Intermixing-driven surface and bulk ferromagnetism in the quantum anomalous Hall candidate $MnBi_6Te_{10}$

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The recent realizations of the quantum anomalous Hall effect (QAHE) in $MnBi_2Te_4$ and $MnBi_4Te_7$ benchmark the $(MnBi_2Te_4)(Bi_2Te_3)_n$ family as a promising hotbed for further QAHE improvements. The family owes its potential to its ferromagnetically (FM) ordered $MnBi_2Te_4$ septuple layers (SL). However, the QAHE realization is complicated in $MnBi_2Te_4$ and $MnBi_4Te_7$ due to the substantial antiferromagnetic (AFM) coupling between the SL. An FM state, advantageous for the QAHE, can be stabilized by interlacing the SL with an increasing number n of Bi_2Te_3 layers. However, the mechanisms driving the FM state and the number of necessary QLs are not understood, and the surface magnetism remains obscure. Here, we demonstrate robust FM properties in $MnBi_6Te_{10}$ ($n = 2$) with $T_c \approx 12\,K$ and establish their origin in the Mn/Bi intermixing phenomenon by a combined experimental and theoretical study. Our measurements reveal a magnetically intact surface with a large magnetic moment, and with FM properties similar to the bulk. Our investigation thus consolidates the $MnBi_6Te_{10}$ system as perspective for the QAHE at elevated temperatures.

I. INTRODUCTION

Theory provides a seemingly straightforward avenue towards novel quantum effects such as the quantum anomalous Hall (QAH) effect [1–5] and axion electrodynamics [6–9], namely to induce a long-range ferromagnetic (FM) order in topological insulators (TI) [10, 11]. The vision of observing Majorana fermions and implementing topological qubits at superconductor/QAH insulator interfaces [12], ultra low-power electronics [13] and applications in spintronics [14] has ignited substantial experimental efforts in this direction. Yet, hitherto the QAH effect (QAHE) has only been demonstrated in the (sub-) kelvin range [3, 4, 15]. The experimental realization of the QAHE is complicated by several simultaneous requirements to a candidate system: The Dirac point (DP) of the parent TI should be well within its bulk band gap; the chemical potential has to be tuned to the DP; the introduced magnetic subsystem should lead to a substantial surface ferromagnetism to open a large exchange gap at the DP; and the material's bulk should remain insulating.

The first materials to exhibit the QAHE were extrinsically doped $(V/Cr)_x(Bi,Sb)_{2-x}Te_3$, which consist of van-der-Waals coupled quintuple layers (QL, see Fig. 1). However, band engineering by tuning the Bi/Sb ratio does not move the DP sufficiently above the valence band [16], V/Cr impurity bands overlap with the alleged exchange gap [17] and residual bulk conductance destroys

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