Abstract

Spintronics aims to exploit spin and charge degrees of freedom of electrons for next-generation information technologies. A central concept in this field is the spin current, the flow of spin angular momentum. Manipulating magnetization via spin current offers significant advantages over conventional magnetic-field approaches, such as lower power consumption, compatibility with device miniaturization, and potentially faster operation. To fully harness these advantages, developing efficient methods for spin current generation remains a central challenge in spintronics. In fact, such methods have been explored across a variety of systems both theoretically and experimentally, including ferromagnetic metals, magnetic insulators, and nonmagnetic heavy metals and semiconductors. Recently, unconventional magnetic systems with noncollinear or noncoplanar spin configurations have attracted increasing attention as potential platforms for spin current generation. In particular, topological spin textures, characterized by nontrivial topological numbers, are especially appealing due to their several intriguing features, including emergent electromagnetic fields originating from the Berry phase and spin dynamics, as well as rich phase transitions that are tunable by external stimuli. While spin current generation in these textures, especially skyrmions, has been actively studied, several key aspects remain unclear. Indeed, spin current generation by topological spin textures beyond skyrmions has been far less explored. Moreover, the influence of spin–orbit coupling, which often plays an important role in spin transport, has not been sufficiently investigated.

In this thesis, we investigate spin current generation via two-dimensional topological spin textures: a skyrmion crystal (SkX) with out-of-plane magnetization, a bimeron crystal (BmX) with in-plane magnetization, and a meron crystal (MX) with zero net magnetization. We show that these distinct spin textures generate spin currents with characteristic spin polarization directions. In the absence of spin–orbit coupling, the SkX and BmX generate spin currents polarized along their magnetization directions, whereas the MX yields no spin current. Upon introducing spin–orbit coupling, while the behavior of the SkX does not qualitatively change, the BmX generates nonzero spin currents in multiple polarization directions. Notably, the MX, despite its zero net magnetization, exhibits a pronounced spin current with out-of-plane spin polarization, driven by an enhanced spin Berry

curvature associated with characteristic band degeneracy. We further demonstrate that the electronic and spin transport properties of each texture are governed by their magnetic symmetries. Our results highlight the topological spin textures as efficient sources of spin current even without net magnetization, expanding the design for spintronics devices based on topological magnetic metals.