Non-local Signatures of Edge States Arising from Substrate-Induced Spin-Orbit Coupling in Graphene-on-Chromia

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Edge states provide a path to dissipationless current flow in a conductor and can give rise to rich behavior in mesoscopic systems, in which the unintended disorder, and/or deliberately engineered features in the confining potential, can generate inter-edge state scattering. At low temperatures, the scattering is a coherent process, yielding a variety of phenomena that arise from quantum interference among the scattered modes. Among these include transmission resonances, conductance fluctuations, and the Aharonov-Bohm effect, all of which have long been studied in common metals and semiconductors. Two-dimensional (2D) materials are especially ripe for the manifestation of edge-state phenomena and novel signatures of edge-state transmission have recently been reported in graphene-based mesoscopic systems [1,2]. While for practical purposes, approaches that can generate edge states without the need for large external magnetic fields are highly desired, the weak spin-orbit coupling native to graphene is not conducive to this objective. Nonetheless, it is now understood that, by placing graphene on an appropriate substrate, its spin transport can be "engineered" through proximity coupling that both mediates a magnetic interaction and breaks the translational symmetry of pristine graphene [3]. Of importance here, we have previously shown evidence of robust spin transport in graphene on chromia, which could be attributed to the symmetry-breaking influence of that substrate [3].

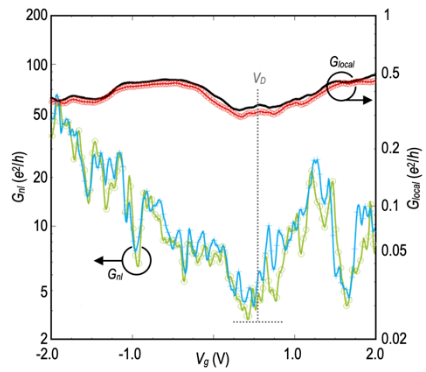

Fig.1. The left axis shows non-local conductance fluctuations as a function of gate voltage for a graphene-on-chromia transistor. The right axis shows corresponding measurements of the local conductance. Vertical axes have logarithmic scales and note the much larger amplitude of fluctuation in non-local (G_{nl}) vs. local (G_{local}) conductance. Temperature is 3 K.

In this work, we report on studies of non-local spin transport in graphene-on-chromia heterostructures that is consistent with conduction via proximity-induced edge states. Low-temperature (3 K) measurements performed in the spin-Hall geometry for this system reveal pronounced (gate-voltage induced) conductance fluctuations, whose amplitude is substantially larger than those exhibited in corresponding local measurements. The spectral content of these fluctuations is found to be invariant to the application of an (out-of-plane) magnetic field (as high as 7 T), pointing to the presence of edge-like modes that are not impacted by any tendency to undergo cyclotron motion within the bulk of the 2D material. To account for our observations, we formulate a Landauer-Büttiker model of quantum transport in graphene that treats the impact of (induced) SOC on the non-local conductance. The model reproduces the key features of experiment and shows that these arise from an interplay between topologically protected edge currents – analogous to the conductive modes of a 2D topological insulator – and bulk-like conduction, as the carrier density in the 2D channel is gated. The edge modes arise from induced SOC in the graphene, while the bulk contribution is strongly affected by the presence of substrate-induced charge puddling. The observation here of robust, gate-controlled, oscillations in the non-local conductance may possibly be leveraged in future implementations of spintronic devices, such as the spin-based field-effect transistor.

References

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