Coherent Electron Scattering in Mesoscopic Bismuth Selenide Devices

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Topological insulators, where an insulating bulk is surrounded by conducting 2D surface states, have been a subject of much study due to the long coherence times promised by the Dirac-like surface states. In particular, topological insulators have shown many examples of coherent electron scattering such as weak anti-localisation (WAL) and universal conductance fluctuations (UCFs), both of which arise from quantum mechanical self-interference effects. Both of these scattering processes are sensitive to dephasing by electron-electron interactions and typically have coherence lengths on the order of hundreds of nanometers. Crucially, WAL is largely scale-independent and occurs at low magnetic fields, whereas UCFs can only occur if the dimensions of the system are of the order of the relevant coherence length, but affects the system over a much wider field range. Understanding how these two mechanisms of coherent transport within this class of materials evolves with changing device properties is key to designing devices that take advantage of the topologically protected surface states.

We have performed a detailed study into the magnetotransport of devices of the topological insulator Bi_2Se_3 grown by MBE and patterned by optical lithography. We find that devices show UCFs that reproduce themselves regardless of the rate or direction in which the magnetic field is swept, even up to voltage probe separations of 250 µm (shown in Fig. 1a, for the device with circumference of 510 µm), despite the coherence length from WAL being 170±10 nm. Additionally, the spectrum of the UCFs seems to vary with the circumference of the shortest loop between the voltage probes, rather than merely their separation. This implies that the UCFs (highlighted in Fig. 1b) arise from a state that is surface-dependent. We will present this and further data, including detailed comparison between samples of varying dimensions and at various temperatures, to show that the phase coherence lengths associated with WAL arise from a combination of bulk and surface states, whereas the UCFs arise largely from the topologically protected surface states.

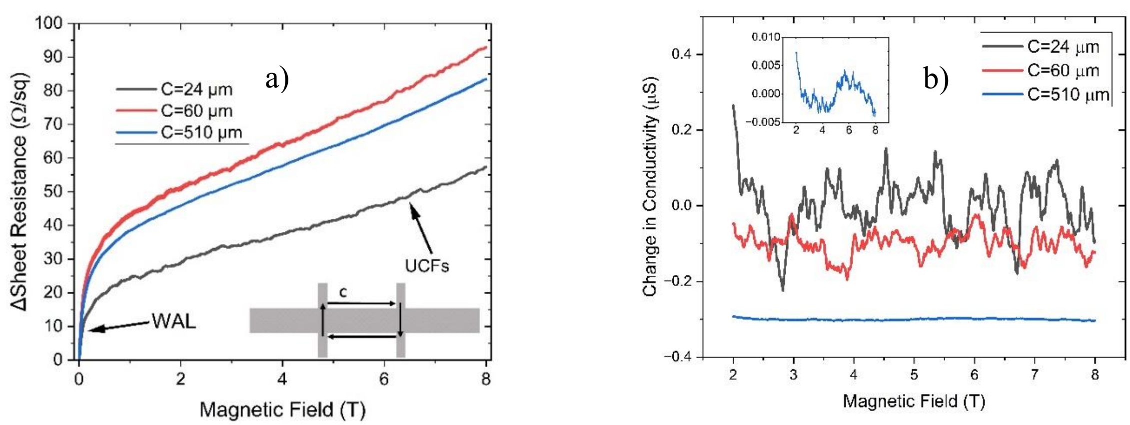

Fig. 1: Evidence of coherent scattering within Bi_2Se_3 devices. Fig. 1a) shows the magnetoresistance of 3 typical hall bars, with their circumference (C) listed, and shown schematically in the inset. The magnetoresistance contribution from UCFs and WAL is highlighted with arrows. Fig. 1b) shows the amplitude of the UCFs (extracted by subtracting a quadratic background from the traces in Fig. 1a). The curves are artificially offset for clarity. The inset shows a magnified view of the C=510 µm trace, showing the existence of UCFs, even at these comparatively large device dimensions.