

量子物理学・ナノサイエンス第 114 回特別セミナー

Exploring Emergent Electromagnetic Properties through Advanced Electron Microscopy

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概 要

The (scanning) transmission electron microscopy (S(TEM)) is a useful tool for realizing nanometric topological spin textures, such as magnetic skyrmions. The skyrmion possesses a "topological invariant" known as the "winding number" [1]. Due to its topological characteristics, it can be driven by extremely low current densities (five orders of magnitude lower than that of domain walls) [2], making it highly anticipated for applications in next-generation energy-saving devices, high-capacity information storage media, and reservoir computing elements.

Skyrmions was predicted in condensed matter theory as a spatial structure (texture) formed by electron spin arrangements in strong electron systems [3]. Using Lorentz TEM, we experimentally demonstrated the chirality and topology of well-defined two-dimensional (2D) skyrmions [4]. Additionally, in-situ Lorentz TEM clarified ultra-low current-driven dynamics of skyrmions [5] and their antiparticles, known as antiskyrmions [6], and controlled topological transformations between skyrmion and antiskyrmion by magnetic fields.

In addition to the 2D topological spin textures observed in thin films by Lorentz TEM, the existence of particle-like topological spin textures was also predicted in three dimensions (3D). In samples with a certain thickness, (anti)skyrmions extend along the thickness direction of the sample, forming 3D (anti)skyrmion strings [7]. To visualize such 3D topological spin textures, we improved the high-resolution scalar/vector-field electron tomography technique, termed tomographic integrated differential-phase-contrast microscopy, which enables the mapping of (anti) skyrmion strings composed of spin hedgehogs and antihedgehogs, revealing hybrid topological spin textures, including surface vortices and spin (anti) hedgehogs deep within the bulk [8]. The spatially and time-resolved tomographic iDPC operates over a wide temperature range from 95 K to room temperature, enabling real-space observations of various 3D topological spin textures and their dynamics [9], providing valuable insights into the topological aspects of various 3D spin textures emerging in magnets [10].

References

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