Demonstrating a weak topological insulator in bismuth iodide

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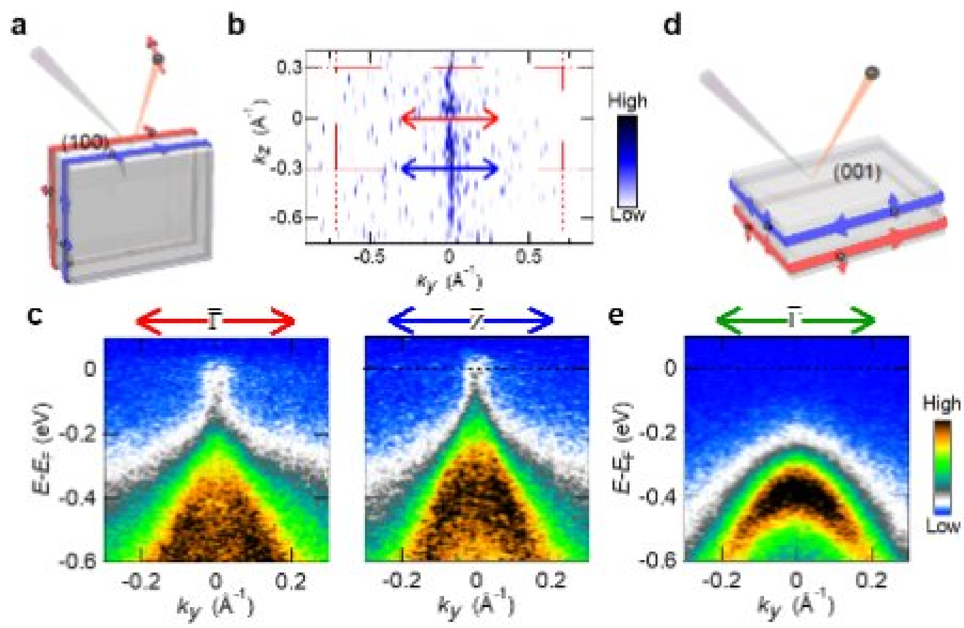

Figure 1. a) Schematic geometry for nARPES at the topological side surface (the (100) plane) of β-Bi4I4. b) ARPES intensity plot at the Fermi energy for the (100) plane. c) ARPES band maps around the Γ‾ point and the Z‾ point of the (100) plane. d) Schematic geometry for nARPES at the topologically dark surface (the (001) plane). e) ARPES band map around the Γ‾ point of the (001) plane. Credit: Diamond Light Source

Topological insulators are one of the most exciting discoveries of the 21st century. They can be simply described as materials that conduct electricity on their surface or edge, but are insulating in their interior bulk. Their conductive properties are based on spin, a quantum mechanical property, and this suppresses the normal scattering of electrons off impurities in the material, or other electrons, and the amount of energy that is consequently lost to heat. In contrast to superconductors, topological insulators can work at room temperature, offering the potential for our current electronics to be replaced with quantum computers and 'spintronic' devices that would be smaller, faster, more powerful and more energy efficient. Topological insulators are classified as 'strong' or 'weak', and experimental confirmations of the strong topological insulator (STI) rapidly followed theoretical predictions. However, the weak topological insulator (WTI) was harder to verify experimentally, as the topological state emerges on particular side surfaces, which are typically undetectable in real 3-D crystals. In research recently published in *Nature*, a team of researchers from Japan used synchrotron techniques to provide experimental evidence for the WTI state in a bismuth iodide crystal.

The quasi-one-dimensional (1-D) bismuth iodide crystals α-Bi4I4 and β-Bi4I4 have very similar structures, differing only in their stacking sequences along the c-axis. This small difference in structure leads to a substantial difference in the resistivity of the two phases, in both absolute magnitude and temperature dependence. At room temperature first-order transitions occur between the two crystal phases, with the more resistive α-phase forming preferentially when the sample is slowly cooled.

The research team used laser-based angle-resolved photoemission spectroscopy (ARPES) measurements with high energy and momentum resolutions to determine the electronic structures of α-Bi4I4 and β-Bi4I4. They observed a superposition of the ARPES signals from the (001) and (100) planes in these experiments, because the laser spot was much larger than each terrace and facet exposed on a cleaved surface. In β -Bi4I4, they observed a Dirac-cone-like energy dispersion near the

Fermi energy, EF—anomalous state that was not detected in the trivial α-Bi4I4, and which should be due to a topological surface. A similar quasi-1D state was confirmed through ARPES at a higher photon energy. The only possible explanation for the observed quasi-1D Dirac state is that it derives from the topological side surface (100) of a WTI.

To examine the WTI surface exclusively, they turned to a surface-selective ARPES technique—nano-ARPES. Nano-ARPES (nARPES) is an exciting development in synchrotron techniques, which combines the high spatial resolution of a microscope with the energy- and momentum-resolution of the ARPES technique. The nARPES branch of beamline I05 features an endstation that delivers spatially-resolved ARPES from ultra-small spots sizes. Using a photon beam focused to a spot of less than 1 μm in size, the team were able to observe the (100) plane without any contamination.

The WTI state

The researchers obtained a microscopic intensity map for a tiny cleavage surface, using nARPES before angle-resolved measurements

They then observed a quasi-one-dimensional Dirac topological surface state at the side surface (the (100) plane), while the top surface (the (001) plane) is topologically dark with an absence of topological surface states. Their results visualised the WTI state realized in β-Bi4I4, and showed that a crystal transition from the β-phase to the α-phase drives a topological phase transition from a non-trivial WTI to a normal insulator at room temperature.

The WTI state identified could have several different scientific and technological implications. Because it is regarded as the 3-D analogue of the Quantum spin Hall (QSH) insulator, and could generate highly directional spin current over a wide side surface of the 3-D crystal, its discovery should stimulate further in-depth study of exotic quantum phenomena. In bismuth iodide the emergence of robust spin currents can be controlled by selecting crystal phases that are either topological or non-topological, at around room temperature.

This research is a therefore a step towards basic and technological research into 3-D analogues of QSH insulators, and may ultimately lead to new electronic and spintronic technologies.

More information: Ryo Noguchi et al. A weak topological insulator state in quasi-one-dimensional bismuth iodide, *Nature* (2019). DOI: 10.1038/s41586-019-0927-7

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