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Application Note
Topological Insulators

“Not since the isolation of graphene has a new material generated as much excitement among physicists as the discovery of topological insulators.” Highlights in Nature vol 6 2010.
A topological insulator is as an insulator that has a metallic boundary when placed next to a vacuum or an ordinary insulator (See for example J. E. Moore, Nature 464(2010)08916.)
These exotic materials can possibly be used in technological applications such as spintronics and quantum computing.

The band structure of the surface that makes up the boundary between the crystal and vacuum can be probed using the surface sensitive technique of angular resolved photoemission spectroscopy (ARPES). Scienta Omicron hemispherical analysers measures the kinetic energy (E_{kin}) and take-off angle (q) (in the direction of the slit width) of photoelectrons. The spectrum can then be transformed into k-space revealing the band structure of the material.

Topological insulators are one of the hottest topics in condensed-matter physics today and ARPES is a key technique in the investigations. In fact, when discovering the first topological insulator, Bi_xSb_{1-x}, Scienta Omicron ARPES analysers were used to probe the surface bands of the material (Hsieh et al. Nature 452(2009)06843).

Since the discovery of $Bi_{1-x}Sb_x$ several more topological insulators have been studied with ARPES. For a review see for example M. Z. Hasan and C. L. Kane arXiv:1002.3895v1 [cond-mat.mes-hall].
Here we present results from Hsieh et al. using Scienta Omicron hemispherical analysers and the ARTOF analyser.

Sb(111): It has been theoretically speculated that the novel topological order in $Bi_{1-x}Sb_x$ materials originates from the parities of the electrons in pure Sb. Measurements on pure metallic Sb show a single-surface band forming a Fermi surface enclosing G.
This suggests that pure Sb carries a p geometrical (Berry’s) phase and chirality. Figure 1 and 2 show ARPES of Sb(111).

For more information see Hsieh et al. Science 323(2009)919.

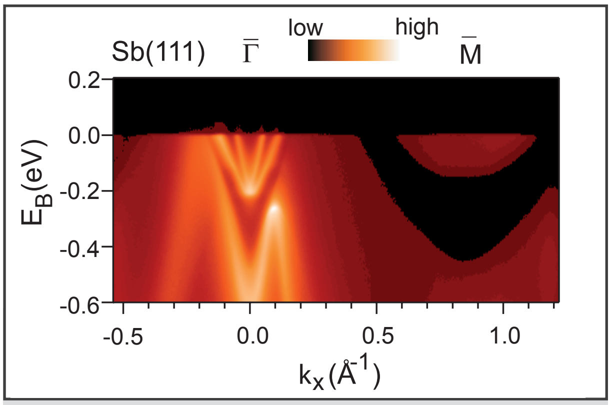

Figure 1: ARPES spectrum of Sb(111) along the G –M direction.

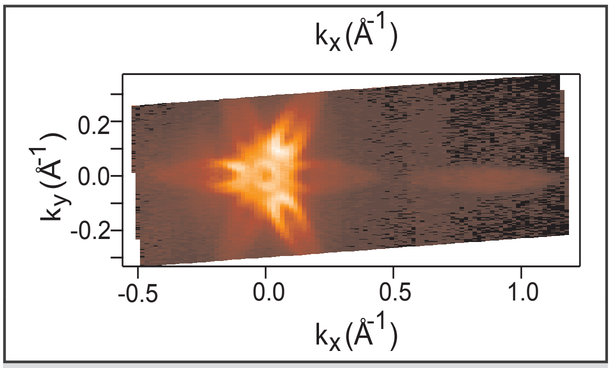

Figure 2: Fermi surface ARPES intensity map of Sb(111) at Fermi level in the kx–ky plane.

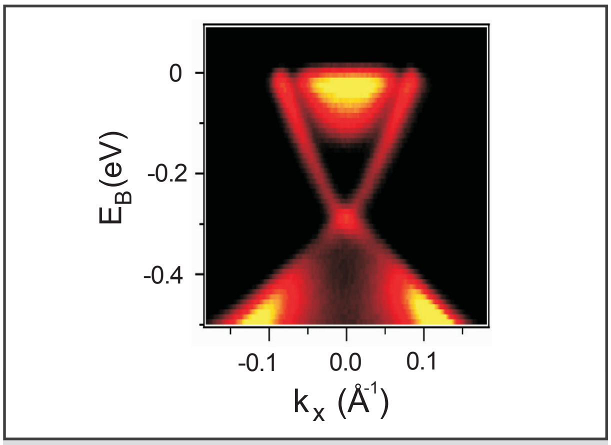

Figure 3: ARPES spectrum of surface Dirac point in the ground state of Bi_2Se_3 at a position of 0.3 eV below the Fermi level.

Fermi level tuning with NO_2 in Bi_2Se_3: Figure 3 shows the surface Dirac point in the ground state of Bi_2Se_3 at a position of 0.3 eV below the Fermi level. This is not a desired position of the Dirac point if the material should be in the topological quantum transport regime. By dosing with NO_2 molecules it is possible to move the Dirac point to the Fermi level.

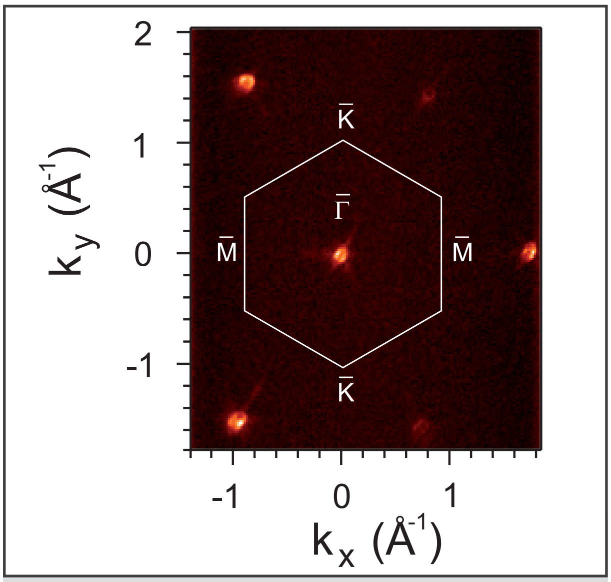

Figure 4: Fermi surface ARPES intensity map of NO_2 doped $Bi_2(Se/Te)_3$ spanning several Brillouin zones.

Figure 4 shows a Fermi surface map where the material has been tuned so that the density of helical Dirac electrons is moved to the spin degenerate Kramers point and topological transport regime. For details see Hsieh et al, Nature 460(2009)08234.

Probing topological insulators with ARTOF: In figure 2 and 4 the Fermi surface in the k parallel plane are displayed. These figures are accomplished by adding several individual spectra (such as shown in figure 1 and 3) probed in different reciprocal space directions together. Using the ARTOF a full ±15° cone of k parallel reciprocal space can be recorded in one sweep, as shown for Bi_2Se_3 in figure 5. Note that the displayed data is one point of many in a pump-probe experiment for exploring ultra fast dynamics.

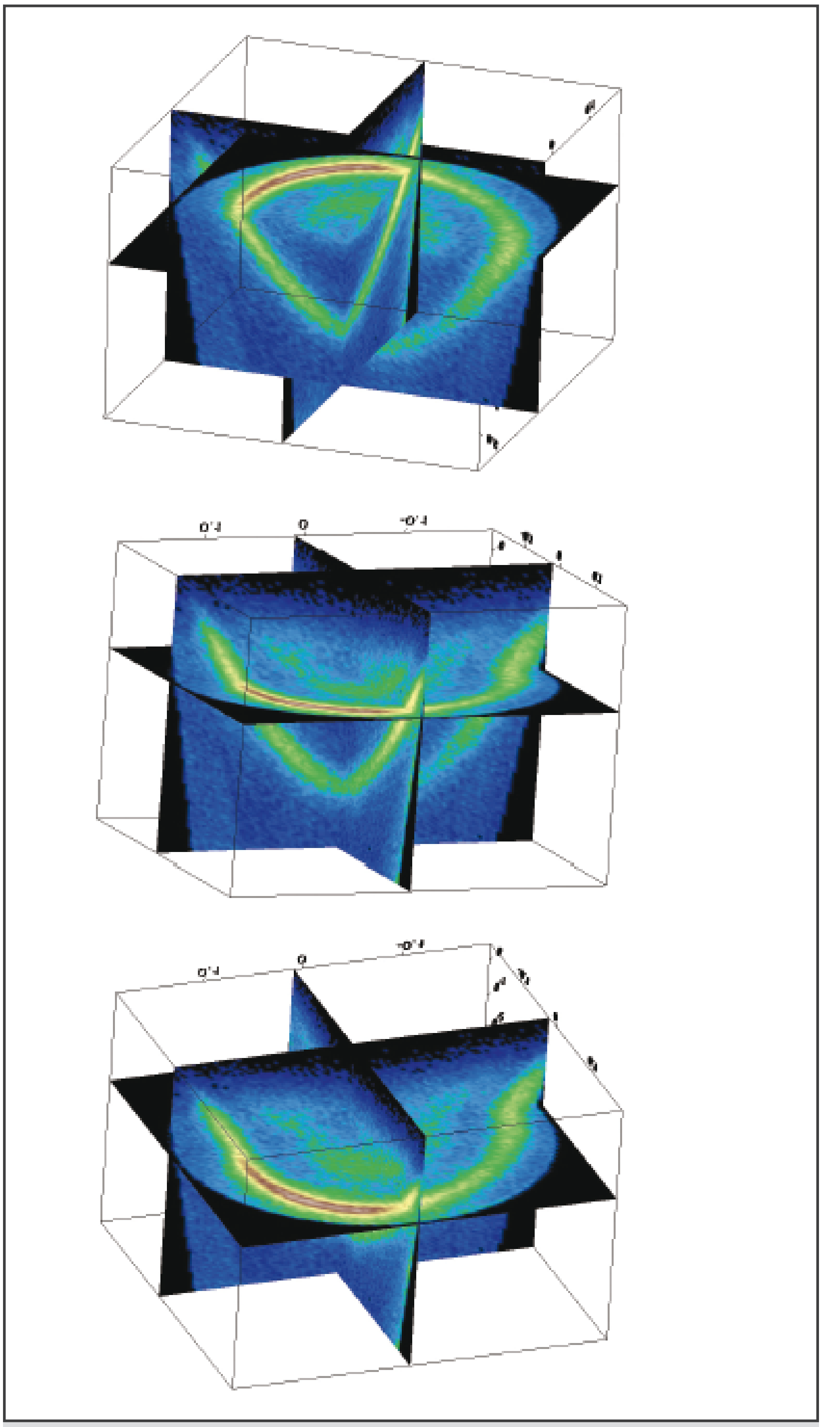

Figure 5: ARTOF ARPES spectra of Bi_2Se_3.

Data courtesy: In manuscript, Gedik Group, MIT, USA (http://web.mit.edu/gediklab).
This application note was made in collaboration with David Hsieh (dhsieh@mit.edu) and the Gedik Group, MIT, USA (ARTOF data).

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