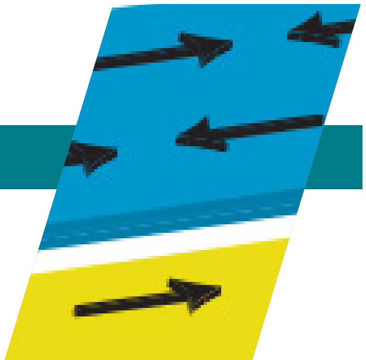
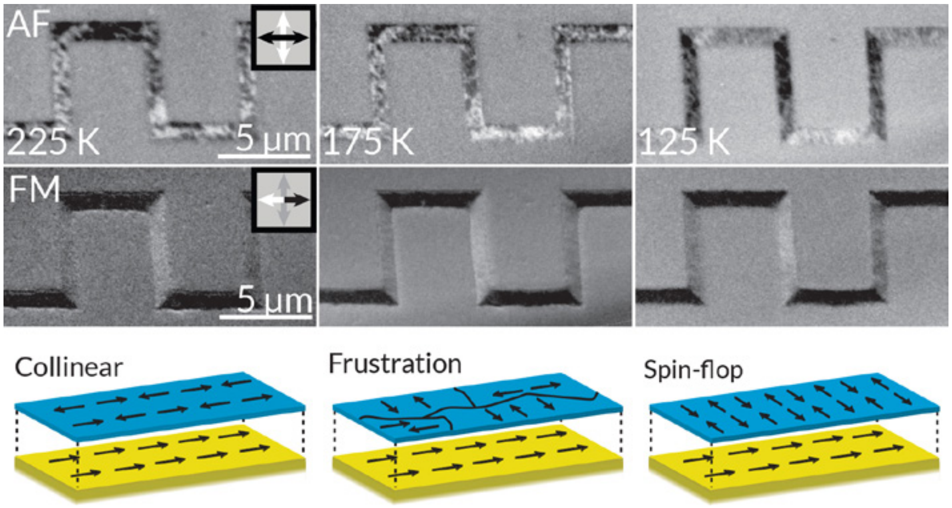
ADVANCED LIGHT SOURCE



MATERIALS SCIENCES

Controlling Spin in Antiferromagnetic Nanostructures



"Square wave" patterns of various line thicknesses were lithographically imprinted onto a thin antiferromagnetic (AF) layer grown on top of a ferromagnetic (FM) layer. Photoemission electron microscopy (PEEM) revealed how the AF and FM spin configurations were affected by changes in temperature (shown here) as well as line width and applied magnetic fields. Top row: PEEM images of the AF domain pattern. Middle row: PEEM images of the FM domain pattern. Bottom row: Schematic representation of AF (blue) and FM (yellow) spin configurations corresponding to the images above.

Scientific Achievement

Researchers using the Advanced Light Source (ALS) discovered that the spin configuration of a nanostructured antiferromagnetic material can be affected by the dimensions of features imprinted onto the material.

Significance and Impact

The results suggest that nanoscale patterning can be a viable tool for engineering spin configurations in future antiferromagnetic spintronic devices.

Antiparallel spins: a double-edged sword

The inclusion of antiferromagnetic (AF) materials in future information technology hardware is an enticing prospect, promising fast, energy-efficient devices with unparalleled robustness of the encoded information. Unlike their ferromagnetic (FM) cousins, AF materials are magnetically compensated (i.e., there is no net magnetization, since the material's antiparallel spins cancel each other out). Therefore, AF-based spintronic components would not be adversely affected by infringing stray fields. However, the absence of a net magnetization is a double-edged sword, as it also renders the spin configuration notoriously difficult to control. A "handle" for manipulating spin will be important for future AF spintronic devices.

A pattern of competing forces

$LaFeO_3$ (LFO) is a prototypical antiferromagnet belonging to the complex oxides, a class of materials known for their wide range of functional properties. Nano- and microstructures (e.g., patterns such as lines) defined in crystalline LFO thin films display a distinct spin orientation near their edges, an apparent anisotropy imposed by the patterning. Could this lead to a way to manipulate spin? While such "shape anisotropies" have been thoroughly studied in ferromagnets, the "AF shape effect" is far less understood.

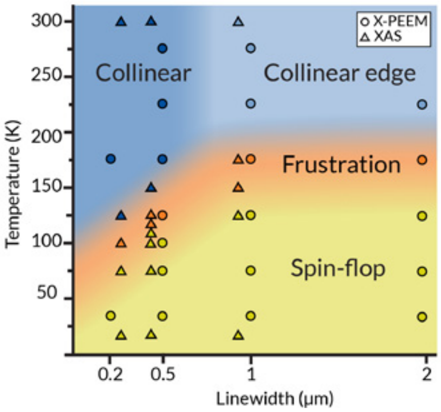
In addition, when a thin film of LFO is epitaxially grown on top of the ferromagnet $La_{0.3}S4_{0.7}MnO_3$ (LSMO), another handle for controlling the AF spin configuration is introduced: the interface exchange coupling between the layers. Whereas the AF shape effect leads to parallel alignment of AF spins and FM moments, the interface exchange coupling prefers perpendicular alignment, commonly referred to as the "spin-flop" transition. By investigating the impact of these competing forces as a function of structural dimensions, temperature, and applied magnetic fields, researchers can better understand the origins and engineering opportunities offered by these phenomena.

Probing the magnetic order of antiferromagnets

To probe the magnetic spin configuration of AF/FM bilayers, the researchers used polarized x-ray absorption spectroscopy (XAS) at ALS Beamline 4.0.2 and x-ray photoemission electron microscopy (PEEM) at ALS Beamline 11.0.1 for magnetic imaging. Taking advantage of the polarized x-rays from an undulator source, the FM and AF orderings were measured independently, relying on circular and linear magnetic dichroism at the Mn $L_{2,3}$ and Fe $L_{2,3}$ edges, respectively.

The results showed a distinct temperature dependence of the AF/FM spin configuration for the nanostructured bilayers. At elevated temperatures (higher than 200 K), the AF spin configuration is dominated by the shape effect imposed by the patterning, with collinear arrangement of the FM and AF spins. At lower temperatures, the interface exchange coupling overrides this AF shape effect, forcing a perpendicular spin alignment. Moreover, the transition temperature between collinear and spin-flop alignments was found to be tunable by varying the dimensions of the structure. Finally, application of a 0.3 T external magnetic field had no observable impact on the AF/FM spin alignment in this system.

In summary, the work demonstrates a temperature-dependent spin alignment, tunable by varying structural dimensions and insensitive to an applied magnetic field. The findings demonstrate how patterning can be used to control the AF spin order in thin-film nanostructures.



Compilation of data from X-PEEM and XAS measurements, demonstrating the linewidth and temperature dependence of the AF/FM line structures.

Norwegian University of Science and Technology co-authors. Top row: Ambjørn Dahle Bang, Ingrid Hallsteinsen, and Fredrik Olsen. Bottom row: Sam Slöetjes, Erik Folven, and Jostein Grepstad.

Contact: Ambjørn Dahle Bang (ambjorn.bang@ntnu.no)

Publication: A.D. Bang, I. Hallsteinsen, F.K. Olsen, S.D. Slöetjes, S.T. Retterer, A. Scholl, E. Arenholz, E. Folven, and J.K. Grepstad, “Néel vector reorientation in ferromagnetic/antiferromagnetic complex oxide nanostructures,” *Appl. Phys. Lett.* **114,** 192403 (2019), doi:10.1063/1.5094604.

Researchers: A.D. Bang, F.K. Olsen, S.D. Slöetjes, E. Folven, and J.K. Grepstad (Norwegian University of Science and Technology); I. Hallsteinsen (Norwegian University of Science and Technology and ALS); S.T. Retterer (Oak Ridge National Laboratory); and A. Scholl and E. Arenholz (ALS).

Funding: Research Council of Norway and U.S. Department of Energy, Office of Science, Basic Energy Sciences Program (DOE BES). Operation of the ALS is supported by DOE BES.

BERKELEY LAB

U.S. DEPARTMENT OF ENERGY
Office of Science

Published by the
ADVANCED LIGHT SOURCE
COMMUNICATIONS GROUP