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Interlayer Interaction in Three-Layer Films Obtained by Chemical Deposition

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Abstract—The results from experimental investigations on the dependences of the displacement field of hysteresis loop H_E and the saturation field of the polar Kerr effect H_S on the thickness of nonmagnetic interlayers in three-layer films obtained by chemical deposition are presented. Possible mechanisms responsible for oscillating variations in H_S at interlayer thicknesses are presented.

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INTRODUCTION

Three-layer films formed by ferromagnetic layers with different coercive forces and nonmagnetic interlayers are the simplest of multilayer structures in which spin-dependent effects occur. They are thought to be most promising for developing devices in the spintronics field, e.g., reading heads for the magnetic recording of information [1].

In this work, we present the results from investigations on the magnetic properties of three-layer films obtained by chemical deposition. Highly coercive (HC) and low coercive (LC) layers consist of polycrystalline and amorphous CoP alloys, respectively, while nonmagnetic interlayers consists of amorphous NiP layers. It was shown that if an LC layer is formed by NiP alloy, there is considerable improvement in the quality of the interface, observed in the dependences of the hysteresis loop's displacement field and the saturation field of the Kerr polar effect on the interlayer thickness.

EXPERIMENTAL

The structure of three-layer films obtained by chemical deposition is shown in Fig. 1. The HC layer was made of the CoP polycrystalline alloy with a P content of ~2.5 wt %; its thickness d_3 was 12 nm and its coercive force was 400 Oe. The P content in the CoP amorphous layer was ~5.5 wt %. The nominal Ni content in the LC layer, which was made of CoNiP amorphous alloy, was ~25 wt % at the same P concentration. The thickness of this layer d_1 was 10 nm. The intermediate nonmagnetic (NM) interlayer was made of amorphous Ni—P alloy with a P content of ~10 wt %.

A typical hysteresis loop of an LC layer is asymmetric (Fig. 2a), and its center is shifted by magnitude H_E relative to the zero value of the magnetic field to the side opposite the magnetization of the HC layer (toward positive values).

The bias field in the films with LC layers made of CoP diminishes as interlayer thickness d_2 increases (Fig. 2); a double drop in H_E compared to its value when there is no interlayer is observed at $d_2 \sim 5$ nm. For the films in which the LC layers were made of CoNiP alloy, the bias field diminished more abruptly: a twofold decrease in H_E was observed at $d_2 \sim 1$ nm, and H_E fell from 50 to 5 Oe as d_2 varied from 0 to 1 nm. Such an abrupt decline in the bias field revealed oscillating variations in the saturation field of the Kerr polar effect on the interlayer thickness, as is shown in Fig. 3.

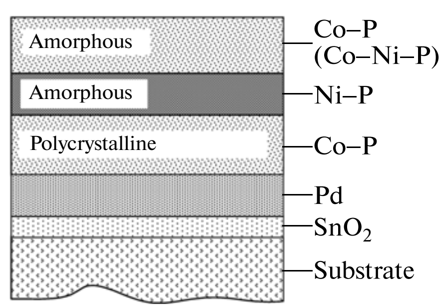

Fig. 1. Sandwich structure obtained by chemical deposition.

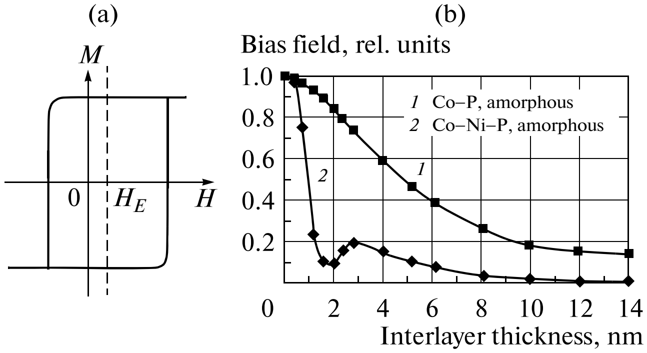

Fig. 2. (a) Hysteresis loop of the LC layer and (b) dependence of the bias field on the thickness of the nonmagnetic interlayer.

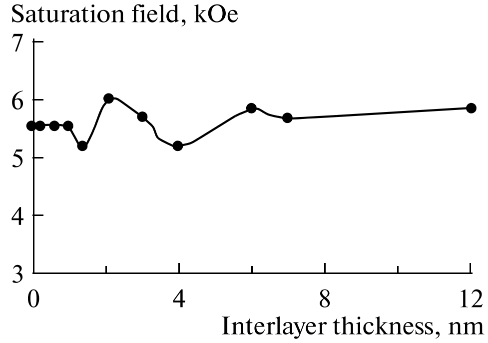

Fig. 3. Dependence of the saturation field for the Kerr polar effect on interlayer thickness.

RESULTS AND DISCUSSION

The interlayer interaction between magnetic layers in three-layer structures is in many respects determined by the quality of the nonmagnetic interlayers separating ferromagnetic layers.

It is known that the phosphorus in CoP alloy is not an interstitial impurity and is mainly distributed over the grain boundaries [2]. This feature of phosphides could cause cobalt-enriched regions to be separated by a phosphorus interlayer. The same situation would be also observed for NiP alloys. In this case, the CoNi alloy could form at the interfaces of amorphous CoP/NiP layers. Adding Ni as we obtaining a LC layer initially forms CoNi bonds, preventing the formation of bonds between the Co and Ni atoms in the interface. Such features of phosphide alloys with Co and Ni could explain the differences observed for interfaces between (a) CoP/NiP layers and (b) CoNiP/NiP layers. The interaction between magnetic layers that is observed for LC layers made of CoP alloy is in many aspects determined by disruptions at the interfaces between the LC–NM layers. The most probable cause of such disruptions is interdiffusion of the Co and Ni atoms into the interface and the formation of CoNi magnetic alloy, leading to effective NM interlayer thinning and direct interaction between magnetic alloys. Introducing Ni into CoP alloy prevents the formation of CoNi alloy at the interfaces of LC–NM layers. The thickness of the nonmagnetic interlayer stabilizes, and the quality of the interface improves.

If we accept that the interatomic distances in an amorphous layer made of NiP are equal to the interatomic distances of the β phase in the face-centered cubic lattice of Ni (≈3.5 Å [3]), the loop shift disappears at a distance of ~2–3 atomic distances. These values are close to the thicknesses of metallic interlayers in spin-valve structures [4], at which direct exchange between magnetic layers disappears.

The saturation field of the Kerr polar effect for a thin three-layer film if we ignore the anisotropy field can be expressed in the form

$$H_S = 4\pi M_1 - \Delta H, \quad (1)$$

where M_1 is the magnetization of the LC layer and ΔH is an additional magnetic field associated with the interaction between the LC and HC layers.

Possible reasons for ΔH include the following:

(i) Lack of cohesion in the LC layer, which could lead to holes through the LC layer and the formation of regions of HC phase inside it [5]. Magnetic charges could then appear on the film surface, generating a demagnetizing field and causing the negative sign of ΔH in expression (1). In our case, however, an additional field appears in the interlayer, preventing the propagation of the HC phase into the LC layer.

(b) Interlayer exchange interaction, associated with spin-polarized conductivity electrons in the metal interlayer. In this case, the interaction between the layers periodically change the sign from ferromagnetic (FM) to antiferromagnetic (AFM) when we vary the interlayer thickness, resulting in the values of H_S.

The energy of the interlayer exchange per area unit can be estimated using the expression [6]

$$J_{IL} \simeq \pm\frac{1}{2}\Delta H \times M_1 \times d_1. \quad (2)$$

Signs (+) and (–) correspond to the FM and AFM interactions.

Substituting M_1 = 480 Gs and ΔH ~ 500 Oe into (2), we find

$$J_{IL} \sim 1.2 \times 10^{-1}\ \text{erg/cm}^2.$$

CONCLUSIONS

Additional investigations are necessary to finally confirm the proposed mechanism for determining variations in the saturation field of the Kerr polar effect in the investigated films.

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