Signatures of Magnetic and Topological Hall Effects in $Mn_2BiSbTe_5$: An Anomalous Low-Temperature Transition

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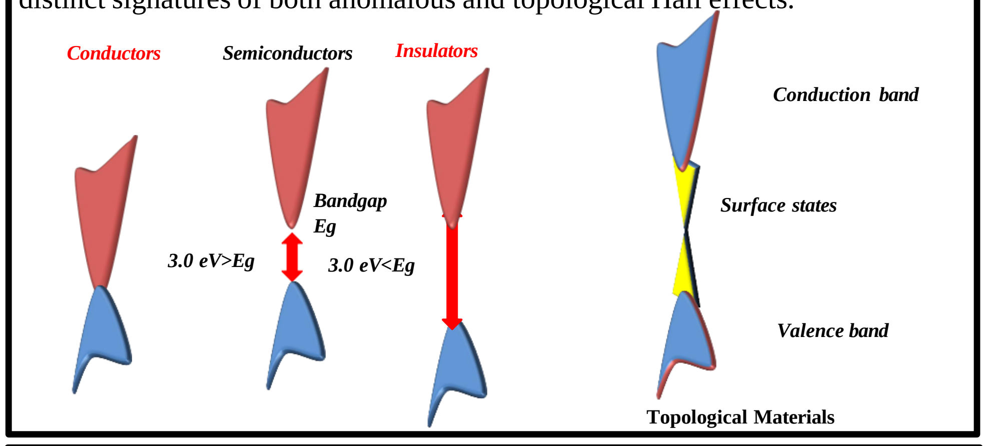
Abstract - We report a comprehensive investigation of $Mn_2BiSbTe_5$, a new member of the Mn-based tetradymite family of magnetic topological insulators (MTIs). High-quality single crystals were grown and characterized using structural, spectroscopic, and transport probes. Raman spectroscopy reveals vibrational modes consistent with the crystal symmetry, while XPS confirms the chemical composition and elemental valence states. Magnetization and magneto-transport measurements identify a magnetic transition below 20 K, with a sharp anomaly in the derivative of magnetization marking the onset of long-range order. A bifurcation between zero-field-cooled and field-cooled magnetization suggests cluster spin-glass behavior. Hall resistivity measurements further uncover a topological Hall effect, attributed to real-space spin chirality and nontrivial topological transport. The tunable interplay between magnetic ordering and topological response establishes $Mn_2BiSbTe_5$ as a promising platform for realizing axion insulator phases, anomalous quantum Hall states, and topology-driven spin transport, advancing the development of bulk MTIs for quantum electronics and spintronics.

Keywords – Magnetic Topological Insulators, Anomalous hall effect, Topological hall effect, Axion Insulator, Magnetoresistance

Introduction/Hypothesis

Magnetic topological insulators (MTIs) have emerged as a fascinating class of quantum materials where nontrivial band topology coexists with long-range magnetic order. Among them, Mn-based tetradymite compounds such as $MnBi_2Te_4$ have attracted considerable attention for hosting quantum anomalous Hall (QAH) and axion insulating states. In this context, $Mn_2BiSbTe_5$ represents a newly explored member of this family, featuring an intergrowth of magnetic and nonmagnetic layers that offers tunable magnetic and electronic properties. The partial substitution of Bi with Sb provides an additional degree of freedom to tailor the spin–orbit coupling and exchange interactions, potentially stabilizing novel topological phases. This study focuses on the synthesis, structural characterization, and magneto-transport behavior of $Mn_2BiSbTe_5$ single crystals, revealing intriguing low-temperature magnetic transitions and distinct signatures of both anomalous and topological Hall effects.



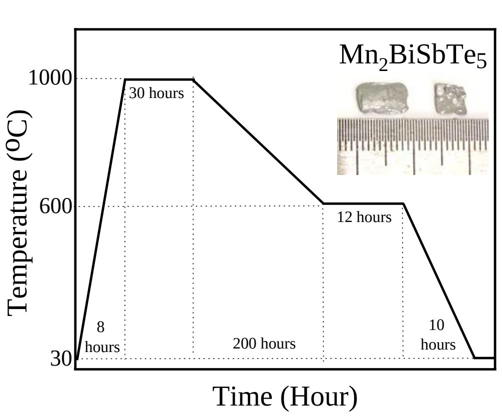
Objectives/ Innovation

- To synthesize high-quality single crystals of $Mn_2BiSbTe_5$ using the flux-growth method and confirm their structural integrity.
- To investigate the magnetic ordering and determine the nature of low-temperature magnetic transitions.
- To analyze magneto-transport properties, focusing on the emergence of anomalous and topological Hall effects.
- To compare the physical properties of $Mn_2BiSbTe_5$ with related Mn-based tetradymite compounds ($MnBi_2Te_4$, $Mn_2Sb_2Te_5$) for understanding structure–property correlations.
- To explore the potential of $Mn_2BiSbTe_5$ as a platform for realizing magnetic topological quantum phenomena.

Methodology

Single Crystal Growth:

- $Mn_2BiSbTe_5$ single crystals were grown using the flux method with a controlled stoichiometric ratio of high-purity Mn, Bi, Sb, and Te.
- The mixture was sealed in an evacuated quartz ampoule, heated to 950 °C, and slowly cooled to promote crystal formation as shown in Fig.1.



Structural Characterization:

- Powder X-ray diffraction (XRD) was performed to confirm phase purity and lattice parameters.
- Energy-dispersive X-ray spectroscopy (EDS) verified elemental composition and homogeneity.

Magnetic Measurements:

- Temperature- and field-dependent magnetization (M–T and M–H) were recorded using a SQUID magnetometer to study magnetic transitions.

Transport Measurements:

- Longitudinal and Hall resistivity (ρ_{xx}, ρ_{xy}) were measured using a Quantum Design PPMS under varying magnetic fields (up to ±9T).
- Data were analyzed to separate ordinary, anomalous, and topological Hall contributions.

Results

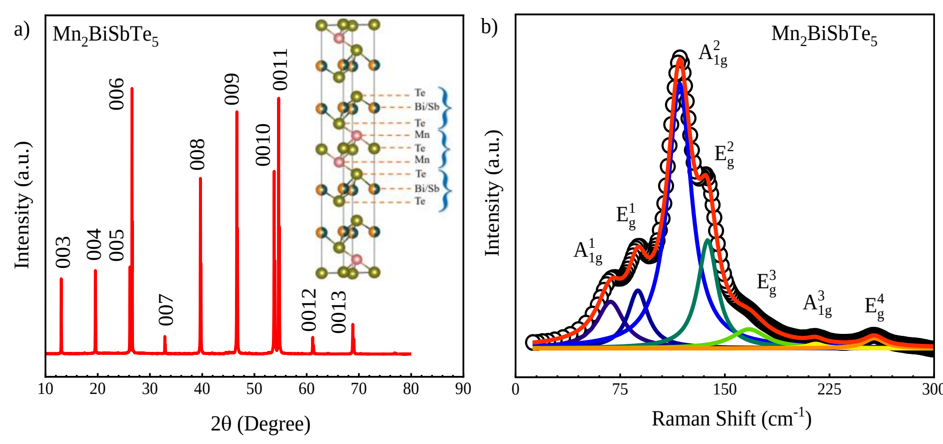


Fig. 2. (a) X-ray diffraction pattern of $Mn_2BiSbTe_5$ single crystals showing intense (00l) reflections and high crystallinity. The inset illustrates the crystallographic unit cell with a 9L stacking sequence along the c-axis. **(b)** Room-temperature Raman spectrum measured with a 514 nm excitation laser, displaying five characteristic vibrational modes.

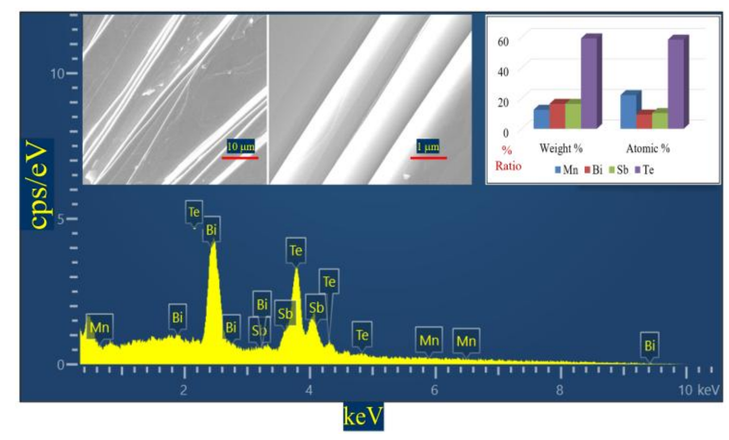


Figure 2. (c) Energy-dispersive X-ray spectroscopy (EDS) spectrum confirming the presence of Mn, Bi, Sb, and Te, with the inset showing elemental quantification. The top-right inset presents SEM images at two different magnifications, revealing layered growth consistent with van der Waals stacking.

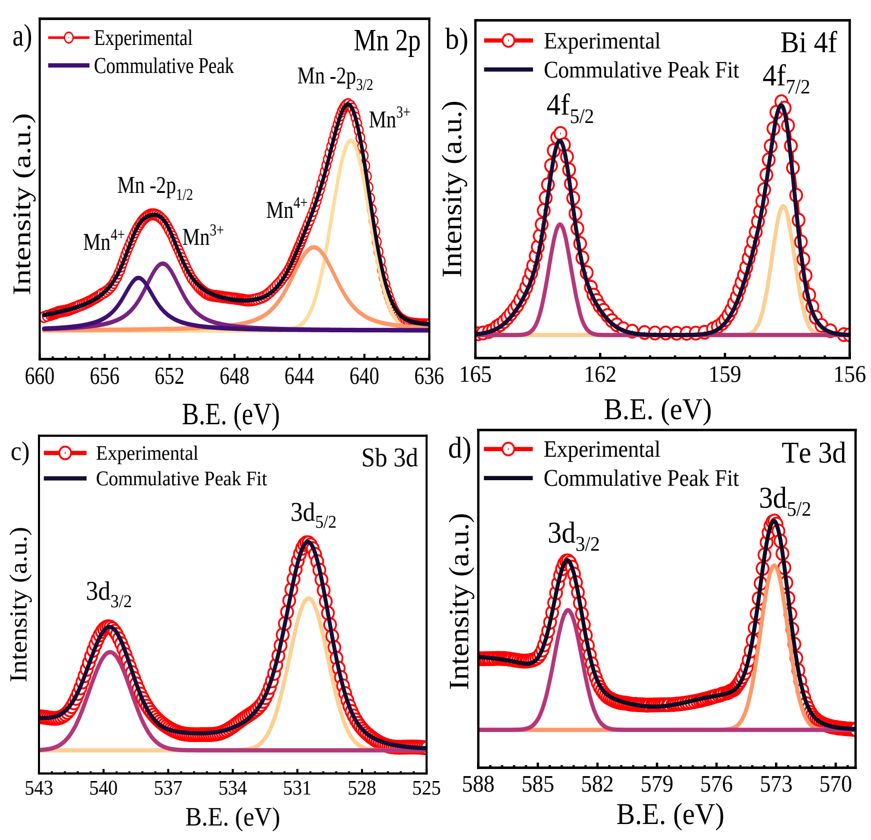


Fig. 3. High-resolution XPS spectra of $Mn_2BiSbTe_5$ showing the chemical states of:
(a) Mn 2p with spin–orbit-split peaks corresponding to Mn^{3+}/Mn^{4+},
(b) Bi 4f with fitted $4f_{7/2}$ and $4f_{5/2}$ peaks, **(c)** Sb 3d with characteristic $3d_{5/2}$ and $3d_{3/2}$ spin–orbit components, and **(d)** Te 3d with deconvoluted $3d_{5/2}$ and $3d_{3/2}$ peaks.

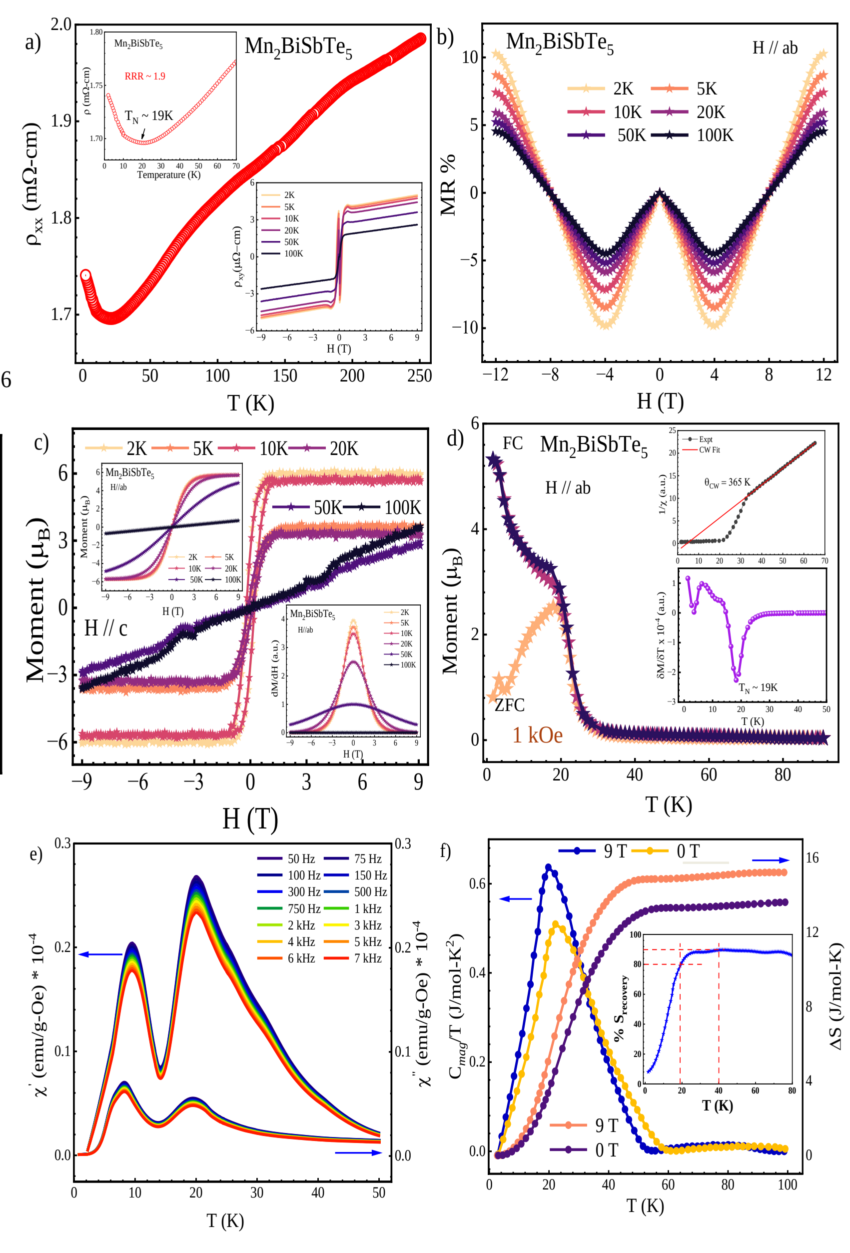


Fig. 4. (a) Temperature-dependent resistivity (ρ–T) showing a kink at ~19 K and residual resistivity ratio (RRR) ~1.9, Top-left inset: zoomed view near the anomaly. Bottom-right inset: total Hall resistivity (ρ_{xy}) between 2–100 K. **(b)** Field-dependent magnetoresistance (MR%), showing a crossover from negative to positive MR **(c)** Isothermal magnetization curves measured between 2–100 K for **H // c**. Clear hysteresis with finite coercivity is observed at 2–20 K, with rapid saturation near ~5.8 μ_B per Mn. The in-plane response (**H // ab**, top left inset) increases more gradually and does not saturate up to 9 T, evidencing strong uniaxial anisotropy. The differential susceptibility (bottom right inset) highlights the anisotropic field response and the suppression of long-range order above 50 K. **(d)** Temperature-dependent magnetization under zero-field-cooled (ZFC) and field-cooled (FC) Lower inset: ${}^{\delta M}/_{\delta T}$ confirming a sharp transition at T_N ~19 K. Upper inset: Curie–Weiss fit with θ_{CW} ~365 K. **(e)** AC susceptibility (χ′ and χ″) measured at multiple frequencies, revealing twin peaks associated with long-range magnetic order and dynamic spin phenomena. **(f)** Magnetic specific heat divided by temperature $\left({}^{C_{mag}}/_{T}\right)$ at 0 T and 9 T, showing a λ-type anomaly at T_N and field-induced modifications of magnetic ordering and entropy release. Inset: percentage recovery of magnetic entropy (ΔS).

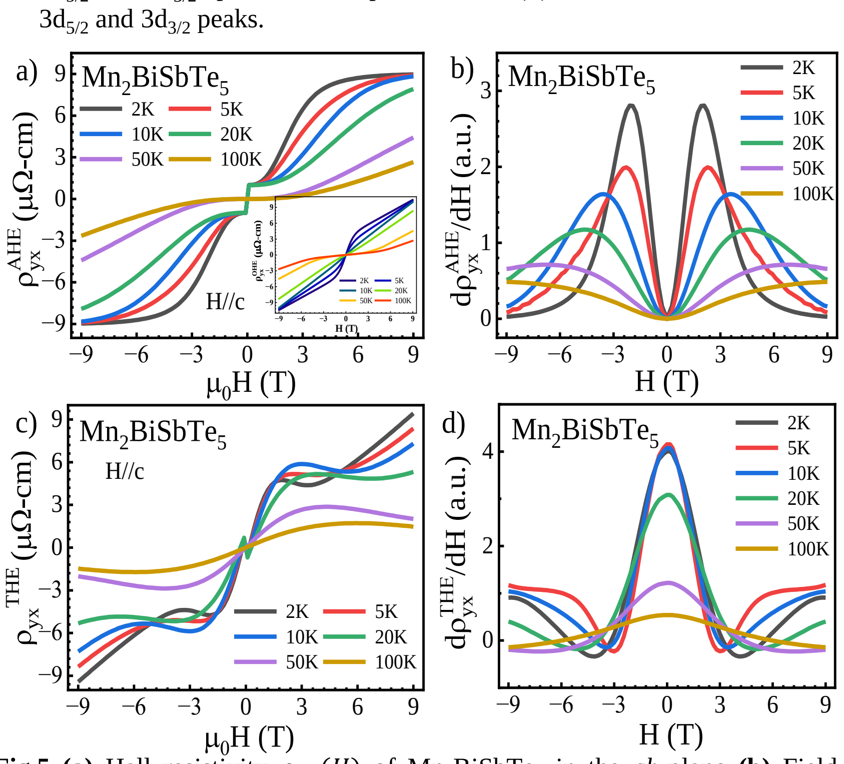


Fig.5 (a) Hall resistivity $\rho_{yx}(H)$ of $Mn_2BiSbTe_5$ in the *ab*-plane **(b)** Field derivative ${}^{d\rho_{yx}^{THE}(H)}/_{dH}$ of the Hall resistivity, having the sharp peaks at low temperatures, **(c)** Extracted topological Hall resistivity $\rho_{yx}^{THE}(H)$ obtained by subtracting ordinary and anomalous Hall components, and in the inset, the OHE. **(d)** First derivative ${}^{d\rho_{yx}^{THE}(H)}/_{dH}$ shows sharp low-field peaks at 2–10 K,

Conclusion

- $Mn_2BiSbTe_5$ single crystals exhibit high structural quality with well-defined magnetic ordering at low temperatures.
- $Mn_2BiSbTe_5$ exhibits dual nature of antiferromagnetism and ferromagnetism with T_N ~ 19K.
- Distinct anomalous and topological Hall signals confirm the coexistence of magnetism and nontrivial band topology.
- These results establish $Mn_2BiSbTe_5$ as a promising platform for exploring magnetic topological quantum phenomena.

References