Microfluidic Access to Two-Dimensional Quantum States

Mohammad Mehmandoust and Michael Ruck
Technische Universität Dresden, Faculty of Chemistry & Food Chemistry, Chair of Inorganic Chemistry II, Dresden, Germany

Mohammad.mehmandoust@tu-dresden.de

Abstract

Topological insulators (TIs) exhibit symmetry-protected surface states that are robust against backscattering, enabling near-dissipationless transport. These properties make TIs promising for nanoelectronics, spintronics, and quantum information technologies.[1] Realizing their potential requires thin, two-dimensional (2D) architectures to access and control topological states— precisely the interface that our research addresses. Bi_2TeI is a layered dual topological insulator with weak surface states and higher-order hinge states, whose van der Waals layers enable ultrathin exfoliation.[2] However, controlled exfoliation preserving crystallinity, stoichiometry, and size remains challenging, as conventional methods introduce disorder or degradation that can suppress the intrinsic dual topological states of Bi_2TeI. To address this, we introduce a new microfluidic electrochemical exfoliation strategy combining confined shear forces with controlled hydrogen evolution. A custom-designed zigzag microchannel enables spatially defined ion transport and bubble-assisted interlayer separation under continuous flow. By systematically optimizing various parameters, we define processing windows that reduce thickness to the tens-of-nanometers range while preserving micrometer-scale lateral dimensions. Structural characterization confirms the preservation of crystallinity and phase integrity. This approach provides a scalable and controllable route to convert bulk dual topological insulators into device-compatible 2D nanosheets, in which we directly observe intrinsic quantum properties. High structural quality in these nanosheets bridges fundamental topological materials chemistry with practical quantum device architectures.

References

[1] C. L. Kane, E. J. Mele, Phys. Rev. Lett. 2005, 95, 146802.
[2] M. Lê Anh, P. Potapov, A. Lubk, T. Doert, M. Ruck, npj 2D Mater. Appl. 2021, 5, 22.

Figures

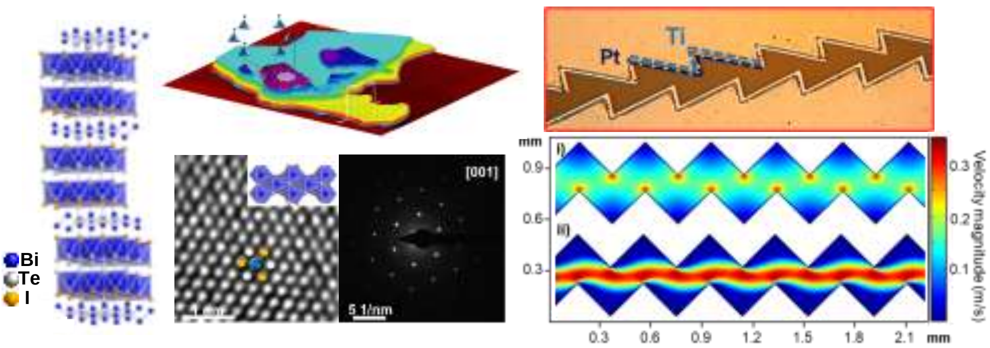

Figure 1: Left to right: Crystal structure of Bi_2TeI; AFM image showing a flake thickness of ~50 nm together with HRTEM and SAED indicating a [001] diffraction pattern, confirming preserved crystallinity and the layered structure after exfoliation; optical image of a zigzag Pt/Ti microfluidic channel; and simulation illustrating the impact of laminar flow and zigzag path design on localized forces over time.