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MAGNETIC DICHROISM EFFECT OF BINARY ALLOYS USING CIRCULARLY-POLARIZED X-RAYS

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We have studied the magnetic properties of CoNi binary alloy films with various atomic compositions using soft x-ray magnetic circular dichroism (XMCD) technique. The alloy films were deposited on a single Cu(100) crystal *in situ* using our well-established epitaxial growth technique to achieve a layer-by-layer growth and a metastable fcc structure, with all the films exhibiting an in-plane magnetic anisotropy. The high density, circularly-polarized x-ray beam was supplied by the Elliptically Polarizing Undulator at the Stanford Synchrotron Radiation Laboratory. Utilizing the element-specific ability and nanostructure magnetization sensitivity of this technique, we have been able to perform the absorption measurements at L_2 and L_3 edged of Co and Ni atoms and observed large dichroism signals. The extraction of spin moment and orbital moment for varying elemental stoichiometry using magneto-optical sum rules is discussed.

INTRODUCTION

X-Ray magnetic circular dichroism (XMCD) technique has attracted a tremendous amount of attention recently because of its ability to probe the magnetic system on an elementally-specific basis. Combining the novel synchrotron radiation sources with advanced thin film growing techniques, highly desirable information about the spin-orbit interaction and exchange-splitting can be extracted from both linear dichroism and circular dichroism effects. The orbital ($\langle L_2 \rangle$) and spin ($\langle S_Z \rangle$) contributions to the magnetic moment for individual orbitals and individual elements are related to the shape and integration signals of the dichroism spectra.

Difference groups have been working on the theoretical foundations as well as the experimental details. A pair of magneto-optical sum rules for calculating the ground-state expectation values of spin and orbital moment from XMCD signals have been proposed [1–5]. The applicability of these sum rules to experimental systems were checked experimentally [6–8], and the results on Fe and Co films, as well as Co/Pd multilayers have provided some verification, with the work on Co/Pd multilayers suggesting an enhanced orbital magnetic moment of Co atoms compared to that in bulk Co [6].

The XMCD technique measures the difference of the x-ray absorption using left-handed circularly-polarized light and right-handed circularly-polarized light of a magnetic system, with the wave-vector of the polarized photons being parallel or antiparallel to the sample magnetization. The excitations are from a core level absorption edge, typically L, M, or N shell. In our experiment, the excitations from 2p core level to 3d empty valence band were measured, so that the absorption were from the $L_{2,3}$ edges.

According to the above magneto-optical sum rules, the total area of the dichroism spectrum is a measure of $<L_Z>$, while the difference of the L_3 with twice the L_2 area is proportional to $<S_Z>$ [4,5].

In this paper, we report our study on CoNi films with various atomic concentrations using the XMCD technique. We will show the large dichroism signals at L_2 and L_3 edges for both Co and Ni atoms. From the relation between the integrated dichroism signals and the spin and orbital moments for each element, we demonstrate that the effective spin moment is a linear function of the composition.

EXPERIMENT

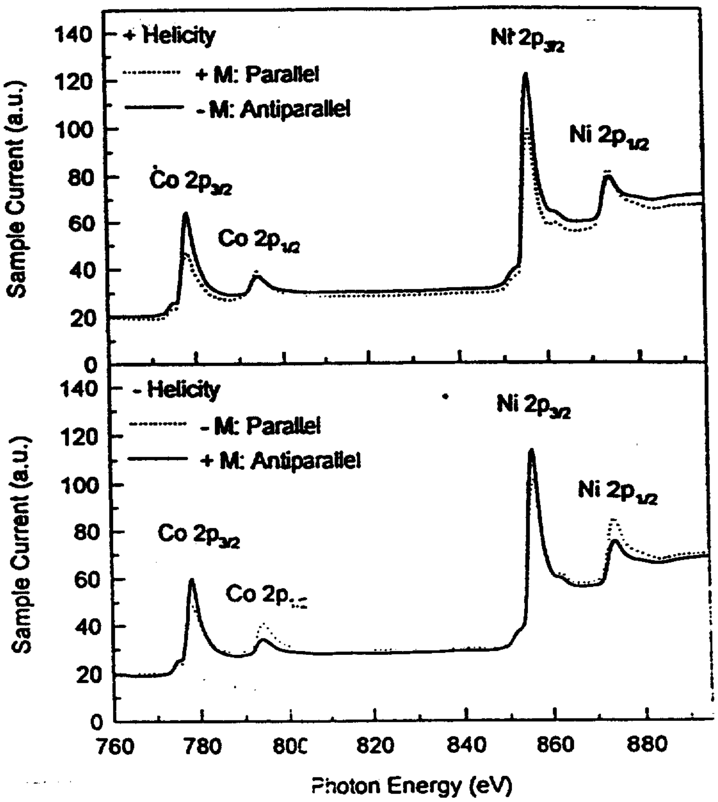
The XMCD experiment was performed at the Stanford Synchrotron Radiation Laboratory on beamline 5–2, using the soft x-radiation from the Stanford Electron Positron Asymmetric Ring (SPEAR). The grating monochromator was set to select the 550–1000eV range for this experiment, and an elliptically-polarizing undulator (EPU) was used to vary the helicity of the magnetic field and hence the polarization of the emitting x-ray [9]. The EPU was designed to supply highly-polarized photons: higher than 95% for the range where the 2p white lines of Co, Ni, and Cu were detected.

The ultrathin films of CoNi alloy were deposited on a clean Cu(100) single crystal substrate at room temperature, by simultaneously evaporating both materials with the calibrated fluxes controlled to achieve the desired atomic compositions. The thickness was estimated to be 4.3±0.7 ML for $Co_{0.25}Ni_{0.75}$, $Co_{0.55}Ni_{0.45}$, and $Co_{0.70}Ni_{0.30}$ films, and 6±1 ML for a pure Ni and a pure Co film. During the XMCD measurement the pressure was maintained in the 10^{-10} Torr range, while during evaporation the pressure was worse because of the limited time for degassing the preparation system. This would introduce a certain amount of C and O contamination into the grown films. The crystalline structure of these films has been studied earlier and the conclusion of a pseudomorphic layer-by-layer growth with fcc structure has been drawn [10].

After the deposition, the film was then magnetically saturated by a capacitor voltage discharger. The magnetic field was applied in the plane of the film as well as the direction of the incident light to accomplish a longitudinal configuration since our previous surface magneto-optic Kerr effect (SMOKE) study has confirmed an in-plane magnetic anisotropy for these ultrathin alloy films. In addition, our SMOKE measurements have shown that the Curie temperature for CoNi alloys follows an empirical finite-size scaling law as a function of film thickness [10, 11]. Fo the films that were used in this room temperature XMCD study, the thicknesses were controlled so that the Curie temperatures were above room temperature. The soft x-ray illuminated onto the magnetic films at a 20° grazing angle. An Au mesh was placed in the x-ray beam path and the photoelectron current was collected from a channeltron which was used to normalize the sample current, thereby minimizing any fluctuation in photon flux. Meanwhile, the sample current was measured as a function of the photon energy at the configurations where the x-ray polarization was parallel and antiparallel to sample magnetization, alternatively.

RESULTS AND DISCUSSION

The normalized sample current versus photon energy for 4.3 ML $Co_{0.25}Ni_{0.75}$/Cu(100) is shown in Figure 1. The dashed lines represent the spectra for the parallel configuration, and the solid lines for the antiparallel one. The dichroism effect can be seen clearly from the comparison of them.



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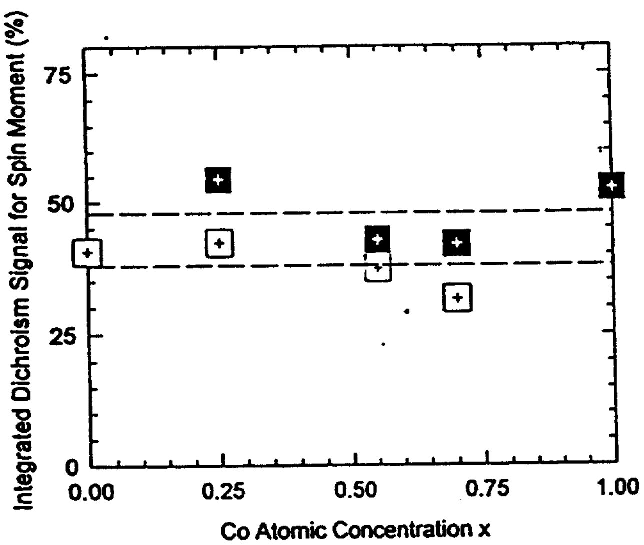

Figure 2. The integrated dichroism signal for spin moment <m_{spin}> (in the unit of %) for both Co and Ni atoms that we have calculated using the integration part of the magneto-optical sum rule, as a function of Co atomic concentration. The average values for Co and Ni are represented by two dashed lines.

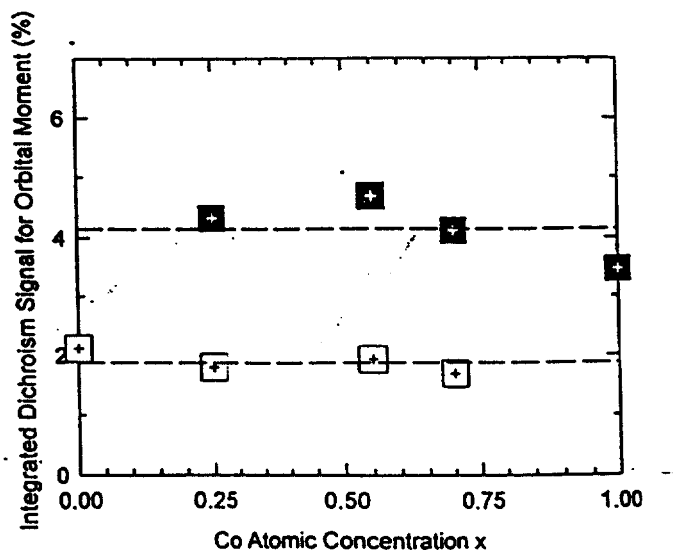

Figure 3. The integrated dichroism signal for orbital moment <morb> (in the unit of %) for both Co and Ni atoms that we have calculated using the integration part of the magneto-optical sum rule, as a function of Co atomic concentration. The average values for Co and Ni are represented by two dashed lines.

Similar dichroism spectra were achieved on the films with different atomic concentrations. On some of the spectra, a satellite structure was observed at about 6eV higher than the 2p peak, which was explained by a charge-transfer effect from a viewpoint of the configuration interation on the basis of the Anderson impurity model [12].

The spin and orbital magnetic moments can be determined from the XMCD spectra using the magneto-optical sum rules [4, 5]. The results of one analysis are shown in Figure 2 (spin) and Figure 3 (orbital moments).

SUMMARY

We have produced a set of CoNi alloy films with various atomic compositions, and calculated the integrated dichroism signals for the spin and orbital moment of Co and Ni atoms from the XMCD spectra utilizing soft x-rays provided by synchrotron radiation. We have observed large dichroism signals at L_3 and L_2 edges for both Co and Ni atoms. The results of integrating the dichroism signals have demonstrated that the magnetization density in this fcc ordered binary system with (100) surface symmetry is a linear function of the atomic composition. This supports an alloy composition of a high spin component (Co) and a low-spin component (Ni), the magnetization density of which reflects stable local moments across the whole compositional range of this binary alloy.

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