Magnetic Nanostructures Studied by Spin Polarized Low Energy Electron Microscopy.

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Using spin polarized low energy electron microscopy (SPLEEM) we study the assembly and self-organization of nanostructures, and investigate correlations between structure and magnetic properties.

The controlled preparation of remarkably regular, periodic arrays of nanostructures is possible in the Fe/W(110) system. By controlling substrate step structure, temperature, and deposition conditions, it is possible to start from essentially flat epitaxial films and prepare either periodic arrays of parallel nanowires, or arrays of three-dimensional Fe islands, on top of a wetting layer. Using the SPLEEM to map local magnetization directions during *in-situ* preparations illustrates the strong correlation between nanostructure geometry and magnetic properties. For example figure 1 shows how the assembly of a nanowire-array from initially flat Fe films is accompanied with an in-plane rotation of the magnetic easy-axis by 90 degrees.

By tracking magnetization direction during sample preparation, the SPLEEM is also useful to probe the coupling between magnetic layers in multilayer stacks. From the literature, many systems are known where parallel or antiparallel coupling of ferromagnetic layers through non-magnetic spacers can be observed. New results suggest the interesting possibility that the magnetic coupling between the two ferromagnetic Fe layers in the Fe/NiO/Fe(001) trilayer system might be perpendicular [1,2]. On a Fe(100) crystal magnetized in the surface plane [3], we prepared structures with different combinations of NiO spacer and Fe overlayer thicknesses *in-situ*, and used the SPLEEM to track relative local magnetization orientations of substrate and overlayers. Indeed, we find that structures can be prepared where the top Fe layer is magnetized in-plane, and shows a uniaxial magnetic anisotropy perpendicular to the magnetization of the Fe substrate.

Effects such as exchange-biasing and magnetoresistance in multilayer systems with parallel or antiparallel magnetization have already found important applications. Magnetic multilayer systems displaying stable, perpendicular coupling have been less explored, and SPLEEM is a promising technique to study these structures.

[1] H. Ohldag et al., Phys. Rev. Lett. 86 (2001) 2878.
[2] M. Finazzi, et al., Phys. Rev. B69 (2004) 14410.
[3] L. Duò et al., Surf. Sci. 518 (2002) 234.

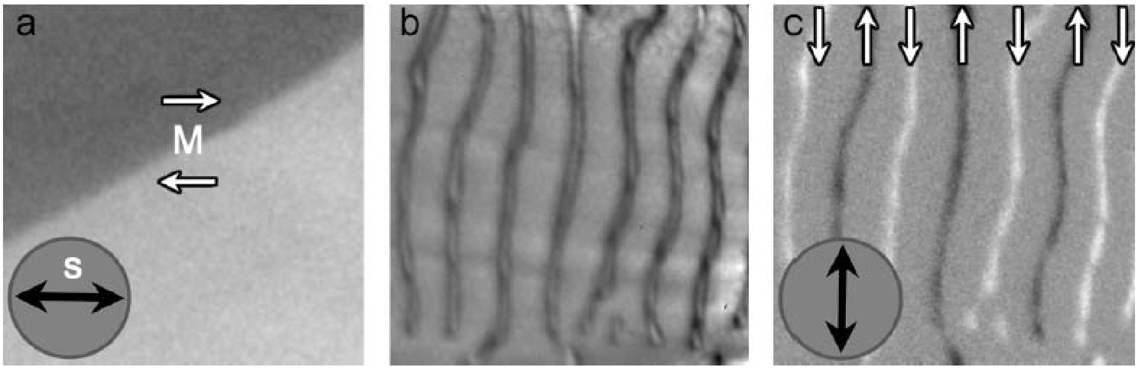

Figure 1: Black arrows in dials indicate spin-polarization of illuminating electron beam, white arrows indicate local sample magnetization direction. Images are 3.5μ × 3.5μ. (a) Before annealing, SPLEEM image shows horizontal in-plane magnetization of continuous 24 monolayer thick Fe/W(110) film. (b) LEEM image of annealed film shows self-organized array of Fe nanowires (dark, elongated features). (c) SPLEEM image of same nanowire array. Magnetization of wires is again in-plane, but orthogonal to easy axis of continuous film.

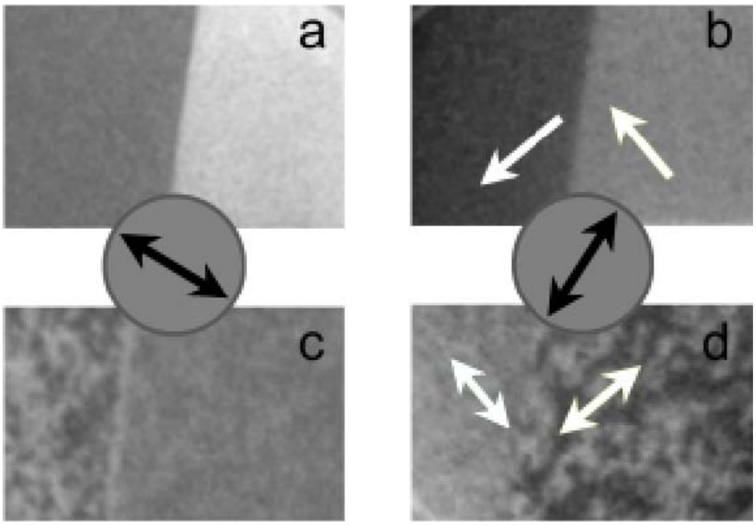

Figure 2: SPLEEM images of Fe(001) surface before (a,b) and after (c,d) deposition of 2 monolayers of NiO followed by deposition of 5 monolayers Fe. Images (a) and (b) show 3 µm × 4 µm region of clean Fe(001) substrate. Two magnetic domains meet at domain boundary, which runs vertically through the middle of the images. Dials with black arrows indicate polarization of electron beam (-60° in (a) and (c), and +30° in (b) and (d)).Left domain in (a) shows gray contrast, indicating that magnetization in this region is orthogonal to beam polarization shown in dial under (a). For right domain, contrast vanishes in (b), indicating that magnetization in right domain is orthogonal to dial shown under (b). From observed contrast we find magnetization directions indicated by white arrows in (b). After deposition of trilayer structure, contrasts visible in (c) and (d) indicate that magnetization of domains in Fe overlayer is perpendicular to magnetization directions originally present in the substrate. Small regions with bright and dark contrast visible in (c) and (d) are domains in the Fe overlayer, magnetized along directions indicated by white double-headed arrows in (d).