Spintronics Fundamentals

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Brooks Tellekamp

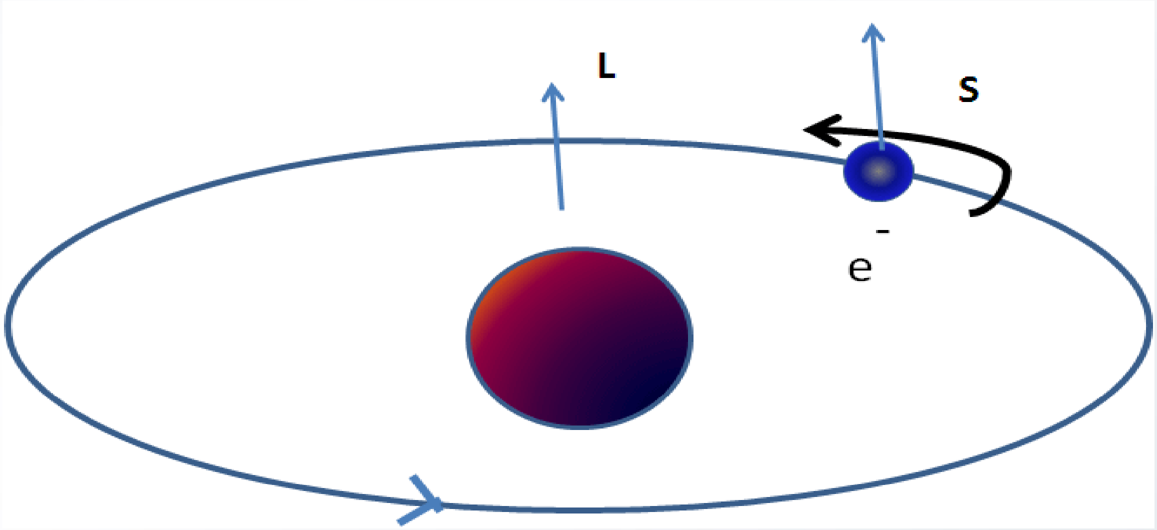
Georgia Institute of Technology

Outline

- **Atomic Spin**
- **Field Spin Effects**
- **Parts of a Spintronic Device**
- **Spintronic Devices**
- **Quantum Possibilities**
- **Benefits**
- **Issues with Modern Spintronic Technology**

Atomic Spin

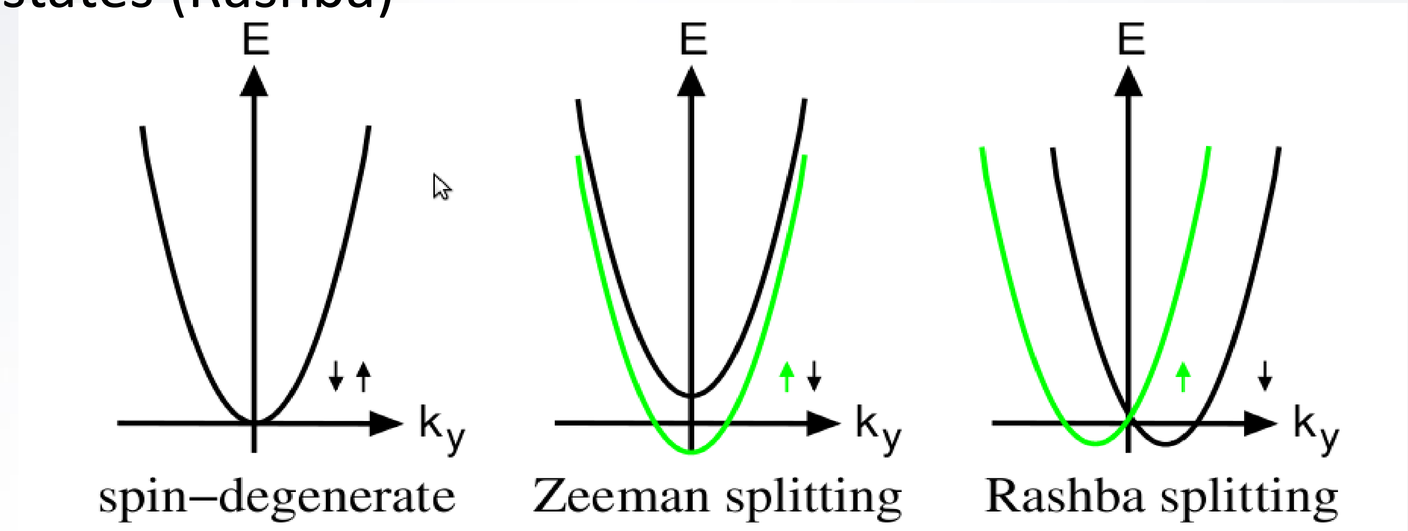
- Two discrete states - spin up and spin down
- Spin indeterminate (useful for quantum computing possibilities)
- Spin up and spin down electrons have different wavefunctions and different energies in certain materials
- The nucleus also has an orbital associated spin, which gives rise to spin-orbit interactions



http://www.nitt.edu/home/academics/departments/physics/faculty/lecturers/justin/students/magnetic/origin/

Zeeman Effect/Rashba Effect

- Spin-orbital interactions give rise to different effects.
  - In the presence of a magnetic field, the energy states of fermions such as electrons will split into discrete spectral lines (Zeeman)
  - In the presence of a perpendicular electric field the magnetic moment of the electron shifts and the electron spin and nuclear orbit interact, causing energy states split into distinct states (Rashba)



http://www.massey.ac.nz/~uzuelick/Cluster09.pdf

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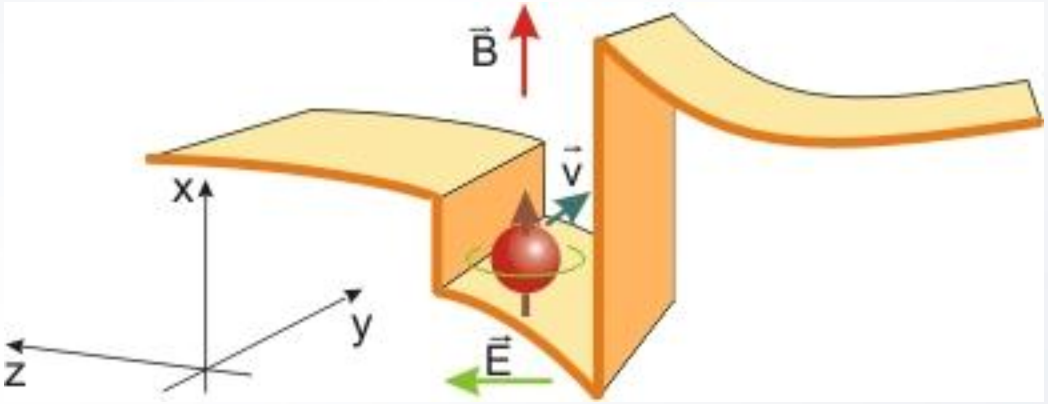
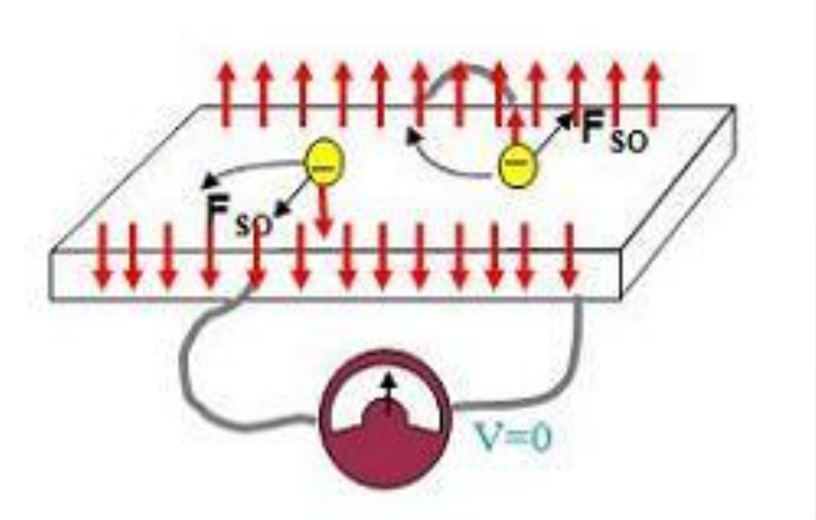
Zeemen Effect/Rashba Effect

- In Rashba splitting, multiple quantum energy states are created by doping a quantum well asymmetrically
- This difference in conduction band levels creates a field, called constant inversion asymmetry, which allows the Rashba effect to occur
- Control of this field allows electron spin states to be manipulated



Spin Hall Effect

- In the presence of a perpendicular electric field, the magnetic moment of spin electrons are modified.
- The electric and magnetic fields propel the electrons to either side of the material they are in, depending on their spin characteristics
- So by applying a field across a spin polarized region, spin states can be filtered



http://www.phy.cam.ac.uk/research/oe/nanospintronics.php

Spin Injection

- Ferromagnetic material injection methods:
  - A ferromagnetic material is joined to the semiconductor, causing "pinning" of the spin states
  - Directing a current through a ferromagnetic material will polarize it's electrons
  - Doping semiconductors heavily with ferromagnetic materials can have the same effect
- Optical orientation – circularly polarized photons transfer their angular momentum to electrons
- Spin Hall Effect – using a perpendicular electric field to separate spin up and spin down electrons

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Spin Detector

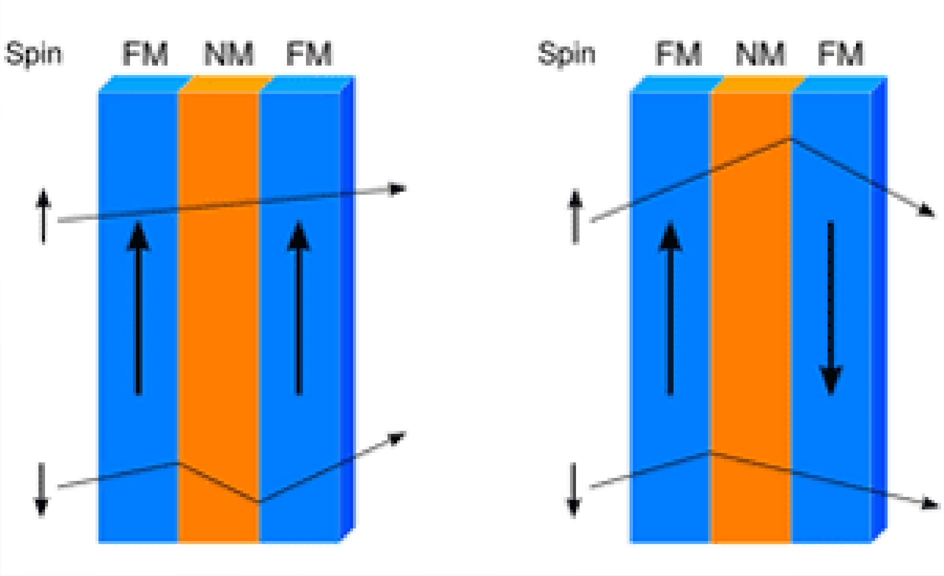
- Resistance is the simplest way to detect spin
  - For a pinned ferromagnetic material higher resistance indicates opposite spin of carriers, while lower resistances indicate the spin carriers are in line with the pinning level
  - This can be easily measured as current or voltage changes, depending on the configuration of the detector

Spin Transport and Manipulation

- Spin transport becomes an issue because of carrier lifetime.
  - Spin polarized electrons collide and lose their spin, high mobility is key
- Manipulated by:
  - Rashba Effect (applied electric fields)
  - Zeeman Effect (applied magnetic fields)
  - Circularly polarized light

Spin Valve

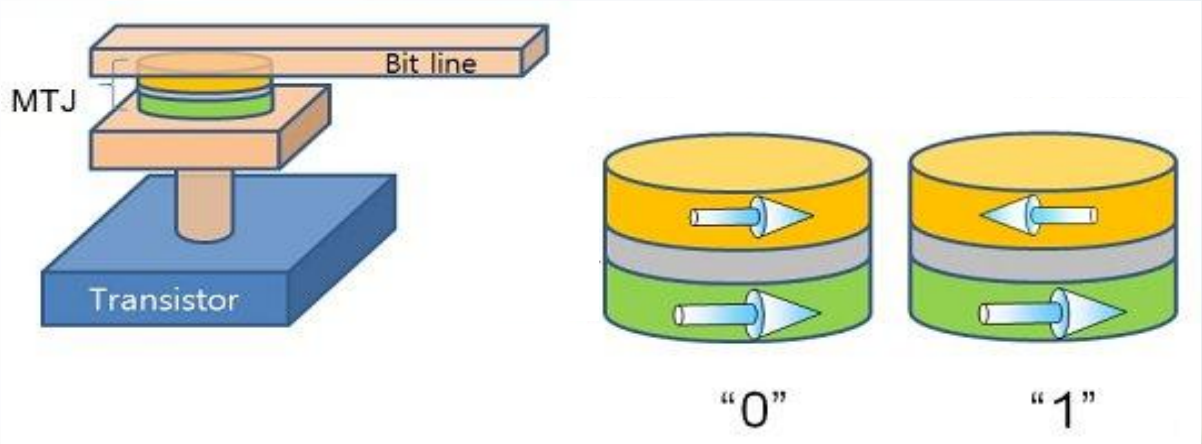
- The most basic spintronic device, comprised of two ferromagnetic layers separated by a nonmagnetic layer
  - One layer is pinned with another ferromagnet
  - The other layer orients based on the surrounding field
  - When the orientation of the two layers is parallel, the resistance is low due to low scattering
  - When the orientation is antiparallel, large electron scattering causes high resistance
  - Used for HDD



http://www.physicscentral.com/explore/action/magnetoresistance-1.cfm

Magnetic Tunnel Junction

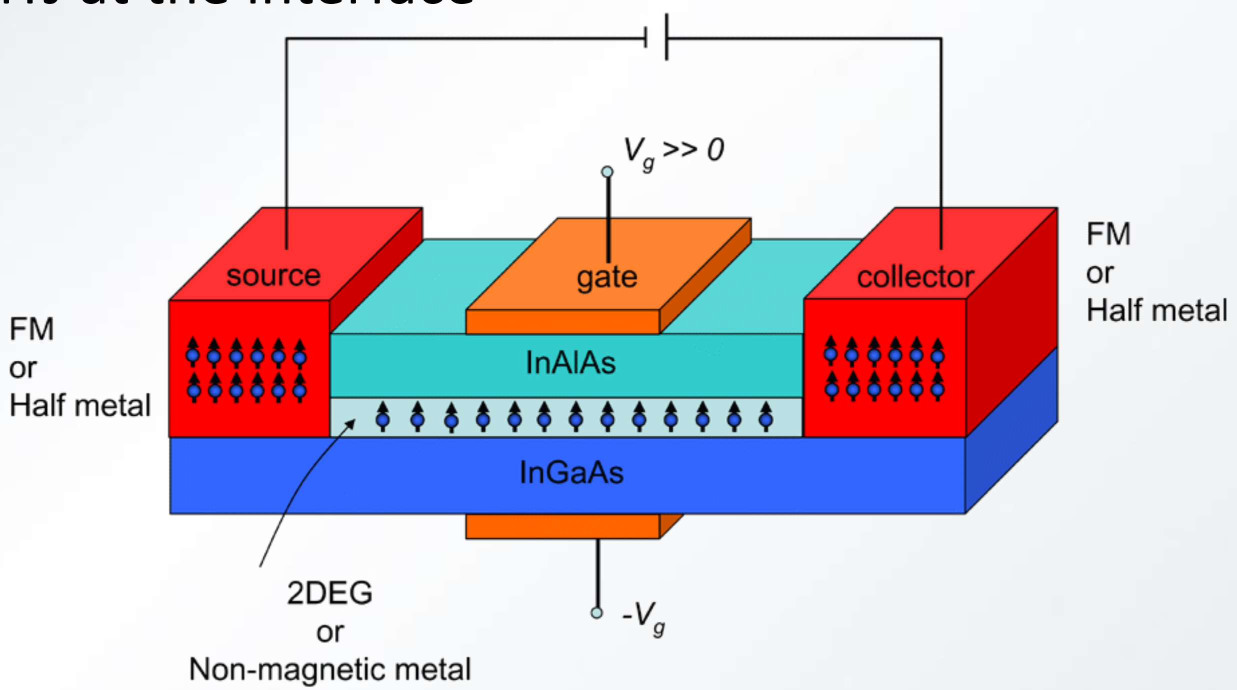
- Similar in structure to a spin valve, with a thin nonmagnetic layer through which electrons can tunnel
- With a bias applied across the ferromagnetic contacts, tunneling occurs when both spins are oriented in the same direction
  - Controlled by a small external magnetic field
  - Used for MRAM and spin injection



http://www.sciencetimes.co.kr/article.do?todo=view&atidx=0000035145

Spin-FET

- Field effect device based on electron spin
- Gate applied field modifies spin in the channel due to the Rashba effect
- With an applied field, the spin stays oriented and low resistance at the detector allows for transistor-type switching through the use of a MTJ at the interface



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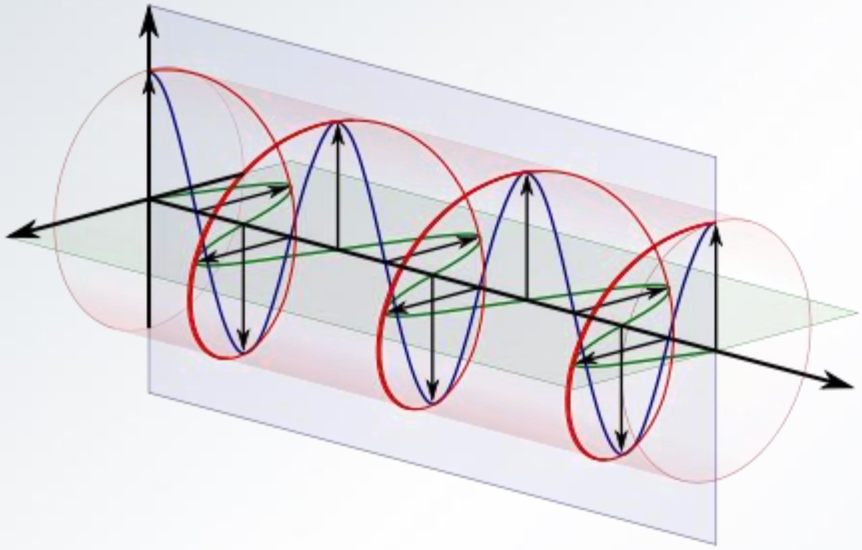
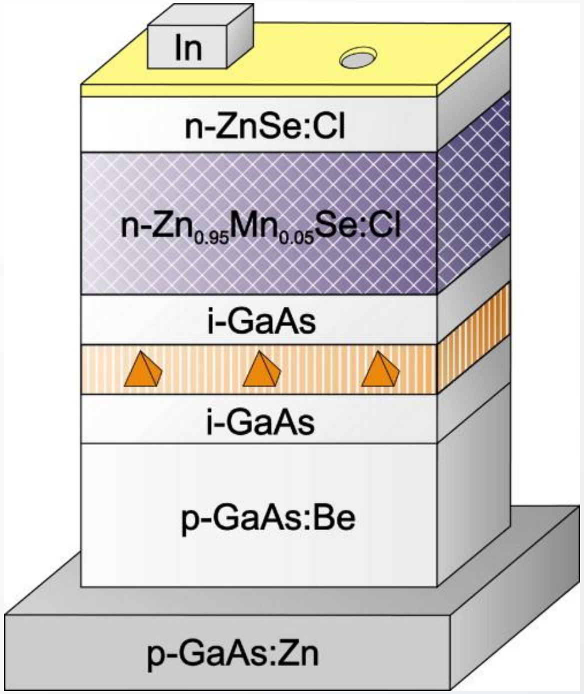
Optically polarized LEDs

- **A polarized spin current is pumped into a quantum well LED structure, and circularly polarized photons are emitted.**



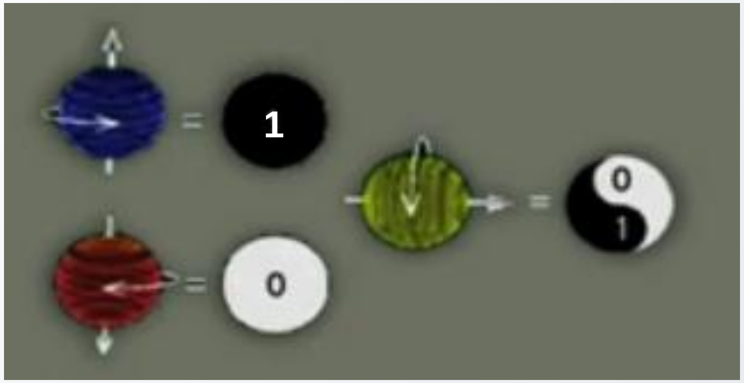


Asshoff, Pablo, Andreas Merz, Heinz Kalt, and Michael Hetterich. "A Spintronic Source of Circularly Polarized Single Photons." Applied Physics Letters, 98.11 (2011): 112106-112108.

http://www.g3tct.co.uk/diversity.html

Quantum Devices – Theorizing for the Future

- Using the ideas of uncertainty along with the indeterminate quantum state exhibited by electrons, quantum devices have become a possibility.
- Electron spin can represent the state of a “qubit”, and a quantum machine could then simultaneously occupy a superposition of any number of 2^n states for n qubits, or spin electrons
- Diamond packed with many nitrogen defects provides a room temperature semiconductor with acceptors acting as electron traps, where the spin can be manipulated on an individual electron level by magnetic fields or optical filtering



Quantum Computing

- Interpretation of such data could allow for the implementation of many quantum algorithms to solve problems that have no solution in real space.
- For the interested mind, here is a presentation at a TEDx conference at Cal Tech on quantum computing using spintronics devices
- http://www.youtube.com/watch?v=g9NAUPbqAvE

Benefits

- Size – Because spintronic devices rely on the spin of one electron to carry data, devices can theoretically be scaled down to an atomic level.
- Energy Efficient – Spintronic devices require much less power to operate
- Potential for quantum computing due to uncertainty of states
- Research has been done in the field of spintronic memristors, using the time decay of spin polarization and other properties to provide hysteresis through the application of an electric field

Obstacles

- Most ferromagnetic doped semiconductors only operate at very low temperatures
  - Some options have been discovered, for example Co:ZnO
  - These are expensive
- Interface impurities between a ferromagnetic and semiconductor layer destroys much of the spin polarization, introducing the need for such room temperature semiconductors
- Carrier lifetime of spin electrons is still very low
- Spin detection devices are still primitive