SPINTRONICS AND SPINTRONIC DEVICES

Thesis · November 2011

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BITS Pilani, K K Birla Goa

A SEMINAR REPORT ON

SPINTRONICS
AND
SPINTRONIC DEVICES

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

In

ELECTRICAL AND ELECTRONICS ENGINEERING

Submitted by

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CERTIFICATE

Certified that seminar work entitled " SPINTRONICS AND SPINTRONIC DEVICES " is a bonafide work carried out in the seventh semester by " VINEETH KARTHA (08401033) " in partial fulfillment for the award of Bachelor of Technology in " *ELECTRICAL AND ELECTRONICS ENGINEERING* " from University of Kerala during the academic year 2011.

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ACKNOWLEDGEMENT

I express my sincere gratitude to Prof. Jayaprakash, Professor and Head, Prof. Sheela.S , Staff Advisor, Department of Electrical & Electronics Engineering, Government Engineering College, Barton Hill, Thiruvananthapuram, for their expert advice and timely guidance in preparation of the seminar.

I express my heartfelt thanks to Prof. K.L.Sreekumar, Assistant Professor, Prof. B.Mayadevi, Professor, Smt. Arlene Davidson, Lecturer, Smt. Anu, Lecturer,Mr. Vinod, Lecturer, Guest Lecturer Mr. Vinith, Department of Electrical & Electronics Engineering, Government Engineering College, Barton Hill, Thiruvananthapuram, for their kind co-operation, encouragement and help.

I thank God Almighty for showering his blessings on me without which this report would have been impossible.

Last but not the least, I wish to place on record my gratefulness to my parents, friends and classmates for their suggestions, criticisms and assistance towards the improvement and successful completion of the report.

VINEETH KARTHA

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ABSTRACT

Spintronics also known as magneto electronics,is an emerging technology that exploits both the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices. Spintronics emerged from discoveries in the 1980s concerning spin-dependent electron transport phenomena in solid-state devices. This includes the observation of spin-polarized electron injection from a ferromagnetic metal to a normal metal(1985),and the discovery of giant magneto resistance(1988). The origins of spintronics can be traced back even further to the ferromagnet/superconductor tunneling experiments,and initial experiments on magnetic tunnel junctions. The use of semiconductors for spintronics can be traced back at least as far as the theoretical proposal of a spin field-effect-transistor by Datta and Das in 1990. Recently integrated magnetic/spintronic device micro arrays have demonstrated great potentials in both biomedical research and practices. Also they have been widely used in creation of Magnetoresistive Random Access Memories. Motorola has developed a 1st generation 256 Kb MRAM based on a single magnetic tunnel junction and a single transistor and which has a read/write cycle of under 50 nanoseconds. The IBM-Infineon MRAM Development Alliance has recently developed a prototype 16Mb MRAM. Thermal Assisted Switching (TAS) which is being developed by Crocus Technology, and Spin Torque Transfer (STT) on which Crocus, Hynix, IBM, and several other companies are working. Another design in development, called Racetrack memory, encodes information in the direction of magnetization between domain walls of a ferromagnetic metal wire. The Seminar Spintronics and Spintronic devices will give an introduction on spintronics and will deal with the recent advances of spintronic devices like the MRAM, and will make a comparison of the other memories available at present and the advantage of the MRAM and its technical feasibility, the seminar will also cover spintronic logic devices and spintronic Devices in Magnetic BioSensing.

LIST OF ABBREVIATIONS

MRAM	- Magnetic Random Access Memory
TAS	- Thermal Assisted Switching
STT	- Spin Transfer Torque
AMR	- Anisotropic Magneto Resistance
GMR	- Giant Magneto Resistance
Fe	-Iron
Cr	- Chromium
Cu	-Copper
RKKY	- *Ruderman-Kittel-Kasuya-Yosida* Coupling mechanism
AFM	- Anti FerroMagnetic
FM	- FerroMagnetic
TMR	-Tunnel Magneto Resistance
MTJ	- Magnetic Tunnel Junctions
NVRAM	- Non Volatile Random Access Memory

INTRODUCTION

In our conventional electronic devices charge of electron used to achieve functionalities and also semi conducting materials for logical operation and magnetic materials for storage, but spintronics manipulates the electron spin and resulting magnetic moment,to achieve improved functionalities and also magnetic materials are used for processing and storage. These spintronic devices are more versatile and faster than the present one.

Spintronics (" ***SPIN TR****ansport electr****ONICS*** "), also known as magneto electronics, is an emerging technology that exploits the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices.}

Conventional electronic devices rely on the transport of electrical charge carriers - electrons in a semiconductor such as silicon. Now, however, physicists are trying to exploit the 'spin' of the electron rather than its charge to create a remarkable new generation of 'spintronic' devices which will be smaller, more versatile and more robust than those currently making up silicon chips and circuit elements. During that 50-year period, the world witnessed a revolution based on a digital logic of electrons. From the earliest transistor to the remarkably powerful microprocessor in your desktop computer, most electron IC devices have employed circuits that express data as binary digits, or bits—ones and zeros represented by the existence or absence of electric charge.

Moore's Law, which holds that microprocessors will double in power every 18 months as electronic devices shrink and more logic is packed into every chip. Moore's Law has run out of momentum as the size of individual bits approaches the dimension of atoms—this has been called the end of the silicon road map. For this reason and also to enhance the multi-functionality of devices investigators have been eager to exploit another property of the electron—a characteristic known as spin. Spin is a purely quantum phenomenon .

A BRIEF HISTORY

Two experiments in 1920’s suggested spin as an additional property of the electron. One was the closely spaced splitting of Hydrogen spectral lines, called fine structure. The other was Stern –Gerlach experiment, which in 1922 that a beam of silver atoms directed through an inhomogeneous magnetic field would be forced in to two beams. These pointed towards magnetism associated with the electrons.

In 1965, Gordon Moore, Intel's co-founder, predicted that the number of transistors on an integrated circuit would double every 18 month. That prediction, now known as Moore’s Law, effectively described a trend that has continued ever since, but the end of that trend—the moment when transistors are as small as atoms, and cannot be shrunk any further—is expected as early as 2015.

Magnetoresistance is the property of a material to change the value of its electrical resistance when an external magnetic field is applied to it. The effect was first discovered by William Thomson (more commonly known as Lord Kelvin) in 1856, but he was unable to lower the electrical resistance of anything by more than 5%. This effect was later termed Anisotropic Magnetoresistance (AMR) to distinguish it from GMR. Spintronics came into light by the advent of Giant Magneto Resistance (GMR) in 1988. GMR is 200 times stronger than ordinary Magneto Resistance. It results from subtle electron – spin effects in ultra multi-layers of magnetic materials that cause a huge change in electrical resistance. Giant magneto resistance is a quantum mechanical magneto resistance effect observed in thin film structures composed of alternating ferromagnetic and non magnetic layers.

The 2007 Nobel Prize in physics was awarded to Albert Fert and Peter Grunberg for the discovery of GMR. The effect is observed as a significant change in the electrical resistance depending on whether the magnetization of adjacent ferromagnetic layers are in a parallel or an anti-parallel alignment. The overall resistance is relatively low for parallel alignment and relatively high for anti-parallel alignment. GMR is used by hard disk drive manufactures.

GIANT MAGNETO RESISTANCE

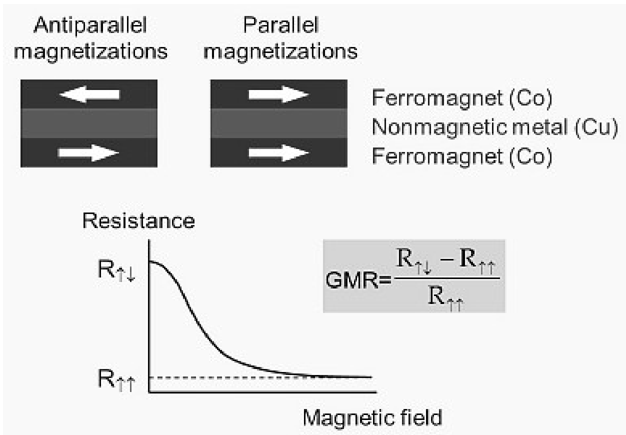
DISCOVERY:

GMR was independently discovered in 1988 in Fe/Cr/Fe trilayers by a research team led by Peter Grunberg, who owns the patent, and in Fe/Cr multilayers by the group of Albert Fert of the University of Paris-Sud, who first saw the large effect in multilayers (up to 50% change in resistance) that led to its naming, and first correctly explained the underlying physics. The discovery of GMR is considered as the birth of Spintronics.

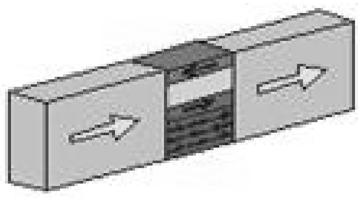
Grunberg and Fert have received a number of prestigious prizes and awards for their discovery and contributions to the field of Spintronics, including the Nobel Prize in Physics in 2007.

THEORY:

Like other magnetoresistive effects, giant magnetoresistance (GMR) is the change in electrical resistance of some materials in response to an applied magnetic field. It was discovered that the application of a magnetic field to magnetic metallic multilayers such as Fe/Cr and Co/Cu, in which ferromagnetic layers are separated by nonmagnetic spacer layers of a few nm thick, results in a significant reduction of the electrical resistance of the multilayer. This effect was found to be much larger than other magnetoresistive

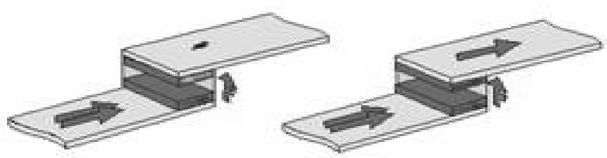


effects that had ever been observed in metals and was, therefore, called "giant magnetoresistance". In Fe/Cr and Co/Cu multilayers the magnitude of GMR can be higher than 100% at low temperatures.



The change in the resistance of the multilayer arises when the applied field aligns the magnetic moments of the successive ferromagnetic layers, as is illustrated schematically in the figure below. In the absence of the magnetic field the magnetizations of the ferromagnetic layers are antiparallel. Applying the magnetic field, which aligns the magnetic moments and saturates the magnetization of the multilayer, leads to a drop in the electrical resistance of the multilayer. Usually resistance of multilayer is measured with the **Current in Plane (CIP)**. For instance, Read back magnetic heads uses this property. But this suffers from several drawbacks such as; shunting and channeling, particularly for uncoupled multilayers and for thick spaced layers diminish the CIP magneto resistance. Diffusive surface scattering reduces the magneto resistance for sandwiches and thin multilayers.

To erase these problems we measure with **Current Perpendicular to the Plane (CPP),** mainly because electrons cross all magnetic layers, but a practical difficulty is encountered the perpendicular resistance of ultra thin multilayers is too small to be measured by ordinary techniques.



The use of Micro fabrication techniques for CPP measurements, from 4.2 to 300k was first shown for Fe/Cr multilayers, where the multilayers were etched into micropillars to obtain a relatively large resistance (a few milli ohms). These types of measurements have confirmed the larger MR for the CPP configuration, but they suffer from general complexity of realisation and measurement techniques. Experiments using electro deposited nanowires showed CPP MR up to **15%** at room temperature

TYPES OF GMR

MULTILAYER:

Two or more ferromagnetic layers are separated by a very thin (about 1 nm) non-ferromagnetic spacer (e.g. Fe/Cr/Fe). At certain thicknesses the RKKY[1] coupling between adjacent ferromagnetic layers becomes anti ferromagnetic, making it energetically preferable for the magnetizations of adjacent layers to align in anti-parallel. The electrical resistance of the device is normally higher in the anti-parallel case and the difference can reach more than 10% at room temperature. The interlayer spacing in these devices typically corresponds to the second anti ferromagnetic peak in the AFM-FM oscillation in the RKKY coupling. The GMR effect was first observed in the multilayer configuration, with much early research into GMR focusing on multilayer stacks of 10 or more layers.

GRANULAR:

Granular GMR is an effect that occurs in solid precipitates of a magnetic material in a non-magnetic matrix. In practice, granular GMR is only observed in matrices of copper containing cobalt granules. The reason for this is that copper and cobalt are immiscible, and so it is possible to create the solid precipitate by rapidly cooling a molten mixture of copper and cobalt. Granule sizes vary depending on the cooling rate and amount of subsequent annealing. Granular GMR materials have not been able to produce the high GMR ratios found in the multilayer counterparts.

1 It refers to a coupling mechanism of nuclear magnetic moments or localized inner d or f shell electron spins in a metal by means of an interaction through the conduction electrons.

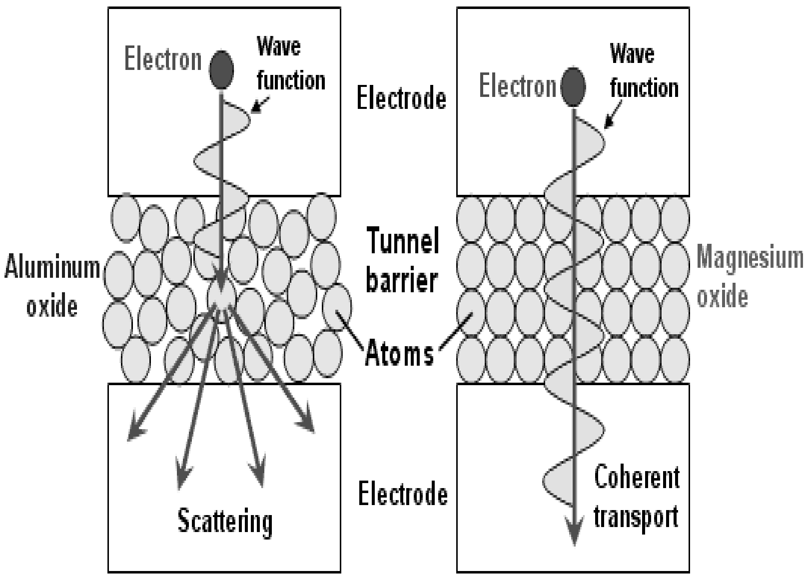
PSEUDO SPIN VALVE:

Pseudo-spin valve devices are very similar to the spin valve structures. The significant difference is the coercivities of the ferromagnetic layers. In a pseudo-spin valve structure a soft magnet will be used for one layer; where as a hard ferromagnet will be used for the other. This allows an applied field to flip the magnetization of the hard ferromagnet layer. For pseudo-spin valves, the non-magnetic layer thickness must be great enough so that exchange coupling minimized. This reduces the chance that the alignment of the magnetization of adjacent layers will spontaneously change at a later time.

TUNNEL MAGNETORESISTANCE

The Tunnel magnetoresistance (TMR) is a magnetoresistive effect that occurs in magnetic tunnel junctions (MTJs). This is a component consisting of two ferromagnets separated by a thin insulator. If the insulating layer is thin enough (typically a few nanometers), electrons can tunnel from one ferromagnet into the other. Since this process is forbidden in classical physics, the tunnel magnetoresistance is a strictly quantum mechanical phenomenon.

Magnetic tunnel junctions are manufactured in thin film technology. On an industrial scale the film deposition is done by magnetron sputter deposition; on a laboratory scale molecular beam epitaxy, pulsed laser deposition and electron beam physical vapor deposition are also utilized. The junctions are prepared by photolithography.



The direction of the two magnetizations of the ferromagnetic films can be switched individually by an external magnetic field. If the magnetizations are in a parallel orientation it is more likely that electrons will tunnel through the insulating film than if they are in the oppositional (antiparallel) orientation. Consequently, such a junction can be switched between two states of electrical resistance, one with low and one with very high resistance.

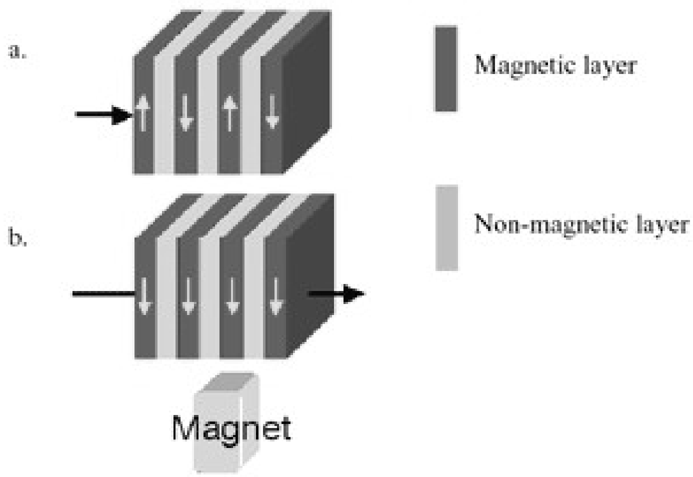
The effect was originally discovered in 1975 by M. Jullière (University of Rennes, France) in Fe/Ge-O/Co-junctions at 4.2 K. The relative change of resistance was around 14%, and did not attract much attention. In 1991 T. Miyazaki (University Tohoku, Japan) found an effect of 2.7% at room temperature. Later, in 1994, Miyazaki found 18% in junctions of iron separated by an amorphous aluminum oxide insulator and J. Moodera found 11.8% in junctions with electrodes of CoFe and Co. The highest effects observed to date with aluminum oxide insulators are around 70% at room temperature.

Since the year 2000, tunnel barriers of crystalline magnesium oxide (MgO) are under development. In 2001 Butler and Mathon independently made the theoretical prediction that using iron as the ferromagnet and MgO as the insulator, the tunnel magnetoresistance can reach several thousand percent. The same year, Bowen et al. were the first to report experiments showing a significant TMR in a MgO based magnetic tunnel junction [Fe/MgO/FeCo(001)]. In 2004, Parkin and Yuasa were able to make Fe/MgO/Fe junctions that reach over 200% TMR at room temperature. Today (2009) effects of up to 600% at room temperature and more than 1100% at 4.2 K are observed in junctions of CoFeB/MgO/CoFeB .

The read-heads of modern hard disk drives work on the basis of magnetic tunnel junctions. TMR, or more specifically the magnetic tunnel junction, is also the basis of MRAM, a new type of non-volatile memory. The 1st generation technologies relied on creating cross-point magnetic fields on each bit to write the data on it, although this approach has a scaling limit at around 90-130 nm. There are two 2nd generation techniques currently being developed: Thermal Assisted Switching (TAS) and Spin Torque Transfer (STT) on which several companies are working Further, magnetic tunnel junctions are also used for sensing applications.

SPIN VALVE

Two ferromagnetic layers are separated by a thin (about 3 nm) non-ferromagnetic spacer, but without RKKY coupling. If the coercive fields of the two ferromagnetic electrodes are different it is possible to switch them independently. Therefore, parallel and anti-parallel alignment can be achieved, and normally the resistance is again higher in the anti-parallel case. This device is sometimes also called a spin valve. Spin valve GMR is the configuration that is industrially most useful, and is used in hard drives. Stuart Parkin and two groups of colleagues at IBM's Almaden Research Center, San Jose, Calif, quickly recognized its potential, both as an important new scientific discovery in magnetic materials and one that might be used in sensors even more sensitive than MR heads. Parkin first wanted to reproduce the Europeans' results. But he did not want to wait to use the expensive machine that could make multilayers in the same slow-and-perfect way that Grunberg and Fert had. So Parkin and his colleague, Kevin P. Roche, tried a faster and less-precise process common in disk-drive manufacturing: sputtering. To their astonishment and delight, it worked! Parkin's team saw GMR in the first multilayers they made. This demonstration meant that they could make enough variations of the multilayers to help discover how GMR worked, and it gave Almaden's Bruce Gurney and co-workers hope that a room-temperature, low-field version could work as a super-sensitive sensor for disk drives.

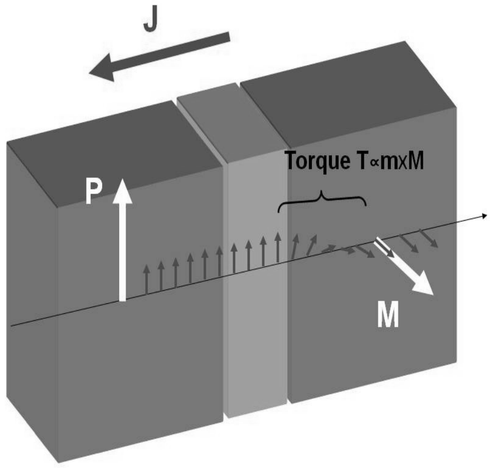


The key structure in GMR materials is a spacer layer of a non magnetic metal between two magnetic metals. Magnetic materials tend to align themselves in the same direction. So if the spacer layer is thin enough, changing the orientation of one of the magnetic layers can cause the next one to align itself in the same direction. Increase the spacer layer thickness and you'd expect the strength of such "coupling" of the magnetic layers to decrease. But as Parkin's team made and tested some 30,000 different multilayer combinations of different elements and layer dimensions, they demonstrated the generality of GMR for all transition metal elements and invented the structures that still hold the world records for GMR at low temperature, room temperature and useful fields. In addition, they discovered oscillations in the coupling strength: the magnetic alignment of the magnetic layers periodically swung back and forth from being aligned in the same magnetic direction (parallel alignment) to being aligned in opposite magnetic directions (anti-parallel alignment). The overall resistance is relatively low when the layers were in parallel alignment and relatively high when in anti-parallel alignment. For his pioneering work in GMR, Parkin won the European Physical Society's prestigious 1997 Hewlett-Packard Europhysics Prize along with Gruenberg and Fert. Searching for a useful disk-drive sensor design that would operate at low magnetic fields, Bruce Gurney and colleagues began focusing on the simplest possible arrangement: two magnetic layers separated by a spacer layer chosen to ensure that the coupling between magnetic layers was weak, unlike previously made structures. They also "pinned" in one direction the magnetic orientation of one layer by adding a fourth layer: a strong anti ferromagnet. When a weak magnetic field, such as that from a bit on a hard disk, passes beneath such a structure, the magnetic orientation of the unpinned magnetic layer rotates relative to that of the pinned layer, generating a significant change in electrical resistance due to the GMR effect. This structure was named the spin valve. Gurney and colleagues worked for several years to perfect the sensor design that is used in the new disk drives. The materials and their tiny dimensions had to be fine-tuned so they 1) could be manufactured reliably and economically, 2) yielded the uniform resistance changes required to detect bits on a disk accurately, and 3) were stable -- neither corroding nor degrading -- for the lifetime of the drive. "That's why it's so important to understand the science," Parkin says. "IBM's intensive studies of GMR enabled us to enhance considerably the performance of some low-field sensors."

The chief source of GMR is "spin dependent" scattering of electrons. Electrical resistance is due to scattering of electrons within a material. By analogy, consider how fast it takes you to drive from one town to another. Without obstacles on a freeway, you can proceed quickly. But if you encounter heavy traffic, accidents, road construction and other obstacles, you'll travel much slower. Depending on its magnetic direction, a single-domain magnetic material will scatter electrons with "up" or "down" spin differently. When the magnetic layers in GMR structures are aligned anti-parallel, the resistance is high because "up" electrons that are not scattered in one layer can be scattered in the other. When the layers are aligned in parallel, all of the "up" electrons will not scatter much, regardless of which layer they pass through, yielding a lower resistance.

SPIN TRANSFER TORQUE

Spin-transfer torque is an effect in which the orientation of a magnetic layer in a tunnel magnetoresistance or spin valve can be modified using a spin-polarized current. Charge carriers (such as electrons) have a property known as spin which is a small quantity of angular momentum intrinsic to the carrier. An electrical current is generally unpolarized (consisting of 50% spin-up and 50% spin-down electrons); a spin polarized current is one with more electrons of either spin. By passing a current through a thick magnetic layer, one can produce a spin-polarized current. If a spin-polarized current is directed into a magnetic layer, angular momentum can be transferred to the layer, changing its orientation. This can be used to excite oscillations or even flip the orientation of the magnet. The effects are usually only seen in nanometer scale devices.



Spin-transfer torque can be used to flip the active elements in magnetic random access memory. Spin-transfer torque random access memory, or STT-RAM, has the advantages of lower power consumption and better scalability over conventional MRAM which uses magnetic fields to flip the active elements. The name STT-RAM was first coined by Grandis, Inc. Spin-transfer torque technology has the potential to make possible MRAM devices combining low current requirements and reduced cost; however, the amount of current needed to reorient the magnetization is at present too high for most commercial applications, and the reduction of this current density alone is the basis for current academic research in spin electronics.

Hynix Semiconductor and Grandis formed a partnership in April 2008 to explore commercial development of STT-RAM technology. On August 1, 2011, Grandis announced that it had been purchased by Samsung for an undisclosed sum. Hitachi and Tohoku University demonstrated a 32-Mbit STT-RAM in June 2009.

MAGNETIC RANDOM ACCESS MEMORY

You hit the power button on your television and it instantly comes to life. But do the same thing with your computer and you have to wait a few minutes while it goes through its boot up sequence. Why can't we have a computer that turns on as instantly as a television or radio? IBM, in cooperation with Infineon, is promising to launch a new technology in the next few years that will eliminate the boot-up process. Magnetic random access memory (MRAM) has the potential to store more data, access that data faster and use less power than current memory technologies. The key to MRAM is that, as its name suggests, it uses magnetism rather than electrical power to store data. This is a major leap from dynamic RAM (DRAM), the most common type of memory in use today, which requires a continuous supply of electricity and is terribly inefficient. Twenty-five years ago, DRAM overtook ferrite core memory in the race to rule the PC memory market. Now it looks like ferromagnetic technology could be making a comeback, with IBM Corp. and Infineon Technologies charging a joint team of 80 engineers and scientists with the task of making magnetic RAM (MRAM)

All modern hard disks are equipped with two different heads , one for writing and the other for reading. The principle of the writing head is quite simple, i.e., generation of a magnetic field as electricity passes through the head. The head focuses this magnetic field generated to the area on the disk surface where the bit is to be written. Conceptually the technique for reading is the reverse of that of writing, i.e., using electromagnetic induction and it was the technique used in earlier hard disks. But as the storage density increased, it became very difficult to read a bit from the disk surface as there was the interference of magnetic fields from the neighboring bits.

A small electrical current is kept flowing through the reading head. When a bit passes under the head, due to the presence of the magnetic field associated with the bit, the electrical resistance of head changes which alters the current flowing through it. This change in the current flow is so significant that it can be easily detected.

Magnetoresistive 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, but its proponents believe that the advantages are so overwhelming that MRAM will eventually become dominant. Unlike conventional RAM chip technologies, in MRAM data is not stored as electric charge or current flows, but by magnetic storage elements.

The elements are formed from two ferromagnetic plates, each of which can hold a magnetic field, separated by a thin insulating layer. One of the two plates is a permanent magnet set to a particular polarity; the other's field will change to match that of an external field. A memory device is built from a grid of such "cells". Reading is accomplished by measuring the electrical resistance of the cell. A particular cell is (typically) selected by powering an associated transistor which switches current from a supply line through the cell to ground. Due to the magnetic tunnel effect, the electrical resistance of the cell changes due to the orientation of the fields in the two plates. By measuring the resulting current, the resistance inside any particular cell can be determined, and from this the polarity of the writable plate. Typically if the two plates have the same polarity this is considered to mean "0", while if the two plates are of opposite polarity the resistance will be higher and this means "1". On comparison with existing memory technologies, MRAM is faster than SRAM, have a higher storage density than DRAM, the power requirement is less than that of DRAM and it is faster than FLASH. MRAM is the Memory of the future. If the researches turn up, it will replace both Volatile and Non Volatile Primary memories.

HISTORY:-

2000 - IBM and Infineon established a joint MRAM development program.

2000 - Spintec laboratory's first Spin Torque Transfer patent.

2002 - NVE Announces Technology Exchange with Cypress Semiconductor.

2003 - A 128 kbit MRAM chip was introduced, manufactured with a 180 nm lithographic process

2004 - Infineon unveiled a 16-Mbit prototype

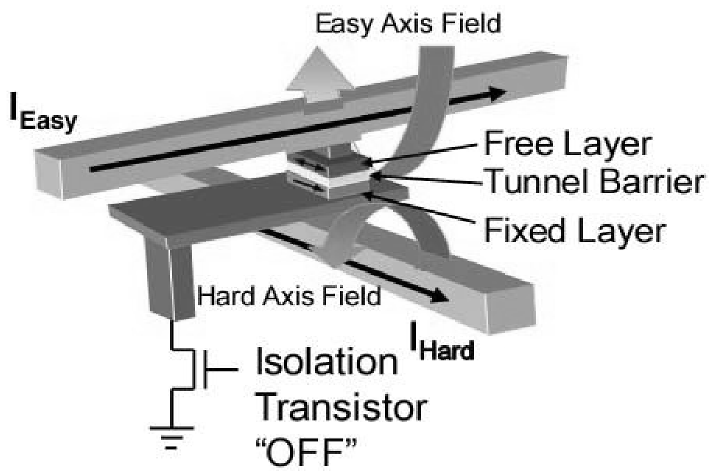
2005 - Sony announced the first lab-produced spin-torque-transfer MRAM

2007 - Tohoku University and Hitachi developed a prototype 2 Mbit Non-Volatile RAM Chip employing spin-transfer torque switching

2008 - Scientists in Germany have developed next-generation MRAM that is said to operate with write cycles under 1 ns.

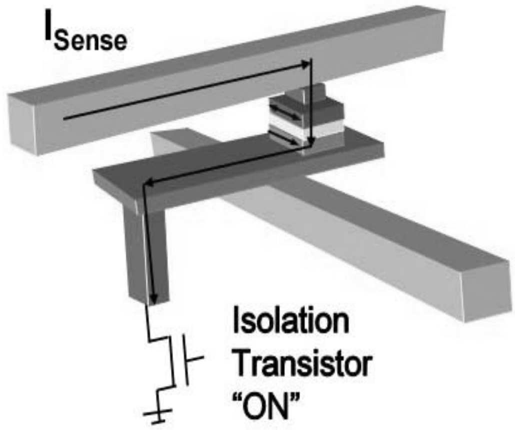
2009 - Hitachi and Tohoku University demonstrated a 32-Mbit spin-transfer torque RAM

HOW MRAM WORKS:-

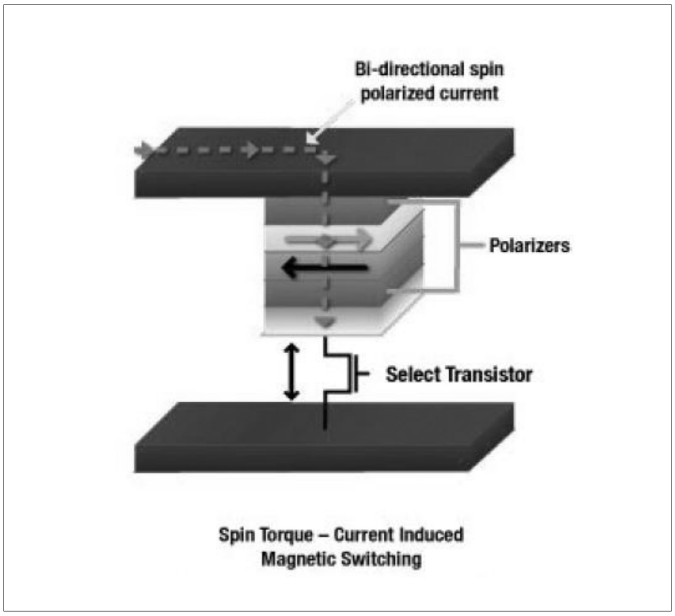


MRAM (Magnetoresistive Random Access Memory) uses electron spin to store data. Memory cells are integrated on an integrated circuit chip, and the function of the resulting device is like a semiconductor static RAM (SRAM) chip, with potentially higher density and the added feature that the data are nonvolatile, that is data are retained with power off. Typical "classic"or "conventional" MRAM uses spin-dependent tunnel junction memory cells and magnetic row and column write lines as illustrated.

The spin-dependent tunnel junction produces a large change in resistance depending on the predominant electron spin in a storage layer. The tunnel barrier is as thin as a few atomic layers--so thin that electrons can "tunnel" through the normally insulating material, causing a resistance change. Row and column magnetic write lines allow data to be written to a selected cell in a two-dimensional array:



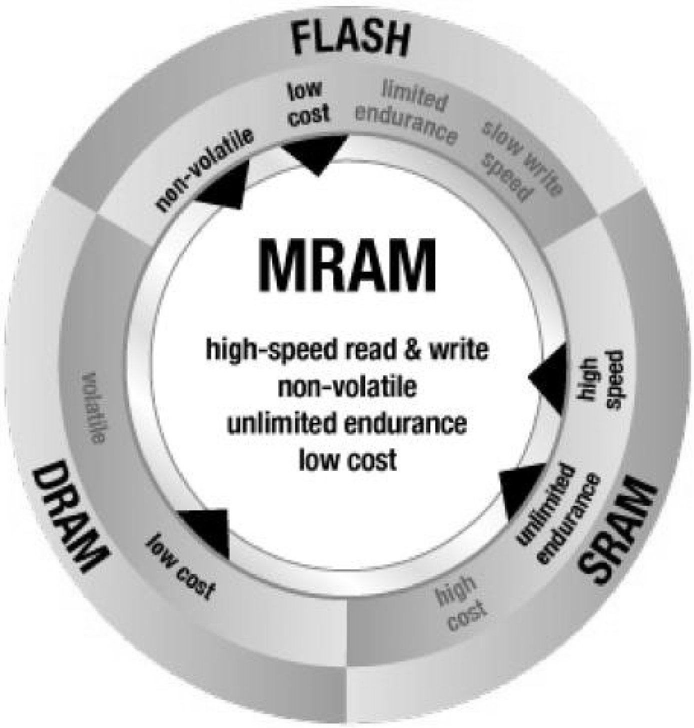
Data are written by small electrical currents in the write lines that create a magnetic fields, which flip electron spins in the spin-dependent tunnel junction storage layer, thus changing the junction's resistance. Data is read by the tunneling current or resistance through the tunnel junction. Next-generation MRAM could reduce cell size and power consumption. Potential next-generation designs include Spin-Momentum Transfer, Magneto-Thermal MRAM, and Vertical Transport MRAM. Spin-Momentum Transfer (also "Spin-Transfer," "Spin Injection," or "Spin Torque Transfer") MRAM is based on changing the spin of storage electrons directly with an electrical current rather than an induced magnetic field. This method has the potential to significantly reduce MRAM write currents, especially with lithographic feature sizes less than 100 nanometers. M-T MRAM uses a combination of magnetic fields and ultra-fast heating from electrical current pulses to reduce the energy required to write data.



The Table below shows the comparison of various memory types

COMPARISON OF EXPECTED MRAM FEATURES WITH OTHER MEMORY TECHNOLOGIES				
	SRAM	DRAM	Flash	MRAM
Read Time	Fast	Moderate	Moderate	Moderate-Fast
Write Time	Fast	Moderate	Slow	Moderate-Fast
Nonvolatile	No	No	Yes	Yes
Refresh	N/A	Yes	N/A	N/A
Minimum Cell Size	Large	Small	Small	Small
Low Voltage	Yes	Limited	No	Yes

MRAM is a combination of the advantages of existing technologies.



SPIN VALVE TRANSISTOR

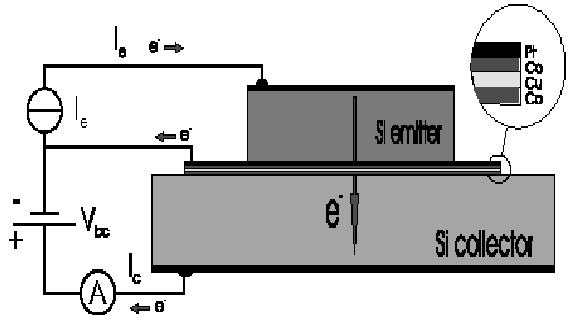
A spin valve multilayer serves as a base region of an n silicon metal base transistor structure. Metal base transistors have been proposed for ultrahigh frequency operations because of 1. Negligible base transport time. 2. Low base resistance, but low gain prospects have limited their emergence. The first evidence of a spin valve effect for hot electrons in Co/Cu multilayers is the spin valve transistor. In this we see a very large change in collector current (215% at 77K) under application of magnetic field of 500 Oe.

In spin valve transistor (SVT) electrons are injected in to metallic base across a Schottky barrier (Emitter side) pass through the spin valve and reach the opposite side (Collector side) of transistor. When these injected electrons traverse the metallic base electrons are above Fermi level, hence hot electron magneto transport should be considered in **Spin Valve Transistor (SVT).**

The transport properties of hot electrons are different from Fermi electrons .For example spin polarisation of Fermi electrons mainly depends on **Density Of States (DOS)** at Fermi level, while the spin polarisation of hot electron is related to the density of unoccupied states above the fermi level.

For the preparations of transistor we apply direct bonding, both to obtain device quality semiconductor material for the emitter and to allow room temperature processes.

CONSTRUCTION:



The starting material for both emitter and collector is a 380um, 5-10Ocm, n-si (100) wafer. After back side n++ implantation ,wafer is dry oxidised to anneal the implant and to form a SIO_2 layer .After depositing a Pt ohmic contact on to the back side, wafer is sawn in to 10X10mm collector and 1.6X1.6mm emitters. Collector is subsequently dipped in HNO_3, 2% HF to remove the native oxide on silicon fragments,5% Tetra methyl Ammonium Hydroxide at 90˚, and buffered HF to remove thermal oxide .following each step the collector is rinsed in demineralised water. After this procedure base multilayer (Cu 2nm/Co 1.5nm), is rf sputtered through a laser cut metal shadow mask on to the collector substrate defining square base regions slightly larger than the emitter surface. Directly after cleaning the emitter in a similar manner its hydrophobic surface is contacted to the multilayer surface, forming a bond through spontaneous adhesion.

Here metal parts were laid down directly on to the doped Silicon base layer, which resulted in the information of metal silicides at the interface. These degrade device performance due to the large depolarising effect they have on the flow of spin polarized charge carriers through the interface which severely reduces the magnetic sensitivity of devices.

WORKING:

The energy band diagram of the bonded Co/Cu of spinvalve transistor is shown below.

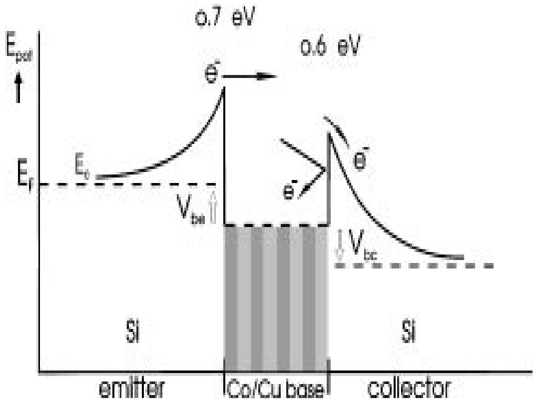


Fig. 2 Energy Band Diagram

The collector barrier height about **0.7eV** while the emitter barrier height is **0.6eV**.The emitter and collector Schottky barrier are in forward and reverse bias respectively as illustrated by the CB configuration in Fig. 1. The emitter bias accelerates the electrons towards the emitter barrier, after which they constitute the hot **"Ballistic"** electrons in the base. The probability of passing the collector barrier is limited by the collisions in the base which effect their energy and trajectory by optical phonon scattering in the semiconductor and by quantum mechanical reflections at the base collector interface. For a base transistor with a single metal base film, this can be expressed by the CB current transfer ratio or current gain.

$$\alpha_o = (J_c - J_{leak}) / J_e = \alpha_c \alpha_e \alpha_{qm} e^{-w/y}$$

Where

α_e = emitter efficiency

α_c = collector efficiency

α_{qm} = quantum mechanical transmission

W = base width

And λ is the hot electron mean free path (MFP), in the base. The factor $e^{-w/\lambda}$ represents the probability of transmission of the hot electrons through the base. J_c is the total collector current, J_{leak} is the collector leakage current, determined by the reverse biased collector Schottky barrier and J_e is the injected emitter current. The α_c and α_e depend among others, on the type and quality of the semi conductors. In the SVT under consideration, the thickness of the individual layers (Co/Cu) are much smaller than the spin-slip diffusion length (a few nm as compared to several tens of nm). Neglecting, therefore, spin flip scattering, we consider the spin up and spin down electrons to carry the current in parallel (two current model). Further more it has been shown that in this limit no spin relaxation occurs in the CPP-MR and that consequently the perpendicular transport properties can be very simply described by considering a network of serial resistance for each channel of electrons corresponding to the resistance's of successive layers and interfaces.

APPLICATIONS:

Spin transistors have huge potential for incorporation in stable, high sensitivity magnetic field sensors for automotive, robotic, mechanical engg. & data storage applications. This may also be used as **Magnetically Controlled Parametric Amplifiers & Mixers,** as magnetic signal processors, for control of brush less DC motors & as Magnetic Logic elements. In log applications they have the advantage over conventional semiconductor chips that they do not require power to maintain their memory slate. It finds its application towards **Quantum Computer**, a new trend in computing. Here we use **Qubits** instead of bits.Qubit also represents only 1& 0 but here they show superposition these classical states. But it is in pioneering stage.

There are major efforts ongoing at Honeywell, IBM, Motorola in developing RAM based on spin valves and metal tunnel junctions such devices called MRAM have demonstrated faster speed, high density low power consumption, non volatility and radiation harness they are promising replacements for the Semi Conducting RAM currently used.

ADVANTAGES:

- Traditional transistors use on & off charge currents to create bits – the binary 0&1 of Computer information. Quantum spin field effect transistor will use up & down spin states to generate the same binary data.

- A currently logic is usually carried out using conventional electrons, while spin is used for memory. Spintronics will combine both.

- In most Semi Conducting transistors the relative proportion of the up & down carries types are equal. If Ferro Magnetic material is used as the carrier source then the ratio can be deliberately skewed in one direction.

- Amplification and / or switching properties of the Device can be controlled by the external magnetic field applied to the device.

- One of the problems of charge current electrons is that we pack more devices together, the chip heats up. Spin current releases heat but it is rather less.

ADVANTAGES

1. Non-Volatile memory
2. Low power Consumption
3. Spintronics does not require unique and specialised semiconductors
4. Spin life time is relatively long on the order of nanoseconds.
5. compared to normal RAM chips,
6. spintronic RAM chips will:
    - increase storage densities
    - have faster operation

LIMITATIONS

1. Controlling spin for long distances.
2. Difficult to INJECT and MEASURE spin.
3. Interference with nearest field.
4. Control of spin in Silicon is difficult.

CONCLUSION

Interest in spintronics arises, in part, from the looming problem of exhausting the fundamental physical limits of conventional electronics. 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.

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