SCANNING ELECTRON MICROSCOPY WITH POLARIZATION ANALYSIS (SEMPA) INVESTIGATIONS OF MULTILAYER MAGNETISM

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Mulitlayers consisting of various combinations of 1-10 nm thick ferromagnetic, antiferromagnetic and nonmagnetic films have numerous applications in magnetic recording, non-volatile data storage, and sensor technologies. One key aspect to understanding how these devices work is being able to image their magnetic structure. SEMPA is well suited for this job, because of its surface sensitivity and compatibility with thin film growth and surface analysis techniques. This talk will review the SEMPA technique and describe the use of SEMPA in two examples; one in which the magnetization is imaged while growing a multilayer, and another which examines the magnetization while depth profiling a multilayer by ion milling.

A SEMPA investigation of the magnetic exchange coupling in an Fe/Cr/Fe sandwich is shown in Figs. 1 and 2.[1] A wedge shaped Cr interlayer was grown as shown in Fig. 1 in order to measure the Cr thickness dependence of the exchange coupling. Nearly perfect atomic scale order was achieved in the growth of this system by using a single crystal Fe whisker substrate and thermal deposition. This degree of perfection was required in order to observe coupling oscillations that reverse direction with almost every single atomic layer change in the Cr thickness as seen in the SEMPA image of the top Fe film shown in Fig. 2(a). The actual oscillatory coupling period is 2.105 ± 0.005 Cr layers as determined by accurately measuring the thickness of the wedge with Reflection High Energy Electron Diffraction (RHEED) (Fig. 2(c)). This slight difference between the oscillatory coupling period and the lattice leads to phase slips in the coupling order at about 24, 44 and 64 Cr layers. SEMPA's surface sensitivity also allows imaging the magnetic order in the bare Cr layer. Comparing Figs 2 (b) and (d) shows that the Cr couples antiferromagnetically to the top Fe film.

SEMPA can also be used, along with ion milling, to depth profile the layer-by-layer magnetization of a multilayer. Figures 3 and 4 show such a procedure used to investigate the magnetic structure of a $[Co(6nm)/Cu(6nm)]_{20}$ multilayer.[2] A SEMPA image overview of an ion milled crater is shown in Fig. 3. The magnetic domain structure of the individual Co layers is clearly seen, although some magnetic contrast also is visible through the thin Cu layers. The alignment of the magnetization in successive layers determines the magnetoresistance of the multilayer. This alignment can be measured using SEMPA images of successive layers as shown in Figs. 4 (a) and (c). From these images one can see strong antiparallel correlations between the Co domains in adjacent layers. This observation can be made more quantitative by taking the difference in magnetization direction between the two images, $\Delta(\phi)$, and plotting a histogram of the differnce image as shown in Fig. 4(d).[3]

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[1] J. Unguris, R. J. Celotta, D.T. Pierce, *Phys. Rev. Lett.*, 67 (1991) 140

[2] J.A. Borchers,J.A. Dura, J. Unguris, D.A. Tulchinsky, M.H. Kelley and C. F. Majkrzak, *Phys. Rev. Lett.*, (1999) in press

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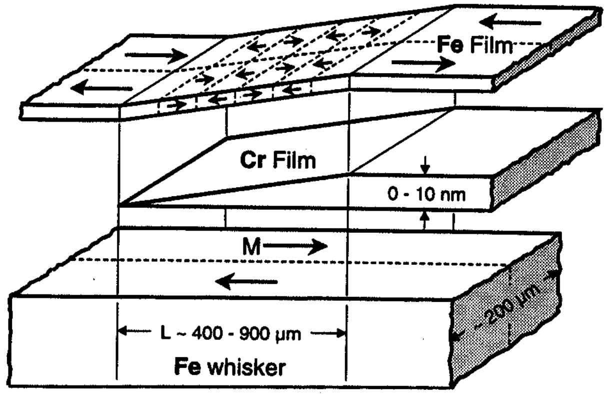
1



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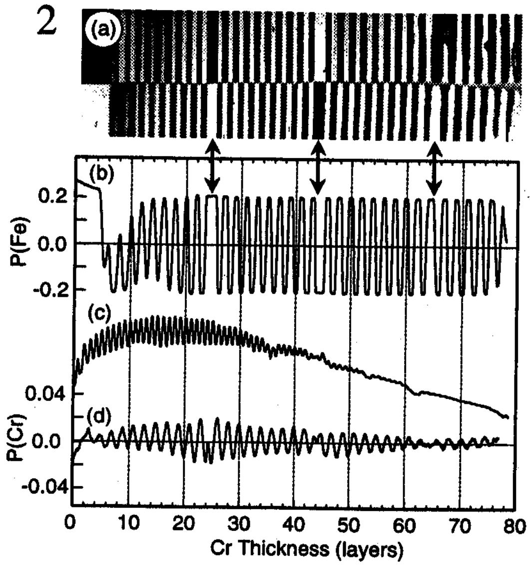

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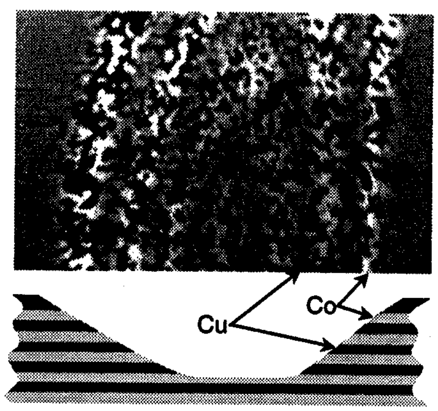

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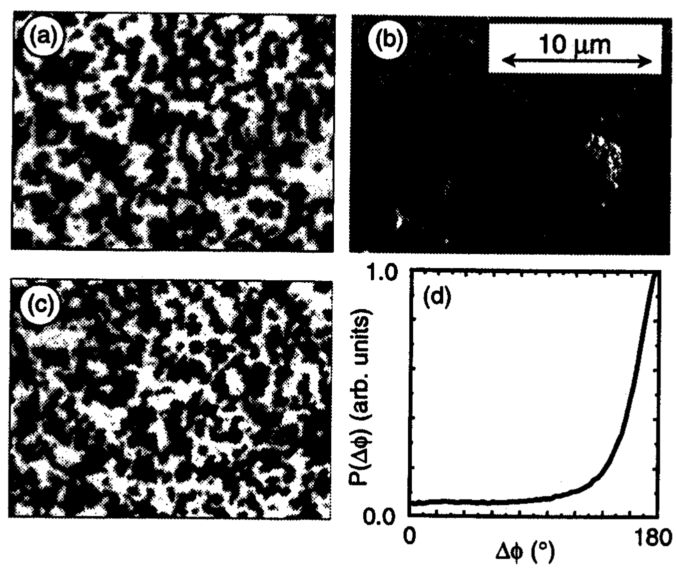

FIG. 1. Schematic of the Fe/Cr/Fe sample structure used in Fig. 2.

FIG. 2. (a) SEMPA image of the top Fe film in Fig. 1. (b)Line scan from the SEMPA image with phase slips in the oscillatory coupling indicated by the arrows. (c) RHEED line scan along the Cr wedge. (d) Bare Cr SEMPA scan.

FIG. 3. SEMPA image of an ion milled crater in a Co/Cu multilayer.

FIG. 4. (a) SEMPA image of first (top) Co film magnetization and (b) topography. (c) SEMPA image of second Co layer. (d) Histogram of difference in magnetization direction between the two layers. (180° corresponds to antiparallel alignment.)