American Journal of Quantum Chemistry and Molecular Spectroscopy
2019; 3(2): 41-47
http://www.sciencepublishinggroup.com/j/ajqcms
doi: 10.11648/j.ajqcms.20190302.13

Review Article

A Review Paper on Spintronics and Its Role to Improve Electronic Devices

Senamaw Mequanent Zegeye

Collage of Natural and Computational Science, Department of Physics, Debre Markos University, Debre Markos, Ethiopia

Email address:
sinamawi@gamil.com

To cite this article:
Senamaw Mequanent Zegeye. A Review Paper on Spintronics and Its Role to Improve Electronic Devices. *American Journal of Quantum Chemistry and Molecular Spectroscopy*. Vol. 3, No. 2, 2019, pp. 41-47. doi: 10.11648/j.ajqcms.20190302.13

Received: August 4, 2019; **Accepted**: August 23, 2019; **Published**: November 5, 2019

Abstract: This review paper deals with Spintronics and its role to improve electronic devices. There is a occurring continuously interest for faster and higher density with lower power forms of information processing and storage, which could not be met by electronics devices whose base is the electron flow charge. In this review an Attempts was done on the other fundamental property of an electron, which is called as spin, have given rise to a new, rapidly evolving field, known as spintronics, an acronym for spin transport electronics. In Spintronics is a new technology was developed in which the spin of electrons is altered in addition to the charge of it for device functionality. In this review I am motivated to study fundamental logics of spin, and basic Spintronics technology including its advantages and utilization in various applications like Quantum computing, Magnetic Random Access Memory (MRAM) and Quantum Cryptography. The primary focus is on the technological description in Spintronics, its devices, working principle of Spintronics, its advantages and disadvantages, and its challenges.

Keywords: Spintronics, Quantum Computing, Quantum Cryptography

1. Introduction

1.1. Background of the Study

Conventional electronic devices ignore the spin property and rely strictly on the transport of the electrical charge. Adding the spin degree of freedom provides new effects, new capabilities and new functionalities.

Spin does not replace charge current just provide extra control. Spintronics is a field of electronics concerned with the detection and manipulation of electron spin in solid-state physics. This differs from fundamental electronics in that in addition to electron charge, the electron spin is taken into account and exploited as a further degree of freedom with possible effects toward increasing the efficiency of data storage and transfer. Spintronics is a fundamental application in quantum computing. Spintronics is an emerging technology in applied physics and engineering to make use of spin properties instead of, or in addition to electron charge to carry information, thereby offering opportunities for novel micro- and Nano-electronic devices. Introduced in 1996, spintronics (the word coined by Wolf) was originally the name for a Defense Advanced Research Projects Agency (DARPA) program managed by Wolf. Spintronics emerged from discoveries in the 1980s concerning spin-dependent electron transport phenomena in solid-state devices. This includes the observation of spin-polarized electron injection from a ferromagnetic metal to a normal metal by Johnson and Silsbee in 1985, and the discovery of giant magneto resistance independently by Albert Fert in France and Peter Gruenberg in Germany in 1988 [1].

The origins of spintronics can be traced to the ferromagnetic or superconductor tunneling experiments pioneered by Meservey and Tedrow and initial experiments on magnetic tunnel junctions by Julliere in the 1970s. The use of semiconductors for spintronics began with the theoretical proposal of a spin field-effect-transistor by Datta and Das in 1990 and of the electric dipole spin resonance by Rashba in 1960. Work in spintronics has emerged from research into spin behavior in metallic devices. Metal-based spintronics is already being used in state-of-the art computer hard drives and other magnetic devices [2, 3].

The ability to exploit the spin degree of freedom in semiconductors promises new logic devices with enhanced functionality, higher speeds and reduced power consumption. Crucially, these devices could be fabricated with many of the tools already used in the electronics industry, thereby speeding up their development [4, 5]. Indeed, the spin of the electron has attracted renewed interest recently because it promises a wide variety of new devices that combine logic, storage and sensor applications. Moreover, these spintronic devices might lead to quantum computers and quantum communication based on electronic solid-state devices, thus changing the perspective of information technology [5].

I am interested to study this topic to clarify the role played by a pure quantum mechanical property, electron spin, for Spintronic device operation which depends on unbalanced spin orientation in materials. In conventional electronic materials, electron spins are randomly arranged in both the up and the down state which sum up to zero, and no transport properties are therefore dependent on spin. A spintronic device requires generation or manipulation of a spin-polarized population of electrons, resulting in an excess of spin up or spin down electrons. It is also my interest to know more about spin and its fundamental properties, for my future studies.

1.2. Statement of the Problem

There is a constant demand for faster, higher density, and lower power forms of information processing and storage. This inevitably leads to the need to make individual devices such as transistors, memory nodes and hard disk read-heads smaller and smaller. But as the feature size of electronic devices continues shrinking, the working principle is being dominated by quantum effects where counterintuitive ideas such as wavelike behavior, is more dominant for particles such as the electron; leading to fundamentally power dissipation due to leakage from quantum mechanical tunneling and the variability due to quantum fluctuations and thermal activation processes such as thermal diffusion and other effects dominating reliability and robustness issues.

In addition, as the feature size is further reduced, electric current (and number of electrons in a given device) will be further reduced, adding to other issues such as lack of current drive and thus additional variability problems. Spintronics would offer the best possible solution to the problems associated with miniaturization mentioned above.

They are completely separate technologies, they are manufactured in different ways, and they are physically separate pieces computer. If the hard drive crashes, it has been replaced; if the CPU dies, it has been replaced; leading to economic loss. The reviewer gives the idea behind Spintronics to merge the two functions together, so that memory is not a distinct function from processing.

Basic questions expected to be answered by this review are the following:

a. What is spintronics and how spintronics could work?
b. What are the major challenges of spintronics?
c. What are the advantage and disadvantage of spintronics?
d. What are the major applications of spintronics?

1.3. Objective of the Study

1.3.1. General Objective

The general objective of this review work is to review Spintronics and its role to improve conventional electronics.

1.3.2. Specific Objectives

The specific objectives of this review work are the following:

i. To explain spintronics and it'sworking principle;
ii. To describe and the major applications of spintronics;
iii. To describe the advantages, disadvantage and the major challenges to spintronics.

1.4. Significance of the Study

This review paper is concerned about the spintronics and its role to improve conventional electronics. After successful completion, this research will be expected to have the following significance.

i. It will give for readers and students the opportunity of having information about spintronics and its role to improve conventional electronics.
ii. It contributes to acquire fundamental knowledge for better understanding of the uses of spintronics technology for the future and recent world.
iii. It will be expected to serve as a base for those who want to continue further study on the same title.

2. Review Literature

2.1. Spintronics

Spintronics, also known as spin electronics or flux-tronics, is the study of the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices [7].

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 solid state materials. Spintronic devices make use of spin properties instead of, or in addition to electron charge to carry information, thereby offering opportunities for novel micro- and Nano-electronic devices [8].

2.1.1. The Electron's Spin Degree of Freedom

An electron is a negatively charged particle that surrounds the positively charged nucleus in fixed orbits. It is characterized by three basic properties: charge, mass and spin. Electron around the nucleus has orbital angular momentum due to its spin around the nucleus and spin angular momentum due to its spin on its own axis. The spin of the electron can be in any of the two directions with the magnetic field pointing up or down. In quantum mechanics and particle physics, spin is an intrinsic form of angular momentum carried by elementary particles, composite particles, and atomic nuclei. Spin is a quantum mechanical property that arises when the rotational momentum of a particle, in this case an electron, creates a tiny magnetic field. It is a purely quantum, microscopic characteristic that has no equivalent on macroscopic scale. As the name suggests, spin was originally conceived as the rotation of a particle [9].

i. Experimental Evidence for the Existence of the Spin

The existence of spin was confirmed experimentally by Stern and Gerlach in 1922 using silver (Ag) atoms. Silver has 47 electrons; 46 of them form a spherically symmetric charge distribution and the 47th electron occupies a 5s orbital. If the silver atom were in its ground state, its total orbital angular momentum would be zero: l=0 (since the fifth shell electron would be in a 5s state). In the Stern–Gerlach experiment, a beam of silver atoms passes through a non-uniform magnetic field. We would expect classically to see on the screen a continuous band that is symmetric about the undeflected direction. According to Schroedinger's wave theory; however, if the atoms had an orbital angular momentum l, we would expect the beam to split into an odd (discrete) number of 2l+1 components. Suppose the beam's atoms were in their ground state l=0, there would be only one spot on the screen, and if the fifth shell electron were in a 5p state (l=1), we would expect to see three spots.

Experimentally, however, the beam behaves according to the predictions of neither classical physics nor Schrödinger's wave theory. Instead, it splits into two distinct components. This result was also observed for hydrogen atoms in their ground state (l=0), where no splitting is expected. To solve this puzzle, Goud smit and Uhlenbeck postulated in 1925 that, in addition to its orbital angular momentum, the electron possesses an intrinsic angular momentum which, unlike the orbital angular momentum, has nothing to do with the spatial degrees of freedom. By analogy with the motion of the Earth, which consists of an orbital motion around the Sun and an internal rotational or spinning motion about its axis, the electron or, for that matter, any other microscopic particle may also be considered to have some sort of internal or intrinsic spinning motion. This intrinsic degree of freedom was given the suggestive name of spin angular momentum [10].

ii. The Fundamentals of Electron Spin

a. Except for its mass and elementary charge, an electron has an intrinsic angular momentum, called spin.
b. Each spin has two arbitrary orientations, and its magnitudes are $\pm\hbar/2$ ($\hbar$ is Planck constant divided by 2π). When all electron spins in solid align along the same direction, a ferromagnet forms.
c. In a magnetic field, an electron has different energies when electron spin is parallel or anti-parallel with the field.
d. Directional motion of electrons circulates an electric charge. In a conventional electric circuit, electron spins of charge carriers are random, and the current does not exhibit spin properties.
e. Directional and coherent motion of electron spin circulates a spin current, which will carry or transport information and control quantum spin in a spintronic device [11].

2.1.2. Arrangements of Spin in Materials

In conventional electronic materials, electron spins are equally present in both the up and the down state, and no transport properties are dependent on spin. A spintronic device requires generation or manipulation of a spin-polarized population of electrons, resulting in an excess of spin up or spin down electrons.

A net spin polarization can be achieved either through creating an equilibrium energy split between spin up and spin down. Methods include putting a material in a large magnetic field (Zeeman Effect), the exchange energy present in a ferromagnet or forcing the system out of equilibrium by the method of spin relaxation [12].

Spins can arrange themselves in a variety of ways that are important for spintronic devices. They can be completely random, with their spins pointing in every possible direction and located throughout a material in no particular order or these randomly located spins can all point in the same direction, called spin alignment [13].

2.1.3. Spintronic Materials

Ferromagnetic Materials

In a ferromagnetic material, such as iron or cobalt, the spins of certain electrons on neighboring atoms tend to line up. In a strongly magnetized piece of ferromagnetic material, this alignment extends throughout much of the metal. When a current passes through the ferromagnet, electrons of one spin direction tend to be obstructed. This result in a current called as spin polarized current in which all the electron spins point in the other direction. A ferromagnet can even affect the flow of a current in a nearby nonmagnetic metal.

Ferromagnetic Semiconductor

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

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

Half-magnetic Semiconductor

As name suggests the half – magnetic ferromagnet 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. Half-metallic magnets, in which one spin channel is conductive [13].

The spin polarization can be calculated theoretically by the below given relation.

$$Pn = (n\uparrow - n\downarrow)/(n\uparrow + n\downarrow) \tag{1}$$

Where: Pn = spin polarization

$n\uparrow$= the number of spin up population

$n\downarrow$=the number of spin down population

If $n\downarrow = 0$; $Pn = 1$ in this case only majority spins are there and the spin polarization is 100%. Such materials are known as ferromagnetic half metals with 100% spin polarization.

If $n\uparrow = 0$; $Pn = -1$, this case is the same as before but only majority spins are in opposite direction, and the spin polarization is 100% as before. Such materials are also known as ferromagnetic half metals with 100% spin polarization.

If $n\uparrow = n\downarrow$; $Pn = 0$ (only for paramagnetic or normal metal. The up (↑) and down (↓) spins related to energy [14].

2.2. Basic Spintronic Technology Description

2.2.1. Giant Magneto-resistance (GMR) Effect

Recording devices, such as computer hard disks, already employ the unique properties of magnetic materials. Data are recorded and stored as tiny areas of magnetized materials such as iron and chromium. 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 magneto-resistance. Giant magneto-resistance (GMR) is a quantum mechanical magneto-resistance effect observed in thin-film structures composed of alternating ferromagnetic and non-magnetic conductive layers.

The effect is observed as significant change in the electrical resistance depending on whether the magnetization of adjacent ferromagnetic layers is in a parallel or an antiparallel alignment. The overall resistance is relatively low for parallel alignment and relatively high for antiparallel alignment. The magnetization direction can be controlled, by applying an external magnetic field. The effect is based on the dependence of electron scattering on the spin orientation.

The GMR effect arises from the asymmetry in the spin-dependent scattering at the non-magnetic/magnetic interfaces for spin-up and spin-down electrons. When the magnetic layers have parallel magnetization directions, spin-up conduction electrons will be weakly scattered, and spin-down electrons will be strongly scattered. The spin up channel will short the current leading to a low resistance state. When the magnetic layers have anti parallel magnetization directions, both spin-up and spin-down electrons will alternatively be strongly and weakly scattered, leading to a high a resistance state [14].

One of the application of GMR is read heads used in the Hard drives; allows the storage capacity of a hard disk to be increased significantly. Data is stored through magnetism but we need to access the data. For this purpose read heads are used. Magneto resistive devices can sense the changes in the magnetic field to a small extent, which is applicable to the current devices [15].

2.2.2. Magnetic Tunnel Junction (MTJ) Effect

Magnetic Tunnel Junction (MTJ) is a tunnel junction used for logic and memory applications, which combines magnetism, electronics and promises high read/write speed, non-volatility, infinite endurance [16].

MTJ are one of the important devices of spintronics. A MTJ consist of two ferromagnet separated by an insulating layer of around them. It is also defined by the relative orientation of parallel resistance and antiparallel resistance just like Giant Magneto-resistance. For practical application one of the layers is pinned and known as the reference layer while other magnetic layer store a binary state based on the relative orientation of the two ferromagnetic layers.

The Tunnel magneto resistance (TMR) is a magneto resistive effect that occurs in magnetic tunnel junctions (MTJs). This is a component consisting of two Ferro magnet separated by a thin insulator. If the insulating layer is thin enough (typically a few nanometres), electrons can tunnel from one ferromagnet into the other. Since this process is forbidden in classical physics, the tunnel magneto resistance is a strictly quantum mechanical phenomenon [17].

The Semiconductor is often called Tunnel Barrier as it acts as the barrier between two ferromagnetic layers. If the resistance is high then the number electrons tunnelling are low and if the resistance is low then the electrons tunnelling are high [18].

3. Spintronic Devices

In ordinary electronic devices, the spins point at random and play no role in determining the resistance of a wire or the amplification of a transistor circuit. Only the charge and flow of electrons as particles matters. Spintronic devices, in contrast, rely on differences in the transport of "spin up" and "spin down "electrons [19].

3.1. Spin Valve

A Spin Valveis 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, in order to exploit the Giant Magneto resistive effect.

The magnetic layers of the device align "up" or "down" depending on an external magnetic field. Layers are made of two materials with different magnetic coactivity, due to the different cervicitis one layer ("soft" layer) changes polarity at small magnetic fields while the other ("hard" layer) changes polarity at a higher magnetic field. As the magnetic field across the sample is swept, two distinct states can exist, one with the magnetizations of the layers parallel, and one with the magnetizations of the layers anti – parallel [20].

If 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. Spin valves are not only highly sensitive magnetic sensors but these can also be made to act as switches by flipping magnetization in one of the layers parallel or anti parallel as in a convectional transistor memory device [21].

$$\Delta R = (RAP - RP)/RP) \quad (2)$$

ΔR-change in resistance of Spin Valve
$RAp -$ resistance of ant parallel configuration
Rp-Resistance of parallel configuration
Resistance of parallel configuration:

$$1/RP = 1/(R\uparrow + R\uparrow) + 1/(R\downarrow + R\downarrow) \quad (3)$$

$$RP = 2R\uparrow R\downarrow/(R\uparrow + R\downarrow) \quad (4)$$

Resistance of anti-parallel configuration:

$$1/RAP = 1/\,(R\uparrow + R\downarrow)\ + 1/\,(R\uparrow + R\downarrow) \tag{5}$$

$$RAP =\ (R\uparrow + R\downarrow)/2 \tag{6}$$

Using equation (2) to (6),

$$\Delta R\ =\ (R\uparrow - R\downarrow)\ 2/\,(4R\uparrow R\downarrow) \tag{7}$$

3.2. Disk Read/Write Heads

Disk read/write heads are the small parts of a disk drive, that move above the disk platter and transform platter's magnetic field into electrical current (read the disk) or vice versa – transform electrical current into magnetic field (write the disk) [22]. The separate read head uses the magneto resistance (MR) and giant magneto resistance effect which changes the resistance of a material in the presence of magnetic field [23].

3.3. Quantum Computers

One of most ambitions devices is the spin based quantum based computer in solid state structures using electron spin for this purposes is an obvious idea since fermions with ½ spin is a natural and intrinsic qubit. Spin based quantum computation requires that the quantum states remain coherent, or undisturbed by interactions with the outside world, for a long time, and the states need to be controlled precisely. Because of the requirement of very long coherence time for a quantum computer, electrons spin have been proposed as qubits, since spins inherently have long coherence times because they are immune to the long-range electrostatic Coulomb interactions between charges. To perform a computation, some initial state is imposed on the spins, and this state is allowed to evolve in time through a process of entanglement. (Quantum entanglement means that the spins of particles polarized together remain correlated, even though they may become spatially separated.) These properties give a quantum computer the ability to, in effect, operate in parallel—making many computations simultaneously. Spintronics uses qubits, so the "spin up" and "spin down" superposition states of 0 or 1 allow 8 qubits to represent every number between 0 and 255 simultaneously. Since the electron can spin in either direction, magnet field can orient in two ways either up or down. When the binary digits are used to encode the information, it can have four bits. That is, low (0) up, high (1) up, low (0) down and high (1) down called quantum bits (qubits) and this adds to the additional two states to the conventional binary states of high and low which accounts for the added capacity and speed for spintronic devices. The information is stored into the spins as a particular quantum bit. The result is that spintronics can be used to hold and carry much more information than conventional electronics. Power consumption is also dramatically reduced. They also have an added on advantage that the information can be stored for few nanoseconds which is relatively a longer time than conventional devices which makes spintronic devices suitable for making memory storage for quantum computing [24].

3.4. Spin Field Effect Transistors (SFET)

It is based on spin injection and spin detection by a ferromagnetic source and drain. In SFET both drain and source are ferromagnetic. It is not controlled by magnetic field but by gate bias.

A spin FET would have several advantages over a conventional FET. Flipping an electron's spin takes much less energy and can be done much faster than pushing an electron out of the channel. There is also a possibility of changing the orientation of the source or drain with a magnetic field, introducing an additional type of control that is not possible with a conventional FET [25].

3.5. The Importance of Spintronics

The movement of spin, like the flow of charge, can also carry information among devices. One advantage of spin over charge is that spin can be easily manipulated by externally applied magnetic fields, a property already in use in magnetic storage technology. Another more subtle (but potentially significant) property of spin is its long coherence, or relaxation, time—once created it tends to stay that way for a long time, unlike charge states, which are easily destroyed by scattering or collision with defects, impurities or other charges. Spin states can be set quickly, which makes transferring data quicker, and because electron spin is not energy-dependent, spin is non-volatile – information sent using spin remains fixed even after loss of power [26].

3.6. Advantages and Limitations

Some of the advantages of spintronics are:-

i. Non-Volatile memory
ii. Low power Consumption
iii. Spintronics does not require unique and specialized semiconductors
iv. Spin life time is relatively long on the order of nanoseconds.
v. compared to normal RAM chips, spintronic RAM chips will:
vi. increase storage densities
vii. have faster operation

Some limitation spintronics are:-

a. Controlling spin for long distances.
b. Difficult to INJECT and MEASURE spin.
c. Interference with nearest field.
d. Control of spin in Silicon is difficult.

4. Summary and Conclusion

4.1. Summary

In ordinary electronic devices, the spin point at random and play no role in determining resistance of wire or amplification of transistor circuit. Spintronic is field of electronic concerned with detection and manipulation of electron spin. This is different from fundamental electronics in addition of electron charge, electron spin increase efficiency of data storage and transfer. Spintronics is the fundamental application of quantum computing. Spin is rotation of particle. The existence of spin was confirmed experimentally in 1922 using silver (Ag) atom.

In conventional electronic material, electron spins are equally present in both up and down state and no transport properties are dependent on spin, but spintronics devices requires generation of spin polarized of electron, resulting excess spin up and down electron. Some of spintronics materials are ferromagnetic material, Ferromagnetic semi-conductor, and half magnetic semiconductor. Giant magneto-resistance (GMR) effect is quantum mechanical magneto-resistance effect observed in thin film structure composed ferromagnetic and non-magnetic conductive layer.

Magnetic tunnel junction (MTJ) effect is tunnel junction used for logic and memory applications, which combine magnetism, electronics and high read/write speed, non-volatility, infinite endurance. Spin valve is device consisting of two more conducting magnetic material that alternate its electrical resistance depending on alignment of magnetic layer. It is simplest and most successful spintronics devices.

Disk read/write head are small parts of disk drive. Move disk platter and transform platter magnetic field into electrical current or vice-versa.

Quantum computer is a computer based on computational model which use quantum mechanics. Both hardware and software construct based on principle of quantum mechanics. The basic unit of information in quantum computer is called qu-bit. Quantum computer is spin based quantum based computer in solid state structure using electron spin.

Spin field effect transistor (SFET) based on spin injection and spin detection by ferromagnetic source and drain. It has several advantages than conventional FET. Importance of spintronics are spin can be easily manipulated by externally applied magnetic field, they can be set quickly, they are non-volatile, information sent using spin remain fixed. Some advantage of spintronic are non-volatile memory, low power consumption, RAM chip have faster operation.

4.2. Conclusion

In this review paper it was observed that, the spin of electron has attracted renewed interest because it promises a wide variety of new devices that combine logic, storage and sensor applications. Spintronics devices might lead to quantum computer and quantum communication based on electronics solid state devices, thus changing perspective of information technology in 21st century.

Acknowledgements

First and for the most, I would like to thank the almighty God for giving me strength to do this review paper.

Secondly, my deepest and whole gratitude goes to my family specially my beloved childYonatan Senamaw with his mother Kelebie Tamiru for their moral and financial support, encouragement and advice throughout my education at large.

References

[1] Wolf S. A. (2003). Spintronics, Proc. IEEE, Vol. 91, (pp. 5).

[2] Beiser A., (2003). Concepts of Modern Physics, CA: McGraw-Hill, (pp. 229-231).

[3] DattaS. and Das B., Electronic analogy of the electro optic modulator, Applied Physics Letters 56, in press.

[4] Rohit A. (March-2013), International Journal of Advanced Computer Research, (ISSN (print): 2249-7277, Vol. 3, (pp. 1).

[5] Mechael RoukesL., Caltech (August 2003), Spin Electronics, University of California, pp. (1-19).

[6] Wolf SA, Awschalom DD, Buhrman RA (November 2001) Spin-Based Electronics Vision for the Future, Sciencemag.org, Vol. 294, pp. (5-7).

[7] Wolf, S. A (2006), Spintronics retrospective and perspective". IBM Journal of Research and Development, Volume 50.

[8] Akriti Srivastava S. R., http://www.physics.umd.edu/rgroups/spin/intro.html, in press.

[9] Merzbacher, Eugen (1998), Quantum Mechanics, 3rd ed., pp. (372–380).

[10] Zettili N. (2009), Quantum Mechanics Concepts and Applications, 2nd ed., Jacksonville State University, pp. (295-297).

[11] ChappertC., the Emergence of Spin Electronics in Data Storage, in press.

[12] Wiśniewski, P. Giant anisotropic magneto-resistance and magneto-thermo power in cubic 3: 4 uranium pnictides, Applied Physics Letters, Vol. 90 in press.

[13] Ziese, M. and Thornton, M. J., Spin Electronics (Lecture Notes in Physics series), Vol. 569, Springer-Verlag, Heidelberg, in press.

[14] Stoner E. C, wohlfarth E. P. (1999), A mechanism of magnetic hysteresis in heterogeneous alloys, Philos. Trans. R, Vol. 240, pp. (599-642).

[15] AmiparaP. M. D. (2014), Nano Technology-Spintronics, IOSR Journal of Electronics and communication Engineering, pp. (14-18).

[16] AttemaJ. J, de Wijs G A andde Groot R A (2007), Spintronics, Spintronic materials based on main-group elements of Physics, iop publishing, journal of physics: condensed matter, J. Phys.: Condens. Matter 19, pp. (11).

[17] Zhao W. S., (2009), Spin transfer torque (STT)-MRAM based runtime reconfiguration FPGA circuit ACM Trans. Embedded Compute., Volume 9, pp. (141–1416).

[18] Ikeda S. (2008), Tunnel magneto resistance of 604% at 300K by suppression of Ta diffusion in CoFeB/MgO/CoFeB pseudo-spin-valves annealed at high temperature, Appl. Phys. Lett., Vol. 93.

[19] Das Sarma S. (2011), Theoretical perspectives on spintronics and spin-polarized transport. IEEE Transactions on Magnetics, in press.

[20] Datta, Suprio and Das Biswajit (Feb 2015), Electronic analog of the electro – optic modulator, Applied Physics Letter, Vol. 56, pp. (12).

[21] Fert Albert, (2009) the Present and future of spintronics, in press.

[22] Johnson Mark, Future of spintronics Available, not published.

[23] M. Julliere, Tunnelling between Ferromagnetic film, www.sciencedirect.com /B6TVM-46R3N-100/2/19703cfc68400679356dce9a76e942, in press.

[24] Parmar MN, MV, Chaudhari JM and Patel CD, Spintronics Journal of Enginee ring Research and Studies, www.technicaljournalsonline.com/jers/current.html, Vol. 11, in press.

[25] Wolf SA (2016), Spintronics A retrospective perspective IBM Journal of Research and Development, vol. 50, in press.

[26] Dassarma., http://www.americanscientist.org/articles/01articles/dassarma.html, in press.