2DCC MIP at Penn State, DMR-1539916

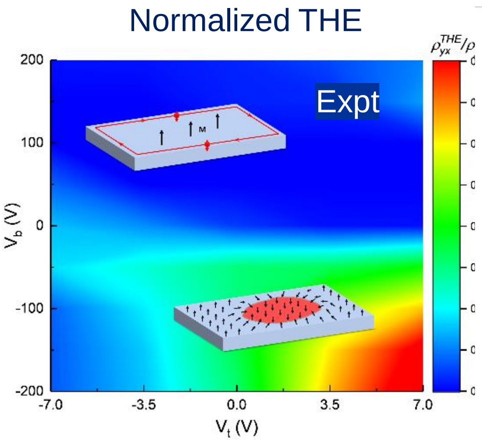
In-house Research- 2021

Mapping the phase diagram of the quantum anomalous Hall and topological Hall effects

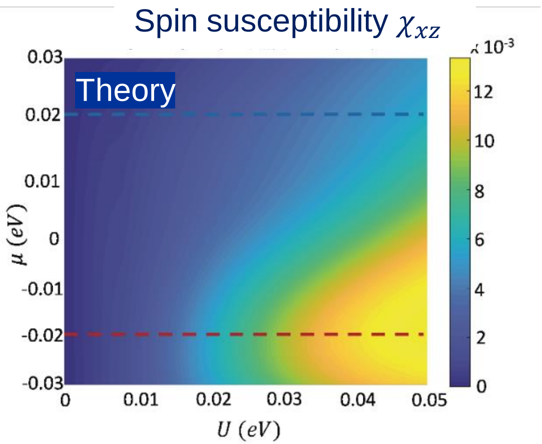
Run Xiao, Di Xiao, Jue Jiang, Jae-Ho Shin, Fei Wang, Yi-Fan Zhao, Ruo-Xi Zhang, Anthony Richardella, Ke Wang, Morteza Kayyalha, Moses H. W. Chan, Chao-Xing Liu, Cui-Zu Chang, Nitin Samarth (2DCC, Penn State)

Project Summary: The interplay between topology in momentum space and topology in real space creates a vibrant playground for studying emergent phenomena in condensed matter physics. Topology in momentum space manifests in nontrivial band structures and is directly revealed by the quantum anomalous Hall effect (QAHE) observed in magnetically-doped topological insulators (TIs). Topology in real space is often associated with chiral magnetic spin textures in certain magnetic materials and manifests as the topological Hall effect (THE). These effects are typically only seen in separate samples engineered to have distinct characteristics.

2DCC experimentalists used molecular beam epitaxy to grow magnetic TI heterostructures (Cr-doped $(Bi,Sb)_2Te_3$ multilayers) wherein the interplay between the QAH effect and the THE could be studied in a single sample geometry. The development of a robust protocol for fabricating dual-gated devices enabled the systematic variation of the chemical potential and the asymmetric potential in these devices. This yielded a phase diagram of the interplay between the QAHE and THE. **2DCC theorists developed an analytical model** for this phase diagram by evaluating the dual gate dependence of the Dzyaloshinskii-Moriya interaction (DMI) and carrier density. The excellent qualitative agreement between experiment and theory provides strong evidence for the existence of a THE in the system studied, opening a route for understanding and manipulating chiral magnetic spin textures in real space. *Editor's Suggestion* in *Physical Review Research (Letters) 3, L032004, 2021*.



Variation of the normalized THE measured as a function of the bottom gate voltage (y-axis) and top gate voltage (x-axis). The former determines the chemical potential while the latter determines the asymmetric potential.



Theoretical calculation of the off-diagonal component of spin susceptibility (χ_{xz}) as a function of the chemical potential (y-axis) and asymmetric potential (x-axis). The strength of the DMI and magnitude of the THE is proportional to χ_{xz}.