Term paper

On

<u>SEMICONDUCTOR SPINTRONICS</u>

AMITY INSTITUTE OF NANOTECHNOLOGY

AMITY UNIVERSITY, NOIDA, UTTAR PRADESH

SUPERVISOR: DR.D.SAHU

Assistant Professor-III

Amity Institute of Nanotechnology
Amity University, Noida

Submitted By:

R. Pragadeeshwara Rao.

A1223313010

B.tech+M.tech:5 (Nanotechnology)

Amity Institute of Nanotechnology

DECLARATION

I, **R. Pragadeeshwara Rao.**, student of **B.Tech + M.Tech : 5 (Nanotechnology)** hereby declare that the project titled “**Semiconductor Spintronics**” which is submitted by me to Department of **Amity Institute of Nanotechnology**, Amity University Uttar Pradesh, Noida, in partial fulfilment of requirement for the award of the degree of **B.Tech+M.Tech in Nanotechnology** , has not been previously formed the basis for the award of any degree, diploma or other similar title or recognition.

The Author attests that permission has been obtained for the use of any copy righted material appearing in the Project report other than brief excerpts requiring only proper acknowledgement in scholarly writing and all such use is acknowledged.

Signature :

Place : Noida

Date : Name: R.Pragadeeshwara Rao.

CERTIFICATE

On the basis of declaration submitted by **R.Pragadeeshwara Rao.** student of **B. Tech + M.Tech: 5 (Nanotechnology)**, I hereby certify that the project titled "**Semiconductor Spintronics**" which is submitted to **Amity Institute of Nanotechnology**, Amity University Noida, Uttar Pradesh, in partial fulfilment of the requirement for the award of the degree of **B.Tech + M.Tech in Nanotechnology**, is an original contribution with existing knowledge and faithful record of work carried out by him under my guidance and supervision.

To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Date:

Dr.D.Sahu

Assistant Professor-III

Amity Institute of Nanotechnology

Amity University Uttar Pradesh, Noida

ACKNOWLEDGEMENT

I would like to convey my gratitude to the Faculty Guide, Dr. Diptiranjan sahu, for his guidance and for the time and knowledge he bestowed upon me. Also, I would like to thank my family for their constant and invaluable support.

CONTENTS

Declaration..ii

Certificate..iii

Acknowledgement...iv

Abstract...vi

List of figure…………………………………………………………vii

1. INTRODUCTION 1

1.1 GMR 1
1.2 PROPERTIES OF MAGNETIC ION 2

2. INJECTION OF SPIN POLARIZED ELECTRON 3

2.1 INTRODUCTION...3
2.2 MODEL OF SPIN INJECTION..3
2.3 SPIN INJECTION IN SEMICONDUCTOR 4

3. SPIN RELAXATION IN SEMICONDUCTOR 7

3.1 Introduction 7
3.2 Mechanism...8

4. References…...…………………………………………………………..10

ABSTRACT

Semiconductor spintronic is a research area of about twenty years old and a interesting and challenging subject which has wide range of future application in technology. This paper focus on GMR, spin injection, spin relaxation and introduction to Domain wall RM.

LIST OF FIGURES

1. Figure 1: Shape of the domain wall
2. Figure 2: A standard model of spin injection, F is the ferromagnetic material such as Fe, Co etc. C is the contact region between ferromagnetic and non-magnetic material, N is the non-magnetic material. The non-equilibrium spin is manipulated on N by passing the current from F to N. Here the contact region is extremely small
3. Figure 3:Spin relaxation mechanism (I)Elliot-Yafet mechanism (II) D'ya-konov-perel' mechanism (III) Bir-Aronov-Pikus Mechanism

PART 1: INTRODUCTION

1.1 GMR

Magnetoresistance is a fractional change in the electrical resistance of Material when subjected to a magnetic field,

$$M_R = \frac{\Delta R}{R}$$

Where ΔR = |the resistance at H_0 – the resistance at the saturation field H_s|
When and electric field is applied in a metal a current flows parallel to the applied electric field, from that we know the electrical resistivity (ρ). If the magnetic field is applied with the electric field , the conduction electron are stimulated to have helical transportation instead of linear path between two collisions and the resistivity of the specimen will be increased, this phenomena is called as ordinary magnetoresistance. In a ferromagnetic material such as Fe, Ni, Co there is a increase in magneto resistance when the magnetic field is parallel to current density (longitudinal magnetoresistance) and decreases when the magnetic field is perpendicular to current density(Transverse magnetoresistance), Hence it is known as anisotropic magnetoresistance. In the GMR both transverse and longitudinal magnetoresistance decreases with increase in magnetic field. Generally the GMR is due to spin dependent scattering of conduction electron with one spin electron scattered more than the electron with other spin moment [9]. A Noble price for finding Gaint Magnetoresistance effect is given to Albert Fert and Peter Grunberg in 2007,the GMR phenomena is based on the electron scattering, the electron resistance of conduction electron is due to the electron scattering in the material. They used ferromagnetic multilayer to this experiment, with the magnetic moment parallel to each other the resistance is normal but when the magnetic moment of the ferromagnetic layer is changed with the external magnetic field the resistivity is unbelievably increased. This profound phenomena is a one step development in spintronics. With the help of this effect, the application are in sensors of low magnetic field, magnetic hard disk. The read heads of magnetic hard disk drive have increased the storage density [8] also they are used in the domain wall race track memory which is discussed below.

1.2 PROPERTIES OF MAGNETIC IONS

The transition metal ion exhibit transition from highly electropositive elements of s-block to least electropositive elements of p-block. The atomic radii of Fe is 117, Co 116, Ni 115. The transition metal are the good conductor of electricity. Their magnetic properties are determined by number of paired spin electrons. The paramagnetic properties are because of the presence of unpaired electron and di-amagnetic properties are due to the absence of unpaired electron, there few substances that have magnetic properties highly as compared to ordinary metals they are called ferromagnetic substances they are Fe, Co, Ni.

1.3 Domain and Bloch wall Race track memory:

The atomic moments are aligned parallel in a ferromagnetic material (domain), each domain becomes a small magnets and a ordinary domain usually contains 10^{13} atoms. A typical domain wall is shown in the figure-1. The domains are formed to reduce the magnetostatic energy of material which is a magnetic PE contained on the flux lines. The size and shape of the domain can be found by minimizing the (1) Magnetostatic energy (2) Magnetocrystalline Anisotropy energy and (3) Domain Wall Energy. The direction of the magnetization in one domain is gradually changed to the direction of the near domain in a Domain wall region [10].These domain wall can be used to store data in the form of bits, we know that the storage capacity with the low dimension area is a problem in technology. This problem can be overcome with the Domain wall race track memory, the domain wall is moved when a spin current[11] is applied in one terminal of nanowire, these phenomena is used to design a Bloch(domain) wall race track memory by Stuart S.P. Parkin, *et al*. A ferromagnetic Nanowire with number of domain wall is fabricated in Si substrate in a 3D geomentry in order to increase the storage capacity of the memory device, when applying a spin current, the domain wall moves in the direction of current, while applying a magnetic field the domain wall disappear[12]. Hence with the Bloch wall new types of memory device.

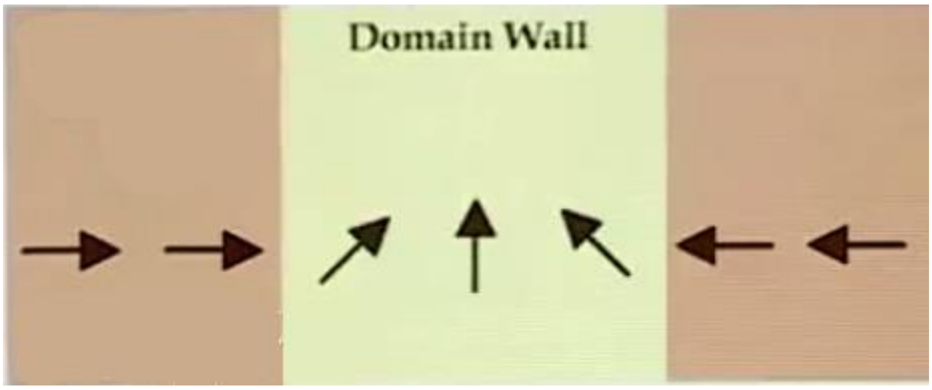

Figure 1: Shape of the domain wall

PART 2: Injection of Spin Polarized Electron.

2.1 INTRODUCTION

The spin injection is a important concept in Spintronics. It is important to understand the fundamental physics of electron spin transport in the main structural components that make up novel devices. The electron is electrically injected from a ferromagnetic material (such as Co,Fe,Ni and their alloys) to a non-magnetic material and semiconductor. The technique such as optical spin orientation and spin resonance is also used in spin polarized electron transport. Spin injection from a ferromagnetic (FM) source into a semiconductor (more generally, into a normal conductor N) across a resistive tunnel or Scotty contact (T) is controlled by three competing resistances: R_{FM} and R_N, the effective resistances of FM and N conductors, and R_C a contact resistance. The spin injection coefficient of the junction is controlled by the largest of these three resistances. The resistance R_C is very small for a "perfect" contact, $R_C \approx 0$ and $R_{FM} \ll R_{N.}$ we know that the electron has intrinsic spin angular momentum(ђ/2) and also it carries a charge. So electron possess both spin and charge during the transport. In FM the spin are polarized hence when the electric current flows through it due to the net flow of spin it is called spin current. The spin travelling in the FM are injected to a non-magnetic material it is called as spin injection.

2.2Model of Spin Injection

The objective is to inject spins in a nonmagnetic material with the help of ferromagnetic metal. This can be achieve by connecting the ferromagnetic metal and non-magnetic metal as shown in figure 2. The current is flowing through the F/C/N interface. We know that in ferromagnetic metal the spins are not in equilibrium or the spin conductivities(+/-) are not equal, hence the usual current in ferromagnetic is with the spin current ($I_+ - I_-$), when the electron having the spin current crossed the F/C/N interface from ferromagnetic metal to non-magnetic metal the conductivities of spin-up and spin-down electron will result in spin accumulation over a certain distance from x=0 and the injection of spin or accumulation of non-equilibrium spin in non-magnetic material is associated with spin-up and spin-down electrochemical potential, the magnitude of the electrochemical potential(μ) difference is called the spin accumulation.

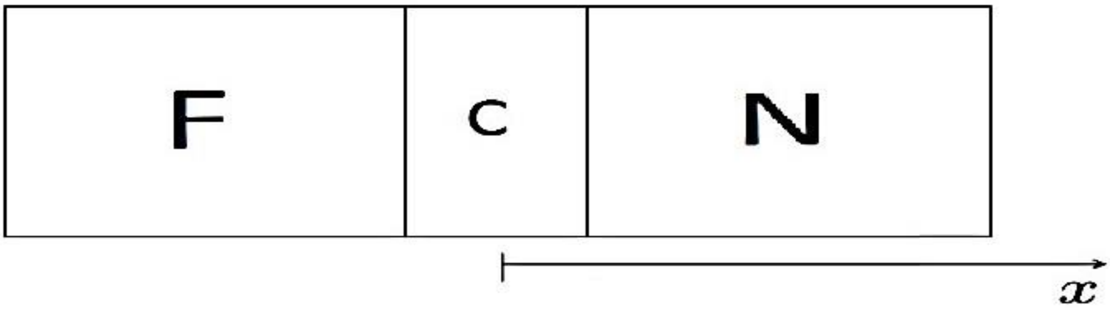

FIGURE 2: A standard model of spin injection, F is the ferromagnetic material such as Fe, Co etc. C is the contact region between ferromagnetic and non-magnetic material, N is the non magnetic material. The non-equilibrium spin is manipulated on N by passing the current from F to N. Here the contact region is extremely small.

2.2.1Spin injection efficiency.

The spin injection efficiency is given by Pj

$$P_j = \frac{R_F P_{\sigma F} + R_c P_\Sigma}{R_F + R_c + R_N} = \langle P_\sigma \rangle_R.$$

With the help of the above equation spin accumulation in the non-magnetic(N) region can be found,

$$\mu_{sN}(0) = -jP_j R_N$$

With the density spin polarization.

$$P_n(0) = -jeR_N \frac{g_N}{n} P_j.$$

2.3 SPIN INJECTION IN SEMICONDUCTOR

Unlike metal the semiconductor are widely used in devices such as transistor, MOSFET, CMOS, etc,.The possibility of new device functionalities/performance can be achieved form the semiconducting material. Densities of the carrier can be varied via doping profile. The electrical properties is easily altered by the gate voltage (V_G), because the density of the carrier are lower than metals. The spin diffusion length in Si/GaAs is long. spin diffusion length in these semiconductors is long, with values of many microns being reported for Si or GaAs. There is a great challenge in finding an effective way of injecting the spin-polarized electrons into these semiconductor. It is difficult to create a spin-polarized current in a semiconductor at the desired room temperature, it is not like in normal magnetic material. Naturally semiconductor are mostly nonmagnetic, so it important to achieve non equilibrium spin in order to create a spin-polarized current. We can think of transferring the spin from a magnetic material to the semiconductor like injection of spin form magnetic material to nonmagnetic material which is not easily occurring due to the fundamental law. For all the devices the potential application is necessary, these potential and novel application can be achieved with the help of semiconductor spintronics. One of the device is the spin field-effect-transistor which was first proposed by Supriyo Datta and Biswajit Das[13], it is commonly known as Datta-Das spin transistor. The Datta-Das transistor is have a tri-layer structure similar to the conventional transistor (like emitter, base and collector) with magnetic source connected by semiconductor channel and gate. The source and the drain are made of magnetic material (ferromagnetic material), the spin carriers is injected from emitter and detected by the collector. The switching action is similar to ordinary FET, when the spins of the carrier are parallel to the collector they can flow so the state is called as "ON" state and if they are antiparallel the carrier cannot flow so it is switched to the "OFF" state. The carriers spin plays the important role in this device, the states can be changed from ON to OFF with the help of Gate. Both the FET and spin FET are having the same principle of operation, then why do we need the spin FET when we already have FET, one of the reason is the power consumption is very less in the spin FET and also the switching action is faster. It is necessary to understand and overcome the problems in spin transfer in a semiconductor to make such kind of devices.

2.3.1Conductivity Mismatch

There conductivity mismatch between ferromagnetic metal and semiconductor was observed by Schmidt *et al* [5]. There is a large difference in the densities of states for ferromagnetic and semiconductor materials, electrons with majority spin begin to occupy the available states, the chemical potential for adding a majority spin electron to semiconductor becomes much larger than for the minority spin electrons.

When the minority spin electrons cross or transferred across the interface, the chemical potential for the two spin types cancel out and hence the semiconductor is left with no net spin polarization. To overcome such problem several approaches can be considered (by introducing a barrier between the metal and semiconductor or by altering the spin injector conductivity) to achieve spin polarized transport in semiconductor.

2.3.2Dilute Magnetic Semiconductors

By replacing the ferromagnetic metal with a semiconductor that has magnetic properties conductivity mismatch problem can be resolved. The properties of the semiconductor can be changed by doping material. By introducing transition metal ions such as Mn, Fe, Co, Ni etc., via doping into the semiconductor will become ferromagnetic, these type of material are called Dilute Magnetic Semiconductor. The Dilute magnetic semiconductor have sufficiently low curie temperatures however resent research have reached curie temperatures approximately 210 K[6]. They show very small magnetic moments (~10-6 emu), there is a possibilities of identifying such magnetic fields from the impurity sources either extrinsic or intrinsic. Defects are necessary for room temperature Ferromagnetism observations[7]. The impurity sources are clusters (usually nanoclusters of transition metal ion), some of them are due to non- uniform solubility and Spinel's as secondary phase[8].

PART 3: **SPIN RELAXATION IN SEMICONDUCTORS**

3.1 INTRODUCTION

The field of Spintronics deal with the electron spin properties (ђ/2) that is becoming popular in electronics. New spin devices have amazing technology improvement and there are factors that makes the spin conduction electrons attractive for advance technology and devices [1]:

1) Electron spin can store information,

2) The spin information can be transferred as it is attached to mobile carriers, and

3) The spin information can be detected.

The information is stored in the form of the bit spin up (HIGH) and spin (LOW) or vice versa. As soon as the non-equilibrium spin get accumulated the Non-magnetic material or metal, the electron starts to regain the polarization of the spin electron, this is called spin relaxation and the time taken for the relaxation is called spin relaxation time. The spin relaxation is categorized by the mechanism they are given below

1) Elliot-Yafet Mechanism
2) D'yakonov-Perel' Mechanism
3) Bir-Aronov-Pikus Mechanism
4) Hyperfine-interaction Mechanism

3.2 MECHANISM

Elliot-Yafet Mechanism

The first suggestion for spin relaxation is given by Elliott in 1954, explaining that spin relaxation occurs via phonons or impurities scattering when the lattice ions give induced spin –orbit coupling in wave function of the electron[1]. The spin Eigen state is the ad mixture of both SO coupling and Bloch states of the real crystal[4]. The only presence of SO coupling interaction does not cause the spin relaxation in the system, it only caused when the carries (or electron) are scattered during the

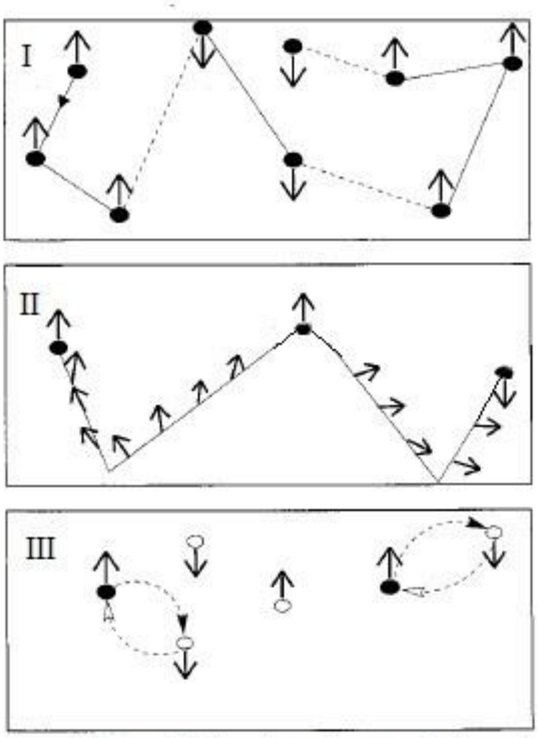

Figure 3:Spin relaxation mechanism (I) Elliot-Yafet mechanism (II)D'yakonov-perel' mechanism (III) Bir-Aronov-Pikus Mechanism

transport[2]. The electron have to experience hundreds of scattering before the spin relaxation. This mechanism is dominant in small band gap semiconductor[3].

D'yakonov-Perel' Mechanism

D'yakonov and perel' found a mechanism of spin relaxation for a system that have no inversion symmetry in the year of 1971[2].The group III-V and II-VI semiconducting material are materials without inversion symmetry. electrons are scattered due to the fluctuating magnetic field due to the lack of inversion symmetry .these randomizing spin scattering leads to the spin relaxation. D'yakonov-perel' is important in high band gap semiconductor[4].

Bir-Aronov-Pikus Mechanism

This mechanism can be mostly seen in Bipolar Semiconductors. The electron and holes have different spin moment, in a doped semiconductor the scattering occurs with the reason of spin exchange by holes and it was shown by Bir *et al.*in 1975 and the name of the mechanism called as Bir-Aronov-Pikus mechanism[3]. This mechanism is effective in heavily doped substrate where the probability of electron exchange with the holes is higher at low temperatures.

Hyperfine-interaction Mechanism

Hyperfine-interaction[1] is the interaction between the magnetic moment of nuclei and magnetic moment of electrons ,which is a important mechanism happens in confined quantum dots. The electron and nuclei has a intrinsic spin, in this mechanism the spins relax with their mutual magnetic field.

References

1. Spin relaxation of conduction electrons by J. Fabian and S. Das Sarma.
2. SEMICONDUCTOR SPINTRONICS by Jaroslav Fabian *et al* PACS:72.25.b,72.25.Rb,75.50.Pp,85.75.-d.
3. Spintronics: Fundamentals and applications by Jaroslav Fabian *et al* 2004.
4. Spin relaxation of conduction electrons by Jaroslav Fabian *et al* 1999.
5. High Temperature Ferromagnetism in GaAs-based Heterostructures with Mn Delta Doping A.M.Nazmul *et al PACS numbers: 75.50.Pp, 72.20.My, 71.55.Eq, 72.25.Dc*
6. A basic obstacle for electrical spin-injection from a ferromagnetic metal into a diffusive semiconductor G. Schmidt, D. Ferrand, L. W. Molenkamp
7. Room Temperature Ferromagnetism in $Ga_{1-x}H_xN$ (x=0.0 and 0.05) Diluted Magnetic Semiconductor Thin Films Ghulam Murtaza Raia *et al.*
8. Nanomagnetism and spintronics ,Faik Mikailzade 2009,p.121,C-6
9. Gholamreza Nabiyouni,GMR in Electrodeposited Superlattices(Spring 2009),p.154
10. Goldman, A., Modern Ferrite Technology (2006),p.17-20 ISBN:978-0-387-28151-3
11. Colm C. Faulkner, Domain Walls for Logic and Data Storage Applications(2009),p.359-362
12. Stuart Parkin, The Spin on Electronics!, KITP public lecture, 4/11/2013 20:00
13. S. Datta, B. Das, Electronic analog of the electro-optic modulator, Appl. Phys. Lett. 56 (1990) 665–667.