Exploring Emergent Electromagnetic Properties through Multi-dimensional Electron Microscopy

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The emergent electromagnetic properties in strongly correlated electron systems arise from exotic electron spin and polar textures [1,2]. To realize spin and polar textures such as three-dimensional (3D) skyrmion strings [3], monopoles and antimonopoles [4], and even electron-dipolar vortex textures [2] in these materials, vector-field electron tomography (3D electron microscopy) [5] and 4D scanning transmission electron microscopy (4D-STEM) are essential [2]. Here, we demonstrate cryogenic scalar/vector-field electron tomography, enabling 3D mapping of spin textures at nanometer resolution and at temperatures well below room temperature [6]. This method allows direct visualization of 3D topological spin textures, including magnetic hopfions [7]. Furthermore, 4D-STEM combined with charge distribution analysis has been applied to twisted bilayer chalcogenides, revealing twist-angle-dependent in-plane polar structures in 2D systems. Together, these advances multi-dimensional electron microscopy as a powerful platform for directly probing real-space topology and elucidating the associated emergent electrical responses.

Acknowledgements The author acknowledges Yi-Ling Chiew, Nobuto Nakanishi, Fehmi Yashin, Dong Yu, Yukako Fujishiro, Naoya Kanazawa, Yoshihiro Iwasa, Naoto Nagaosa, and Yoshinori Tokura for collaborations on the present work. This work was supported in part by RIKEN TRIP program, by Grants-In-Aid for Scientific Research (Grant Nos. 23H05431, 23H04522, 23H01841, 24H00197, 24H02231 and 24K00583) from the JSPS, and by the JST-CREST program (Grant No. JPMJCR20T1).

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