Final Report for DOE grant DE-FG02-85ER45222

We have completed studies of Bi_2Se_3 and Bi_2Te_3 (001) surfaces:

- The measured surface phonon dispersions are shown in the figure above,they reveal:

  1. The absence of surface acoustic Rayleigh modes in the measured surface phonon dispersions. The reason lies in the nature of He scattering. As was mentioned above, He atoms at thermal energies scatter directly from phonon-induced surface charge density oscillations and not the ions, so that absence of events related to surface acoustic phonons indicates a strong suppression of their interactions with DFQs!

     This observation was recently supported by surface transport measurements on Bi_2Se_3 thin films, which revealed a thermally-activated behavior which precludes DFQ coupling to surface acoustic phonons. The activated behavior was attributed to a strong coupling of DFQs to an optic phonon mode of $\omega \sim 8$ meV, which, again, is in agreement with the location of the low-lying optic mode we reported. Moreover, recent theoretical studies considered the interaction of DFQs with long-wavelength surface acoustic modes. In all three the strength of the epc was found to be quite small, which is consistent with the absence of acoustic Rayleigh phonons in HASS data.

  2. The presence of a strong Kohn anomaly in the low-lying surface optical phonon mode in both systems, signaling a strong coupling of DFQs to this mode.

- The electron-phonon coupling parameter λ associated with this low-lying optical mode was calculated, for the first time, from the measured phonon dispersions, and was found to be unusually large:

- $\lambda = 0.7$ and $\lambda = 2.0$ for Bi_2Se_3 and Bi_2Te_3, respectively. This result was supported by recent ultra-high resolution (1 meV) ARPES measurements which reported $\lambda \sim 3$ at about 10 K.

Publications

1. Xuetao Zhu, L. Santos, R. Sankar, S. Chikara , C. Howard, F. C. Chou, C. Chamon and M. El-Batanouny, *Interaction of Phonons and Dirac Fermions on the Surface of Bi2Se3: A Strong Kohn Anomaly*, arXiv:1108.2470, (2011).

2. Xuetao Zhu, L. Santos, R. Sankar, S. Chikara , C. Howard, F. C. Chou, C. Chamon and M. El-Batanouny, *Interaction of Phonons and Dirac Fermions on the Surface of Bi2Se3: A Strong Kohn Anomaly*, and associated Online Supplementary Material, Phys. Rev. Lett. **107**, 186102 (2011).

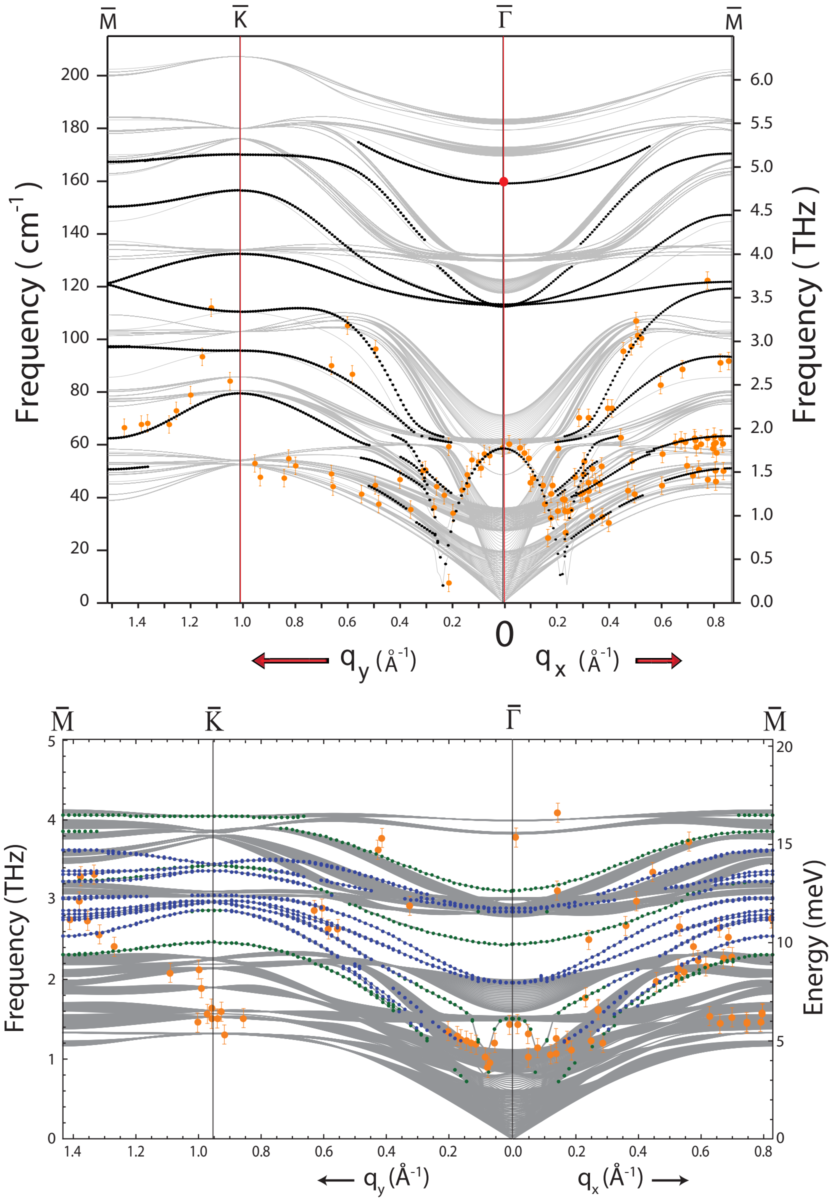

Figure 1: (001) surface phonon dispersion curves, Top: Bi_2Se_3, Bottom: Bi_2Te_3, taken from showing a parabolic dispersive branch up to $q = 2k_F$. Experimental data are shown as orange dots with error bars, and calculated surface dispersions curves, using the pseudo-charge model are shown as blue/green dots. The gray background represents the projection of bulk phonon bands on the SBZ.

3. Xuetao Zhu, L. Santos, C. Howard, R. Sankar, F. C. Chou, C. Chamon and M. El-Batanouny, *Electron-phonon Coupling on the Surface of the Topological Insulator Bi2Se3: Determined from Surface Phonon Dispersion Measurements*, arXiv:1201.6346, (2012).

4. Xuetao Zhu, L. Santos, C. Howard, R. Sankar, F. C. Chou, C. Chamon and M. El-

Batanouny, *Electron-phonon Coupling on the Surface of the Topological Insulator Bi2Se3: Determined from Surface Phonon Dispersion Measurements*, Phys. Rev. Lett. **108**, 185501 (2012).

5. E. M. McIntosh, P. R. Kole, M. El-Batanouny, D. M. Chisnall, J. Ellis, and W. Allison, *Measurement of the phason dispersion of misfit dislocations on the Au(111) surface*, Phys. Rev. Lett. **110**, 086103 (2013).

6. Colin Howard, M. El-Batanouny, R. Sankar, and F. C. Chou, *Anomalous behavior in the phonon dispersion of the (001) surface of Bi2Te3 determined from helium atom-surface scattering measurements*, Phys. Rev. **B 88**, 035402 (2013)