A Review of Spintronics based Data Storage

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Abstract

Electron based data storage techniques, be they volatile or non-volatile, are ubiquitous. Spintronics, Spin Electronics or Magneto Electronics, is a new field of research (c. 1988) based on the rotation of electrons known as their spin or magnetic moment. Any motion of an electric charge generates a magnetic field around it. So the spin of an electron creates a tiny magnetic field. This weak magnetic field could only be detected with the advent of the Giant Magneto Resistance (GMR). GMR has enabled more sensitive data reading. The next step is to directly use the spin states to store information in computers and other electronic devices. Spintronics could lead to memory devices that do not need power.

Keywords: Giant Magneto Resistance, Tunnel Magneto Resistance, MRAM

1. Introduction

Electrons have the basic properties of mass, charge and spin. Until recently most data storage and processing devices made use of only the charge property of an electron. In Spintronics the aim is to use the ***spin*** state as well, which can be “up” or “down”. The spin of an electron creates a tiny magnetic field that makes the electron act like a tiny magnet. Just as the positive or negative values of an electrical charge are used to store data as 0s and 1s, the “up” and “down” states of the spin of an electron can be used to store data. Unlike volatile charge-based data storage spin-based storage is non-volatile. As an example, the Random Access Memory (RAM) of a computer needs to be continuously powered to prevent data loss. Spintronics based Magneto Resistive RAM (MRAM) is a memory device that does not need to be continuously powered.

Modern electronics is based on the manipulation of electrical ***charge*** in semiconductor devices. To increase the processing speed and power it relies on the miniaturization of these devices. Spintronics employs two degrees of freedom - the ***charge*** as well as the ***spin*** - of conducting electrons to create a new class of electronic devices that will be smaller in size but with a quantum increase in processing speed and functionalities.

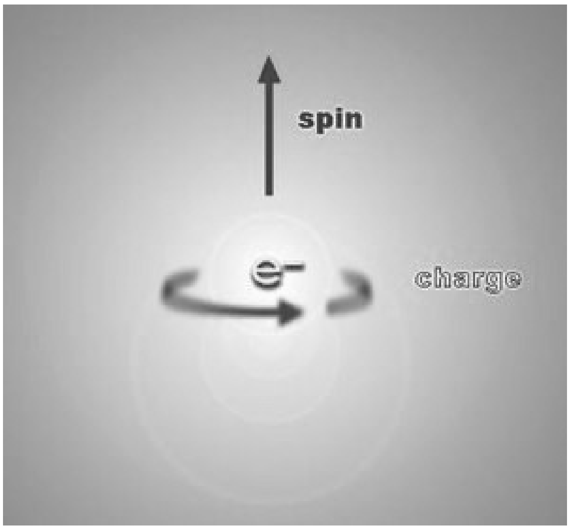

Fig 1.1: Two degrees of freedom – charge and spin

The first major breakthrough in Spintronics was the discovery of the Giant Magneto Resistance (GMR) effect in 1988 by Albert Fert and Peter Gruenberg. Another recent breakthrough product is Magneto Resistive RAM (MRAM), which uses electron spin to store information.

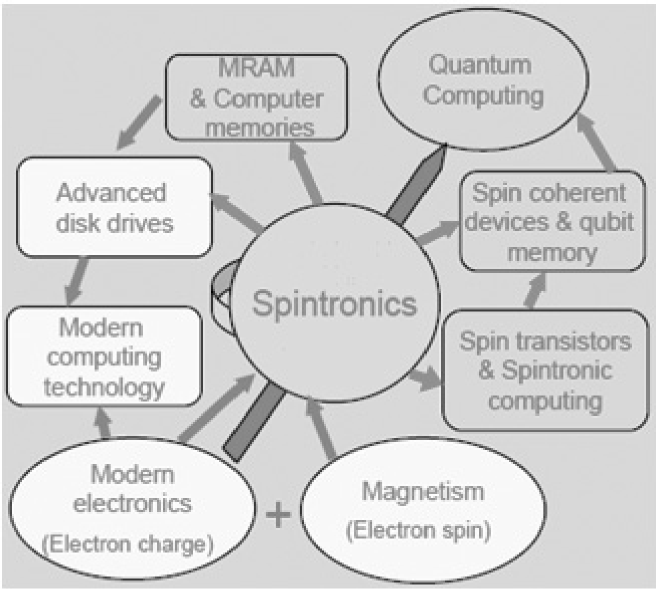

Fig 1.2: Applications of Spintronics

2. Giant Magneto Resistance (GMR)

The discovery of Giant Magneto Resistance (GMR) effect by French theoretician Albert Fert and German experimenter Peter Gruenberg led to the advent of Spintronics.

A Giant Magneto Resistive (GMR) device is made of at least two ferromagnetic layers separated by a spacer layer as shown in the figure below. When the two magnetization vectors of the ferromagnetic layers are aligned, the electrical resistance will be lower than if the ferromagnetic layers are anti-aligned. This is known as the GMR effect. The measure of this differential in current constitutes a magnetic field sensor.

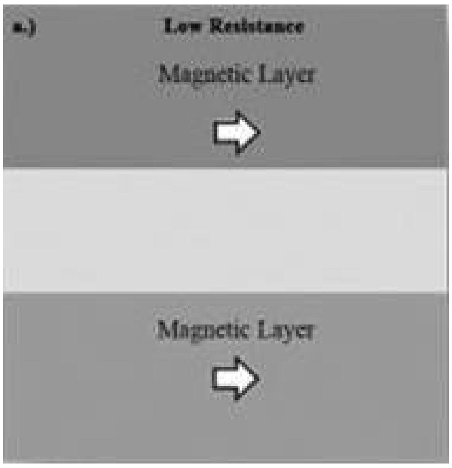

Fig 2.1a: Magnetic Layers aligned

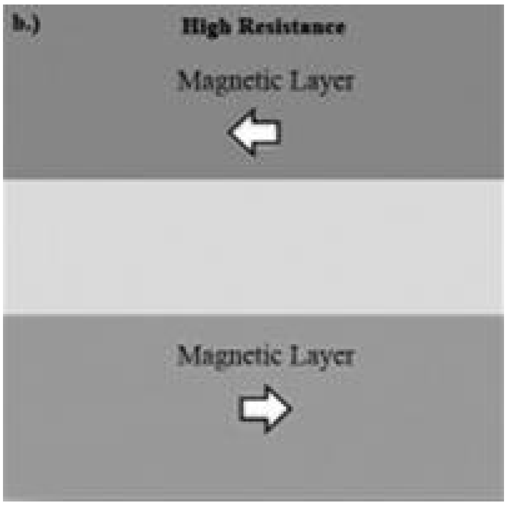

Fig 2.1b: Magnetic Layers anti-aligned

Two variants of GMR have been applied in devices:

Current-in-Plane (CIP): In this type of device the electric current flows parallel to the layers. It is most commonly used in magnetic read heads.

Current-Perpendicular-to-Plane (CPP): In this type of device the electric current flows in a direction perpendicular to the layers. It is the basis for Tunnel Magneto Resistance (TMR).

Data storage demands have continued to increase from 5 Exabytes in 2003 to last year's 160 Exabytes of new data. The GMR effect was used in the development of data-storage devices that were physically smaller but allowed increasingly denser packing of the information. The first commercial devices using the GMR effect, produced in 1997, had a 40-fold increase in data density when compared with semi-conductor devices. Data on hard disc drives is stored as a directed magnetic field in particles. GMR technology is an extremely sensitive means of detecting this magnetic field and its direction. The more sensitive the data reader, the more the data that can be stored on a disc. With GMR technology there has been a 10,000 fold increase in the capacity of hard disc drives. This technology is now used in computer storage, personal music players, PDAs, cell phones and other devices.

3. Tunnel Magneto Resistance (TMR)

This is the most recent important discovery in the field of Spintronics. This has application in MRAM devices. Tunneling Magneto Resistance (TMR) is a device where two ferromagnetic layers are separated by a thin (about 1 nm) insulator layer and the electric current tunnels through or flows in a direction perpendicular to the layers (CPP). The change in the tunneling current between the magnetic layers depends on the relative magnetization directions of the two ferromagnetic layers. The resistance is normally higher in the anti-aligned case as compared to CIP and hence more sensitive. In 2007, MgO based TMR devices completely displaced CIP based devices.

4. Magneto Resistive RAM (MRAM)

Magneto Resistive Random Access Memory (MRAM) is a non-volatile computer memory (NVRAM) technology, which has been under development since the 1990s. Continued increases in density of existing memory technologies – notably Flash RAM and DRAM – kept MRAM in a niche role in the market. Proponents of MRAM claim that the advantages are so overwhelming that MRAM will eventually become dominant for all types of memory.

Conventional RAM chip technologies store data as electric charge or current flows. In MRAM tunnel junctions are used to store the information, typically a"0" for aligned state and "1" for anti -aligned state.

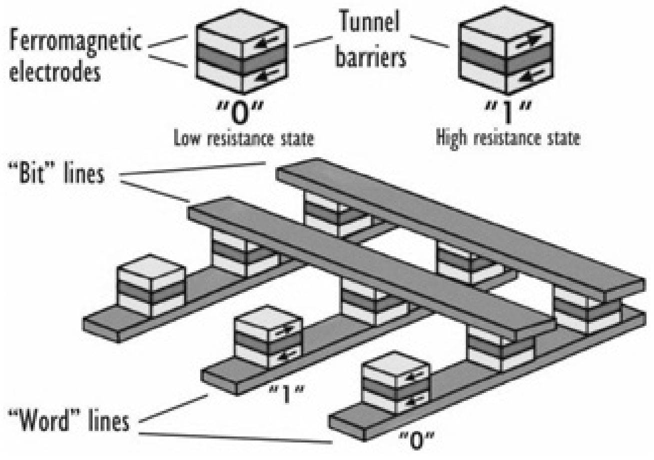

Fig 4.1a: Working of MRAM

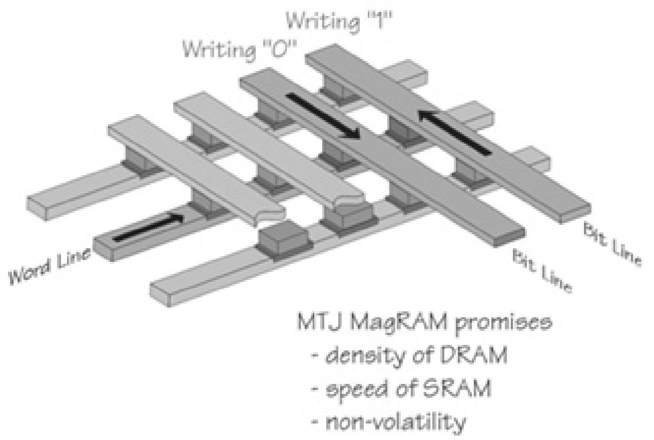

Fig 4.1b: Working of MRAM

MRAM uses electron spin to store information; while requiring less power than conventional magnetic storage technologies. It combines the density of DRAM (dynamic random access memory) with the speed of SRAM (static random access memory) and the non-volatility of Flash memory.

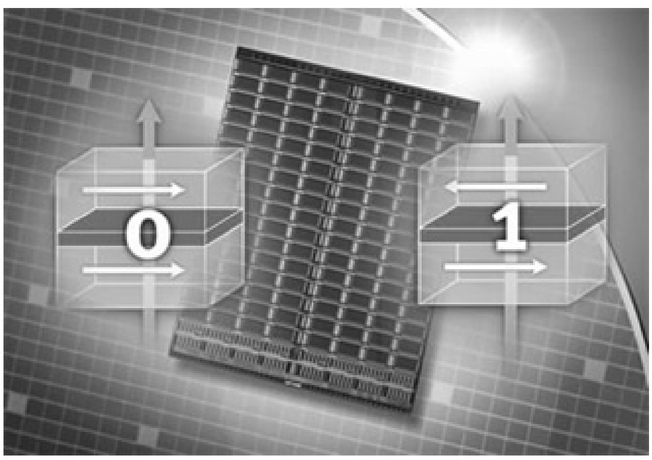

Fig 4.2: MRAM Computer chips

Electron spin is already making its mark on the computer industry with the development of MRAMs. Computers that utilize MRAM do not need to be booted up to move hard-drive data into memory. It could even lead to computers that "boot up" instantly.

5. Spintronics

5.1 Ferroelectric Spintronics

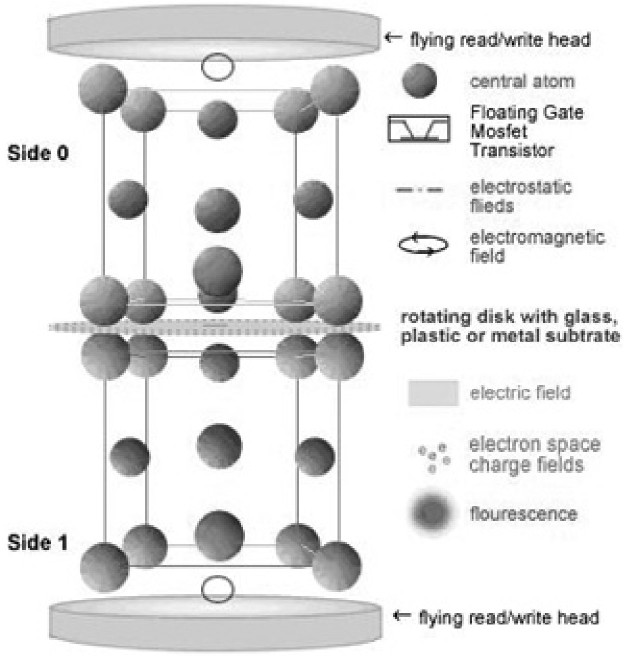

Fig 5.1: Read and Write Operations using Spintronics

The two layers in a GMR device are made up of two different ferromagnetic materials. The spin of the electrons in the upper layer change direction depending on the electromagnetic radiation due to the flow of the current, be it CIP or CPP. Whereas, the spin of the electrons in the lower layer do not change direction (due to the current flow) but are influenced by the change of direction in the spin of the electrons in the upper layer. Laser or photons cannot be used on ferromagnetic material used in disk drives because photons destroy the orientation of the 0s and 1s, or severely damage the orientation.

Today’s hard drives cannot use electromagnetic flux transversal to write or cause individual electron spin. In general, they cause many magnetic particles in an area on the disk to change magnetic direction. The number of magnetic particles needed for the GMR head to be able to tell 0s and 1s apart is defined by terms like margin, bit density, resolution, overwrite, signal to noise ratio, write and erase currents, bandwidth of the data channel, track density and many other measurement terms related to the magnetic recording material.

Colossal Storage proposes using ferroelectrics because the bit densities can be scaled down to the nanometer while still maintaining non-volatility of the bits using interference, diffraction, reflection, entanglement, electrostatic fields, electromagnetic fields, and Spintronics for data detection.

Optical Spintronics for optical data storage is the future because it can use much higher electro magnetic spectrum frequencies with functions taking advantage of controlling the electrons for use in reading and writing of stored information while maintaining non-volatility and extending the shelf life beyond magnetic hard drives capabilities.

5.2 Plastic Spintronics

Spintronics uses magnetic fields to control the spin of electrons. In the current issue of the Journal of Advanced Materials, Epstein and his coauthors report using a magnetic field to make nearly all the moving electrons inside a sample of plastic, spin in the same direction, an effect called spin polarization. Achieving spin polarization in plastic is the first step in converting this material into a read/re-writable memory storage medium.

The advent of plastic electronics opens up many opportunities for new technologies such as flexible displays and inexpensive solar cells. Plastic Spintronics devices would weigh less than traditional electronics devices and cost less to manufacture. Using plastic may solve another problem currently faced by developers: spinning electrons must be able to move smoothly between components made of different materials. But transition from one material to another can sometimes alter the spin of an electron and hence the data stored in that electron's spin would be lost.

6. 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. These devices are smaller, faster and multi-purpose devices with larger storage capacity and low power consumption. 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.

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