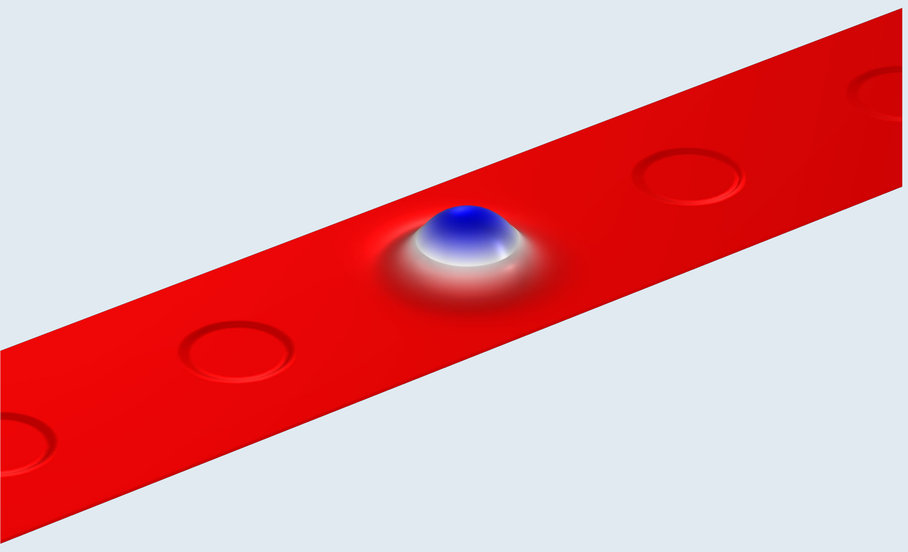

Magnetic Skyrmion Shift Register

Skyrmion data storage by inhomogeneous perpendicular magnetic anisotropy and data shift by spin-orbit torque of current pulses

Chensong Hua (华辰松) and Weichao Yu (余伟超)
22110190020@m.fudan.edu.cn
Institute for Nanoelectronic devices and Quantum computing, Fudan University, Shanghai, 200433, China

Method

The dynamics of spins can be illustrated by the Landau-Lifshitz-Gilbert (LLG) equation, in which the effective field includes Heisenberg exchange interaction, anisotropy, external magnetic field, Dzyaloshinskii-Moriya interaction (DMI) and the magnetic dipolar field. Most of the interactions are built in the Micromagnetics Module, while the magnetic dipolar field should be solved along with the AD/DC module. The spin-orbit torque (SOT) generated by spin-polarized currents is an additional torque term on the right hand side.

- LLG equation: $\frac{\partial \mathbf{m}}{\partial t} = -\gamma \mathbf{m} \times \mathbf{H}_{\text{eff}} + \alpha \mathbf{m} \times \frac{\partial \mathbf{m}}{\partial t} + \boldsymbol{\tau}_{\text{SOT}}$ ⟷ Maxwell equation: $\nabla \cdot \mathbf{H}_{\text{dipole}} = -M_{\text{s}} \nabla \cdot \mathbf{m}$
- Effective magnetic field: $\mathbf{H}_{\text{eff}} = \frac{2A}{\mu_0 M_{\text{s}}} \nabla^2 \mathbf{m} + \frac{2K}{\mu_0 M_{\text{s}}} (\mathbf{m} \cdot \hat{\mathbf{u}}) \hat{\mathbf{u}} + \mathbf{H}_{\text{ext}} + \frac{2D}{\mu_0 M_{\text{s}}} \left[(\nabla \cdot \mathbf{m}) \hat{\mathbf{z}} - \nabla m_z \right] + \mathbf{H}_{\text{dipole}}$

Skyrmion Data Storage

Skyrmion is a kind of topologically protected spin texture which can be dynamically driven by spin torques. Here the inhomogeneity of perpendicular magnetic anisotropy in the indentations is applied to generate a strong pinning effect on the skyrmions for storage as data bits.

- Topological charge: $C = \frac{1}{4\pi} \int \mathbf{m} \cdot (\partial_x \mathbf{m} \times \partial_y \mathbf{m}) d^2x = \pm 1$

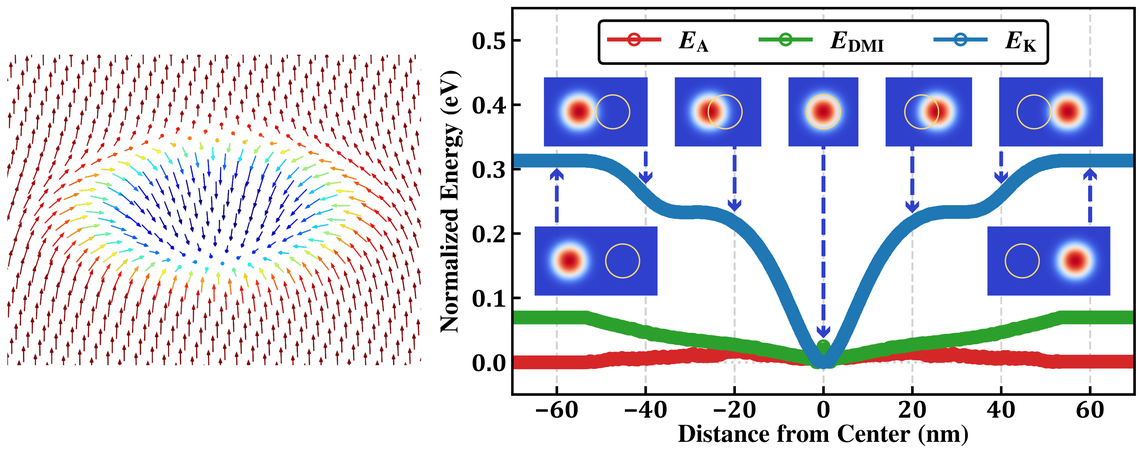

FIGURE 1. Left: Profile of a Néel-type skyrmion. Right: Skyrmion energy at different distances from the center of the indentation.

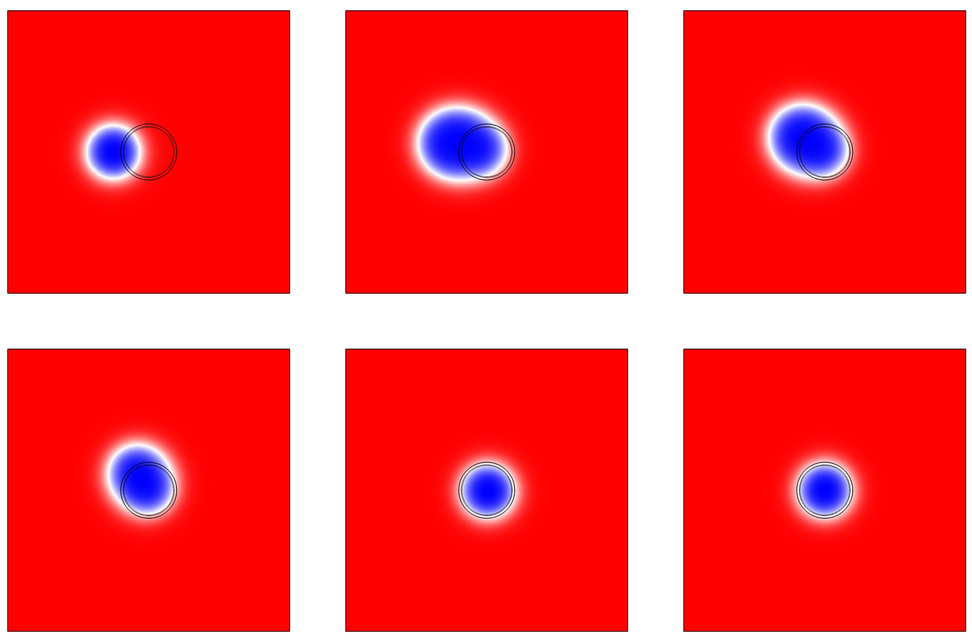

FIGURE 2. A skyrmion captured by an indentation spontaneously. Screenshots for every 0.3ns.

Skyrmion Data Shift

Different spin-polarized current pulses can be applied to the racetrack to generate the spin-orbit torque for data shifts. Skyrmion sequences can be created as the initial states for further manipulations on the whole data string.

- Spin-orbit torque : $\boldsymbol{\tau}_{\text{SOT}} = -\gamma \frac{\hbar \theta_{\text{sh}} j_{\text{HM}}}{2\mu_0 e M_{\text{s}} t_{\text{FM}}} \mathbf{m} \times (\mathbf{m} \times \mathbf{p})$

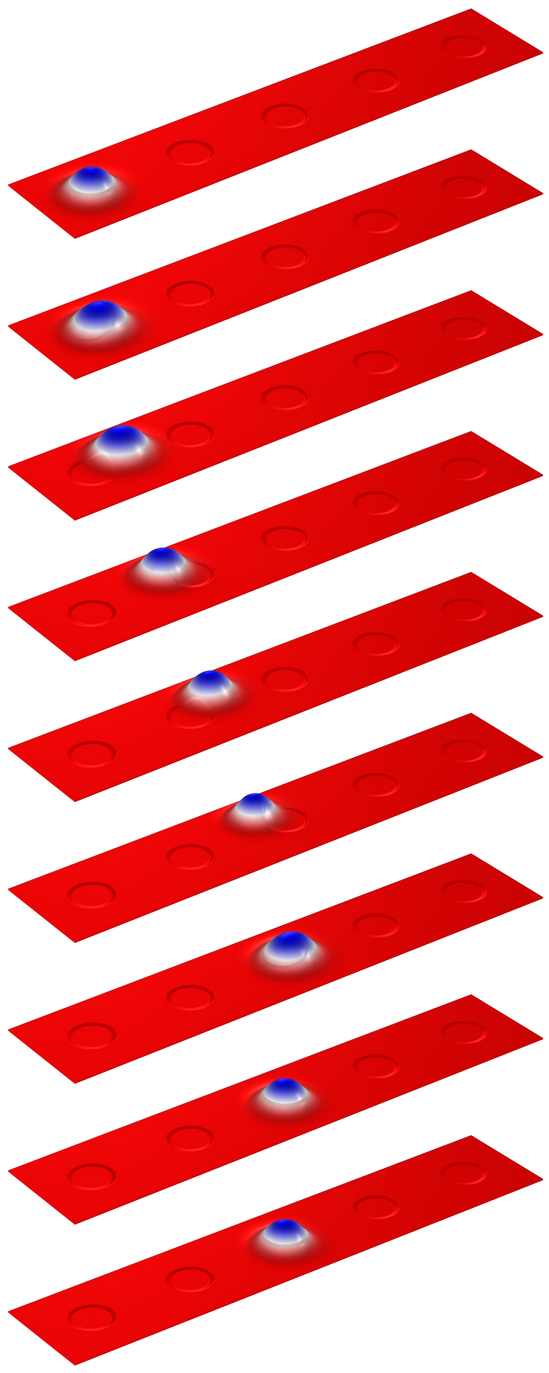

FIGURE 3. A single data bit shifts two sites. Screenshots for every 0.5ns.

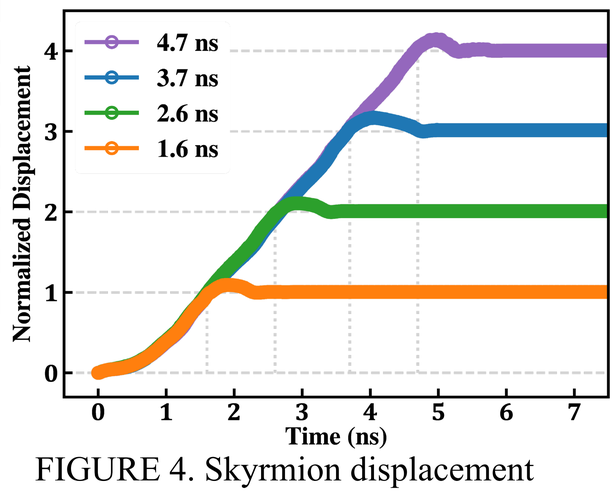

FIGURE 4. Skyrmion displacement under different pulse durations.

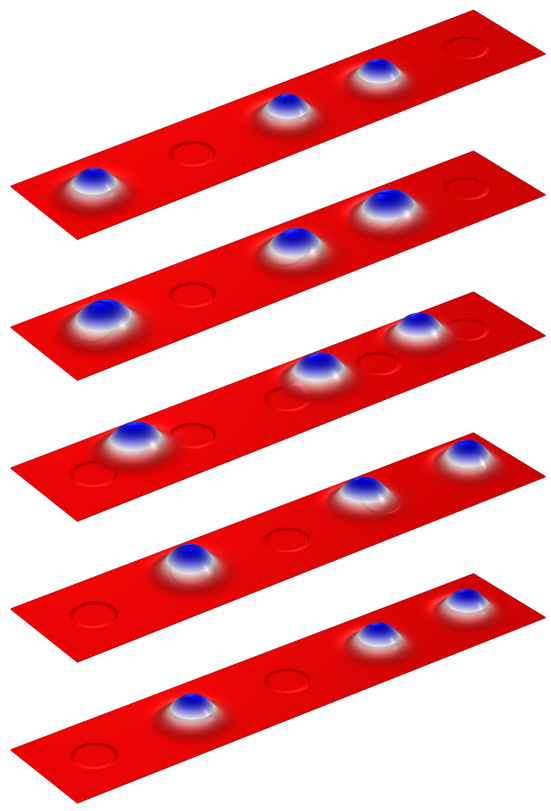

FIGURE 5. The overall shift of a “1011” data string. Screenshots for every 0.6ns.

References

[1] L. Zhao, C. Hua, et. al., Sci. Bull. 69, 2370 (2024).
https://cn.comsol.com/blogs/micromagnetic-simulation-with-comsol-multiphysics