Review of: "Reversible writing/deleting of magnetic skyrmions through hydrogen adsorption/desorption"

Fehmi Yasin[1], Xiuzhen Yu[1]

1 RIKEN

Potential competing interests: The author(s) declared that no potential competing interests exist.

Topological charge-carrying magnetic skyrmions are collections of spins which twist in such a way as to wind the unit sphere over the skyrmion's area[1][2]. Skyrmions' domain wall twists are either Néel- (Fig. 1a) or Bloch-type (Fig. 1b), and their integer topological charge $S = \frac{1}{4\pi}\int_A \mathbf{n} \cdot \left(\partial_x \mathbf{n} \times \partial_y \mathbf{n}\right) dx\, dy = -1$ makes them especially resistant to annihilation by external stimuli such as heat flow, electric current and magnetic fields. However, such stimuli may be used to drive rapid skyrmion motion at low densities[3][4], or even induce controlled topological transformations to spin textures of different topological charge such as antiskyrmions (Fig. 1c, $S = +1$) or non-topological bubbles ($S = 0$)[5].

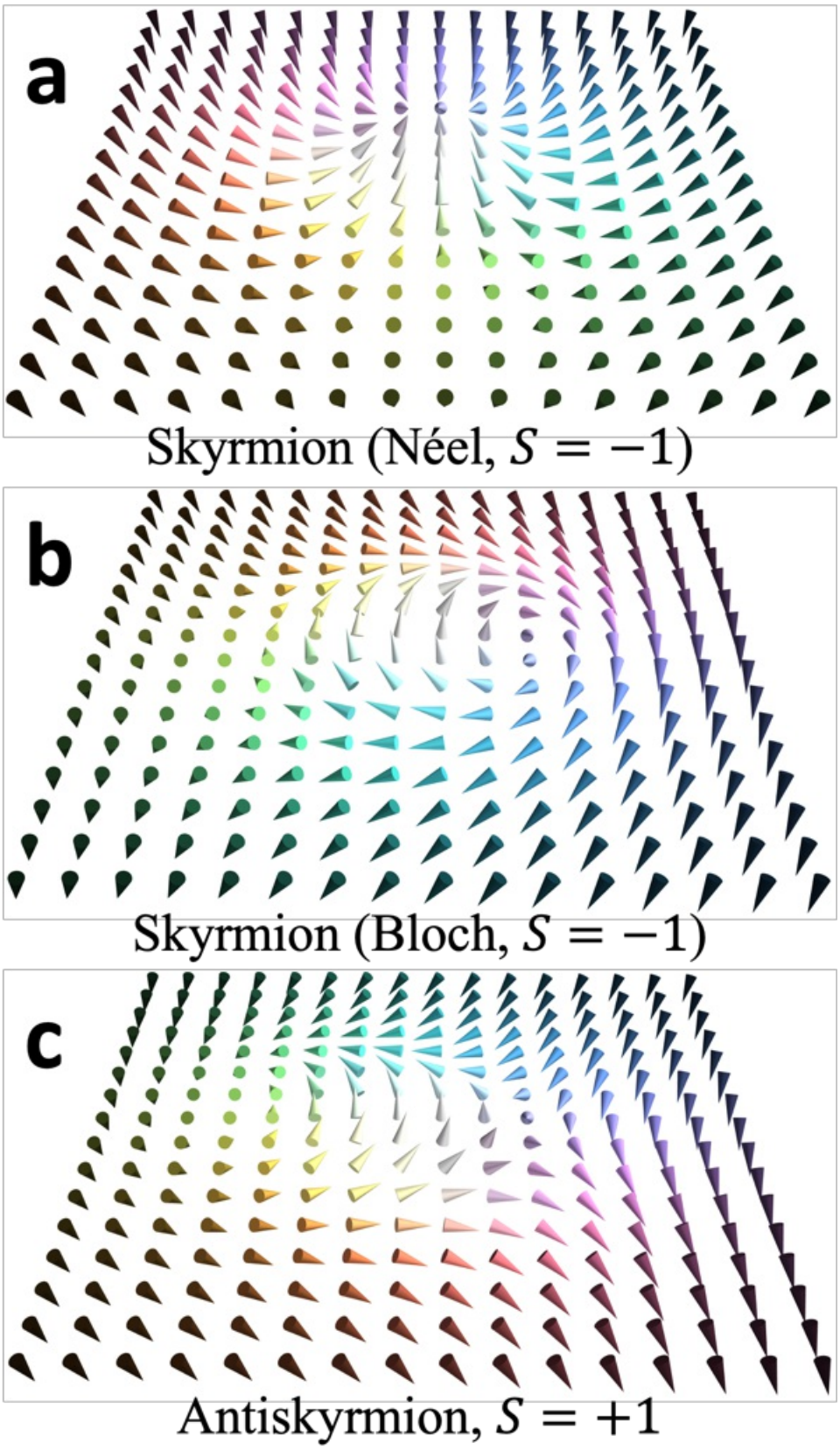

***Figure 1 Schematics of topological spin textures. a**-**c**, Illustrations of a (**a**) Néel-type skyrmion (S = -1), (**b**) Bloch-type skyrmion (S = -1) and (**c**) antiskyrmion (S = +1). Skyrmions tend to be stable in crystal structures that break inversion-symmetry (e.g. chiral crystals) and exhibit Dzyaloshinskii-Moriya (DM) interaction between spins, whereas antiskyrmions are generated via an anisotropic DM interaction.*

One can imagine that these characteristics make topological spin textures particularly promising for use in spintronics devices. Moreover, skyrmions may be written and deleted using an external magnetic field, spin-polarized current injections[6], thermal excitations[7], laser light pulses[8] and applied gate voltages[9]. Now, writing in *Nature Communications*, Gong Chen and colleagues have discovered that hydrogen chemisorption/desorption on the surface of Ni and Co films creates/annihilates skyrmions within the Ni/Co/Pd/W thin films[10]. While the effects of hydrogen chemisorption on magnetic atoms have been studied for several decades,[11] this work employs the process on skyrmions to great effect in the absence of other external stimuli for the first time.

Using spin-polarized low-energy electron microscopy (SPLEEM), they measured the time-dependent dynamics of the out of plane magnetization (n_z) after increasing the H_2 pressure a small amount (≈ 0.7 L). They find that the hydrogen adsorption induces an in-plane anisotropy attributable to the cobalt site binding, resulting in Néel-type skyrmion creation. Impressively, they demonstrate that this ambient temperature, field-free process is reversible upon termination of the H_2 flux. Monte-Carlo simulations over a range of perpendicular magnetic anisotropy (PMA) values support their experimental findings and reveal three critical ranges of PMA values in which hydrogen chemisorption-induced skyrmion creation is 1) absent, 2) reversible and 3) irreversible. Additionally, they characterize the effect of O_2 chemisorption on similar thin films, finding that it too enables tuning of the system's PMA.

In the skyrmionics road map laid out, in part, by Alex Fert and colleagues almost one decade ago, they pointed out that in order for skyrmions to become the basic building block of a new generation of spintronics devices, there must be a mechanism by which they are easily inserted in real devices and moved or excited at low energy cost.[12] Chen and his colleagues' work offers a new twist that inspires chemistry-based device designs. Gas adsorption is contactless, low energy and may be site-specific, especially with modern nanometric etching and deposition technology. Their observation that chemisorption occurs only at the surface allows for both reversibility of the skyrmion creation process and localization of the skyrmion creation to desired sites.

Such a design is illustrated in Fig. 2, in which the addition of a chemisorption-inhibiting strip of atoms in the center of the device allows for skyrmion writing at two user-defined sites, after which the skyrmions may also be driven into motion using any of the skyrmion-driving forces. Furthermore, Chen and his colleagues' proposed mechanism for skyrmion creation/annihilation is the fine tuning of local anisotropy due to chemisorption of hydrogen or oxygen with the thin film's surface atoms. This suggests that the introduction of these or other elements at particular sites in a device may be used towards alternative ends including the creation of pinning sites to either hold skyrmions in place or chemically alter their racetrack. The exploration of the world of magnetic skyrmions continues with gusto, and the tools are now firmly in place for functional spintronics devices to be built.

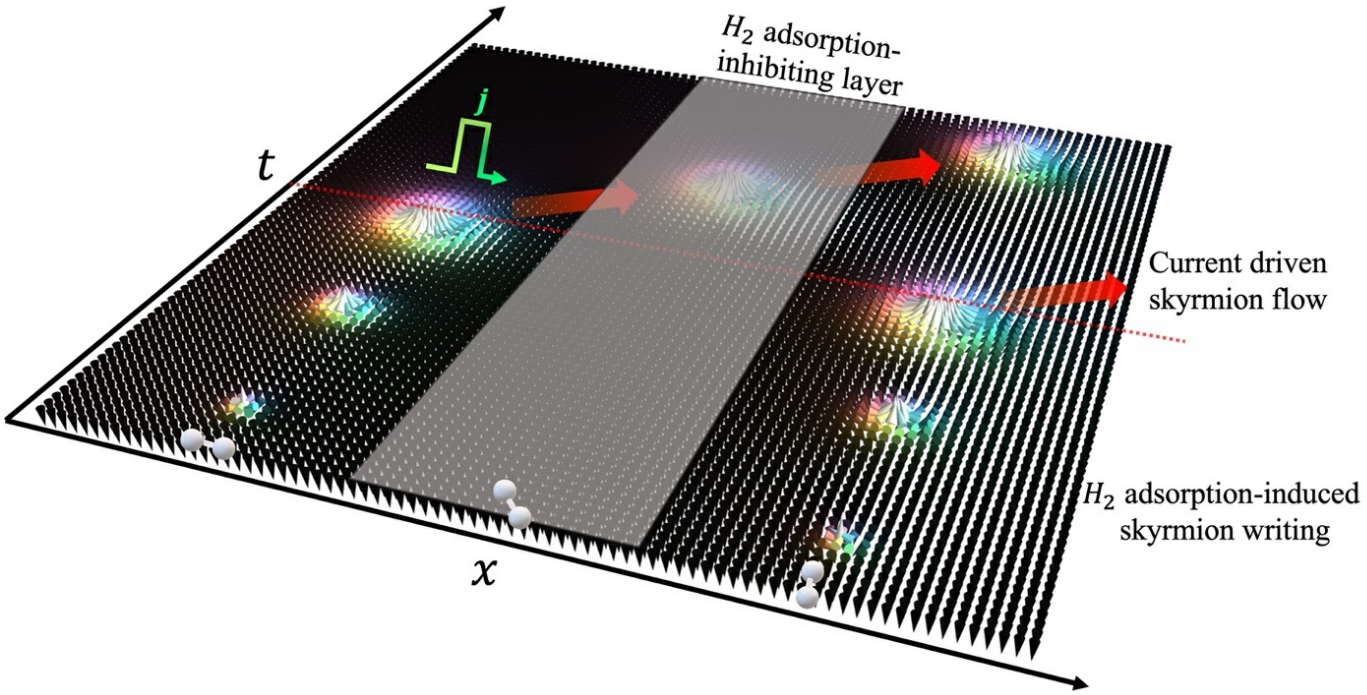

Figure 2 Site-selective hydrogen chemisorption-induced skyrmion writing and current driven flow motion. *Schematic of a potential skyrmionics device in which skyrmions are written in sites where hydrogen is allowed to bond with the surface atoms. There are three sites marked along the x axis with H_2 molecules, and magnetic skyrmion growth is illustrated along the time axis marked by 't.' Sites coated with an H_2 adsorption-inhibiting layer, however, remain unchanged by the introduction of H_2 at the surface. After creation, the skyrmions are driven into motion via an electric current with density* **j** *[$A \cdot m^{-2}$].*

References

1. ^*T. H. R. Skyrme. (1962). A unified field theory of mesons and baryons. Nucl Phys. 31(C):556–569. doi:10.1016/0029-5582(62)90775-7*
2. ^*A. N. Bogdanov, D. A. Yablonskii. (1989). Thermodynamically stable "vortices" in magnetically ordered crystals. The mixed state of magnets. Zh Eksp Teor Fiz. 95(1):178. Available from: http://www.jetp.ac.ru/cgi-bin/e/index/e/68/1/p101?a=list*
3. ^*X. Z. Yu, N. Kanazawa, W. Z. Zhang, T. Nagai, T. Hara, et al. (2012). Skyrmion flow near room temperature in an ultralow current density. Nat Commun. 3(1):988. doi:10.1038/ncomms1990PubMed PMID: 22871807*
4. ^*Xiuzhen Yu, Fumitaka Kagawa, Shinichiro Seki, Masashi Kubota, Jan Masell, et al. (2021). Real-space observations of 60-nm skyrmion dynamics in an insulating magnet under low heat flow. Nat Commun. 12(1):5079. doi:10.1038/s41467-021-25291-2PubMed PMID: 34426575*
5. ^*Ajaya K. Nayak, Vivek Kumar, Tianping Ma, Peter Werner, Eckhard Pippel, et al. (2017). Magnetic antiskyrmions above room temperature in tetragonal Heusler materials. Nature. 548(7669):561–566. doi:10.1038/nature23466PubMed PMID: 28846999*
6. ^*Niklas Romming, Christian Hanneken, Matthias Menzel, Jessica E. Bickel, Boris Wolter, et al. (2013). Writing and deleting single magnetic skyrmions. Science. 341(6146):636–639. doi:10.1126/science.1240573*
7. ^*Zidong Wang, Minghua Guo, Heng An Zhou, Le Zhao, Teng Xu, et al. (2020). Thermal generation, manipulation and*

thermoelectric detection of skyrmions. Nat Electron. 3(11):672–679. doi:10.1038/s41928-020-00489-2

8. ^*G. Berruto, I. Madan, Y. Murooka, G. M. Vanacore, E. Pomarico, et al. (2018). Laser-Induced Skyrmion Writing and Erasing in an Ultrafast Cryo-Lorentz Transmission Electron Microscope. Phys Rev Lett. 120(11):117201. doi:10.1103/PhysRevLett.120.117201PubMed PMID: 29601740*
9. ^*Pin Jui Hsu, André Kubetzka, Aurore Finco, Niklas Romming, Kirsten Von Bergmann, et al. (2017). Electric-field-driven switching of individual magnetic skyrmions. Nat Nanotechnol. 12(2):123–126. doi:10.1038/nnano.2016.234PubMed PMID: 27819694*
10. ^*Gong Chen, Colin Ophus, Alberto Quintana, Heeyoung Kwon, Changyeon Won, et al. (2022). Reversible writing/deleting of magnetic skyrmions through hydrogen adsorption/desorption. Nat Commun. 13(1):1350. doi:10.1038/s41467-022-28968-4PubMed PMID: 35292656*
11. ^*M. Weinert, J. W. Davenport. (1985). Chemisorption of H on Magnetic Ni(001). Phys Rev Lett. 54(14):1547–1550. doi:10.1103/PhysRevLett.54.1547*
12. ^*Albert Fert, Vincent Cros, João Sampaio. Skyrmions on the track. Nature Nanotechnology.: Nature Publishing Group 2013. pp. 152–156. doi:10.1038/nnano.2013.29PubMed PMID: 23459548*