Spectroscopy and Microscopy in Condensed Matter Physics

Assignment 3 Due: 16/07/19

1. STM measurement of Mn-doped Bi2Te3

Download the files 'topo.mat' and 'didv.mat'. 'topo.mat' contains the $120 \times 120 nm^2$ topographic landscape over which the dI/dV spectra in 'didv.mat' were measured. The spectrum at every point is taken from 360meV to -65meV.

a. Topography - Plot the topographic landscape. The triangular dips are Mn ions substituting Bi one layer below the Te cleave plane. Estimate the doping level given that the every atomic layer is triangular with a lattice constant of 4.385Å.

b. dI/dV spectrum - Plot the spatially averaged density of states dI/dV(E). Identify in it the onset of the bulk conduction and valence bands and the bulk semiconducting gap which hosts the Dirac surface states. Note that the surface states may coexist in energy with the bulk bands (which promotes deviations from Dirac dispersion). Compare the STM spectrum to the momentum integrated spectrum obtained from ARPES and identify the energy shift of the chemical potential due to Mn doping.

c. QPI - Calculate dIdV(q,E)=FT{dIdV(r,E)} at E=210meV and 60meV. Note, that the boundaries of the Fourier-space field of view are set by $\pm\pi/a$ and its resolution by $2\pi/L$, where a and L are the real space resolution and field of view, respectively. Use the crystal symmetries to enhance the signal to noise. The QPI patterns capture all possible scattering processes within the hexagonally warped and the linear energy ranges of the dispersion.

d. JDOS – Plot the ARPES data, I(k,E), of the corresponding energies. One way to relate the QPI data to the dispersion is to calculate all scattering processes available in a quantity called the joint density of states JDOS(q,E)=∫dk I(k,E) I(k+q,E). Plot the JDOS from the ARPES data for the two energy values. Identify the peaks and patterns you find in the JDOS(q,E) with specific scattering process within the band structure I(k,e) by drawing arrows corresponding to the momentum transfer q from initial to final k-values.

e. Spin protection – Some of the peaks predicted by the JDOS naïve calculation are absent in the QPI data. Explain their absence by considering the spin texture of the hexagonally warped band structure predicted modeled in Liang Fu's paper.

2. **SQUID measurements of current distribution in HgTe/CdTe quantum wells**

Download the file 'squid.mat'. It contains the local SQUID measurements of the magnetic field profile induced by current flowing between two adjacent leads in a quantum spin Hall state formed in a HgTe/CdTe quantum well [*Nature Materials* **12** 787-791 (2013)].

a. Magnetization mapping – plot the magnetization data. Identify the source-drain current leads by comparing to the data in the manuscript. Plot the magnetization profile averaged along the translational invariant segment in the region between the current leads.

b. Self-induced field – The SQUID loop is sensitive only to the out-of-plane component of the field (B_z). Plot the z-component of a field induced above a current carrying wire, 2 wires and a filament of a finite width (You may either quote known results or use the Biot-Savart law to derive them).

c. Magnetization to current inversion – use a linear combination of the profiles in (2) to find the best fit to the magnetization profile from (1). What is the distribution of current between left, right edges and bulk regions? Discuss the deviation from a flow in an ideal quantum spin Hall bar.