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Evolution of Novel Chiral Spin Textures in Fe/Gd Based Multilayer Thin Films

William S. Parker[1*], Sergio A. Montoya[2], Eric E. Fullerton[2] and Benjamin M. McMorran[1]

[1.] Department of Physics, University of Oregon, Eugene, Oregon, USA.
[2.] Center for Memory and Recording Research, University of California San Diego, La Jolla, California, USA.
* Corresponding author: wparker4@uoregon.edu

Magnetic spin textures such as skyrmions and chiral domain walls have attracted extensive study due to their possible spintronics applications [1]. However, direct characterization of the spin structure of skyrmions and magnetic spin textures poses an experimental challenge. To better understand their structure, we use Lorentz transmission electron microscopy (LTEM) to track their evolution from well-studied magnetic domain walls (DWs).

Magnetic skyrmions were first predicted as a result of the Dzyaloshinskii-Moriya interaction present in materials with broken inversion symmetry [2]. As a result, the bulk of skyrmion research has focused on such materials. However, topologically equivalent chiral bubbles, or dipole skyrmions, can be stabilized in centrosymmetric multilayer thin films by the competition between long-range dipole and short-range domain wall energies [3]. The lack of any symmetry-breaking mechanism means that spin textures in these materials have no preferred chirality, further extending the range of textures that can be observed.

Recently, a novel biskyrmion phase consisting of bound pairs of skyrmions with opposite helicities was observed in centrosymmetric Fe/Gd multilayer thin films [4] (Fig. 1), using a combination of LTEM and resonant X-ray techniques. However, LTEM is sensitive to the projected in-plane magnetic field, and resonant X-ray techniques access the projected out-of-plane magnetization. This complicates the identification of complex magnetic spin textures, as multiple structures may yield qualitatively similar projected magnetic fields, and there has been subsequent debate over the true spin structure of the reported biskyrmion phase [5, 6].

Here, rather than attempting to directly characterize the structure of the novel texture, we use LTEM to track its evolution from the well-studied stripe domain phase. In LTEM mode, the objective lens is not needed, so it can be used to apply a uniform out-of-plane magnetic field while simultaneously imaging.

We first apply an out-of-plane magnetic field, tilting the sample slightly so there is a small field component in the plane of the sample. This causes striped DWs to form, alternatingly aligned and anti-aligned with the in-plane component, which matches previous results [3]. As the applied field is then increased, the striped DWs split along their length, and the aligned DWs form the center of the novel texture, while the anti-aligned DWs form closure loops (Fig. 2). This supports the idea that the center of the novel texture is a magnetic domain wall, and that the observed magnetic induction is caused by a pair of counter-rotating vortices. Full understanding of these textures will require knowledge of the 3D structure, and thus surface sensitive techniques like SEMPA, SPLEEM, and MFM will be vital moving forward. This material is based upon work supported by the National Science Foundation under Grant No. 2105400 [7].

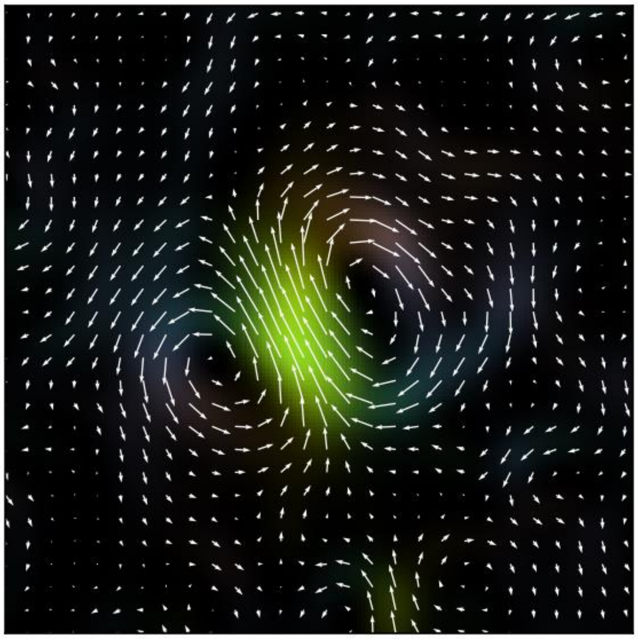

Figure 1. The projected in-plane field of the novel texture.

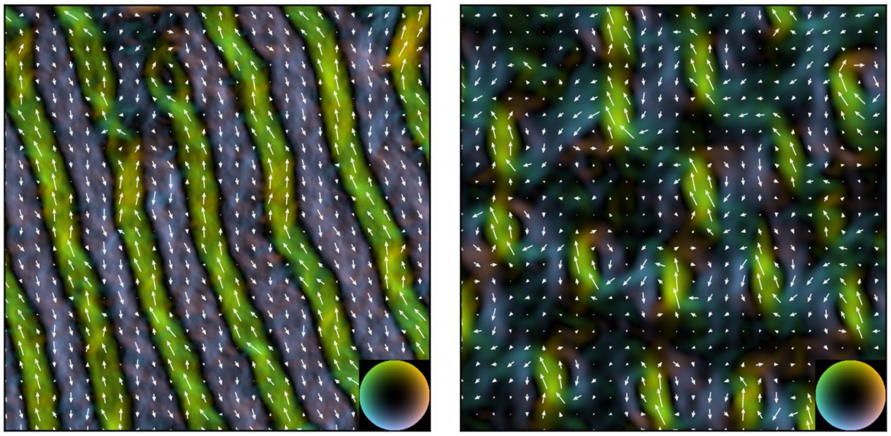

Figure 2. Stripe domains breaking into the novel phase.

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[7] Samples were fabricated by Sergio Montoya and Eric Fullerton at the Center for Memory and Recording Research, UC San Diego. LTEM images were acquired by William Parker at the CAMCOR Nanofabrication Facility, University of Oregon, with the help of Josh Razink.