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Editorial: Generation, detection and manipulation of skyrmions in magnetic nanostructures

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Editorial on the Research Topic
Generation, Detection and Manipulation of Skyrmions in Magnetic Nanostructures

With the rapid accumulation of data in science, technology, and social activity in the development of modern society, it is becoming increasingly urgent and important to find efficient and effective methods to store and process information with low power consumption. The skyrmion, a curling field configuration, was originally proposed by nuclear physicist Skyrme [1] and it was recently realized in a wide class of magnetic materials with chiral exchange interactions [2–4]. Due to their compact shape and small size down to a few nanometers, good thermal stability, and low driven current density, magnetic skyrmions have become promising building blocks for high-density storage and fast information processing applications. In a dozen years, this field dubbed as skyrmionics has attracted significant attention for exploring fundamental physics as well as for practical applications.

This research topic entitled “*Generation, Detection, and Manipulation of Skyrmions in Magnetic Nanostructures*” aims to address the recent developments in the field of skyrmionics. Particularly, the featured topics include the interplay of skyrmions and spin waves, pinning effects of disorder and defects on skyrmion motion, and the design of spintronic devices with information encoded in skyrmions and other magnetic solitons.

Two articles present the interplay of spin waves and magnetic skyrmions. *Guan et al.* show that an antiferromagnetic skyrmion driven by double circularly-polarized spin waves could move along the intersection of the two microwave sources. Here the skyrmion Hall effect is strongly suppressed because the effective transverse forces acting on the skyrmions generated by the left-handed and right-handed spin waves cancel each other. This theoretical proposal may help to guide skyrmion motion in a desirable trajectory. Yao et al. considered skyrmion generation by spin waves reflected from a curved surface. Usually, spin-wave energy is too small to overcome the barrier between a skyrmion and a ferromagnetic state. Here the authors carefully design a parabolic film edge such that the intensity of spin waves totally reflected from the edge is strongly enhanced to switch the magnetization at the focal point of the system. With continuous excitation of spin waves, more magnetic energy is accumulated and finally leads to the generation of a skyrmion in a transient time. Then the microwave source is switched off and the spins relax toward a steady skyrmion configuration. This finding may enable all magnonic control of skyrmion generation and motion, which in principle works for both magnetic metals and insulators.

Pinning effects of disorder, defects and artificial pits on skyrmion dynamics in a magnetic system are also reported in this research topic. Matsumoto et al. experimentally study the magnetic skyrmions confined to surface-pit corrals with various geometries. They find that skyrmions are deformed in both shape and size under the influence of the boundaries defined by the surface-pit corrals. Deformed skyrmions with opposite polarities may coexist inside a corral even in the absence of external fields. These experimental findings may provide guidance to confine and deform skyrmions in a desirable way. Employing a particle-based approach, Reichhardt and Reichhardt investigate the dynamics of a driven skyrmion interacting with an array of other skyrmions and quenched disorder in a magnetic thin film. In particular, the authors find that the quenched disorder could weaken the drag effect of the skyrmion arrays and thus increase the skyrmion velocity. The nature and amount of noise of skyrmion velocity fluctuations are analysed in detail. These results deepen our understanding of skyrmion dynamics in disordered films, while the essential results may be relevant for other particle-based systems. Wan et al. show that the exchange and fourth-order magneto-crystalline anisotropies can deform a skyrmion lattice and further induce pinning effects to rotate the skyrmion lattice. These findings complement and deepen our understanding on the pinning effects of skyrmions [5–8].

Two articles study potential applications of magnetic skyrmions. Hoffmann et al. theoretically show that a bound state of a skyrmion-antiskyrmion pair could exist in a so-called rank-one magnetic material, where the Dzyaloshinskii-Moriya interaction is reduced to only one non-zero component. This finding suggests that binary information ("0" and "1") carried by the skyrmion and antiskyrmion pair could form a stable sequence in a magnetic racetrack. By applying a spin current with proper spin polarization, the authors further demonstrate that a skyrmion-antiskyrmion sequence could be collectively displaced along a desired direction without showing the skyrmion Hall effect. The distance of adjacent skyrmions is kept unchanged during propagation because the skyrmion and the antiskyrmion move in step. This finding provides a promising design for skyrmion-based racetrack memory, where the information is coded in the types of magnetic solitons [9], instead of in the appearance or absence of magnetic solitons. It also complements the traditional proposals of magnetic racetrack memory based on magnetic domain walls [10]. A perspective article by Zivieri discusses information storage and coding based on the information entropy of skyrmions.

Besides magnetic skyrmions, a few more magnetic structures are also studied. Chen et al. report an exotic Néel-type kink spin texture stabilized in the corners of square-shaped nanostructures and describe how these kinks can be created, annihilated, and reversed in polarity by spin-polarized currents. Chen et al. observe two types of domains in the kagome metal DyMn6Sn6, consisting of a type-I domain with a belt structure and a type-II domain with a complex stripe structure. As the temperature changes, the type-II domain may transform into the type-I domain and even disappear, and vice versa. This finding provides a fresh insight into the spin texture in kagome crystals and may further help to understand the relation between novel electronic states and magnetic states in these materials.

In conclusion, this research topic provides a timely update on the recent advances in skyrmion physics and its applications in spintronic devices. We hope that the collection of works will not only advance our understanding of the creation, dynamics, and manipulation of magnetic skyrmions, but will also inspire more interest from the community of science, engineering, and general audience to accelerate the development of skyrmionics.

Author contributions

HY provided the first draft of the editorial. XZ and CR reviewed, revised and finalized the article.

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