Tuning the Quantum Oscillations of Dirac Surface Electrons in a Topological Insulator by Ionic Liquid Gating

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Introduction

In as-grown crystals of the topological insulator (TI) Bi_2Te_2Se (BTS), the Fermi energy E_F typically lies high above the Dirac point. This hampers the investigation of novel properties of the states near the Dirac point. We have used ionic liquid (IL) gating to tune E_F. Both the period and amplitude of the surface Shubnikov de Haas (SdH) oscillations were observed to change systematically with the applied gating voltage V_g. Analysis of the SdH period shows that E_F can be shifted towards Dirac point by ~50%. The surface mobility is also enhanced by IL gating. This approach provides a promising way to improve the quality of the TI surface states.

Experimental

Measurements were performed at the NHMFL in the 45-Tesla Hybrid (Cell 15). The BTS sample and Au gate electrode are immersed in the ionic liquid DEME-TFSI inside a cell as shown in the inset of Fig. a. To set the gate voltage V_g, we warm the sample above the glass transition of DEME-TFSI (220 K).

Results and Discussion

The as-grown BTS crystals are *n*-type with resistivity values of 1-4 Ωcm at 4 K. As shown in **Figure (a)**, the sample resistance *R* at 4K is increased by ~40% with V_g = -2.8 V, consistent with the depletion of bulk carriers by a negative V_g. **Figure (b)** plots the SdH oscillations in curves of *R vs. B* (a smooth background has been subtracted). Initially, at V_g = 0, the oscillations are too weak to be resolved, even at *B* = 45 T. However, at V_g = -1.5 V the SdH oscillations become well-resolved. As V_g is changed from 0 to -6V, we observe an increase in the oscillation period, consistent with a decrease in the 2D Fermi Surface section. At V_g = -6V, E_F is reduced to only 88 meV above the Dirac point. The SdH amplitudes also increase with $|V_g|$, consistent with enhanced surface mobility. A fit to the standard Lifshitz expression gives a mobility of 3,000 cm^2/Vs at V_g = -6V. **Figure (c)** plots the fields at the resistivity maxima vs. the integers. At 45 T, we have entered the n=1 Landau Level of the Dirac surface states. The combination of high *B* and IL gating allows the Berry phase in BTS to be determined more accurately. The extrapolation to 1/*B*→0 gives an intercept at *n* = -1/2, confirming the π-Berry phase predicted for Dirac surface states.

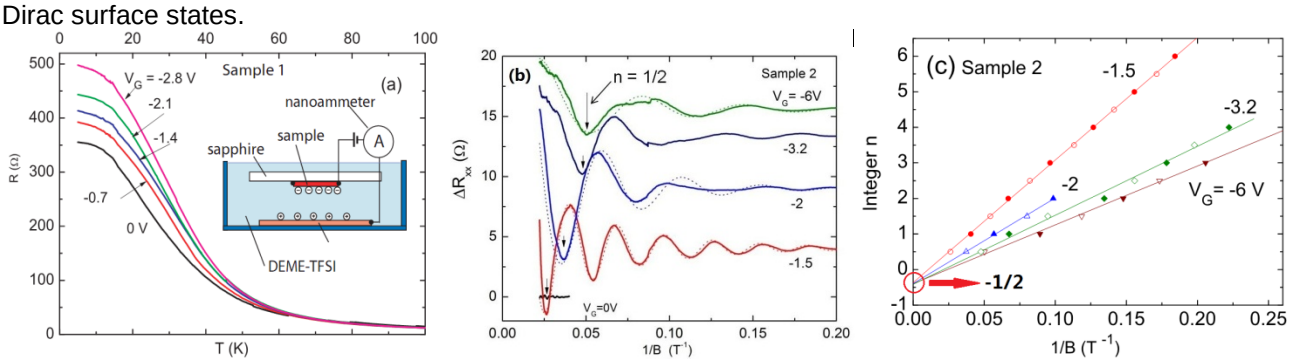

Figure (a): Plots of the resistance *R* vs. *T* in BTS for selected gate voltages V_g. The inset shows the cell used for IL gating.
Figure (b): The SdH oscillations in MR for values of Vg = 0 to -6 V. Both the period and amplitude increase with |Vg|.
Figure (c): The Landau index plot of the fields at the resistivity maxima vs. integers *n*. At all negative gating voltages, the intercepts in the limit 1/*B* →0 gives *n* = -½ consistent with the π-Berry phase for the Dirac spectrum [From Ref. 1].

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References

1. Jun Xiong, Yuehaw Khoo, Shuang Jia, R. J. Cava, N. P. Ong, "Tuning the quantum oscillations of surface Dirac electrons in the topological insulator Bi_2Te_2Se by liquid gating", arXiv: 1211.1906v2.