Photoemission Electron Microscopy and X-Ray Magnetic Circular Dichroism of $Fe_xNi_{(1-x)}$ Thin Films on Cu(111)

Y.Sato[1], T.F.Johnson[1], S.Chiang[1], X.D.Zhu[1], D.P.Land[2], J.A.Giacomo[1]
F.Nolting[3], and A.Scholl[3]

[1]Dept. of Physics, University of California, Davis, CA 95616
[2]Dept. of Chemistry, University of California, Davis, CA 95616
[3]Advanced Light Source, Lawrence Berkeley National Laboratory,Berkeley, CA 94720

INTRODUCTION

Our research focuses on controlling the structure, composition and the resultant magnetic properties of metal alloy thin film growth at the atomic level. Better understanding and control of surface/interface magnetism is relevant to the application of the giant magneto-resistive effect to read heads for magnetic recording. We have studied $Fe_xNi_{(1-x)}$ alloy thin films for their technological relevance to the above mentioned technology. The dependence of the magnetism on the stoichiometry x is one of the questions of interest. In addressing this problem, the structure of the thin film must be also considered. In terms of crystal structure, a well known "Invar effect" exists in bulk FeNi alloy because of structural incompatibilities of the two elements. Pure Fe is stable in bcc phase whereas pure Ni has fcc structure. A bulk alloy containing more than 65% Fe transforms to bcc by a Martensitic transformation, and the magnetization falls to zero. In thin film alloys, the problem may become more complex because of the effect of substrate structure and interface properties. On the other hand, how this structural change affects the magnetic order in the film is not well known. A simultaneous study of film structure, magnetic structure and magnetism is needed to better understand the system.

Several studies on $Fe_xNi_{(1-x)}$ alloy thin films have been reported[1,2,3,4]. Information on the growth, structure, and magnetic moments as a function of thickness and concentration has been obtained using various techniques such as low energy electron diffraction (LEED), reflection high energy electron diffraction (RHEED), photoelectron diffraction, surface magneto optical Kerr effect (SMOKE), X-ray magnetic linear dichroism (XMLD), Mossbauer spectroscopy, and superconducting quantum interference device (SQUID) magnetometry. We have used the photoemission electron microscope (PEEM2) at the Advanced Light Source (beamline 7.3.1.1) to study this film system. PEEM has the unique capability of imaging the film's magnetic structure with high spatial resolution and elemental specificity. Simultaneously, quantitative magnetic information can be obtained using magnetic circular dichroism in X-ray absorption spectroscopy. At two different thicknesses, we have made sixteen samples and studied the dependence of magnetic structure on varying Fe concentration and substrate quality (x = 0, 0.28, 0.55,0.6, 0.66, 0.74, 1.0 at 10Å≅5ML, x = 0.9, 0.25, 0.33, 0.42, 0.5, 0.55, 1.0 at 20Å ≅10ML). We have observed clear ferromagnetic domain structures of the film on a Cu(111) surface for $x \leq 0.60$ at room temperature.

RESULTS

Samples with high Fe content (x=0.66, 0.74 at 5ML) have been observed to be non-magnetic at room temperature. All other alloy samples ($x \leq 0.6$, 5ML and 10ML) showed clear ferromagnetic contrast. This trend of reduction in Curie temperature at higher Fe concentration is also observed by spin resolved photoemission spectroscopy measurements carried out at the Advanced Light Source (beamline 7.0.1.2). A pure Ni film at 5ML thickness was non-magnetic at room temperature. According to a SMOKE measurement, 5ML is approximately the thickness where the Curie temperature becomes less than room temperature for Ni/Cu(111)[5].

Fig. 1 shows typical ferromagnetic images with a 12μ m field of view for a 5ML thick $Fe_{0.6}Ni_{0.4}$ film on Cu(111). Each image is obtained by dividing an image acquired at the L3 Fe (or Ni) edge by one acquired at the L2 Fe (or Ni) edge. The images show alignment of the magnetic domains for

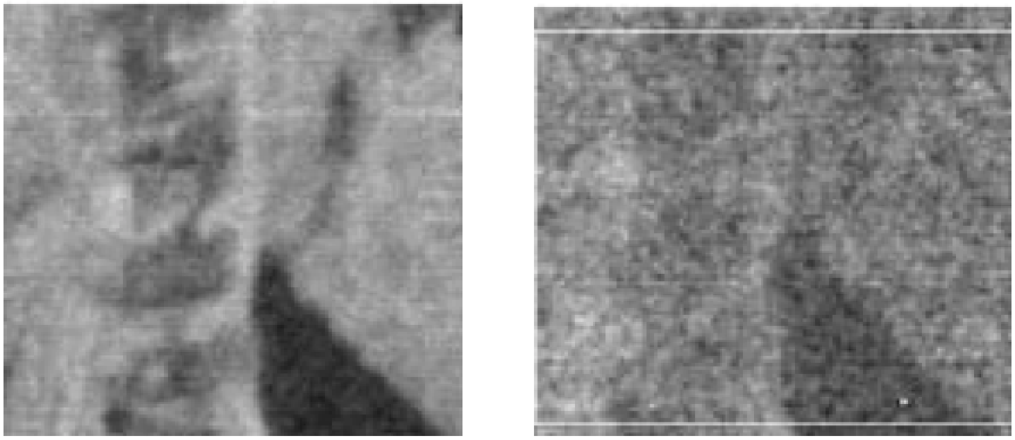

Fig. 1. XMCD ferromagnetic images with a 12μ m field of view for a 5ML thick $Fe_{0.6}Ni_{0.4}$/Cu(111).
Left: Fe XMCD contrast, Right: Ni XMCD contrast.

Fe and Ni, suggesting that Fe and Ni form a good alloy on this surface. By comparing the images shown in Fig. 2 and Fig. 3, we find a clear dependence of the domain structures on film thickness and substrate quality. Fig. 2 shows magnetic contrast images of 5ML alloy films on a mechanically polished substrate. On these samples, observed magnetic structures appear to correlate to surface topographic features. No regular apperance of domain structure was seen. Comparison of the image at the pre-absorption edge, which shows only topographic contrast, with the magnetic contrast image clearly shows the correlation between surface structural features and the formation of magnetic domains. An experiment showed that magnetic contrast observed at room temperature disappears gradually upon heating. Contrast is recovered again as the sample temperature is lowered below the Curie temperature. This also confirms the relation between domain structure and surface geometric structures. These observations are consistent for each 5ML sample analyzed. In contrast, for 10ML films on an electropolished substrate as shown in Fig. 3, pinning due to surface defects is observed less frequently. Magnetic structures and textures appear to be more uniform and the sizes of the structures were smaller and on the order of 1-3μ m. At the alloy composition of x=0.44, regular, periodic appearance of larger domain structures (5-10μ m width and 70μ m length), defined by 180º domain walls, are observed, as shown in Fig. 4. By observing the two images shown in Fig. 4, we conclude that alloy film at this composition and thickness show in-plane magnetization.

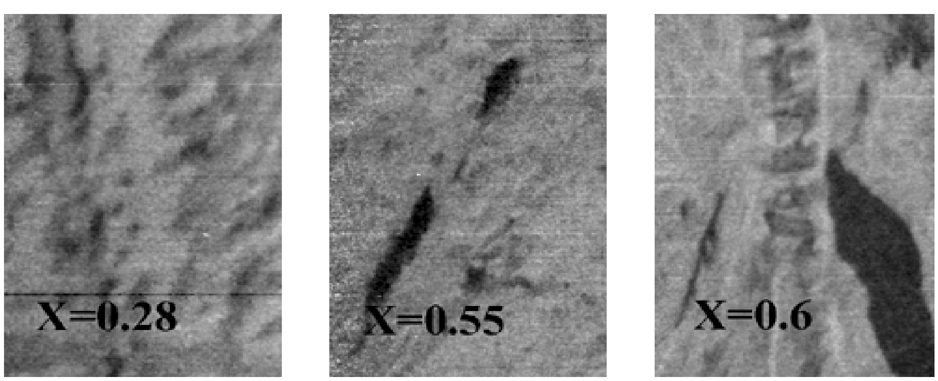

Fig. 2. XMCD ferromagnetic images with H22μ m×V30μ m field of view for 5ML films with varying Fe composition x.

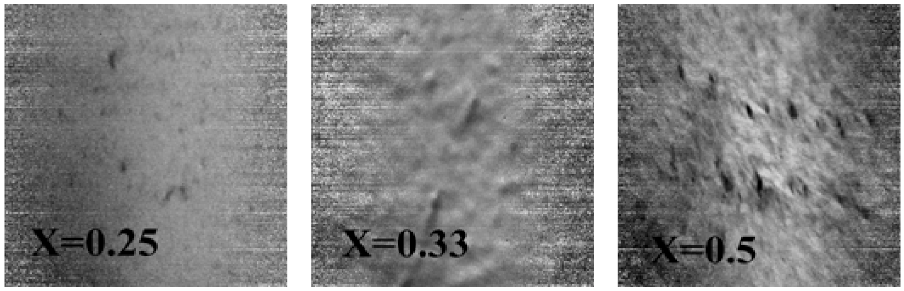

Fig. 3. XMCD ferromagnetic images with H65µ m×V65µ m field of view for 10ML films with varying Fe composition x.

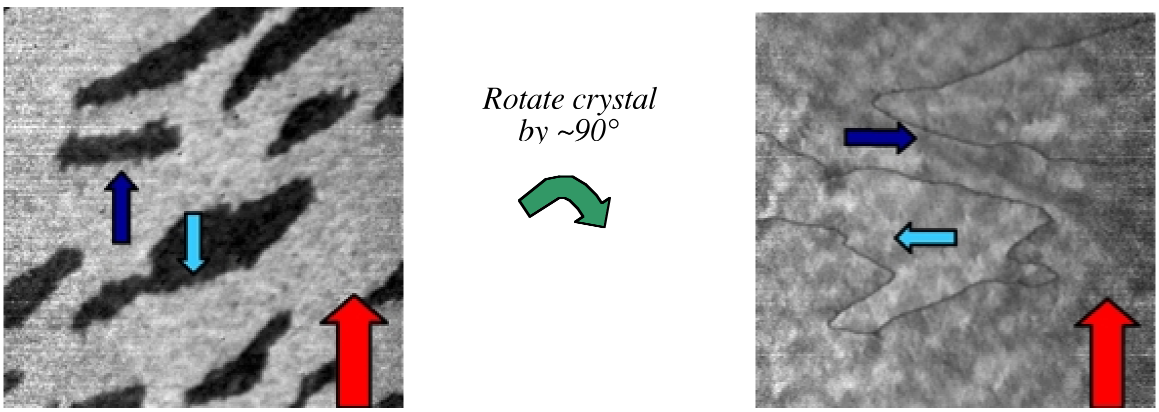

Fig. 4. XMCD ferromagnetic images with Right: H45µ m×V45µ m and Left: H45µ m×V45µ m field of view for 10ML thick $Fe_{0.56}Ni_{0.44}$/Cu(111). Smaller arrows indicate the magnetization direction and larger arrows show the direction of the incident photon momentum.

REFERENCES

1. F.O.Schumann, S.Z.Wu, G.J.Mankey, and R.F.Willis *Phys. Rev. B* **56** 2668 (1997)
2. F.O.Schumann, R.F.Willis, K.G.Goodman, and J.G.Tobin *Phys. Rev. Lett.* **79** 5166 (1997)
3. J.W.Freeland, I.L.Grigorov, and J.C.Walker *Phys. Rev. B*. **57** 80 (1998)
4. R.Schellenberg, H.Meinert, N.Takahashi, F.U.Hillebrecht, and E.Kisker *J. App. Phys.* **85** 6214 (1999)
5. R.Zhang, and R.F.Willis *Phys. Rev. Lett.* **86** 2665 (2001)

This work was supported by the Campus Laboratory Collaboration Program of the University of California Office of the President and by the Director, Office of Energy Research, Office of Basic Energy Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Principal investigator: Shirley Chiang, Department of Physics, University of California, Davis, CA 95616-8677. Email: chiang@physics.ucdavis.edu. Telephone: 530-752-8538.