Imaging the Breakdown and Restoration of Topological Protection in Magnetic Topological Insulator $MnBi_2Te_4$

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Quantum anomalous Hall (QAH) insulators transport charge without resistance along topologically protected chiral 1D edge states. Yet, in magnetic topological insulators to date, topological protection is far from robust, with zero-magnetic field QAH effect only realized at temperatures an order of magnitude below the Néel temperature T_N, though small magnetic fields can stabilize QAH effect. Understanding why topological protection breaks down is therefore essential to realizing QAH effect at higher temperatures. Here a scanning tunnelling microscope is used to directly map the size of exchange gap (Eg,ex) and its spatial fluctuation in the QAH insulator 5-layer $MnBi_2Te_4$. Long-range fluctuations of Eg,ex are observed, with values ranging between 0 (gapless) and 70 meV, appearing to be uncorrelated to individual surface point defects. The breakdown of topological protection is directly imaged, showing that the gapless edge state, the hallmark signature of a QAH insulator, hybridizes with extended gapless regions in the bulk. Finally, it is unambiguously demonstrated that the gapless regions originate from magnetic disorder, by demonstrating that a small magnetic field restores Eg,ex in these regions, explaining the recovery of topological protection in magnetic fields. The results indicate that overcoming magnetic disorder is the key to exploiting the unique properties of QAH insulators.