**Signatures of Helical Edge Transport in Millimetre-Scale Thin Films of Na3Bi**

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****A two-dimensional topological insulator (2DTI) has an insulating bulk and helical spin-polarised edge modes robust to backscattering by non-magnetic disorder. While ballistic transport has been demonstrated in 2DTIs over short distances, larger samples show significant backscattering and a nearly temperature-independent resistance whose origin is unclear. 2DTI edges have shown a spin polarisation, however the degree of helicity is difficult to quantify from spin measurements. Here, we study 2DTI few-layer Na3Bi on insulating Al2O3. Magnetic field suppresses spin-flip scattering in the helical edges, resulting in a giant negative magneto resistance (GNMR), up to 80% at 0.9 T. Comparison to theory indicates >98% of scattering is helical spin scattering significantly exceeding the maximum (67%) expected for a non-helical metal. GNMR, coupled with non-local measurements demonstrating edge conduction, thus provides an unambiguous experimental signature of helical edges that we expect to be generically useful in understanding 2DTIs.

Fig. 1. Resistance as a function of magnetic field at *T* = 5.3 K for bulk-conducting film (as grown, dotted line) and edge-conducting film (0.015 ML F4-TCNQ coverage, solid line). Fits to theory for exchange-mediated scattering for helical, dashed line, and non-helical, dot-dashed line, edges are also shown.

Fig.1 shows the longitudinal magneto resistance (MR) of 2 nm Na3Bi in a perpendicular magnetic field as a function of F4-TCNQ surface doping which turns the Fermi level of as grown films (dotted line) from the bulk conduction band, into bulk band gap (solid line), the edge conduction regime. The finite edge resistance in 2DTIs with weak temperature dependence has been explained as due to exchange-mediated scattering from local moments due to spatial fluctuations of the Fermi energy, above the Kondo temperature *T*K. Exchange-mediated scattering from magnetic impurities is a known source of negative MR in metals: Magnetic fields polarize local moments, making spin-flip scattering inelastic and unfavourable once the Zeeman energy exceeds the thermal energy. We modify the theory for local-moment scattering (Van Peski-Tinbergen and Dekker 1963; Béal-Monod and Weiner 1968) above *T*K, to restrict scattering to only processes involving spin-flip. Fig.1 shows a fit to the model with only free parameter, impurity gyromagnetic ratio *g* = 32.3. We also show the expected MR for a hypothetical non-helical metal, where the only scattering is via exchange interaction, but spin-preserving scattering is allowed; in this case the maximum MR is 2/3 (67%). Generic metals with other scattering processes would show lower MR.

**References**

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