Magneto-optical investigation of Co/Pd multilayers

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Abstract. The magnetic and magneto-optical properties of chemical precipitated Co/Pd multilayers have been investigated. The Co layer thickness was equal to 50 Å, and Pd one tPd was varied from 5 to 40 Å. The existence of exchange coupling between Co layers through Pd spacer layers and its oscillatory behavior (from ferromagnetic (F) to antiferromagnetic (AF) ordering) were discovered. It was found that period of F-AF-F oscillations is equal to 4-6 Å. It was established that transverse Kerr-effect (TKE) spectra of Co/Pd multilayers distinguish from those of Co-single-layer films and are modified with variation of tPd value. This result was explained by the spin polarization of Pd layers.

Key words: magnetic, magneto-optical properties, multilayers, transverse Kerr-effect, oscillation, exchange coupling.

I. INTRODUCTION

During the last years multilayer structures based on ultrathin ferromagnetic (Co, Fe, NiFe) and paramagnetic (Cr, Cu, Ag, Au, Wa) layers attracted a great deal of attention owing to a number of unique properties such as a large perpendicular magnetic anisotropy (PMA), an enhanced Kerr rotation at short wave length, a giant magneto-resistance effect and an oscillation of the exchange coupling between adjacent ferromagnetic layers (FL) across a nonmagnetic spacer layers (NML) with changes of FL or NML thickness. This interest was further enhanced by possibility of wide use of multilayers in technical applications. At the present time there are an enormous number of publications (see, for example, Proceedings of ICM, MRS-symposiums and so on) in which the results on the investigation of multilayers are presented. Analysis of the existent data showed that the interlayer exchange coupling in Pd/Co multilayers and induced magnetic polarization are yet not well studied. Here however need to note the works where the results on the experimental [1-3] and theoretical [4] investigation of Co/Pd multilayers with PMA are presented and also the works [5, 6] where influence of Pd spacer layer on the exchange coupling between ferromagnetic layers in Fe/Pd/Fe trilayers had been studied.

In this paper we describe the results on the investigation of magnetic and magneto-optical properties of Co/Pd multilayers with an in-plane magnetic anisotropy (MA).

II. EXPERIMENTAL

The studied samples were prepared by means of chemical precipitation of water-solute Pd- and Co-metal sols on glass substrates. Both metals had fcc-structure. The Co-layer thickness was equal to 50 Å and the thickness of Pd spacer layer tPd was varied from 5 to 40 Å. Multilayers were consisted of three Co/Pd bilayers. Their periodicity was confirmed by low angle X-ray diffraction.

The investigation of magnetic and magneto-optical properties of Co/Pd multilayers were performed on the magneto-optical micromagnetometer and by using of spectroscopic technique (described in [7, 8]) by means of transverse Kerr-effect (TKE) - δ. Here δ = Δl/ I0 where I0 is the intensity of reflected from the studied sample light at M = 0 (M is the sample magnetization) and Δl is the change of I0 caused by the magneto-optical effect at M ≠ 0. We used a modulation method of registration of magneto-optical signals. So the alternating magnetic field H with frequency f = 80 Hz was applied parallel to the sample surface and perpendicular to the plane of light incidence.

III. RESULTS AND DISCUSSION

Preliminary investigation showed that Co-single layer films with 50Å-thickness have an in-plane easy axis of the magnetization and their easy axis saturation field is equal to 50 Oe. Fig. 1 shows the typical magnetization curves δ(H)/δs ~ M(H)/Ms of Co/Pd multilayers with different Pd spacer layer thickness in the 0 < H < 150 Oe magnetic field range.

Fig. 1. Typical magnetization curves of Co/Pd multilayers: tPd = 5Å (curves 1,2); tPd = 7Å (3,4); tPd = 18Å (5,6); tPd = 21Å (7,8).
Analysis of these data allowed to arrive at the next conclusion. There are multilayers in which the magnetization curves are similar to those of Co-single-layer films. Their in-plane easy axis saturation fields $H_s$ are less than 150 Oe, coercivity varies by a small amount with $t_{pd}$-changing and the ratio of the remanent magnetization to the saturation magnetization are equal to 0.7 - 0.9. Moreover there are multilayers in which both magnetization curves distinguish to lesser degree and their magnetization increases with enlarging of the magnetic field up to 0.4-0.6 kOe. It is evident [9, 10] that the received data can be explained by the existence of the exchange coupling between Co-layers through Pd-spacers and its oscillatory behaviour (from ferromagnetic (F) to antiferromagnetic (AF) ordering). In the case of AF-ordered structures the saturation field $H_s$ are significantly larger than $H_s$- magnitudes of F-ones. Fig. 3 shows the dependence of the saturation field $H_s$ on the thickness of Pd layer.

One can see that the magnitude of $H_s$ oscillates as a function $t_{pd}$ with a period of approximately 4-6 Å. The observed distinction of the magnetization curves in AF-ordered structures can be caused by the different orientation of the magnetic field with respect to the axis of AF-ordering and the existence of inclined structures.

It was discovered that the thermic annealing of the studied samples for 0.5 h at 370 °C influences on their magnetic properties. In particular, the values of the saturation fields increases at 2 - 2.5 times.

In order to obtain a better understanding of the magneto-optical properties of Co/Pd multilayers at the first TKE spectra were measured on Co single layer films with $t_{Co}$ varying from 20 to 1000 Å (see Fig. 4). The spectroscopic measurements were performed at the 65°-angle of light incidence from the sample normal and in the $1.5 < \hbar \omega < 4$ eV photon energy range.
These data allowed to receive the dependence of TKE on Co-film thickness at the fixed photon energy (see Fig. 5).

One can see that at the fixed $\hbar\omega$ the value of TKE increases linearly with enlarging of $t_{Co}$ up to 150 - 200 Å. In the range of 250 to 1000 Å of $t_{Co}$ TKE have a constant magnitude. So it was experimentally shown that the Kerr-effect is sensitive to the magnetization up to a certain depth range below the surface of ferromagnetic — the information depth $t_{inf}$. This result correlates very well with computations [11]. We believed that the value of $t_{inf}$ can be estimated from experimental data by the one of $t_{Co}$ beginning with which TKE is constant. It was discovered that in the $1.6<\hbar\omega<4$ eV photon energy range the magnitude of $t_{inf}$ ~ 120 - 200 Å. It was established that the value of $t_{inf}$ decreases as the photon energy of incident light increases.

Fig. 6 shows typical TKE spectra of Pd/Co multilayers with different values of Pd-layer thickness.

One can see that TKE spectra of Co/Pd multilayers distinguish from those of Co-single-layer films. In particular, with increasing of $t_{pd}$ TKE peak at $\hbar\omega = 1.7$ eV reduces and in the $2.8 < \hbar\omega < 4$ eV photon energy range the values of TKE for all Co/Pd multilayers are greater than those of Co-ultrathin films (see. Fig. 4).

The observed peculiarities of TKE spectra in Co/Pd multilayers can be explained by the next. Common reduction of TKE in Co/Pd multilayers in comparison with that of Co thick film is caused by decreasing of $t_{inf}$ due to both the presence of Pd layer and the enlargement of its thickness. Moreover the modification of these spectra in comparison with those of Co-single-layer films caused by the influence of Pd on magneto-optical properties of the studied samples [1, 12]. It is known [13, 14] that Pd exhibits a large paramagnetic susceptibility and becomes ferromagnetic in magnetic alloys, containing Fe, Co, Ni. Because of the high spin-orbit energy of 4d states of Pd, there are the disturbances of the band structure of Co due to the overlap of electronic 3d and 4d wavefunctions in adjacent Co and Pd layers (3d-4d hybridization, exchange polarization). In consequence of
it, Pd layers are spin-polarized. The spin-polarized Pd in Co/Pd multilayers contributes considerably to the Polar Kerr effect both in CoPd alloys and Co/Pd multilayers with PMA [1]. Our data allowed to conclude that Pd influences strongly on transverse Kerr effect in Co/Pd multilayers with an in-plane MA.

CONCLUSIONS

The strong influence of Pd spacer layers on the magnetic and magneto-optical properties of Co/Pd multilayers was discovered. For the first time, an oscillatory behaviour of the exchange coupling between Co-layers through Pd spacer layer was established. It was found that the crossing from ferromagnetic to antiferromagnetic coupling realizes at small distance (~ 4 - 6 Å). Here appropriately to point out that our investigation, performed by means of Ferromagnetic resonance method, confirmed the above described result. The comparison of the magnetic properties of Co/Pd multilayers with those of Co/Mo, Ta multilayers [15] showed that in the first case the saturation fields Hs of AF-ordered structures are smaller than in the second (~ at 2 - 2.5 times). This fact allowed to conclude that the antiferromagnetic exchange coupling between magnetic layers in Pd/Co multilayers is more weak than in Co/Mo, Ta ones.

It was established that the shape of the magneto-optical spectra of Co/Pd multilayers are significantly distinct from those of Co thick films. In particular, the characteristic peak in TKE spectrum of bulk Co around 1.7 - 1.9 eV is no longer present in those of Co/Pd multilayers with tPd > 18 Å. At the same time the Pd-spin polarization and spin-orbit coupling enhancement of TKE was observed in the ultraviolet (UV) photon energy range. Here one can note that in accordance with recent calculations [4] UV peak of magneto-optical signals in Co/Pd multilayers can be observed around 5 - 5.5 eV. We plan experimentally to verify this fact in the future.

REFERENCES