

Thickness-Dependent Fermi Surface Evolution in Ultrathin $\text{Bi}_{0.85}\text{Sb}_{0.15}$ Films Probed by Shubnikov–de Haas Oscillations

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$\text{Bi}_{1-x}\text{Sb}_x$ was the first experimentally identified three-dimensional topological insulator, hosts spin-momentum-locked surface states protected by time-reversal symmetry [1,2]. Its high mobility and large spin Hall angle make it attractive for spin–orbit-torque devices [3]. In ultrathin films, surface-state hybridization opens a gap [4], quantum confinement forms subbands, and the interfacial asymmetry induces Rashba splitting [5]. As a result, the conducting channels and their Fermi surfaces are expected to depend strongly on thickness in the few-bilayer (BL) range.

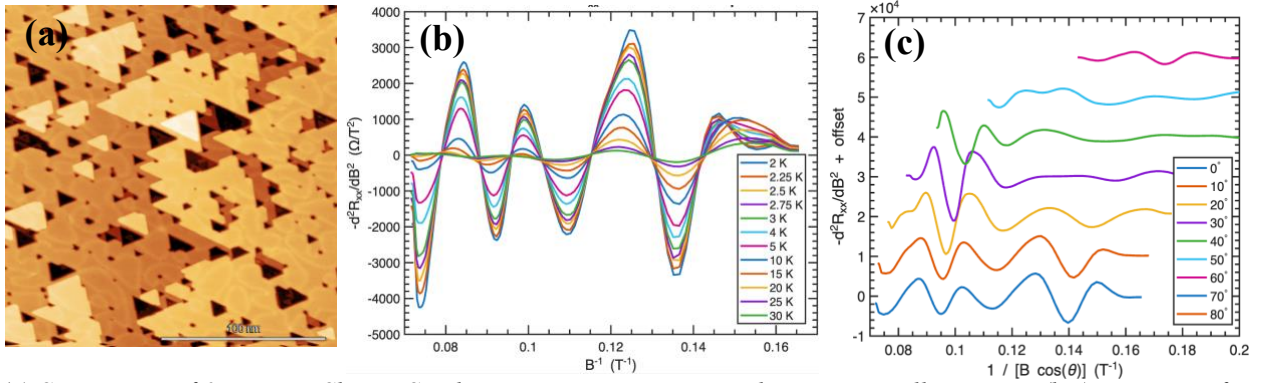


Fig. 1. (a) STM image of 3 BL $\text{Bi}_{0.85}\text{Sb}_{0.15}$ - Single orientation terraces can be seen as well as strain (b,c) Negative of second derivative of the resistance for the presented SdH -oscillations showing temperature dependence and angle dependence of Longitudinal Resistance.

This work uses Shubnikov–de Haas (SdH) oscillations to track the Fermi surface of $\text{Bi}_{0.85}\text{Sb}_{0.15}$ films from 2 BL to 10 BL grown on $\text{InSb}(111)\text{B}$. The native oxide on the $\text{InSb}(111)\text{B}$ substrate was removed by annealing with an impinging atomic H-flux at 300 °C in ultrahigh vacuum (UHV) giving a (3×3) surface reconstruction. The surface was subsequently exposed to an Sb_4 flux to mitigate In droplet formation, followed by annealing to obtain back the well-ordered (3×3) surface reconstruction. BiSb was grown on this surface by MBE with the substrate held at room temperature, and then post-growth it was annealed at 80–120 °C for 1h, forming a (1×1) surface reconstruction. Growth was monitored by RHEED, and surface morphology was characterized by STM [Fig. 1(a)]. Hall bars with a channel length of 20 μm and width of 5 μm were fabricated to minimize geometric effects and enable accurate magnetotransport measurements. SdH frequencies, effective masses, and tilt-angle dependence together assign each oscillation to a specific channel (hybridized surface state, confined subband, or interface state). At 2 BL, an increase in resistance to the $\text{M}\Omega$ range at 1.8 K, together with STM evidence of island formation, indicates incomplete film coalescence and substrate-dominated transport. The challenges of achieving continuous films in this ultrathin limit, and the growth optimizations addressing them, will be discussed. The 3 BL film lies between the hybridization-gapped 2 BL and effectively gapless 4 BL regimes [4]. In this film, R_{xx} shows multiple distinct SdH frequencies [Fig. 1(b,c)] with effective masses of $\approx 0.30, 0.35$, and $0.34 m_e$. The nearly equal masses of the latter two disfavor independent Dirac pockets and point to spin-split contours of a single band. The full thickness series will show how the Fermi surface pockets evolve from the hybridized to the topological regime, with implications for engineering transport channels in BiSb -based spintronic devices.

References

- [1] L. Fu and C. L. Kane, Phys. Rev. B **76**, 045302 (2007). [2] D. Hsieh et al., Nature **452**, 970 (2008). [3] N. H. D. Khang, Y. Ueda, and P. N. Hai, Nat. Mater. **17**, 808 (2018), [4] P. Corbae et al., arXiv:2409.11705 (2024), [5] Y. Zhang et al., Nat. Phys. **6**, 584 (2010).

Supplemental Information

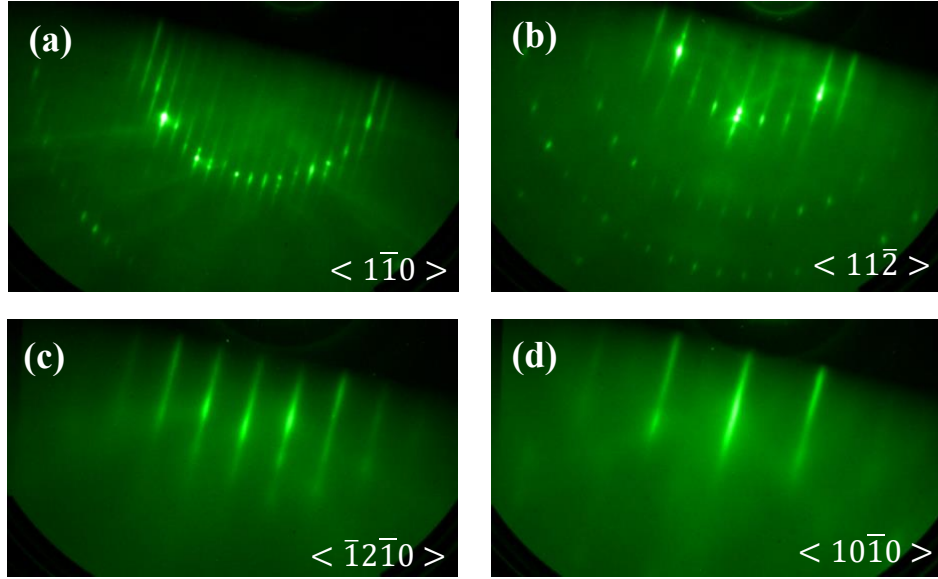


Fig. 2. RHEED patterns and epitaxial alignment of the (a,b) (3x3) InSb(111)B substrate and (c,d) the (1x1) BiSb(0001)_{hex}

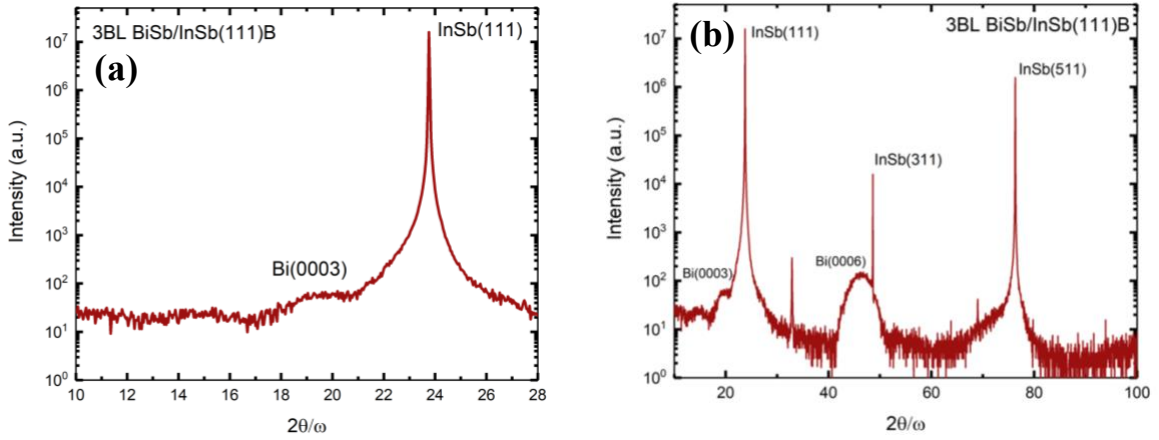


Fig. 3. XRD spectra for 3BL. The BiSb (0003) peak is parallel to the InSb(111) peak. The fringe spacing for each curve reflects the film thickness.

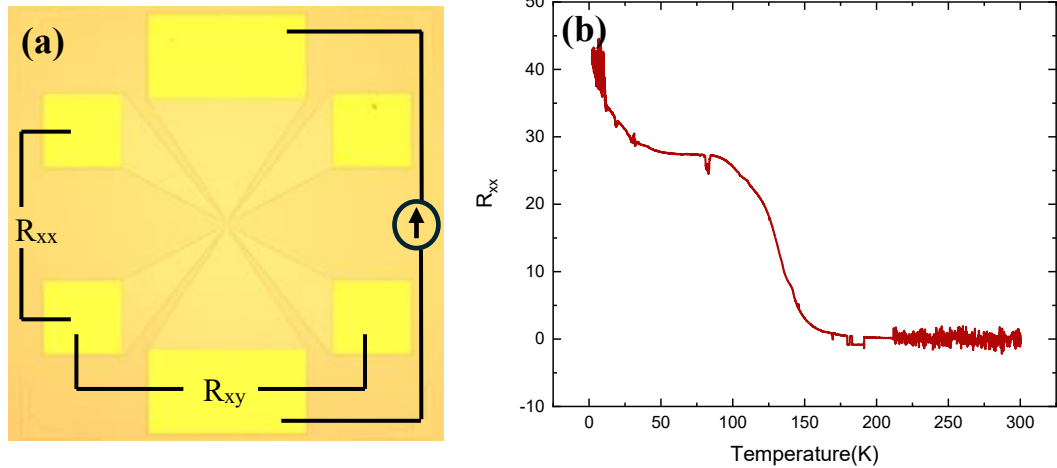


Fig. 4.(a) Hall bar fabricated on grown film for transport measurements. **(b)** Temperature vs. Longitudinal Resistance of the 3BL film showing carrier freeze out near 50K.