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Magnetic moments in Fe–Co/Pt superlattices

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ABSTRACT

The element specific spin and orbital moments for Fe and Co in $Fe_{40}Co_{60}$/Pt (0 0 1) superlattices, with layer thicknesses $d_{FeCo} = 4-10$ ML and $d_{Pt} = 8$ ML, have been studied by X-ray magnetic circular dichroism with focus on the interfacial magnetic moments of the $Fe_{40}Co_{60}$ layers. The spin moments of Fe and Co showed the same relative decrease at the interfaces with respect to the bulk alloy. The change at the interface was found to be −0.9(1) of the bulk alloy spin moment. The orbital moment for Fe also decreased at the interfaces, whereas the Co orbital moment did not show any appreciable change at the interfaces. In addition, SQUID measurements of the total magnetization allowed the extraction of the induced Pt magnetic moment, which was found to be 0.6(3) μ_B/atom and is discussed with respect to previous studies.

1. Introduction

Tetragonally distorted Fe–Co alloys have recently attracted a large interest due to the predicted high uniaxial out-of-plane anisotropy combined with a large saturation magnetic moment [1,2], making this type of materials highly suitable for magnetic recording applications. For a particular range of c/a ratios, 1.20–1.25, combined with an alloy composition of about 40 at% Fe, the uniaxial anisotropy is predicted to reach a maximum of 800 μeV/atom.

Recently we have presented the realization of a tetragonally distorted Fe–Co alloy in the form of Fe–Co/Pt superlattices [3–5]. These structures also showed a uniaxial out-of-plane easy axis for thin Fe–Co layers [4]. However, the magnitude of the uniaxial anisotropy was about one-fourth of the theoretical maximum [4]. A more detailed investigation of the uniaxial anisotropy [5] revealed that a large portion of the uniaxial anisotropy indeed originates from a strain contribution.

Since, so far, no studies have concerned the behavior of the magnetic moment at the interfaces of this three component system the present investigation is aimed at determining the magnetic moments. In order to resolve the separate contributions from Fe and Co, X-ray magnetic circular dichroism (XMCD) measurements have been conducted at the L_2/L_3 edges of each element. In addition the total magnetic moment has been determined by SQUID magnetometry, allowing a study of the induced Pt magnetic moment, which is expected to be of appreciable magnitude since Pt is an easily polarized material [6,7].

2. Experimental details

The Fe–Co/Pt superlattices were grown on $10 \times 10 \times 0.5$ mm^3 MgO(0 0 1) substrates with UHV-based magnetron sputtering. The base pressure in the system was below 1×10^{-9} mbar prior to deposition. Argon, with a purity better than 99.9999%, at a pressure of 4 mTorr was used as sputtering gas. The samples were deposited from targets consisting of elemental Fe, Co and Pt. Nominal alloy composition was 40 at% Fe in the Fe–Co layers. This particular alloy will be denoted as FeCo throughout the remainder of the paper. The details of the growth can be found elsewhere [3]. Hereafter the samples will be referred to by their nominal thicknesses in monolayers (ML), where 1 ML FeCo corresponds to 1.43 Å and 1 ML Pt corresponds to 1.96 Å. The FeCo layer thickness was varied between 4 and 10 ML while the Pt thickness was kept constant at 8 ML. The number of bilayer repetitions was 20 for all samples.

The samples were structurally characterized with Cu K_α X-ray diffraction and X-ray reflectivity on a Siemens D5000 in the Bragg–Brentano geometry with a secondary graphite monochromator. Mean lattice constants for the superlattices were measured through reciprocal space maps around the (0 0 2) and (2 0 4) reflexes on a Philips X'pert, also operating with Cu K_α radiation

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and equipped with Göbel mirrors as primary and secondary optics.

The chemical composition of the samples was determined by X-ray photoelectron spectroscopy (XPS) measurements on a Scienta ESCA-300 spectrometer, using Al Kα radiation (1486.7 eV). The measurements were done over the peaks corresponding to Fe 3p, Co 3p and Pt 4f on a reference sample consisting of 500 Å FeCo capped with 10 Å of Pt. The electron take-off angle was 90° and the energy resolution of the electron analyzer was set to 0.4 eV.

The easy direction of the magnetization was determined from hysteresis loops recorded at room temperature using both the longitudinal and polar magneto-optical Kerr effect (MOKE). Room temperature (300 K) XMCD measurements at the L_2 and L_3 absorption edges of Fe and Co were carried out at beamline D1011 at the MAXII synchrotron in MAX-Lab, Sweden. The degree of circular polarization at this beamline has been measured to be $p_c = 0.85$ [8]. The samples were first magnetized in the easy direction, in-plane [1 1 0] as determined from MOKE measurements, by a pair of *in situ* coils. Three sequential spectra were recorded in each state of remanence, i.e. parallel and antiparallel to the photon spin, respectively, in order to verify the stability of the magnetic moment and the reproducibility of the signal. All XMCD spectra were recorded in total electron yield with the incident beam at a grazing angle of 45°. This has been shown to yield a fair magnetic signal while saturation effects are negligible [9]. The reference sample was also measured, in order to calibrate the magnetic moment values.

3. Results and discussion

All the X-ray reflectivity measurements and X-ray diffraction measurements showed satellite reflections arising from the superstructure as well as Kiessig fringes originating from the total thickness of the film. An example from the 10/8 sample can be seen in Fig. 1. The extracted bilayer thickness from the X-ray reflectivity did not deviate more than one ML from the nominal thickness, indicating reproducible deposition conditions. The full line in Fig. 1 is a refinement of the data using the GenX program [10]. The extracted thicknesses for FeCo and Pt are 14.5 and 13.9 Å, respectively, which corresponds to 10.1 ML FeCo and 7.2 ML Pt. These values are in good agreement with the nominal. The disappearance of the second satellite is due to the similar thicknesses of FeCo and Pt. From the reciprocal space maps around the (0 0 2) and (2 0 4) reflexes the in-plane and out-of-plane lattice parameters were extracted by measuring the difference in reciprocal space coordinates between the two reflexes. This procedure increases the reliability of the measured lattice parameters, since it removes uncertainties in the position of the reciprocal space origin [11].

The composition of the FeCo layers was determined from the areas of the Fe and Co 3p peaks in the XPS spectra. The obtained composition for the 500 Å reference sample was 47 ± 10 at% Fe, somewhat higher than the nominal value.

The XMCD data were normalized and a linear background was subtracted from the spectra to make them coincide in the pre-edge and post-edge regions. Fig. 2 shows the electron yield spectra and XMCD signal from the 10/8 sample. As can be seen in the left panel some features are observed above the Fe L_2 edge. This is ascribed to the Pt N_1 edge which should be located at 725.4 eV [12]. The same features are also seen in the pre-edge region in the Co spectra, shown in the right panel of Fig. 2. All the spectra from the superlattice samples show the same features, but they are not present in the data from the alloy film. The data were analyzed according to the sum rules [13,14]. Since the superlattice samples

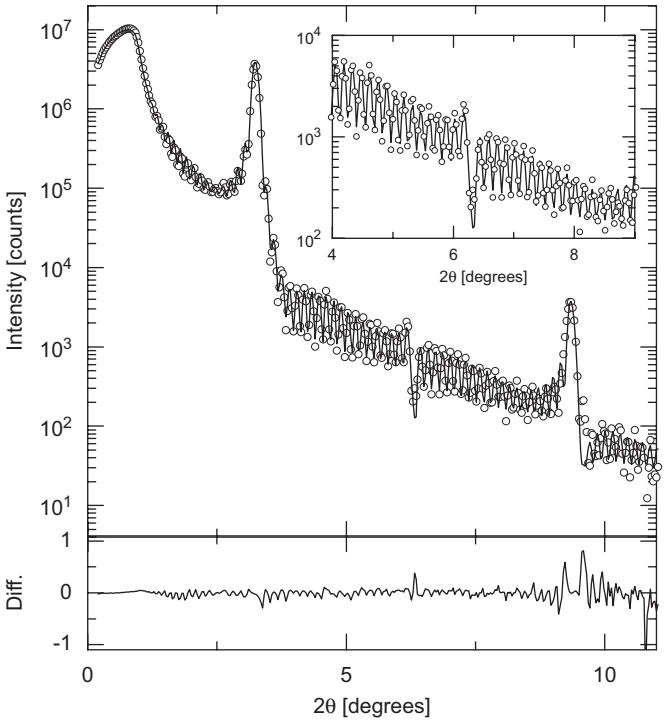

Fig. 1. X-ray reflectivity (circles) from sample 10/8 and the result from the structural refinement (full line). The lower panel shows the logarithmic difference between the data and simulation. Note the reflections from the superstructure and the inset showing the high frequency Kiessig fringes from the total thickness. The second Bragg peak is suppressed due to the similarity in FeCo and Pt layer thicknesses.

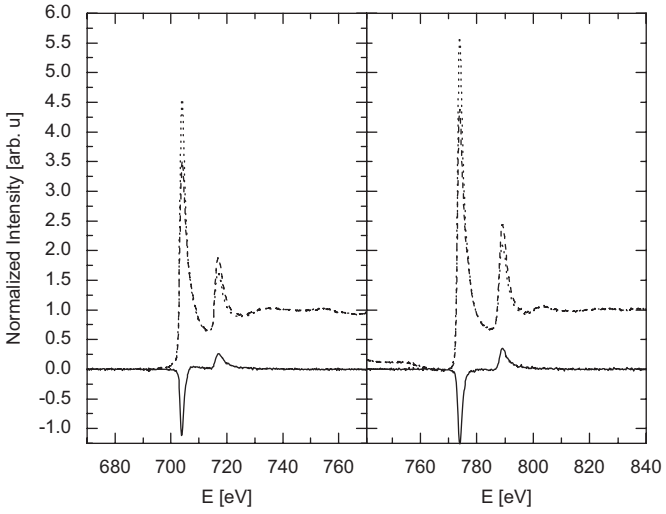

Fig. 2. Total electron yield spectra from sample 10/8 showing the absorption (dashed lines) for two different directions of the magnetization and their difference (solid line). The left panel shows the Fe edges and the right panel shows the Co edges.

did not have full remanence the magnetic moments as obtained by XMCD were scaled by the remanent value as obtained by MOKE. In addition none of the samples showed an easy out-of-plane anisotropy; no superlattice could be saturated by a magnetic field of 1.3 T out-of-plane, as seen by polar MOKE. The obtained spin and orbital moments, normalized to the bulk reference alloy, are presented in Table 1. The absolute values of the spin magnetic moments for Fe and Co are also presented.