Expecting the Realization of a Spintronic Semiconductor

This report features the work of Christopher J. Butler, Minn-Tsong Lin, and their co-workers published in Nature Comms. ***5****, 4066 (2014).*

Semiconductor devices operate through an ability to manipulate the electronic charges by means of electric fields, whereas devices based on the manipulation charges' spin degree of freedom are called spintronic devices. Much effort has been devoted to incorporate the fundamental electron charge and its intrinsic spin in a semiconductor device in a controllable fashion. Materials containing atomic centres with large atomic number, *Z*, that possess a strong spin-orbit interaction have been proposed for such an application, especially several surfaces such as that of Bi, or those incorporating large-*Z* atoms on alloying Bi or Pb with noble metals,[1] but these materials are based on metal substrates that inhibit tuning of the spin splitting with an external electric field. A need hence arises to investigate semiconductor materials that feature a large spin splitting, particularly in cases where splitting in both valence and conduction bands can provide versatile tuning of spin transport properties.

In 2014, Minn-Tsong Lin led a research team from National Taiwan University and revealed a naturally formed BiTeI *p-n* junction-like nanostructure on a Rashba semiconductor surface; their findings might pave a way to design a Rashba spin-split spintronic device on a nanometre scale.

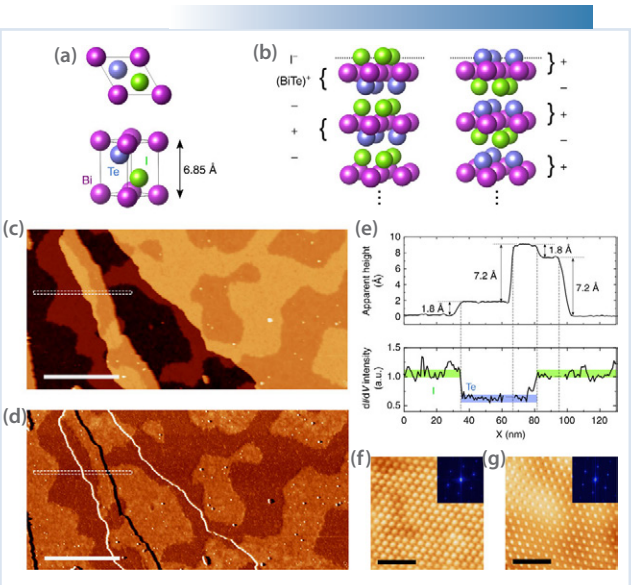

Fig. 1: STM observation of two surface terminations on cleaved BiTeI surfaces. (Reproduced from Ref. 2)

BiTeI is a semiconductor that exhibits a giant Rashba spin splitting both at the surface and in the bulk. For BiTeI, both conduction and valence bands exhibit Rashba spin splitting, and either band, depending on the surface termination, can be shifted so that it crosses the Fermi level near the surface. BiTeI crystals are composed of a sequence of Bi, Te and I layers; the structure is shown in Fig. 1. These BiTeI trilayers are themselves bonded by a van der Waals force; the weakly bonded plane between Te and I provides the cleavage planes of the crystal. Also shown in Fig. 1 are the topography from a scanning tunnelling microscope (STM) (c), and d*I*/d*V* (d) map for a typical BiTeI surface[2] cleaved in vacuum; the mappings indicate a variation of surface termination from one to another of the constituent elements of the crystal.

To understand the surface chemical composition and band alignment, high-resolution photoelectron microscopy and spectroscopy (HRPEM/S) based on synchrotron radiation provides the most suitable tool. The team performed advanced research in the TLS, utilizing the scanning photoelectron microscope (SPEM) end station at **BL09A1**, to unveil how the surface termination alters the surface band bending. In their work, the BiTeI crystals were cleaved *in situ* near 295 K in the SPEM UHV chamber with base pressure 5×10^{-10} Torr, revealing clean and well ordered BiTeI surfaces; the HRPEM/S experiments were then immediately performed in the same UHV system.

The X-ray beam was incident on both terminations, yielding a total photoemission signal with a contribution roughly even from each surface termination, as schemati-

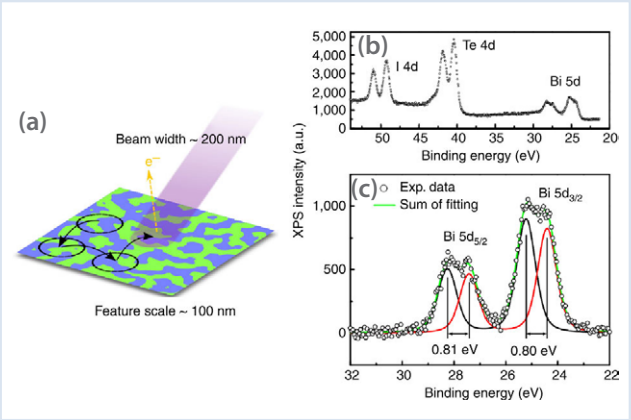

Fig. 2: Photoemission spectra for a cleaved BiTeI surface. (a) An illustration of HRPEM/S measurement using SPEM. (b) HRPEM/S spectrum showing signals for the constituent elements of BiTeI. (c) Magnified Bi 5d peaks show a separation into two contributions with a splitting in binding energy about 0.8 eV. (Reproduced from Ref. 2)

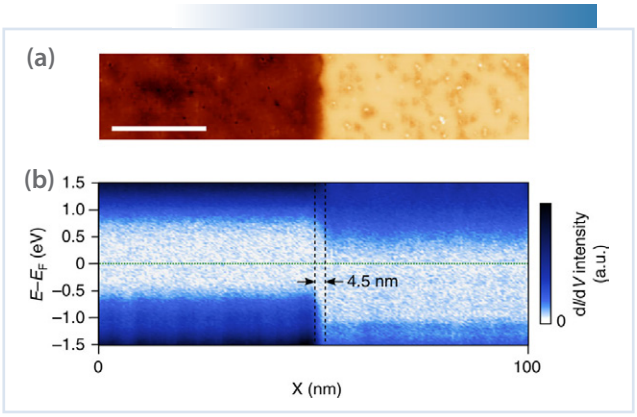

Fig. 3: Spatially resolved tunnelling spectra. (a) STM topography showing the boundary between areas of I- (left) and Te- (right) terminated surface. Scale bar, 20 nm. (b) Spatially resolved STS measurements with an emphasis on resolving the lateral behaviour at the junction. Vertical dashed lines enclose the transition region between the characteristic electronic structures of the two terminations. (Reproduced from Ref. 2)

cally illustrated in Fig. 2(a). The HRPEM/S spectra show Bi signals suppressed relative to signals of Te and I. The Bi signal exhibits a splitting in energy about 0.8 eV, as seen in Fig. 2(c). This splitting in the Bi 5d peaks is attributed to the differing surface polarizations of the two terminations represented in the total signal. Photoelectrons from Bi in the Te-terminated surface are expected to have an increased binding energy, whereas those from Bi in the I-terminated surface have a decreased binding energy. Because the signals from Bi in the two terminations have roughly equal intensities, Bi was deduced to be in the second layer down in regions of both types; Te and I are thus thought to form the surface terminations. These candidates for the two terminations are consistent with those expected from the bulk crystal structure, for which cleavage along the van der Waals-bonded planes would leave Te or I as the terminating layer, with Bi buried beneath.

To visualize directly the evolution of the local electronic structure on a nanometer scale across the boundary between areas of distinct terminations, spatially resolved STS measurements were performed, as shown in Fig. 3. Tunneling spectra were recorded along a path crossing the boundary and compared with the corresponding topography map, in Fig. 3(a). The shifting of the semiconductor band gap is clearly observed, with a transition corresponding to the topographic step between the two regions.

The spatially resolved tunneling spectra reveal *p*-*n* junction-like electronic structure at the lateral boundary between surfaces of Te and I terminations. This boundary represents a lateral junction of a type in which the relative position of the Fermi level is shifted with respect to the band edges, due principally to the surface polarization, rather than by distribution of doping concentrations. The junction is sharp, with a transition from *p*-like to *n*-like electronic structure over a distance ~4.5 nm.

According to Christophers' report, as the valence band in the *p*-like region and conduction band in the *n*-like region both exhibit Rashba spin splitting, the observed nanostructure might represent a Rashba *p*-*n* junction, as previously speculated by Crepaldi *et al.*,[3] and might open a possibility for related device concepts. Further, these workers have demonstrated a possible avenue for a design of electronic properties in nano-scale Rashba spin-split systems by selection of polar surface terminations and control of their spatial distributions. (Reported by Chia-Hao Chen)

References

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