Magnetization reversal mechanism of perpendicularly exchange-coupled composite L10-FePt/CoCrPt bilayers

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Magnetization reversal mechanism in perpendicularly exchange-coupled composite hard/soft L10-FePt/CoCrPt bilayers with different soft layer thickness has been studied using magnetometry and magnetotransport measurements. For thin soft layers, the magnetization reversal process can be described by the rigid model. For thick soft layers, a different magnetization reversal process is observed which consists of three stages. An exchange-spring spin structure is first formed from the positive saturation magnetic field to small negative magnetic field. In the second stage, a Néel wall is driven and squeezed. In the last stage, multiple domain structure is formed laterally to reduce the dipolar interaction and the magnetization reversal is accomplished by the pinned domain wall motion in the hard layer. © 2009 American Institute of Physics. [DOI: 10.1063/1.3148300]

I. INTRODUCTION

For magnetic recording media, small grain size is desirable for the increasing density of information storage and thus strong magnetic anisotropy is required to overcome the thermal instability.1–3 Strong anisotropy can result in switching magnetic field larger than the available magnetic field of the write heads. In order to reduce the switching field, exchange-coupled hard/soft bilayers with the constituent layers of particulate structure have been proposed4,5 and fabricated.6,7 Magnetic properties and in particular the magnetization reversal mechanism of the exchange-spring bilayers have been studied extensively both experimentally and theoretically.8–15 It is generally believed that the magnetization reversal process can be described by the rigid model for thin soft layers, where the magnetization of the soft and the hard layers rotate in synchronization. For thick soft layers, the magnetization reversal process begins with the initiation of an exchange-spring structure where a domain wall is formed within the soft layer. With increasing opposite magnetic field, the domain wall is driven into the hard layer with decreasing wall thickness.9,11 In conventional hard/soft bilayers with in-plane anisotropy, with longitudinally applied magnetic field, the magnetization is parallel to the domain wall and the areal energy density of the wall is reasonably low, and thus the planar Bloch wall is favored. In the perpendicular exchange-coupled bilayers, with applied magnetic field along the film normal direction, the magnetization has a nonzero component perpendicular to domain wall, i.e., the Néel wall is formed. Since the areal energy density of the Néel wall can become very high, multiple domains will be formed during switching. It is of significant scientific and technological interests to experimentally prove this hypothesis.

In this paper, perpendicularly exchange-coupled L10-FePt/CoCrPt bilayers with different soft layer thickness are fabricated and magnetization reversal process is studied. As the magnetically hard layer, the (001) L10-FePt has perpendicular anisotropy due to its large magnetocrystalline anisotropy constant.16 As the magnetically soft layer, the CoCrPt layer has a particulate structure which provides the control of the intergrain exchange coupling to enhance the signal to noise ratio.1,2,6

II. FABRICATIONS AND MEASUREMENTS

The Fe52Pt48(=FePt)/Co64Cr17Pt19(=CoCrPt) bilayers were prepared by dc magnetron sputtering from an FePt and a CoCrPt composite target. The FePt layer was directly grown on MgO (100) single crystal substrate at 500 °C to induce the L10 phase. Afterwards, the samples were annealed in vacuum at the same temperature for 2 h before they were cooled down to 150 °C for subsequent CoCrPt deposition. Through this, the particulate structure can be formed in the CoCrPt layer. The structure of samples was characterized by a Rigaku x-ray diffractometer (XRD) and a JEM-2010 high resolution transmission electron microscope (TEM). Veeco Nanoscope III magnetic force microscope (MFM) was employed to probe the domain pattern of the samples. Magnetic properties were measured by a vector vibrating sample magnetometer of model 7407 from LakeShore Co. Magnetoresistance (MR) was measured by standard four-point probe with applied magnetic field perpendicular to the film plane.

III. RESULTS AND DISCUSSION

XRD spectra of representative FePt/CoCrPt bilayers with different CoCrPt layer thickness are shown in Fig. 1(a). Only fct (001) and (002) diffraction peaks appear for the L10 FePt layers. Therefore, the FePt layer grows epitaxially on single crystal (100) MgO. The CoCrPt hcp (0002) diffraction peak overlaps with fcc (200) peak of MgO. The cross-section TEM image shown in Fig. 1(b) clearly indicates that the

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CoCrPt consists of two sublayers. Due to the lattice mismatch between crystalline CoCrPt and FePt,2,16 a thin amorphous CoCrPt sublayer is formed at the interface to stimulate the subsequent growth of the column structure.

The out-of-plane hysteresis loops of FePt/CoCrPt bilayers with two representative CoCrPt thickness are shown in Figs. 2a and 2b. With a soft layer thickness \(t_{\text{SL}}\) of 2.7 nm and 20 nm, the coercivity \(H_C\) is determined to be 1.8 and 0.7 kOe, respectively. \(H_C\) of these bilayers shows significant reduction from that of about 4.0 kOe for the single layer FePt films (not shown). With thin soft layers such as \(t_{\text{SL}} = 2.7\) nm, the hysteresis loop is squared and the magnetization reversal process can be described by the rigid model.1 In order to understand the magnetization reversal mechanism, the angular dependence of \(H_C\) with respect to the angle between the external magnetic field and the film normal direction \(\theta_H\) has also been measured. In these experiments, \(H_C\) is found to increase with increasing \(\theta_H\) and the magnetization reversal process is accompanied by the pinned domain wall motion.17,18 This can be further proved by the zero \(m_z\) during the hysteresis loop of \(\theta_H = 0\) for the thin soft layer, as shown in Fig. 2a.

With thick soft layers such as \(t_{\text{SL}} = 20\) nm, a different magnetization reversal process is observed in which three stages can be identified. First, the magnetization reversal process starts at a positive nucleation field of 3.0 kOe. The magnetization along the external magnetic field decreases gradually, while the magnetic component in the film plane increases when the external magnetic field is decreased from 3.0 kOe to the critical negative field of \(-0.3\) kOe. Measurements have shown that the magnetization reversal process in this region is reversible. In order to further confirm the spin structure, the MFM imaging at the remanent state is measured, as shown in Fig. 3. At \(H = 0\), there is no additional planar magnetic contrast, that is to say, there is no lateral domain structure at the remanent state although the remanent ratio is smaller than one. An exchange-spring structure is suggested to be formed in the soft layers.11 Second, when the external magnetic field becomes more negative than \(-0.3\) kOe, \(m_x\) and \(m_y\) decrease sharply. It is suggested that during this stage, the exchange spring is squeezed. The magnetization of the soft layer is reversed and the Néel domain wall is located near the interface between the soft and the hard layers,11 which is shown schematically in Fig. 4a.

In the third stage, as the magnetic field is smaller than the negative coercive field, \(m_y\) is almost equal to zero, while \(m_x\) approaches saturation. In order to further reveal the domain structure during this final magnetization reversal process, MR curves were studied. As shown in Fig. 5a, antisymmetric MR peaks are observed at negative and positive coercive fields. Similar phenomenon has been observed in perpendicularly magnetized Co/Pt multilayers,19 where near the coercive field, the stripe domain structure is formed. The magnetization and thus the resulted Hall electric field are antiparallel in neighboring domains, causing the redistribution of the electric field and additional sheet resistance. The antisymmetric MR peaks are the fingerprints of the multidomain structure in perpendicularly magnetized films. Therefore, the results in Fig. 5a reflect the multiple domain structure when the exchange spring is squeezed. The domain structure during the switching is schematically shown in Fig. 4b. Moreover, the magnetization reversal process is accompanied by the pinned domain wall motion,17,18 as revealed by the angular dependence of the switching field \(H_{\text{SW}}\) in Fig.
Here, $H_{SW}$ corresponds to the MR peak, at which the hard layer is in the multiple domain state and the domain wall is depinned. Accordingly, $H_{SW} \propto H_P \cos \theta_{HF}$, in which the pinning field $H_P$ is equal to $H_C(\theta_{HF}=0)$.

It is meaningful to compare the magnetization reversal mechanism between planar and perpendicular exchange-spring bilayers. For soft/hard bilayers, the exchange spring is initially formed, in which the domain wall is parallel to the film plane. With in-plane anisotropy/perpendicular anisotropy, the magnetizations are parallel/perpendicular to the film plane near zero magnetic field, and thus the Bloch/Néel domain wall is formed. The Bloch wall has a low areal domain wall energy, whereas the Néel domain wall areal energy is higher due to the demagnetization energy.\textsuperscript{20,21} If the hard/soft bilayers have the geometry of single grain and each grain consists of the soft and the hard layers, the lateral multidomain structure may disappear.\textsuperscript{14,17} If the grains are coupled strongly and the multigrain model holds, the lateral multidomain structure may occur.\textsuperscript{15} For perpendicular exchange-spring bilayers, the multidomain structure is laterally formed to reduce the demagnetization energy. Similar magnetization reversal process is observed in other exchange-spring FePt/CoCr, FePt/permalloy, and FePt/Co bilayers. The magnetization reversal mechanism is expected to be universal for the perpendicular exchange-spring bilayers. Finally, it should be pointed out that the magnetization reversal process is also influenced by the strength of the interlayer interaction.
exchange coupling. In the absence of the interlayer coupling, the magnetization reversal of the two layers is independent of each other. With increasing interlayer coupling, the magnetization reversal process can be expected to change. For example, the remanent ratio is increased while the switching field is decreased. In most cases, such as in the present L10-FePt/CoCrPt bilayers, the soft/hard bilayers have intermediate interlayer coupling, that is to say, the interlayer coupling is close to that of bulk materials.

IV. CONCLUSION

A series of perpendicularly exchange-coupled L10-FePt/CoCrPt bilayers was prepared and the magnetization reversal process was studied. Compared with single FePt layer films, $H_C$ of the bilayers is greatly reduced. For thin soft layers, the magnetization reversal process can be described in terms of the rigid model where magnetizations in both layers are always coupled together. For thick soft layers, the magnetization reversal process can be divided into three different periods. In the first period, the exchange spring is formed in the soft layer. Then, the Néel wall is driven toward the hard layer. Finally, the multiple domain structure is laterally formed to reduce the domain wall energy of the Néel wall and the magnetization reversal is accomplished by the pinned wall motion in the hard layer.

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