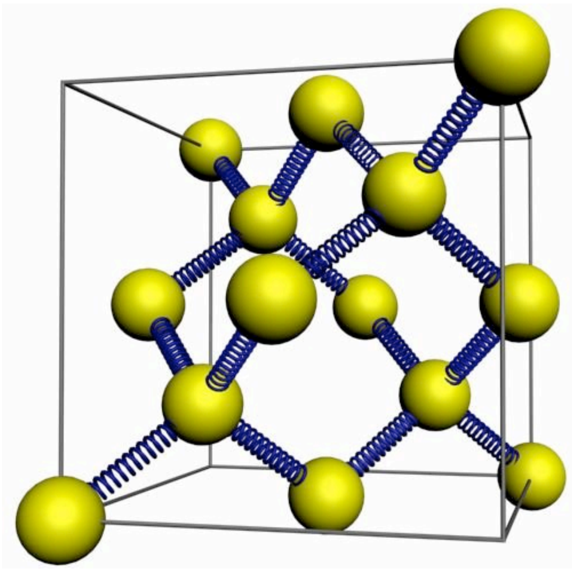
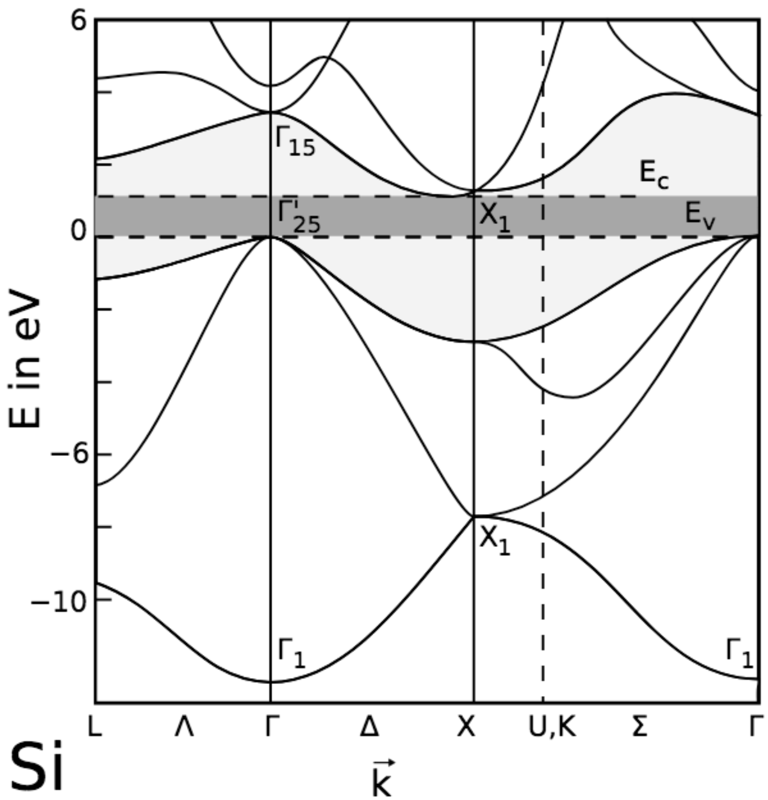




PH575 Spring 2019

Fundamentals of the condensed state:
Where are the electrons?
How do they determine the properties?

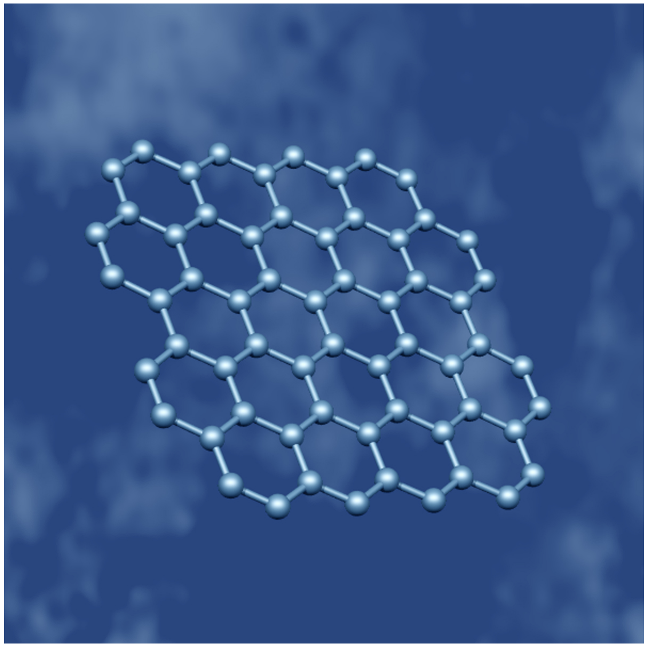
Start with a single atom and build up solid in real space as a huge molecule by considering interactions between atoms (more intuitive -> amorphous, defective materials)

Traditional momentum-space (*k*-space) approach exploits periodicity (less intuitive -> works well for crystals, some properties).

Class research?

- Graphene
- Carbon nanotubes
- Your research here …

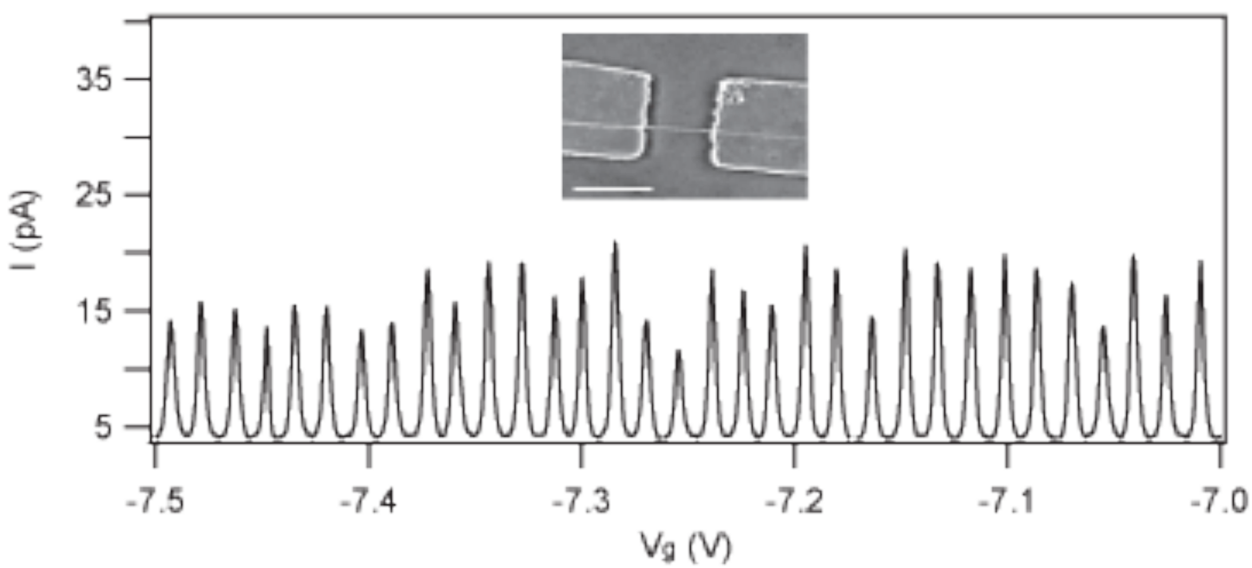
Graphene



- No defects
- Very high conductivity, mobility
- Highest thermal conductivity
- Quantum hall effect

Carbon nanotubes

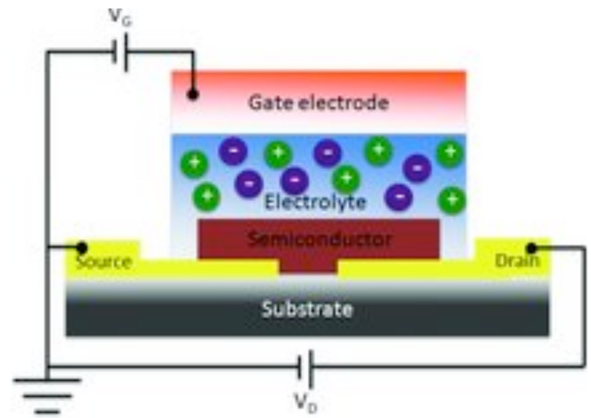
- Rolled-up graphene
- Stronger than steel
- High mobility

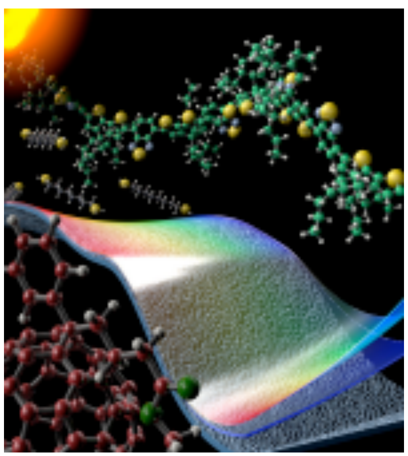


Why does the I-V characteristic look like this?

Organic Electronics

- Organic FETs
- Polymer solar cells
- Organic LEDs





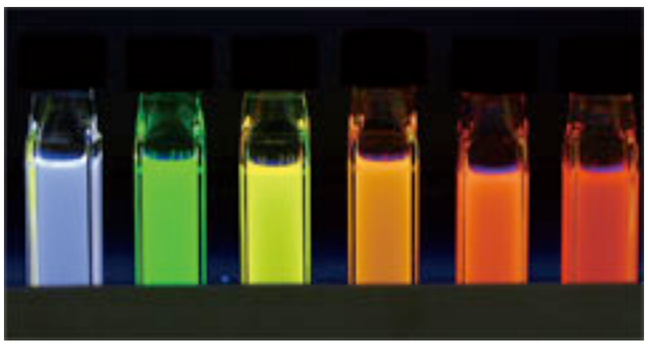
Why does the I-V characteristic look like this?

Silicon

- Most perfect material we've ever made in production
- Underlies current technological era
- Prototypical semiconductor
- GaAs (III-V), ZnTe (II-VI) …..

Quantum-confined systems

- Quantum well lasers
- Quantum dots



1nm →→→→→→ 5nm

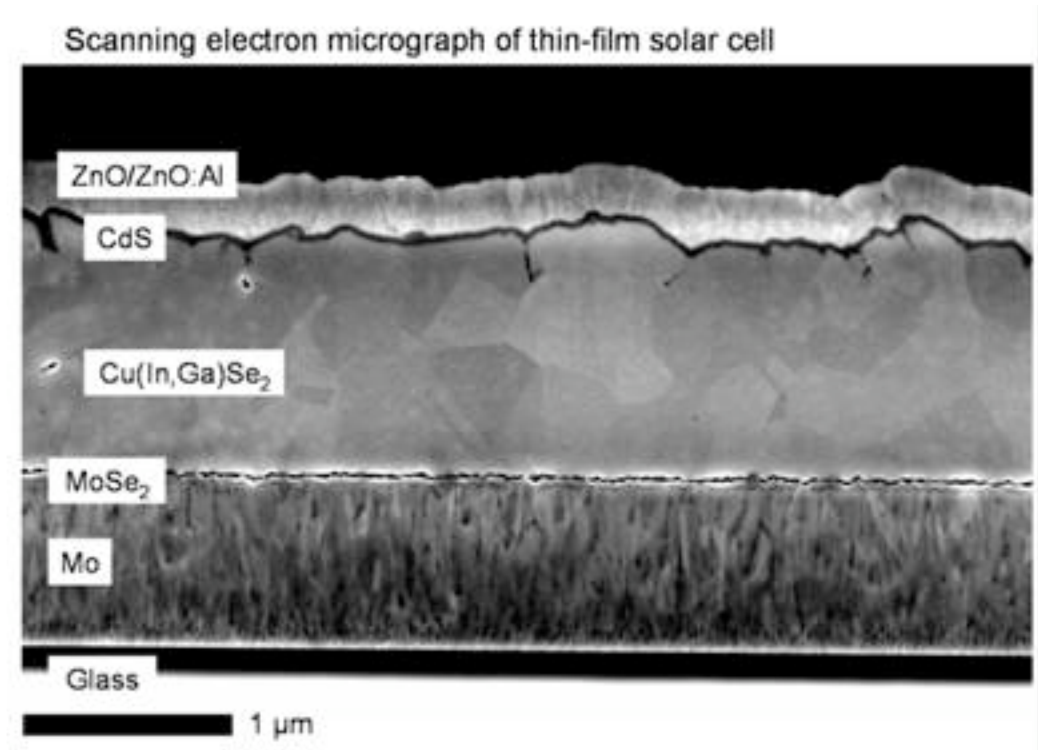
http://www.aist.go.jp/aist_e/aist_today/2006_21/hot_line/hot_line_22.html

GaInP/AlInP Quantum Well Laser Diode

http://www.optics.rochester.edu/workgroups/wicks/research.html

Cu(In,Ga)Se_2 (CIGS)

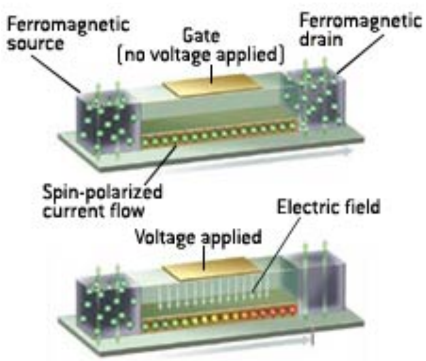
- Solar cell materials



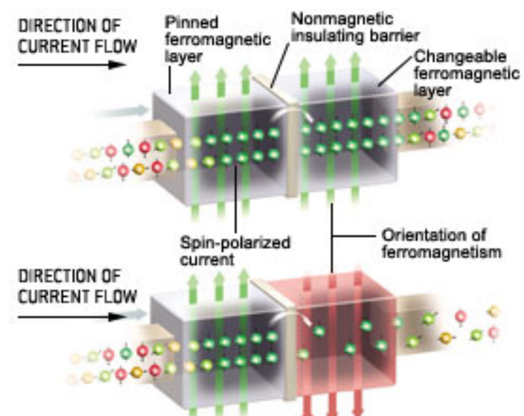
http://www.hmi.de/people/daniel.abou-ras/SEM.htm

$Ga_{0.95}Mn_{0.05}As$

- Spintronics
- Dilute magnetic semiconductor - new electronics by control of spin?



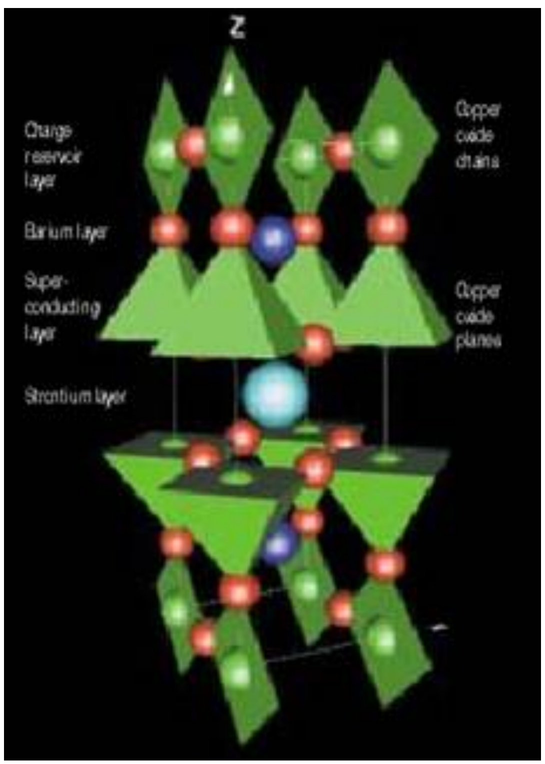
Spin transistor

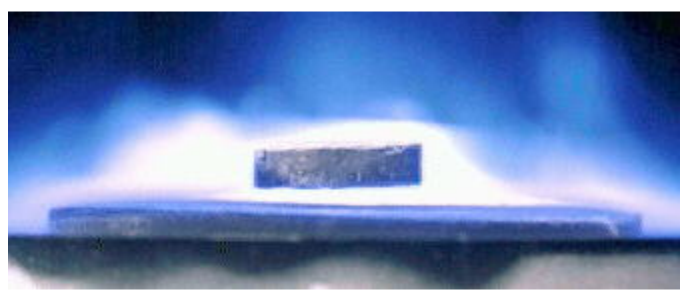


Semiconductor Spintronic Devices

$YBa_2Cu_3O_7$

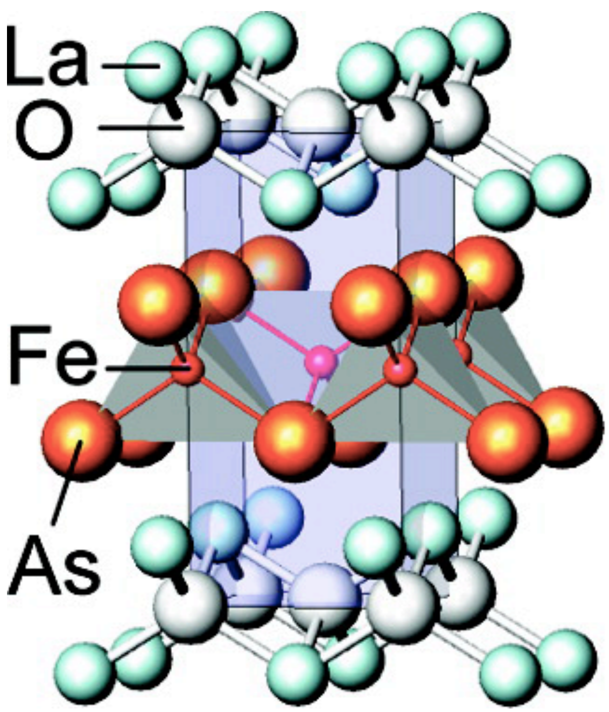
- 90-K high-temperature superconductor
- We still don't really know why it works



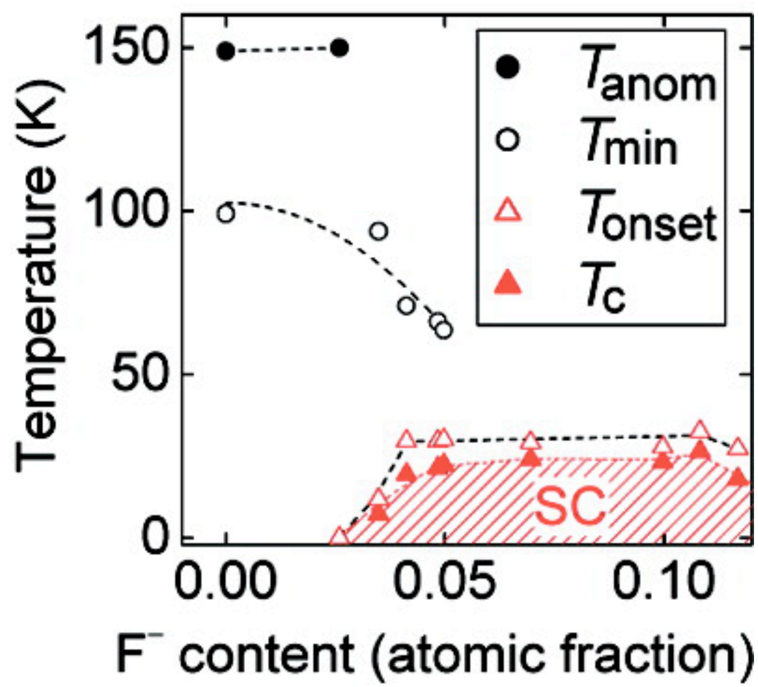


La[$O_{1-x}F_x$]FeAs

- Hosono *et al.*, 2008
- 26-K HTSC with Fe in it!

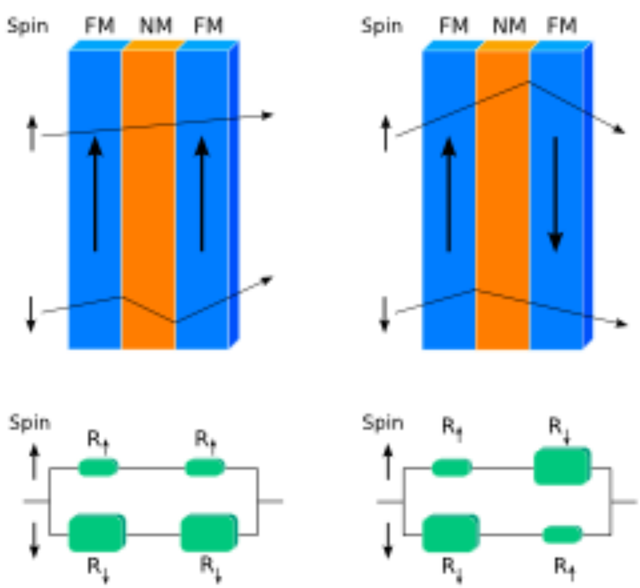


J. Am. Chem. Soc., 2008, 130 (11), 3296-3297



Giant Magnetoresistance (GMR)

- Read heads

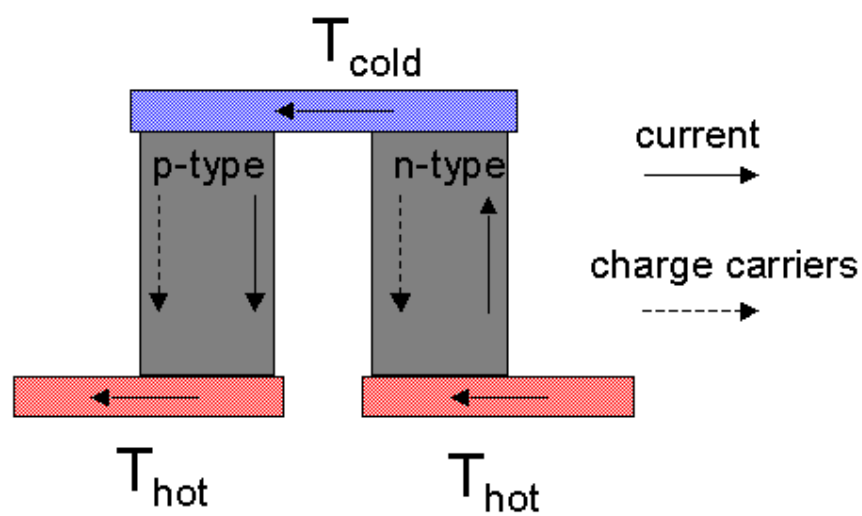


In_2O_3:Sn

- Representative of transparent conductors, transparent semiconductors
- ZnO:Al, SnO_2:F, IGZO, IZO

Thermoelectrics

- Na_xCoO_2
- Bi_2Te_3
- $zT = \alpha^2\sigma T/\kappa$

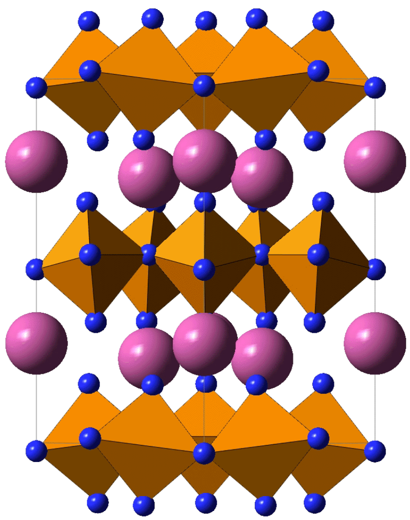


Ferroelectrics

- $BaTiO_3$ PZT (lead zirconate titanate)
- Tunable capacitors, ferroelectric memory (like ferromagnetic)

Multiferroics

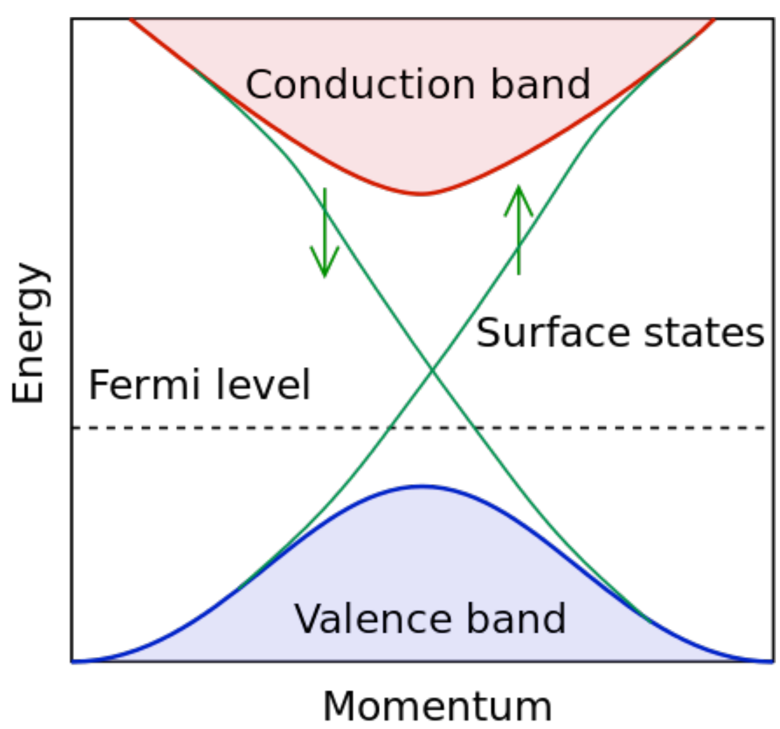
- Some combination of ferromagnetism (or antiferromagnetism), ferroelectricity, or ferroelasticity in same material.
- $HoMnO_3$



Metamaterials

- Photonic crystals (semiconductors with light)
- Negative index materials (sub-wavelength focusing, …)

Topological insulators



Symmetry-protected conducting surface states

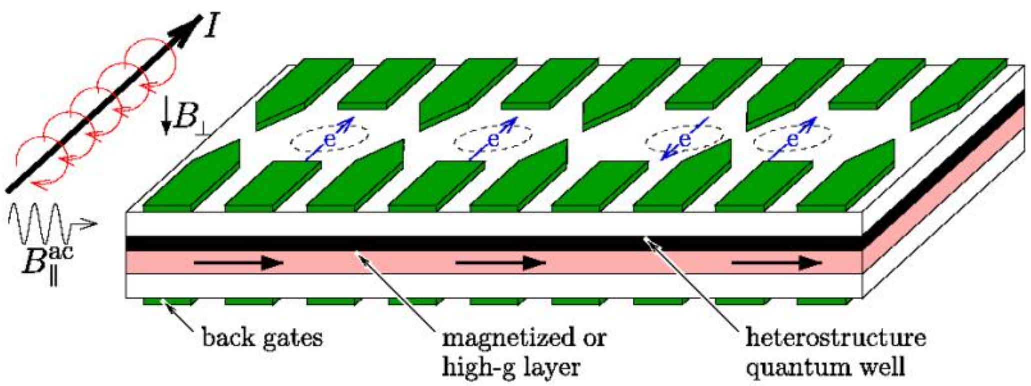
2008: Sb/Bi, Sb, Bi_2Se_3,Bi_2Te_3, Sb_2Te_3

Majorana particles can occur at the interface between a TI and a superconductor. QC applications?

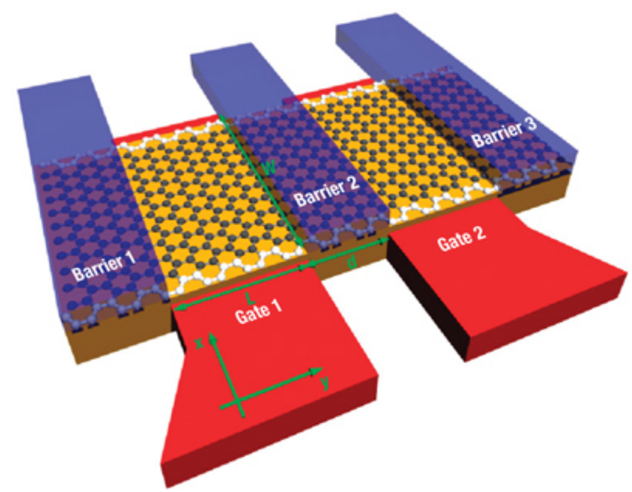
- https://en.wikipedia.org/wiki/Topological_insulator#/media/File:Topological_insulator_band_structure.svg

Qubits & quantum computing

- Quantum computing on a chip?



magnetic-based



Graphene-based

The future

- Solid state lighting
- Solid state batteries
- Solid state heating/cooling
- Solar cells
- Catalysts
- Spintronics
- Quantum computing
- Metamaterials
- Liquid Crystals