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Pseudo spin valve thin films with crossed magnetic anisotropies

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ABSTRACT

A systematic analysis of both magnetic and magneto-transport properties is presented for a pseudo spin valve system consisting of two ferromagnets having crossed magnetic anisotropies and being separated by a Cu spacer. One ferromagnetic layer with perpendicular easy axis consists of a [Co/Pt] multilayer whereas the other ferromagnetic layer with in-plane easy axis is represented by a single Co layer. We investigated the influence of the magnetic reversal behavior and the related magneto-transport properties as a function of the Co layer thickness next to the Cu spacer layer. Furthermore, the Cu spacer layer thickness was varied in the $[Co/Pt]_3/Co/Cu/Co$ pseudo spin valve system, revealing a linear $R(H)$ dependence and a room temperature GMR ratio up to 2% for a Cu layer thickness of 15 Å.

1. Introduction

Devices based on the tunneling magnetoresistance (TMR) and the giant magnetoresistance (GMR) effect have a wide field of applications, for example as in magnetic field sensors, used for instance in the automobile industry [1] or as read heads in hard disk drives [2]. Further possible applications include magnetoresistive random access memories based on the spin transfer torque effect [3–6], which can be combined with pseudo spin valve (PSV) systems. Of particular interest are PSV based sensors, consisting of magnetic films with perpendicular magnetic anisotropy (PMA), which have mainly been based on [Co/Ni] [7,8], [Co/Pd] [9–11], and [Co/Pt] [12,13] multilayered systems. However, due to the large hysteresis observed in these PSV thin films, they are not particularly suitable for field sensing applications. By choosing one ferromagnet with PMA and one with an in-plane easy axis, separated by a spacer layer guaranteeing exchange decoupling, large hysteresis effects can be avoided when the magnetic field is applied perpendicular to the film plane.

In this work, $[Co/Pt]_3/Co/Cu/Co$ PSV thin films, exhibiting crossed magnetic anisotropies, were investigated with the focus on the magnetization reversal behavior, GMR ratio, and the field sensitivity in dependence of the Cu and Co layer thicknesses for out-of-plane applied magnetic fields.

2. Experimental

The sample preparation was carried out by dc magnetron sputter deposition at ambient temperatures using Ar as process gas at a pressure of 3.5 μbar. As substrates, thermally oxidized p-Si(100) substrates with a 100 nm thick amorphous silica layer were used. The layer stacks are as follows: substrate/Pt(50)/$[Co(4)/Pt(8)]_3$/Co(t_{oop})/Cu(15)/Co(t_{ip})/Pt(30) (thicknesses given in Ångström), where t_{oop} and t_{ip} are the thicknesses of both Co layers next to the Cu spacer. In a further series the Cu thickness (x) was varied between 8 and 28 Å.

The magnetic properties of the samples were characterized by polar magneto-optical Kerr effect (p-MOKE) magnetometry and superconducting quantum interference device-vibrating sample magnetometry (SQUID-VSM). The room temperature magnetoresistance (MR) was measured by a four-point probe method in current-in-plane (CIP) geometry with the external magnetic field applied perpendicular to the sample surface (out-of-plane).

3. Results and discussion

SQUID-VSM $M(H)$ hysteresis loops of a PSV sample with $t_{oop} = 4$ Å and $t_{ip} = 16$ Å are shown in Fig. 1 for in-plane as well as out-of-plane applied magnetic fields. The observed loops are characteristic for all the investigated samples, revealing crossed anisotropies. In out-of-plane field geometry, the sharp switching around zero field belongs to the [Co/Pt] multilayer reversal, exhibiting a rather low coercivity in the range of 200 Oe. At higher magnetic fields the magnetization variation is due to the hard axis behavior of the single

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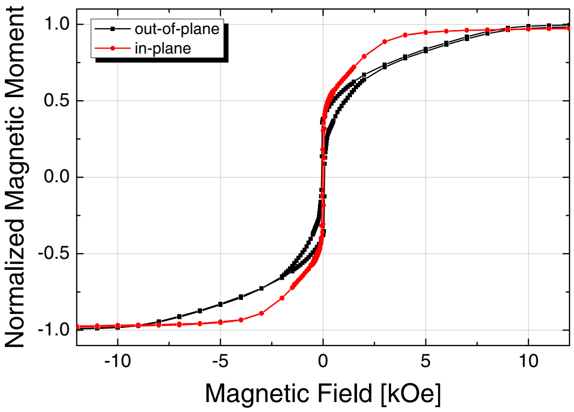

Fig. 1. Room temperature in-plane and out-of-plane SQUID-VSM *M(H)* hysteresis loops of the following sample: substrate/Pt(50)/[Co(4)/Pt(8)]$_3$/Co(4)/Cu(15)/Co(16)/Pt(30), thicknesses are given in Ångström.

top Co layer, revealing in-plane anisotropy with a small hysteresis (less than 300 Oe) and an anisotropy field H_A of about 10 kOe. For the in-plane loop the situation is reversed, the [Co/Pt] multilayer showing a reduced H_A value of about 5 kOe and a rather small hysteresis. Please note that for both ferromagnetic layers the magnetization vectors are never parallel to each other, except at magnetic saturation.

The corresponding MR behavior was investigated for different Co layer thicknesses next to the Cu spacer layer. In a first series, the top Co layer thickness t_{ip} was varied from 8 Å to 24 Å keeping $t_{\mathrm{oop}} = 4$ Å constant. The influence of different magnetic anisotropy contributions is thereby changed: at low t_{ip} thicknesses (<8 Å), the surface and interface anisotropy dominates, causing a perpendicular magnetic anisotropy [14], whereas with increasing Co layer thickness the shape anisotropy promotes an in-plane easy axis of the single Co layer as shown in Fig. 2a. With increasing t_{ip} the shape anisotropy becomes stronger as expressed by an increase in saturation field. The different t_{ip} thickness allows for tuning the sensitive field range of the PSV structure and its MR dependence, which is shown in Fig. 2b. However, the thickness of the Co layer also determines the amount of spin-polarization. From Fig. 2b it is obvious that the top Co layer thickness, defining the sensitive field range, correlates with the GMR ratio such that the maximum resistance change is reduced to almost one third with decreasing t_{ip}. Furthermore, it has to be noted that the sensitivity S_F in the particular field range where a linear *R(H)* dependence is observed decreases with increasing t_{ip}. While it reaches values of $S_F = 0.18\%$/kOe for $t_{\mathrm{ip}} = 8$ Å, it is continuously reduced to $S_F = 0.14\%$/kOe for $t_{\mathrm{ip}} = 24$ Å, which corresponds to a degradation of about 20%. The latter is most probably induced by the in-plane measurement geometry, which promotes shunting currents. For this thickness series the overall $R(H)$ dependence does not change and a wide field range with a linear resistance change appears. Please note that the apparently larger hysteresis present in the MR measurements compared to the p-MOKE loops shown in Fig. 2a originates from the hysteresis of the pole shoe material of the MR setup used.

In a second series, the thickness of the topmost Co layer of the [Co/Pt] multilayer (t_{oop}) was varied from 0 Å to 8 Å with a fixed $t_{\mathrm{ip}} = 16$ Å. In case of $t_{\mathrm{oop}} = 0$ Å there are just three repetitions of the multilayered structure and the Cu spacer is in direct contact with the 8 Å thick Pt layer. In this series the magnetic reversal of the top Co layer is not influenced by t_{oop} as can be seen in Fig. 3a. For $0 \le t_{\mathrm{oop}} \le 6$ Å the [Co/Pt] multilayer keeps full remanence ($M_r/M_s = 1$) but the coercivity increases with increasing t_{oop} (see inset in Fig. 3a). For $t_{\mathrm{oop}} = 8$ Å the demagnetizing field becomes too strong and the magnetization reversal is now dominated by the formation of perpendicular magnetic domains before remanence. This is driven by the additional stray field of the top Co layer, as confirmed by a reference sample without the upper bilayer of Cu and Co which still reveals $M_r/M_s = 1$. However, in this series a maximum GMR ratio of 2% is obtained in the sample with the thickest Co layer where the effect of additional lateral domains in the [Co/Pt] multilayer is clearly visible, which further increases the resistance change by around 0.3 pps (Fig. 3b). Furthermore, for this sample a field sensitivity of $S_F = 0.21\%$/kOe in the linear field range between 1 kOe and 7 kOe is obtained.

In a third series, the Cu spacer layer thickness x was varied between 8 Å and 28 Å using the following layer stack: substrate/Pt(50)/[Co(4)/Pt(8)]$_3$/Co(4)/Cu(x)/Co(16)/Pt(30) (thicknesses given in Ångström). P-MOKE hysteresis loops are presented in Fig. 4 for the whole thickness series. For $x \ge 13$ Å the exchange coupling through the Cu spacer is negligible and thus the corresponding hysteresis loops are almost identical to each other. Conversely, for smaller thicknesses the exchange coupling becomes dominant, showing a decreased coercivity of the [Co/Pt] multilayer at $x = 10$ Å (see inset of Fig. 4) until the coercivity as well as the remanent magnetization completely vanishes at $x = 8$ Å. In this case a full in-plane PSV system is suggested from the hysteresis loop, which is induced by the strong magnetic coupling to the thick Co top layer. A selection of CIP-MR measurements is shown in Fig. 5a. In the following the *R(H)* behavior of the sample with thinnest Cu spacer layer ($x = 8$ Å) is discussed: Starting from saturation (both layers are aligned to the applied perpendicular magnetic field) and reducing the field, there is a near-linear increase in resistance, caused by the rotation of the Co top layer towards the in-plane direction. At around 1.45 kOe a maximum in electrical resistance develops.

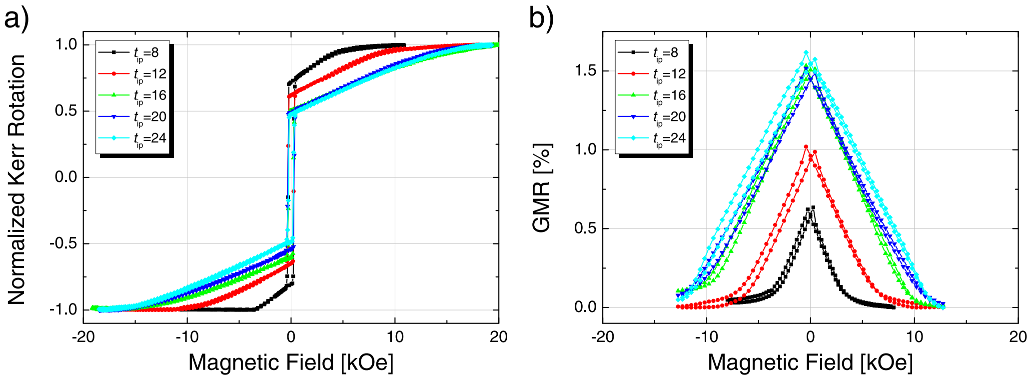

Fig. 2. (a) P-MOKE hysteresis loops of the top Co layer thickness series (t_{ip}): substrate/Pt(50)/[Co(4)/Pt(8)]$_3$/Co(4)/Cu(15)/Co(t_{ip})/Pt(30), thicknesses are given in Ångström. In (b) the corresponding CIP-MR loops are presented for perpendicular applied magnetic fields.