devoted to the modification produced by annealing in evaporated amorphous Fe/Tb multilayers. Both structural and magnetic changes were investigated by transmission ^{57}Fe Mössbauer spectrometry in the temperature range 90-300 K because it gives a direct and local characterization of the Fe layers.

II. Experimental

Fe/Tb multilayers were grown by alternate vapor deposition and condensed onto substrates kept at liquid nitrogen temperature (T_s = 90 K) to suppress diffusion at the interface. Deposition was made in a high vacuum chamber, with a pressure better than 10^{-8} Torr. Iron was evaporated from an electron gun crucible and terbium from a boat source heated by joule effect according to a procedure previously published [7]. The substrates were float glass plates for X-ray and kapton foils ^{57}Fe Mössbauer analyses. Before exposure to atmosphere, the samples were covered by 140Å amorphous silicon to prevent oxidation. Characterization of the sample regarding periodicity, interface quality and lattice structure of the individual layers were performed by X-ray diffraction and transmission electron microscopy [8]. A special attention focused here on [Fe(19Å)/Tb(40Å)] sample with amorphous Fe layers. The samples were isothermally annealed at T_{an} = (530 ± 3) K for different durations t_{an} (4 h and 24 h) in a vacuum tubular furnace under a pressure less than 10^{-6} Torr. The optimal annealing temperature was fixed below that threshold to avoid any deterioration. For additional experimental details, the reader is referred to our publication [9]. Transmission Mössbauer spectra were recorded using a conventional spectrometer equipped with ^{57}Co (10 mCi) source in a rhodium matrix. Samples were folded to enough material and were investigated, before and after annealing, by ^{57}Fe Mössbauer spectrometry at different temperatures, the incident - beam direction being perpendicular to the plane of layers.

I. Result and discussion

Transmission Mössbauer spectra have been collected from [Fe(19Å)/Tb(40Å)]70 before and after annealing during 4h at various temperature measurement T_m. Some of them are pictured in figure

1. All the spectra are broad, indicating a large variety of environnements of Fe atoms and characteristic of

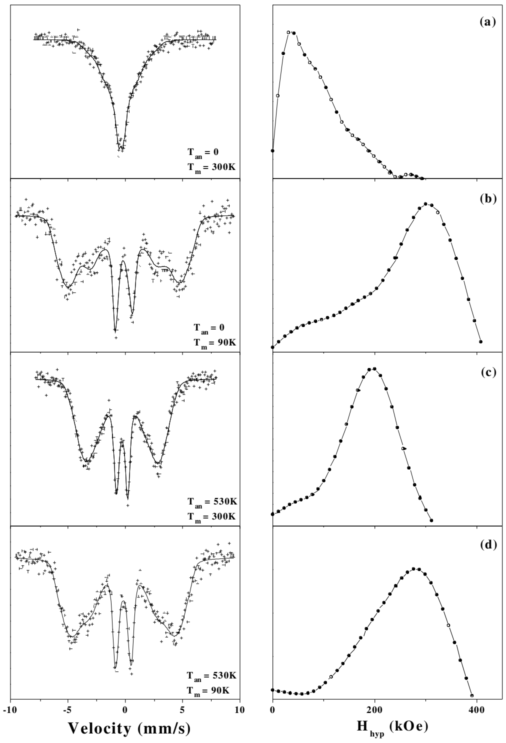

FIG. 1 : Transmission ^{57}Fe Mössbauer spectra and corresponding hyperfine field distributions collected at different temperatures T_m for [Fe(19Å)/Tb(40Å)] before and after annealing for 4 h at 530 K.

magnetic amorphous alloys. They have been analysed in terms of distribution of hyperfine field $P(H_{hyp})$. Comparing the distributions at room temperature (Figures 1a and 1b) for the untreated and the annealed sample, we notice a shift of the probability from the lower hyperfine field region to the higher one. The same evolution is noted for both the untreated and the annealed sample, when the temperature T_m decreases. At 300 K the average hyperfine field $<H_{hyp}>$ initially 79 kOe, rise to 175 kOe. This increase in $<H_{hyp}>$ is due to the increase in T_C. In Figure 2a, we have drawn the dependence of the average hyperfine field $<H_{hyp}>$ versus T_m before and after annealing. Values of T_C were estimated by extrapolating the $<H_{hyp}>$ to zero. They are respectively 325 and 385K before and after annealing the sample. However, these temperatures are lower than the Curie temperature of the homogenous alloy of the same composition ($T_C^{alloy} \approx 410K$) [10].

The magnetic texture of the sample is revealed by the intensity X of the middle peaks relative to the inner ones of the Mössbauer spectrum. Theoretically, the intensities of the peaks are in the ratio 3:X:1:1:X:3, with $X = \frac{4\sin^2\varphi}{(1+\cos^2\varphi)}$, where is the angle between the - ray and the average direction of the magnetic moments of the iron atoms. As the - ray is

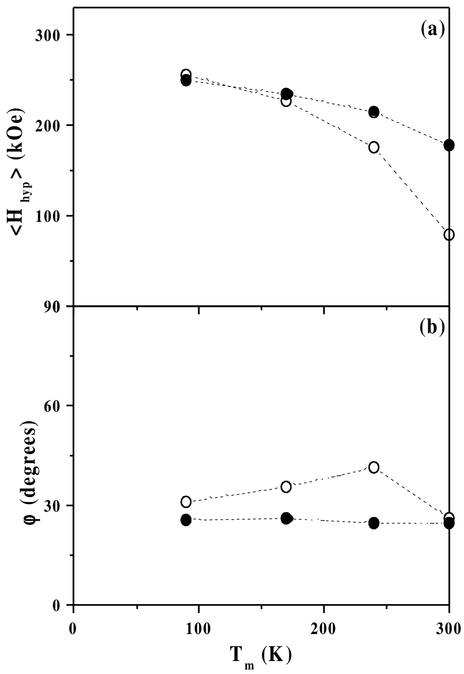

FIG. 2: Evolution of the the mean hyperfine field $<H_{hyp}>$ (a) and the average angle (b) versus T_m for [Fe(19Å)/Tb(40Å)] before (◦) and after (•) annealing for 4 h at 530 K.

perpendicular to the plane of the sample, X = 4 (φ = 9 0°) corresponds to the case where the magnetic moments of iron are completely in the plane of the layers, X = 0 (φ= 0°) if they are perpendicular to it and X = 2 (φ= 54,73°) to a random orientation. The values of φ as calculated using the fitted parameters are shown in figure 2b. Before annealing, the sample show strong perpendicular magnetic anisotropy (PMA) with average canting angle <φ> of about 28° at T_m = 90 K and exhibits a maximum at 200 K where the interior of the iron layers is formed by amorphous iron with Curie temperature T_C 200 K [11]. After annealing, the iron layers exhibits a very strong texture with iron magnetic moments almost perpendicular to the plane of the film, <φ>= 25°. Also we can note that the value of is not changed when increasing T_m indicating the reinforcement of the PMA and its stabilisation for all the temperature range 90–300 K. Annealing the sample during 24 h do not produce any change in the values of the average hyperfine field and the angle . Thus, after annealing, the increase of the PMA and that of T_C is a result of the atomic rearrangements explained by i) the crystallization of the pure

amorphous Fe [11] in the center of the Fe layers, and ii) demixing at the interface between the Fe and Tb layers.

IV. Conclusion

In the present work, Fe(19Å)/Tb(40Å) multilayer were prepared on kapton substrate by vacuum evaporation. The sample was studied by Mössbauer spectrometry. The result indicates that after annealing, the PMA is reinforced and stabilized for all the temperature range 90-300 K. This enhancement of the PMA is related to:

- Crystallization of the pure amorphous Fe in the center of the Fe layers.
- Demexing at the interface between the Fe and Tb layers.

References :

[1] L. T. Baczewski, M. Piecuch, J. Durand, G. Marchal and P. Delcroix, Phys. Rev. B40 (1989) 11237.

[2] K. Cherifi, C. Dufour, M. Piecuch, A. Bruson, Ph. Bauer, G. Marchal and Ph. Mangin, J. Magn. Magn. Mater. 93 (1991) 609.

[3] M. Sajieddine, Ph. Bauer, C. Dufour, K. Cherifi, G. Marchal and Ph. Mangin, J. Magn. Magn. Mat. 113 (1992) 243.

[4] K. Mibu, N. Hosioto and T. Shinjo, Nucl. Inst. Meth. B76 (1993).

[5] F. Richomme, J. Teillet, A. Fnidiki, P. Auric and Ph. Houdy, Phys. Rev B54 (1996) 416.

[6] S. Honda, S. Nishimura and T. Kusuda, IEEE Trans. Magn 25 (1989) 4027.

[7] C. Dufour and G. Marchal, R. Sc. Ins. 62 (1991) 2984.

[8] M. Sajieddine, Ph. Bauer, A. Bruson and G. Marchal, Sol. State Comm. 99 (1996) 965.

[9] M. Sajieddine, Ph. Bauer, G. Marchal and A. Nourreddine, C. R. Acad. Sci. Paris, t. 327, Série IIb (1999) 523.

[10] P. Hansen, C. Clausen, G. Much, M. Rosenkranz, and K. Witter, J. Appl. Phys. 66 (1989) 756.

[11] J. Teillet, A. Fnidiki, F. Richomme, P. Boher and Ph. Houdy, J. Magn, Magn. Mat 123 (1993) 359.