SPINTRONICS

The Future Technology

Presented by

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ABSTRACT:
“Spintronics” uses the spin of electrons instead or in addition to the charge of an electron. Electron spin has two states either “up” or “down”. Aligning spins in material creates magnetism. Moreover, magnetic field affects the passage of spin-up and spin-down electrons differently. The paper starts with the detail description of the fundamentals and properties of the spin of the electrons. It is followed by an account of new Spin Field Effect Transistors and then it proceeds with a note on magneto resistance, the development of Giant magneto resistance (GMR) and devices like Magneto Random Access Memory, which are the new version of the traditional RAMs. It describe how this new version of RAMs which can revolutionize the memory industry. And the next versions of Race Track Memory were explained in a detailed manner. It also specifies the differences between electronic devices and spintronic devices. It also gives the hurdles due to the presence of holes. This paper also discusses about a Quantum computer, which uses qubits rather than normal binary digits for computations. Finally it ends with a note on why we should switch on this technology.

SPINTRONICS:

Spintronics, or spin electronics, refers to the study of the role played by electron (and more generally nuclear) spin in solid state physics, and possible devices that specifically exploit spin properties instead of or in addition to charge degrees of freedom. Imagine a data storage device of the size of an atom working at a speed of light. Imagine a microprocessor whose circuits could be changed on the fly. One minute is could be optimized for data base access.
The above-mentioned things can be made possible with the help of an exploding science – “spintronics”. Spintronics which deals with spin dependent properties of an electron instead of or in addition to its charge dependent properties, Conventional electronics devices rely on the transport of electric charge carries electrons. But there are other dimensions of an electron other than its charge and mass i.e. spins. This dimension can be exploited to create a remarkable generation of spintronic devices. It is believed that in the near future spintronics could be more revolutionary than any other thing that nanotechnology has stirred up so far.

**The Logic of Spin:**

Spin relaxation (how spins are created and disappear) and spin transport (how spins move in metals and semiconductors) are fundamentally important not only as basic physics questions but also because of their demonstrated value as phenomena in electronic technology.

Researchers and developers of spintronic devices currently take two different approaches. In the first, they seek to perfect the existing GMR-based technology either by developing
new materials with larger populations of oriented spins (called spin polarization) or by making improvements in existing devices to provide better spin filtering. The second effort, which is more radical, focuses on finding novel ways both to generate and to utilize spin-polarized currents—that is, to actively control spin dynamics. The intent is to thoroughly investigate spin transport in semiconductors and search for ways in which semiconductors can function as spin polarizer’s and spin valves. This is crucial because, unlike semiconductor transistors, existing metal-based devices do not amplify signals (although they are successful switches or valves). If spintronic devices could be made from semiconductors, however, then in principle they would provide amplification and serve, in general, as multi-functional devices. Perhaps even more importantly, semiconductor-based devices could much more easily be integrated with traditional semiconductor technology.

In addition to the near-term studies of various spin transistors and spin transport properties of semiconductors, a long-term and ambitious subfield of spintronics is the application of electron and nuclear spins to quantum information processing and quantum computation. The late Richard Feynman and others have pointed out that quantum mechanics may provide great advantages over classical physics in computation. However, the real boom started after Peter Shor of Bell Labs devised a quantum algorithm that would factor very large numbers into primes, an immensely difficult task for conventional computers and the basis for modern encryption. It turns out that spin devices may be well suited to such tasks, since spin is an intrinsically quantum property.
Spintronic Devices:

The first scheme for a spintronic device based on the metal-oxide-semiconductor technology familiar to microelectronics designers was the field effect spin transistor proposed in 1989 by Supriyo Datta and Biswajit Das of Purdue University. In a conventional field effect transistor, electric charge is introduced via a source electrode and collected at a drain electrode. A third electrode, the gate, generates an electric field that changes the size of the channel through which the source-drain current can flow, akin to stepping on a garden hose. This results in a very small electric field being able to control large currents.
In the Datta-Das device, a structure made from indium-aluminium-arsenide and indium-gallium-arsenide provides a channel for two-dimensional electron transport between two ferromagnetic electrodes. One electrode acts as an emitter, the other a collector (similar, in effect, to the source and drain, respectively, in a field effect transistor). The emitter emits electrons with their spins oriented along the direction of the electrode’s magnetization, while the collector (with the same electrode magnetization) acts as a spin filter and accepts electrons with the same spin only.

In the absence of any changes to the spins during transport, every emitted electron enters the collector. In this device, the gate electrode produces a field that forces the electron spins to precess, just like the precession of a spinning top under the force of gravity. The electron current is modulated by the degree of precession in electron spin introduced by the gate field.

Another interesting concept is the all-metal spin transistor developed by Mark Johnson at the Naval Research Laboratory. Its trilayer structure consists of a nonmagnetic metallic layer sandwiched between two ferromagnets. The all-metal transistor has the same design philosophy as do giant magneto resistive devices: The current flowing through the structure is modified by the relative orientation of the magnetic layers, which in turn can be controlled by an applied magnetic field. In this
scheme, a battery is connected to the control circuit (emitter base), while the direction of the current in the working circuit (base-collector) is effectively switched by changing the magnetization of the collector. The current is drained from the base in order to allow for the working current to flow under the “reverse” base-collector bias (ant parallel magnetizations). Neither current nor voltage is amplified, but the device acts as a switch or spin valve to sense changes in an external magnetic field. A potentially significant feature of the Johnson transistor is that, being all metallic, it can in principle be made extremely small using nanolithographic techniques (perhaps as small as tens of nanometres). An important disadvantage of Johnson’s transistor is that, being all-metallic, it will be difficult to integrate this spin transistor device into existing semiconductor microelectronic circuitry.

GIANT MAGNETO RESISTANCE:

Giant Magnetoresistance (GMR) is a quantum mechanical effect observed in thin film structures composed of alternating ferromagnetic and nonmagnetic metal layers. The effect manifests itself as a significant decrease in resistance from the zero-field state, when the magnetization of adjacent ferromagnetic layers are antiparallel due to a weak anti-ferromagnetic coupling between layers, to a lower level of resistance when the magnetization of the adjacent layers align due to an applied external field. The spin of the electrons of the nonmagnetic metal align parallel or antiparallel with an applied magnetic field in equal numbers, and therefore suffer less magnetic scattering when the magnetizations of the ferromagnetic layers are parallel. Giant Magnetoresistance (GMR) came into picture in 1988, which lead the rise of spintronics. It results from subtle electron-spin effects in ultra-thin ‘multilayer’ of magnetic materials, which cause huge
changes in their electrical resistance when a magnetic field is applied. GMR is 200 times stronger than ordinary Magnetoresistance.

**Types of GMR:**

**Multilayer GMR:**

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 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 several 10% at room temperature. The interlayer spacing in these devices typically corresponds to the second antiferromagnetic 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.

**Spin-valve GMR:**

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 spin-valve. Spin-valve GMR is the configuration that is most industrially useful, and is the configuration used in hard drives.

**Granular GMR:**

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.

**Applications:**
As stated above, GMR has been used extensively in the read heads in modern hard drives. Another application of the GMR effect is in non-volatile, magnetic random access memory (MRAM). Another important application of spintronics is hard drive, race track memory and quantum computer.

1) Magnetoresistive Random Access Memory:

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.

Description:

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". Data is written to the cells using a variety of means. In the simplest, each cell lies between a pair of write lines arranged at right angles to each other, above and below the cell. When current is passed through them, an induced magnetic field is created at the junction, which the writable
plate picks up. This pattern of operation is similar to core memory, a system commonly used in the 1960s. This approach requires a fairly substantial current to generate the field, however, which makes it less interesting for low-power uses, one of MRAM's primary disadvantages. Additionally, as the device is scaled down in size, there comes a time when the induced field overlaps adjacent cells over a small area, leading to potential false writes. This problem, the half-select (or write disturb) problem, appears to set a fairly large size for this type of cell. One experimental solution to this problem was to use circular domains written and read using the giant magnetoresistive effect, but it appears this line of research is no longer active.

A newer technique, spin-torque-transfer (STT) or Spin Transfer Switching, uses spin-aligned ("polarized") electrons to directly torque the domains. Specifically, if the electrons flowing into a layer have to change their spin, this will develop a torque that will be transferred to the nearby layer. This lowers the amount of current needed to write the cells, making it about the same as the read process. There are concerns that the "classic" type of MRAM cell will have difficulty at high densities due to the amount of current needed during writes, a problem STT avoids. For this reason, the STT proponents expect the technique to be used for devices of 65 nm and smaller. The downside is that, at present, STT needs to switch more current through the control transistor than conventional MRAM, requiring a larger transistor, and the need to maintain the spin coherence. Overall, however, the STT requires much less write current than conventional or toggle MRAM.

2) HARD DISK:

Advances have already been made, with basic spintronic devices already inside the vast majority of computers and laptops. For example, most hard drives today use a "spin valve", a device that reads information off the individual disks or platters that make up a hard drive. "That enabled a thousand fold improvement in the storage capacity of disk drives from
when we introduced it in 1998," said Dr Stuart Parkin of computer giant IBM and the inventor of the device. He describes the spin valve as part of "the first generation" of spintronic devices, relatively simple structures built of magnetic materials. Second generation devices, he said, have also recently hit the shelves in the form of a type of computer memory known as MRAM (Magnetoresistive Random Access Memory). These devices are a hybrid of a hard disk and more up to date types of memory, such as flash memory, commonly used in digital cameras. Like flash, MRAM has no moving parts and retains all of its data even when the power is switched off. But, like a hard drive, it stores data as magnetic charges.

**RACETRACK MEMORY:**

It is currently building a spintronic prototype of what calls "racetrack memory", a device that could increase storage density by up to 100 times. It achieves this by building "high-rise" chips. The racetrack is a very tall column of magnetic material; it is essentially a magnetic nanowire standing on end above the surface a silicon wafer," said Dr Parkin. Along the nanowire would be polarised regions, magnetized to point towards the north or South Pole. "The boundary between these regions is a magnetic domain wall and that is where the information is stored."
The domain walls are moved up and down the U-shaped wire by applying a tiny pulse of spin-polarised current - a flow of electrons all spinning in one direction - to either end of the wire. When the electrons make contact with a domain wall it moves it along the wire, shuffling the data like train carriages being shunted around a track. "You're not moving any atoms you're just moving a magnetic orientation," he said. The data would be read by a simple read/write device at the bottom of the "U". A working device would look like a small forest of nanowire covering the surface of a chip. But, it could be some time before racetrack memory is common place. "It will probably take another five years before we have a complete prototype."

**Quantum computer:**

"With quantum computing you are able to attack some problems on the time scales of seconds, which might take an almost infinite amount of time with classical computers," said Professor David Awschalom of the University of California, Santa Barbara. In a quantum computer, the fundamental unit of information (called a quantum bit or qubits), is not binary but rather more quaternary in name. This qubits property arises as a direct consequence of its adherence to the laws of quantum mechanics. A qubits can exist not only in a state corresponding to the logical state 0 or 1 as in a classical bit, but also in states corresponding to a blend or superposition of these classical states. Each electron spin can represent a bit; for instance, a 1 for spin up and 0 for spin down."
With conventional computers, engineers go to great lengths to ensure that bits remain in stable, well-defined states. 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. By having a large number of qubits in superposition of alternative states, a quantum computer intrinsically contains a massive parallelism. Unfortunately, in most physical systems, interactions with the surrounding environment rapidly disrupt these superposition states. A typical disruption would effectively change a superposition of 0 and 1 randomly into either a 0 or a 1, as process called decoherence. State-of-the-art qubits based on the charge of electrons in a semiconductor remain coherent for a few picoseconds at best and only at temperatures too low for practical applications. The rapid decoherence occurs because the electric force between charges is strong and long range. To quantum coherent devices, however, it is disadvantage. As a result, an experiment was conducted on the qubits, which are based on the electron-spin. Electron-spin qubits interact only weakly with the environment surrounding them, principally through magnetic fields that are non-uniform in space or changing in time. The goal of the experiment was to create some of these coherent spin states in a semiconductor to see how long they could survive. Much to the surprise, the optically excited spin states in ZnSe remained coherent for several nanoseconds at low temperatures—1,000 times as long as charge based Qubits.
CONCLUSION:

So with this paper we have proved that the new generation of computing and information technology is on its way to revolutionize the 21st century. We believe it makes sense instead to build on the extensive foundations of conventional electronic semiconductor technology; we exploit the spin of the electron and create new devices and circuits, which could be more beneficial.

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Abstract

Modern electronics is based on the manipulation of electronic charges in semiconductor devices. It relies on the continued miniaturizations of devices for the increase of processing speed and power. Spintronics employs the spin as well as the charge degree of freedom of conduction electrons to create a new class of electronic devices such as charge-based semiconductor devices. Infact, due to this they can store massive amount of energy, which we call as data. This paper reviews the fundamentals and they realize in new trend applications.

Introduction:

Spintronics (a neologism for "spin-based electronics"), also known as magneto electronics, is an emergent technology which
exploits the quantum propensity of electrons to spin as well as making use of their charge state. The spin itself is manifested as a detectable weak magnetic energy state characterized as "spin up" and "spin down".

Conventional use of electron state within a semiconductor is a purely binary proposition, where an electron's state or current represents only 0 or 1, and a range of eight bits can represent every number between 0 and 255, but only one number at a time. Spintronics quantum bits (known as qubits) exploit the "spin up" and "spin down" states as super positions of 0 or 1 with entanglement, so a register consisting of two spintronics qubits would have eight possible states instead of four.

**What is spin:**

In physics, spin refers to the angular momentum intrinsic to a body, as opposed to orbital angular momentum, which is generated by the motion of its center of mass about an external point. In classical mechanics, the spin angular momentum of a body is associated with the rotation of the body around its own center of mass. For example, the spin of the Earth is associated with its daily rotation about the polar axis. On the other hand, the orbital angular momentum of the Earth is associated with its annual motion around the sun.

In quantum mechanics, spin is particularly important for systems at atomic length scales, such as individual atoms, protons, or electrons. Such particles and the spin of quantum mechanical systems ("particle spin") possesses several unusual or non-classical features, and for such systems, spin angular
momentum cannot be associated with rotation but instead refers only to the presence of angular momentum.

**Impressing feature:**

Spintronic devices are used in the field of mass-storage devices; recently (in 2002) IBM scientists announced that they could compress massive amounts of data into a small area, at approximately one trillion bits per square inch (1.5 Gbit/mm²) or roughly 1 TB on a single sided 3.5" diameter disc. The storage density of hard drives is rapidly increasing along an exponential growth curve known as Kryder's Law. The doubling period for the areal density of information storage is twelve months, much shorter than Moore's Law,

**Moore’s Law**: The most popular formulation is of the doubling of the number of transistors on integrated circuits (a rough measure of computer processing power) every 18 months. At the end of the 1970s, Moore's Law became known as the limit for the number of transistors on the most complex chips. However, it is also common to cite Moore's law to refer to the rapidly continuing advance in computing power per unit cost.

A similar law has held for hard disk storage cost per unit of information. The rate of progression in disk storage over the past decades has actually sped up more than once, corresponding to the utilization of error correcting codes, the magnetoresistive effect and the giant magnetoresistive effect. The current rate of increase in hard drive capacity is roughly similar to the rate of increase in transistor count and has been dubbed Kryder's law. However,
recent trends show that this rate is dropping, and has not been met for the last three years.

This table shows the ability of spintronics

<table>
<thead>
<tr>
<th>CD:</th>
<th>Year</th>
<th>Smallest Pit</th>
<th>Spiral Pitch</th>
<th>Layer Capacity</th>
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<tr>
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<td>2004</td>
<td>69nm</td>
<td>100nm</td>
<td>201.0 GB</td>
</tr>
</tbody>
</table>

Another version states that RAM storage capacity increases at the same rate as processing power. However, memory speeds have not increased as fast as CPU speeds in recent years, leading to a heavy reliance on caching in current computer systems.

**An industry driver**

Although Moore's law was initially made in the form of an observation and prediction, the more widely it became accepted, the more it served as a goal for an entire industry. This drove both marketing and engineering departments of semiconductor manufacturers to focus enormous energy aiming for the specified increase in processing power that it was presumed one or more of their competitors would soon actually attain. In this regard it can be viewed as a self-fulfilling prophecy.
The implications of Moore's law for computer component suppliers are very significant. A typical major design project (such as an all-new CPU or hard drive) takes between two and five years to reach production-ready status. In consequence, component manufacturers face enormous timescale pressures—just a few weeks' delay in a major project can spell the difference between great success and massive losses, even bankruptcy. Expressed as "a doubling every 18 months", Moore's law suggests the phenomenal progress of technology in recent years. Expressed on a shorter timescale, however, Moore's law equates to an average performance improvement in the industry as a whole of over 1% a week. For a manufacturer competing in the competitive CPU market, a new product that is expected to take three years to develop and is just two or three months late is 10 to 15% slower, bulkier, or lower in storage capacity than the directly competing products, and is usually unsellable. which observes that the number of transistors in an integrated circuit doubles every eighteen months. Also the hard disk drives use a spin effect to function, the Giant magnetoresistive effect (see below).

In order to make a spintronic device, the primary requirement is to have a system that can generate a current of spin polarised electrons, and a system that is sensitive to the spin polarization of the electrons. Most devices also have a unit in between that changes the current of electrons depending on the spin states.
Spin pumping:

It is a method of generating a spin current, the spintronic analog of a battery in conventional electronics. In order to make a spintronic device, the primary requirement is to have a system that can generate a current of spin-polarized electrons, as well as a system that is sensitive to the spin polarization. Most spintronic devices also have a unit in between these two that changes the current of electrons depending on the spin states. Candidates for such devices include injection schemes based on magnetic semiconductors and ferromagnetic metals, ferromagnetic resonance devices, and a variety of spin-dependent pumps. Optical, microwave and electrical
methods are also being explored. The simplest method of generating a spin polarised current is to inject the current through a ferromagnetic material. The most common application of this effect is a giant magnetoresistance (GMR) device. A typical GMR device consists of at least two layers of ferromagnetic materials separated by a spacer layer. When the two magnetization vectors of the ferromagnetic layers are aligned, then an electrical current will flow freely, whereas if the magnetization vectors are antiparallel then the resistance of the system is higher. Two variants of GMR have been applied in devices, current-in-plane where the electric current flows parallel to the layers and current-perpendicular-to-the-plane where the electric current flows in a direction perpendicular to the layers.

**Spin valve:**

The most successful spintronic device to date is the spin valve. Spin valve is a device consisting of two or more conducting magnetic materials, that alternates its electrical resistance (from low to high or high to low) depending on the alignment of the magnetic layers. The magnetic layers of the device align "up" or "down" depending on an external magnetic field. Layers are made of two materials with different hysteresis curves so one layer ("soft" layer) changes polarity while the other ("hard" layer) keeps its polarity. In the figures below, the top layer is soft and the bottom layer is hard. Spin valves work because of a quantum property of electrons (and other particles) called spin. When a magnetic layer is polarized, the unpaired carrier electrons align their spins to the external magnetic field. When a potential exists across a spin valve, the spin-polarized electrons keep their spin alignment as they move through the device. If these electrons encounter a material with a magnetic field pointing in the opposite direction, they have
to flip spins to find an empty energy state in the new material. This flip requires extra energy which causes the device to have a higher resistance than when the magnetic materials are polarized in the same direction.

This device utilizes a layered structure of thin films of magnetic materials, which changes electrical resistance depending on applied magnetic field direction. In a spin valve, one of the ferromagnetic layers is "pinned" so its magnetization direction remains fixed and the other ferromagnetic layer is "free" to rotate with the application of a magnetic field. When the magnetic field aligns the free layer and the pinned layer magnetization vectors, the electrical resistance of the device is at its minimum. When the magnetic field causes the free layer magnetization vector to rotate in a direction antiparallel to the pinned layer magnetization vector, the electrical resistance of the device increases due to spin dependent scattering. The magnitude of the change, (Antiparallel Resistance - Parallel Resistance) / Parallel Resistance x 100% is called the GMR ratio. Devices have been demonstrated with GMR ratios as high as 200% with typical values greater than 10%. This is a vast improvement over the anisotropic magnetoresistance effect in single layer materials which is usually less than 3%. Spin valves can be designed with magnetically soft free layers which have a sensitive response to very weak fields (such as those originating from tiny magnetic bits on a computer disk), and have replaced anisotropic magnetoresistance sensors in computer hard disk drive heads since the late 1990s.

Future applications may include a spin-based transistor which requires the development of magnetic semiconductors exhibiting room temperature
ferromagnetism. The operation of MRAM or magnetic random access memory is also based on spintronic principles.

**Applications and some works**

**Design for a semiconductor computer circuit based on spin of electrons**

For the design for a semiconductor computer circuit based on the spin of electrons, they say the device would be more scalable and have greater computational capacity than conventional silicon circuits.

The researchers used a novel geometry to overcome the weakness of the magnetic signal, the current limitation to developing spintronics in silicon semiconductors.

**Discovery could dramatically advance field of spintronics**
NanoTech have demonstrated for the first time how the spin properties of electrons in silicon--the world's most dominant semiconductor, used in electronics ranging from computers to cell phones--can be measured and controlled.

The discovery could dramatically advance the nascent field of spintronics, which focuses on harnessing the magnet-like “spin” property of electrons instead of solely their charge to create exponentially faster, more powerful electronics such as quantum computers.

**On atomic level, nature differentiates between image and mirror image of magnetic structures - May lead to applications in “spintronics”**

On the atomic level nature differentiates between the image and mirror image of magnetic structures.

With the aid of computer simulations, detected a so-called “homochiral” magnetic structure in a thin metal layer, as described in an article published in the current edition of the journal 'Nature'.

There is no version with mirror-image spin. The researchers found this surprising selectivity very exciting since, on the one hand, it opens up a
whole new research area and, on the other hand, it may also lead to applications in “spintronics”, a promising field of future technology.

**Important advance in emerging field of "spintronics"**

Researchers have made an important advance in the emerging field of "spintronics" that may one day usher in a new generation of smaller, smarter, faster computers, sensors and other devices, according to findings reported in today's issue of the journal Nature Nanotechnology.

The research field of "spintronics" is concerned with using the "spin" of an electron for storing, processing and communicating information.

**Spinning electrons like some disorder**

Using ultra short pulses of laser light to reveal precisely why some electrons, like ballet dancers, hold their spin positions better than others—work that may help improve spintronic devices, which exploit the magnetism or "spin" of electrons in addition to or instead of their charge. One thing spinning electrons like, it turns out, is some disorder.

**Nanowires may pave way for new type of LED**

A long-sought semiconducting material that may pave the way for an inexpensive new kind of light emitting diode (LED) that could compete with today's widely used gallium nitride LEDs, according to a new paper in the journal Nano Letters.

To build an LED, you need both positively and negatively charged semiconducting materials; and the engineers synthesized zinc oxide (ZnO) nanoscale cylinders that transport positive charges or "holes" – so-called "p-type ZnO nanowires." They are endowed with a supply of positive charge carrying holes that, for years, have been the missing ingredients that prevented engineers from building LEDs from ZnO nanowires. In contrast, making "n-type" ZnO nanowires that carrier negative charges (electrons) has not been a problem. In an LED, when an electron meets a hole, it falls into a lower energy level and releases energy in the form of a photon of light.

Can conventional semiconductors learn new tricks? - Introducing spintronic properties and spin injection into silicon

Ways to introduce spintronic properties and a phenomenon called spin injection into silicon.

"For information processing and advanced logic operations, it would be particularly desirable to integrate seamlessly magnetic materials with
silicon, Rather than displace all that we've learned about silicon through the decades, my work tries to build on it."

New nanotechnology field - New way to control the quantum state of an electron's spin

Study in nanotechnology to create a third field that the researchers believe will lead to revolutionary advances in computer electronics, among many other areas.

First confirmed "spintronic" device incorporating organic molecules

Researchers at the National Institute of Standards and Technology have made the first confirmed “spintronic” device incorporating organic molecules, a potentially superior approach for innovative electronics that rely on the spin, and associated magnetic orientation, of electrons. The physicists created a nanoscale test structure to obtain clear evidence of the presence and action of specific molecules and magnetic switching behavior.

Future trends

As of Q1 2006, current PC processors are fabricated at the 90 nm level and 65 nm chips are just being rolled out by Intel (Pentium D & Intel Core). A decade ago, chips were built at a 500 nm level. Companies are working on using nanotechnology to solve the complex engineering problems involved
in producing chips at the 45 nm, 30 nm, and even smaller levels—a process that will postpone the industry meeting the limits of Moore's Law.

recent computer industry technology "roadmaps" predict (as of 2001) that Moore's Law will continue for several chip generations. Depending on the doubling time used in the calculations, this could mean up to 100 fold increase in transistor counts on a chip in a decade. The semiconductor industry technology roadmap uses a three-year doubling time for microprocessors, leading to about nine-fold increase in a decade. In Early 2006, IBM researchers announced that they had developed a technique to print circuitry only 29.9 nm wide using deep-ultraviolet (DUV, 193-nanometer) optical spintronics.

**Conclusion**

So in the end we can say that spintronics is a gift for semiconductor technology and for massive storage devices and its advancement will make us more secured in areas like nanotechnology, medical applications, laser and other connected fields.

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ABSTRACT

Spintronics is a new branch of electronics in which electron spin, in addition to charge, is manipulated to yield a desired electronic outcome. All spintronic devices act according to the simple scheme: (1) information is stored (written) into spins as a particular spin orientation (up or down), (2) the spins, being attached to mobile electrons, carry the information along a wire, and (3) the information is read at a terminal. Spin orientation of conduction electrons survives for a relatively long time (nanoseconds, compared to tens of femtoseconds during which electron momentum and energy decay), which makes spintronic devices particularly attractive for memory storage and magnetic sensors applications, and, potentially for quantum computing where electron spin would represent a bit (called qubit) of information. Spintronics (spin-based electronics) pertains to microelectronic devices that rely on electron spin rather than charge for memory and logic applications. This issue focuses on MRAM (magnetic random access memory), offering the potential for nonvolatile, on-chip storage—and on spin-based phenomena in semiconductors, offering the potential for devices that would function at exceptionally low power.

In order to make a spintronic device, the primary requirement is to have a system that can generate a current of spin polarized electrons, and a system that is sensitive to the spin polarization of the electrons. Most devices also have a unit in between that changes the current of electrons depending on the spin states.

Spintronics involves adding the additional degree of freedom of electron spin to the phenomenon of electronic transport. The topics that will be discussed include magnetoresistance such as GMR and CMR and how these phenomena have led to devices such as spin valves and spin sensors. Also to be discussed are spin tunnel junctions and the potential of spintronic devices to be used in MRAM (Magnetic Random Access Memory). The utility of nanophase particles (Quantum Dots) for spintronics applications provides interesting quantum confinement effects. The developing research on half metallic materials will also be presented. Half metals are conductors of electrons with one polarization but are insulators to electrons with opposite polarization. Finally, the developing new research initiative of spins in semiconductors (SPINS) will be discussed.
What is Spintronics?

Spintronics is a new emerging field of basic and applied research in physics and engineering where “neglected” magnetic degree of freedom of an electron—its spin—is envisaged to be exploited for classical and quantum information processing. While metallic spintronics has already delivered functional devices (GMR read heads in large capacity hard disk drives), and magnetic RAM of insulator spintronics (magnetic tunnel junctions) is expected to hit the market soon, current basic physics research is mostly focused on semiconductor spintronics. Although creation of inhomogeneous spin distribution does not require energy penalty (in contrast to charge distributions of conventional electronics), spin is not conserved whereas charge is. Thus, efforts in semiconductor spintronic research are focused on basic problems, such as: coherent manipulation of electron spin at a given location, transporting spins between different locations within conventional semiconductor environment, all-electrical spin control via spin-orbit interactions, diluted magnetic semiconductors, and fixed or mobile spin qubits for quantum computing.

Spin, which is assigned a value of “up” or “down,” is a quantum-mechanical property of electrons. Like charge, spin can be encoded with binary data.

Giant Magnetoresistance (GMR)

When two ferromagnetic layers are separated by a paramagnetic thin layer, electrical resistance of the multilayer changes depending on the orientations of the magnetizations.
of ferromagnetic thin layers. When the directions of the magnetizations are the same, the possibility of electron scattering at the interface of paramagnetic/ferromagnetic layers become smaller, resulting in low electrical resistance. However, if the directions of the magnetizations of the two ferromagnetic layers are opposite, the electron with opposite spin orientation with respect to the magnetization of the electrode layer is scattered (spin dependent electron scattering). The electrical resistance of the multilayer becomes higher than the case for the same directions of the magnetizations. This phenomenon is called giant magnetoresistance (GMR), because its value is much higher than the MR value obtained from anisotropic MR that appear from normal ferromagnetic materials.

Giant Magnetoresistance (GMR)

By sputter depositing ferromagnetic film on top of antiferromagnetic layer, the orientation of the magnetization of thin films can be "pinned" by the exchange coupling between the moment of the antiferromagnetic layer and the thin ferromagnetic layer. The thickness of the ferromagnetic layer must be thinner than the exchange length of the material. The magnetization of the other ferromagnetic layer can be easily changed by applying external field if the film is made of soft magnetic thin film. By this configuration, the MR changes sensitively depending on the external magnetic field, thus can be used as high sensitive read head for hard disk drives. As the areal density of magnetic recording media increases, the size of the bit is becoming more and more smaller. So the development of very sensitive GMR devices is required.

Tunnel Magnetoresistance (TMR)

When two ferromagnetic layers are separated by an insulator thin layer, electrical resistance of the multilayer in the perpendicular direction to the film changes depending on the orientations of the magnetizations of ferromagnetic thin layers because of spin dependent electron tunneling between the two ferromagnetic layers. When the directions of the magnetizations of the two ferromagnetic electrodes are the same, the possibility of electron tunneling between the two ferromagnetic electrode through the insulator layer becomes larger, resulting in larger tunneling current. However, if the directions of the
magentizations of the two ferromagnetic electrodes are opposite, the electron with opposite spin orientation with respect to the magnetization of the ferromagnetic electrode cannot be tunneled. Then the tunneling electron current become smaller compared to the case for the same directions of the magnetizations. This phenomenon is called tunneling magnetoresistance (TMR), because its value is reaching to 100% at room temperature.

By sputter depositing ferromagnetic film on top of antiferromagnetic layer, the orientation of the magnetization of thin films can be "pinned" by the exchange coupling between the moment of the antiferromagnetic layer and the thin ferromagnetic layer. The thickness of the ferromagnetic layer must be thinner than the exchange length of the material. The magnetization of the other ferromagnetic layer can be easily changed by applying external field if the film is made of soft magnetic thin film. By this configuration, the MR changes sensitively depending on the external magnetic field, thus can be used as high sensitive magnetoresistive devices such as magnetic random memory (MRAM). However, due to its large electrical resistance, the applications to a read head for hard disk drive (HDD) is considered to be difficult. So the effort to decrease the electrical resistance by thinning the tunneling barrier is being attempted for potential applications to read heads.

**Spin Transistor**

The magnetically-sensitive transistor (also known as the spin transistor or spintronic transistor--named for spintronics, the technology which this development spawned), originally developed in the 1990s and currently still being developed, is an improved design on the common transistor invented in the 1940s. The spin transistor comes about as a result of research on the ability of electrons (and other fermions) to naturally exhibit one of two (and only two) states of spin: known as "spin up" and "spin down". Unlike its namesake predecessor, which operates on an electric current, spin transistors operate on electrons on a more fundamental level; it is essentially the application of electrons set in particular states of spin to store information.

One advantage over regular transistors is that these spin states can be detected and altered without necessarily requiring the application of an electric current. This allows for detection hardware (such as hard drive heads) that are much smaller but even more
sensitive than today's devices, which rely on noisy amplifiers to detect the minute charges used on today's data storage devices. The potential end result is devices that can store more data in less space and consume less power, using less costly materials. The increased sensitivity of spin transistors is also being researched in creating more sensitive automotive sensors, a move being encouraged by a push for more environmentally-friendly vehicles.

A second advantage of a spin transistor is that the spin of an electron is semi-permanent and can be used as means of creating cost-effective non-volatile solid state storage that does not require the constant application of current to sustain. It is one of the technologies being explored for Magnetic Random Access Memory (MRAM).

Because of its high potential for practical use in the computer world, spin transistors are currently being researched in various firms throughout the world, such as in England and in Sweden. Recent breakthroughs have allowed the production of spin transistors, using readily-available substances, that can operate at room temperature: a precursor to commercial viability. Electron spin is already making its mark on the computer industry with the development of magnetic random access memory chips, or MRAMs. Computers that utilize MRAM don't need to be booted up to move hard-drive data into memory; MRAM can also store data in a much smaller space and access it much more quickly, while consuming far less power than today's charge-based memory.

The most successful spintronic device to date is the spin valve. This device utilizes a layered structure of thin films of magnetic materials, which changes electrical resistance depending on applied magnetic field direction. In a spin valve, one of the ferromagnetic layers is "pinned" so its magnetization direction remains fixed and the other ferromagnetic layer is "free" to rotate with the application of a magnetic field.

When the magnetic field aligns the free layer and the pinned layer magnetization vectors, the electrical resistance of the device is at its minimum. When the magnetic field causes the free layer magnetization vector to rotate in a direction antiparallel to the pinned layer magnetization vector, the electrical resistance of the device increases due to spin dependent scattering. The magnitude of the change, (Antiparallel Resistance - Parallel Resistance) / Parallel Resistance x 100% is called the GMR ratio.

Devices have been demonstrated with GMR ratios as high as 200% with typical values greater than 10%. This is a vast improvement over the anisotropic magnetoresistance
effect in single layer materials which is usually less than 3%. Spin valves can be designed with magnetically soft free layers which have a sensitive response to very weak fields (such as those originating from tiny magnetic bits on a computer disk), and have replaced anisotropic magnetoresistance sensors in computer hard disk drive heads since the late 1990s.
The technology

What will it do? Data storage is one of the first likely uses of spintronics. The idea is that electron spin will add up to quicker and more densely packed data storage. You can already see the fruits of electron spin in GMR - it is behind the read/write heads in today's hard disks. After that, maybe we could devise semiconductor materials that manipulate the spin of electrons just as we now mess around with their charge. Thus could be born a new approach to electronics, and one that could smash the physical barriers that limit what we do with charge based semiconductor devices. Electronics has done wonders of miniaturisation in the 50 years or so since the first transistor - so why bother? Because there are physical limits to Moore's Law, the self-fulfilling prophesy that we can double the number of chips on a piece of semiconductor real estate every 18 months or so.

By using a unique experimental technique, the research team was able to demonstrate that contrary to conventional scientific wisdom, spin current moves through a semiconductor at a slower rate than does charge current. Depending on the application, this effect, which is called "spin Coulomb drag," could prove to be either an advantage or a disadvantage for future spintronic technologies. "Spin Coulomb drag results because the motion of spin through the semiconductor is sensitive to collisions between electrons, whereas the transport of charge is not," says Orenstein. "When electrons bump into one another, the mutual repulsion of their negative charges creates a drag on their spin current, which is a relative motion between individual electrons, but not on their charge current, which is the collective transport of all the electrons in motion."

Any Money In This?

"Spintronics has a number of potentially groundbreaking applications that are set to drive next-generation electronics." That's what the analysts say at market-research firm Frost & Sullivan. "While GMR can arguably be considered the driving force for spintronics at present, the biggest potential of spin-based devices is in embedded memories." It is known as MRAM, magnetoresistive random access memory. Then
there is the general hysteria surrounding nanotechnology. Being really really small, spintronics rides that bandwagon too. There is certainly plenty of R&D cash going into spintronics, with more than a dozen active labs in the USA alone. Some of the bigger companies, such as IBM, are players too. There are even some start-ups in the spin space. Indeed, one, NVE Corporation, has been around since 1989, is quoted in NASDAQ, and describes itself as "a leader in the practical commercialization of spintronics, a nanotechnology that many experts believe represents the next generation of microelectronics". NVE licenses its technology. Agilent is one customer.

Applications

Spintronic devices are used in the field of mass-storage devices; recently (in 2002) IBM scientists announced that they could compress massive amounts of data into a small area, at approximately one trillion bits per square inch (1.5 Gbit/mm²) or roughly 1 TB on a single sided 3.5" diameter disc. The storage density of hard drives is rapidly increasing along an exponential growth curve. The doubling period for the areal density of information storage is twelve months, much shorter than Moore's Law, which observes that the number of transistors in an integrated circuit doubles every eighteen months. Also the hard disk drives use a spin effect to function, the Giant magnetoresistive effect

Future applications may include a spin-based transistor which requires the development of magnetic semiconductors exhibiting room temperature ferromagnetism. The operation of MRAM or magnetic random access memory is also based on spintronic principles.

Conclusion

So Spintronics is a new a branch in which electron spin, in addition to charge, is manipulated to yield a desired electronic outcome. The topics that are discussed include magnetoresistance such as GMR and CMR and how these phenomena have led to devices such as spin valves. Also we have discussed about the spin transistor and MRAMs. Futurologists and high-tech gurus anticipate that the next big thing in
the electronics industry will be spintronics, devices based on electron spin — smaller,
fastier, and more versatile than today's devices, which are based on electron charge.

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ABSTRACT:

Our paper explains about the spintronics, or spin electronics, referring to the study of the role played by electron (and more generally nuclear) spin in solid state physics, and possible devices that specifically exploit spin properties instead of or in addition to charge degrees of freedom. The combination of magnetic engineering and Electronics leads to spintronics.

The Spintronics devices and how they act are explained. The logic behind the Spintronic-devices combine the advantages of magnetic materials and semiconductors. The different spintronics devices diagrams are shown in the figures.

Major applications of spintronics which have recently come into the market are Magnetoresistive random access memory (MRAM) discussed. A brief introduction of MRAM along with the MR2A16A (a 4 Mbit MRAM device). The working process of MR2A16A (a 4 Mbit MRAM device) with suitable diagrams of it, is mentioned.

The MRAM description---MRAM is based on magnetic memory elements integrated with CMOS. The elements are formed from two ferromagnetic plates, each of which can hold a magnetic field, separated by a thin insulating layer. The simplified structure of an MRAM cell along with its block diagram, the working process of reading and writing of data into the cell is explained. Each memory element uses a magnetic tunnel junction (MTJ) device for data storage. The data is stored as a magnetic state, rather than charge, and sensed by measuring the resistance without disturbing the magnetic state. The change in resistance with the magnetic state of the device is an effect known as magnetoresistance, hence the name “Magnetoresistive” RAM.

MRAM description--The MRAM architecture is an application of spintronics that combines magnetic-tunnel-junction (MTJ) and CMOS technologies. The MTJ is composed of a fixed magnetic layer, a thin dielectric tunnel barrier, and a free magnetic layer.

Comparison of MRAM with the other devices in the aspects of—density, power consumption, speed and overall performance.

The application of Magnetoresistive random access memory (MRAM) in various fields and spintronics applications are mentioned.
INTRODUCTION:

Magnetoelectronics, Spintronics, or spin electronics, involves the study of active control and manipulation of spin degrees of freedom in solid-state systems. This is a new technological discipline which aims to exploit the subtle and mind-bendingly esoteric quantum properties of the electron to develop a new generation of electronic devices. The word is a blend of electronics with spin, the quantum property it exploits.

Howard Johnson is father of the breakthrough science called spintronics. Electrons, in addition to their negative charge, also possess a spin (properties of a small magnet).

Every electron exists in one of two states, spin-up or spin-down; it is possible to make a sandwich of gold atoms between two thin films of magnetic material that will act as a filter or valve that only permits electrons in one of the two states to pass. The filter can be changed from one state to the other using a brief and tiny burst of current. From this simple device it’s hoped to make incredibly tiny chips that will act as super-fast memories whose contents will survive loss of power.

Coming to Spintronic-devices:

The history of spintronics began with the discovery of the physical phenomenon called giant magnetoresistance (GMR) in 1988, and progressed through the realization of tunnel magnetoresistance (TMR) in 1995.
These device technologies are already in practical use as magnetic heads for hard disks and new nonvolatile memories (MRAM). However, the performances of GMR and TMR devices are approaching their limit, creating an anxious need, from the application end, for realization of a magnetoresistive device of even higher performance.

Spintronic-devices combine the advantages of magnetic materials and semiconductors. They are expected to be non-volatile, versatile, fast and capable of simultaneous data storage and processing, while at the same time consuming less energy. Spintronic-devices are playing an increasingly significant role in high-density data storage, microelectronics, sensors, quantum computing and bio-medical applications, etc.

All spintronic devices act according to the simple scheme:
(1) information is stored (written) into spins as a particular spin orientation (up or down),
(2) The spins, being attached to mobile electrons, carry the information along a wire, and (3) the information is read at a terminal.
Spin orientation of conduction electrons survives for a relatively long time (nanoseconds, compared to tens of femtoseconds during which electron momentum and energy decay), which makes spintronic devices particularly attractive for memory storage and magnetic sensors applications, and, potentially for quantum computing where electron spin would represent a bit (called qubit) of information.
APPLICATION OF SPINTRONICS:

MAGNETORESISTIVE RANDOM ACCESS MEMORY (MRAM)

INTRODUCTION:

Magnetoresistive random access memory (MRAM) is a nonvolatile memory that's been in development for over 15 years, but only recently has come onto the market. Magnetoresistive Random Access Memory (MRAM) combines a magnetic device with standard silicon-based microelectronics to obtain the combined attributes of non-volatility, high-speed operation and unlimited read and write endurance not found in any other existing memory technology.

MRAM uses magnetic moments, rather than an electric charge, to determine the on–off state of the memory bit cell. It allows a single memory solution to replace multiple memory options within one chip—helping to enable faster, more cost–effective solutions for next-generation memory–intensive products. MRAM is a nonvolatile memory technology that protects data in the event of power loss and does not require periodic refreshing. The MR2A16A (a 4 Mbit MRAM device), is the ideal memory solution for applications that must permanently store and retrieve critical data quickly.

An overview of Freescale’s MRAM technology and describe the MR2A16A, a 4 Mbit MRAM device. The memory is based on a 1-transistor, 1-magnetic tunnel junction (1T1MTJ) memory cell that employs a novel bit structure and approach for operation. The MR2A16A is fabricated with a 0.18μm CMOS process using five levels of metal, including program current lines clad with highly permeable material for magnetic flux concentration. We describe how the cell architecture, bit structure, and the toggle switching mode are combined to provide significantly improved operational performance and manufacturability as compared to MRAM based on conventional switching.
MRAM DESCRIPTION

MRAM is based on magnetic memory elements integrated with CMOS. 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".

THE SIMPLIFIED STRUCTURE OF AN MRAM CELL
Reading of data from cell:

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".

Writing data to the cells:

Data is written to the cells using a variety of means. In the simplest, each cell lies between a pair of write lines arranged at right angles to each other, above and below the cell. When current is passed through them, an induced magnetic field is created at the junction, which the writable plate picks up.

Each memory element uses a magnetic tunnel junction (MTJ) device for data storage. The MTJ is composed of a fixed magnetic layer, a thin dielectric tunnel barrier, and a free magnetic layer. When a bias is applied to the MTJ, electrons that
are spin polarized by the magnetic layers traverse the dielectric barrier through a process known as tunneling. The MTJ device has a low resistance when the magnetic moment of the free layer is parallel to the fixed layer and a high resistance when the free layer moment is oriented anti-parallel to the fixed layer moment. This change in resistance with the magnetic state of the device is an effect known as magnetoresistance, hence the name “Magnetoresistive” RAM.

A memory array consisting of many MRAM cells with digit and bit lines for cross-point writing and isolation transistors controlled by word lines

The data is stored as a magnetic state, rather than charge, and sensed by measuring the resistance without disturbing the magnetic state. Using a magnetic state for storage has two main benefits:
1) The magnetic polarization does not leak away with time like charge does, so the information is stored even when the power is turned off; and
2) Switching the magnetic polarization between the two states does not involve actual movement of electrons or atoms and thus has no known wear-out mechanism.

**MRAM ARCHITECTURE:**

The MRAM architecture is an application of spintronics that combines magnetic-tunnel-junction (MTJ) and CMOS technologies. The MTJ is composed of a fixed magnetic layer, a thin dielectric tunnel barrier, and a free magnetic layer. When applying a current bias to the MTJ, electrons start moving and become spin-polarized by the magnetic layer as they traverse the dielectric. If the magnetic vectors are parallel on both layers, a low resistance is detected and the result is a zero; otherwise, a high resistance is detected and the result is a one.

Freescale's 4-Mbit MRAM offers 35-ns symmetrical read/write with a data retention greater than 10 years, making it a solid alternative to battery-backed SRAM.
Comparison with other systems:

1. Density:-

The main determinant of a memory system's cost is the density of the components used to make it up. Smaller components, and less of them, means that more "cells" can be packed onto a single chip, which in turn means more can be produced at once from a single silicon wafer, which improves yield and it is directly related to cost.

To be worth putting into wide production, however, it is generally believed that MRAM will have to move to the 65 nm size of the most advanced memory devices, which will require the use of STT.

2. Power consumption:-

The capacitors used in DRAM lose their charge over time, memory assemblies using them must periodically refresh all the cells in their chips. This demands a constant power supply.

In contrast, MRAM requires no refresh at any time. Not only does this mean it retains its memory with the power turned off, but also that there is no constant power draw.

3. Speed:-
Speed is limited by the speed at which the current stored in the cells can be drained (for reading) or stored (for writing). MRAM operation is based on measuring voltages rather than currents, so there is less "settling time" needed. MRAM devices with access times on the order of 2 ns, somewhat better than even the most advanced DRAMs built on much newer processes.

4. Overall:-

MRAM has similar speeds to SRAM, similar density of DRAM but much lower power consumption than DRAM, and is much faster and suffers no degradation over time in comparison to Flash memory. It is this combination of features that some suggest make it the "universal memory", able to replace SRAM, DRAM and EEPROM and Flash. This also explains the huge amount of research being carried out into developing it.

MRAM devices with access times on the order of 2 ns, somewhat better than even the most advanced DRAMs built on much newer processes.

Applications:

Proposed uses for MRAM include devices such as:

- **Aerospace** and military systems
- **Digital cameras**, **Notebooks**, **Smart cards**
- **Mobile telephones**, **Cellular base stations**, **Personal Computers**
- Battery-Backed **SRAM** replacement
- Datalogging specialty memories
- **Personal Computers**
- Battery-Backed **SRAM** replacement
- Datalogging specialty memories

CONCLUSION:

In future spintronics devices place an important roll in the electronics equipments, because of important advantages of it. There are

- Spintronics does not require unique and specialised semiconductors, therefore it can be implemented or worked with common metals, such as Copper, Aluminium and Silver.
- Spintronics devices would consume less power compared to conventional electronics, because the energy needed to change spin is a easy compared to energy needed to push charge around.
- Since Spins don’t change when power is turned off, the memory remains non-volatile.