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MAGNETIC X-RAY CIRCULAR DICHROISM IN FE CO PT MULTILAYERS

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ABSTRACT

Magnetic x-ray circular dichroism in x-ray absorption has been used to investigate the ternary multilayer system, Fe Co Pt. Samples were prepared by planar magnetron sputter deposition and carefully characterized, using a variety of techniques such as grazing-incidence and high-angle x-ray scattering, Auger depth profiling and cross-section transmission electron microscopy. As previously reported, the Fe9.5Å Pt9.5Å exhibits a large dichroism in the Fe 2p absorption. Interestingly while the Co9.5Å Pt9.5Å has no measurable dichroism, the Fe4.7Å Co4.7Å Pt9.5Å sample has a dichroism at both the Fe 2p and Co 2p absorption edges. These and other results will be compared to slab calculation predictions. Possible explanations will be discussed.

INTRODUCTION

The last several years have witnessed a massive growth in the research and development of nanoscale magnetic materials. Perhaps the best review is provided by the Falicov Report[1] on "Surface, Interface, and Thin-Film Magnetism." Three general lessons can be derived from this report: (1) Magnetism is one of those special cases where fundamental research can directly lead to technological applications; (2) The key to understanding and manipulation of magnetic properties is the subtle yet overwhelming interplay of atomic geometric structure and local magnetic properties. For example, the giant magneto-resistance effect (GMR), which is already being explored for technological exploitation[2,3,4], appears to be intimately coupled to interfacial and thin film effects and probably will require elementally-specific probes for an explicit determination of the underlying causes[5,6,7]. This also appears to be the case for spin valves[8,9,10], another source of device miniaturization in read heads and magnetic sensors. [While it may eventually be found that these two effects are fundamentally connected, for now it appears that the GMR effect (up to 60%) is dependent upon an anti-ferromagnetic coupling through a non-ferromagnetic layer while the spin valve effect ($\leq$ 10%) is associated with an uncoupled ferromagnetic layer[9], which can be controlled externally.]; (3) The importance of probes with a direct spin-dependence. A very recent illustration of this is the development of the magnetic x-ray circular dichroism (MXCD) using x-ray absorption[11-15] and photoemission[16,17] as a probe of surface, monolayer, and multilayer magnetism. It is this advantage of elemental selectivity and spin specificity from MXCD x-ray absorption that we have to utilized, coupled to extensive structural characterization using techniques such as x-ray diffraction and transmission electron microscopy[18], plus spin-dependent slab calculations[19], to investigate Fe Co Pt magnetic multilayers.

SAMPLE PREPARATION AND CHARACTERIZATION

The Fe Co Pt multilayer samples are prepared using magnetron sputter deposition. The deposition chamber is cryogenically pumped to a base pressure of 1.3 x 10^{-5} Pa. A circular array of magnetron sources is situated 20 cm beneath an oxygen-free copper platen. The magnetron sources are operated in the dc mode at a 330–390 Volt discharge. An argon working gas pressure of 0.40 Pa is used at a flow rate of 15.5 cc $min.^{-1}$. The substrates are sequentially rotated over each source at 1.0 rev. $min.^{-1}$. The target materials are > 0.9994 pure. The polished Si substrates are cleaned with a procedure consisting of a detergent wash, deionized water rinse, alcohol rinse, and a N_2 gas drying prior to deposition. The substrates remain at a temperature between 293 and 306 K during the deposition. The sputter deposition rates, between 0.02 and 0.50 nm $sec.^{-1}$, are monitored using calibrated quartz crystals. The quartz crystals indicate the component layer thicknesses and the layer pair thicknesses, d_{FeCoPt}^{XTC}. The multilayer films are grown to a 0.2 μm thickness. Samples were futher characterized with x-ray diffraction, transmission electron microscopy and Auger depth profiling, as described elsewhere[18,20,21].

MXCD AND SLAB CALCULATION RESULTS

The MXCD measurements were performed at Stanford Synchrotron Radiation Laboratory (SSRL) on a spherical grating monochromator having the ability to generate soft x-rays with a high degree of circular polarization. This beamline (BL 8–2) is part of the UC/National Laboratories facilities at SSRL[22,23]. The absorption measurements were made in a total electron yield mode. Samples were magnetized *in situ* with a pulse coil, and the absorption was measured in remanence. For 3*d* transition metals, MXCD in x-ray absorption is observed as a polarization-dependent intensity variation in the L_2 and L_3 edges. A typical example of the Fe Co Pt multilayers is shown in Figure 1. The polarization dependence requires that the incident x-ray helicity (either parallel or anti-parallel to the direction of propagation) be aligned or anti-aligned with the sample magnetization[18,20,21]. When these vectors are perpendicular, the polarization dependence vanishes. The spectra in Figure 1 are for a grazing x-ray incidence angle of 80° from the sample normal. The solid curve is for a nearly anti-parallel arrangement of x-ray helicity and majority electron spin, and the dashed curve for a nearly parallel geometry. The intensity differences for for the L_2 and L_3 white lines are apparent. Our measurements demonstrate that the magnetization for the Fe Co Pt samples is in the plane of the multilayer films. It has also been shown that the relative strengths of the L_2 and L_3 absorption edges contain information about the spin-dependent density of states above the Fermi level and, therefore, about the spin and orbital magnetic moments of the material[18,20,21]. Interestingly in the case of Figure 1, there is an observable MXCD effect at both the Fe 2p and Co 2p edges. Preliminary analysis indicates for Fe_x Co_y $Pt_{9.5Å}$, little or nor MXCD effect if x = 0 and 0 ≤ y ≤ 10Å or if 0 < x < 4Å and 2Å ≤ y ≤ 4Å. A significant MXCD effect is observable for y = 0 and 5Å ≤ x ≤ 12Å or 4Å < x and 4Å < y. Further analysis, using branching ratio and sum rule approaches, is in progress[18,20,21].

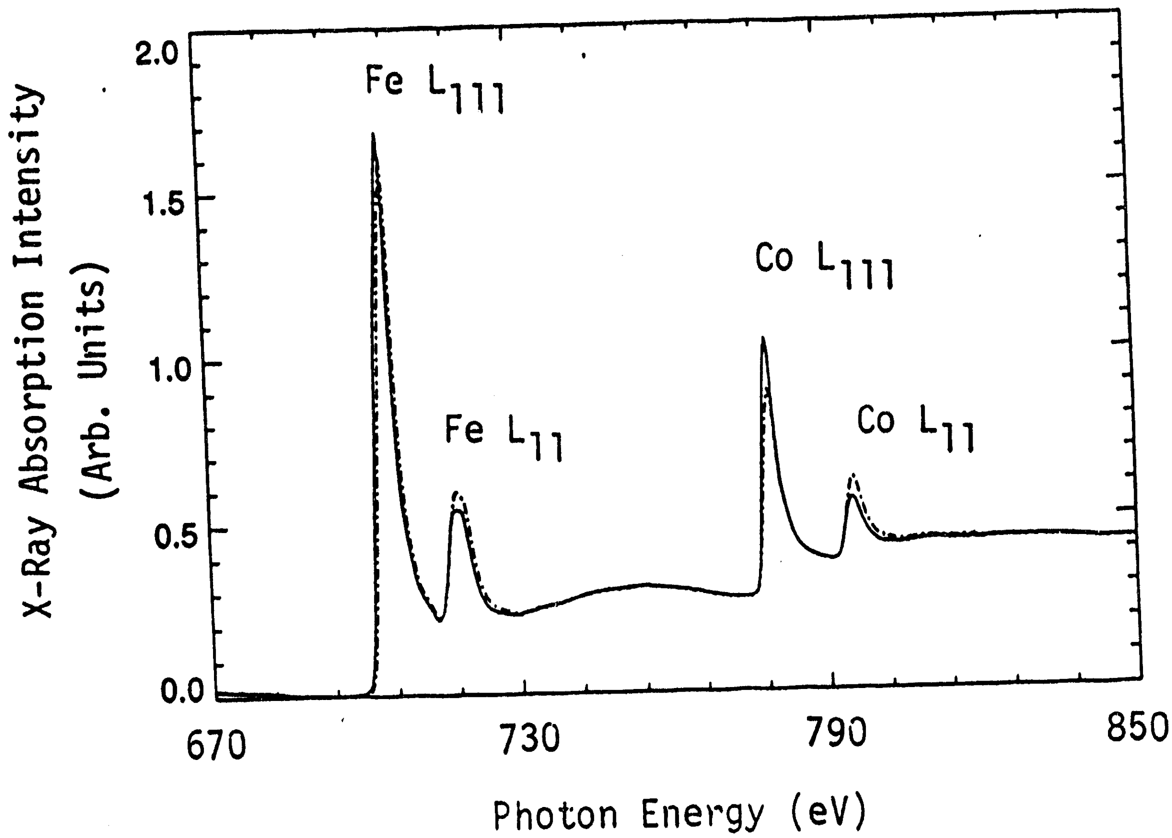

Figure 1. The x-ray absorption spectra of $Fe_{4.7Å}$ $Co_{4.7Å}$ $Pt_{9.5Å}$ using circularly-polarized x-rays. See text for details.

This raises an important question: Is the observation of an MXCD effect a true moment transfer or only a proximity effect from the nearby polarized Fe conduction states? To address this issue, we have begun a modeling of the system using a slab calculational method. Preliminary results are shown in Figure 2. Here the structures are all fcc with a = 3.81Å, extracted from x-ray diffraction results. In this case large moments are seen for both Fe and Co in both the binary (x = 0 or y = 0) and ternary cases. Further calculations with adjustments of spacings will be necessary before any additional insight can be gained.

MXCD in Fe Co Pt Multilayers
Preliminary Slab Calculation Results
Magnetic Moments (in Bohr magnetons)

----	Pt	0.15	----	Pt	0.16
----	Pt	0.007	----	Pt	0.01
----	Pt	0.15	----	Pt	0.01
0000	Fe	2.82	----	Pt	0.16
0000	Fe	2.78	****	Co	1.92
0000	Fe	2.82	****	Co	1.88
			****	Co	1.88
			****	Co	1.92

----	Pt	0.15	----	Pt	0.16
----	Pt	-0.04	----	Pt	0.00
----	Pt	-0.04	----	Pt	0.02
----	Pt	0.15	----	Pt	0.15
0000	Fe	2.84	0000	Fe	2.83
0000	Fe	2.78	0000	Fe	2.77
0000	Fe	2.78	****	Co	1.85
0000	Fe	2.84	****	Co	1.94

Figure 2. Slab calculation results for $(Fe_{3ML}\ Pt_{3ML})n$, $(Fe_{4ML}\ Pt_{4ML})n$, $(Co_{4ML}\ Pt_{4ML})n$ and $(Fe_{2ML}\ Co_{2ML}\ Pt_{4ML})n$. ML stands for monolayer. 1 ML $\approx$ 2.2Å in these systems.

SUMMARY

We are using a combined approach based upon magnetic x-ray circular dichroism with x-ray absorption, structural characterization and theoretical simulations with slab calculations to probe the structure-property relationships in magnetic Fe Co Pt multilayers. Thickness dependences, template effects, and interfacial mixing are all crucial contributions that need to be isolated, controlled and understood. The issue of moment transfer versus proximity conduction band polarization is being investigated further.

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