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Author
Scholl, A.

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Imaging of Domain Structures and Magnetization Dynamics Using X-ray Photoemission Electron Microscopy (X-PEEM)

A. Scholl*

* Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

X-ray Photoemission Electron Microscopy (X-PEEM) is a hybrid technique that combines characteristics of x-ray spectroscopy techniques and of electron microscopy. In such a microscope, x-ray emitted secondary electrons form a map on an electron-sensitive detector of the local x-ray absorption of the sample surface. This image provides information about the elemental and chemical composition of the sample, its surface topography, and its electronic and magnetic structure. X-PEEM is also called a spectro-microscopy technique because spectroscopic information is obtained from microscopic areas of the sample. X-PEEM does not require in-situ sample preparation, and it is moderately surface sensitivity with a probing depth of about 5 nanometers. The spatial resolution of state-of-the-art instruments is limited mostly by chromatic aberrations to several ten nanometers. Although limited, this resolution is well beyond that of optical techniques and allows the study of many laterally inhomogeneous systems, e.g., of magnetic domains, of lithographically patterned surfaces or also of polymer blends and minerals. Aberration correction methods that are currently being developed are expected to extend the spatial resolution of X-PEEM down to a few nanometers. The use of synchrotron radiation makes X-PEEM very versatile. By tuning the x-ray wavelength to the characteristic absorption edge of an element, separate information about the properties of each constituent in a complex system can be obtained. X-ray magnetic linear and circular dichroism, XMLD and XMCD, provide quantitative information about the magnetic structure. For dynamics studies the pulsed structure of synchrotron radiation can be utilized using a pump-probe methodology. The x-ray pulse length of about 70 ps determines the ultimate time resolution of this technique.

I will first give an overview over imaging of ferromagnet/antiferromagnet surfaces and interfaces, a research area that X-PEEM revolutionized because of its unique ability to image both systems at high spatial resolution and with chemical specificity. Microscopic antiferromagnetic domains in a thin epitaxial film were first observed on $LaFeO_3$ films [1]. I will discuss the interface coupling induced correlation of magnetic domains in ferromagnetic layers grown on antiferromagnetic surfaces, Fig. 1, in particular the dependence with the domain size of the local, unidirectional exchange coupling, also called exchange bias. Pulsed-field-dependent imaging of the ferromagnet showed that the bias scaled inversely with the domain diameter [2], a dependence that had been predicted applying a random-field model [3].

I will then discuss time-resolved X-PEEM imaging of the precessional dynamics of magnetic vortices, 3-dimensional magnetic curls [4]. The vortex dynamics is imaged at 100 nanometers spatial resolution and 70 picosecond temporal resolution using stroboscopic x-ray imaging. It will be demonstrated that the vortex chirality or handedness, which is determined by the out-of-plane magnetization of the 10-nm-size vortex core, governs the sub-ns dynamics of the micron-size structure, leading to a gyrotropic motion of the vortex center. The dynamics is initiated by a ~300 ps field pulse triggered by a laser hitting a fast GaAs photoswitch. The measured vortex speed and the internal magnetic field at the vortex core will be compared to micromagnetic simulations.

References

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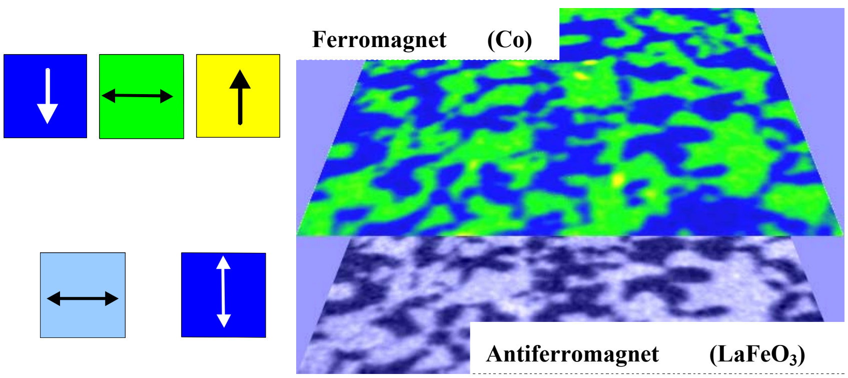

FIG. 1. Coupled ferromagnetic and antiferromagnetic domains imaged using X-PEEM.