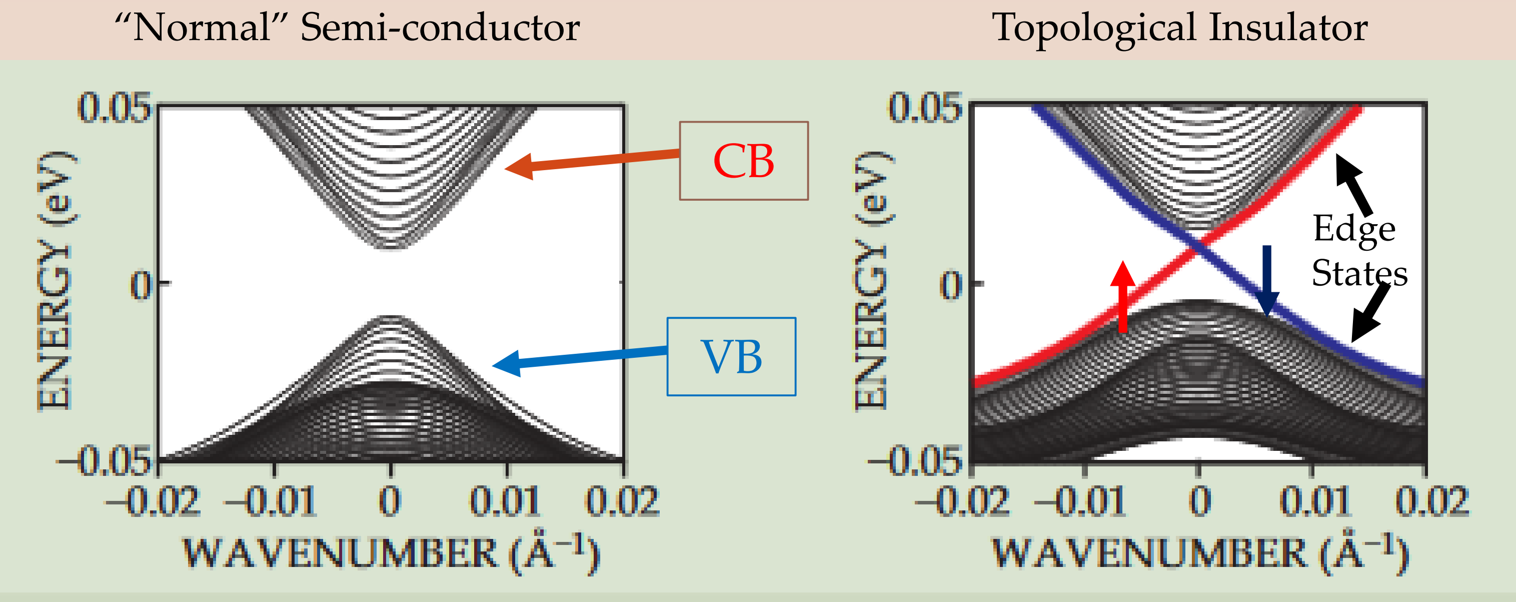
Fabrication of Bubble-Free hBN-Encapsulated 2D WTe_2 Devices

Caleb Anderson
Advisor: David Cobden
17 July 2016

What? Topological Insulator (TI)

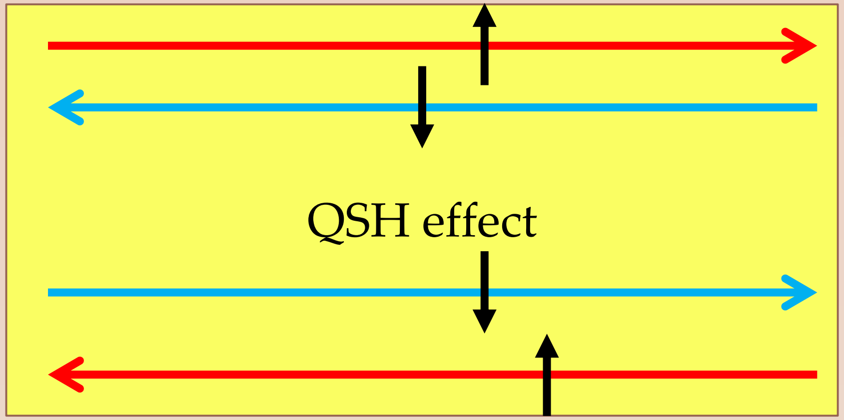
- Strong spin-orbit coupling in compounds of heavy element inverts
- Have conducting edge states but insulating (band-gap) bulk states.
- Time reversal symmetry (reverse time, invert momenta states): Edge states are topologically protected from disorder or scattering.
- Consequence is the Quantum Spin Hall Effect (QSHE)

Adapted from X-L. Qi and S-C. Zhang, The Quantum Spin Hall Effect and Topological Insulators, Physics Today **63** (1), 33 (2010).

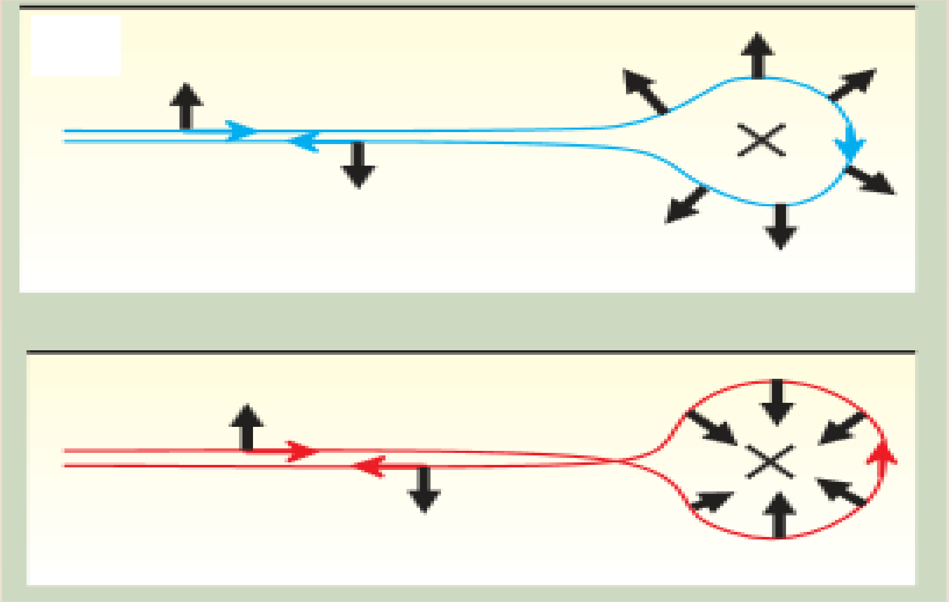


What? 2D TI: Quantum Spin Hall (QSH) Effect

- Net spin along edge: two "lanes" per edge of forward and backward movers.
- Spin-up and spin down travel opposite direction along channels.
- Backscattering of electrons destructively interferes; allows perfect transmission.

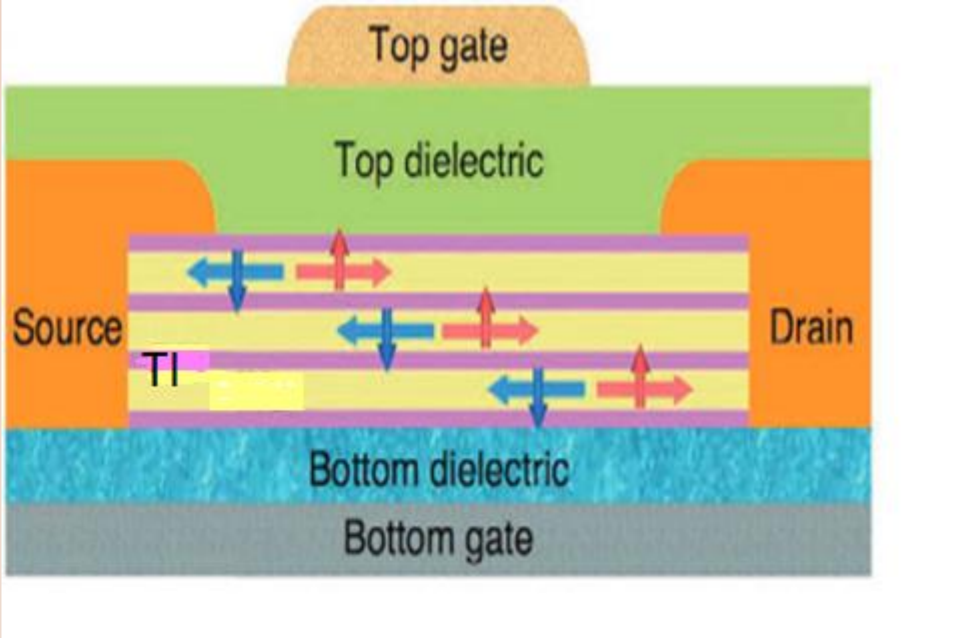


Adapted from X-L. Qi and S-C. Zhang, Physics Today **63** (1), 33 (2010).



Why? TI Applications

- TI+superconductor: Majorana fermions for Quantum computing.
- TI+ferromagnetic film: write magnetic memory electrically.
- 2D van der Waals heterostructured Topological Field-Effect Transistor (vdW-TFET) devices
  - Rely on gating edge state conductance via electric fields.
  - (Theoretically) Quicker electronic response times from rapid phase transitions.

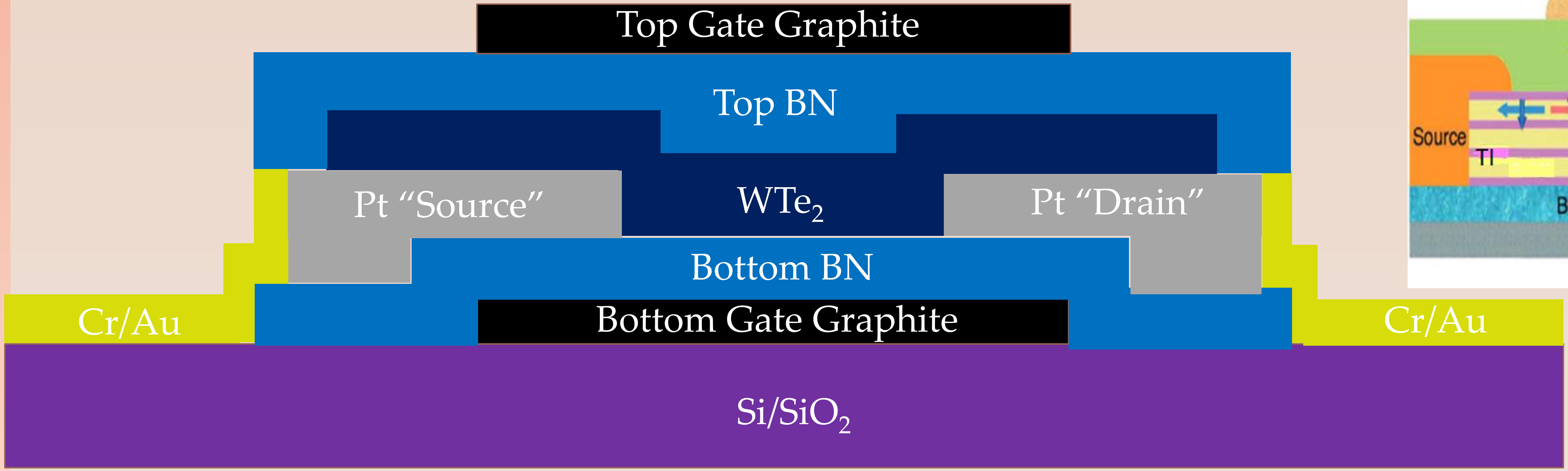


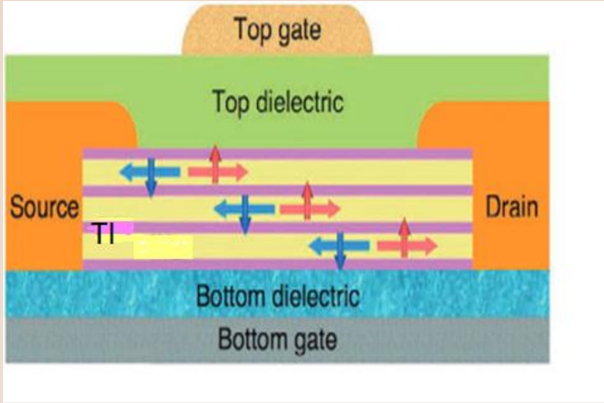
How? Encapsulated 2D WTe_2 vdW-TFET Devices

- WTe_2
  - Part of class of proposed TIs in monolayer form.
  - Monolayer WTe_2 proposed to be only stable TI in its family

    Qian, X., Liu, J., Fu, L. & Li, J. Quantum Spin Hall Effect and Topological Field Effect Transistor in Two-Dimensional Transition Metal Dichalcogenides. *Science* **346,** 1344–1347 (2014).

- We fabricate WTe_2 vdW-TFET devices to study transport properties.

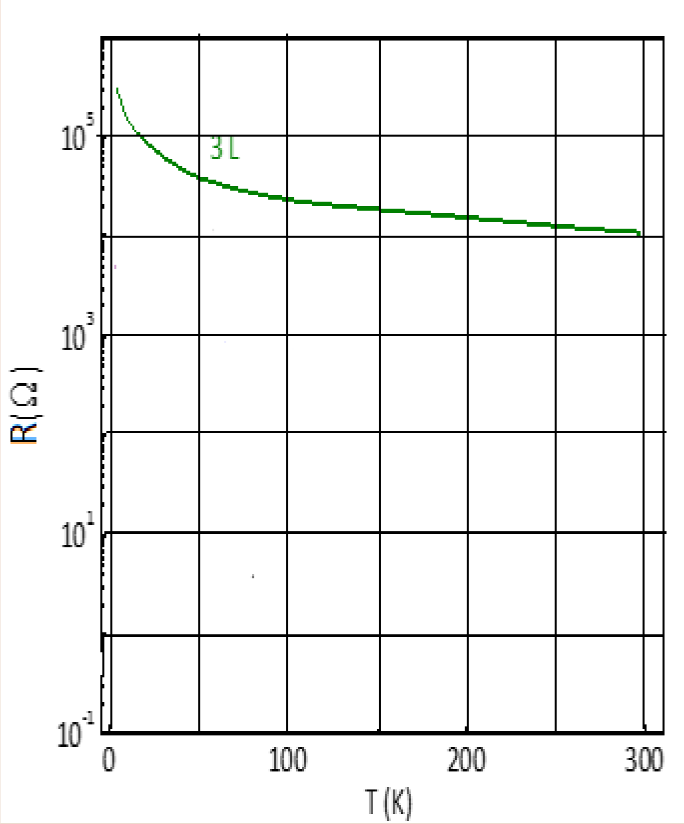




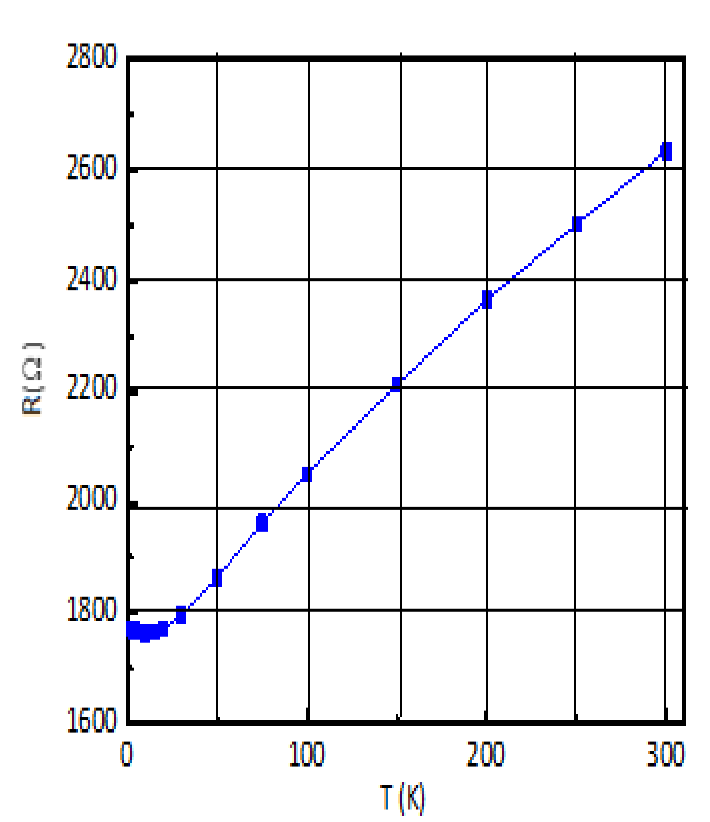
Problem: Devices Need Encapsulation

- WTe_2 oxidizes in air.
- Without encapsulation, see insulating behavior.
- Use of hexagonal Boron Nitride (hBN) as dielectric.
  - Inert
  - Filters surface disorders
- Encapsulation: preserve semimetallic characteristics.

Non-encapsulated 3L WTe_2



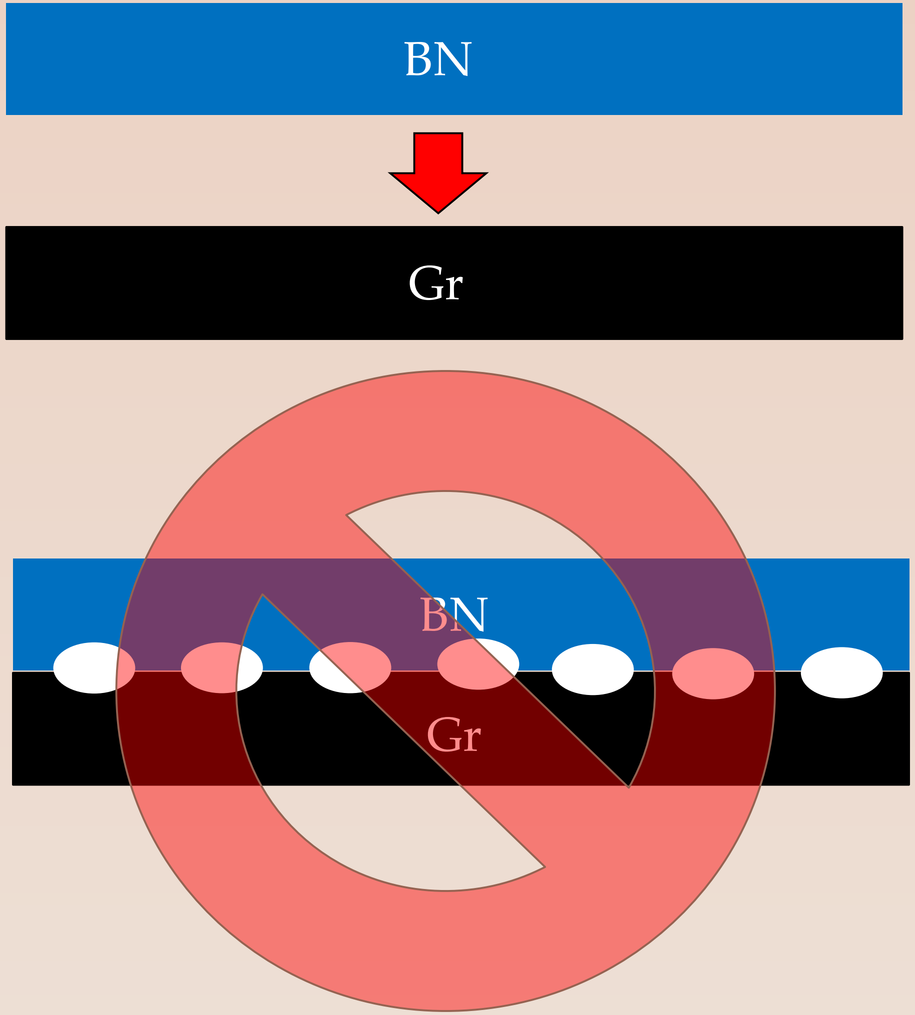
hBN-Encapsulated 3L WTe_2



❖ $V_{tg} = 100\mu V$; $V_{bg} = 0$

My Job: Fabrication of Bubble-Free Encapsulating Gates

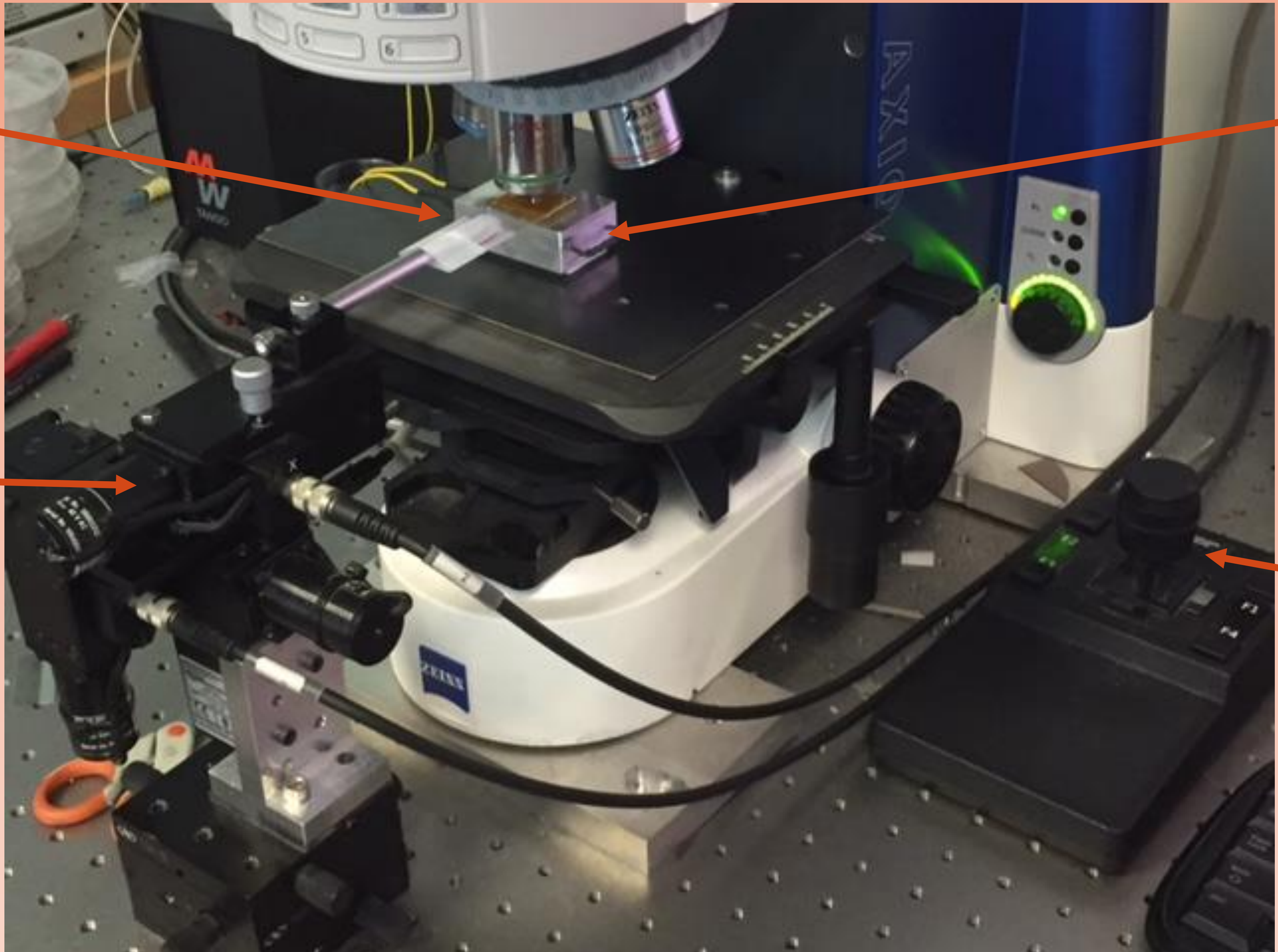
- Lab group works an "assembly line" of device fabrication.
- Devices involve transferring layers of materials.
- Formation of interlayer air bubbles via vdW-forces reduces conductivity.
- Develop method of making bubble-free encapsulating graphite gates.



Transfer Set-Up

PDMS/PC stamp

Heating transfer stage

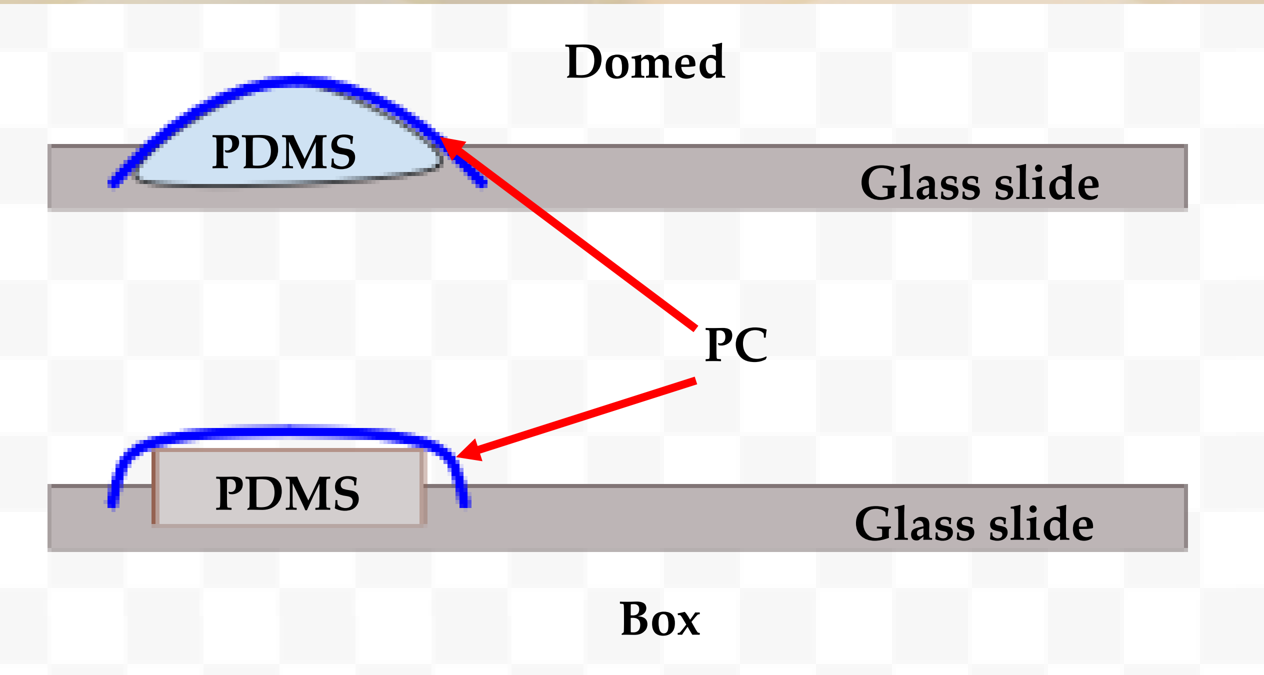


Manipulator

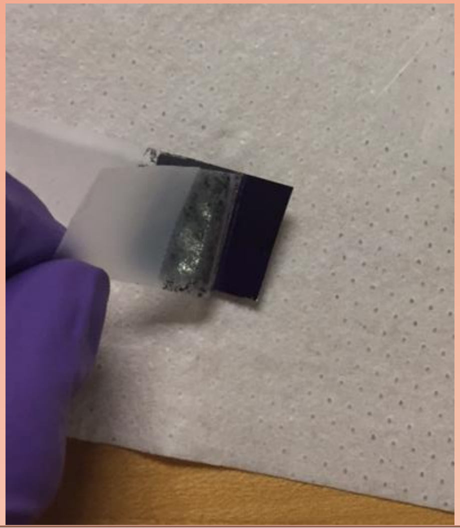
Manipulator joystick

My REAL Work: Domed Stamps vs Box Stamps

- Increased tension allows stamps to function at higher temperatures.
- Transfers at higher temps. tend to be more bubble-free.
- Transfer mechanism differs:
  - Picked-up layer adsorbs to above layer vs. pressing down.



Exfoliating, Searching, AFMing…



“Scotch tape method” exfoliation on SiO_2

Search for ideal flakes under optical microscope.

AFM scan for clean BN, Gr.

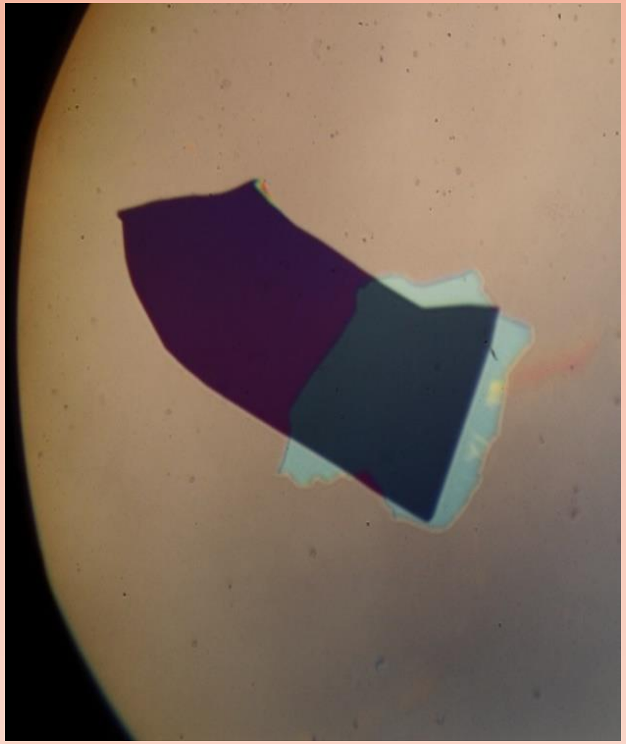
Transfer and Meltdown

Test new dome vs. old box stamps.

Pick up BN.

Align BN on Gr, melt down stamp using heating transfer stage.

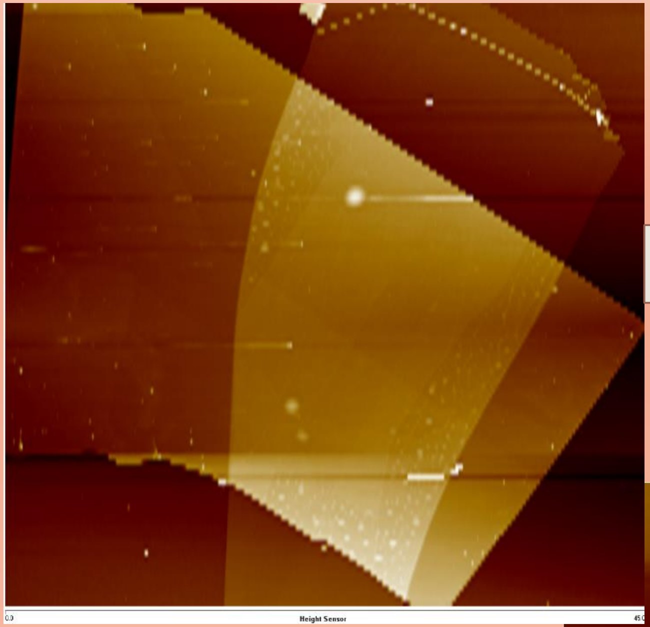
Heterostructure, some PC remain on SiO_2.



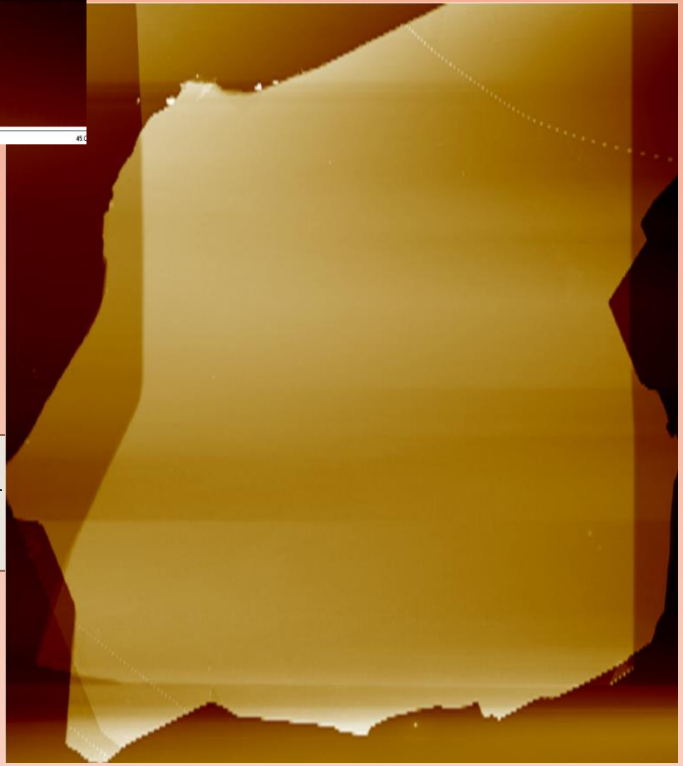
Cleaning the Gate

Dissolve PC with intermixed baths of chloroform and IPA.

Further cleansing through annealing.



Bubbles—no good!

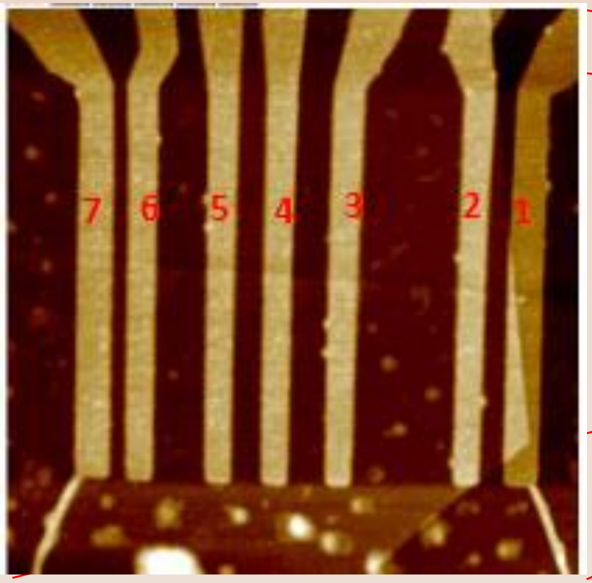


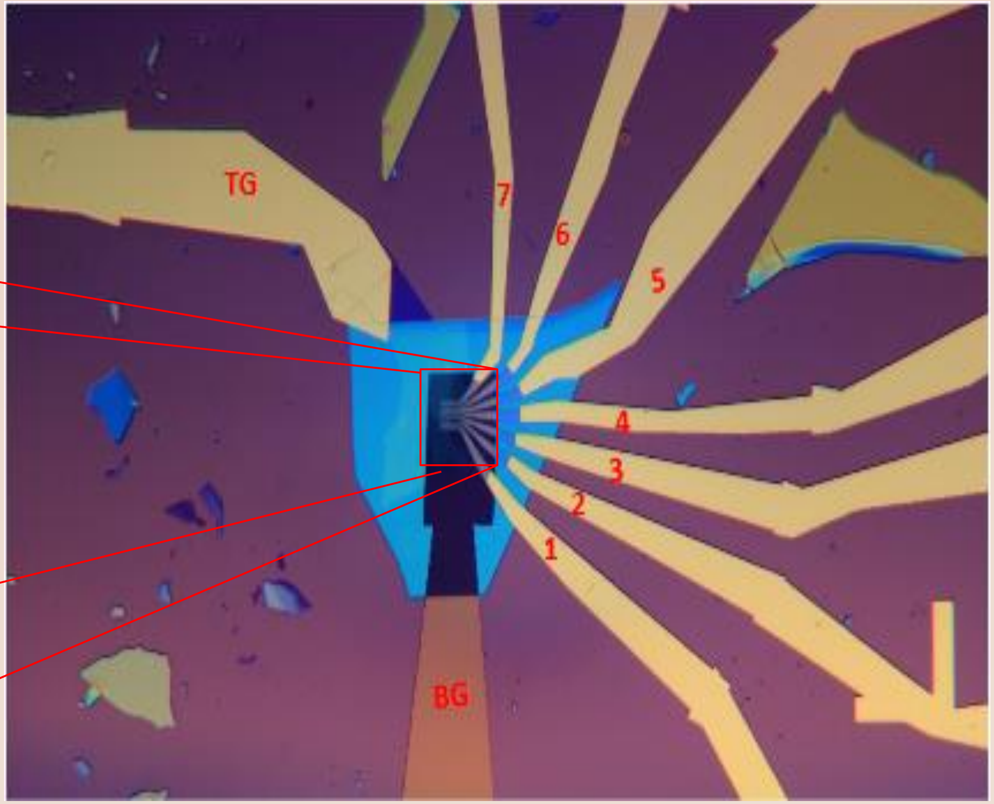
Bubble-free and ready for use.

Completed WTe_2 Device

- Rest of lab adds more layers in analogous fashion.
- Use of additional fabrication techniques.
  - Electron-beam lithography.
  - Metal evaporation and deposition.
  - Wire-bonding.

Pt contacts close-up.





Future Work

- Apply bubble-free fabrication technique to subsequent layers.
- Fabricate more devices with WTe_2 (with my gates?)
- Currently working on bilayer device.
- Quantity of measurements:
  - Vary temp.
  - Vary gate voltage
  - B-field strength.
  - Top vs. bottom gates.

Summary

- Topological insulators have topologically protected conducting edge channels.
- Quantum Spin Hall Effect splits edge state into “traffic lanes” of spin-up and spin down movers.
- TI applications: quantum computing, electrically written magnetic memory, and faster electronic response time.
- Lab uses possible TI WTe_2 to fabricate encapsulated vdW-TFETs to explore electronic properties of material.
- I helped develop “bubble-free” hBN-encapsulated gates for use in preserving integrity of WTe_2 in device use.
- New bilayer WTe_2 device offers potentially rich data on material.

Thank you!