

Abstract

Topology plays an important role in modern condensed matter physics. Among many topological states of matter, magnetic states with topological spin structures such as magnetic skyrmions and hedgehogs have attracted considerable attention. These topological spin structures often form periodic arrangements, which are called topological spin crystals. They manifest nontrivial quantum transport and optical phenomena through emergent electromagnetic fields associated with the noncollinear and noncoplanar spin textures. One of the challenging problems in this field is flexible generation, annihilation, and control of the spin textures with different topology, leading to their novel functionality. Although this problem has been discussed in several specific cases, the previous studies lack a generic viewpoint. In this thesis, we propose the “spin moiré” picture to facilitate the systematic discussion on the control of the topological spin textures. Moiré is an interference fringe generated by a superposition of waves, which can be modulated in many ways by changing fundamental parameters in the superposition. We theoretically explore the ways to control the spin moirés and their functionalities in analogy with the control of conventional moirés—spin moiré engineering.

We conduct a comprehensive study of spin moiré engineering for several different topological spin crystals spanning from one to three dimensions. In one dimension, we investigate the spin moiré engineering for a superposition of higher harmonic waves, the chiral soliton lattice (CSL). We study the emergent electric field at magnetic resonance and show that the higher frequency resonance modes are more clearly visible than the magnetic ones. We also find that the emergent electric field from the edges of the system becomes comparable to or larger than the bulk responses in realistic system sizes. In addition, we reveal that additional chiral solitons can be introduced into the system by selectively activating the edge mode with a circularly-polarized AC magnetic field. Furthermore, we clarify that the speed and direction of the drift motion of the CSL are controlled by the static and AC magnetic fields. Next, in two dimensions, we study the spin moiré engineering for the skyrmion lattices (SkLs). Through the phase shift between superposed waves and the uniform magnetization, we elucidate the topological phase diagram including the SkLs with the skyrmion number ranging from -2 to 2 . We also clarify that the phase shift and the topological transition can be caused by an

external magnetic field. In addition, we find that the incoherence in the crystallization process of the SkL shows up as dislocations, whose time evolution can be effectively described by the XY model. Finally, in three dimensions, we study the spin moiré engineering for the hedgehog lattices (HLs). By changing the twist angle of superposed waves, we find topological transitions with successive changes in the number of hedgehogs and antihedgehogs. In addition, we systematically clarify the effect of the phase shift in the HLs and find the total number of hedgehogs and antihedgehogs unprecedentedly ranges up to 48. Furthermore, we show that the HL can cause a drift motion by an electric current and the threshold current density reflects the real-space configurations of the hedgehogs and antihedgehogs. Notably, we also discover the perfect hedgehog Hall effect that is a transverse motion of the hedgehogs without showing the longitudinal motion to the current direction.

To summarize, in this thesis, proposing the spin moiré picture, we systematically study the control of the spin textures, their topological properties, and the emergent electromagnetic fields for various topological spin textures. The spin moiré provides a novel platform for intriguing physics distinct from the structural moiré in the layered materials with several advantages: wide dimensionality, vector (spinor) degree of freedom, flexible control through the external fields, nontrivial topological properties, and the emergent electromagnetic phenomena. Our findings based on the spin moiré picture not only establish the versatile tool to study the control of topological magnetism but also pave the way for further exploration of topological spin textures and the resultant emergent electromagnetic phenomena.