

From Epitaxy to Emergent Properties in Topological Quantum Materials

Matthew Brahlek,¹⁺

¹Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831 USA

Interfacing topological materials with other functional materials offers promising platforms for realizing and manipulating novel quantum phenomena, yet their properties are often limited by defects [1], which are compounded by complex materials processing at epitaxial interfaces. Molecular beam epitaxy (MBE) gives the highest level of control over thin-film synthesis, including composition, thickness, substrate termination, strain, and interfacial structure. I will discuss how this high level of control can enable the integration of topological materials with magnetism and superconductivity. Examples include epitaxial MnBi₂Te₄ [2], where thickness and growth conditions reveal the relationship between intrinsic magnetism, defects, and anomalous Hall response, and Fe(Te,Se)/Bi-Te heterostructures [3-4], where engineered interfaces enhance superconductivity in low-dimensional films. I will also highlight how MBE can suppress structural defects in Bi₂Se₃ [5] and selectively stabilize distinct polymorphs of the novel magnetic material MnTe [6]. Together, these results demonstrate how MBE enables both deeper understanding and deliberate design of emergent properties in topological quantum materials.

⁺ Author for correspondence: brahlek@ornl.gov

[1] Brahlek, M. “Criteria for Realizing Room-Temperature Electrical Transport Applications of Topological Materials.” *Advanced Materials* **32**, 2005698 (2020) <https://doi.org/10.1002/adma.202005698>

[2] Mallick, D., et al. “Intrinsic Even-Odd Thickness-Driven Anomalous Hall Effect in Epitaxial MnBi₂Te₄ Thin Films.” *Physical Review Materials* **10**, 044203 (2026) <https://doi.org/10.1103/pqi7-prc1>

[3] Moore, R. G., et al. “Monolayer Superconductivity and Tunable Topological Electronic Structure at the Fe(Te,Se)/Bi₂Te₃ Interface.” *Advanced Materials* **35**, 2210940 (2023). <https://doi.org/10.1002/adma.202210940>

[4] Chen, A.-H., et al. “Interfacially Enhanced Superconductivity in Fe(Te,Se)/Bi₄Te₃ Heterostructures.” *Advanced Materials* **36**, 2401809 (2024). <https://doi.org/10.1002/adma.202401809>

[5] Mazza, A. R., et al. “Nucleation and Antiphase Twin Control in Bi₂Se₃ via Step-Terminated Al₂O₃ Substrates.” *Advanced Functional Materials* **36**, e13054 (2026) <https://doi.org/10.1002/adfm.202513054>

[6] Chen, A.-H., et al. “Programmable Phase Selection between Altermagnetic and Noncentrosymmetric Polymorphs of MnTe on InP via Molecular Beam Epitaxy.” *ACS Applied Materials & Interfaces* **18**, 15654–15664 (2026) <https://doi.org/10.1021/acsami.5c14582>