# 2D Materials and Devices

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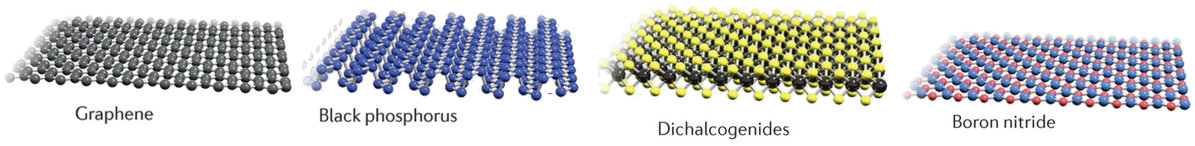
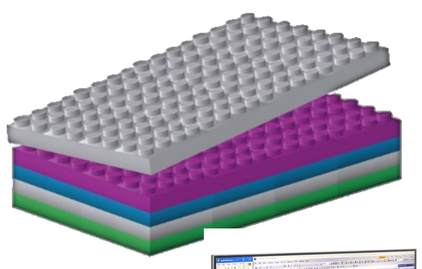
MONASH University

## Atomically Thin Materials

**New materials just one or a few atoms thick:**

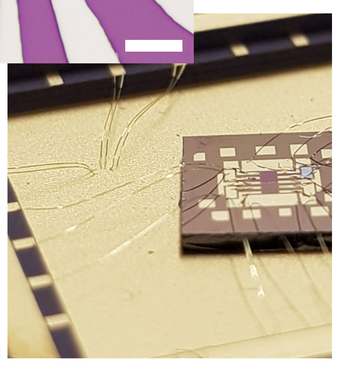



**Stacking materials to make "van der Waals heterostructures" with new physical properties**



Van der Waals Transfer setup in Fuhrer Lab

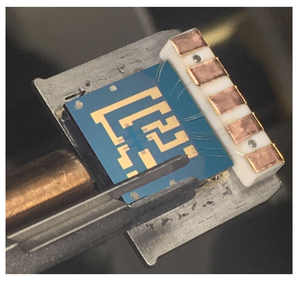
**Micro- and nano-fabrication to make electronic devices**



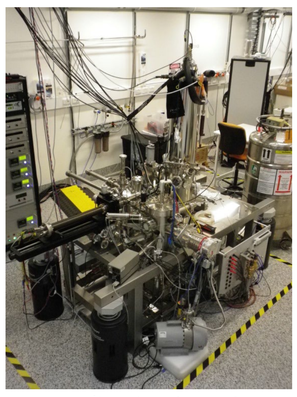
## Scanning Tunnelling Microscopy

- Ultra-high vacuum, low-temperature (5 K)
- Magnetic field (1 T)
- Electrical contacts to sample devices
- Molecular beam epitaxy growth of materials

- Atomic resolution imaging
- Scanning tunnelling spectroscopy (measures local density of states)
- Quasi-particle Interference (probes electron scattering to reconstruct Fermi surfaces)



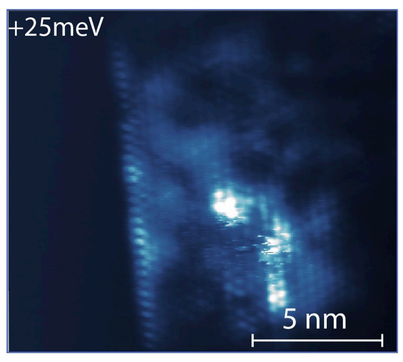
sample holder for simultaneous electrical measurements and STM

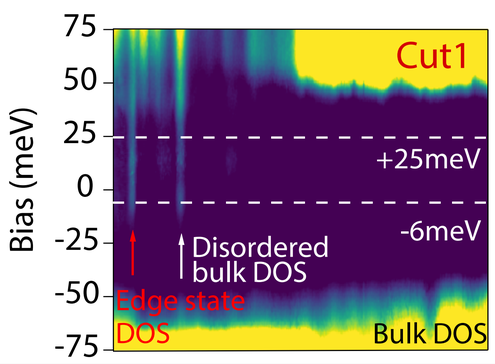


MBE/STM in Fuhrer Lab

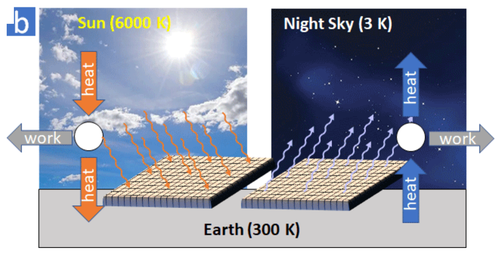
**Imaging topological edge state and bulk disorder in $MnBi_2Te_4$**

Qile Li et al. & Mark Edmonds group, Arxiv:2301.06667

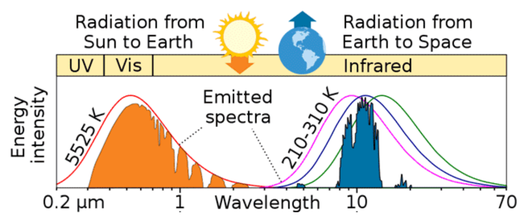


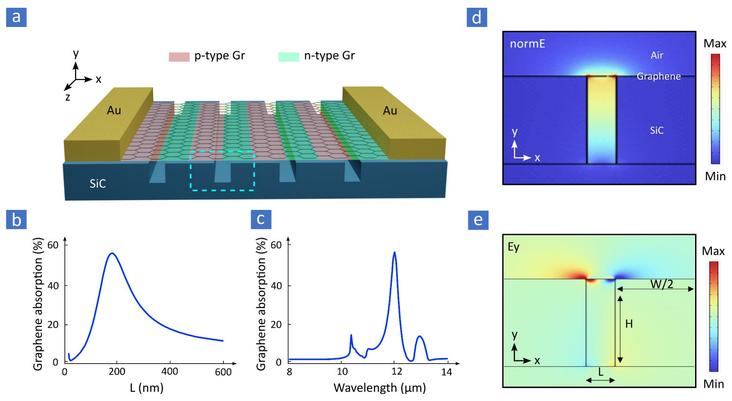

## Graphene for Harvesting Energy from the Cold Night Sky




**Outgoing thermal radiation from Earth (300 K) to space (3 K) can do work**




**Thermal radiation at room temperature in "mid-IR window" 8-13 μm**

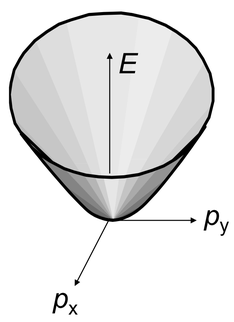



- **Plasmonic nanostructures can make graphene efficiently emit in mid-IR**
- **Generate power through hot-electron photothermoelectric effect**

## Topological Materials

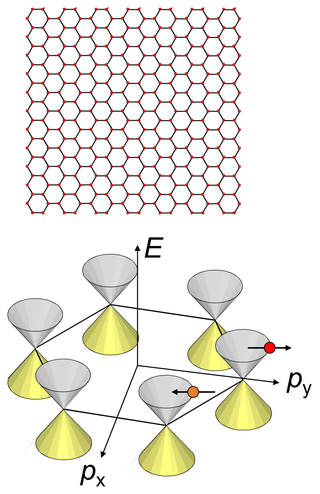
The periodic potential in a solid can give rise to an effective single-particle Hamiltonian which is qualitatively different than Schrodinger equation for a free electron.

free electron



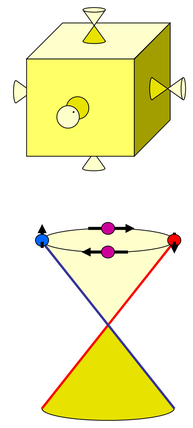

$$H = \frac{p^2}{2m_e}$$

graphene




$$H = v_F(\boldsymbol{\sigma}\cdot\mathbf{p})$$

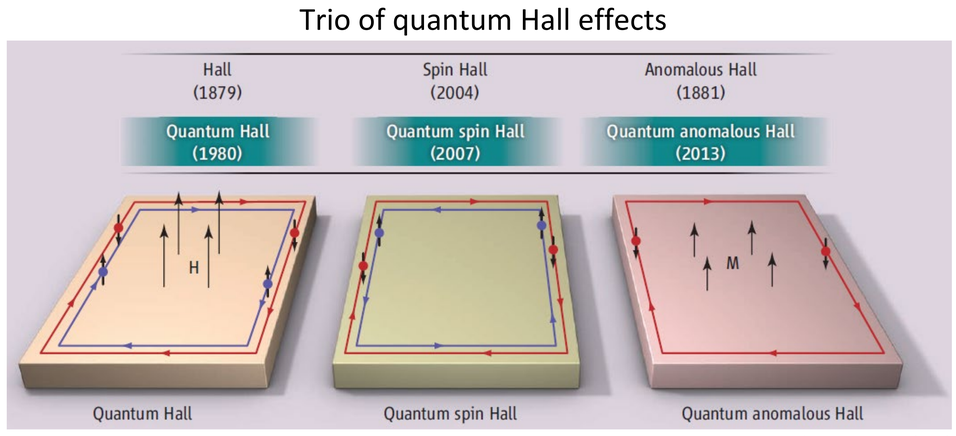
3D strong topological insulator



$$H = v_F(\boldsymbol{\sigma}\cdot\mathbf{p})$$

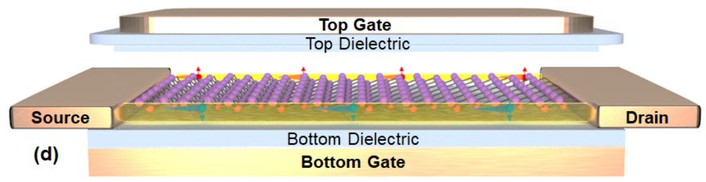
The topology of electronic bands describes new phases of electronic matter, with new excitations occurring on the boundaries between phases of different topology.

Trio of quantum Hall effects




S. Oh Science 340, 154 (2013)

## Topological Transistor




C. Liu, D. Culcer, Z. Wang, M.T. Edmonds & M.S. Fuhrer, *Nano Letters* **20**, 6306 (2020)

- New concept for a transistor using lower energy than silicon CMOS
- Uses electric field to switch a material from conventional insulator ("OFF") to topological insulator ("ON")
- Three patents/patent applications

**Electric-field-tuned topological phase transition in ultrathin $Na_3Bi$**

Collins et al., *Nature* **564**, 390–394 (2018)