Spin Transport in Topological Insulators and in Graphene/Topological Insulator Heterostructures

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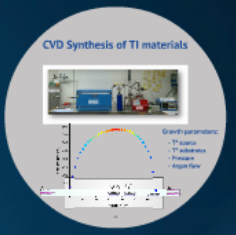

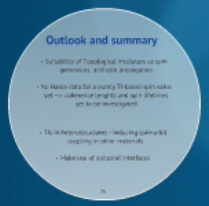

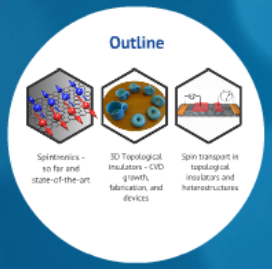

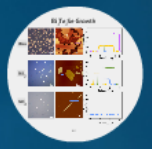

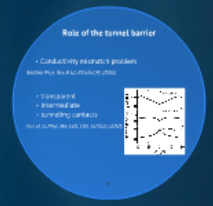

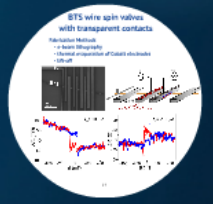

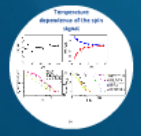

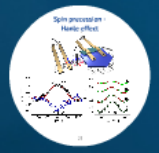

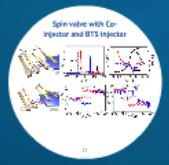

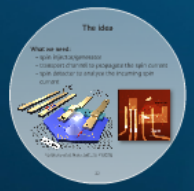

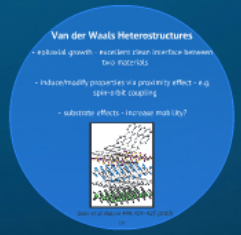

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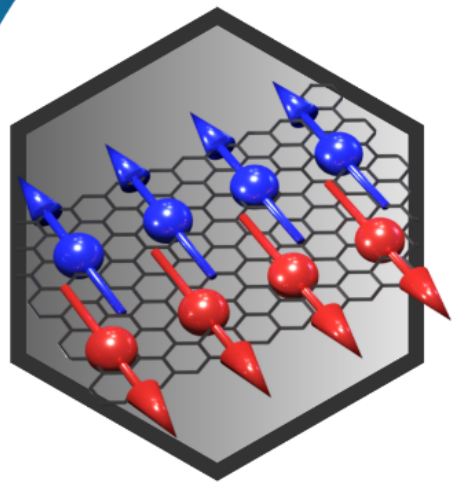
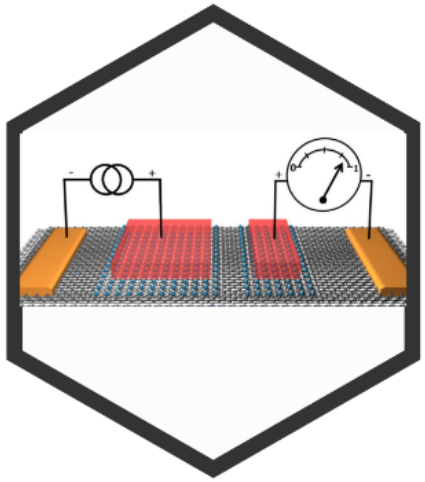
Outline



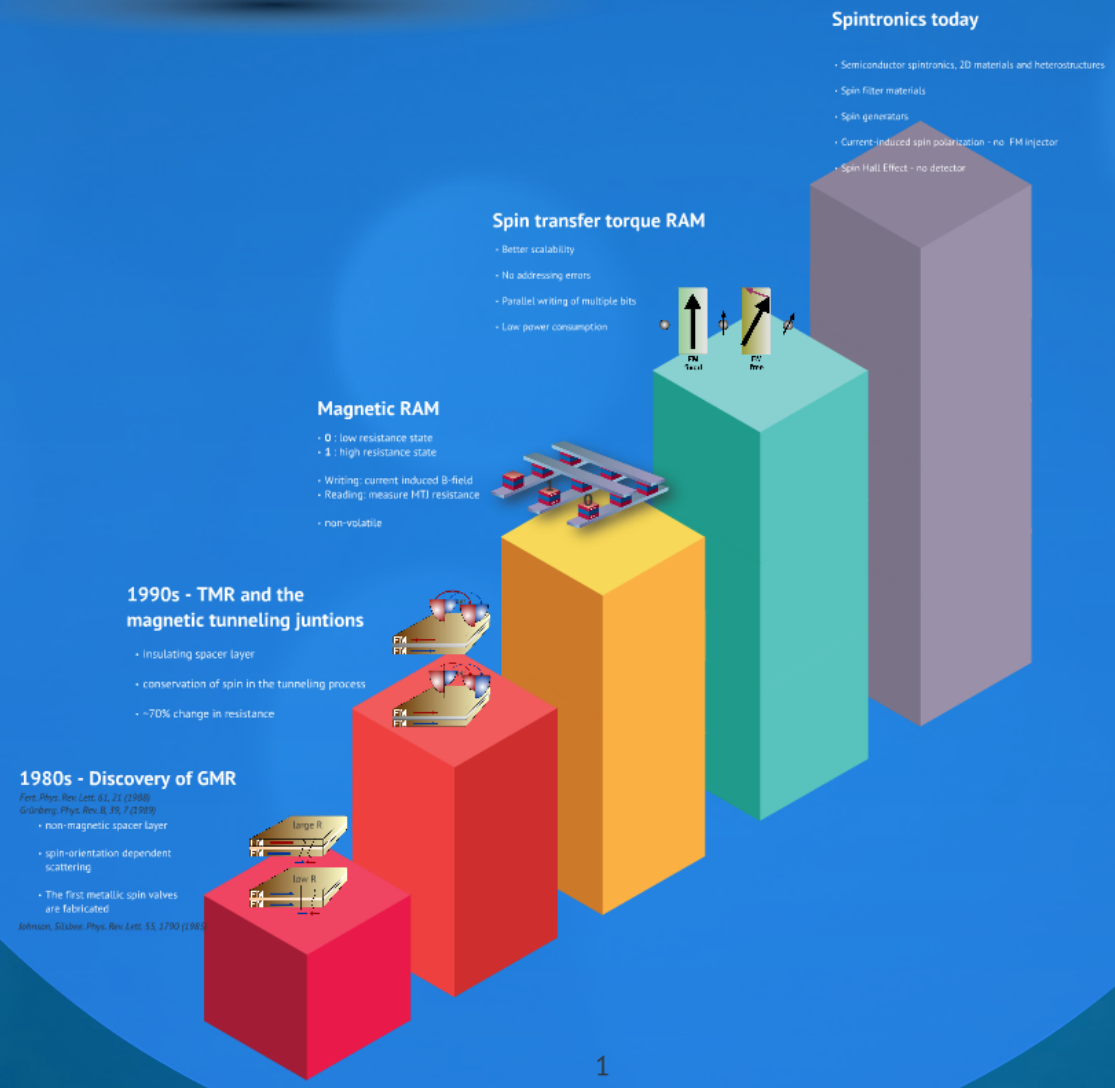
Spintronics - so far and state-of-the-art

3D Topological insulators - CVD growth, fabrication, and devices



Spin transport in topological insulators and heterostructures

Spintronics

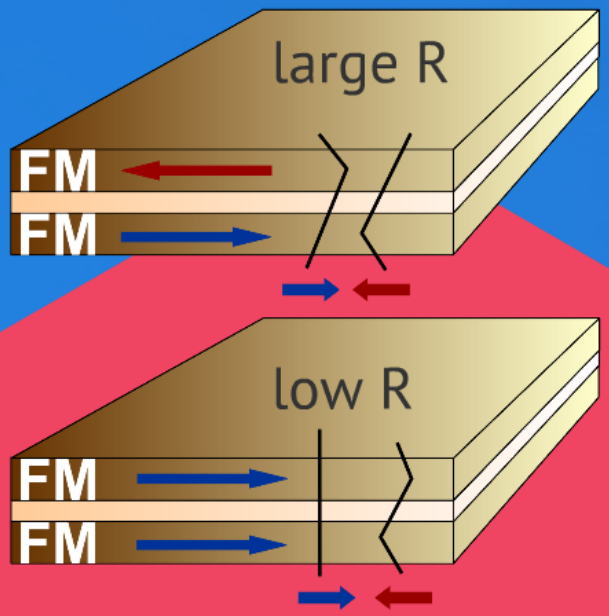


1980s - Discovery of GMR

Fert. Phys. Rev. Lett. 61, 21 (1988)
Grünberg. Phys. Rev. B, 39, 7 (1989)

- non-magnetic spacer layer
- spin-orientation dependent scattering
- The first metallic spin valves are fabricated

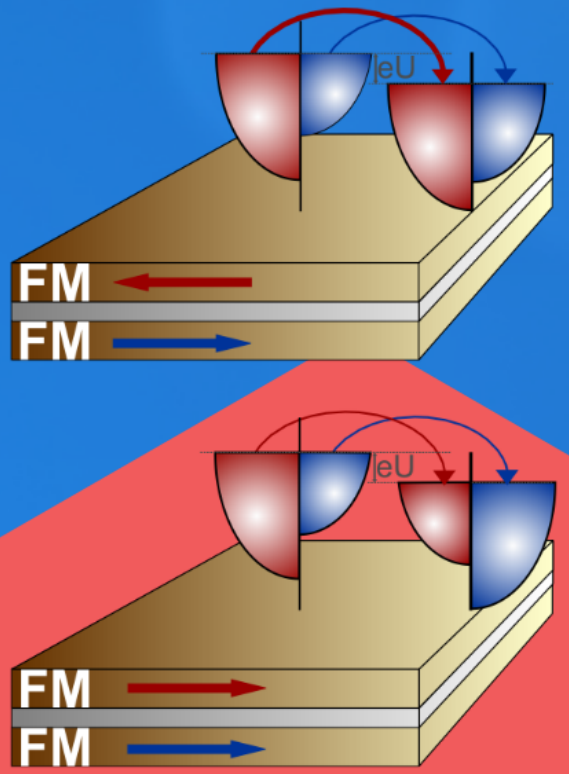
Johnson, Silsbee. Phys. Rev. Lett. 55, 1790 (1985)



- non-volatile

1990s - TMR and the magnetic tunneling juntions

- insulating spacer layer
- conservation of spin in the tunneling process
- ~70% change in resistance



covery of GMR

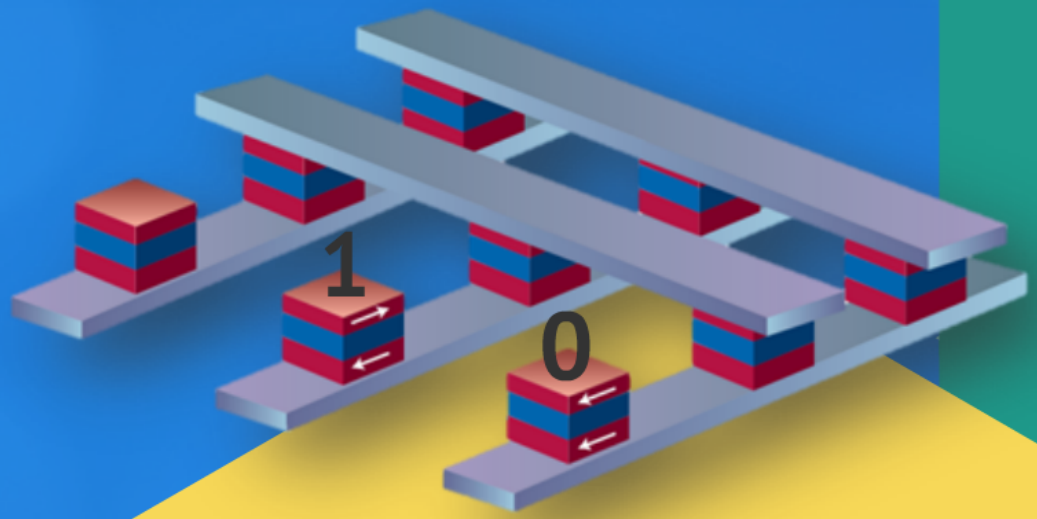
• Low power consumption

Magnetic RAM

- **0** : low resistance state
- **1** : high resistance state

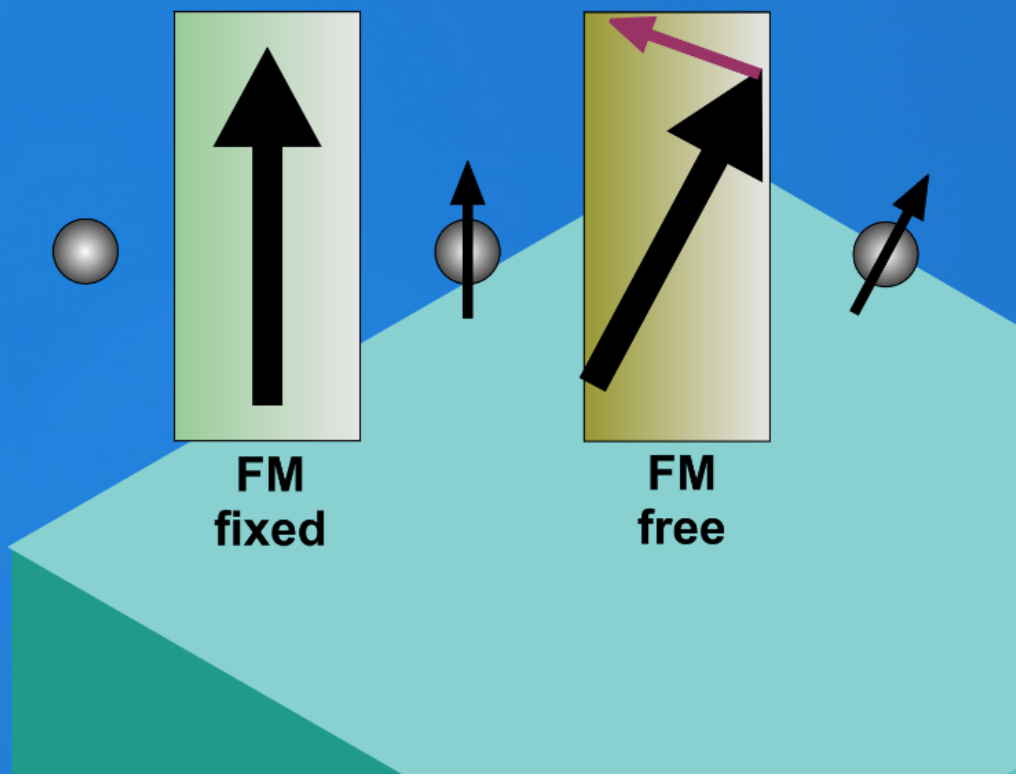
- Writing: current induced B-field
- Reading: measure MTJ resistance

- non-volatile



Spin transfer torque RAM

- Better scalability
- No addressing errors
- Parallel writing of multiple bits
- Low power consumption



Spintronics today

- Semiconductor spintronics, 2D materials and heterostructures
- Spin filter materials
- Spin generators
- Current-induced spin polarization - no FM injector
- Spin Hall Effect - no detector

However downscaling becomes problematic...

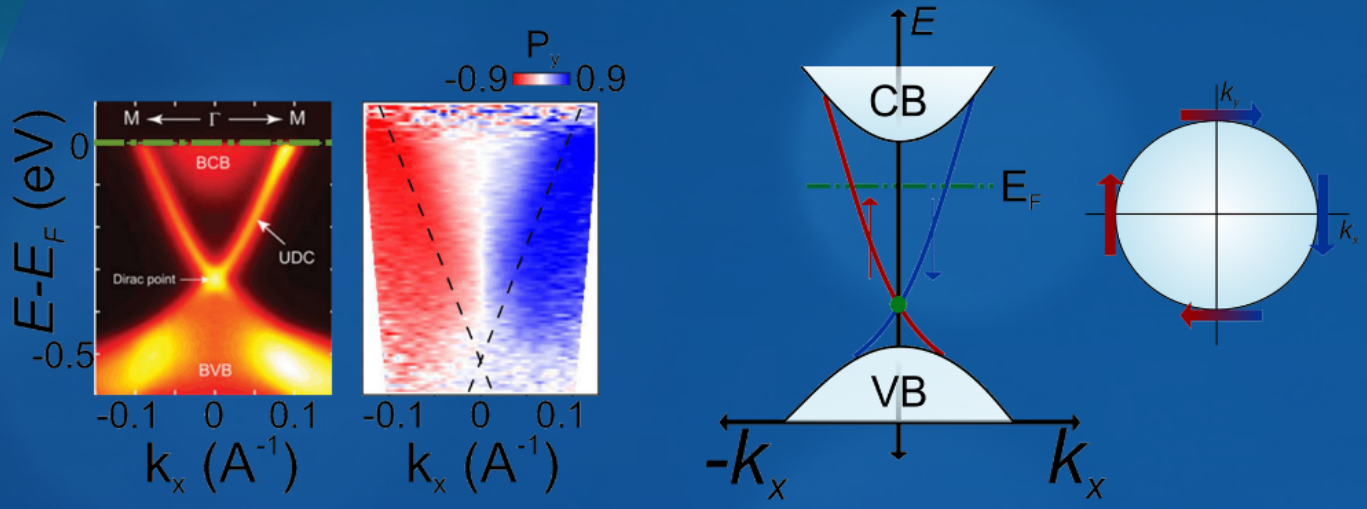
- External magnetic fields needed to induce spin switching (i.e. extra wires addressing neighboring bits in MRAM)
- quantum effects at the nanoscale (e.g. tunneling)
- stray magnetic fields

All-electric spintronics

To solve this...

- Go „all-electric“ - control of the spin orientation using purely electrical means
- Spin-transfer torque (STT) MRAM - *Everspin*
- Tunneling Anisitropic Magnetoresistance (TAMR)
- Ferromagnetic insulators as spin filters – e.g. EuO, EuS
- Materials with strong spin-orbit coupling as spin generators

Topological insulators in all-electric spintronics



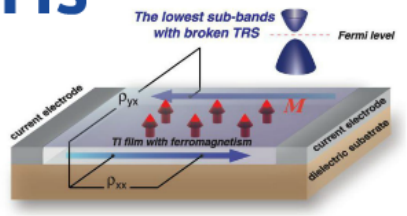
- Surface states as a spin generator
- TI as a spin channel in spintronic devices

Advantage - no ferromagnetic injector electrode needed!

State of the art spin transport in TIs

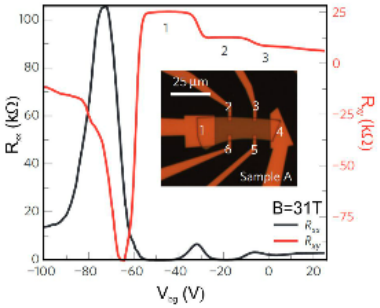
Interaction of TI surface states and magnetic materials - QAHE

Chang et al. Science 340, 6129, 167-170 (2013)



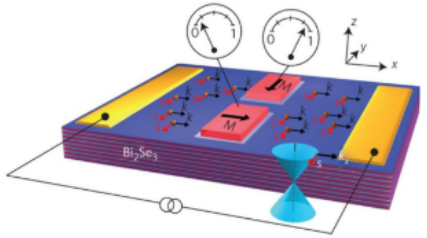
Quantum Hall Effect in a TI

Xu et al. Nat. Phys. 10, 956–963 (2014)



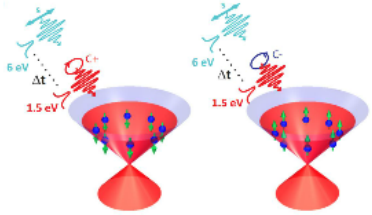
Current-induced spin polarization in TIs

Li et al. Nat. Nanotechnol. 9, 218–224 (2014)



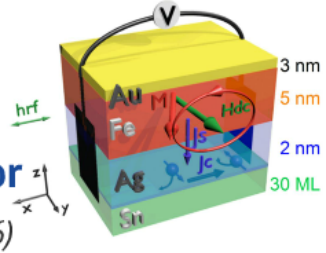
Ultrafast spin-polarization control of Dirac fermions in TIs using circularly polarized light

Sánchez-Barriga et al. Phys. Rev. B 93, 155426 (2016)



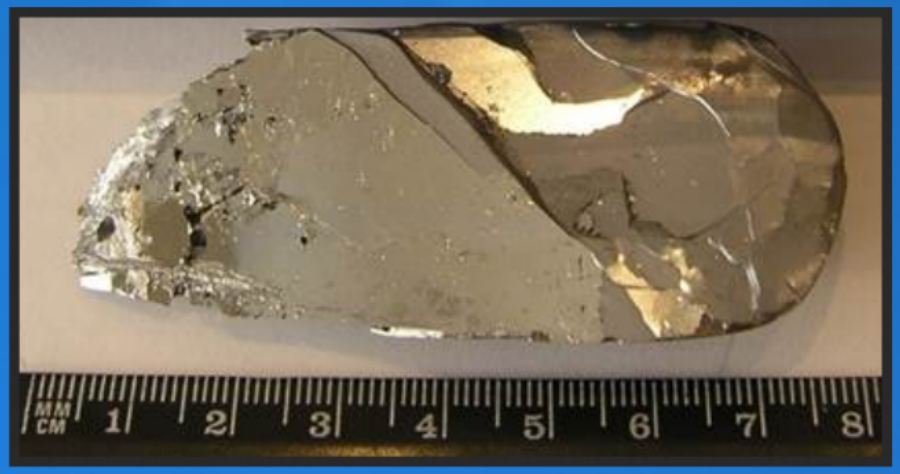
Spin to Charge Conversion at RT by Spin Pumping into a Topological Insulator

Rojas-Sánchez et al. Phys. Rev. Lett. 116, 096602 (2016)

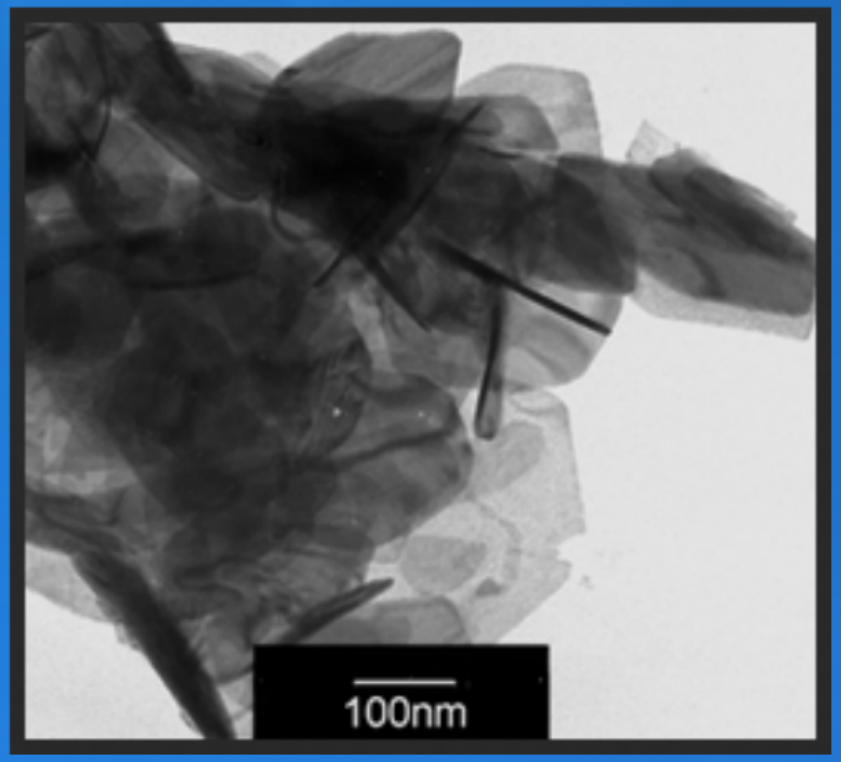


How to fabricate TI materials?

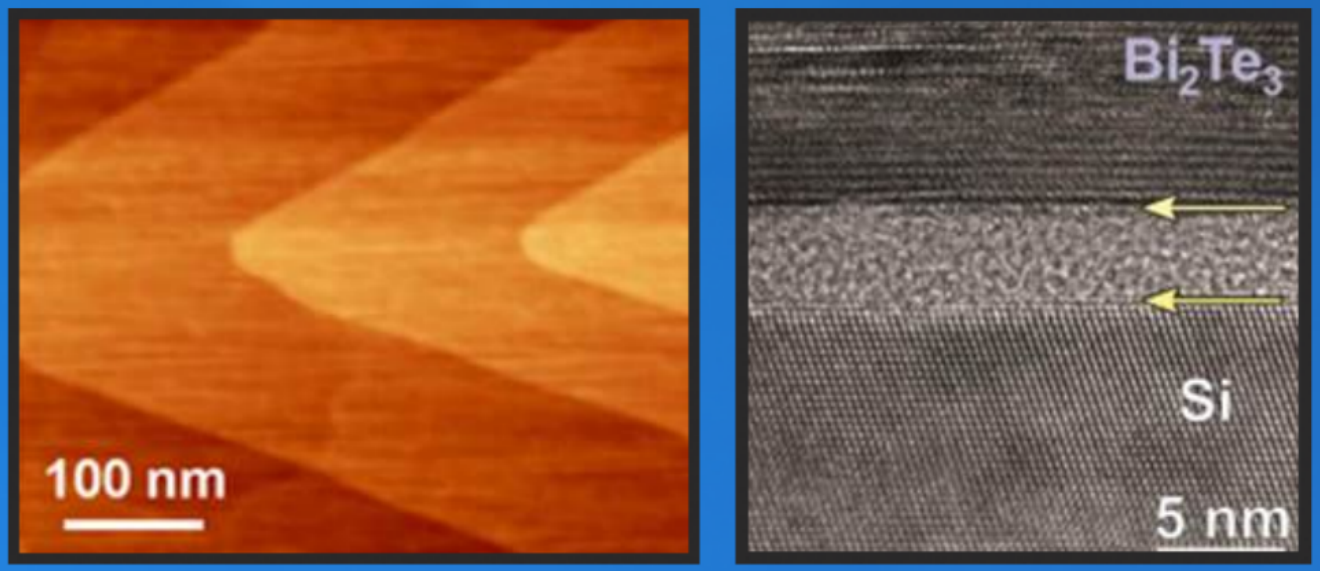
Bridgman method



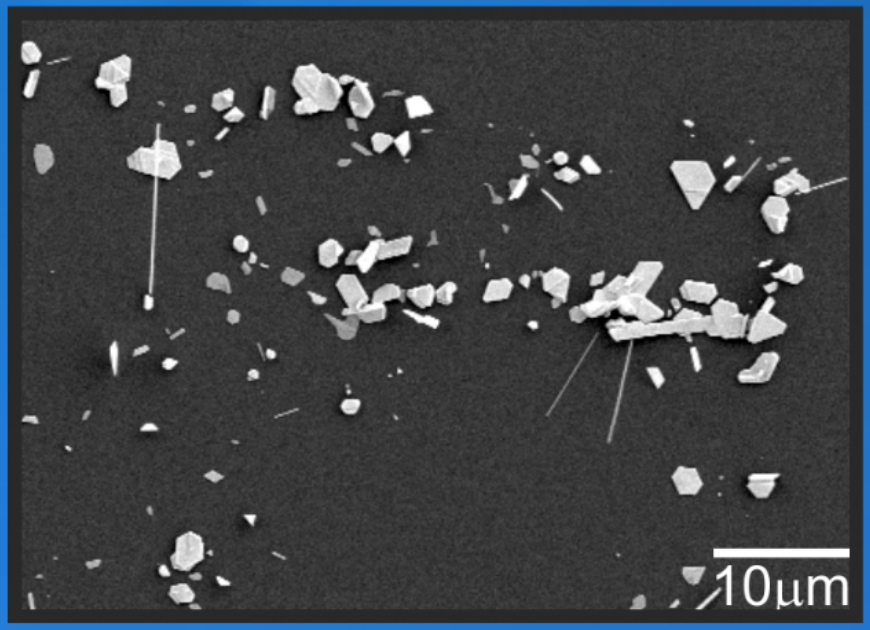
Chemical synthesis



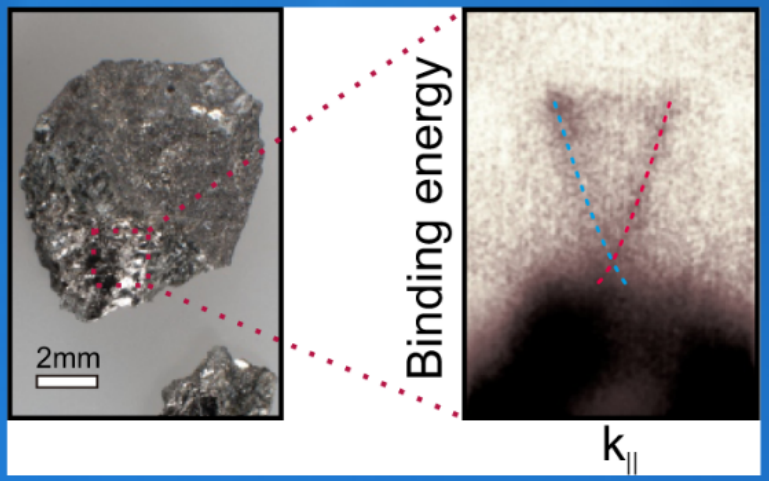
MBE/PLD



CVD

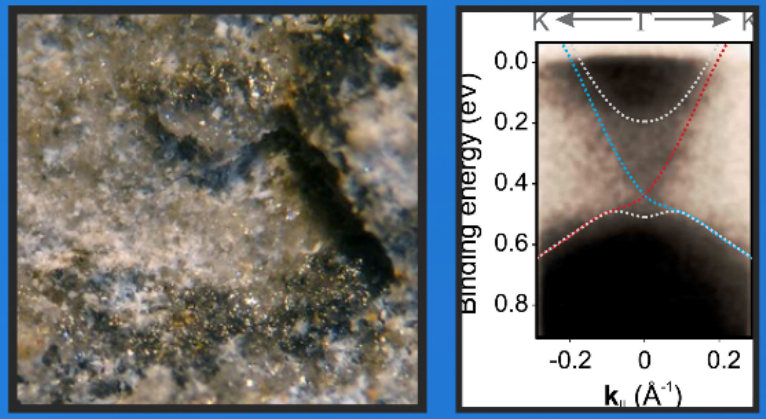


Kawazulite



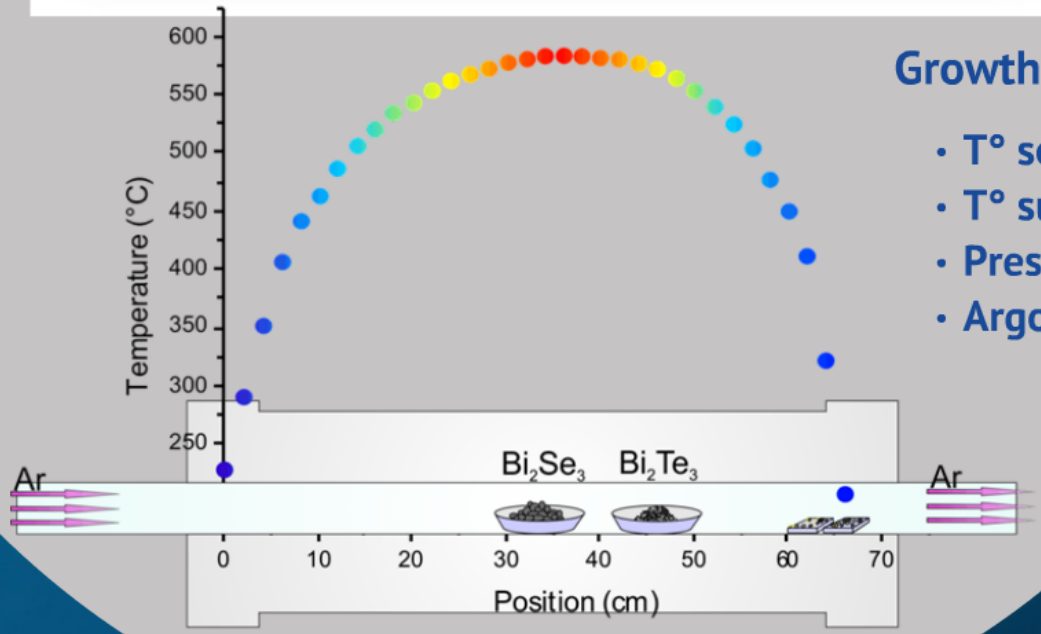
Gehring et al. Nano Lett. 13 (3), pp 1179–1184 (2013)

Aleksite



Gehring, Vaklinova et al. Scientific Reports 5, 11691 (2015)

CVD Synthesis of TI materials

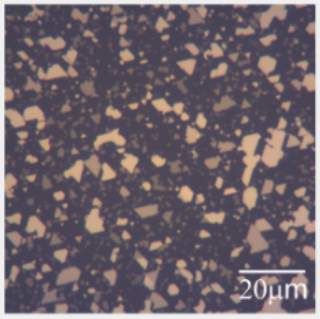


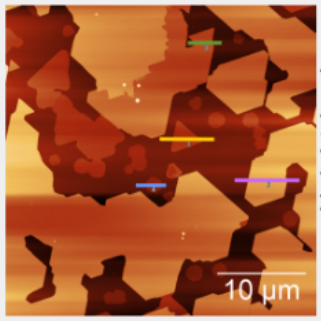
Growth parameters:

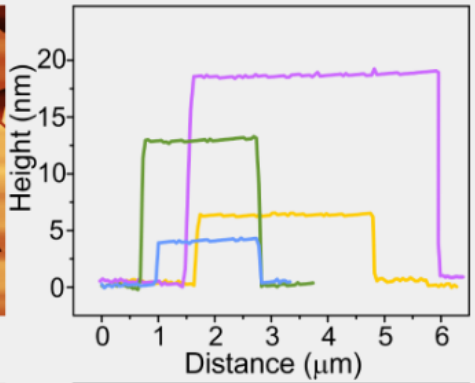
- T° source
- T° substrates
- Pressure
- Argon flow

Bi_2Te_2Se Growth

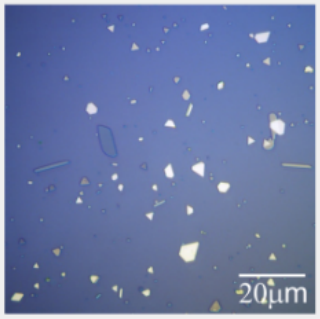
Mica

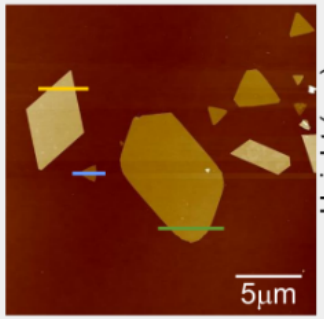


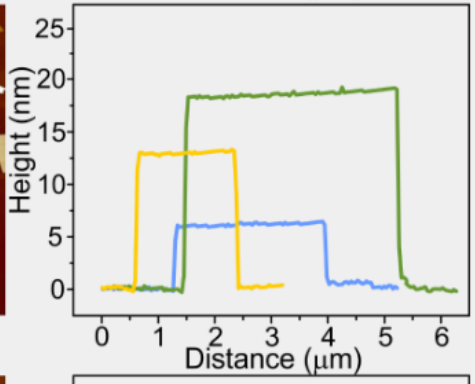




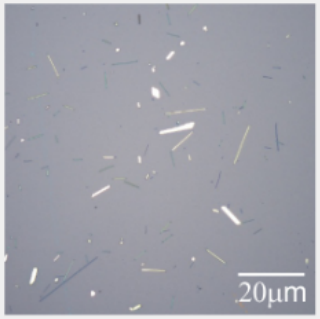
SiO_2

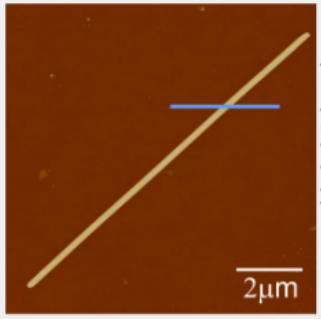


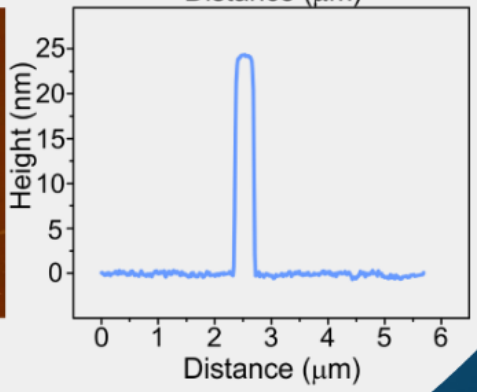




SiO_2







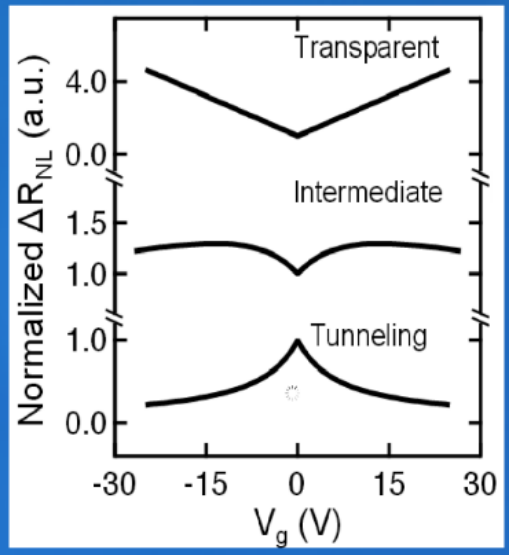
Role of the tunnel barrier

- Conductivity mismatch problem

Rashba. Phys. Rev. B 62, R16267(R) (2000)

- transparent
- intermediate
- tunneling contacts

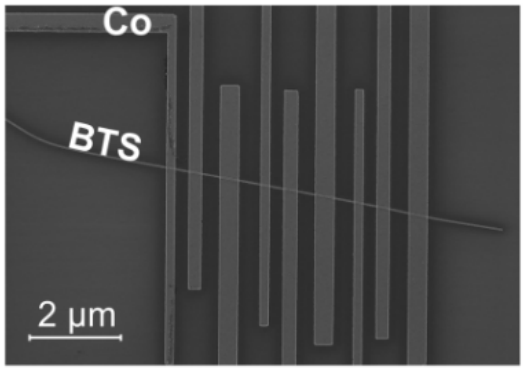
Han et al. Phys. Rev. Lett. 105, 167202 (2010)

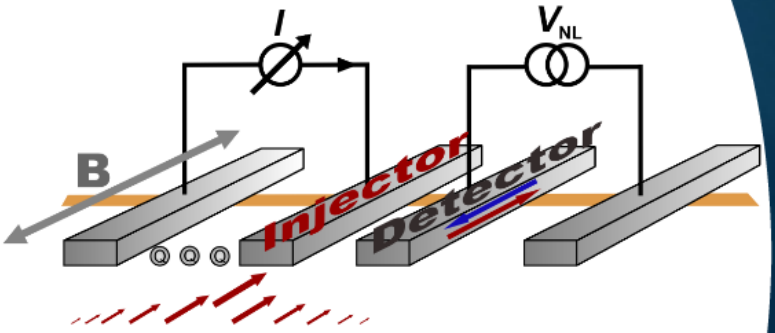


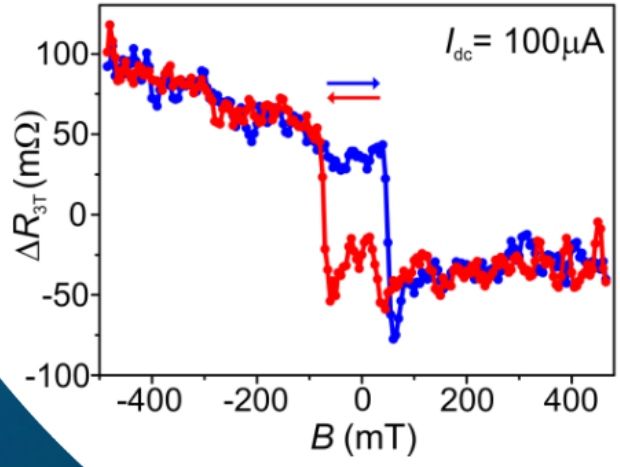
BTS wire spin valves with transparent contacts

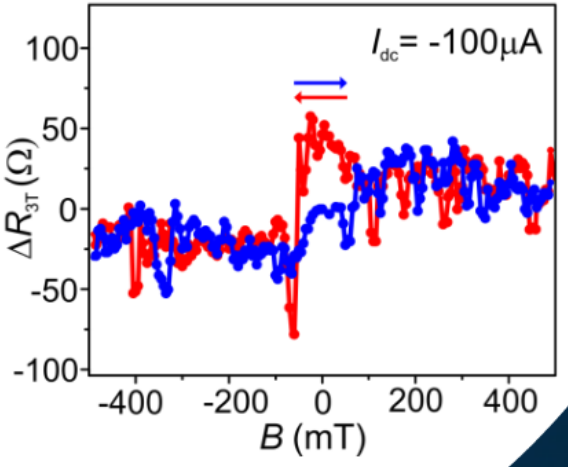
Fabrication Methods

- e-beam lithography
- thermal evaporation of Cobalt electrodes
- lift-off







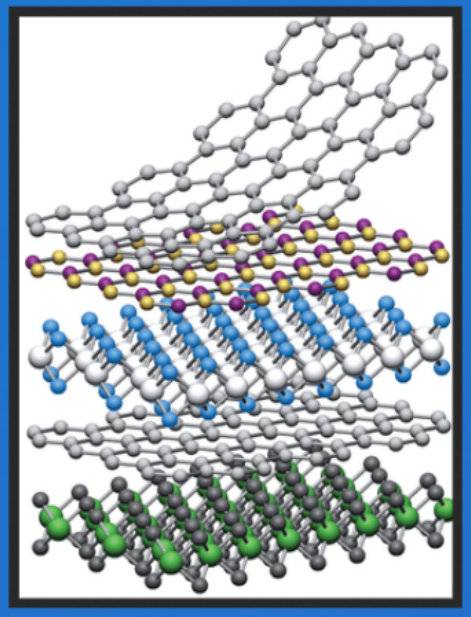


Van der Waals Heterostructures

- epitaxial growth - excellent clean interface between two materials

- induce/modify properties via proximity effect - e.g. spin-orbit coupling

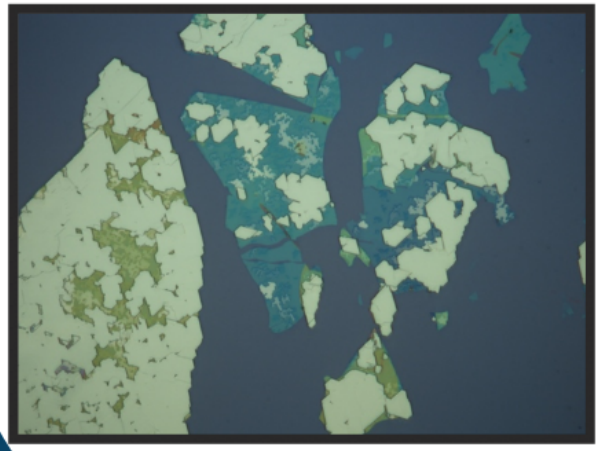
- substrate effects - increase mobility?

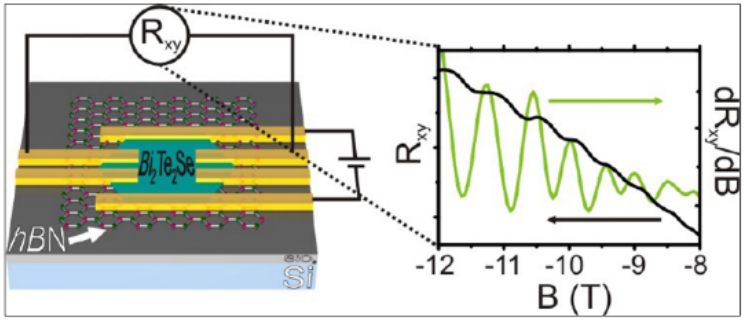


Geim et al. Nature 499, 419–425 (2013)

BTS on hBN

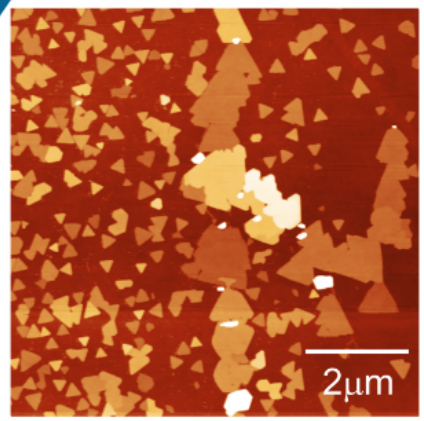
- Exfoliated hBN - atomically flat growth substrate
- epitaxial growth - lattice mismatch ~ 2.9%
- increased mobility - Shubnikov - de Haas oscillations

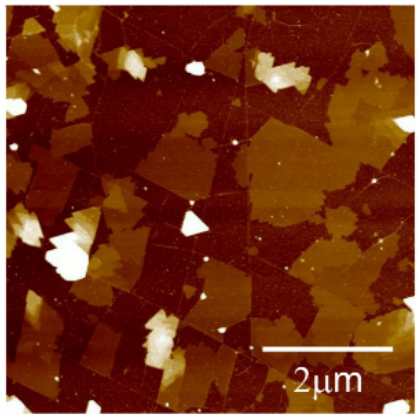


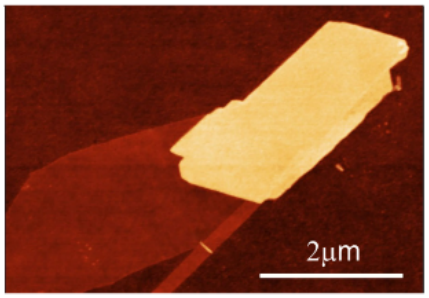


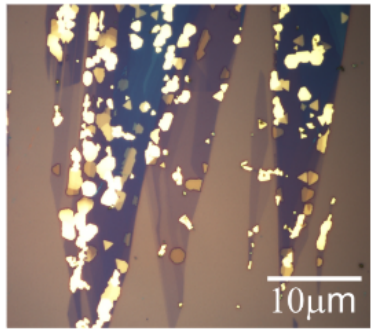
Gehring et al. Nano Lett., 12, 10 (2012)

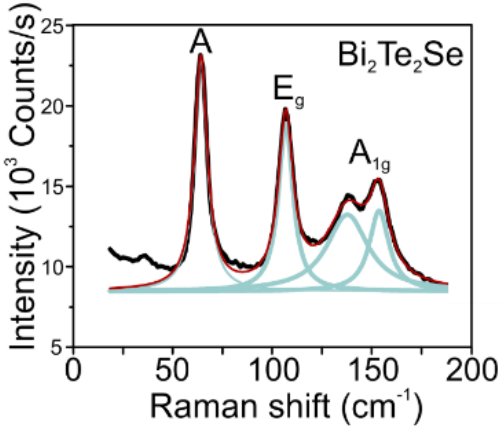
BTS on Graphene

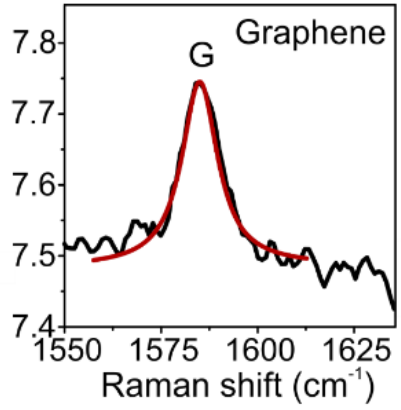










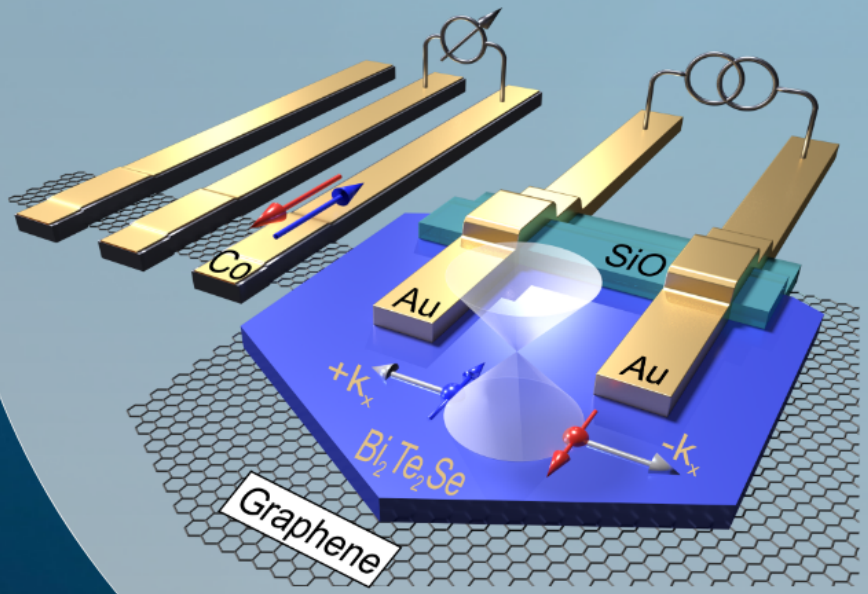


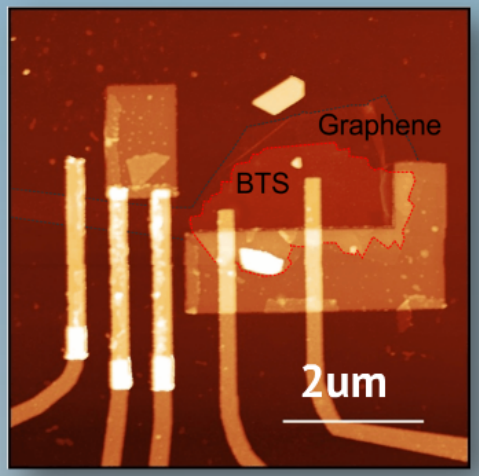
Can we use this heterostructure for spin-transport?

The idea

What we need:

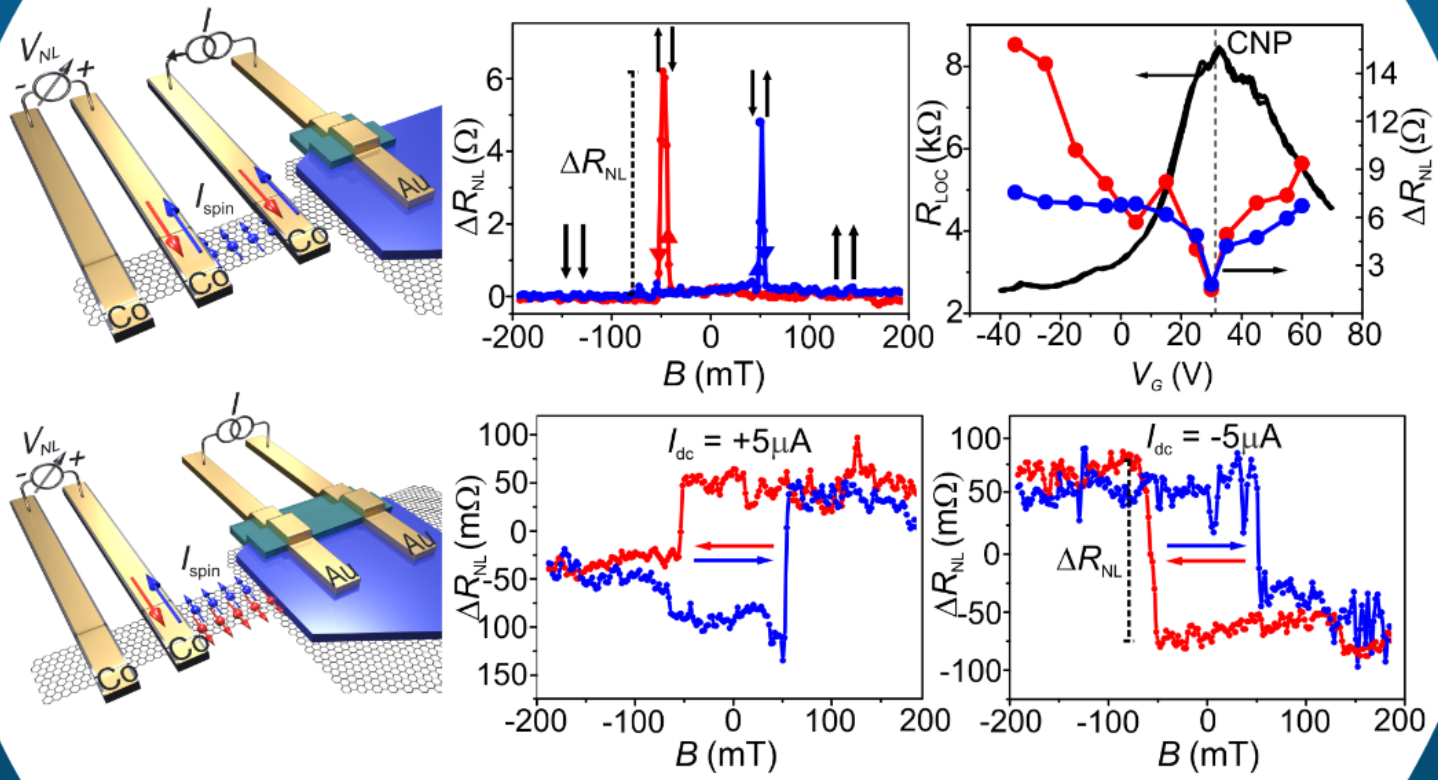
- spin injector/generator
- transport channel to propagate the spin current
- spin detector to analyze the incoming spin current



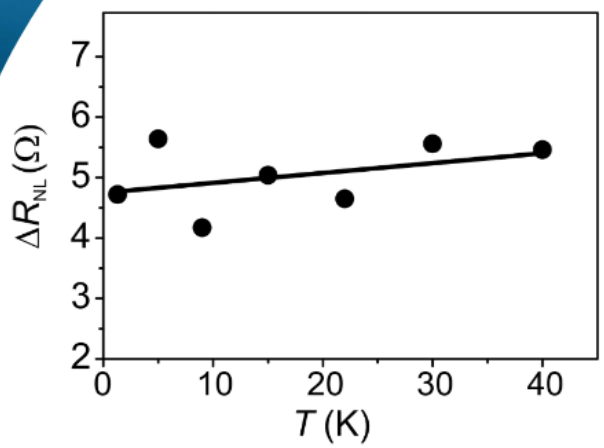


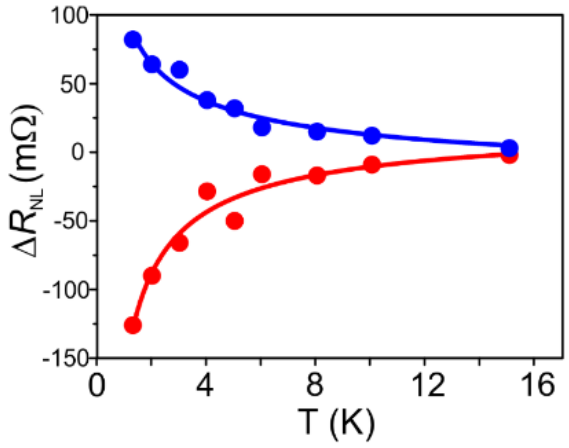
Vaklinova et al. Nano Lett., 16, 4 (2016)

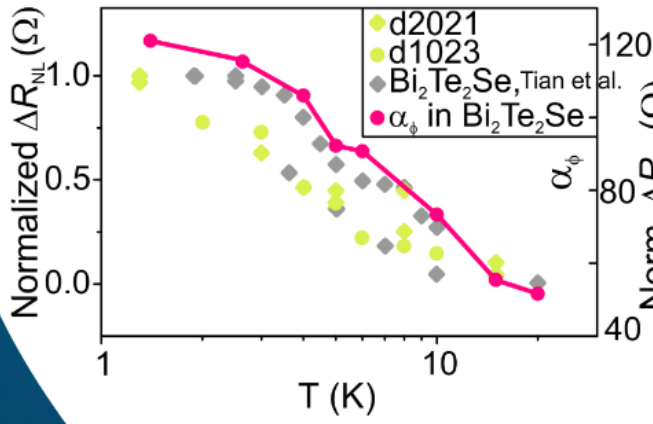
Spin valve with Co-injector and BTS injector

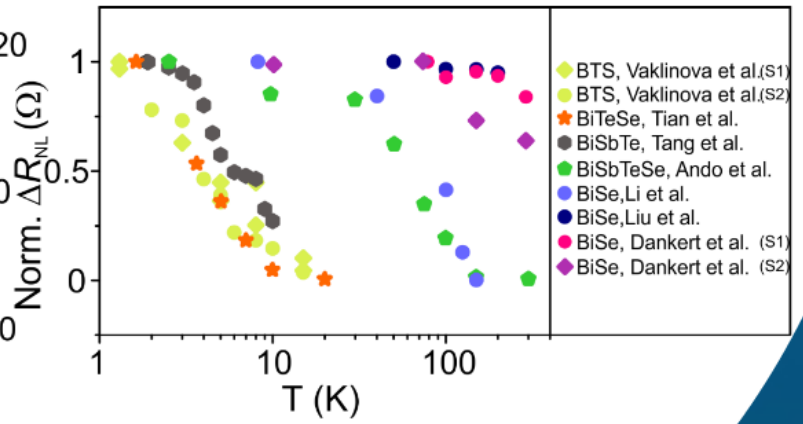


Temperature dependence of the spin signal

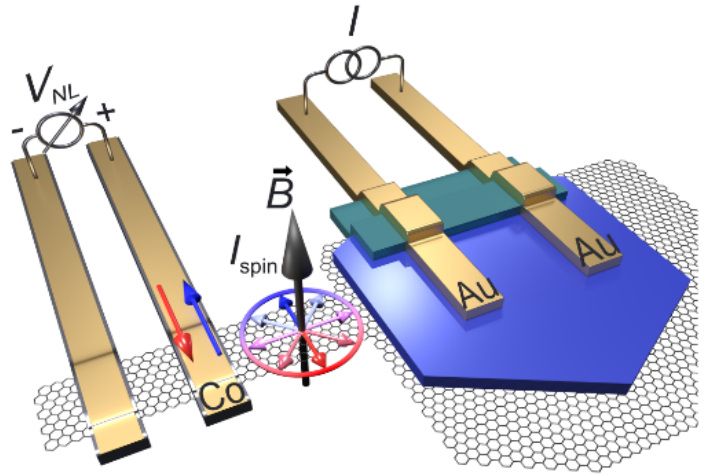


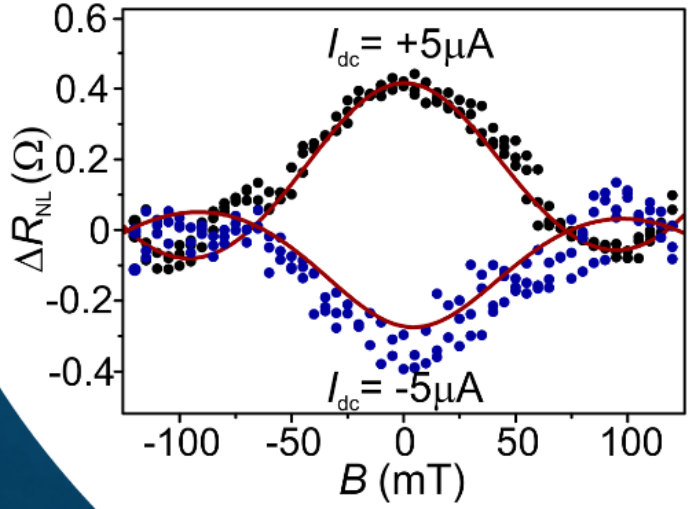


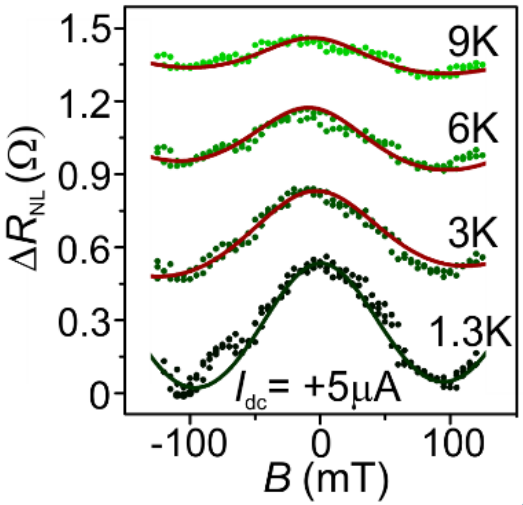




Spin precession - Hanle effect







Outlook and summary

- Suitability of Topological insulators as spin generators and spin propagators

- No Hanle data for a purely TI-based spin valve yet --> coherence lenghts and spin lifetimes yet to be investigated

- TIs in heterostructures - inducing spin-orbit coupling in other materials

- Make use of epitaxial interfaces