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Magnetic x-ray linear dichroism in the photoelectron spectroscopy of ultrathin magnetic alloy films

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The magnetic structure of nanoscale alloy films has been probed using the magnetic x-ray linear dichroism in photoelectron spectroscopy. FeNi and CoFe epitaxial films were grown on Cu(001), in situ and using molecular beam epitaxy techniques. The magnetic x-ray linear dichroism measurements were made at the Spectromicroscopy Facility of the Third Generation Advanced Light Source. Because soft x-rays were used to generate photoemission from the 3p core levels, both elemental selectivity and magnetic sensitivity were achieved simultaneously. © 1996 American Institute of Physics. [S0021-8979(96)41808-9]

A full elucidation of the underlying principles driving magnetic properties in complex systems will require the applications of probes which couple elemental specificity and magnetic sensitivity. Two important classes of magnetic devices, spin valves and giant magnetoresistance (GMR) materials, are typically composed of several nanoscale layers or aggregations composed of different elements or alloys. The ultra-thin nature of these films or clusters further complicates the picture by introducing the impact of interfacial effects, including pseudomorphic strain and spin-specific scattering at the interfaces. One avenue to address such issues is to build epitaxial ultrathin alloy films and probe them directly using techniques that are both elementally selective and magnetically sensitive. Here we report the beginnings of such a study, using CoFe and FeNi films grown with molecular beam epitaxy (MBE) techniques and investigated with magnetic x-ray linear dichroism (MXLD) in the core-level photoelectron spectroscopy of the 3p states of Fe, Co, and Ni. (See Fig. 1.)

The measurements were made at the Spectromicroscopy Facility (Beamline 7) of the Advanced Light Source at Lawrence Berkeley Laboratory. Extraordinarily bright, linearly polarized x-rays were generated by the U 5.0 undulator and wavelength selection was achieved using the spherical grating monochromator, with a resolving power of over 8000. The photoelectrons were detected using the angle-resolving, multichannel, 5.4 in. radius, Perkin–Elmer hemispherical deflector system. Sample alignment (including pseudomorphic growth), cleanliness, and composition were measured using the hemispherical deflector and a separate Mg Kα source, thus freeing up the beamline for other uses during our periods of sample preparation. The actual MXLD measurements (Fig. 2) used the highly polarized synchrotron radiation and were performed with a total instrumental energy resolution bandpass of <100 meV and angular resolution of 2°. The angle of incidence of the x-rays was 30° relative to the surface plane. The electrons were collected along the surface normal, i.e., “normal emission.” Typically, the magnetic alloy was magnetized in the plane of the surface but perpendicularly to the plane containing the emission direction (surface normal) and the Poynting vector and electric polarization vector of the x-rays. Thus, the “transverse-chiral” condition necessary for MXLD was achieved: reversing the magnetic field causes two mirror-image configurations which are equivalent but totally nonsuperimpossible. By comparing spectra from these configurations, it is possible to directly probe the magnetic perturbations of the elementally specific electronic structure of the systems.

The alloy systems under consideration were CoFe and FeNi. Ultra-thin films of each were grown on Cu(001) at room temperature, using well-developed MBE techniques. Studies of the bulk electronic structures have been performed, but the properties of these pseudomorphic overlayers are further complicated by epitaxial strain and other nanoscale effects. Examples of our spectroscopic results are shown in Figs. 3 and 4. In this energy regime, the
cross sections for the Fe, Co, and Ni 3p are strongly photon-energy dependent; hence, the peaks do not scale with concentration without further correction. The asymmetry in the case of the Fe and Co in Fig. 3 is actually underestimated. It would be appropriate to set the prepeak region, before the Co and Fe, respectively, to zero for these calculations. (See Figs. 3 and 4.)

Presently, we are pursuing studies of these systems where we vary the thickness and composition of the magnetic overlayers and probe the 3p levels of each element. In essence, we are attempting to use the MXLD measurements as element-specific, surface magnetometers. Our initial studies suggest a concentration dependent quenching similar to that observed in bulk Invar but with different elementally specific contributions than those of the bulk. It appears that template and thickness dependent relaxation effects may be competing in this system. Additional studies will include not only MXLD but also surface magneto-optic Kerr effect (SMOKE) measurements. Furthermore, analysis based upon the MXLD effects may not be as straightforward as it might seem: it is not clear that simple perturbative models are accurate. In fact, for the 3p levels of Fe, Co, and Ni, it may be that simple perturbative pictures fail and that both the spin-orbit and exchange splitting need to be dealt with on an equal footing (Fig. 5). However, as one moves across the series from Fe to Ni, the ratio of magnetic moment to spin orbit splitting decreases substantially, suggesting the plausibility of a perturbative approach for Ni. This is reflected also in Fig. 4. Thus, our initial results are promising in terms of understanding key effects in magnetic nanoscale films, including such possibilities as strain-modified invar quenching, but it may be that more sophisticated analysis, including multiple-scattering calculations and more extensive examination of thickness and composition effects.

We are using the elementally specific and magnetically sensitive technique of MXLD photoelectron spectroscopy to probe nanoscale magnetic alloys. These structures are the building blocks of many new magnetic devices, including spin-value and GMR materials. The variation of classical...
magnetic effects, such as Invar quenching, due to pseudomorphotropic strain and other nanoscale perturbations, is being investigated.

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