Spintronics

Presented by,

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Introduction

• Spintronics is an emergent nano technology which deals with spin dependent properties of an electron instead of or in addition to its charge dependent properties.

• Where as, 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

• Due to the special features it became one of the rapidly emerging fields
Future Demands

• Moore’s Law states that the number of transistors on a silicon chip will roughly double every eighteen months.

• In near future this spintronic devices make a revolution than any other thing that nano technology stirred up so far.

• 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.
Fundamentals of spin

- In addition to their mass and electric charge, electrons have an intrinsic quantity of angular momentum called spin.
- In a magnetic field, electrons with "spin down" have different energies.
- In an ordinary electronic circuit, the spins are oriented at random and have no effect on current flow.
- Spintronic devices create spin-polarized currents and use the spin to control current flow.
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
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
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.
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 promises:
  – Density of DRAM
  – Speed of SRAM
  – Non-volatility like flash
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
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
Quantum computer

• In a quantum computer the fundamental unit is qubit which is not binary but rather more quaternary in name
• This qubit property arises from the quantum laws of mechanics
• A qubit not only exist logic 0, logic 1 or simultaneously as both 0 and 1
Each electron spin can represent a bit; for instance, a 1 for spin up and 0 for spin down.

A quantum computer, in contrast, lies on encoding information within quantum bits, or qubits, each of which can exist in a superposition of 0 and 1.

A typical disruption would effectively change a superposition of 0 and 1 randomly into either a 0 or a 1, as process called decoherence.
Spin qubits

1. In a conventional computer every bit has a definite value of 0 or 1. A series of eight bits can represent any number from 0 to 255, but only one number at a time.
2. Electron spins restricted to spin up and spin down could be used as bits.
3. Quantum bits, or qubits, can also exist as super positions of 0 and 1, in effect being both numbers at once. Eight qubits can represent every number from 0 to 255 simultaneously.
4. Electron spins are natural qubits; a tilted electron is a coherent superposition of spin up and spin down and is less fragile than other quantum electronic states.
5. Qubits are extremely delicate: stray interactions with their surroundings degrade the superposition extremely quickly, typically converting them into random ordinary bits.
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
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