Introduction to Spintronics

INTRODUCTION

- Conventional electronic devices ignore the spin property and rely strictly on the transport of the electrical charge of electrons

- Adding the spin degree of freedom provides new effects, new capabilities and new functionalities

Future Demands

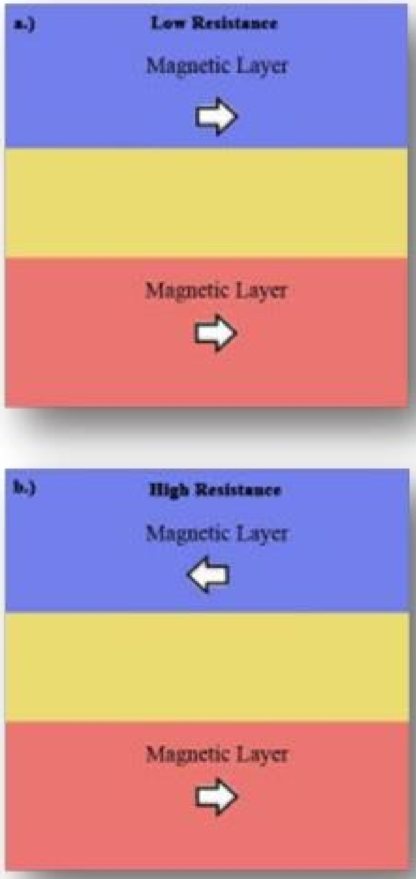
- Moore's Law states that the number of transistors on a silicon chip will roughly double every eighteen months
- By 2008, it is projected that the width of the electrodes in a microprocessor will be 45nm across
- As electronic devices become smaller, quantum properties of the wavelike nature of electrons are no longer negligible
- Spintronic devices offer the possibility of enhanced functionality, higher speed, and reduced power consumption

Advantages of Spin

- Information is stored into spin as one of two possible orientations
- Spin lifetime is relatively long, on the order of nanoseconds
- Spin currents can be manipulated
- Spin devices may combine logic and storage functionality eliminating the need for separate components
- Magnetic storage is nonvolatile
- Binary spin polarization offers the possibility of applications as qubits in quantum computers

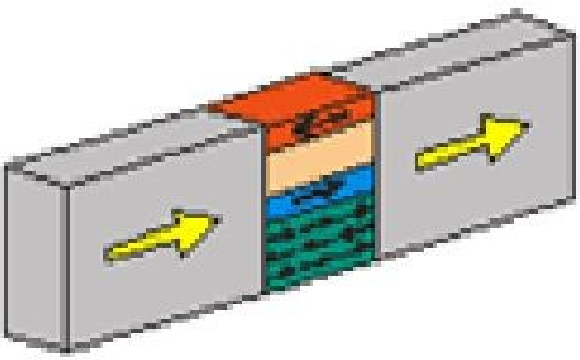
GMR

- 1988 France, GMR discovery is accepted as birth of spintronics
- A Giant MagnetoResistive device is made of at least two ferromagnetic layers separated by a spacer layer
- When the magnetization of the two outside layers is aligned, lowest resistance
- Conversely when magnetization vectors are antiparallel, high R
- Small fields can produce big effects
- parallel and perpendicular current



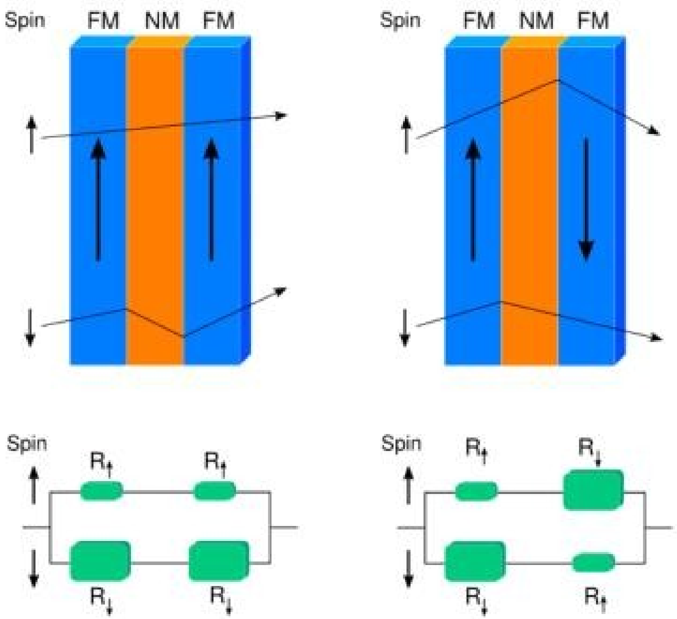
Parallel Current GMR

- Current runs parallel between the ferromagnetic layers
- Most commonly used in magnetic read heads
- Has shown 200% resistance difference between zero point and antiparallel states



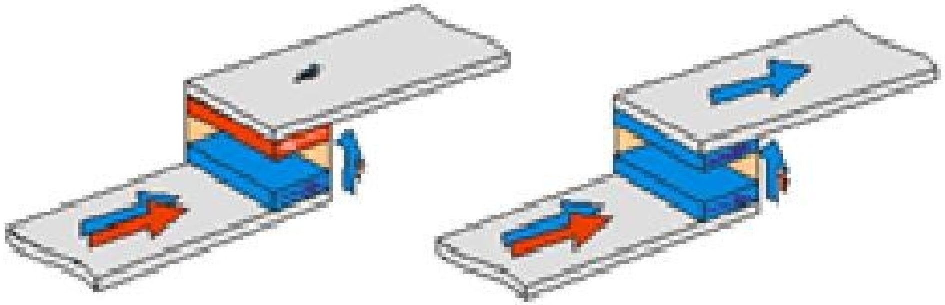
Spin Valve

- Simplest and most successful spintronic device
- Used in HDD to read information in the form of small magnetic fields above the disk surface



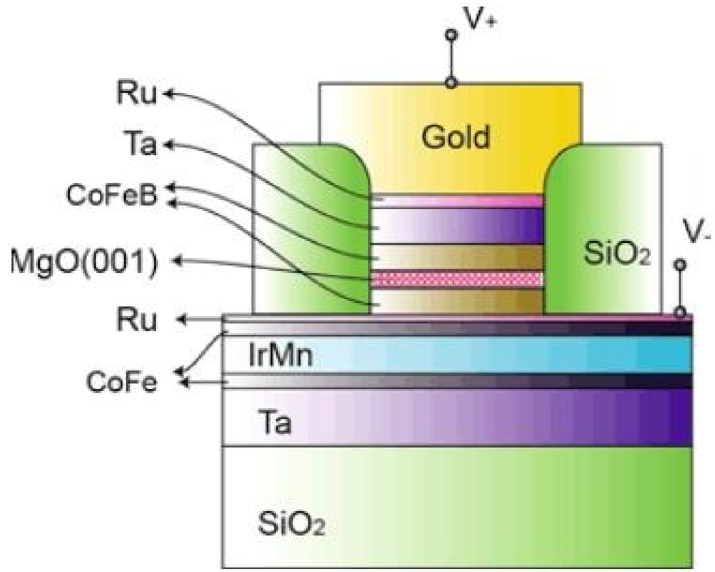
Perpendicular Current GMR

- Easier to understand theoretically, think of one FM layer as spin polarizer and other as detector
- Has shown 70% resistance difference between zero point and antiparallel states
- Basis for Tunneling MagnetoResistance



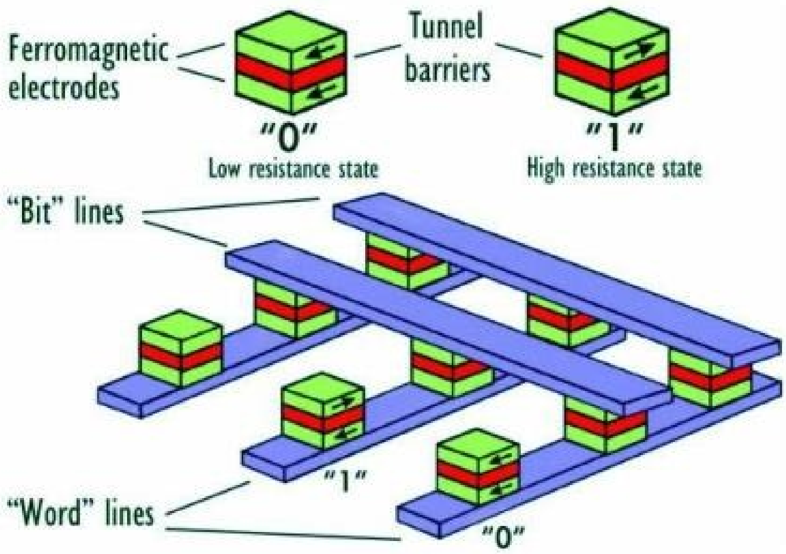
Tunnel Magnetoresistance

- Tunnel Magnetoresistive effect combines the two spin channels in the ferromagnetic materials and the quantum tunnel effect
- TMR junctions have resistance ratio of about 70%
- MgO barrier junctions have produced 230% MR



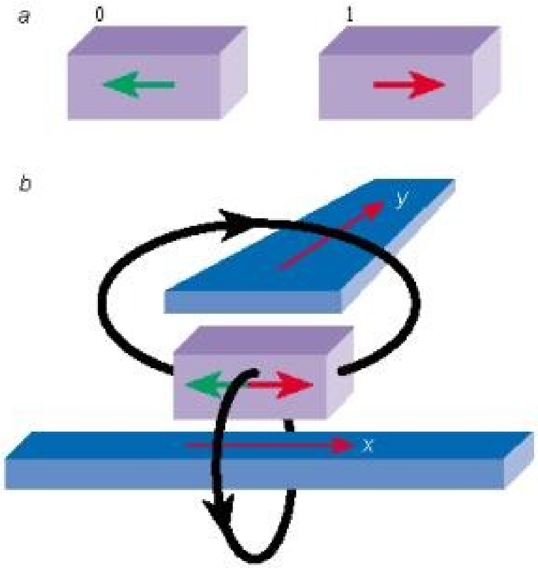
MRAM

- MRAM uses magnetic storage elements instead of electric used in conventional RAM
- Tunnel junctions are used to read the information stored in Magnetoresistive Random Access Memory, typically a”0” for zero point magnetization state and “1” for antiparallel state



MRAM

- Attempts were made to control bit writing by using relatively large currents to produce fields
- This proves unpractical at nanoscale level

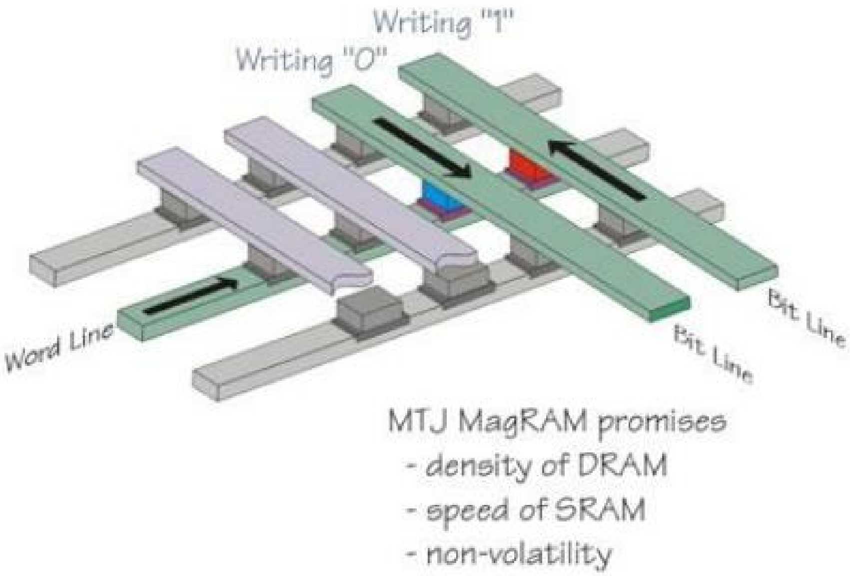


Spin Transfer

- Current passed through a magnetic field becomes spin polarized
- This flipping of magnetic spins applies a relatively large torque to the magnetization within the external magnet
- This torque will pump energy to the magnet causing its magnetic moment to precess
- If damping force is too small, the current spin momentum will transfer to the nanomagnet, causing the magnetization will flip
- Unwanted effect in spin valves
- Possible applications in memory writing

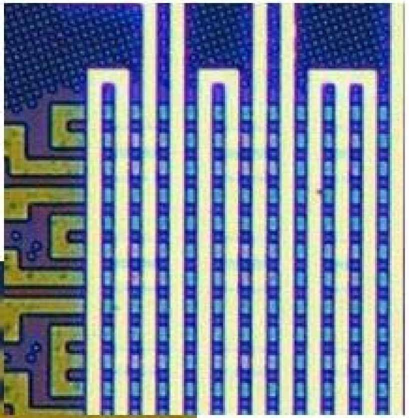
MRAM

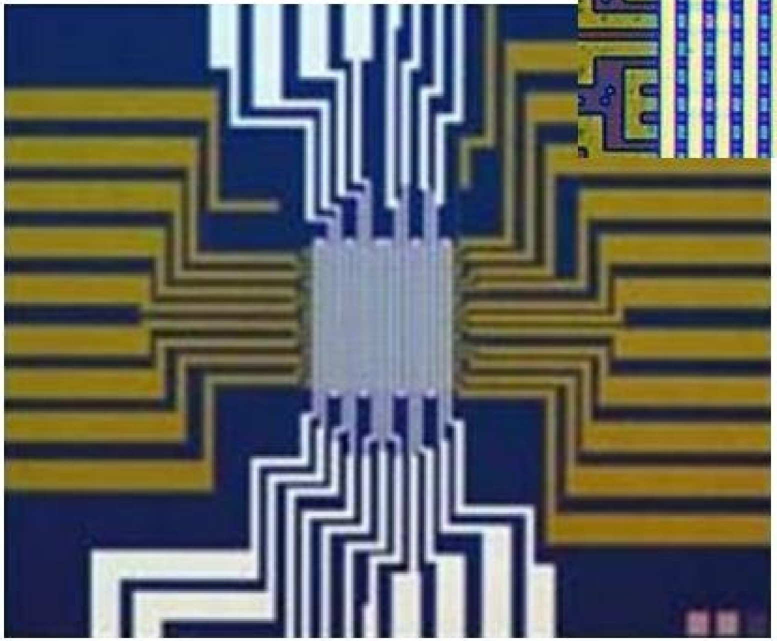
- The spin transfer mechanism can be used to write to the magnetic memory cells
- Currents are about the same as read currents, requiring much less energy



MRAM

- MRAM promises:
  - Density of DRAM
  - Speed of SRAM
  - Non-volatility like flash



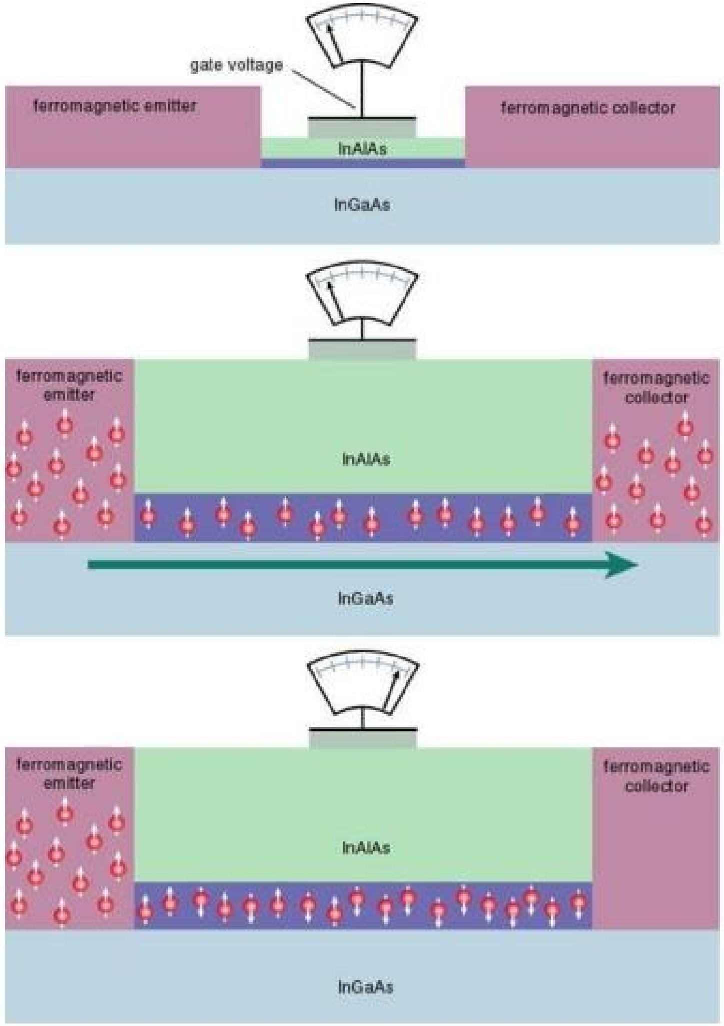


Spin Transistor

- Ideal use of MRAM would utilize control of the spin channels of the current
- Spin transistors would allow control of the spin current in the same manner that conventional transistors can switch charge currents
- Using arrays of these spin transistors, MRAM will combine storage, detection, logic and communication capabilities on a single chip
- This will remove the distinction between working memory and storage, combining functionality of many devices into one

Datta Das Spin Transistor

- The Datta Das Spin Transistor was first spin device proposed for metal-oxide geometry, 1989
- Emitter and collector are ferromagnetic with parallel magnetizations
- The gate provides magnetic field
- Current is modulated by the degree of precession in electron spin



Magnetic Semiconductors

- Materials like magnetite are magnetic semiconductors
- Development of materials similar to conventional
- Research aimed at dilute magnetic semiconductors
  - Manganese is commonly doped onto substrate
  - However previous manganese-doped GaAs has transition temp at -88°C
- Curie temperatures above room must be produced

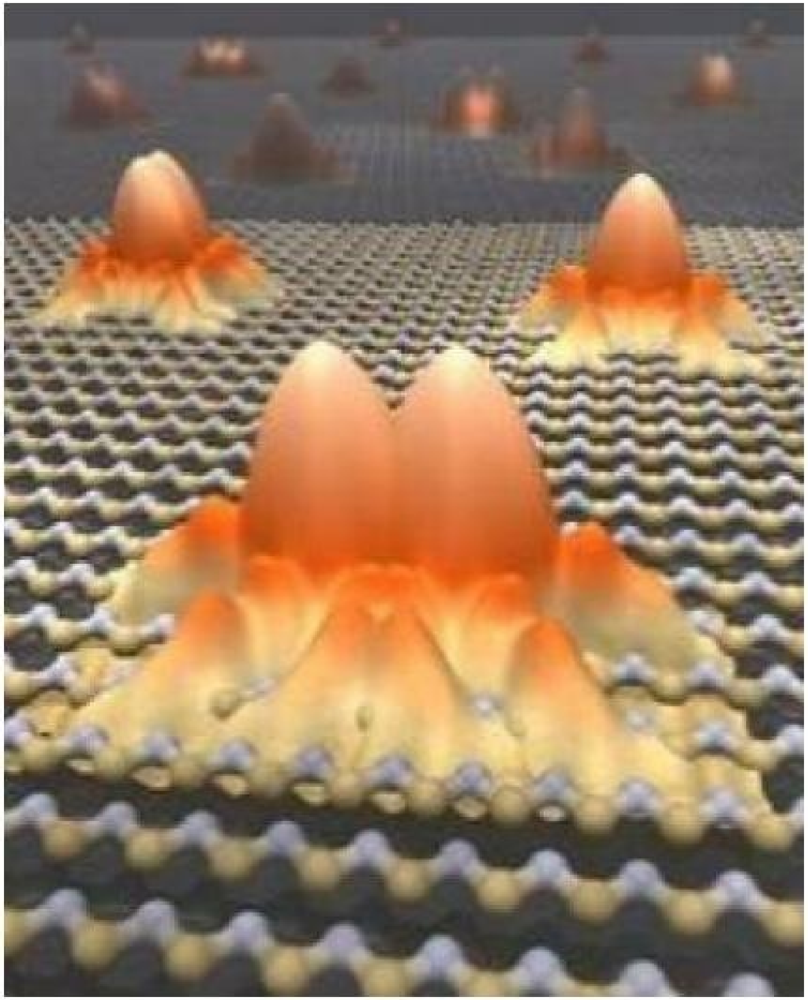
Current Research

- Weitering et al. have made numerous advances
  - Ferromagnetic transition temperature in excess of 100 K in (Ga,Mn)As diluted magnetic semiconductors (DMS's).
  - Spin injection from ferromagnetic to non-magnetic semiconductors and long spin-coherence times in semiconductors.
  - Ferromagnetism in Mn doped group IV semiconductors.
  - Room temperature ferromagnetism in (Ga,Mn)N, (Ga,Mn)P, and digital-doped (Ga,Mn)Sb.
  - Large magnetoresistance in ferromagnetic semiconductor tunnel junctions.

Current Research

- Material science
  - Many methods of magnetic doping

- Spin transport in semiconductors



Conclusion

- Interest in spintronics arises, in part, from the looming problem of exhausting the fundamental physical limits of conventional electronics.
- However, complete reconstruction of industry is unlikely and spintronics is a “variation” of current technology
- The spin of the electron has attracted renewed interest because it promises a wide variety of new devices that combine logic, storage and sensor applications.
- Moreover, these "spintronic" devices might lead to quantum computers and quantum communication based on electronic solid-state devices, thus changing the perspective of information technology in the 21st century.

THANK YOU