Influence of Temperature on Magnetic Properties of $Tb_{26}Co_{74}/Co/Fe_{20}Ni_{80}$ Films with Exchange Bias

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Influence of temperature on magnetization process was investigated in exchange coupled $Tb_{26}Co_{74}/Co/Fe_{20}Ni_{80}$ films. Temperature dependences of exchange bias field and coercivity of the $Fe_{20}Ni_{80}$ layer were obtained for films with various thicknesses of the Co spacer. The results obtained were interpreted in terms of changes of magnetic interface localization.

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1. Introduction

Magnetic multilayers with unidirectional magnetic anisotropy, which reveals itself as a shift of the hysteresis loop of the soft magnetic layer along the magnetic field axis, have been studied intensively for the last two decades [1–6]. Thin films consisting of exchange coupled $Fe_{20}Ni_{80}$ and Tb–Co layers are of substantial fundamental and applied interest [1–6]. Due to the proper combination of magnetic and magnetoresistive properties such films have been used in magnetic sensors [5].

Previously hysteresis properties of these layered structures were shown to be determined mostly by the character and effectiveness of the interlayer coupling, which in turn is defined by structural and chemical condition of interfaces. Interlayer region can be modified artificially by introduction of the ultrathin nonmagnetic spacer [4] or by selective annealing of the seed permalloy layer [5]. This paper is devoted to the study of influence of temperature on unidirectional anisotropy in exchange coupled sandwiches based on $Tb_{26}Co_{74}$ ferrimagnetic layer and $Fe_{20}Ni_{80}$ soft magnetic layer separated by the ultrathin Co spacer.

2. Experimental details

Multilayer samples were obtained by high frequency ion sputtering of mosaic Tb–Co, alloyed $Fe_{20}Ni_{80}$, and Co targets in Ar medium at 2×10^{-3} mm Hg. Layers were deposited on glass substrates at presence of the uniform magnetic field oriented parallel to the samples plane. The final layered structure was $SiO_2/Tb_{26}Co_{74}/Co/Fe_{20}Ni_{80}$. Compositions of the layers were controlled by X-ray fluorescent analysis using Nanohunter spectrometer.

Thicknesses of $Tb_{26}Co_{74}$ and $Fe_{20}Ni_{80}$ layers were 110 nm and 50 nm correspondingly. Interface was modified by introduction of the Co spacer with nominal thickness varied from 0.3 nm to 1.5 nm.

According to data of X-ray diffraction analysis $Fe_{20}Ni_{80}$ layer was nanocrystalline, $Tb_{26}Co_{74}$ layer in amorphous condition. As was shown in [7], ferrimagnetic ordering is typical for amorphous Tb–Co layer of the chosen composition. Moreover, rare earth magnetic sublattice dominates for the entire temperature range considered ($5 \div 350$ K). Another specific feature of the amorphous layers used is strong in-plane uniaxial anisotropy, which has been formed as a result of application of technological magnetic field during the samples deposition.

Magnetic measurements were carried out using MPMS-XL-7 EC.

3. Results and discussion

Figure 1a,b shows dependences of the reduced magnetic moment (m_s is the saturation magnetic moment of the sample) on the magnetic field applied in sample's plane along easy axis of the $Tb_{26}Co_{74}$ layer measured at temperatures 5 K and 300 K. Both loops demonstrate stepped character, which reflects layer-by-layer magnetization. Such magnetization reversal mechanism is typical for all samples under investigation.

Magnetization process is mostly determined by ferrimagnetic structure of the amorphous layer as well as the interlayer exchange coupling. As was mentioned earlier [7], in amorphous $Tb_{26}Co_{74}$ layer Tb sublattice is dominating and arranged antiparallel to magnetic moment of Co sublattice, which in turn is ferromagnetically coupled to magnetic moment of the permalloy layer. Application of the strong enough magnetic field leads to the parallel arrangement of $Tb_{26}Co_{74}$ and $Fe_{20}Ni_{80}$ magnetizations accompanied by formation of the domain-wall-like magnetic interface inhomogeneity. When external magnetic field is decreased below some critical point, this inhomogeneity becomes energetically

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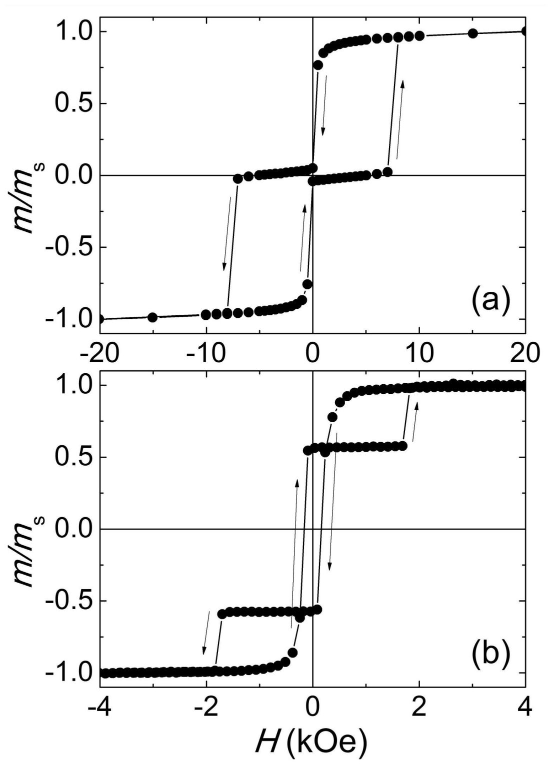

Fig. 1. Hysteresis loops of $Tb_{26}Co_{74}$/Co(0.8 nm)/$Fe_{20}Ni_{80}$ films measured along the easy axis at 5 K (a) and 300 K (b).

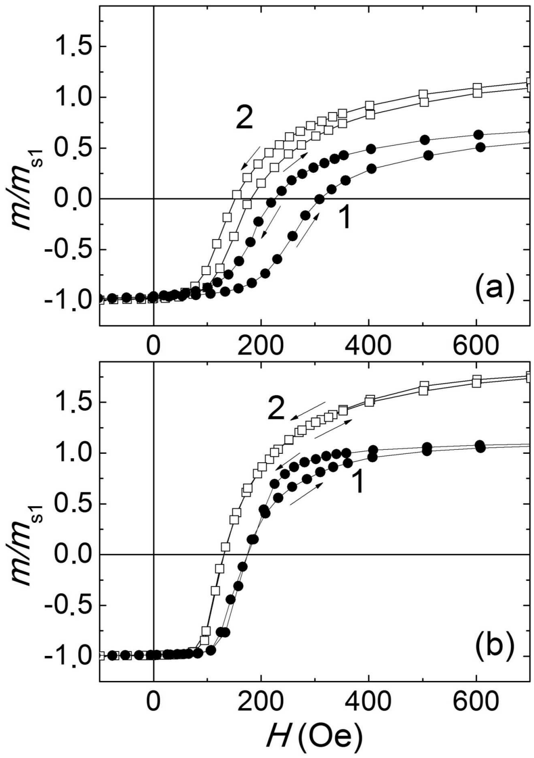

Fig. 2. Hysteresis loops of $Tb_{26}Co_{74}/Fe_{20}Ni_{80}$ (curve 1) and $Tb_{26}Co_{74}$/Co(0.8 nm)/$Fe_{20}Ni_{80}$ (curve 2) films measured along the easy axis at 5 K (a) and 300 K (b).

unfavorable and magnetic moment of the permalloy layer becomes antiparallel to the direction of the applied magnetic field. In the hysteresis loops it can be observed as a low-field magnetization jump (Fig. 1a) [1]. The second high-field jump corresponds to magnetization reversal of the amorphous layer, which makes magnetic moments of the two layers parallel again.

For higher temperature magnetic moment of the amorphous layer decreases substantially. As a result, in the central part of the hysteresis loop measured at 300 K overlap of ascend and descend brunches is observed (Fig. 1b).

In Fig. 2a,b low-field hysteresis loops corresponding to the permalloy layer measured on $Tb_{26}Co_{74}/Fe_{20}Ni_{80}$ and $Tb_{26}Co_{74}/Co/Fe_{20}Ni_{80}$ films are presented (here m_{s1} is a saturation magnetic moment of the permalloy layer in the film without spacer). Hysteresis loops for both samples were measured at 5 K and 300 K in the magnetic field range not exceeding coercivity of the $Tb_{26}Co_{74}$ layer and should only reflect magnetization process of the $Fe_{20}Ni_{80}$ layer. However, for all samples with Co spacer value of the reduced magnetic moment is large than one. This is more likely the evidence of partial involvement of $Tb_{26}Co_{74}$ in the low-field magnetization process. Qualitatively this assumption is confirmed by lower average slope of the hysteresis loops measured on samples with spacer. According to Fig. 2b, introduction of the Co spacer leads to the decreased shift of the hysteresis loop. This peculiarity can also be the consequence of the effective increase of magnetic moment of the soft magnetic layer due to displacement of the magnetic interface into the amorphous layer.

Coercivity and exchange bias field of the low-field hysteresis loops (Fig. 2a) increase for temperature decrease, whereas asymptotic character of magnetization is extended to the higher field range. This fact is more likely the result of reinforcement of the interlayer exchange coupling, which takes place due to the enhancement of magnetic ordering in amorphous layer [7].

Summarized data on temperature dependences of magnetic properties of the permalloy layer in $Tb_{26}Co_{74}/Co(L_{Co})/Fe_{20}Ni_{80}$ films with various thickness of Co spacer L_{Co} are presented in Fig. 3a,b. As can be seen in Fig. 3a, temperature dependences of the exchange bias field H_e demonstrate nonmonotonic behavior. As was proposed earlier [1], such phenomenon can be explained in terms of strong enhancement of value and dispersion of magnetic anisotropy of the amorphous layer at temperatures below 100 K. Introduction of 0.8 nm Co spacer does not lead to changes in character of $H_e(T)$ dependence, but lower the overall level of the exchange bias field. It should be noted that H_e values measured at room temperature for samples with and without 0.3 nm Co spacer are almost identical. This feature might be the consequence of discontinuity of the cobalt spacer. Similar peculiarity was observed for Tb–Co/Ti/$Fe_{20}Ni_{80}$ films with ultrathin Ti spacer [4].

Interesting dependences are observer for the film with $L_{Co} = 1.5$ nm. In temperature range of 250 K to 350 K magnetization of the film is switched as for single layer, which is the evidence of the strong interlayer coupling. Stepped character of the hysteresis loop is observed only at temperatures below 250 K. This transition is caused by the increase of magnetization and coercivity of the amorphous layer with temperature decrease.

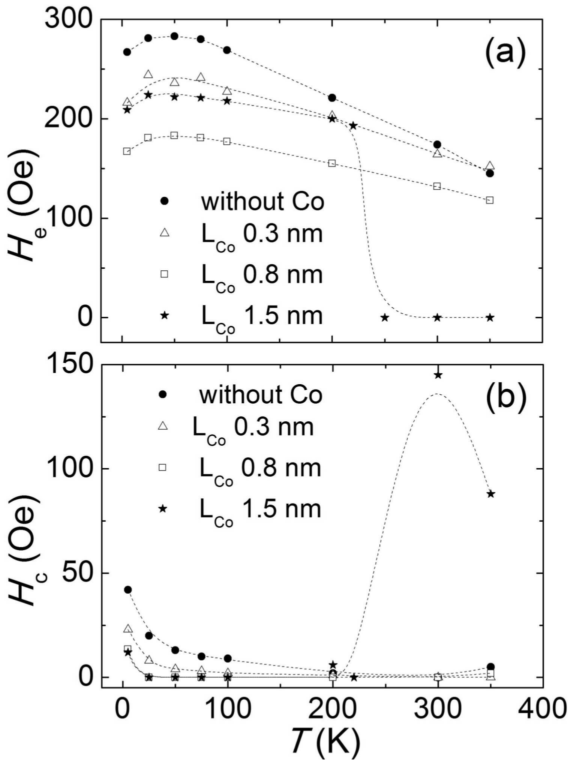

Fig. 3. Dependences of the exchange bias field H_e (a) and coercivity H_c (b) of the ferromagnetic layer on temperature for $Tb_{26}Co_{74}/Co(L_{Co})/Fe_{20}Ni_{80}$ films with various thickness of the cobalt spacer.

Dependences $H_c(T)$ obtained from low-field hysteresis loops are mostly identical for all samples. They are characterized by the increase of H_c in the low-temperature region, which is the result of enhancement of the interlayer coupling and increased coercivity of the $Tb_{26}Co_{74}$ layer [1,6].

4. Conclusions

Influence of the Co spacer on the exchange bias and hysteresis properties of the permalloy layer in $Tb_{26}Co_{74}/Fe_{20}Ni_{80}$ films has been investigated. Introduction of the spacer was shown to cause substantial qualitative and quantitative changes of temperature dependences of exchange bias field and coercivity. According to the proposed assumption, such effect is the consequence of exchange coupling enhancement as well as partial involvement of the amorphous ferrimagnetic layer in low-field magnetization process.

Acknowledgments

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