Prospects For Room Temperature Magnetic Semiconductors And Their Applications

By

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Dedication

This work is dedicated to :

My Father: **I missed you my dear! You left fingerprints of grace on my life. You won't be forgotten.**

and

My mother: **Thanks for always being there for me.**

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Abstract

This project is a review of prospects for room temperature magnetic semiconductors and their applications. We also studied general properties of semiconductors related to and found that their conductivity increases as temperature increase. Moreover, diluted magnetic semiconductors (DMS) are understood as a class of magnetic semiconductor in which a fraction of the cations are substitutionally replaced by magnetic ions. Finally, by using Heisenberg model of magnetic interaction we demonstrated the dispersion relation of magnons, average number of magnons, density of state for three dimension or bulk system and found that magnons dispersion is affected by magnetic spins from the magnetic dopant, the increase of density of state with energy, variation of number of magnons with temperature and lattice constant of the host material.

Chapter 1

Introduction

1.1 Semiconductors

Starting with the development of the transistor by Bardeen, Brattain, and Shockley in 1947, the technology of semiconductor has exploded. With the creation of integrated circuits and chips, semiconductor devices have penetrated into large parts of our lives. The modern desktop or laptop computer would be unthinkable without microelectronic semiconductor devices. A semiconductor is a material with electrical conductivity due to electrons flow inter-mediate in magnitude between that of a conductor and an insulator. One could called a semiconductor a narrow-gap insulator in the sense that its energy gap between the highest filled band (the valance band) and the lowest unfilled band (the conduction band) is typically of the order of one electron volt. The electrical conductivity of a semiconductor is consequently much less than that of a metal. In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current is often schematized as being carried by the flow of electrons or by the flow of positively charged 'holes' in the electron structure of the materials. Semiconductor intrinsic electrical properties, in an intrinsic semiconductor the number of electrons in the conduction band is equal to the number of holes in the valence band, are often permanently modified by introducing impurities by a process known as Dopant and the materials which added to the semiconductor are called Dopant. Usually it is sufficient to approximate that each impurities atom adds one electron or one hole that may flow freely. Upon the addition of a sufficiently large proportion of impurity dopant, semiconductor will conduct electricity nearly

as well as metals. Depending on the kind of impurity, a doped region of semiconductor can have more electrons or holes, and is named N-type or P-type semiconducting material, respectively. Junction between N-type and P-type semiconductors creates electric field, which causes electrons and holes to be available to move away from them, and this effect is critical to semiconductor device operation. Over a certain temperature range, donors can add electrons to the conduction band and acceptor can add holes to the valence band as temperature is increased. This can cause the electrical resistivity to decrease with increasing temperature giving a negative coefficient of resistance. This is to be contrasted with the opposite behaviour in metals [1].

Elemental semiconductors include antimony, arsenic, boron, carbon, germanium, selenium, silicon, sulfur, and tellurium. Silicon is the best-known of these, forming the basis of most integrated circuits (ICs). Common semiconductor compounds include gallium arsenide, indium antimonide, and the oxides of most metals. Of these, gallium arsenide (GaAs) is widely used in low-noise, high-gain, and weak-signal amplifying devices. Some of the properties of semiconductor materials were observed throughout the mid 19th and first decades of the 20th century. The first practical application of semiconductors in electronics was the 1904 development of the cat's-whisker detector, a primitive semiconductor diode widely used in early radio receivers. Developments in quantum physics in turn allowed the development of the transistor in 1947 [2] and the integrated circuit in 1958.

1.2 Magnetism

In order to understand why semiconductors are traditionally not magnetic and how it is possible to introduce magnetic behavior in these materials, it is first necessary to look at the fundamental origins of magnetic behavior, and then analyze how magnetic behavior can be exploited in the development of dilute magnetic semiconductor compounds. Magnetism in material is due to electron spin about its axis and orbital motion about the nuclei as shown in Fig 1.1 Bohr suggested a fundamental quantity later called the Bohr magneto

which is the strength of the magnetic field associated with an isolated electron. This magnetic field is a constant and can be calculated as follows. $\mu_B = \frac{eh}{4\pi m} = 9.27 \times 10^{-24} Am^2$ where, e the charge of an electron, h is plank's constant and m is the mass of electron.

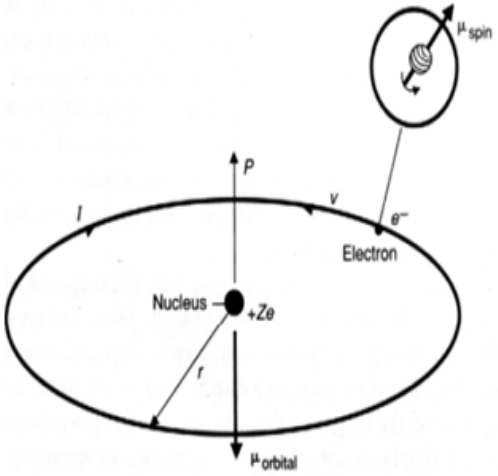

Figure 1.1: Origin of the magnetic moments in atoms due to an electron orbiting the nucleus ($\mu_{orbital}$) and to the electron spin about its axis ($\mu_{spin} = \mu_B$)

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1.3 Diluted Magnetic Semiconductor

The mass, charge, and spin of electrons in the solid state lay the foundation of the information technology we use today. Semiconductor devices generally take advantage of the charge of electrons, whereas magnetic materials are used for recording information involving electron spin. If both the charge and spin of electrons can be used to further enhance the performance of devices, so called spintronics, we may then be able to use the capability of mass storage and processing of information at the same time, thus leading to a brand new era of information technology.

Diluted magnetic semiconductors (DMS) in which the semiconductor captions are partially substituted by magnetic elements, is one of the important materials for the

realization of spintronics. The ability to synthesize DMS 1-dimensional nanostructures could provide new building blocks for spintronics as well as open up new opportunities for fundamental physical studies. The materials challenge is great because both magnetic and electronic doping is required, and the interaction between magnetic doping spins and free carriers must be engineered to achieve thermally robust doping spin carrier coupling, Fig 1.2 shows the difference between structure of magnetic, nonmagnetic and diluted magnetic semiconductures [3]. Magnetism and semiconducting properties are known to coexist in some ferromagnetic semiconductors, such as europium chalcogenides and ferromagnetic or ferromagnetic semiconducting spinels [4]. The first DMSs to be identified were II-VI semiconductor alloys like $Zn_{1-x}Mn_xTe$ and $Cd_{1-x}Mn_xTe$.

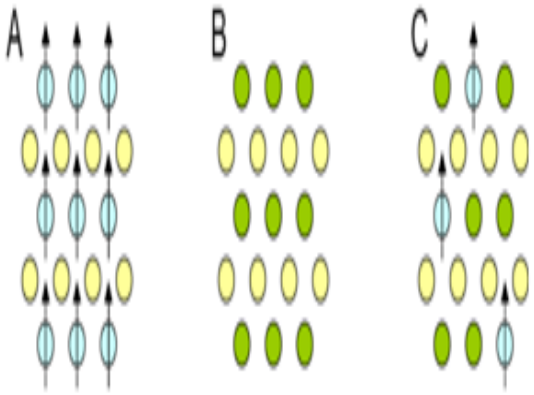

Figure 1.2: Schematic showing (A) a magnetic semiconductor, (B) a non-magnetic semiconductor material, and (C) a diluted magnetic semiconductor

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Chapter 2

Semiconductors and Magnetism

2.1 General Properties of Semiconductors

A semiconductor is a material with electrical conductivity that of a conductor and an insulator. Semiconductors possess specific electrical properties. A substance that conducts electricity is called a conductor, and a substance that does not conduct electricity is called an insulator. Semiconductors are substances with properties some where between them. Electrical properties can be indicated by resistivity. Conductors such as gold, silver and copper have low resistance and conduct electricity easily. Insulators such as rubber, glass and ceramics have high resistance and are difficult for electricity to pass through it. Their resistivity might change according to the temperature for example. At a low temperature, almost no electricity passes through them. But when the temperature rises, electricity passes through them easily. Semiconductors containing almost no impurities conduct almost no electricity. But when some elements are added to the semiconductors, electricity passes through them easily. Semiconductors comprising a single element are called elemental semiconductors, including the famous semiconductor material Silicon. On the other hand, semiconductors made up of two or more compounds are called compound semiconductors, and are used in semiconductor lasers, light-emitting diodes, etc. A large number of atoms gather to form a crystal, and interacts in a solid material, then the energy levels became so closely spaced that they form bands. Metals, semiconductors and insulators are distinguished from each other's by their band structures.

In metals, the conduction band and the valence band come very closer to each other

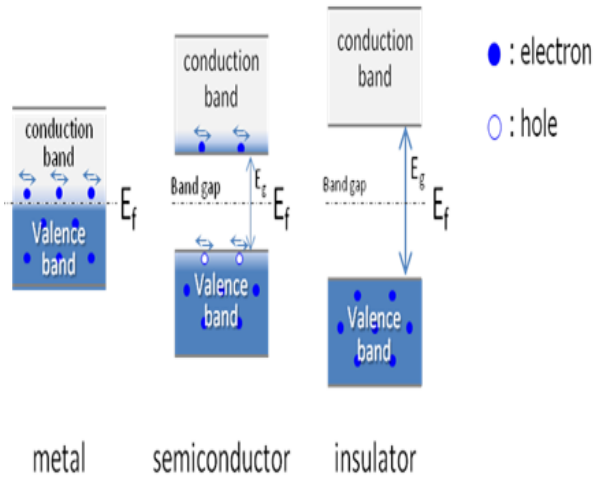

Figure 2.1: Their band structures are shown in the figure below.

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and may even overlap, with the Fermi energy E_f some where inside. This means that the metal always has electrons that can move freely and so can always carry current. Such electrons are known as free electrons. These free electrons are responsible for current that flows through a metal. In semiconductors and insulators, the valance band and conduction band are separated by a forbidden energy gap of sufficient width, and the Fermi energy is between the valence and conduction band. To get to the conduction band, the electron has to gain enough energy to jump the band gap. Once this is done, it can conduct. There is enough thermal energy to allow electrons to jump the gap fairly easily and make the transitions in conduction band, given the semiconductor limited conductivity. At low temperature, no electron possesses sufficient energy to occupy the conduction band and thus no movement of charge is possible. At absolute zero, semiconductors are perfect insulators, The density of electrons in conduction band at room temperature is not as high as in metals, thus cannot conduct current as good as metal. The electrical conductivity of semiconductor is not as high as metal but also not as poor as electrical insulator. That is why, this type of material is called semiconductor - means half conductor.

The band gap for insulators is large so very few electrons can jump the gap. Therefore, current does not flow easily in insulators. The difference between insulators and semiconductors is the size of the band gap energy. In insulator where forbidden gap is very large and as a result the energy required by the electron to cross over to the conduction band is practically large enough. Insulators do not conduct electricity easily. That means the electrical conductivity of insulator is very poor. Semiconductor crystal used for IC (integrate circuit) is high purity single crystal silicon of 99.99%, but when actually making a circuit, impurities are added to control the electrical properties. Depending on the added impurities, they become n-type and p-type semiconductors.

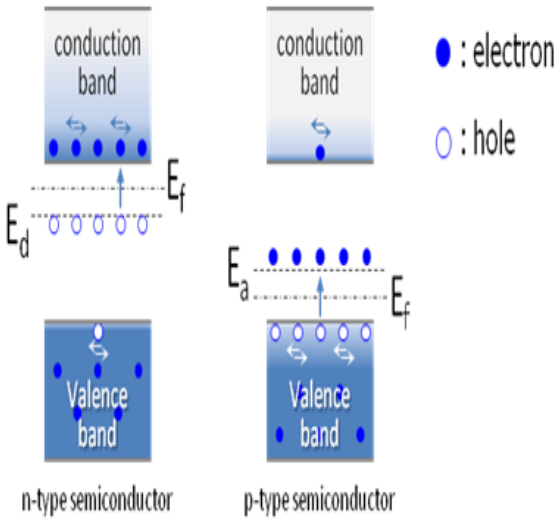

Figure 2.2: Schematic diagram showing added impurities, they become n-type and p-type semiconductors

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Pentavalent phosphorus (P) or arsenic (As) are added to high purity silicon for n-type semiconductors. These impurities are called donors. The energy level of the donor is located close to the conduction band, that is, the energy gap is small. Then, electrons at this energy level are easily excited to the conduction band and contribute to the conductivity. On the other hand, trivalent boron (B) etc. is added to p type semiconductor. This is called an acceptor. The energy level of the acceptor is close to the valence band. Since there are no electrons here, electrons in the valence band are excited here. As a result, holes are formed in the valence band, which contributes to the conductivity.

N-type Semiconductors.

When pentavalent impurity atom is added to pure semiconductor its conductivity increases. Let us consider Arsenic is added to Germanium. The five outermost electrons of Arsenic will try to acquire stable state. For acquiring a stable state, they need 8 electrons in the outermost shell. Thus, out of 5 electrons of outermost shell of Arsenic, 4 electrons will form the covalent bond with outermost 4 electrons of Germanium and acquire stability. The remaining one electron is the free electron. Arsenic atom will donate this single electron.Thus, pentavalent impurities are called donor impurities. This free electron will take part in conduction and increase conductivity. In this way for every covalent bond, there will be one electron in excess. Thus, it has electron as majority charge carriers. Electrons are negatively charged particles. Thus, it is called N-type i.e. Negative type Semiconductors. It also has positive charge ions. When donor impurities donate one electron to the crystal, it becomes a positive ion with one +ve charge because it has donated one electron. Thus, N-type semiconductor has electrons as majority charge carriers and ions (positively charged) as minority charge carriers.

P-type Semiconductor, So 3 electrons of Gallium atom will form covalent bonds with 3 electrons of Silicon atom. One electron of Silicon atom is left. It cannot become free electron because neither Silicon atom has attained stability or Gallium. The trivalent impurity is known as acceptor impurities. So, this electron will try to form the covalent bond with Gallium. Since Gallium does not have an extra electron so the covalent bond is devoid of an electron. This devoid of an electron is considered as holes. Holes are positive

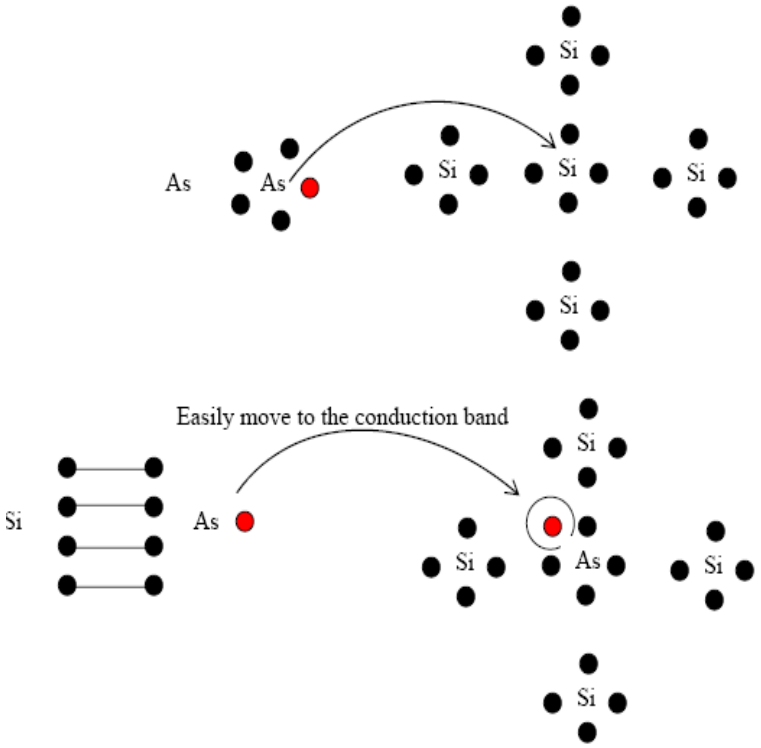

Figure 2.3: Schematic diagram showing N - Type Semiconductor

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charge carrier. Thus, P-type Semiconductors has majority charge carriers as holes and electrons as minority charge carriers. This is the reason it is called P-type semiconductors or Positive type Semiconductors. Holes are responsible for conduction in the P-type semiconductor.

Construction of P - type Semiconductors

When trivalent impurity atoms are added to pure semiconductor, its conductivity shows a significant increase. In this case, electrons are not majority charge carriers here. Let us consider one atom of Gallium is added to 10 million parts of Silicon. The three outermost electrons of Gallium will try to acquire stability. For acquiring stability, they need 8 electrons in the outermost shell. But Silicon has only 4 electrons in its outermost shell as shown in Fig 2.4 below.

Some Properties of Semiconductors are discussed below.

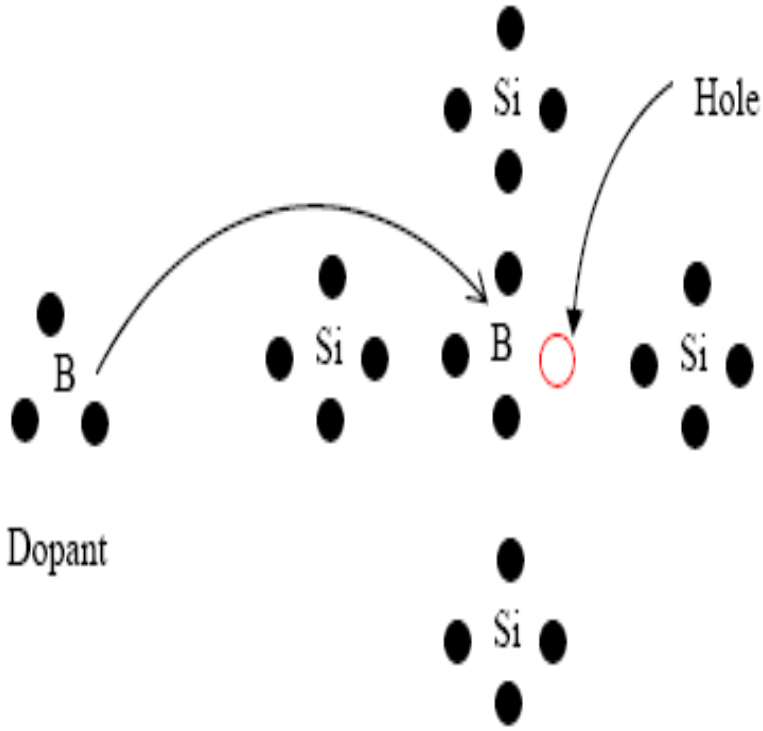

Figure 2.4: Schematic diagram showing P - Type Semiconductor

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2.1.1 Electrical Conductivity

The process of doping makes it easier to have control on the electrical conductivity. When the doping is changed, the semiconductor can conduct both holes and electrons without being changed. When the doping is done on a higher level, degeneracy happens which can make the material behave like a metal. If an amorphous film of the semiconductor is formed, then it will be have like an insulator only. On the basis of these properties, many electronic devices came into the picture like transistors, diodes etc.

2.1.2 Optical Properties

There may be a direct or indirect band gap existing in semiconductors. The semiconductors with direct band gap are able to emit a photon when excitation is done by the wavelength required. On the basis of this property, the development of applications like LEDs, lasers etc came in action. The semiconductors with indirect band gap can be made of the type direct band gap by simply alloying.

2.1.3 Photoconductivity

An electron-hole pair can be produced by illuminating a p-n junction. These electron-hole pairs can then be collected electrodes in the circuit which will now pass current. Because of this property, the development of photo detectors and solar cells was possible.

2.1.4 Variable Conductivity

Semiconductors in their natural state are poor conductors because a current requires the flow of electrons, and semiconductors have their valence bands filled, preventing the entry flow of new electrons. There are several developed techniques that allow semiconducting materials to behave like conducting materials, such as doping or gating. These modifications have two outcomes: n-type and p-type. These refer to the excess or shortage of electrons, respectively. An unbalanced number of electrons would cause a current to flow through the material [1].

2.2 Classifications of Semiconductors

2.2.1 Intrinsic or Pure Semiconductors

There are two ways to define an intrinsic semiconductor. In simple words, an intrinsic semiconductor is one which is made up of a very pure semiconductor material. In more technical terminology be that an intrinsic semiconductor is one where the number of holes is equal to the number of electrons in the conduction band. The forbidden energy

gap in case of such semiconductors is very minute and even the energy available at room temperature is sufficient for the valence electrons to jump across to the conduction band. Another characteristic feature of an intrinsic semiconductor is that the Fermi level of such materials lies some where in between the valence band and the conduction band. Fermi level, it refers to that level of energy where the probability of finding an electron is 0.5 or half.

Silicon and Germanium, which belong to the fourth group element, behave like a semiconductor. Each atom of silicon and germanium share an electron with their neighbours. A Silicon atom and its neighbours share a pair of electrons in covalent bonding. Whenever a covalent bond break, an electron-hole pair is formed. To remove the valence electrons from the outer shells a semiconductor atom needs the energy of the order 1.1eV. The vacancy in the covalent bond is called a hole. Any other electron can fill this hole. In other words, a hole shifts from one covalent bond to another. We can assume that the hole is a positive charge carrier since the direction of the hole is opposite to that of the electron. In an intrinsic semiconductor, electrons and holes move in random directions and the number of free electrons (n_e) and holes (n_h) remain same.

2.2.2 Extrinsic Semiconductors and Doping Process

Extrinsic semiconductors

When a suitable metallic impurity is added to an intrinsic or pure semiconductor, it is known as extrinsic semiconductor. The properties of Semiconductor are varied by adding impurity atom. This is called doping, i.e., adding impurity deliberately to improve conductivity. One impurity atom is added to 10 million atoms of an intrinsic semiconductor.The materials chosen for doping are deliberately chosen in such a manner that either they have 5 electrons in their valence band, or they have just 3 electrons in their valence band. Such dopants are known as pentavalent or trivalent dopants respectively. The type of dopant also gives rise to two types of extrinsic semiconductors namely P-type and N-type semiconductors. A pentavalent doping such as Antimony are known

as donor impurities since they donate an extra electron in the crystal structure which is not required for covalent bonding purposes and is readily available to be shifted to the conduction band. This electron does not give rise to a corresponding hole in the valence band because it is already excess, therefore upon doping with such a material, the base material such as Germanium contains more electrons than holes, hence the nomenclature N-type intrinsic semiconductors.On the other hand when a trivalent doping such as Boron is added to Germanium additional or extra holes get formed due to the exactly reverse process of what was described in the upper section. Hence this doping which is also known as acceptor creates a P-type semiconductor. Hence electrons are the majority carriers (of current) in N-type while holes are minority carriers. The reverse is true of P-type semiconductors. Another difference is that whereas the Fermi level of intrinsic semiconductors is somewhere midway between the valence band and the conduction band, it shifts upwards in case of N-type while it drifts downward in case of P-type due to obvious reasons. Having learnt about various types of semiconductors, we will now see what happens in case the N-type and P-type semiconductor materials are joined together to form a junction known as the P-N junction and how is it useful for digital electronics. Depends on the type of impurity added, the extrinsic semiconductors are divided into;

N-type (negative semiconductors):- It is formed when the pentavalent impurity is added to an intrinsic semiconductor. The pentavalent material is categorized in Group - V of the periodic table. These materials have 5 electrons in their outermost shell. Therefore, they are called pentavalent material. Pentavalent impurities are Phosphorus, Antimony, Arsenic, etc. The N-type semiconductor has a large number of electrons in the conduction band and less number of holes in the valence band, so electrons are called majority carriers and holes are called minority carriers. A pentavalent impurity such as phosphorous or arsenic is added to the silicon crystal. Out of five valence electrons, four silicon atoms take part in covalent bonding with one arsenic/phosphorus atom. The fifth electron is loosely bound to the silicon atom. Such a silicon crystal is still electrically neutral as the extra electron does not show up as an additional charge in the atom. Arsenic and Phosphorus are called as N-type impurities. When these impurities are added

to pure semiconductor material like silicon (Si) or germanium (Ge), they form an n-type material. Fig 2.5.

P-type (Positive semiconductor):- It is formed when the trivalent impurity

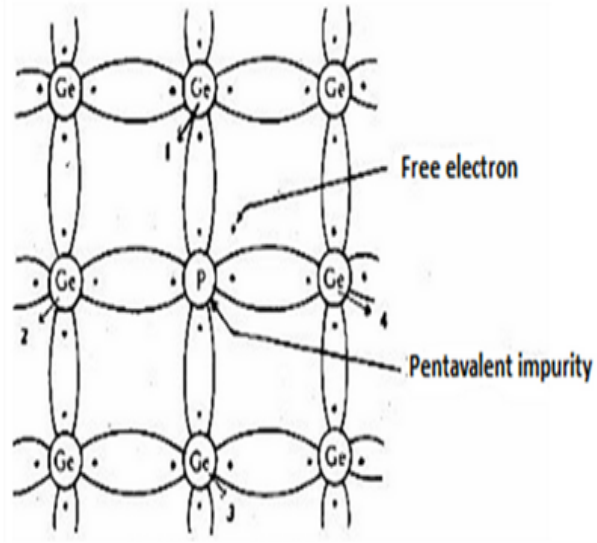

Figure 2.5: Schematic diagram shows pentavalent impurity added to an intrinsic semiconductor

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is added to an intrinsic semiconductor. Trivalent materials are categorized in Group - III of the periodic table. These materials have 3 electrons in their outermost shell. Therefore, they are called trivalent material. Trivalent impurities are Boron, Gallium, Indium, etc. The P-type semiconductor has a large number of holes in the conduction band and less number of electrons in the valence band, so holes are called majority carriers and electrons are called minority carriers. A trivalent impurity such as Boron is mixed with the silicon atoms. Boron can share three valence electrons with the silicon atom; the boron atom takes one electron from nearby covalent bonds with the silicon atom in order to complete eight electrons in its valence shell. As the trivalent impurity atoms accept electrons from the silicon atom, it is known as an acceptor impurity. The p-type silicon crystal so obtained is called p-type extrinsic semiconductor and the holes created are

extrinsic carriers.Indium, aluminium and boron are called as P-type impurities. When these impurities are added to pure semiconductor material they form a P-type material. The process of inserting impurity element (atom) into the lattice of a pure material is called doping. In general the N-type semiconductor material contains an excess of negative charge carriers. Similarly, when the pure material is doped with an impurity which has three electrons in its valence shell (i.e. a trivalent impurity) it will become a p-type (i.e. positive type) semiconductor material. The P-type material contains an excess of positive charge carriers. Fig 2.6.

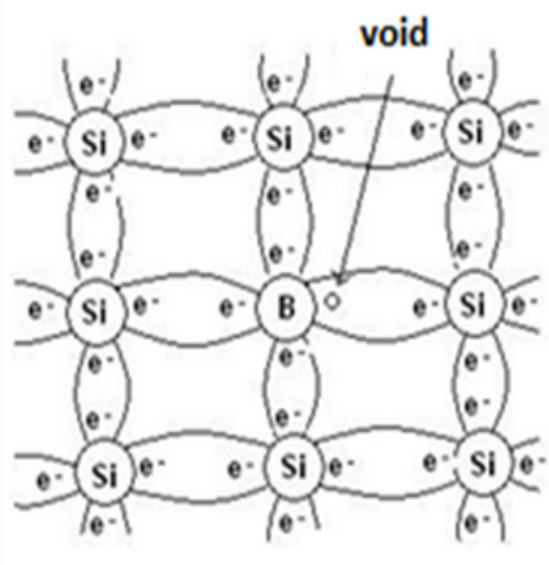

Figure 2.6: Schematic diagram shows trivalent impurity added to an intrinsic semiconductor

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Doping process

Doping is the process of adding impurities to intrinsic semiconductors to alter their properties. Normally trivalent and pentavalent elements are used to dope Silicon and Germanium. When an intrinsic semiconductor is doped with Trivalent impurity it becomes a P-type semiconductor. The P stands for Positive, which means the semiconductor is

rich in holes or Positive charged ions. When we dope intrinsic material with Pentavalent impurities we get N-Type semiconductor, where N stands for Negative. N-type semiconductors have Negative charged ions or in other words have excess electrons in it.

2.3 Applications of Semiconductors

2.3.1 Light Emission

In certain semiconductors, excited electrons can relax by emitting light instead of producing heat. These semiconductors are used in the construction of light-emitting diodes and fluorescent quantum dots. Gallium arsenide and aluminum phosphate, which were developed in the 1960s, are made into the light-emitting diodes (LEDs) used as displays in digital clocks, microwave ovens, and countless other electronic devices. Those same materials can be shaped to form a reflecting cavity that amplifies and directs the light it produces, creating a semiconductor laser. Semiconductor lasers are often paired with photoelectric cells in automatic doors, burglar alarms, bar-code readers, and fiber-optic communications devices. Semiconductors have large thermoelectric power factors making them useful in thermoelectric generators, as well as high thermoelectric figures of merit making them useful in thermoelectric coolers [1].

Diode

Diode is an electronic component with two electrods called anode and cathode. Diode are made up semiconductors materials such as silicon, germanium or selenium. Diode is used as rectifiers, signal limiters, voltage regulators, switches,signal modulators,signal mixers and oscillators. A diode is its tendency to conduct electronic current in only one direction. Semiconductor diodes can be designed to produced direct current (Dc) when visible light, infrared transmission (IR) or ultraviolet (uv) energy strikes them. The semiconductor diode formed from a layer of P-type semiconductor joined to a layer of n-type semiconductor materials and is important electronic component [15].

2.3.2 Transistor

Transistor is a semiconductor device that can function as a signal amplifier or a switch electronics signal. a type of switch circuit using a NPN transistor. In a transistor a very small current input signal flowing emitter to base to control a much large current which flow from the system power supply, through the transistor emitted to collector through the load and back to the power supply. There are different types to transistors: Bipolar transistors are considered as current driven device and have low input impedance. Field Effect Transistor (FET's) are refer to as voltage driven devices which have high input impedance [15].

2.3.3 Photovoltaic Cell

Photovoltaic cell is a form of photo diode. The base layer of a photo voltaic solar cell is made up of p-type semiconductor material when light strikes the junction between n-type and p-type of semiconductors, electrons flow through the structure of the cell [15].

2.4 Magnetic Ordering

2.4.1 Diamagnetism

Diamagnetic materials exhibit a type of magnetism known as diamagnetism. Materials which are weakly repelled to the magnet or external magnetic field are called diamagnetic materials. Diamagnetic materials have all the Paired electrons, i.e., the electrons occupy the same orbital of an atom but orbiting and spinning in opposite direction and thus diamagnetic materials have no net magnetic moment or magnetic field strength. When diamagnetic materials are place in the magnetic field of magnet, it creates a slight magnetic field that opposes the external magnetic field. Diamagnetic materials produce the weak magnetic field as the result of change in orbital motion of electrons due to the external magnetic field. Magnetic permeability of the diamagnetic material is less than the permeability of free space. The ability of a particular material to support the magnetic field with in itself is called magnetic permeability. When diamagnetic materials are placed in the external magnetic field, the magnetic field strength or magnetic

moment inside the diamagnetic material is less than magnetic moment or magnetic field strength in the air surrounding the material. Diamagnetism was discovered and named in 1845 by Michael Faraday. Some diamagnetic materials are copper, lead, silicon, bismuth. Superconductors are considered as perfect diamagnetic materials. These materials exhibit both perfect conductivity and perfect diamagnetism at very low temperatures. The phenomenon of perfect diamagnetism in superconductors is called as Meissonier effect. Superconductors are mainly used for running magnetically levitated super fast trains. Although diamagnetism is in all solid states existent, it can be observed only in atoms or ions with complete filled electron shells. Otherwise the weak diamagnetism is obscured by other types of magnetic ordering. In diamagnetism a magnetic moment is induced by an external magnetic field. The electrons process in direction of the field and act against the inducing field according to the Lenz rule. Therefore, the susceptibility is negative and small ($10^{-9} < |X_{dia}| < 10^{-5}$) [6].

2.4.2 Para-magnetism

Para-magnetism is a weak form of magnetism observed in substances which display a positive response to an applied magnetic field. This response is described by its magnetic susceptibility per unit volume, which is a dimensionless quantity defined by the ratio of the magnetic moment to the magnetic field intensity. Para-magnetism is observed, for example, in atoms and molecules with an odd number of electrons, since here the net magnetic moment cannot be zero. It occurs in nonmagnetic substances like graphite, copper, silver and gold, and in the super conducting state of certain elemental and compound metals. The negative magnetic susceptibility in these materials is the result of a current induced in the electron orbits of the atoms by the applied magnetic field. The electron current then induces a magnetic moment of opposite sign to that of the applied field. The net result of these interactions is that the material is shielded from penetration by the applied magnetic field.

Paramagnetic materials exhibit a type of magnetism known as para magnet. Materials which are slightly attracted to a magnet are called paramagnetic materials. When paramagnetic materials are placed in the strong external magnetic field, it gets weakly magnetized. Paramagnetic materials has more unpaired electrons, i.e., the electron occupy the orbital of an atom singly rather than a pair. Fig 2.7.

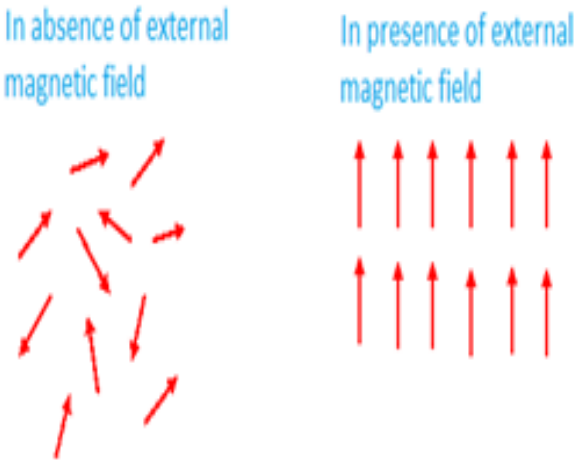

Figure 2.7: Schematic diagram showing in the absence and presence of external magnetic field

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The individual atom of a paramagnetic material has a permanent magnetic moment or magnetic field strength of its own. The permanent magnetic moment is generally due to the spinning and orbiting of unpaired electrons in the atom.In pure Para-magnetism, the magnetic moment or magnetic field strength of the electron does not interact with each other and are randomly aligned in the absence of strong external magnetic field, resulting in zero net magnetic field strength. In the presence of strong external magnetic field, the magnetic moment of the electrons are aligned in the direction of applied magnetic field, resulting the magnetic field strength in the direction of applied external magnetic-field.

Magnetic permeability of the paramagnetic material is greater than or equal to 1. The ability of a particular material to support the magnetic field with in itself is called magnetic permeability. Paramagnetic materials continue to hold magnetism only in the presence of strong external magnetic field, in the absence of strong external magnetic field paramagnetic materials lose their magnetism. Some paramagnetic materials are sodium, calcium, aluminium and copper chloride. Para-magnetism exists in atoms or ions with partly filled orbital's possessing unpaired electrons, so that uncompensated magnetic moments can occur. In absence of magnetic fields and long-range interactions, the magnetic moments are distributed statistically.Hence, an average macroscopic magnetic moment vanishes. The magnetic moments can be aligned by an external magnetic field [8]. The susceptibility of Para-magnetism is positive and in an order of magnitude of $(10^{-3} < |X_p ara| < 10^{-2})$. Three manifestations of the pare-magnetism can be distinguished: the Van Vleck pare-magnetism, the Langevin pare-magnetism and the Pauli pare-magnetism. The Langevin pare-magnetism appears for magnetic moments of atoms or ions in then ground state. The magnetization is given thermodynamically for N ions in a volume V by:

$$M = -\frac{N}{V}(\frac{\partial F}{\partial B}) \tag{2.1}$$

$M = (n)\frac{\partial F}{\partial B}$ with the number of magnetic moments per unit volume n. The free energy F is defined by

$$e^{-\frac{F}{K_\beta T}} = \sum e^{-\frac{g\mu_B B}{K_\beta T}} \tag{2.2}$$

For low temperature it is sufficient to provide the n = 2J + 1 lowest states. Therefore follows for macroscopic magnetization of free magnets moments $\mu = -g\mu_B J$ without interaction, i.e. the spins be regarded as independent from one another.

$$M = (ng\mu_B J B_J(y)) \tag{2.3}$$

with $y = (\frac{g\mu_B JB}{K_\beta T})$. In the equation (2.3) is

$$g = 1 + (\frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}) \tag{2.4}$$

The Lande g-factor of electrons, μ_B the Bohr magneto and $BJ(y)$ the Brillion function and described by

$$B_J(y) = \frac{2J+1}{2J}\coth(\frac{2J+1}{2J}) - \frac{1}{2J}\coth(\frac{y}{2J}) \tag{2.5}$$

For high temperatures and weak magnetic fields the Brillion-function can be simplified, so that the susceptibility can be described by the classical Curie law

$$x_{para}^{Langevin} = \frac{C}{T} \quad with \quad the \quad curie \quad constant \tag{2.6}$$

In contrast the Van Vleck Para-magnetism is temperature independent. It arises from magnetic moments of excited states. In case of non-vanishing orbital angular momentum J = 0, the Van Vleck Para-magnetism is about three orders weaker than the Langevin Para-magnetism and, thus, is negligible. The Pauli Para-magnetism finally arises from the magnetic moment of delocalized electrons and, therefore, is important for metals.

2.4.3 Ferromagnetism

Ferromagnetic materials exhibit a type of magnetism known as ferromagnetism. Materials which are strongly attracted to a magnet are called ferromagnetic materials. When ferromagnetic materials are placed in the strong external magnetic field, it gets strongly magnetized.

These materials continue to hold magnetism even in the absence of strong external magnetic field. Ferromagnetic materials have some unpaired electrons, so their atoms have some net magnetic field strength. The individual atom of a ferromagnetic material exhibits a permanent magnetic moment or magnetic field strength of its own. The permanent magnetic moment is generally due to the spinning and orbiting of unpaired electrons in the atom. In ferromagnetic materials, the magnetic moment or magnetic field strength of the electrons interact with each other in such a way that magnetic moment of group of atoms are spontaneously aligned them self in one particular direction. The

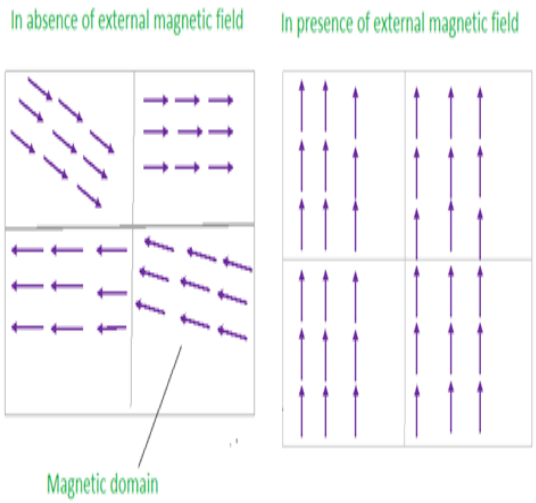

Figure 2.8: Schematic diagram showing in the absence and presence of external magnetic field

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magnetic moments of group of atoms that are aligned in one particular direction is called as magnetic domain. Some ferromagnetic materials are iron, nickel, steel and cobalt. One group of materials having very different magnetization from the first two group Known as ferromagnetic. First magnetic susceptibility x is positive and very large; about 10^7 times greater than x in paramagnetic materials. This means that the material under an applied field will create a very large magnetization. Second, large magnetic field can be retained after the applied field is removed. The most important ferromagnetic element is Fe, Co, and Ni. A large rare earth element; gadolinium (Gd), is also ferromagnetic below 16^0C. FeCo and Ni are transition metals and have unpaired inner 3d electrons. Fe atom has four unpaired 3d electrons, Co has three unpaired 3d electrons and Ni has two unpaired 3d electrons. The spin of the 3d electron of adjacent atoms align in parallel to applied field induces diamagnetic and paramagnetic effect when the field is removed; the effect is disappear by a phenomenon called spontaneous magnetization.This parallel alignment of atomic magnetic dipoles occurs in microscopic regions called magnetic domains. If the

domains are randomly oriented, there will be no net magnetization in a bulk sample. If the domains are aligned in a magnetic field, the magnetic induction of the specimen will be very strong [6]. The positive susceptibility follows the Curie-Weiss law:

$$x^{ferro} = \frac{C}{T - \theta} \tag{2.7}$$

where Θ is the Curie-Weiss temperatures called ordering temperature of the ferromagnetic phase. With the temperature passes finally into paramagnetic phase. These second phase transitions occur at Θ.

2.4.4 Antiferromagnetism

In the presence of a magnetic field, the magnetic dipoles of atoms in some materials align themselves in opposite direction. Therefore, the atoms do not show a net magnetic moment. Manganese (Mn) and chromium (Cr) exhibit this behaviour as they have negative exchange energy [6]. Exchange interaction which is responsible for parallel alignment of spins is extremely sensitive to intern atomic spacing and to the atomic positions. This sensitivity causes anti-parallel alignment of spins. When the strength of anti-parallel spin magnetic moments is equal no net spin moment exists and resulting susceptibilities are quite small [11]. The transition temperature below which the spontaneous anti parallel magnetic ordering takes place is called the Neel temperature. Above the Neel temperature, the substance is Para-magnetic, and the susceptibility obeys the Curie-Weiss law.

$$x^{afm} = \frac{C}{T + T_{Neel}} \tag{2.8}$$

where T_{Neel} is the Neel temperature With a negative paramagnetic Curie temperature, the Neel temperature is similar to the Curie temperature in ferromagnetism. Anti ferromagnetic materials exhibit a type of magnetism known as anti ferromagnetism. In anti ferromagnetic materials the magnetic moments of neigh boring electrons point in opposite direction. Fig 2.9 shows about the direction of electrons.

Therefore, it has zero net magnetic moment. In these materials the alignment of

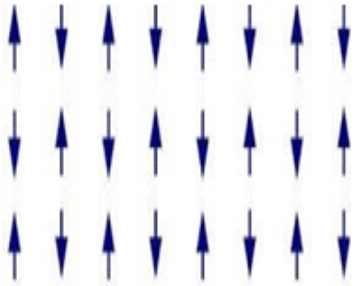

Figure 2.9: Schematic diagram showing neighboring electrons for anti ferromagnetic
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magnetic movement of the atoms are combinations of both parallel and anti parallel. Semiconductors possess specific electrical properties. A substance that conducts electricity is called a conductor, and a substance that does not conduct electricity is called an insulator. Semiconductors are substances with properties somewhere between them. ICs (integrated circuits) and electronic discrete components such as diodes and transistors are made of semiconductors. Common elemental semiconductors are silicon and germanium. Silicon is well-known of these. Silicon forms most of ICs. Common semiconductor compounds are such as gallium arsenide or indium antimonide.

2.4.5 Ferrimagnetism

In some ceramic compounds, different ions have different magnitude of magnetic moments. When these magnetic moments are aligned in an anti parallel manner, there is a net magnetic moment in one direction. Fig 2.10 is a schematic drawing illustrating the arrangement of dipoles for different magnetism. These ceramic magnetic materials are called ferrites. Their magnetic properties are very much like those of ferromagnetic. However, because of their ceramic nature, they have a much lower electrical conductivity than metallic magnets. These properties make them very useful in many electronic applications [6].

Like ferromagnetism, ferrimagnets retain their magnetization in the absence of a field. However, like antiferromagnets, neighboring pairs of electron spins tend to point in opposite directions. These two properties are not contradictory, because in the optimal geometrical arrangement, there is more magnetic moment from the sublattice of electrons that point in one direction, than from the sublattice that points in the opposite direction.

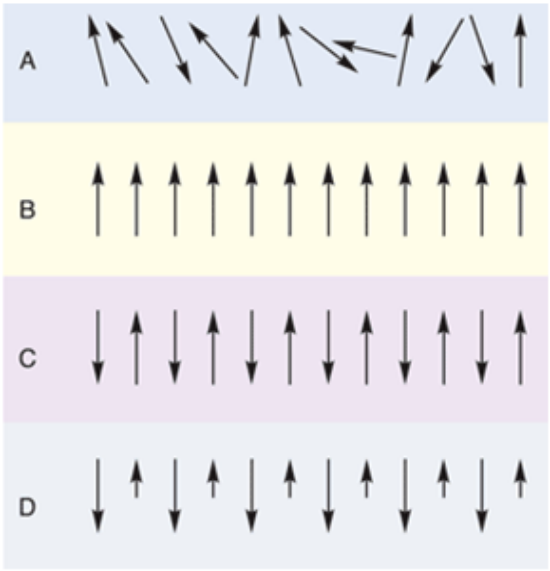

Figure 2.10: Schematic diagram showing the alignment of magnetic dipoles for different type of magnetism: (A) paramagnetic (B) ferromagnetic (C) antiferromagnetic and (D) Ferrimagnetic

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Chapter 3

Overview of Diluted Magnetic Semiconductors (DMSs)

3.1 Introduction to Diluted Magnetic Semiconductors

Diluted magnetic semiconductors (DMS) are materials in which host semiconductors are doped with magnetic impurities, generally atoms of a transition metal such as Manganese (Mn), Iron (Fe), Cobalt (Co) and Chromium (Cr). There is considerable current interest in these materials because they appear to have great potential for use in spin-polarized electronics (spintronics) or in non-volatile computer memory. The discovery of ferromagnetism in (Ga,Mn)As with a relatively high temperature has sparked a rapid increase in the number and variety of such materials studied. The aim of much of this work has been to find higher Curie temperature or useful transport properties. Most of the early work in the field focused on II-VI semiconductors, in which a semiconductor composed of a group II and a group VI element, such as CdTe, is doped with Mn. In the II-VI case, Mn and Cd have same valence, hence each Mn ion introduce a spin$-5/2$ moment, but does not introduce any carriers, unless another dopant with a different valence, such as N (a p-type dopant) is introduced.

A major advance in the field occurred with the ability to dope Mn into III-V semiconductors such as InAs and GaAs. These materials differ from the II-VI DMS because Mn has a different valence to group III elements, and whilst it still introduces a spin$-5/2$ moment, Mn plays the dual role of magnetic ion and acceptor. The low solubility of Mn in

III-V semiconductor was the main barrier to fabrication and it has only recently become to grow such materials using low-temperature molecular beam epitaxial [5].

Following the discovery of a ferromagnetic transition at temperature in excess of 100 K, the diluted III-V magnetic semiconductors, which are realized by doping a semiconducting host materials with low concentration of magnetic impurities (typically manganese), have attracted a great deal of attention from both the experimental and theoretical point of view due to their potential in spintronics application. In DMS, low concentration of magnetic impurities carrying localized magnetic moment (spins) form a diluted spin system. The random spatial distribution of the magnetic impurities breaks the translational symmetry of the crystal and thus greatly complicates the theoretical description of the materials [9].

3.2 DMS from Elemental Semiconductor

3.2.1 Silicon (Si)

Silicon (Si) is most widely used material in semiconductor devices. It possesses lower raw material cost and relatively simple process. Its useful temperature range makes it currently the best promise among the various competing materials. Silicon used in semiconductor device manufacturing is presently fabricated into bowls that are large enough in diameter to allow the manufacture of 300 mm (12 in.) wafers.

3.2.2 Germanium (Ge)

Germanium (Ge) was a widely used in early semiconductor material, but its thermal sensitivity makes less useful than silicon. Nowadays, germanium is often alloyed with silicon (Si) for use in very-high-speed SiGe devices; IBM is a main producer of such devices. Gallium arsenide (GaAs) is also widely used with high-speed devices, but so far, it has been difficult to form large-diameter bowls of this material, limiting the wafer diameter sizes significantly smaller than silicon wafers thus making mass production of Gallium

arsenide (GaAs) devices significantly more expensive than silicon.

3.3 DMS From Compound Semiconductor

3.3.1 (II-VI) Diluted Magnetic Semiconductor

The II-VI DMS are based on semiconductors AB, where A is a group II elements and B is a group VI element (such as CdTe or ZnSe). In the II-VI DMS, some of the divalent sites (Cd/Zn) are substituted by a magnetic element, typically Mn. This fraction is denoted by x, so the DMS we consider is $A_{1-x}Mn_xB$. Mn is also a group II element, but in addition it has a half filed 3d shell, with a total spin given by hand's rule :$S = \frac{5}{2}$. In the absence of other types of doping, the system $A_{1-x}Mn_xB$ is an insulator which exhibits anti-ferromagnetic (AFM) tendencies at low temperature. This is seen, for instance, from measurements of the susceptibility which is found to depend on temperature as $X(t) \sim \frac{1}{T+T_N}$, with a Neel temperature of a few Kelvin. The origin of this AFM tendency is the expected anti-ferromagnetic exchange between the Mn spins. However, for low doping concentration x, the average distance between Mn spins is large and this AFM direct exchange is rather small. In $CdTe/Cd_{1-x}Mn_xTe$, the dilution decreases the influence of ion-ion interaction, which favours an anti-parallel alignment of Mn^{2+} spins at low temperature. When a Mn^{2+} ion occupies a substitution Cd site in cubic CdTe crystal, its free ion terms split due to the cubic crystal field [10].

3.3.2 (III-V) Diluted Magnetic Semiconductors

Soon after the discovery of (In,Mn)As, similar materials have been prepared by introducing Mn atoms into a III-V compound semiconductor [11]. The Mn^{+2} ions in the most widely studied (III, Mn)V alloys provide localized magnetic moments and at the same time act as a source of valence band holes that mediate the exchange interaction between them. Recent experiments have demonstrated that electrical control of the spin properties in these compounds can be used both for manipulation and detection of magnetic signals.

This feature makes them promising candidates for the material background of future spintronics applications which also incorporates the existing semiconductor technologies in a seamless way [12]. The most important and most widely studied prototype materials of the III-V diluted magnetic semiconductor family are (Ga, Mn)As and (Ga, Mn)N. Both of these materials have rather high Curie temperatures, but the electronic properties, and possibly also the origin of magnetism, are quite different.

3.3.3 $(Ga_{1-x}Mn_x)$As Dilute Magnetic Semiconductor

Diluted magnetic semiconductors (DMS) have been studied for three decades in order to search for thermodynamically stable materials with traditional semiconductor characteristics and robust high-temperature Ferro-magnetism for new multifunctional electronics DMS devices. $(Ga_{1-x}Mn_x)As$ is one of the most important DMS systems. Recent years have witnessed two breakthroughs in its curie temperature. A Curie temperature of 110 K (x = 0.053) was achieved in 1998 and 173 K (x = 0.08) in 2005. It is reasonably believed that higher Curie temperature may be achieved in the future [13].

Chapter 4

The Model Hamiltonian

4.1 Dispersion Relation of Magnons

Consider three nearest-neighbor spin each of magnitude '**S**' on a line as shown where coupled by Heisenberg interaction [14].

$$U = -2J\mathbf{S}p.(\mathbf{S}_{p-1} + \mathbf{S}_{p+1}) \tag{4.1}$$

where J is the exchanged integral and $\hbar\mathbf{S}_p$ is the angular momentum of the spin at the site of p. If we treat spins as classical vectors then in the ground state $\mathbf{S}_p.\mathbf{S}_{p-1} = \mathbf{S}^2$ and the exchange energy of the system is given by $U_o = -2JS^2$. The first excited state, considered as an excited state with one particular spin reversed. This for a spin waves for many such classical system and result in formation of magnons. Spin waves are therefore, oscillations in the relative orientations of spins on a lattice. The classical derivation of the magnon dispersion relation which involves the p^{th} spins with the magnetic moment at site p as $\mu_p = -g\mu_B\mathbf{S}_p$. Then substituting into (4.1) for $\mathbf{S}_P$, where

$$\mathbf{S}_p = \frac{-\mu_p}{g\mu_B} \tag{4.2}$$

would give

$$\begin{aligned} U &= -2J\big(\frac{-\mu_p}{g\mu_B}\big)(S_{p-1} + S_{p+1}) \\ &= -\mu_p\big[\big(\frac{-2J}{g\mu_B}\big)(S_{p-1} + S_{p+1})\big] \end{aligned} \tag{4.3}$$

(4.3) is the form of $-\mu_P.\mathbf{B}_p$. The effective magnetic field or exchange field act on p^{th} spin is

$$\mathbf{B}_p = \frac{-2J}{g\mu_B}\big[\mathbf{S}_{p-1} + \mathbf{S}_{p+1}\big] \tag{4.4}$$

where this equation is the effective magnetic field or exchange field that acts on the p^{th} spin.

Now from mechanics the rate of change of the angular momentum $\hbar\mathbf{S}_p$ is equals to the torque, which means

$$\frac{d}{dt}(\hbar\mathbf{S}_p) = \mu_p \times \mathbf{B}_p \tag{4.5}$$

divided (4.5) both sides by $\hbar$, Then

$$\frac{d\mathbf{S}_p}{dt} = \frac{1}{\hbar}\mu_p \times \mathbf{B}_p \tag{4.6}$$

Substituting in terms of $\mu_p = -g\mu_B S_p$ into (4.6), we have

$$\frac{d\mathbf{S}_p}{dt} = \frac{1}{\hbar}(-g\mu_B\mathbf{S}_p \times \mathbf{B}_p) \tag{4.7}$$

Substituting (4.4) into (4.7), we have

$$\begin{aligned}\frac{dS_p}{dt} &= \frac{1}{\hbar}(-g\mu_B\mathbf{S}_p) \times \frac{-2J}{g\mu_B}(\mathbf{S}_{p-1} + \mathbf{S}_{p+1}) \\ &= \frac{2J}{\hbar}\big(S_p \times (\mathbf{S}_{p-1} + \mathbf{S}_{p+1})\big)\end{aligned} \tag{4.8}$$

In cartesian components

$$\mathbf{S}_p = \mathbf{S}_p^x\hat{i} + \mathbf{S}_p^y\hat{j} + \mathbf{S}_p^z\hat{k} \tag{4.9}$$

$$\mathbf{S}_{p-1} = \mathbf{S}_{p-1}^x\hat{i} + \mathbf{S}_{p-1}^y\hat{j} + \mathbf{S}_{p-1}^z\hat{k} \tag{4.10}$$

$$\mathbf{S}_{p+1} = \mathbf{S}_{p+1}^x\hat{i} + \mathbf{S}_{p+1}^y\hat{j} + \mathbf{S}_{p+1}^z\hat{k} \tag{4.11}$$

Then

$$(\mathbf{S}_{p-1} + \ \mathbf{S}_{p+1}) = (\mathbf{S}_{p-1}^x + \mathbf{S}_{p+1}^x)\hat{i} + (\mathbf{S}_{p-1}^y + \mathbf{S}_{p+1}^y)\hat{j} + (\mathbf{S}_{p-1}^z + \mathbf{S}_{p+1}^z)\hat{k} \tag{4.12}$$

Now substituting (4.9),(4.10)(4.11) into (4.8) it becomes:

$$\begin{aligned}\mathbf{S}_p \times (\mathbf{S}_{p-1} + \ \mathbf{S}_{p+1}) = \frac{2J}{\hbar}\big[&S_p^y(S_{p-1}^z + S_{p+1}^z) - S_p^z(S_{p-1}^y + S_{p+1}^y) \\ &+ S_p^z(S_{p-1}^x + S_{p+1}^x) - S_p^x(S_{p-1}^z + S_{p+1}^z) + S_p^x(S_{p-1}^y \\ &+ S_{p+1}^y) - S_p^y(S_{p-1}^x + S_{p+1}^x)\big] \end{aligned} \tag{4.13}$$

$$\frac{dS_p^x}{dt} = \big[\frac{2J}{\hbar}\big]\big[S_p^y(S_{p-1}^z + S_{p+1}^z) - S_p^z(S_{p-1}^y + S_{p+1}^y)\big] \tag{4.14}$$

Similarly for S_p^y and S_p^z

$$\frac{ds_p^y}{dt} = \big[\frac{2J}{\hbar}\big]\big[S_p^z(S_{p-1}^x + S_{p+1}^x) - S_p^z(S_{p-1}^y + S_{p+1}^y)\big] \tag{4.15}$$

and

$$\frac{dS_p^z}{dt} = \big[\frac{2J}{\hbar}\big]\big[S_p^x(S_{p-1}^y + S_{p+1}^y) - S_p^y(S_{p-1}^x + S_{p+1}^x)\big] \tag{4.16}$$

Equations (4.14) - (4.16) involve products of spin components and are nonlinear. If the amplitude of the excitation is small ($S_p^x, S_p^y << S$), we may obtain an approximate set of linear equations by taking $S_p^z = S$ and also $S_{p-1}^z = S_{p-1}^z = S$ and by neglecting terms in the product of S^x and S^y which appear in the equation for $\frac{dS^z}{dt}$. Thus, the linearized equations are, therefore

$$\begin{aligned}\frac{dS_p^x}{dt} &= \big[\frac{2J}{\hbar}\big]\big[S_p^y(S+S) - S(S_{p-1}^y - S_{p+1}^y)\big] \\ &= \big[\frac{2JS}{\hbar}\big]\big[2S_p^y - S_{p-1}^y - S_{p+1}^y\big] \end{aligned} \tag{4.17}$$

and similarly for $\frac{dS_p^y}{dt}$ and $\frac{dS_p^z}{dt}$ is shown given below;

$$\begin{aligned}\frac{dS_p^y}{dt} &= \big[\frac{2J}{\hbar}\big]\big[S(S_{p-1}^x + S_{p+1}^x) - S_p^x(S+S)\big] \\ &= \big[\frac{2JS}{\hbar}\big]\big[(S_{p-1}^x + S_{p+1}^x) - 2S_p^x\big] \\ &= -\big[\frac{2JS}{\hbar}\big]\big[2S_p^x - S_{p-1}^x - S_{p+1}^x\big] \end{aligned} \tag{4.18}$$

$$\frac{dS_p^z}{dt} = 0 \ \Rightarrow \ S_p^z \ = \ S \ = \ constant \tag{4.19}$$

By analogy with phonon problems, we look for traveling wave solutions of (4.17) and (4.18) we have:

$$S_p^x = ue^{i(pka - \omega t)} \tag{4.20}$$

$$S_p^y = \nu e^{i(pka-\omega t)} \tag{4.21}$$

Similarly for $S_{p-1}^x, S_{p+1}^x, S_{p-1}^y \ \ and \ \ S_{p+1}^y$ are shown below:

$$\begin{aligned} S_{p-1}^x &= u e^{i\left[(p-1)ka-\omega t\right]} \\ &= e^{-ika} u e^{i(pka-\omega t)} \end{aligned} \tag{4.22}$$

$$\begin{aligned} S_{p+1}^y &= \nu e^{i\left[(p+1)ka-\omega t\right]} \\ &= e^{ika} \nu e^{i(pka-\omega t)} \end{aligned} \tag{4.23}$$

where u,ν are constant, p is integer and a is lattice constant.

$$\begin{aligned} \frac{dS_p^x}{dt} &= \frac{d(ue^{i(pka-\omega t)})}{dt} \\ &= -i\omega u e^{i(pka-\omega t)} \end{aligned} \tag{4.24}$$

and the same to $\frac{dS_p^x}{dt}$ is as shown below

$$\begin{aligned} \frac{dS_p^y}{dt} &= \frac{d(\nu e^{i(pka-\omega t)})}{dt} \\ &= -i\omega \nu e^{i(pka-\omega t)} \end{aligned} \tag{4.25}$$

Then substituting ,(4.21),(4.23) and (4.24) in to (4.17)

$$\begin{aligned} \frac{dS_p^x}{dt} &= (\frac{2JS}{\hbar})\left[2S_p^y - (S_{p-1}^y) - S_{p+1}^y\right] \\ -i\omega u e^{i(pka-\omega t)} &= (\frac{2JS}{\hbar})\left[2\nu e^{i(pka-\omega t)} - e^{-ika}\nu e^{i(pka-\omega t)} - e^{ika}\nu e^{i(pka-\omega t)}\right] \\ -i\omega u e^{i(pka-\omega t)} &= (\frac{2JS}{\hbar})(e^{i(pka-\omega t)})\left[2\nu - \nu e^{-ika} - \nu e^{ika}\right] \\ -i\omega u e^{i(pka-\omega t)} &= (\frac{2JS\nu}{\hbar})(2 - e^{-ika} - e^{ika}) \\ -i\omega u &= (\frac{2JS\nu}{\hbar})(2 - \cos ka + i\sin ka - \cos ka - i\sin ka) \\ -i\omega u &= (\frac{2JS\nu}{\hbar})(2 - 2\cos ka) \\ -i\omega u &= (\frac{4JS\nu}{\hbar})(1 - \cos ka) \end{aligned} \tag{4.26}$$

and similarly for Substituting (4.20),(4.22) and (4.25) in to (4.18)

$$\begin{aligned}
\frac{dS_p^y}{dt} &= -(\frac{2JS}{\hbar})\big[2S_p^x - (S_{p-1}^x) - S_{p+1}^x\big] \\
-i\omega\nu e^{i(pka-\omega t)} &= -(\frac{2JS}{\hbar})\big[2ue^{i(pka-\omega t)} - e^{-ika}ue^{i(pka-\omega t)} - e^{ika}ue^{i(pka-\omega t)}\big] \\
i\omega\nu e^{i(pka-\omega t)} &= (\frac{2JS}{\hbar})(e^{i(pka-\omega t)})\big[2u - ue^{-ika} - ue^{ika}\big] \\
i\omega\nu e^{i(pka-\omega t)} &= (\frac{2JSu}{\hbar})(2 - e^{-ika} - e^{ika}) \\
i\omega\nu &= (\frac{2JSu}{\hbar})(2 - \cos ka + i\sin ka - \cos ka - i\sin ka) \\
i\omega\nu &= (\frac{2JSu}{\hbar})(2 - 2\cos ka) \\
i\omega\nu &= (\frac{4JSu}{\hbar})(1 - \cos ka) \qquad (4.27)
\end{aligned}$$

(4.26) and (4.27) have the solutions of u and ν if the determinant of the coefficients is equal to zero.

i.e

$$\begin{vmatrix} -i\omega & \frac{4JS}{\hbar}(1 - coska) \\ -\frac{4JS}{\hbar}(1 - coska) & i\omega \end{vmatrix} = 0$$

$$\begin{aligned}
0 = (i\omega)(i\omega) + \frac{4JS}{\hbar}(1 - \cos ka)(\frac{4JS}{\hbar})(1 - \cos ka) \\
-\omega^2 + \big[\frac{4JS}{\hbar}(1 - \cos ka)\big]^2 = 0 \\
-\omega^2 = -\big[\frac{4JS}{\hbar}(1 - \cos ka)\big]^2 \\
\omega^2 = \big[\frac{4JS}{\hbar}(1 - \cos ka)\big]^2 \\
\sqrt{\omega^2} = \sqrt{\big[\frac{4JS}{\hbar}(1 - \cos ka)\big]^2} \\
\omega = \frac{4JS}{\hbar}(1 - \cos ka) = \omega_k \\
\hbar\omega_k = 4JS(1 - \cos ka) \qquad (4.28)
\end{aligned}$$

Equation (4.28)is called **dispersion relation of magnons**.

(4.28) is the dispersion relation for spin waves in one dimension (1D) with nearest neighbor

interaction. Long wavelength approximation ($ka << 1$), the term $\cos ka$ with application of Taylor's expansion becomes :

$$\cos ka \cong 1 - \frac{(ka)^2}{2} \tag{4.29}$$

Substituting (4.29) into (4.28)

$$\hbar\omega_k = (2JSa^2)k^2 \tag{4.30}$$

The frequency is proportional to k^2,in the same limit the frequency of phonon is directly proportional to k.

Similarly the dispersion relation for a ferromagnetic cubic lattice (for Bulk or 3-D system) with nearest neighbor interactions:

$$\hbar\omega_k = 4JS[Z - \sum_{\delta} \cos(k.\delta)] \tag{4.31}$$

Hence,for simple cubic lattice $\cos(k.\delta) \rightarrow$

$$\cos(k_x\delta_x) + \cos(-k_x\delta_x) + \cos(k_y\delta_x) + \cos(-k_y\delta_y) + \cos(k_z\delta_z) + \cos(-k_z\delta_x)$$

$= 2[\cos(k_x\delta_x) + \cos(k_y\delta_y + \cos(k_z\delta_z)]$

$\Rightarrow 2[1 - (\frac{k_x^2+k_y^2+k_z^2}{2})a^2]$ for ka¡¡1 and $\delta_x = \delta_y = \delta_z =$ a

When the summation is over the Z vectors denoted by $\delta \rightarrow$ a. which join the central atom o its nearest neighbors. which for $ka << 1$ reduces to.

$$\hbar\omega_k = (2JSa^2)k^2 \tag{4.32}$$

where $\delta = a$ leading to which is polarization for each value of k.

$$\hbar\omega_k = Dk^2 \tag{4.33}$$

where, $D = 2JSa^2$

Eq.(4.33) is the dispersion relation of magnons in 3D.

4.2 Determination of the Average Number of Magnons

In thermal equilibrium the average value of the number of magnons excited in a single mode is given by the plank's distribution [14].

$\langle n_k \rangle = \frac{1}{e^{\frac{\hbar\omega_k}{k_B T}} - 1}$

where $\beta = \frac{1}{k_B T}$ Then

$$\langle n_k \rangle = \frac{1}{e^{\hbar\omega_k \beta} - 1} \tag{4.34}$$

The total number of magnons excited at a temperature 'T' is

$$\sum < n_k >= \sum_k \frac{1}{e^{\hbar\omega_k \beta} - 1} \tag{4.35}$$

$$\sum_k < n_k >= 4\pi \int \frac{k^2 dk}{e^{\hbar\omega_k \beta} - 1} \tag{4.36}$$

Which can be recasted to

$$\begin{aligned} \sum_k n_k &= \int d\omega D(\omega) < n(\omega) > \\ &= \frac{1}{4\pi^2} (\frac{\hbar}{2JSa^2})^{\frac{3}{2}} \int_0^\infty \frac{\omega^{\frac{1}{2}} d\omega}{e^{\hbar\beta\omega_k} - 1} \end{aligned} \tag{4.37}$$

To find the integration of (4.37) using integration by substitution

i.e let $x = \hbar\beta\omega$ then, $\omega = \frac{x}{\hbar\beta}$ and again $dx = \hbar\beta d\omega$ then $d\omega = \frac{dx}{\hbar\beta}$

$$\begin{aligned} \sum_k < n_k > &= \frac{1}{4\pi^2} (\frac{\hbar}{2JSa^2})^{\frac{3}{2}} \int_0^\infty \frac{\omega^{\frac{1}{2}} d\omega}{e^{\hbar\beta\omega_k} - 1} \\ &= \frac{1}{4\pi^2} (\frac{\hbar}{2JSa^2})^{\frac{3}{2}} \int_0^\infty \frac{(\frac{x}{\hbar\beta})^{\frac{1}{2}}}{e^{\hbar\beta\omega_k} - 1} \frac{dx}{\hbar\beta} \\ &= \frac{1}{4\pi^2} (\frac{\hbar}{2JSa^2})^{\frac{3}{2}} (\frac{1}{\hbar\beta})^{\frac{3}{2}} \int_0^\infty \frac{x^{\frac{1}{2}} dx}{e^x - 1} \\ &= \frac{1}{4\pi^2} (\frac{k_B T}{2JSa^2})^{\frac{3}{2}} \int_0^\infty \frac{x^{\frac{1}{2}} dx}{e^x - 1} \end{aligned} \tag{4.38}$$

Then (4.38) is the definite integral is found in tables and has a value of $(0.0587)4\pi^2$ and it becomes

$$\sum_k < n_k > = \frac{1}{4\pi^2}(\frac{k_B T}{2JSa^2})^{\frac{3}{2}}(0.0587)4\pi^2$$
$$= \gamma T^{\frac{3}{2}} \tag{4.39}$$

Where $\gamma = \frac{1}{4\pi^2}(\frac{k_B}{2JSa^2})^{\frac{3}{2}}(0.0587)4\pi^2$

4.3 Density of State for Bulk System

Now in three dimension (3D) the number of modes of waves vectors less than k is:
The total number of states up on an energy value 'E', which is given by:
$N(E) = \frac{the\ volume\ occupied\ by\ the\ states\ in\ n-space}{volume\ occupied\ by\ a\ single\ state\ in\ n-space}$. which is given by:

$$\begin{aligned} N(E) &= 2\frac{V_k}{V_c} \\ &= 2\big[\frac{(\frac{4\pi}{3})k^3}{(\frac{2\pi}{a})^3}\big] \\ &= 2\big[\frac{a^3k^3}{6\pi^2}\big] \\ &= \frac{1}{3\pi^2}(k^3.a^3) \\ &= \frac{1}{3\pi^2}(k^3) which\ is\ per\ unit\ volume.\ (a^3 = 1) \end{aligned} \tag{4.40}$$

But the energy in terms of wave vector is given by:

$$E = \frac{\hbar^2 k^2}{2m} \quad (\ only\ under\ parabolic\ band\ approximation.) \tag{4.41}$$

From (4.41) given above find the value of k:

$$k = (\frac{2m}{\hbar^2})^{\frac{1}{2}} E^{\frac{1}{2}} \tag{4.42}$$

Now substituting (4.42) into (4.40) then, (4.40) becomes to:

$$N(E) = \frac{1}{3\pi^2}\big[(\frac{2m}{\hbar^2})^{\frac{3}{2}} E^{\frac{3}{2}}\big] \tag{4.43}$$

The density of state of modes of magnon is given by the general equation:

$$D(E) = \frac{dN(E)}{dE} \tag{4.44}$$

To find density of modes of magnon is substituting (4.43) into (4.44)

$$\begin{aligned} D(E) &= \frac{dN(E)}{dE} \\ &= \frac{1}{3\pi^2}\Big[(\frac{2m}{\hbar^2})^{\frac{3}{2}}\frac{d(E^{\frac{3}{2}})}{dE} \\ &= \frac{1}{2\pi^2}(\frac{2m}{\hbar^2})^{\frac{3}{2}}E^{\frac{1}{2}} \\ &= \alpha E^{\frac{1}{2}} \end{aligned} \tag{4.45}$$

Where $\alpha = \frac{1}{2\pi^2}(\frac{2m}{\hbar^2})^{\frac{3}{2}}$

Where E is the energy of electrons in the semiconductors near acceptor level because of that the dopant transition elements such as Mn, Fe, Ni, ... etc are introduced as accepters.

Chapter 5

Results and Discussion

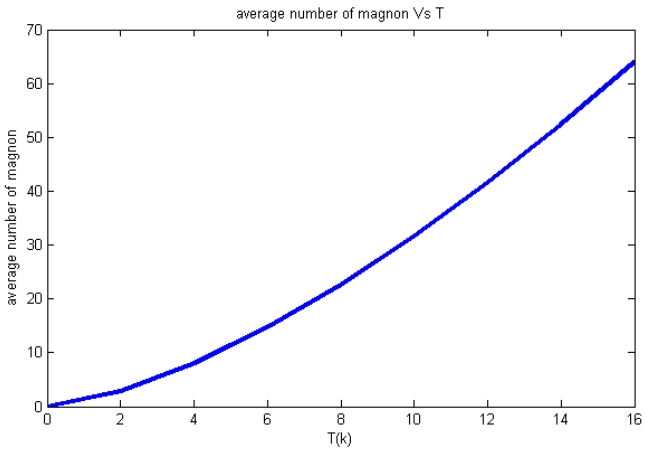

Figure 5.1: Plots of $numberofmagnon$ versus T

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By using (4.39), we plotted Fig , 5.1 and found that as temperature increases number of magnon increase. It is also shown that the number of magnons can be affected by the total number of localized spins, S , and lattice parameter of the host semiconductor a as shown in Fig , (5.2) The rise in lattice parameter/constant a is also known to decrease the total number.

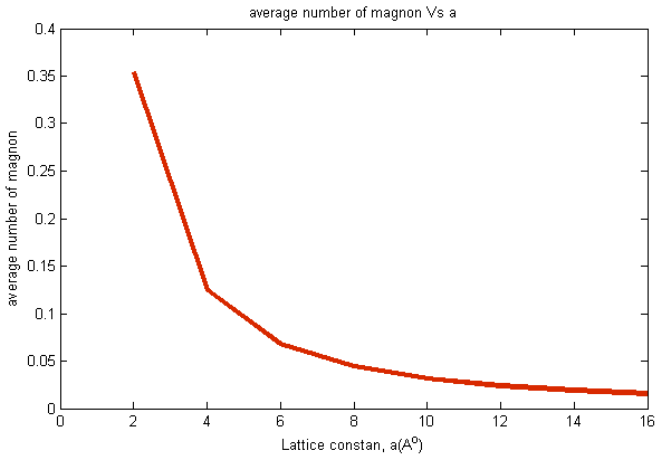

Figure 5.2: Plots of $numberofmagnon$ versus a

.

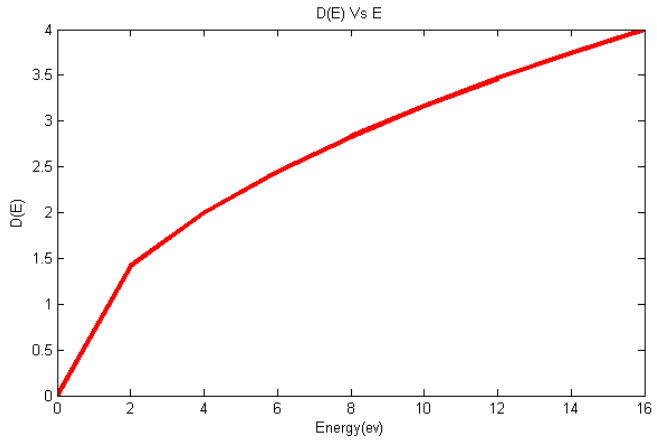

Figure 5.3: Plots of $D(E)$ versus E

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Fig, 5.3 is plotted making use of (4.45). The D(E) increases with E which is near acceptor level in the semiconductor. Transition elements, such as Mn, Fe and Ni, are introduced as acceptors. Hence, D(E) increases as the level moves to wards bottom of the conduction band remarking increase of number of electrons as per the dopant element.

Chapter 6

Conclusion and Summary

A semiconductor is a material with electrical conductivity due to electrons flow intermediate in magnitude between that of a conductor and an insulator. Semiconductor intrinsic electrical properties are often permanently modied by introducing impurities by a process known as doping and the materials which added to the semiconductor is called dopant. Semiconductors which are doped with either with N-or P-type impurities are referred to as extrinsic semiconductors.

There are two types of impurities these are: N-type impurities which add free electron to the semiconductor and semiconductors with this impurities is called N-type semiconductors P-type impurities which contributes hole and semiconductors with this impurities is called P-type semiconductors. Diluted magnetic semiconductors (DMS) are materials in which a host semiconductors is doped with magnetic impurities, generally atoms of a transition metal such as manganese (Mn), iron (Fe), cobalt (Co), chromium.

Diluted magnetic semiconductors are promising candidates for spintronics materials, as they naturally overcome the material incompatibilities in metal-semiconductor interfaces. Of particular interest are the III-V based semiconductor materials made magnetic by inclusion of Mn (or some other suitable transition metal) that can easily be integrated in the existing III-V semiconductor technologies.

In order to exploit the possibilities of this new family of materials it is crucial to understand the fundamental mechanisms behind ferromagnetism in semiconductor based materials (Ga,Mn)As and (Ga,Mn)N are considered as important prototype materials because of their relatively high Curie temperatures T_C , and further these materials provide

us with a good testing ground in the quest for new, similar materials with optimized properties.

Finally, by using Heisenberg model of magnetic interaction we demonstrated the dispersion relation of magnons, average number of magnons, density of state for three dimension or bulk system and found that magnons dispersion is affected by magnetic spins from the magnetic dopant, the increase of density of state with energy, variation of number of magnons with temperature and lattice constant of the host material.

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DECLARATION

I here by declare that this MSc project is my original work and has not been presented for a degree in any other universities, and that all sources of material used for the project have been duly acknowledged.

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Signature: _____

This research project has been submitted to for examination with my approval as university advisor.

Name: Dr. Chernet Amente
Signature: _____

Place and date of submission:

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September 3, 2018