Spectroscopy and Microscopy in Condensed Matter Physics

Problem set 2

1. ARPES measurement of the topological insulator Bi_2Te_3

The zip file contain ARPES data, where each mat file corresponds to measurement at different photon energy (23 eV and 48 eV). The x, y and z vectors correspond to k_x (Å^{-1}), k_y (Å^{-1}) and E (eV), respectively. Please briefly discuss all your answers.

Our first Goal would be to make ourselves familiar with the band structure and identify the bulk/surface bands and the high symmetry axes.

a. Plot constant energy cross-sections viewing the band structure evolution, in intervals of ~20 meV, for both photon energies. Describe the feature you see in words, and pay attention to the differences. Separate the bulk conduction band and surface band, by their photon energy dependence. What is the bulk gap of the material?
b. Given that the crystal has a C_3 (rotation) symmetry and M (reflection) symmetry about Γ-M high symmetry axis, associate the measurement axes with the Γ-M and Γ-K.

We will now take a closer look into the surface band Dirac-like dispersion. The coexistence of the bulk conduction band and Dirac-surface band introduces band-repulsion effect. However, this effect must respect the crystal C_3 symmetry, which gives rise to the satr-like structure you saw in a, which is known as hexagonal warping.

c. Plot the corresponding false-color plots and momentum distribution curves (MDC) along the high symmetry axes. Identify the Dirac point and interpolate the band dispersion in both directions.
d. The hexagonal warping of the Dirac cone at higher energies is discussed in a paper by L. Fu (PRL 103, 266801 (2009)). Use the results presented in this paper to carefully fit the dispersions you interpolated in c (note, how θ is defined with respect to the high symmetry axes). Write the fitting parameters in terms of meaningful physical units.

The hexagonal warping calls for a more careful analysis of SdH oscillations. We will use the data from the last problem set and the fact the Bi_2Te_3 and Bi_2Se_3 have a very similar band structure to look at that.

e. In problem set 1 you calculated the energy difference between the Fermi level E_F and the Dirac point E_D from the period of the SdH oscillations. Using your fit from d, calculate the extremal surface as a function of energy, taking into account the effect of the hexagonal warping, and repeat this exercise. What is $E_F - E_D$ you find? Compare it to the ARPES data?
f. Inspect the Fermi edge of both bulk and surface bands and fit to Fermi-Dirac distribution. Given that the measurement was done at 15 K, is it temperature limited or instrument limited?