A REVIEW REPORT FOR NEXT GENERATION OF CMOS TECHNOLOGY AS SPINTRONICS: FUNDAMENTALS, APPLICATIONS AND FUTURE

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ABSTRACT

As the scaling continues to reduce the physical feature size and to increase the functional throughput, two most outstanding limitations and major challenges among others, are power dissipation and variability as identified by ITRS. This paper presents the expose, in those collective phenomena, spintronics using appropriate order parameters of magnetic moment. It shows that the benefits of the scalability to smaller sizes in the case of spintronics (nanomagnetics) include a much reduced variability problem as compared with today's electronics. In addition, another advantage of using nanomagnets is the possibility of constructing nonvolatile logics, which allow for immense power savings during system standby. However, most of devices with magnetic moment usually use current to drive the devices and consequently, power dissipation is a major issue. Spin-dependent phenomena in semiconductors may lead to devices with new enhanced functionality, such as polarized solid-state light sources (spin light-emitting diodes), novel microprocessors and sensitive biological and chemical sensors. Spintronics (or spin electronics) is an emerging field of basic and applied research in physics and engineering that aims to exploit the role played by electron spin in the solid state material. Spintronics devices make use of spin properties instead of, or in addition to electron charge to carry information, thereby offering opportunities for novel nanoelectronics devices. This paper reviews the background and current status of this subject and some applications of Spontronics.

KEYWORDS: *TMR, MRAM, GMR, spin-FETs, Spin-LEDs, ferromagnetic, spin- orbit coupling Spin precession angle, Spin Hall Effect, Spintronics, magneto electrons, DRAM, spin logic, novel microprocessor, ITRS.*

I. INTRODUCTION

The rapid decrease in computational power and increase in speed of integrated circuits is supported by the very fast reduction of semiconductor devices' feature size. Due to constantly introduced innovative changes in the technological processes, the miniaturization of MOSFETs by Moore's law successfully continues. The 32-nm MOSFET process technology by Intel, involves new high-k dielectric/metal gates, which represents a major change in the technological process since the invention of MOSFETs. Although alternative channel materials with mobility higher than in Si were already investigated, it is believed that Si will still be the main channel material for MOSFETs beyond the 22-nm technology node [9, 12].

With scaling apparently approaching its fundamental limits, the semiconductor industry is facing critical challenges. New engineering solutions and innovative techniques are required to improve CMOS device performance. Strain-induced mobility enhancement is one of the most attractive solutions to increase the device speed, which will certainly maintain its key position among possible technological innovations for future technology generations [12, 13]. In addition, new device architectures based on multigate structures with better electrostatic channel control and reduced short channel effects will be developed. A multigate MOSFET architecture is expected to be introduced for the 16-nm technology node. Combined with a high-k dielectric/ metal gate technology and strain engineering, a multigate MOSFET appears to be the ultimate device for high-speed operation with excellent channel control, reduced leakage currents, and low-power budget.

II. WHY SPINTRONICS IS LEADING?

The miniaturization of microelectronics components by roughly a factor of 40 has taken place from the early days of integrated circuits, starting around 1970. Over this, microelectronics has advanced from the first integrated circuits to present day computer chips containing 100 million transistors. It is now well recognized that further shrinking of the physical size of semiconductor electronics will soon approach a fundamental barrier. The fundamental physical laws that govern the behavior of transistors will preclude them from being shrunk any further and packed in even greater number on computer chips. The continuous shrinking of transistors will result in various problem related electric current leakage, power consumption and heat [11].

On other hands, miniaturization of semiconductor electronic device is making device engineers and physicists feel the looming presence of quantum mechanics-a brilliant physics concept developed in the last century –where counterintuitive ideas such as wavelike behavior, is more dominant for ‘particles’ such as the electron. Electron spin is, after all, a quantum phenomenon. Many experts agree that Spintronics, combined, with nanotechnology would offer the best possible solution to the problems associated with miniaturization mentioned above. Nanoscience and nanotechnology involve the study of extremely tiny devices and related phenomena on a spatial scale of less than one-thousand the diameter of a human hair or roughly half the diameter of a DNA molecule [10, 11].

III. PHYSICS OF SPINTRONICS

Spintronics is also called spin-electronics, where the spin of an electron is controlled by an external magnetic field and polarize the electrons. These polarized electrons are used to control the electric current. The goal of Spintronics is to develop a semiconductor that can manipulate the magnetism. Once we add spin degree of freedom to electronics, it will provide significant versatility and functionality to future electronics products. Magnetic spin properties of electrons are used in many applications such as magnetic memories, magnetic recording (read, write), etc.

The realization of semiconductor of semiconductors that is ferromagnetic. Above room temperature will potentially lead to a new generation of Spintronics devices with revolutionary electrical and optical properties. The field of Spintronics was born in the late 1980s with the discovery of the “giant magneto resistance effect”. The giant magneto resistance (GMR) effect occurs when a magnetic field is used to align the spin of electrons in the material, including a large change in the resistance of a material. A new generation of miniature electronic devices like computer chips light- emitting devices for displays, and sensors to detect radiation, light and magnetic fields are possible with the new generation of Spintronics materials.

In electronic devices, information is stored and transmitted by the flow of electricity in the form of negatively charged subatomic particles called electrons. The zeros and ones of computer binary code are represented by the presence or absence of electron in the semiconductor or other material. In spintronics, information is stored and transmitted using another property of electron, acts like a compass needle, which points either up or down to represent the spin of an electron. Electrons moving through a nonmagnetic material normally have random spins, so the net effect is zero. External magnetic fields can be applied so that the spins are aligned (all up or all down).The effect was first discovered in a device made of multiple layers of electrically conducting materials: alternating magnetic and nonmagnetic layers. The device was known as “spin valve” because when a magnetic field was applied to the device, spin of its electrons went from all up to all down , changing its resistance so that the device acted like a valve to increase or decrease the flow of electrical current, called Spin Valves.

The first scheme of Spintronics devices based on the metal oxide semiconductor technology was the first field effect Spin transistor proposed in 1989 by Suprio Datta and Biswajit Das of Purdue University. In their device, a structure made from indium – aluminum arsenide and Indium- gallium – arsenide provides a channel for two, dimensional electron transport between two ferromagnetic electrodes. One electrode acts as an emitter and other as a collector. The emitter emits electrons with their spins oriented along the direction of electrodes magnetization, while any change to the spins during transport, every emitted electron enters the collector [2].

IV. SPINTRONICS DEVICES

Recording devices, such as computer hard disks, already employ the unique properties of the materials. Data are recorded and stored any tiny areas of magnetized iron or chromium oxides. A "read head" can read this information by detecting minute changes in the magnetic field as the disk rotates underneath it. This induces changes in the head's electrical resistance – also known as magnetoresistance. Spintronic devices, also known as magnetoelectronics, are expected to become the ideal memory media for computing and main operating media for future quantum computing. The first widely acknowledgement breakthrough in the Spintronics was the use of GMR, used in read heads of the hardest drives already mentioned above. A "popular" device that exploits the Spintronics is, for example the Apple iPod 60 GB. Measuring a little more than an inch thickness, this pocket filling divide has a Spintronics based "read head".

Recent discovery of Tunneling Magnetoresistance (TMR) has lead to the idea of magnetic tunnel junction that has been utilized for the MRAM (Magnetic Random Access Memory). Here, one has two magnetic layer separated by an insulating metal oxide layer. Electrons are able to tunnel from one layer to other only when magnetizations of the layers than in the standers GMR devices, known as "spin valves". Spintronic devices, combining the advantages of magnetic materials and semiconductors, are expected to be fast, non-volatile and consume less power. They are smaller than s 100 nanometers in size, more versatile and more robust than the conventional ones making up silicon chips and circuit elements. The potential market is expected to be worth hundreds.

V. SEMICONDUCTOR SPINTRONICS

In spite of the rapid advances in metal-based Spintronics devices (such as GMR devices), a major focus for researchers has been to find novel ways to generate and utilize spin- polarized currents in semiconductors . These include the investigation of spin –transport in semiconductors and exploration of possibilities for making semiconductors function as spin polarizes and spin valves. This is important because semiconductor-based Spintronics devices can easily be integrated with traditional semiconductor technology; they also can serve as multi- functional devices. Further, spins in semiconductor can be more easily manipulated and controlled. Scientists and Engineers claim that a merger of electronics, photonics, and magnetic will provide novel spin base multifunctional devices such as spin-FETs (field-effect transistors), spin-LEDs (light-emitting diodes), spin RTDs (resonant tunneling devices), optical switches operating at terahertz frequencies, modulators, quantum computations, etc.

VI. SPIN INJECTION INTO SEMICONDUCTORS

The goal of spintronics research is to eventually relieve present information technology from solely relying on the charge of electrons. This spin degree of freedom of an electron has shown to be a very viable candidate to save the microelectronics industry from the result of "Moor's Law" which describes a trend of electrical components getting increasingly smaller, eventually reaching atomic scales. Though much progress has been made, a final obstacle needs to be overcome for spintronics to emerge as dominant technology. Spintronics is highly energy efficient, and Spintronic devices generate less heat in operation than semiconductor devices. This unique property may extend the life of Moore's law by having higher integration levels without astronomical heat generation [2].

Since nearly all electronic components currently rely on semiconductors, namely Silicon, it would make sence to interface any new spintronics technology with semiconductors as well. However maintaining spin polarization in a semiconductor can prove to be quite difficult. The major problem is that it is hard to form good atomic interface between a ferromagnetic metal and a semiconductor. Poor interfaces can cause the electron spins to be randomized in direction when electrons transit through the interface

One can eliminate the interface problem by making semiconductors into ferromagnetism. Unfortunately, a semiconductor does not make a good ferromagnetic in general. The magnetic semiconductors often work only at lower temperatures than room temperature, and they are not strongly magnetic.

Just recently, researchers have successfully injected spin polarized current into Silicon from ferromagnet. Since Si has no nuclear spin, there are no hyperfine interactions, resulting in very spin preservation for electrons inside the semiconductor [3].

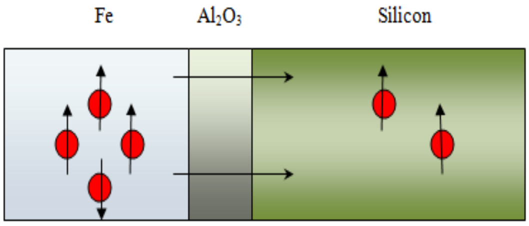

Figure (1): Spin Injunction in Semiconductor [3]

VII. SPIN TRANSISTOR

The basic idea of spin transistor, as proposed by Suprio Datt and Biswajit Das, is to control the spin the spin orientation by applying a gate voltage, as shown in fig.3. A spin –FET, as depicted below, consists of ferromagnetic electrodes and semiconductor channels that contain a layer of electrons and a gate electrode attached to the semiconductor. The source and drain electrodes are ferromagnetic (FM) metals. The spin-polarized electrons are injected from the FM source electrode (FMs), and after entering the semiconductor channels they begin to rotate. The rotation is caused by an effect due to "spin-orbit coupling" that occurs when electrons move through the semiconductor crystal in the presence of an electric field through the gate electrode. The rotation can be controlled, in principle, by an applied electric field through the gate electrode. If the spin orientation of the electron channels is aligned to FM drain (FM_d) electrode, electrons are able to flow into the FM drain electrode. However, if the spin orientation is flipped in the electron layer (as shown in figure above), electrons cannot enter the drain electrode (FM_d).In this way, with the gate electrode the orientation of the electron spin can be controlled. There, in a spin –EFT the current flow is modified by the spin precession angle. Since the spin-FET concept was published in1990, there has been a world-wide effort to develop such a transistor.

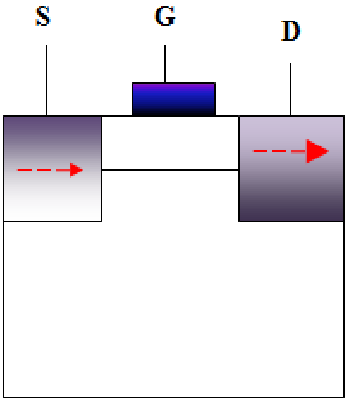

Figure (2): Schematic views of classical spin FET[S: Source, G: Gate, D: Drain,] [4]

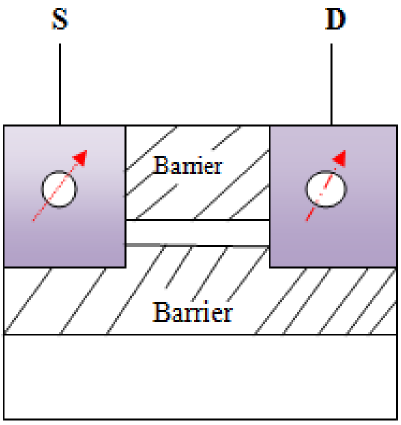

Figure (3): New approach suggested by Bandyopadhyay and Cahay [4]

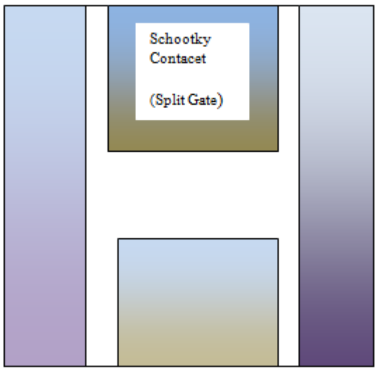

Figure (4): top view of split gates [4]

VIII. SPIN (MAGNETIC) BJT

In an ordinary transistor, specially an n-p-n type transistor, two n-type semiconductors are separated by a p-type semiconductor. Near the n-p-n junction, a gate controls the voltage across the p- type semiconductor. When a voltage is placed across the p-type semiconductor, free electrons either are attracted towards the gate (base) or away from it, depending on the direction of the applied voltage. This lack or presence of gate electrons controls the flow of current between the two n-type semiconductors, allowing the transistor to occupy both and off states.

The problem with electrically-based -transistors is there volatility. When power is shut off, the electrons in the p-type semiconductor are no longer confined to a single region and diffuse throughout, destroying their previous on or off configuration. This is the reason why computers cannot be instantly turned on and off. However, a new type of transistor may change all of this.

In a magnetic transistor, magnetized ferromagnetic layers replace the role of n and p-type semiconductors. Much like in a spin-valve, substantial current can flow through parallel magnetized ferromagnetic layers. However if say, in a three layer structure, the middele layer is antiparallel to the two side layers; the current flow would be quite restricted, resulting in a high overall resistance. If two outside layers are pinned and the middle layer allowed to be switched by an external magnetic field, a magnetic transistor could be made, with on and off configurations depending on the orientation of the middle magnetized layer. Magnetic (spin) transistors are good candidates for logic (spin logic).

IX. SPIN VALVE WITH GIANT MAGNETORESISTANCE

Spintronic device that currently has wide commercial application is the spin valve**.** Most modern hard disk drives employ spin- valves to read each magnetic bit connected on the spinning platters inside A spin-valve is essentially a spin "switch" that can be turned on and off by external magnetic fields.

Basically it is composed of two ferromagnetic layers separated by a very thin non-ferromagnetic layer. When these two layers are parallel, electrons can pass through both easily, and when they are anti-parallel, few electrons will penetrate both layers. The principles governing spin-valve operation are purely quantum mechanical. Generally, an electron current contains both up and down spin electrons in equal aboundance. When these electrons approach a magnetized ferromagnetic layer, one where most or all contained atoms point in the same direction, one of the spin polarizations will scatter more than the other. If the ferromagnetic layers are parallel, the electrons not scattered by the first layer will not be scattered by the second, and will pass through both. The result is a lower total resistance (large current). However, if the layers are antiparallel, each spin polarization will scatter by the same amount, since each encounters a parallel and antiparallel once. The total resistance is then higher than in the parallel configuration (small current).Thus, by measuring the total resistance of the spin valve, it is possible to determine if it in a parallel or antiparallel configuration, and since this is controlled by an external magnetic field, the direction or the other, their orientation can easily be determined with a device using this mechanism.

X. SPIN HALL EFFECT

In order to realize spintronics as a fully operational technology, the ability to manipulate spin polarized electrons with in a conductor is necessary. A phenomenon called the spin Hall effect may be the solution. In the regular Hall effect, in a magnetic field is placed perpendicular to the direction of current. The reason for this is the electrons in the current flow in a conductor; a bias voltage will be created perpendicular to both across the conductor. The reason for this is the electrons in the current interact with the magnetic field and experience a Lorentz force at right angles to the field and direction of current flow. They are pushed to one side of the conductor, and an electric field is created across the conductor.

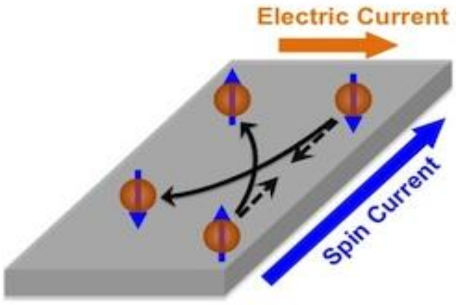

Figure (5): Spin Hall Effect [3]

In the spin Hall Effect, a similar phenomenon occurs. Because the spin of an electron is coupled to its magnetic momentum, if an electric field is placed perpendicular to the direction of current flow, the electrons spin degree of freedom interacts with the field and also experiences a Lorentz force. However, since electron spin can point either up or down, the two types of electrons will separate or move to opposite sides of the conductor. Although it was predicted almost 40 years ago, the spin Hall Effect has received significant interest within the past decade.

XI. SPIN LEDS

Recently, efficient spin injection has been successfully demonstrated in all semiconductor tunnel diode structures by using a spin- polarized DMS as the injector in one case, and using a paramagnetic semiconductor under high magnetic field as a spin filter in the other. In such a case, spin- polarized holes and unpolarised electronics are injected from either side and recombine in a quantum well. The polarization of the injected holes can be left- circularly polarizes light in the electroluminescence spectra.

Among such devices the simplest seems to be the concept of a light emitting diode (LED) with one of the contact layers made ferromagnetic by incorporation of transition metal impurities, a so- called spin LED [4].

XII. CONCLUSION AND FUTURE

This paper presents a summary of Spintronics (spin based electronics), is new upcoming technology for next generation of microelectronics/nanoelectronics devices with scaling apparently approaching its fundamental limits; the semiconductor industry is facing critical challenges. In this paper authors tries to summaries, the spintronics fundamental physics, role of this technology and their applications for development for future of nanoelectronics.

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