Electron interactions in flexible and disordered topological insulator systems based on Bi_2Te_3

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The rapid expansion of the Internet of Things and the anticipated slowdown of Moore's law have created demand for next-generation, wearable-compatible devices that surpass conventional semiconductor scaling. This in turn has intensified research in beyond-CMOS architectures, namely spin-based encoding. Topological insulators (TIs) offer promising platforms for such applications [1], combining strong spin–orbit coupling with a typically semiconducting bulk and spin-polarized topological surface states (TSS) with low dissipation transport. However, progress in the field is limited by a lack of studies on scalable fabrication and the effects of disorder in on TSS transport [2].

This work examines the structural and transport properties of Bi_2Te_3-based systems fabricated through scalable methods. First, we focus on polyimide-grown, sputtered thin films (13 - 191 nm) [3]. Raman spectroscopy, X-ray diffraction, and electron microscopy reveal granular films whose crystalline organization is substantially improved upon ex-situ annealing at temperatures above ~250 °C. The impact of the structural changes on the electronic transport response is studied via temperature-dependent resistivity measurements, which show the emergence of a meta-metallic regime (20 - 100 K), consistent with competing contributions from bulk and surface conduction channels. Isothermal (3 – 20 K) magnetoconductance measurements reveal the characteristic weak antilocalization (WAL) effect. Analysis via the Hikami–Larkin–Nagaoka model reveals a monotonic increase of the pre-factor α with thickness ($\sim 0.5 \rightarrow 1$) consistent with thickness-controlled coupling of the TSS. Concurrently, the decoherence exponent p of the phase coherence length ($L_\phi \propto T^{-p}$) decreases from ~ 0.7 to ~ 0.5 post-annealing, indicating a shift toward transport dominated by 2D channels. This study is extended to hybrid composites formed by chalcogenide nano-pellets embedded in a polymeric matrix. Preliminary results reveal signatures of 2D conduction and effective percolation of TSS across the polymer, including persistent WAL, which reveals a dephasing exponent $p \sim 0.6$, consistent with a mixed 2D–3D decoherence regime arising from simultaneous bulk and surface state conduction.

These results highlight the crucial role of structural engineering in enabling robust surface transport and demonstrate the potential of scalable, flexible TI-based platforms for beyond-CMOS applications.

References

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