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# Chiral spin textures in Fe/Gd based multilayer thin films

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Chiral spin textures like magnetic skyrmions and domain walls have attracted extensive study due to their possible applications in spintronics technologies1. Skyrmions in particular are a strong candidate for binary information carriers in technologies like racetrack memory2. They are topological stable, spatially compact, and easily driven by electrical currents3,4. However, skyrmions are typically only stable in a limited region of phase space - i.e., at certain temperatures, and with an applied external field. To realize their potential in spintronic technologies, skyrmions must be stabilized in commercially viable conditions: at room temperature, with zero applied field, and in a range of physical geometries.

Skyrmions have prototypically been studied in materials with broken inversion symmetry, such as non-centrosymmetric bulk magnets and interfacially asymmetric multilayers5,6. These materials' broken inversion symmetry leads to the noncollinear Dzyaloshinskii-Moriya (DM) interaction, which competes with collinear interactions like the Heisenberg exchange to create stable swirling spin textures. Particularly by manipulating interfacial DM interactions7, progress has been made creating tailored skyrmions at room-temperature and with no applied field8.

However, skyrmions can also be stabilized in multilayer materials lacking symmetry breaking mechanisms. Skyrmions in Fe/Gd multilayers are stabilized by the competition between long-range dipolar energy and domain wall energy, rather than the DM interaction9. Because these materials lack any symmetry-breaking mechanism, they support skyrmion lattices with no preferred helicity - both helicities can exist simultaneously. Preferred helicity can then be introduced and tuned by the introduction of symmetry-breaking layers. Further, Montoya et al. showed that a skyrmion lattice, stable at room temperature and with zero applied field, could by induced in Fe/Gd thin films by applying a magnetic field tilted with respect to the film normal4.

The McMorran group uses Lorentz TEM (LTEM), a spin-sensitive electron microscopy technique, to take real-space images of magnetic thin films like the Fe/Gd multilayers fabricated by Dr. Montoya et. al. LTEM is sensitive to the transverse component of the magnetization, which induces a phase shift in the transmitted electron. By defocussing, this phase shift manifests as contrast, from which we can reconstruct the induced phase using the single image transport of intensity equation (SITIE)10, and thus the transverse magnetic moments (Fig 1).

LTEM is well-suited to the study of magnetic thin films, as the objective lens of the microscope (not needed in the Lorentz configuration), can be used to apply a uniform out-of-plane magnetic field. The thin film can be tilted to apply an in-plane field component - all the while, synchronously imaging the magnetic configuration.

Here, we study an aspect of chiral spin texture behavior highly relevant to spintronic applications: domain behavior near material edges. In particular, we study Fe/Gd multilayers deposited on holey SiN membrane - a SiN support film perforated by a square grid of holes. This configuration presents three interesting regions to study: a "central" region (Fig 2c.), far from any edge effects, and two perpendicular thin stripes (~5μm wide) between adjacent holes (Fig 2a, 2d). We see that edge effects have a highly non-trivial effect on the formation of chiral spin textures, particularly in the presence of tilted external magnetic fields. The interplay between striped domains, skyrmions, coupled skyrmions, and more complex spin textures, which has previously been investigated as a function of out-of-plane applied field strength, is also affected by edge effects and by the angle of the applied field.

These results are a step towards the use of skyrmions in practical spintronic applications, as such applications need to understand and control skyrmions in a variety of geometries.

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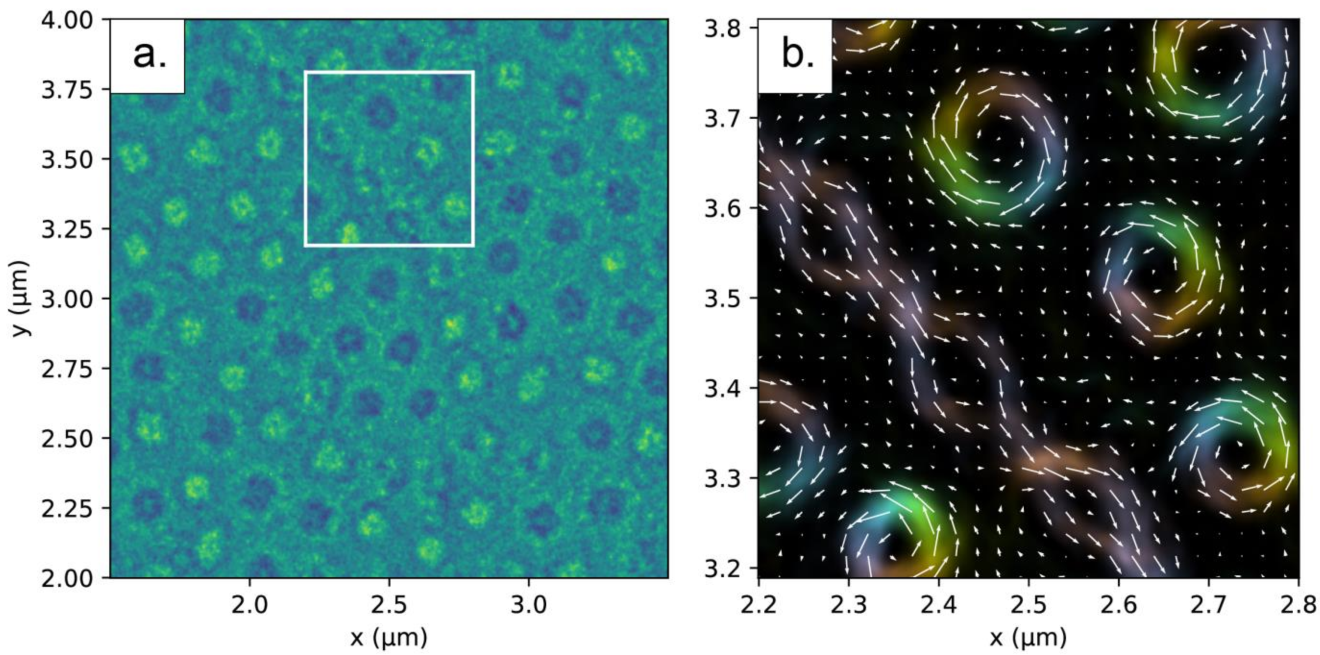


Figure 1. (a) Recorded intensity and (b) reconstructed magnetization using SITIE.

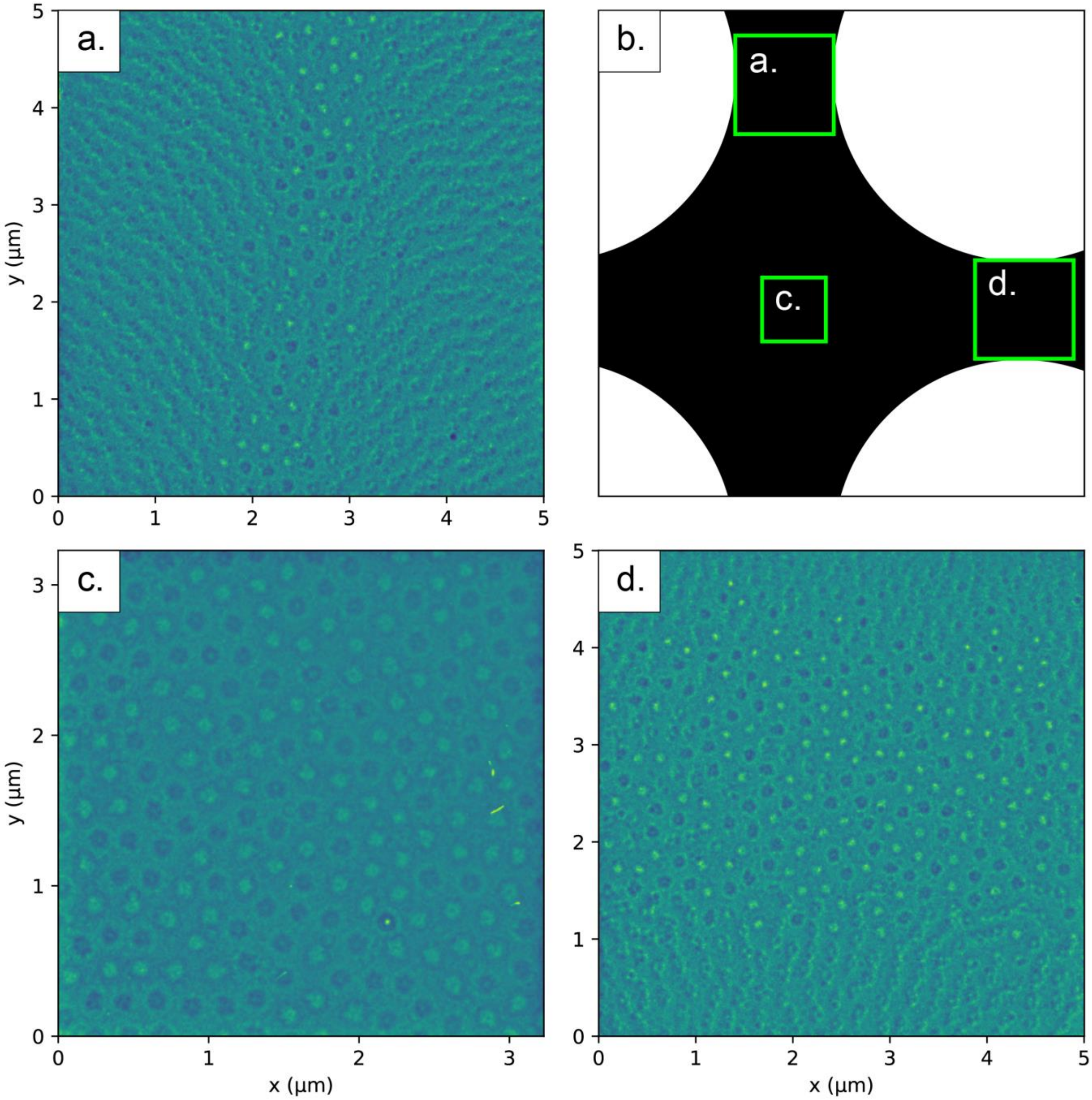


Figure 2. Chiral spin textures in Fe/Gd multilayers in three different regions. The thin film is exposed to a magnetic field normal to its surface, then tilted up to 45º, and then returned to zero tilt, still with an applied field. This results in drastically different skyrmion nucleation in the three regions.

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