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DISCLAIMER

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ABSTRACT

We have prepared Fe_xNi_{1-x} multilayers on Cu(111) in order to learn how to control the structure and magnetism of these thin alloy films, which are relevant to the giant magnetoresistance (GMR) effect used in magnetic disk drive heads. Using the Spectromicroscopy Facility (7.0.1.2) on Undulator Beamline 7.0 at the Advanced Light Source, we have measured X-ray magnetic linear dichroism (XMLD) signals from both Fe and Ni 3p lines for fourteen different thin Ni-Fe alloy films on Cu(111), with Fe concentration ranging from 9% to 84% and for a variety of film thicknesses. The Curie temperature for all of these samples was in the range 200K to 500K. For many of these films, the Curie temperature was considerably lower than was previously seen for similar films deposited on Cu(100). For a particular Fe concentration x, the Curie temperature increases with alloy film thickness. For a specific film thickness, the Curie temperature has a maximum near $x \approx 0.4$.

INTRODUCTION

The ability to control growth at the atomic level has led to renewed interest in the study of magnetism and magnetic materials. This control allows for the study of the relationship between magnetic and structural properties for optimization of magnetic devices based on thin film technologies, as well as testing the theoretical predictions for such systems.[1] We are studying layer-by-layer synthesis of ultrathin metal films by controlling the composition and structure of these films at the monolayer level, including the interfacial region. We have prepared Fe_xNi_{1-x} multilayers using simultaneous evaporation of pure Ni and Fe on Cu(111) in order to better understand the GMR effect in NiFe/Cu systems that are relevant to magnetic disk drive heads.

Using core-level photoelectron spectroscopies on magnetized samples allows for exploitation of the fact that symmetry is broken due to the presence of magnetization. The effect is due to spin-orbit interaction in the presence of exchange interaction. X-ray magnetic linear dichroism (XMLD) is one such technique that clearly exhibits asymmetry due to magnetization. XMLD can be observed in angle resolved, spin-integrated photoemission experiments for p-polarized light under oblique incidence.[2] The first example of this effect was shown on a thin Fe(001) film, for which the Fe 3p core level peak position and line shape changed when the magnetization of the sample was reversed.[2] Because of its dependence on photoemission from a core level, the effect can be used for surface sensitive, element-specific magnetometry. In this study, we have observed this effect for 14 samples of different thicknesses with Fe concentration from 9% to 84%. This paper discusses the temperature dependence of the dichroism signal.

EXPERIMENT

The sample used in the experiment was a copper (111) single crystal, 1 cm in diameter and ~3 mm thick. This crystal was polished mechanically and electrochemically. Laue X-ray diffraction was used to determine that the miscut was within 1°. The sample was mounted in the Spectromicroscopy Facility[3] on Beamline 7 at the Advanced Light Source (ALS), Berkeley, for sample preparation and dichroism experiments. Sample cleaning consisted of cycles of argon ion sputtering (3kV, 20μA) and annealing to 550-600°C. Alloy samples were formed by simultaneous electron beam evaporation of Fe and Ni. Actual composition and thickness of the films were determined *in-situ* by X-ray photoelectron spectroscopy (XPS) with 1250eV photons. Figure 1 is a full range XPS survey scan measured on a $Fe_{0.64}Ni_{0.36}$ alloy sample with thickness of ~5ML. This scan clearly demonstrates the chemical purity of this sample, as there is no evidence of carbon or oxygen contamination. The Cu, Ni, and Fe 2p peaks are clearly observed, as are the Cu and Fe 3p lines. The elemental composition and thickness of such a thin film sample is determined quantitatively from the 2p peak heights in such a scan.

Soft x-ray radiation from Undulator Beamline 7.0 was used to perform XMLD experiments using the SpectroMicroscopy Facility (7.0.1.2). We utilized 190eV p-polarized photons to measure photoemission of Fe and Ni 3p core levels in normal emission with 2° angular resolution. The photon beam was incident at 60° to the surface normal. The magnetization direction was along the [1, -1,0] direction in the plane of the Cu(111) sample and also perpendicular to the plane determined by the electron emission and the propagation direction of the light for maximum contrast upon magnetization reversal.[4] Elementally specific magnetometry of the Ni-Fe alloys on Cu(111) was performed as a function of composition, thickness, and temperature. The dependence of the XMLD signal on temperature was used to obtain an approximate Curie temperature for the samples, as a function of Fe concentration.

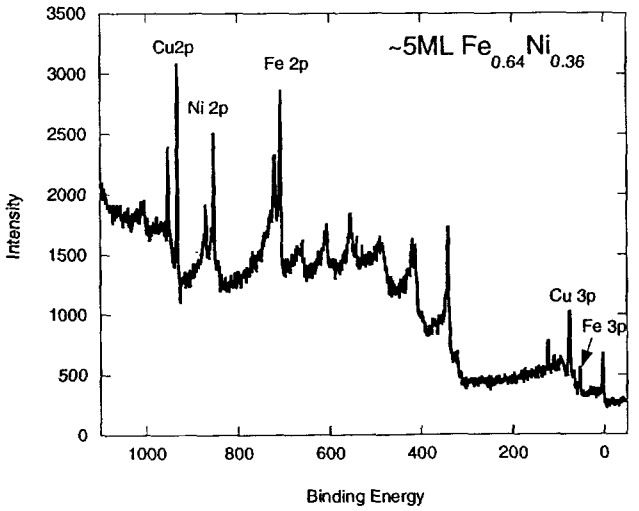

Figure 1. Wide scan survey of a $Fe_{0.64}Ni_{0.36}$/Cu(111) sample using plane polarized soft x-ray radiation at 1250eV. Sample concentrations are determined by normalized peak ratios with corrections for the cross sections and mean free paths.

RESULTS AND DISCUSSION

Figure 2 shows the XMLD effect for Fe concentration of 0.55 and thickness of 10 ML. The Ni and Fe 3p lines were measured with photon energy of 190eV. The upper panel clearly shows that the XPS data are different depending on the orientation of the applied field relative to the sample. The Fe 3p and Ni 3p lines were measured for magnetization up and down, and the difference is the XMLD signal. The lower panel shows the difference between the two spectra in the upper panel and thus exhibits the dichroism effect. We have examined the size of the dichroism signal as a function of both composition and film thickness, and those data will be published separately.[5] We have also measured the dichroism signal from both the Fe and the Ni peaks. The asymmetry, $\frac{\text{MagUp - MagDown}}{\text{MagUp + MagDown}}$, as measured from the XMLD signal, is proportional to the total magnetization of the sample.

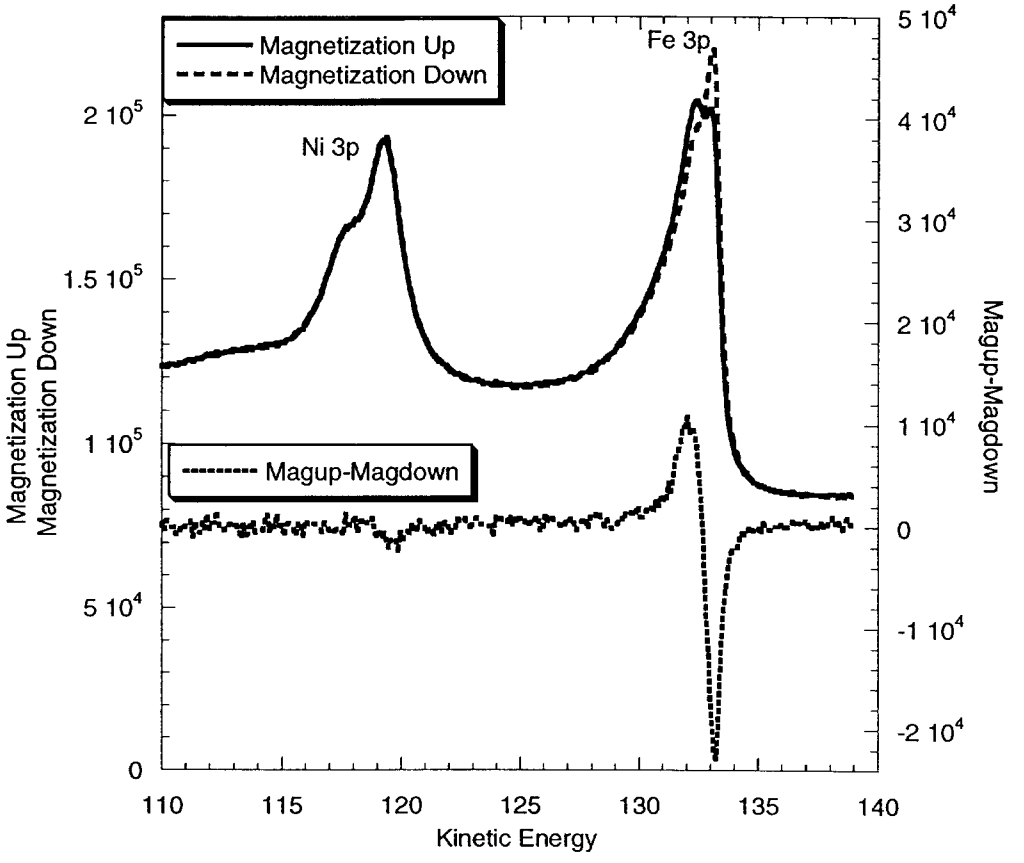

Figure 2. XMLD data from $Fe_{0.64}Ni_{0.36}$ film, 10 ML thick, on Cu(111). Top of figure shows the Ni 3p and Fe 3p XPS lines, measured with photon energy of 190eV, for magnetization up and down. Bottom of figure shows difference spectrum, which is proportional to the dichroism.

Our XMLD spectra clearly indicate that samples of specific thicknesses and Fe concentrations are ferromagnetic. Furthermore, our recent studies using the photoelectron emission microscope (PEEM2) instrument on Beamline 7.3 at the ALS indicate that both Fe and Ni are magnetic and well mixed in these thin alloy films.[6]

Figure 3 shows the asymmetry (in %) as a function of temperature for films with three different Fe concentrations, all ~5ML thick. The manual feedback system resulted in temperature variations of less than ±5°C during the measurement of a dichroism spectrum. Although the data appear to fit the predictions from mean field theory, detailed fits to the theory are still in progress.

An approximate Curie temperature (T_c) for the ferromagnetic samples was extracted by extrapolating asymmetry data as a function of temperature, such as those in Figure 3, to find the temperature at which the magnetic asymmetry disappears. Figure 4 illustrates the change in Curie temperature T_c for varying thickness and concentration. As could be seen in the data in Figure 3, for a particular film thickness, as the Fe concentration x increases, T_c increases until $x \approx 0.4$ and then decreases. For all of our samples, T_c was in the range from 200K to 500K. Note that for even for film thicknesses larger than 5ML, T_c was below room temperature for low Fe

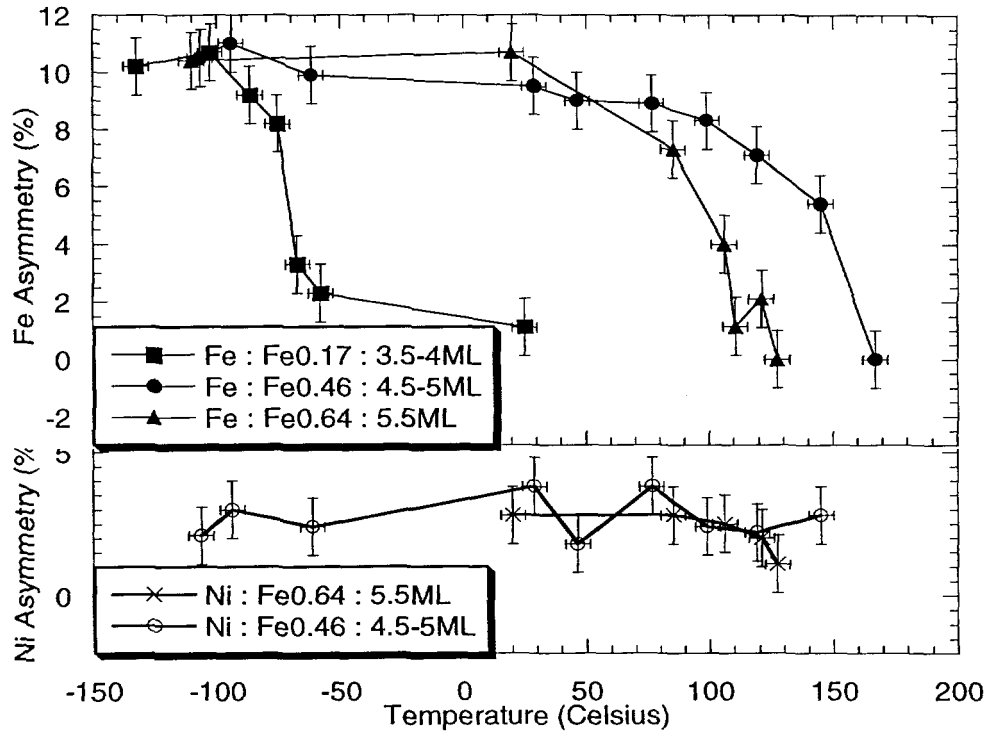

Figure 3. Fe and Ni asymmetry, in percent, as a function of temperature, for three samples, with varying Fe concentration. All thicknesses are about 5ML. The lines are drawn as a guide to the eye.

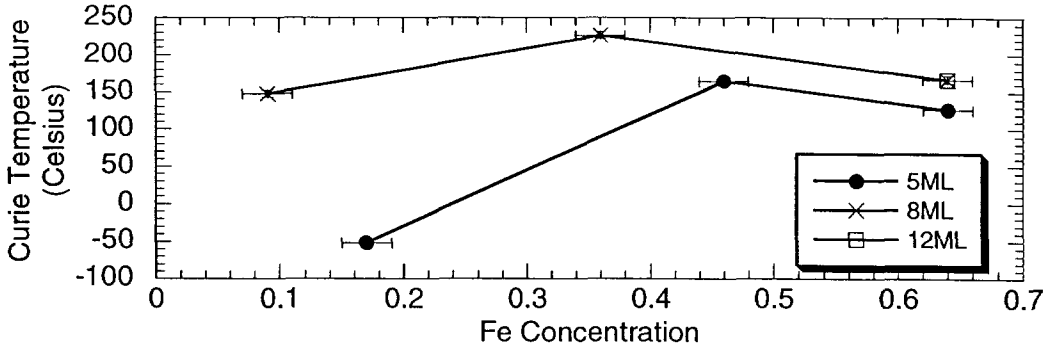

Figure 4. Approximate Curie temperature of Fe_xNi_{1-x}/Cu(111) samples as a function of Fe concentration, for three different film thicknesses. Note the maximum in the Curie temperature occurs near x=0.4.

concentration. In contrast, an earlier XMLD study of Fe_xNi_{1-x} films on Cu(100) found that T_c was above 250K for film thicknesses larger than ~2ML.[7] For a specific Fe concentration, Figure 4 also shows that the Curie temperature increases for higher film thickness.

CONCLUSIONS

This paper has presented dichroism data on thin layers of Fe_xNi_{1-x} on Cu(111). Data on the temperature dependence of the dichroism was shown and discussed. The trends in the Curie temperature as a function of film thickness and concentration were also reviewed. In addition, an ultrahigh vacuum surface magneto-optical Kerr effect (SMOKE) apparatus is under development in our laboratory. This apparatus will make it much easier to measure the Curie temperature of additional thin alloy samples, making it possible to obtain further data as a function of alloy composition and thickness in our own laboratory. Further studies are in progress in our group to study the structure of the Fe_xNi_{1-x} alloy films on Cu(111) in more detail using several other techniques, such as low energy electron microscopy (LEEM), scanning tunneling microscopy (STM), and PEEM, in order to correlate the observed structure of the films with their magnetic behavior.

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