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Real Space Demonstration of Electric Current-Induced Isolated Skyrmion Deformation

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Since the discovery of topological spin textures called magnetic skyrmions [1,2], they have been heralded as candidates for information carriers in future computing applications [3]. To realize this goal, much progress has been made using an electrical current to drive skyrmion motion. Many skyrmion motion applications rely on the assumption that the skyrmions are rigid under electrical current application [4,5]. Here we show experimentally by real space observations of skyrmions under an applied current that skyrmions deform with surprising severity, even by small currents.

In this study, we measure the current-driven real-space deformation of isolated, pinned skyrmions within CoZn at room temperature. We observe that the skyrmions are surprisingly soft, readily deforming during electric current application from a circular shape with radius a_0 into an elliptical shape with a well-defined major axis with semi-major axis length a_f as shown in Figure 1A and 1B, respectively. We find that this axis rotates unidirectionally towards the current direction irrespective of electric current polarity and that the elliptical deformation reverses back upon current termination. Using real space Lorentz transmission electron microscopy images (selected micrographs of a single, pinned skyrmion shown in Figure 2A and 2B), we quantify the average eccentricity e, which increases $\approx 20\%$ during the largest applied current density $|j| = 8.46 \times 10^9\ \mathrm{A/m^2}$ when compared to the skyrmion's intrinsic shape ($j = 0$). Additionally, we demonstrate an approximately 150% average skyrmion core size expansion during current application, highlighting the skyrmions' inherent topological protection. This first evaluation of in-situ electric current-induced skyrmion deformation paints a clearer picture of spin-polarized electron-skyrmion interactions and may prove essential when designing spintronic devices.

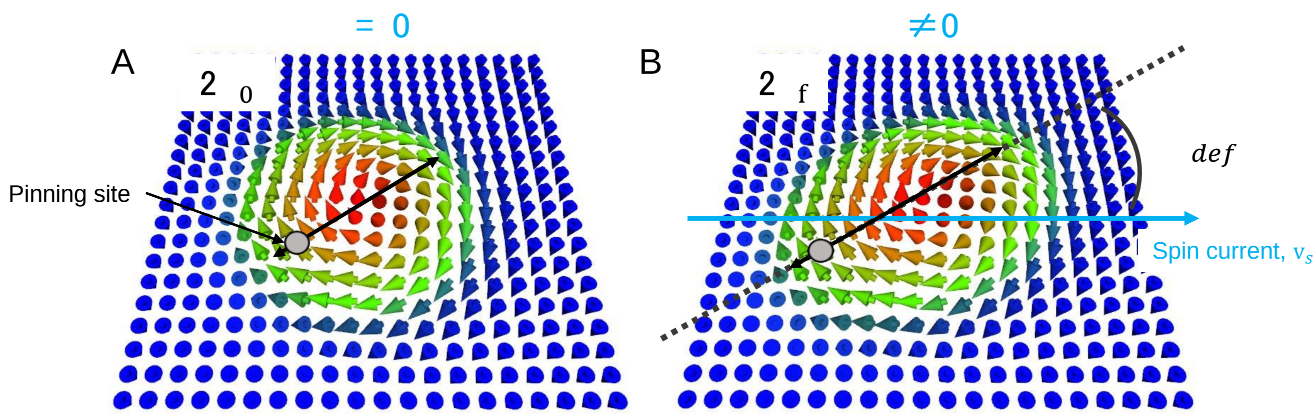

Figure 1. Pinned skyrmion deformation model. (*A*) Schematic illustrating a magnetic skyrmion with skyrmion number $Q = +1$ at zero current. The skyrmion may be thought of as two half-skyrmions (merons) with $Q = +1/2$, drawn in both (a) and (b) as solid red and dark blue half circles. initial skyrmion semi-major axis length a_0 (skyrmion radius) is labelled, and the diameter is drawn by a black double-headed arrow. The skyrmion pinning site is drawn as a gray circle near the skyrmion's domain wall. (*B*) Schematic illustrating the magnetic skyrmion upon application of an electric current. Half of the skyrmion is elongated along the semi-major axis of length a_f, while the other half remains pinned in place at the pinning site. The deformation axis (semi-major axis) is at some angle away from the spin current direction, θ_{def}.

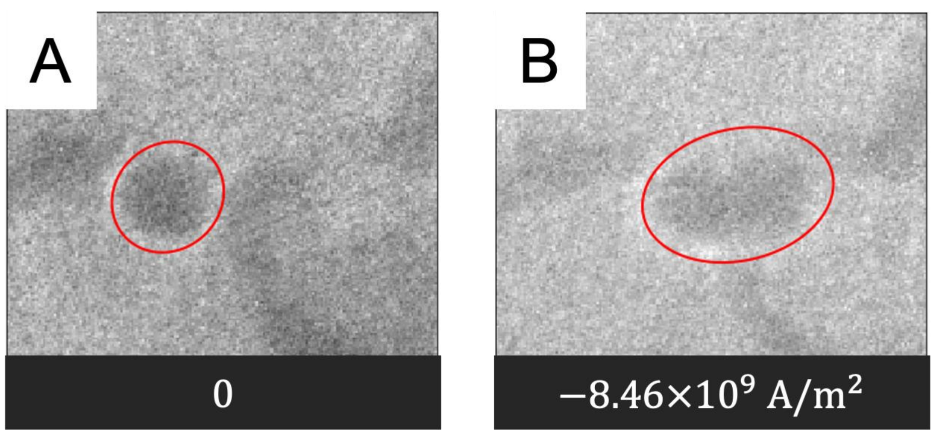

Figure 2. Electric current-induced skyrmion core expansion. (*A*-*B*) Defocused Lorentz TEM real space micrograph of an isolated, pinned skyrmion before (a) and during (b) electric current application with density $j = -8.46$ A/m^2.

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