

Electric-Field Control of Topology in Germanene

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Controlling topological quantum states with an external electric field is a central objective in the development of next-generation low-power electronics. Here, we demonstrate electric-field-driven topological phase transitions in germanene, the germanium analogue of graphene. In two-dimensional epitaxial films, germanene realizes a quantum spin Hall insulator with a sizable bulk bandgap and topologically protected edge states. A perpendicular electric field drives sequential transitions from the topological insulator phase to a Dirac semimetal and to a topologically trivial insulator [1]. Upon lateral confinement, we fabricate zigzag-terminated germanene nanoribbons and identify a critical width of approximately 2 nm below which the two-dimensional topological phase collapses due to edge-state hybridization, see Fig. 1. These ultra narrow nanoribbons are characterized by symmetry-protected end states [2]. In this limit, we achieve reversible all-electric switching of the zero-dimensional boundary modes, establishing atomic-scale control over topological states [3]. These results position germanene as a field-tunable platform for investigating dimensionality-driven topology and for realizing low-energy topological field-effect device concepts.

References:

[1] Bampoulis, P. et al. Phys. Rev. Lett. 130 (2023), 196401.

[2] Klaassen, D. J. et al. Nat. Commun. 16 (2025) 205.

[3] Eek, L. et al. Phys. Rev. Lett. 135 (2025) 206601.

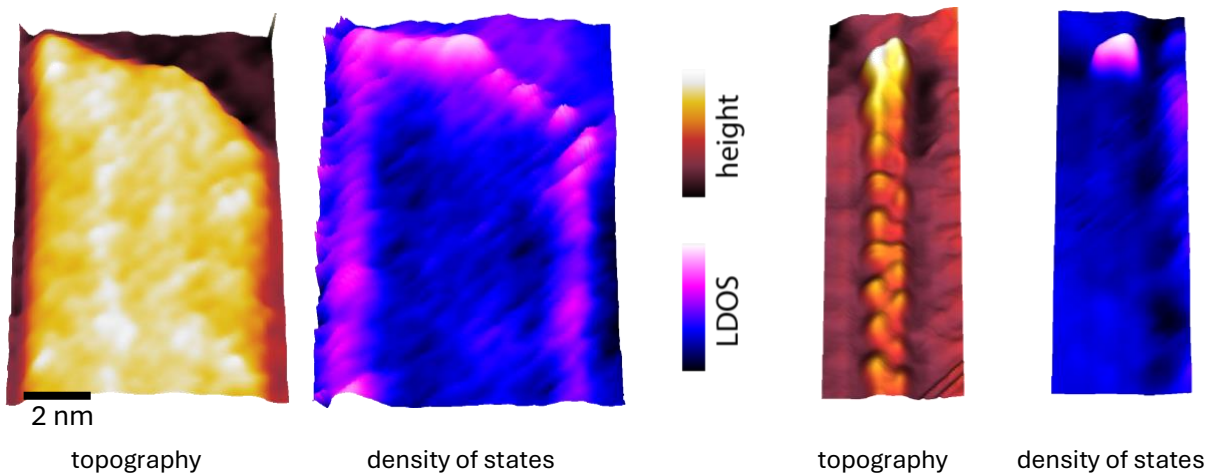


Fig. 1: Width-dependent evolution of electronic states in germanene nanoribbons. For wide nanoribbons (left), the low-energy states are localized along the ribbon edges. When the ribbon width is reduced to the very narrow limit (right), hybridization between opposite-edge states opens a gap, suppressing the extended edge modes and producing states localized at the ribbon ends.