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Quantitative Analysis of Topological, Chiral Spin Textures Stabilized by the Dzyaloshinskii–Moriya Interaction in Co/Pd Multilayers

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Néel skyrmions are of great interest due to their potential applications in a variety of spintronic devices, currently accessible in ultrathin heavy metal/ferromagnetic bilayers and multilayers with a strong Dzyaloshinskii–Moriya interaction (DMI). Since the magnetic contrast in Lorentz TEM is determined by the curl of the magnetization along the beam propagation direction, and for Néel skyrmions the curl of the magnetization lies completely in the plane of the sample (Fig. 1), without sample tilt the Néel-skyrmion spin structure produces no contrast. Here we report on the direct imaging of complex chiral spin structures including Néel skyrmions in an exchange-coupled cobalt/palladium multilayer at room temperature using Lorentz TEM and phase retrieval methods. We reveal the internal spin distribution of the skyrmion core: a 25 nm central region of almost uniform magnetization surrounded by a transition region where the spins progressively rotate from out-of-plane to in-plane. The evolution of the chiral spin structures as a function of magnetic field in the systems is also exposed in detail.

The topological spin structure of the Co/Pd multilayers stabilized by the DMI is governed by the delicate competition between the exchange, demagnetization and anisotropy energies. To further understand the fundamental physics associated with the spin ordering in three-dimensions we developed a quantification technique to investigate mixed Bloch/Néel chiral spin textures (Fig. 2). Analysis of the observed Lorentz intensities based on the full Fresnel propagator under varied imaging conditions, such as defocus values and sample tilt, coupled to corroborative micromagnetic simulations yields vital parameters that dictate the stability and properties of the complex spin texture. Specifically, the degree of mixed Bloch/Néel character, the domain wall width, the strength of the DMI interaction and the exchange stiffness [2]. This approach has broad applicability to an array of prominent topological spin systems.

References:

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[2] JA Garlow et al., Physical Review Letters (2019) under review.
[3] Work at BNL was supported by the US DOE-BES, MSED, under Contract No. DESC0012704.

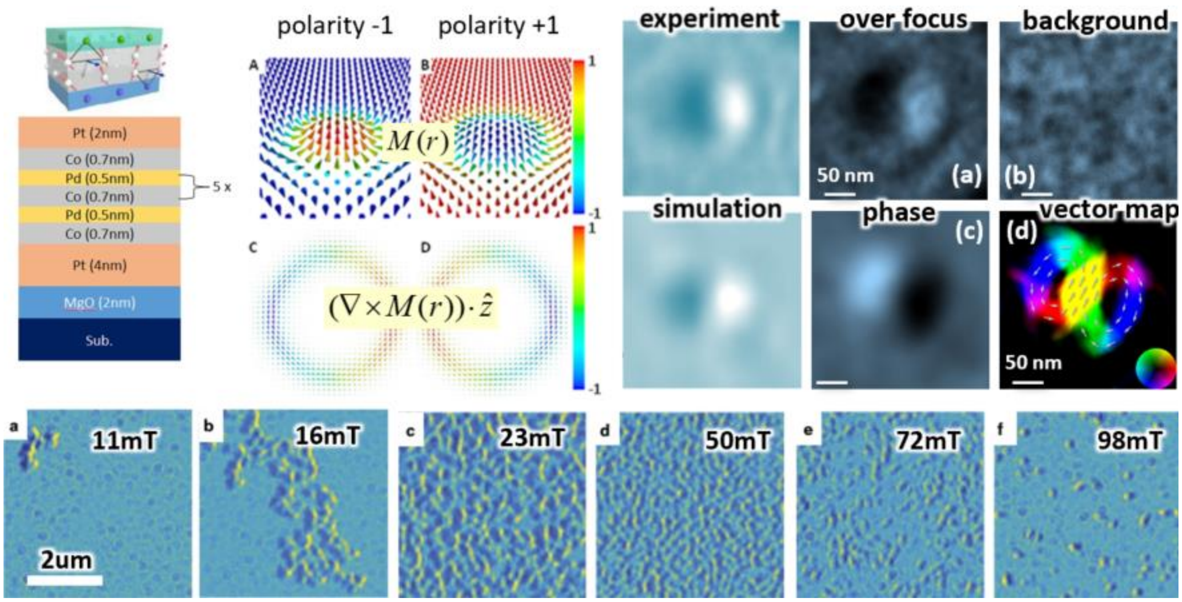

Figure 1. (top left) The Co/Pd multilayer sample geometry and the interfacial Dzyaloshinskii-Moriya interaction (DMI). (middle) Chiral spin texture of a Néel skyrmion with positive (DMI) and a polarity of -1 and +1 (color: normalized out-of-plane component of magnetization) and their corresponding curl of the magnetization (color: normalized y-component of the curl), which, when tilted about the x axis, leads to a non-zero z-component, and results in the formation of Néel skyrmion contrast. (right) Quantitative analysis of Néel skyrmion contrast, comparing experiment with simulation. (bottom row): In situ reversal behavior showing the nucleation and propagation of chiral Néel walls and the formation of skyrmions before saturation. Imaging was performed with a negative defocus and a -30° of tilt along the horizontal direction.

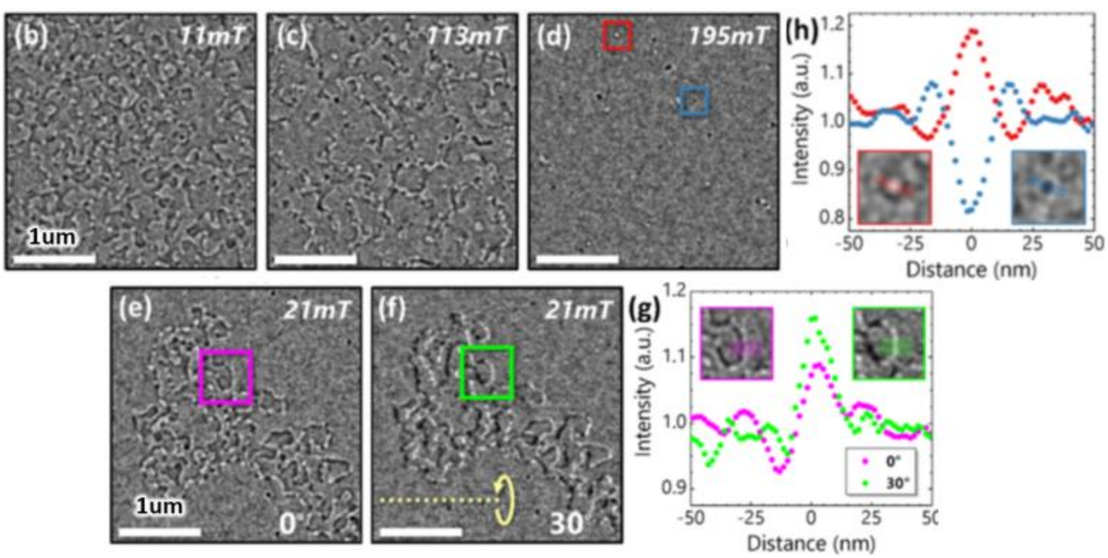

Figure 2. (b-d) Lorentz images of the chiral spin structures as a function of applied fields. At large applied fields, skyrmion-like spin structures with a clear Bloch component are highlighted by the red and blue boxes. (e) 180° domain walls appearing at low applied fields with a decreased density. Contrast of Bloch-lines is observed as alternating bright/dark contrast along the domain wall length. (f) The same region as in (e) after tilting the sample 30° around the tilt axis shown. (g) Line scans acquired from the magenta and green boxes in (e,f) demonstrate asymmetric LTEM contrast at tilt, strongly suggesting mixed-character domain walls. (h) Line scans from the regions highlighted in (d) reveal skyrmion-like structures with opposing Bloch components.

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