Quantum Spin Hall Effect in 1T'-WTe_2

Introduction

Quantum Spin Hall (QSH) insulators are topological insulators that exhibit spin-polarized conduction channels along the edges even in the absence of external magnetic fields (**Figure A**). These insulators, when proximity-coupled with a superconductor, are a prominent candidate in hosting Majorana fermions important for topological quantum computing. Recently, monolayer 1T'–WTe_2 was found to exhibit QSH properties. In this work, we compare scanning tunneling spectroscopic data of QSH states in 1T'–WTe_2 from literature and examine their consistency.

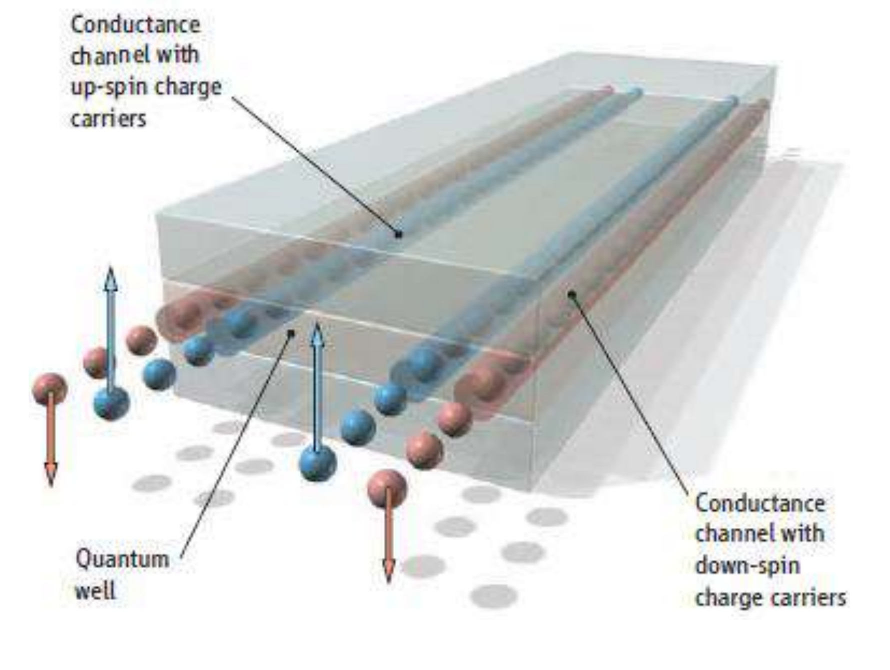

Figure A: Schematic of the spin polarized conduction channels on the edges of a Quantum Spin Hall (QSH) insulator, with the insulating interior bulk matter [1].

Methodology

The samples in the studies used were grown using Molecular Beam Epitaxy (**MBE**) and analyzed using Scanning Tunneling Microscopy and Spectroscopy (**STM/STS**) for their topographic images and electrical properties, respectively (**Figure B**).

MBE[2]

- Epitaxial growth technique via thermal energy reactions in an ultrahigh vacuum chamber.
- Chambers have effusion cells directed towards the substrate, which can be heated up so that constituent elements inside will vaporize.
- Each cell is equipped with shutters to control partial pressures of elements inside the chamber, which is important for producing the desired material, with a certain growth rate.

STM/STS[3]

- An atomically thin tip is brought to ~1 nm from a sample surface in ultrahigh vacuum, and a bias voltage is applied between them.
- Electrons can tunnel through between the sample and STM tip, so topography and local atomic configuration of the sample can be spatially resolved.
- Since the tunnelling current depends on the electron density, the local density of states can also be probed with the STM tip. This technique is called **STS**.

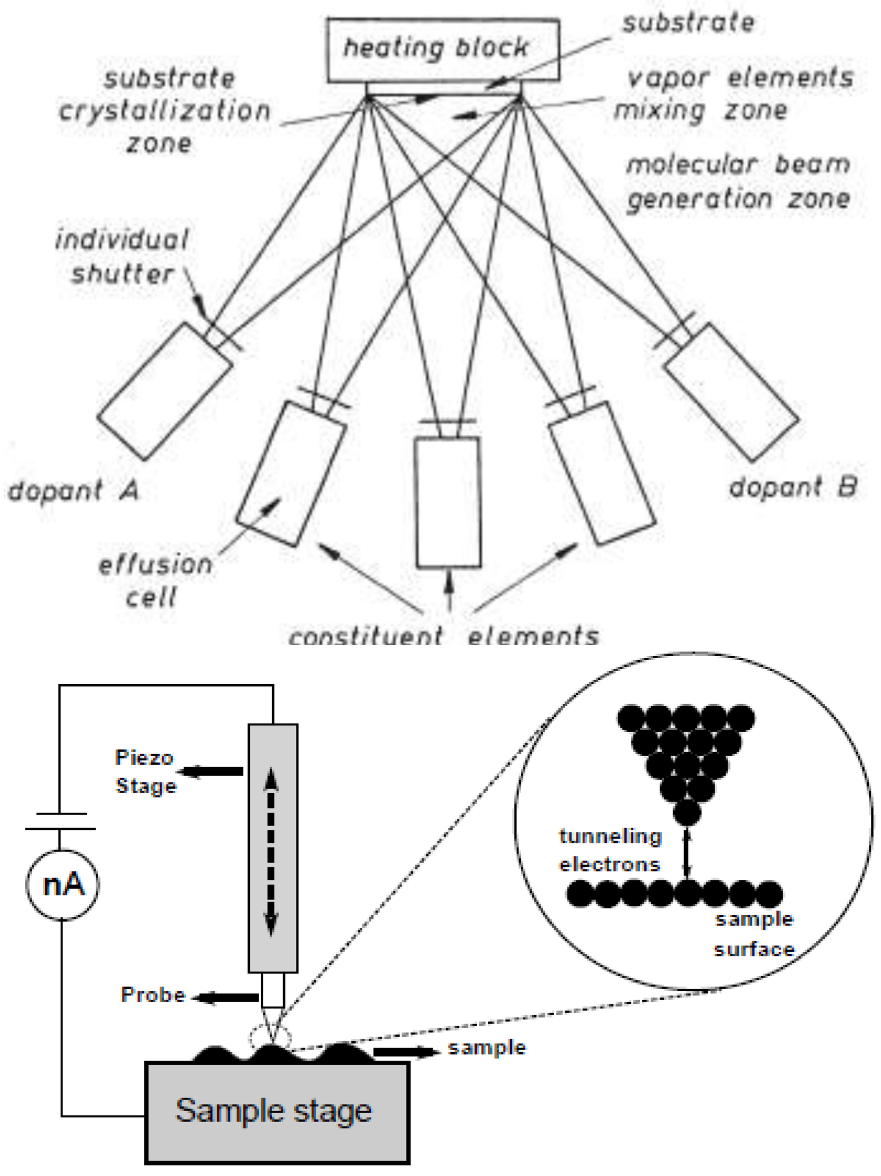

Figure B: Schematic of a Molecular Beam Epitaxy (MBE) chamber[2], and a Scanning Tunneling Microscope (STM)[4], which is used for spectroscopic measurements of the electrical characteristics of grown materials.

Results and Discussion

Figure C shows a topographic image of 1T'–WTe_2 islands grown by Jia *et al.*[5], and a representative height profile across an island. The differential conductance measured on a monolayer island, from the bulk to the edge, is given in **Figure D**. A few key features can be observed:

- Far from the edge, the bulk band gap is very apparent, but gradually loses its clarity as the points get nearer the edge.
- The point near the edge exhibits higher tunnelling conductance; a hallmark of a QSH insulator.
- Points around 5.0 nm from the edge shows a peak in conductance in the conduction band, which only exist at this distance range from the edge[5].

Figure E shows STS results on a 1T'–WTe_2 island by Tang *et al*[6]. The higher conductance measurement along the edge supports the presence of conduction channels. The sample edge also shows a partial filling of the bulk band gap across the Fermi level ($E – E_F = 0$). The V-shaped conductance is investigated further in **Figure F** by plotting the conductance as a function of energy, along the direction away from the edges[6].

The darker colors in **Figure F** show higher tunnelling conductance. Paired with the inset height profile, the edge exhibit a larger local carrier density of states. The bulk also shows insulating properties, with minimal conductance values measured[6].

We note that the data from Tang *et al*. do not show any peaks in conductance, in contrast to Jia *et al*.'s data in **Figure D**. Regardless, the presence of conduction channels along the sample edge and an insulating bulk was shown by both studies. From this observation, we infer that the QSH effect was clearly shown to exist in monolayer 1T'-WTe_2. Additionally, a few key features can be summarized from the two **Figures E** and **F**;

- The edge conductance is always higher than the bulk conductance, on both sides of the Fermi level.
- The edge conduction channels exist up to only about 1.5 nm from the edge of a monolayer island.
- The suppression of the conductance for the edge is thought to be from incommensurate charge order, with some literature citing many-body interactions[5,6].
- The edge does not show a perfect conduction channel across the bulk band gap, as there are some energy levels that are not filled.
- The sample edges are always conducting regardless of the shape, size and edge roughness[6].

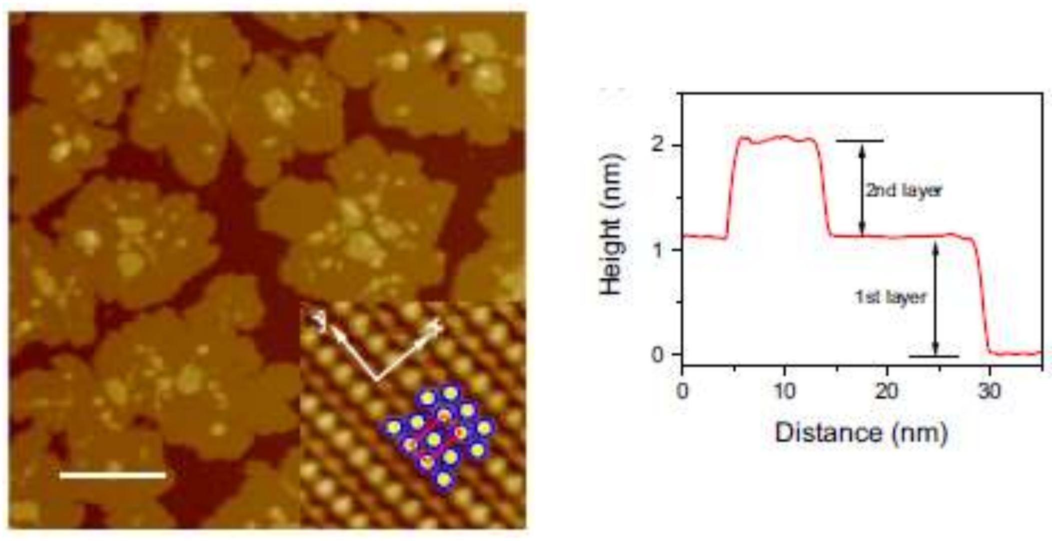

Figure C: An STM topography image of monolayer 1T'-WTe_2 on BLG/SiC (0001). The scale bar is 30 nm. The right panel shows a typical height profile on a 1T'-WTe_2 island[5].

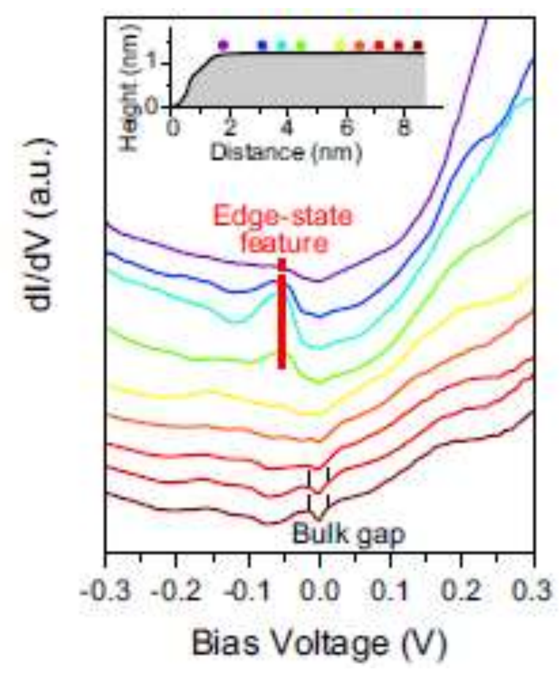

Figure D: Differential conductance spectra of different points from the edge. The colored lines correspond to the colored points on the inset[5].

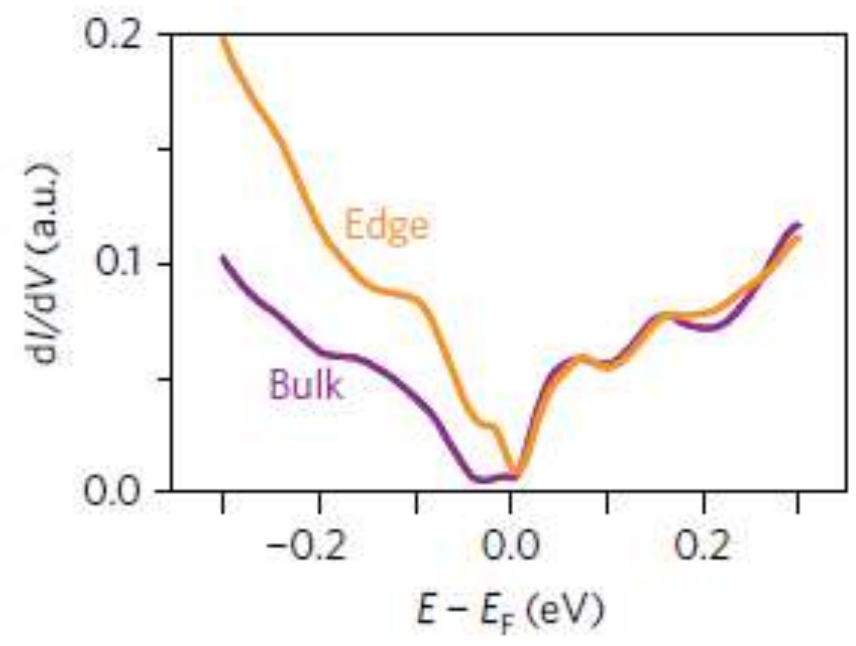

Figure E: Increased conductance across the bulk band gap, with a size of (56 ± 14 meV), with a 'V'-shaped suppression of the tunnelling conductance for the edge[6].

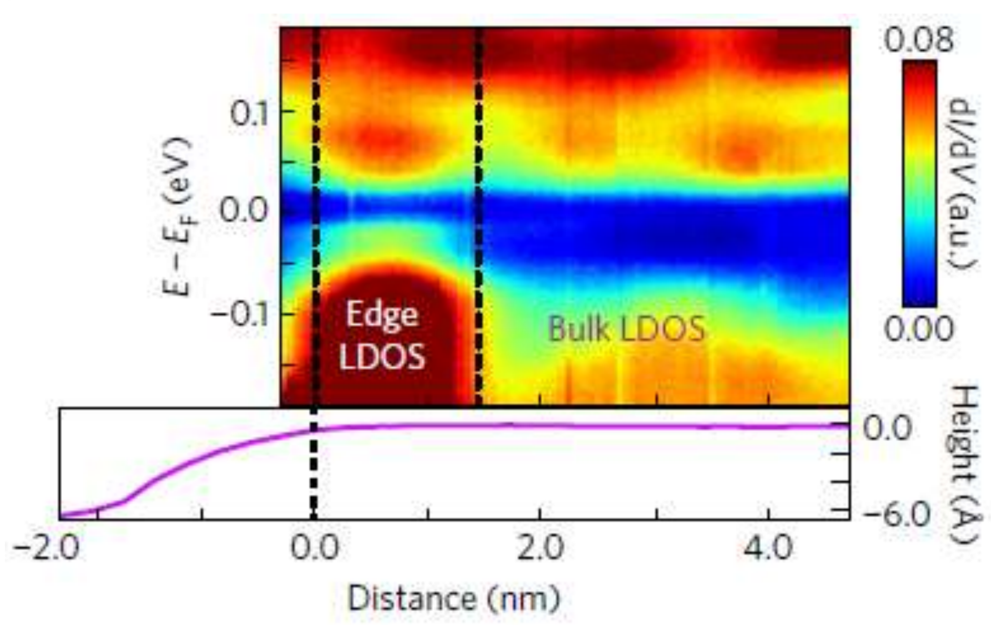

Figure F: Differential conductance spectra of the edge and the bulk of monolayer 1T'-WTe_2 islands[6].

Conclusion

We have compared literature studies on the electronic properties of monolayer 1T'–WTe_2, which were measured via STM/STS. Both studies covered in this work clearly demonstrated the presence of conducting channels along the sample edges and a bulk band gap. These studies thus prove that monolayer 1T'–WTe_2 is indeed a Quantum Spin Hall insulator.

References

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