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Spintronics

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ABSTRACT

As rapid progress in the miniaturization of semiconductor electronic devices leads toward chip features smaller than 100 nanometres in size, engineers and physicists are certainly faced with the alarming presence of quantum mechanics. One such peculiarity is a quantum property of the electron known as spin, which is closely related to magnetism. Devices that rely on an electron's spin to perform their functions form the foundation of Spintronics, also known as Magneto electronics. Information processing technology has thus far relied on purely charge-based devices -ranging from the now old-fashioned vacuum tube to today's million-transistor microchips. Those conventional electronic devices move electric charges around, ignoring the spin that tags along for the ride on each electron.

I.INTRODUCTION

An emerging research field in physics focused on spin-dependent phenomena applied to electronic devices is called Spintronics [1]. The promise of Spintronics is based on manipulation not only of the charge of electrons, but also their spin, which enables them to perform new functions. Currently, the ability to manipulate electron spin is expected to lead to the development of remarkable improvements in electronic systems [2-3] and devises used in photonics, data processing and communications technologies only. Now this paper brings out an innovative idea of extending the hands of Spintronics in MEDICAL FIELD, in the detection of cancer cells even when they are very few in number in the human body [4].

This approach is relied on two important aspects:

- the behaviour of electron spin in a magnetic field
- the cancer cells abnormality over normal cells

1.1SPINTRONICS

Spintronics, or spin electronics, refers to the study of the role played by electron spin in solid state physics, and possible devices that specifically exploit spin properties instead of or in addition to charge degrees of freedom [5]. In Spintronics electron spin, in addition to charge, is manipulated to yield a desired outcome. An electron is just like a spinning sphere of charge. It has a quantity of angular momentum (its "spin") and an associated magnetism, and in an ambient magnetic field its energy depends on how its spin vector is oriented [6-8].

Every electron exists in one of two states, namely, spin-up and spin-down with its spin either +1/2 or ?1/2. In other words, an electron can rotate either clockwise or counter clockwise around its own axis with constant frequency. . Two spins can be "entangled" with each other, so that neither is distinctly up nor down, but a combination of the two possibilities [9-11]. In order to make a Spintronics 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 [12-14]. Most devices also have a unit in between that changes the current of electrons depending on the spin states.

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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 magneto resistance (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. Applications Spintronics 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/mm?) 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, 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 magneto resistive effect (see below). The most successful Spintronics 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 magneto resistance 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 magneto resistance 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 Spintronics principles.

1.2 Limitations of Electronics

Though the field of electronics is considered to be very vast, even his field is attaining its limitations. The two main limitations which is propelling the scientists and researchers new technology are:

Moore's Law

Moore, one of the co- founders of Intel Corporation, visualized in the early 1970's that the number of transistors fabricated in a single chip will double for every 18 months. Now, after almost three decades, the number of transistors fabricated in a single chip is so large that it places severe demands on the material and fabrication technology used.

Gate Width

Some scientist and experts have predicted that by the year of 2008, the width of gate electrode in an FET will be around 45nm, which again places severe

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demands on the material and fabrication technology used. The figure below shows the variation of the gate electrode length over the years.

Alternatives of Electronics

Due to the above mentioned limitations many alternatives for electronics have been considered such as:

- Bottom down approach of fabrication
- Changing the characteristics of info carriers
- Bio-Electronics
- Polymer-Electronics
- Molecular Electronics
- Spintronics

Of the above alternatives Spintronics has gained prominence because of the fact that spin devices can be fabricated with small variations to present fabrication technology whereas other alternatives require complete replacement of present fabrication units. We know that electron will be spinning on its axis. The spin can be parallel or anti – parallel. This spin degree can be used to change the way data is changed or carried. This field of tronics which we in addition to charge of electron, also use the spin of electrons is called SPINTRONICS. Use of the spin provides additional functionalities with increased speed. Now, let us see the main differences between electronics ad spintronics. In present electronics, each function required is designed and fabricated in separate chips and these chips are interconnected to obtain desired functionalities. For example, in order to store the data we will use memory unit, to process data we use processor and to transmit/receive data.

II. RESEARCH AREAS:

The scientist have been performing research on some of the field related to spin of electron which will help us to realize the spin devices and spin application into the real world and replace present electronics. The fields of research are:-

- Creation of spin polarization through optical OR magnetic injection.
- Spin polarization transport through semiconductors and super conductor interface
- Spin relaxation in semiconductors.
- Spin based devices such as PN-junction and amplifiers.
- Spin based quantum computing.
- Feasibility of using phosphorous donor nuclear spins in Si for the purpose of quantum computing and in particular whether SET [Single electron Transistor] can be effectively used as a single electron spin detector.
- Use of NSOM [Near field Scanning Optical Microscopy] to detect electrons in semiconductor quantum dots.
- To detect electron spins using transport experiments, whether electron spin entanglement can be measured using noise correlation measurements, and whether electron spins trapped in gated quantum dots can be used as qubits.

Once the above researches are completed we can start using spin devices. The above fields of research can be understood by analyzing the figure below. The figure in the left shows the spin polarization of electrons in the case of semiconductors and a ferromagnetic material. We are not concerned about spin in semiconductor but we are concerned in the case of ferromagnetic materials. The figure in the right shows one of the two basic spin devices called MTJ [Magnetic Tunnel Junction]. The MTJ is a device with two ferromagnetic structure separated by a silicon layer.

The electron will tunnel from one layer of ferro - magnet to other. The tunneling factor is dependent on the spin of electrons of both he layers. If the spin of the electrons are in the same direction then the tunneling will be high and if the spin direction is I opposite direction then the tunneling is low.The MTJ can be used as a PN-junction, the forward bias of the PN-junction is achieved when spin of the electrons are in the same direction and reverse bias is achieved when spin of the electrons are in opposite direction.

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The proper operation of PN-junction requires the spin of the electron to change as a function of real-time. This can be achieved by using optical or magnetic injection.

2.1 SPIN MATERIALS

The basic materials used in spin devices for manipulation of spin of electrons are the ferromagnetic which have the capability to change the spin polarization on application of magnetic fields.

The spin materials can be classified into two groups:

- Ferromagnetic Semiconductors
- Half-Magnetic ferromagnets

2.2 FERROMAGNETIC SEMICONDUCTOR

These are the materials with complete control over the spin electron. The main advantages of these types of materials are:

- Combined semiconducting and magnetic properties for multiple functionalities
- Easy growth of ferromagnetic-semiconductor nanostructures.
- Easy spin injection

As name suggests the half – magnetic ferromagnets doesn't have full control over spin of the electrons.

The spin materials can be obtained as: Substitution of V, Cr and Mn into GaAs, InAs, GaSb, GaP and INP.

2.3 SPIN DEVICES

There are basically two spin devices which have been fabricated in industries and verified its working. They are:

- GMR [Giant Magneto Resistance]
- MTJ [Magnetic Tunnel Junction]

GMR: - [Giant Magnetic Resistance]

This was the first device manufactured in the industries and is used in almost all commercial electronic equipments. The structure of GMR is very simple with alternate layers of ferro magnetic and non – magnetic layers.

GMR works depending on the orientation of the electrons in the ferro – magnetic layers. The resistance of the GMR device varies depending on the spin orientation. The resistance is high when the orientation of spin is anti-parallel and is low when the spin orientation is parallel.

MTJ: - [Magnetic Tunnel Junction]

This device is not yet used in the industries but will soon its application. The structure of MTJ is very simple with two Ferro magnetic layers separates by a semiconductor layer.

The figure shows the structure of MTJ. As said earlier the direction of spin decides the resistance of the device. The Semiconductor is often called Tunnel Barrier as it acts as the barrier between two ferro magnetic layers. If the resistance is high then the number electrons tunneling are low and if the resistance is low then the electrons tunneling are high.

2.4 SPIN APPLICATION

The applications of spin devices and hence spintronics are vast since it provides many advantages such as speed and size. Since so far only two spin devices [GMR and MTJ] have been proposed, the applications are based on these two devices. Some of the potential applications are:

- Spin LED
- Spin FET
- MRAM

2.4.1 MRAM

The MRAM is the form of the RAM and is acronym for Magnetic Random Access Memory. MRAM basically uses a spin device known as Magnetic Tunnel Junction. The property of Tunnel magneto résistance [MTR] of the MTJ is used in MRAM. The relative change of MTR can reach 70% at room temperature. The figure below shows the structure of the MTJ as well as MRAM.

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The MRAM is presently under development and is expected to reach similar densities and access times as the current SRAM and DRAM, but their main advantages on these volatile semiconductor- based memories is that they retain data even after losing power and hence to helps to decrease the boot – up time of computers. As shown in the figure each junction can store a bit of data. If the polarization of spin is in parallel at both the layers, the resistance will be less and we say that a bit “0” is stored. And if the spin polarization is anti – parallel then resistance is high and we say a bit “1” is stored. The main advantage of MRAM is that it can attain a writing speed of 1000 times to that of the present RAM’s.

2.4.2 SPIN FET

As shown the Source and Drain areas are fabricated using ferro-magnetic material and the channel is fabricated using the semiconductor material. The additional gating effect is via the magnetic field.
The working of the spin FET is illustrated in the upper part of the figure. It illustrates the physics of devices where both injection of spins into semiconductor and detection of spin information are electrical. The ideal situation is when the spin lifetime is much longer than spent by the carriers in semiconductor. As shown a spin polarized current is then easily transmitted in the parallel configuration of emitter and collector, whereas the anti-parallel one leads to spin accumulation and current blockade.

2.4.3 SPIN LED

The figure above shows the structure of spin LED. The LED has a heterostructure as shown. Spin – polarized electrons are injected from a paramagnetic DMS into a GaAs/AlGaAs LED, which leads to emission of circularly polarized light. An injection efficiency of 90% spin polarized current has been demonstrated with this structure.

2.5 ADVANTAGES OF SPINTRONICS

As most of the spintronics devices/applications are on paper all the advantages are just defined based on theoretical findings and they may have some dis-advantages which will/may be known after they are fabricated and used. Some of the advantages of spintronics are:

- The spin devices act as multi-functional units.
- The spin devices and hence spin applications can be realized by making some changes to the present fabrication technology.
- Its easy to grow spin layers. i.e. its very easy to grow alternate layers of ferromagnetic and semiconductor materials.
- The MRAM has all the properties of DRAM SRAM and ROM and hence single memory chip can be used instead of three memory chips.
- As said using single spin chip we can store, process, and transmit the data whereas in present electronic chip this is not possible.

III. CONCLUSION

In this report we have seen the advantages of spintronic devices over the present electronic devices. As said earlier this is the technology which will replace the present electronics era and provides the advantages of speed, size, compactness so on. If the applications such as LED and MRAM can be realized we can attain high efficiency of output in the case of LED and we can attain high writing speed and reading efficiency in the case of MRAM. Though the area of spintronics has some drawbacks which will be realized when the spin devices will be fabricated we may still avoid these drawbacks to large extent.

One drawback of this emerging technology is that since the spintronics is mainly based on the magnetic properties of the material, the magnetic field of the earth may affect the magnetic field inside the spin devices and cause errors. One main disadvantages of this is that the data stored in a MRAM may be altered and hence can lead to errors. Hopefully, this and many unknown effects will be found out and efforts are made to avoid such effects and lead to more reliable, more functional, with greater speed of operation of spin devices will be achieved.

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REFERENCES

[1] Bhatti, S. et al. Spintronics based random access memory: a review. Mater. Today 20, 530–548 (2017).

[2] S. Bhatti, R. Sbiaa, A. Hirohata, H. Ohno, S. Fukami, and S. Piramanayagam, "Spintronics based random access memory: A review," Mater. Today, vol. 20, no. 9, pp. 530–548, 2017, doi: 10.1016/j.mattod.2017.07.007.

[3] Modular Approach to Spintronics. Accessed: Apr. 2018. [Online]. Available: https://nanohub.org/groups/spintronics

[4] Gomonay, O., Jungwirth, T. & Sinova, J. Concepts of antiferromagnetic spintronics. Phys. Stat. Sol. RRL. 11, 1700022 (2017).

[5] Duine, R. A., Lee, K.-J., Parkin, S. S. P. & Stiles, M. D. Synthetic antiferromagnetic spintronics. Nat. Phys. https://doi.org/s41567-018-0050-y (2018).

[6] Zhuang, H. L., Kent, P. R. C. & Hennig, R. G. Strong anisotropy and magnetostriction in the two-dimensional Stoner ferromagnet Fe3GeTe2. Phys. Rev. B 93, (2016).

[7] May, A. F., Calder, S., Cantoni, C., Cao, H. & McGuire, M. A. Magnetic structure and phase stability of the van der Waals bonded ferromagnet Fe 3 − x GeTe 2. Phys. Rev. B 93, (2016).

[8] Liu, S. et al. Wafer-scale two-dimensional ferromagnetic Fe 3 GeTe 2 thin films grown by molecular beam epitaxy. Npj 2D Mater. Appl. 1, 30 (2017).

[9] Tsen, A. W. et al. Nature of the quantum metal in a two-dimensional crystalline superconductor. Nat. Phys. 12, 208–212 (2016).

[10] Huang, B. et al. Layer-dependent ferromagnetism in a van der Waals crystal down to the monolayer limit. Nature 546, 270–273 (2017)

[11] Li, L. J. et al. Controlling many-body states by the electric-field effect in a twodimensional material. Nature 529, 185–189 (2016).

[12] fanasiev, D. et al. Control of the ultrafast photoinduced magnetization across the morin transition in DyFeO3. Phys. Rev. Lett. 16, 097401 (2016).

[13] Baltz, V. et al. Antiferromagnetic spintronics. Rev. Mos. Phys. 90, 015005 (2018).

[14] Jungwirth, T., Marti, X., Wadley, P. & Wunderlich, J. Antiferromagnetic spintronics. Nat. Nanotech. 11, 231–241 (2016).