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X-ray Photoemission Electron Microscopy (X-PEEM) for the study of static and dynamic exchange phenomena

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The magnetic exchange interaction is the basis of long-range magnetic order in magnetic materials such as the magnetic 3d transition metals and oxides. Technologically important devices such as hard disk read heads, magnetic random access memory (MRAM) use the interaction of adjacent magnetic layers by interfacial magnetic exchange, thus realizing desired properties of the device. The progress in sample preparation techniques has allowed tailoring the magnetic properties of materials, especially of samples consisting of layered, ultra-thin films. Precise control over structure and composition thereby gives control over the magnetic structure. The increasing complexity of multi-element, multi-layer, magnetic devices now demands for new experimental approaches for the investigation of their magnetic and chemical structure. Imaging techniques have the particular advantage that they provide information not only about the average, macroscopic properties of a material but also about the lateral distribution of the size and direction of the magnetization which can then be correlated to the chemical structure and the interface coupling in layered samples. In addition to spatial resolution, surface and interface sensitivity is often desired in order to achieve an understanding of the mechanisms of the magnetic coupling in layered samples. High sensitivity to small magnetic signals is thus a prerequisite for studies of interface coupling.

One phenomenon that we want to focus on is the phenomenon of exchange bias at the interface of antiferromagnetic and ferromagnetic materials. This effect is used in giant magneto resistance (GMR) type sensors to pin the magnetization in one of the ferromagnetic layer, which thus acts as a magnetic reference. Exchange bias is an interface effect and therefore knowledge of the interface magnetic structure is essential for the its understanding. So far, a microscopic description has been elusive because of our limited knowledge of the interface properties in exchange biased systems. Here, we will present new results acquired by x-ray absorption spectroscopy and microscopy showing that interfacial, uncompensated magnetic spins are responsible for the observed enhanced coercivity and the unidirectional coupling of exchange bias systems. X-ray Magnetic Circular and Linear Dichroism (XMCD and XMLD) provide information about the internal magnetic structure in the ferromagnet and in the antiferromagnet, in contrast to most other microscopic methods, which are only sensitive to ferromagnetic order.

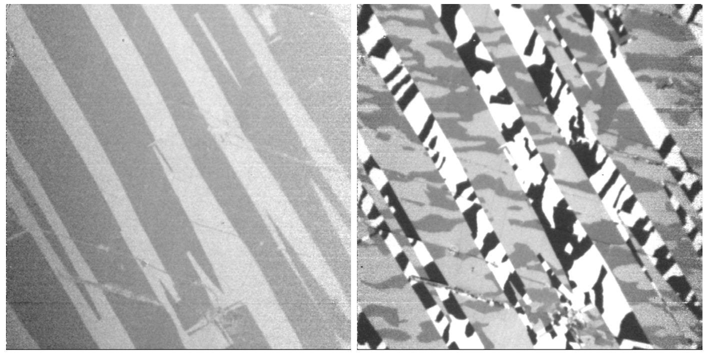

Fig. 1: Images of the antiferromagnetic (left) and ferromagnetic signal (right) from a Co/NiO(001) sample. The left image was obtained with XMLD contrast at the Ni L_2 edge. The right image was obtained at the Fe $L_{2/3}$ edges using XMCD contrast. Different intensities correspond to different directions of the magnetic moment.

We will discuss results obtained on various Mn alloy and transition metal oxide antiferromagnets in contact with ferromagnetic Co layers. Microscopic images of the domain structure were obtained using the X-ray Photoemission Electron Microscope (X-PEEM) at the Advanced Light Source (ALS). Fig. 1 for example shows the one-to-one correspondence of the domain configuration at both sides of the interface in a Co/NiO(001) ferromagnet/antiferromagnet structure. The domain correlation originates from the strong interface magnetic coupling resulting in a uniaxial exchange asymmetry induced by the antiferromagnet. We have furthermore used the ALS elliptically polarized undulator beamline for high precision measurements of the uncompensated moment at the surface of antiferromagnets in exchange bias structures.

The properties of a magnetic device not only depend on the static magnetic structure in the device but also on the dynamics of the magnetization reversal process. We are currently designing a new experimental setup, which will allow stroboscopic measurements using a synchronized synchrotron-laser setup. We expect to achieve 50 ps time resolution at the full spatial resolution of the PEEM microscope, opening new ways of studying dynamic magnetic processes. We will discuss the potential of this new technique especially in view of the possibility of ultrafast magnetization reversal by injection of pulsed, spin-polarized currents.

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