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SPINTRONICS

[1]Manjeet Singh, [2]Manish Shukla
[1,2] A.P., ECE Department, Geeta Engineering College, Haryana, INDIA

Abstract: Spintronics is the science and technology of manipulating the spin degree of freedom of a single charge carrier (electron or hole) or an ensemble of such carriers to encode, store, process and deliver information [1, 2]. Also, it can be explained as science and technology of combining Electronics with magnetism and semiconductors. It is one of the important emerging technologies at present because of it's applications towards the miniaturization of integrated circuits.

I. INTRODUCTION

Spintronics is a multidisciplinary field whose central theme is the active manipulation of spin degrees of freedom in solid-state systems.

Now, question arises is what's the need of Spintronics? Conventional electronic devices rely on the transport of electrical charge carriers - electrons – in a semiconductor and during transport of electrons there is some energy dissipated which is the limiting factor in integrated circuit miniaturization. Now, to remove this limitation we can use the spin property of electrons to transfer the effect from one end of component to other end rather then electronic charge. Thus, there are several advantages of Charge over Spin which is the reason why we are trying to use spin property rather then charge which are (a) Relative immunity to electrical noise. (b) Lower power requirement to manipulate data**.** (c) Faster and smaller devices. (d) Larger storage capacity. Main disadvantages of Spin over charge are (a) Spin is not conserved like charge which makes it difficult if path delay is long. (b) Difficult to inject & measure spin in silicon.

Basic requirements for spintronics development are some phenomena such as (a) Spin Injection (b) Spin Detection and (c) Spin Stabilization. Spin injection can be done optically or electrically depending on the requirement and availability. For spin detection also several methods can be employed; out of which one is to measure the magnetic moment of the elementary particle which would be proportional to the spin as shown in Figure 1.

There are four main areas in spintronics, i.e. (a) Understanding the fundamental physics, such as spin dependent transports across the magnetic/ semiconductor interfaces and spin coherence lengths in semiconductors. (b) Synthesizing suitable spintronics material with Curie temperatures above room temperature, large spin polarization at the Fermi level and matching conductivity between the magnetic and semiconductor materials. (c) Fabricating devices with nanometer feature sizes and developing new techniques for mass production. (d) Integrating spin devices with current microelectronics and computing.

Principle of working of spintronic devices is as shown in the figure 2 taking MRAM as an example. Basic concept used is of variable resistance.

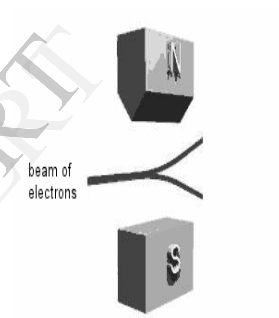

Figure 1: Magnetic moment of the elementary particle is proportional to the spin.

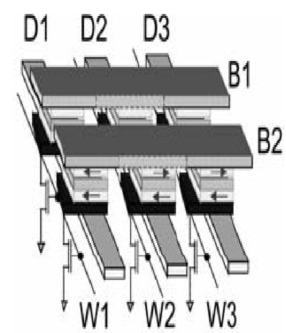

Figure 2: Basic concept of MRAM for reading and writing bits**.**

Variable resistance comes in when both outer layers have same spin the resistance between layers is low and when both layers have opposite spin the resistance between layers is high (i.e. at peak). The low and high resistances can be used as bit's 0 and 1. Thus, we can manipulate the spin to get the desired bits (i.e. apply the current & if we get the current at output the bit is 0 being low resistance & if we would not get any current at output the bit is 1 being High resistance or vice-versa).

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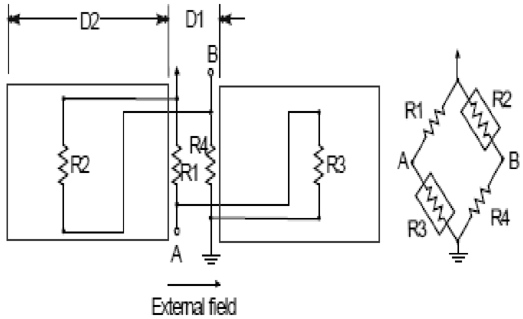

Figure 3. GMR resistors in a Wheatstone bridge sensor. Flux concentrators shown: D1 is the length of the gap between the flux concentrators and D2 the length of one flux concentrator.

II. APPLICATION OF SPINTRONICS

Various applications of spintronics can be (a) Magnetic sensors (b) Spintronic Couplers (c) Magnetic RAM (d) Medical Field (Cancer treatment) and so on.

Most sensor applications are power limited; therefore, high sensor resistance is desirable.

GMR (Giant Magneto resistance) materials are thin film and have relatively high variance in resistance when spin are anti-parallel compared to the case when spins are parallel. A Wheatstone bridge sensor can be made from four such resistors. Small magnetic shields of perm alloy electro- plated over two of the four equal resistors in a Wheatstone bridge protect these resistors from the applied field and allow them to act as reference resistances.

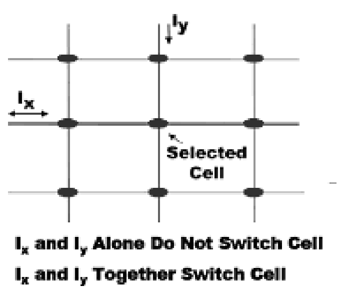

Figure 4: Write criteria or 2D array of magnetic cells.

They have the same temperature coefficient as the active resistors since they are fabricated from the same material. The two other GMR resistors are both exposed to the external field. Figure 3 above shows GMR resistors in a Wheatstone bridge sensor. Flux concentrators shown: D1 is the length of the gap between the flux concentrators and D2 the length of one flux concentrator.

Magnetic Random Access Memory is potentially an ideal memory because it has the properties of non volatility, high speed, low cost and unlimited write endurance. These memories use the hysteresis of magnetic materials for storing data and some form of magneto resistance for reading out the data. Reading out the state of the bit is done by sensingthe differential resistance of the cell when a sense current is passed through it.

Application of Spintronics in medical field is can be very useful for health system in any country. Spintronics can be used to cure cancer. The procedure for doing this experiment is as follows. (a) After surgery and the removal of the tumor, the patient is exposed to a strong magnetic field. (b) Now the polarized electron beam is applied over the unaffected part & spin orientation of electrons are determined using polarimeter. (c) Then the same polarized beam is targeted over the affected part of the body and from the reflected beam, change in spin is determined.

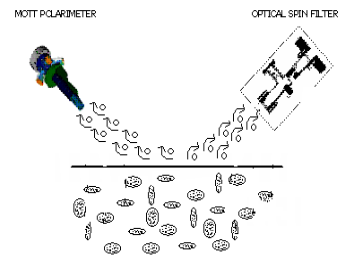

Figure 5: Basic diagram showing the arrangement for detection of cancer cells.

Based on these two values of spin orientation, the presence of the tumor cells can be detected even if they are few in number. Hence, we suggest this method for the detection purpose.

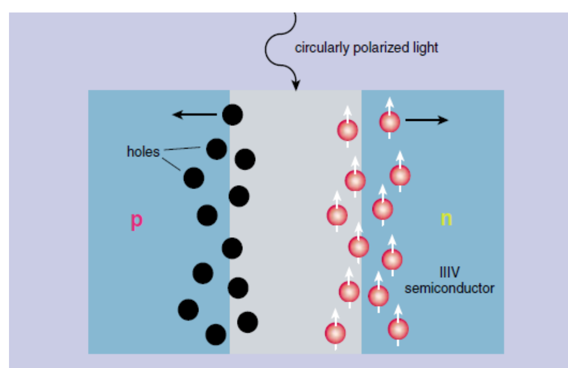

Figure 6: Basic diagram showing the arrangement for Spintronics based Solar Cells.

As shown in Figure 6, concept of solar cell is also introduced using spintronics basics, where sunlight passes through a filter to produce circularly polarized light, which is absorbed in the region between p-type and n-type semiconductors. This creates spin polarized electron hole pairs in this so called depletion layer but if a semiconductor of III- V variety is used (Gallium Arsenide, for example), the polarization is only retained by the electrons. The inherent electric field at the layer

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boundaries sweeps the holes to the p-side and electrons to the n side. Just as with the conventional Solar cell, a wire connected from the p-electrode to the n-electrode will now have current flowing through it, but in this case the current is spin polarized.

III. SPINTRONIC BASED DEVICE MODELING

Modeling of various basic devices such as:- (a) Full Adder [3] (b) Non – Volatile Flip Flop etc. can also be done using the basic concept of spintronics. The resistance of an MTJ element depends on the relative magnetization orientation of free and pinned layers. It is lower for their parallel alignment and higher for their anti parallel alignment. These two resistance states can be identified with logical 1 and 0, respectively.

Furthermore, only the free layer's magnetization orientation could be changed by magnetic field generated from the current line(s). If more than two input lines are passing "positive" current, the resistance is high. If more than two input lines are passing "negative" current, the resistance is low.

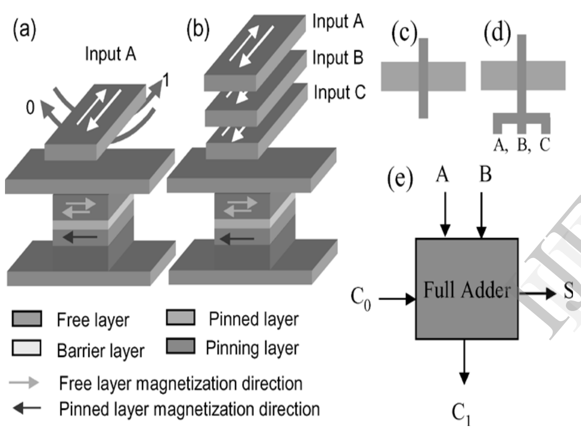

Figure 7: Schematics of a logic MTJ element. (a) With one input line, (b) with three input lines, (c) simpler schematics of logic MTJ element with one input line, (d) simpler schematics of logic MTJ element with three input lines, and (e) schematics of one bit full adder with three inputs (A, B, C) and two outputs (S, C).

The magnetization directions for all layers are remained even without current. The logical information is nonvolatile and can be read out repeatedly by measuring the resistance of the MTJ element without the periodic refreshing.

IV. COMPETING TECHNOLOGIES

The International Technology Roadmap for Semiconductors (ITRS) has identified several competing technologies for future logic applications, like molecular electronics and single electron device. Both of these alternatives are securely in early research stages. It's impossible to predict what technology will emerge as the best to supplant present-day microelectronics technology.

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