量子拓樸自旋電子學的新契機

New Opportunities from Quantum Topological Spintronics

Pin-Jui Hsu[1,3*], Chang-Hua Liu[2,*], Deng-Sung Lin[1,3] and Horng-Tay Jeng[1,4,5,6]

[1] *Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan*

[2] *Institute of Photonics Technologies, National Tsing Hua University, Hsinchu 30013, Taiwan*

[3] *Center for Quantum Technology, National Tsing Hua University, Hsinchu 30013, Taiwan*

[4] *Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan*

[5] *Physics Division, National Center for Theoretical Sciences, Hsinchu 30013, Taiwan*

[6] *Institute of Physics, Academia Sinica, Taipei 11529, Taiwan*

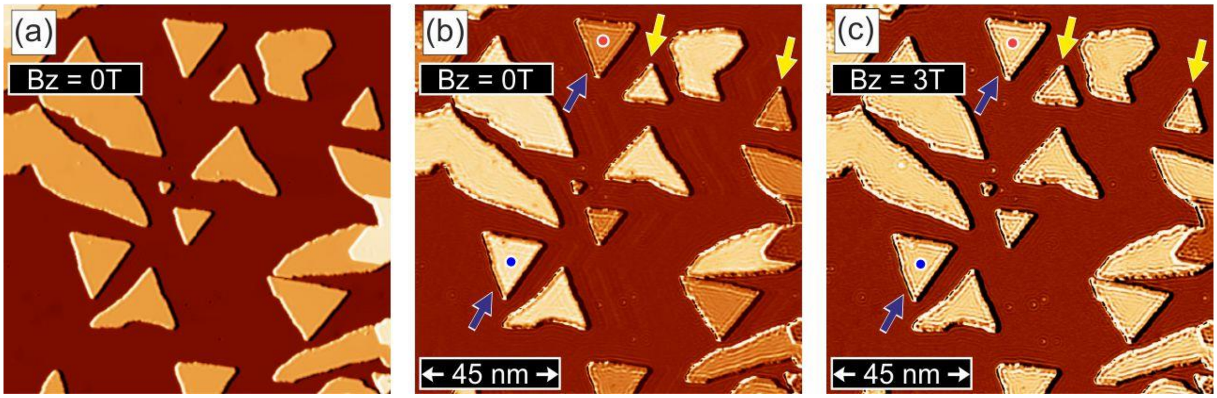
E-mail: pinjuihsu @phys.nthu.edu.tw; chliu@ee.nthu.edu.tw

Given the great advancements in the technology applications of topological spintronics, two-dimensional quantum materials have attracted enormous research interests. In this project, we have combined the experimental and theoretical studies on the electronic structures, photonics, magnetism and topological properties among several different two-dimensional quantum materials. First of all, we have built up the top-notch instrument of ultralow temperature and high magnetic field scanning tunnelling microscopy/spectroscopy (STM/STS) to study the emergent quantum physics and phenomena with high spatial and energy resolution. In addition, the cutting-edge experimental technique of spin-polarized STM/STS has been successfully realized and enables us to resolve the magnetic spin textures down to the atomic scale.

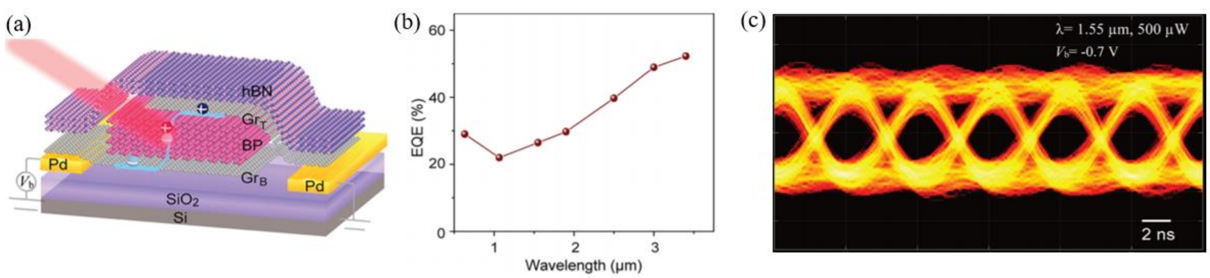
Second, we have developed a high performing photodetector using black phosphorus (BP)-based van der Waals heterostructures. The uniqueness features of our device are summarized as following examples. High speed: We demonstrate our developed BP photodetector can exhibit ultrafast rise (1.8 ns) and fall (1.68 ns) times. In addition, its switching behavior is highly reproducible, as indicated by the eye-diagram measurement.. Ultra-broadband and high quantum efficiency photodetections: By using the direct and narrow band gap BP as the light absorber, our detector can show broadband photoresponses, ranging from the visible to mid-infrared spectral regions. Moreover, by applying a moderate external bias voltage, we demonstrate the strong vertical field could facilitate the dissociation of photoexcited electron-hole pairs, which leads to high external quantum efficiency (up to 52%) of photodetection

Third, magnetic two-dimensional (2D) van der Waals materials have attracted tremendous attention because of their high potential in spintronics. In particular, the quantum anomalous Hall (QAH) effect in magnetic 2D layers shows a very promising prospect for hosting Majorana zero modes at the topologically protected edge states in proximity to superconductors. However, the QAH effect has not yet been experimentally realized in monolayer systems to date. In this work, we study the electronic structures and topological properties of the 2D ferromagnetic transition-metal dichalcogenides (TMD) monolayer 1T-VSe2 by first-principles calculations with the Heyd–Scuseria–Ernzerhof (HSE) functional. We find that the spin-orbit coupling (SOC) opens a continuous band gap at the magnetic Weyl-like crossing point hosting the quantum anomalous Hall effect with Chern number $C = 2$. Moreover, we demonstrate the topologically protected edge states and intrinsic (spin) Hall conductivity in this magnetic 2D TMD system.

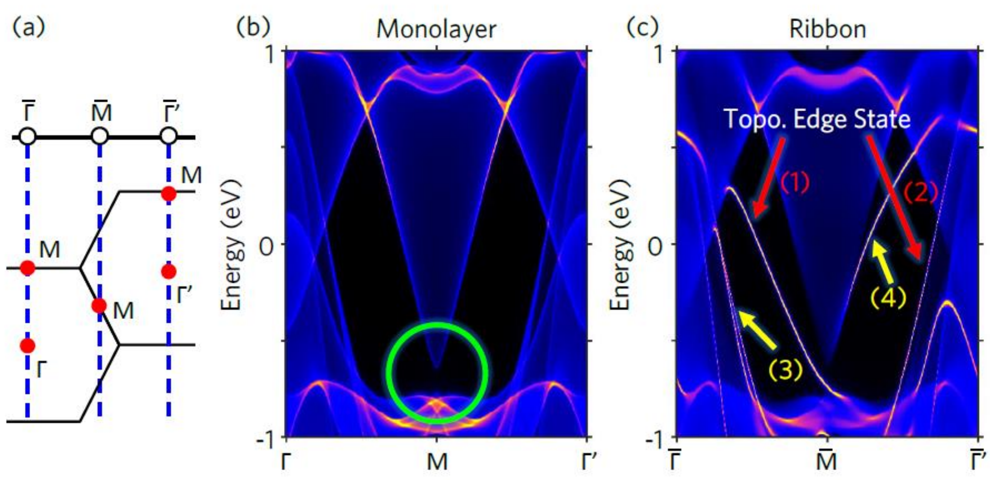
Our results indicate that 1T-VSe2 monolayer serves as a stoichiometric quantum anomalous Hall material.



(a)-(c) Spin-polarized STM measurements on the ferromagnetic Co nanoislands on Cu(111). The ferromagnetic spin contrast can be identified by pairs of Co naoislands (blue and yellow arrows) under the different external magnetic fields.



(a) Device structure of BP-based heterostructures photodetector. (b) Ultra-broadband and efficient photoresponse. (c) Ultrafast and reliable photoresponse.



(a)-(c) 2D and 1D Brillouin zone of 1T-VSe2 monolayer and ribbon at the (010) edge, respectively. The blue dash lines indicate the relation between the high symmetry k-points in the 2D and 1D BZ. Band structure of 1T-VSe2 monolayer calculated from the semi-infinite Green functions method shows four edge states (bright yellow curves). Two of them are topological edge states corresponding to the Chern number C=2 as indicated by the red arrows (1) and (2). The other two edge states are topologically trivial as indicated by yellow arrows (3) and (4).