DETERMINATION OF HALL COEFFICIENT AND BAND GAP OF SEMICONDUCTOR

PROJECT REPORT

Submitted by

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B.Sc. Physics

PROJECT REPORT

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This is to certify that this project "DETERMINATION OF HALL COEFFICIENT AND BAND GAP OF SEMICONDUCTOR" is the work done by MANJU THOMAS.

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Submitted for the university examination held in St. Teresa's College (Autonomous), Ernakulam.

Date: 25.04.2023

Examiners:

ST. TERESA'S COLLEGE (AUTONOMOUS)

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CERTIFICATE

This is to certify that the project report entitled "**DETERMINATION OF HALL COEFFICIENT AND BAND GAP OF SEMICONDUCTOR**" is an authentic work done by MANJU THOMAS, St Teresa's College (Autonomous), Ernakulam, under my supervision at Department of Physics, St Teresa's College (Autonomous), Ernakulam, for the partial requirements for the award of Degree of Bachelor of Science in Physics during the academic year 2022-23.The work presented in this dissertation has not been submitted for any other degree in this or any other university.

Supervising Guide

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DECLARATION

I, MANJU THOMAS final year B.Sc. Physics student, Department of Physics, St. Teresa's College (Autonomous), Ernakulam, do hereby declare that the project work entitled **“DETERMINATION OF HALL COEFFICIENT AND BAND GAP OF SEMICONDUCTOR”**, has been originally carried out under the guidance and supervision of Smt. DR.SREEJA V G, Assistant Professor, Department Of Physics, St. Teresa's College (Autonomous), Ernakulam, in partial fulfillment for the award of the degree of Bachelor of Physics. I further declare that this project is not partially or wholly submitted for any other purpose and the data included in the project is collected from various sources and is true to the best of my knowledge.

ACKNOWLEDGEMENT

I express my sincere gratitude to all those who helped me to achieve the moment of satisfaction. Firstly, I thank God almighty for the immense grace at every stage of the project.

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I owe my deep gratitude to **Dr. Priya Parvathi Ameena Jose** ,Head of the Physics Department, St. Teresa's College, Ernakulam, and other esteemed teachers and non teaching staff, department of physics, for their valuable guidance and suggestions for completing the project.

Last, but not the least I thank my parents and friends for all the support and help they have provided.

I am immensely thankful to all those who have willingly helped me out of their abilities.

DETERMINATION OF HALL COEFFICIENT AND BAND GAP OF SEMICONDUCTOR

ABSTRACT

There is no doubt that semiconductors changed the world beyond anything that could have been imagined before them. Although people have probably always needed to communicate and process data, it is thanks to the semiconductors that these two important tasks have become easy and take up infinitely less time. Semiconductor materials are the building blocks of the entire electronics and computer industry. Small, lightweight, high speed, and low power consumption devices would not be possible without integrated circuits (chips), which consist of semiconductor materials. This paper briefly describes Hall effect and Four probe experiment which provides a method to determine semiconductor type and band gap and a general discussion on semiconductors. We also provide the applications of hall effect and band gap in different sectors of modern electronics and communications.

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CHAPTER 1
INTRODUCTION

1.1 HALL EFFECT

Edwin Herbert Hall discovered the “Hall effect” in 1879 while working on his doctoral thesis in Physics under the supervision of Professor Henry A. Rollin. Dr. Hall was pursuing the question as to whether the resistance of a coil excited by a current was affected by the presence of a magnet. Through a myriad of experiments and failures, Hall discovered that a magnetic field would skew equipotential lines in a current-carrying conductor. This effect is observed as a voltage (Hall voltage, V_H) perpendicular to the direction of current in the conductor. Hall conducted an experiment by putting a thin gold leaf on a glass plate and then tapping off the gold leaf at points down its length. He then conducted other experiments using various materials in place of the gold leaf, and various experimental placements of tapping points.

In 1880, full details of Hall’s experimentation with this phenomenon formed his doctoral thesis and was published in the American Journal of Science and in the Philosophical Magazine. Kelvin, himself a most distinguished scientist, called Hall’s discovery comparable to the greatest ever made by Michael Faraday. The magnitude of this discovery is even more impressive considering how little was known about electricity in Hall’s time. The electron, for instance, was not identified until more than 10 years later. 3 The “Hall effect” remained a laboratory curiosity until the latter half of this century because materials available prior to recent years only produced low levels of Hall voltage. With the advent of semiconductor technology and the development of various III-V compounds, it became possible to produce Hall voltages many orders of magnitude greater than with earlier materials.

The Hall effect is the deflection of electrons (holes) in an n-type (p-type) semiconductor with current flowing perpendicular to a magnetic field. The deflection of these charged carriers sets up a voltage, called the Hall voltage V_H, whose polarity depends on the effective charge of the carrier. The magnitude of the Hall voltage depends on the strength of the magnetic field, the current, and the carrier density. The carrier mobility is determined from the Hall voltage and the resistivity. Thus, the Hall effect is used to measure the charge polarity of the carrier, two-dimensional charge sheet density, and carrier Hall mobility.

1.2 FOUR PROBE METHOD

Many conventional methods for measuring resistivity are unsatisfactory for semiconductors because metal-semiconductor contacts are usually rectifying in nature. Also there is generally minority carrier injection by one of the current carrying contacts.

An excess concentration of minority carriers will affect the potential of other contacts and modulate the resistance of the material. The Four probe method overcomes the difficulties mentioned above and also offers several other advantages. It permits measurements of resistivity in samples having a wide variety of shapes, including the resistivity of small volumes within bigger pieces of semiconductor. In this manner the resistivity of both sides of the p-n junction can be determined with good accuracy before the material is cut into bars for making devices. This method of measurement is also applicable to Germanium, silicon and other semiconductor materials.

Four probe setup contains four sharp probes placed on a flat surface of the material to be measured, current is passed through the two outer electrodes, and the floating potential is measured across the inner pair. If the flat surface on which the probes rest is adequately large and the crystal is big the semiconductor may be considered to be a semi-infinite volume. To prevent minority carrier injection and make good contacts, the surface on which the probes rest, maybe mechanically lapped. A nominal value of probe spacing which has been found satisfactory is an equal distance of 2.0 mm between adjacent probes. This permits measurement with reasonable current of n-type or p-type semiconductor from 0.001 to 50 ohm. cm. In order to use this four probe method in semiconductor crystals or slides it is necessary to assume that

- The resistivity of the material is uniform in the area of measurement.
- If there is minority carrier injection into the semiconductor by the current - carrying electrodes most of the carriers recombine near the electrodes so that their effect on the conductivity is negligible. (This means that the measurements should be made on surface which have a high recombination rate, such as mechanical lapped surfaces)
- The surface on which the probes rest is flat with no surface leakage.
- The four probes used for resistivity measurements contact the surface at points that lie in a straight line.
- The diameter of the contact between the metallic probes and the semiconductor should be small compared to the distance between probes.
- The boundary between the current-carrying electrodes and the bulk material is hemispherical and small in diameter.
- The surfaces of the semiconductor crystal may be either conducting or nonconducting. (a) A conducting boundary is one on which a material of much lower resistivity than semiconductor (such as copper) has been plated. (b) A non-conducting boundary is produced when the surface of the crystal is in contact with an insulator.

1.3 SEMICONDUCTORS

There are certain substances that are neither good conductors (metals) nor insulators (glass). A substance which has crystalline structure and contains very few free electrons at room temperature is called semiconductors. At room temperature, it behaves like an insulator. Its resistivity lies between that of conductor and insulator. If suitable impurities are added to the semiconductors, controlled conductivity can be provided. Some examples of semiconductors are silicon, germanium, carbon etc.

Semiconductors are the basic building block of modern electronics, including transistors, solar cells, light-emitting diodes (LEDs), and digital and analog integrated circuits. The modern understanding of the properties of a semiconductor lies in quantum physics to explain the movement of electrons and holes inside a crystal structure and also in a lattice. The electrical conductivity of a semiconductor material increases with increasing temperature, which is behavior opposite to that of a metal. Semiconductor devices can display a range of useful properties such as passing current more easily in one direction than the other, showing variable resistance, and sensitivity to light or heat. Because the electrical properties of a semiconductor material can be modified by controlled addition of impurities or by the application of electrical fields or light, devices made from semiconductors can be used for amplification, switching, and energy conversion.

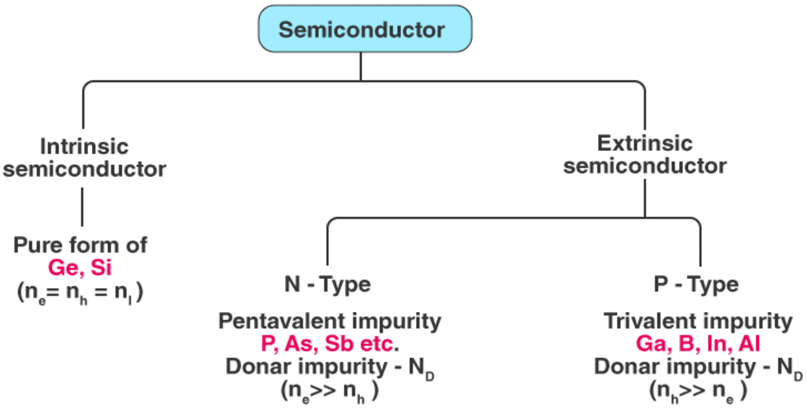
Current conduction in a semiconductor occurs through the movement of free electrons and "holes", collectively known as charge carriers. Adding impurity atoms to a semiconducting material, known as "doping", greatly increases the number of charge carriers within it. When a doped semiconductor contains mostly free holes it is called "p-type", and when it contains mostly free electrons it is known as "n-type". The semiconductor materials used in electronic devices are doped under precise conditions to control the location and concentration of p- and n-type dopants. A single semiconductor crystal can have many p- and n-type regions; the p–n junctions between these regions are responsible for the useful electronic behavior.

Some of the properties of semiconductor materials were observed throughout the mid 19th and first decades of the 20th century. Development of quantum physics in turn allowed the development of the transistor in 1948. Although some pure elements and many compounds display semiconductor properties. Silicon, germanium, and compounds of gallium are the most widely used in electronic devices. A large number of elements and compounds have semiconducting properties, including certain pure elements are found in Group XIV of the periodic table; the most commercially important of these elements are silicon and germanium. Silicon and germanium are used here effectively because they have 4 valence electrons in their outermost shell which gives them the ability to gain or lose electrons equally at the same time. Binary compounds, particularly between elements in groups III and V, such as gallium arsenide, groups II and VI, groups IV and VI, and between different group IV elements, e.g. silicon carbide. Certain ternary compounds, oxides and alloys. Organic semiconductors, made of organic compounds.

Most common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are also known. These include hydrogenated amorphous silicon and mixtures of arsenic, selenium and tellurium in a variety of proportions. These compounds share with better known semiconductors the properties of intermediate conductivity and a rapid variation of conductivity with temperature, as well as occasional negative resistance. Such disordered materials lack the rigid crystalline structure of conventional semiconductors such as silicon. They are generally used in thin film structures, which do not require material of higher electronic quality, being relatively insensitive to impurities and radiation damage. Now-a-days semiconductor materials are used in every sector of modern technology. In technical purposes, high temperature materials are used widely. Therefore it is needed to increase the temperature of semiconducting materials. For these reasons the different properties of these materials varied with temperature.

TYPES OF SEMICONDUCTOR:

Semiconductor may be classified as under:

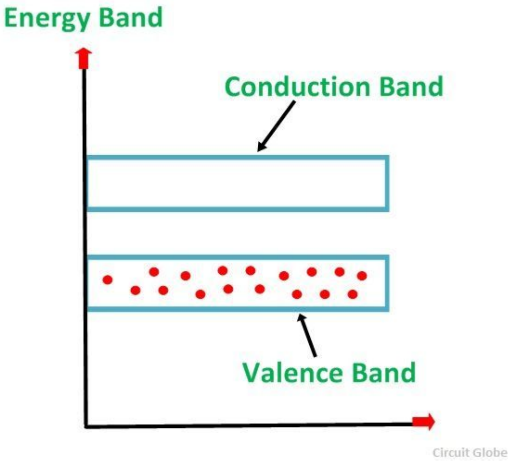


INTRINSIC SEMICONDUCTOR

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.

Examples of such semiconductors are: pure germanium and silicon which have forbidden energy gaps of 0.72 eV and 1.1 eV respectively. The energy gap is so small that even at ordinary room temperature; there are many electrons which possess sufficient energy to jump across the small energy gap between the valence and the conduction bands.

Alternatively, an intrinsic semiconductor may be defined as one in which the number of conduction electrons are equal to the number of holes. Schematic energy band diagram of an intrinsic semiconductor at room temperature is shown in fig below.



EXTRINSIC SEMICONDUCTOR

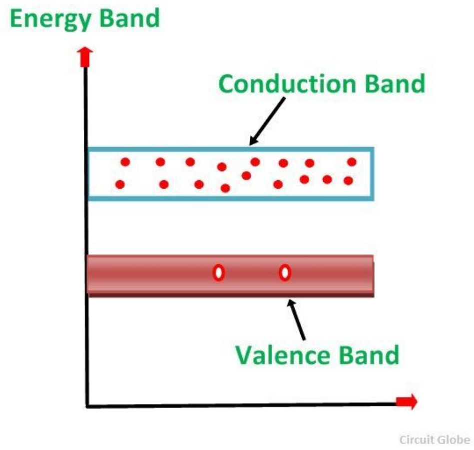
Those intrinsic semiconductors to which some suitable impurity or doping agent or doping has been added in extremely small amounts are called extrinsic or impurity semiconductors.
Depending on the type of doping material used, extrinsic semiconductors can be subdivided into two classes.

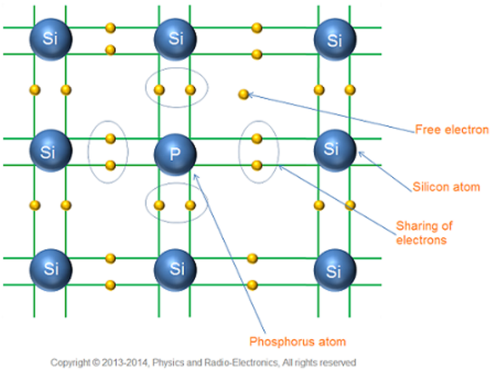
(i) N- type semiconductors and
(ii) P- type semiconductors

.(i) N-TYPE SEMICONDUCTOR

This type of semiconductor is obtained when a pentavalent material like phosphorus is added to pure silicon crystal. As shown in Fig. Below. Each phosphorus atom forms covalent bonds with the surrounding four silicon atoms with the help of four of its five electrons. The fifth electron is superfluous and is loosely bound to the phosphorus atom.

Hence, it can be easily excited from the valence band to the conduction band by the application of electric field or increase in thermal energy. It is seen from the above description that in N-type semiconductors, electrons are the majority carriers while holes constitute the minority.





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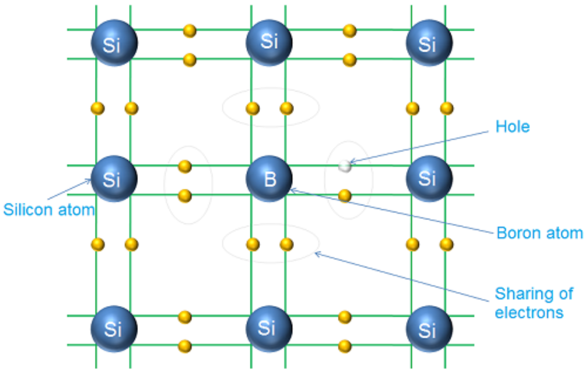
(ii) P-TYPE SEMICONDUCTOR

This type of semiconductor is obtained when traces of a trivalent like boron (B) are added to a pure silicon crystal. In this case, the three valence electrons of a boron atom form covalent bonds with four surrounding silicon atoms but one bond is left incomplete and gives rise to a hole as shown in fig below.

Thus, the boron which is called an acceptor impurity causes as many positive holes in a silicon crystal as there are boron atoms thereby producing a P-type extrinsic semiconductor.

In this type of semiconductor, conduction is by the movement of holes in the valence band.



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1.4 MAJORITY AND MINORITY CARRIERS

In a piece of pure germanium or silicon, no free charge carriers are available at 0k. However, as its temperature is raised to room temperature, some of the covalent bonds are broken by heat energy and as a result, electron-hole pairs are 5 Produced. These are called thermally-generated charge carriers. They are also known as intrinsically-available charge carriers. Ordinarily, their number is quite small.

An intrinsic of pure germanium can be converted into a P-type semiconductor by the addition of an acceptor impurity which adds a large number of holes to it. Hence, a P-type material contains following charge carriers:

(a) Large number of positive holes—most of them being the added impurity holes with only a very small number of thermally generated ones.

(b) A very small number of thermally-generated electrons (the companions of the thermally generated holes mentioned above).

Obviously, in a P-type material, the number of holes (both added and thermally generated) is much more than that of electrons. Hence, in such a material, holes constitute majority carriers and electrons form minority carriers. Similarly, in an N-type material, the number of electrons (both added and thermally-generated) is much larger than the number of thermally generated holes. Hence, in such a material, electrons are majority carriers whereas holes are minority carriers.

1.5 BAND GAP OF GERMANIUM

A semiconductor (either doped or intrinsic) always possesses an energy gap between its valence and conduction bands. For the conduction of electricity, a certain amount of energy is to be given to the electron so that it can jump from the valence band to the conduction band. The energy needed is the measure of the energy gap (E_g) between the top and bottom of valence and conduction bands respectively. In case of insulators, the value of E_g varies from 3 to 7 eV. However, for semiconductors, it is quite small. For example, in case of germanium, $E_g = 0.72$ eV and in case of silicon, $E_g = 1.1$ eV.

In semiconductors at low temperatures, there are few charge carriers to move, so conductivity is quite low. However, with increase in temperature, more charge carriers get sufficient energy to be excited to the conduction band. This led to increase in the number of free charge carriers and hence increase in conductivity. In addition to the dependence of the electrical conductivity on the number of free charges, it also depends on their mobility. The mobility of the charge carriers, however, decreases with increasing temperature. But on the average, the conductivity of the semiconductors rises with rise in temperature. To determine the energy band gap of a semi-conducting material, we study the variation of its conductance with temperature. In reverse bias, the current flowing through the PN junction is quite small and internal heating of the junction does not take place.

CHAPTER 2
THEORY

2.1 HALL EFFECT

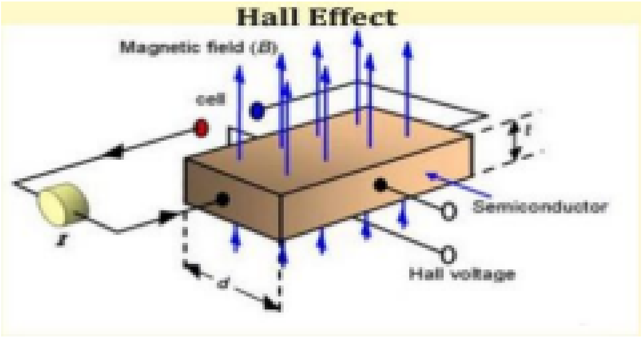
The Hall effect is a conduction phenomenon seen when a current carrying conductor is placed in a magnetic field. It was first discovered in 1879 by Edwin Hall, and is extensively applied in modern physics and material science. The Hall effect can be used to measure conductivity, carrier density, mobility and is used to make contactless sensors and probes for magnetic fields, power dissipation and a variety of other quantities.

The flow of electrons and holes (current) within a conductor changes as a result of applying an external magnetic field. In the absence of such a field, current flows in a relatively straight path between collisions across the terminals of the conductor.1 However, when a magnetic field perpendicular to the direction of current flow is applied, the straight paths between collisions become curved; as the charge carriers now experience what is known as the Lorentz force, which can be expressed as where is the elementary charge, is the charge carrier velocity and the magnetic field.

The Lorentz force deflects the charge carriers towards one end of the conductor, while equal and opposite charge gathers at the opposite end. Charges continue to accumulate at the ends until an electric field is generated so as to cancel out the magnetic field. At this point, charge begins to flow in a straight line, giving rise to the Hall voltage,

When charged particles move through a magnetic field, they are influenced by the Lorentz Force($\vec{F_B}$), whose magnitude is given by

$\vec{F}_B = q(\vec{v} \times \vec{B})$ (1) where q is the charge, $\vec{v}$ is the velocity of the moving particle and $\vec{B}$ is the magnetic field



DETERMINATION OF HALL COEFFICIENT AND CURRENT DENSITY

Let us consider a current 1A passing through a semiconductor slab of breadth 'b', length ‘l’ and thickness 't’ along its length and magnetic field BX applied along its thickness. Consider a free electron associated with the n-type Germanium sab moving in the upward direction which will be acted upon by the Lorentz force. The force acting on the electron is given by

$$Fe = - e V_y B_x \ (1)$$

where

Fe is the Lorentz force acting on an electron moving in the upward direction e- is the electronic charge.

V_y is the velocity of the electron in the Y direction.

B_x is the applied magnetic field in the X direction.

The velocity (V_y) of the electron cannot be determined experimentally. Hence it is replaced by a measurable quantity. The current density in the Y direction. J_y is given by

$$J_y = -en V_y \ (2)$$

Where n is the carrier concentration.

J_y is current density given by

$$J_y = I_y \ (3)$$

Equating Equations (2) and (3) we get the electron velocity as

$$V_Y = I_Y / - nebt \ (4)$$

The terms on the right hand side of Equation(4) indicate that the velocity of the electrons can be measured by knowing the current and physical dimensions of the semiconductor sample. Hence the force acting on the electron is given by

$Fe=-e \times I_y/nebt(B_x)$ (5)

This force acts in the +Z direction and electrons inside the slab will drift towards it as indicated. The accumulation of electrons along the length of the slab on the left hand side results in a negative potential . Similarly, accumulation of holes along the length of the slab on the right hand side of the p- type semiconductor , results in a positive electric field which is also called the Hall electric field. Without the applied magnetic field the charges will move randomly in all possible directions inside the lattice. Application of a magnetic field provides a definite direction for the charge carriers for their movement inside the lattice.

Equilibrium will be established when all the charges have taken their respective positions at the edges of the slab and current will flow in the circuit. At this point the Lorenz force equals the force exerted by the Hall electric field that comes into play, hence we can write

$$Fe= F_H \ (6)$$

$$E_z= V_y B_y \ (7)$$

Substituting for VX (which is not a directly measurable quantity) from equations

$E_z = I_x B_x / -nebt$ (8)

This electric field produced by an n-type semiconductor is negative, whereas the field produced in a case of a p-type semiconductor is positive.

$Be_z = I_x B_x/t$ -net (9)

In this equation n, e and t are constants for a given sample, hence it is replaced by a new constant R_H is given by

$R_H = I/ ne$

Where R_H is called the Hall coefficient.

With this substation thee above equation reduces to

$Be_z =-R_H (I_x B_x)/ t$

V_H is called the Hall voltage, which can be measured along with the Ohmic voltage using a milli voltmeter. Hence the unknown Hall coefficient (R) can be determined by studying the variation of the Hall voltage with magnetic field for a fixed value of current (lx).

Equation gives a straight line plot between V_H and B_H with its slope is given by

Slope -1 = $-R_H I_x/t$ (10)

Passing a known current through the sample and knowing thickness, one can determine its Hall coefficient. With the knowledge of R_H .The carrier concentration can be determined using the relation

$n = 1/eR_H$ (11)

2.2 DETERMINE BAND GAP OF GERMANIUM USING FOUR PROBE METHOD

Resistivity of Germanium (semiconductor) crystals or slices:

In order to use this four probe method in germanium crystals or slices it is necessary to assume that: The resistivity of the material is uniform in the area of measurement and a non conducting boundary is produced when the surface of the crystal is in contact with an insulator. The derivation of equations given below are involved. For each case it is assumed that the probes are equally spaced (spacing =s).

We assume that the metal tip is infinitesimal and samples are semi infinite in lateral dimensions. For bulk samples where the sample thickness, W >> S , the probe spacing, we assume a spherical protrusion of current emanating from the outer probe tips. The resistivity is computed to be

$\rho_0 = (V/I) \times 2\pi s$

where

V = floating potential difference between the inner probes, unit: volt

I =current through the outer pair of probes, unit: ampere

s = spacing between point probes, unit: meter

ρ_0= resistivity, unit: ohm meter

Formula Used :

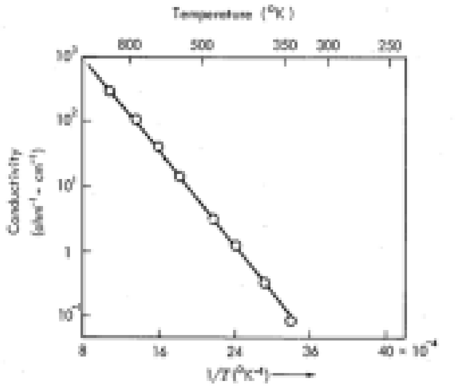
Resistivity of a semiconductor is

$\rho = A \exp (Eg/2k_BT)$

Where Eg is Band Gap in eV
k_B is Boltzmann constant $=8.617\times10^{-5}$ eVK-1
and T is absolute Temperature

Principle :

Ohm's law: If physical conditions (like temperature, mechanical stress) remains unchanged, then potential difference across two ends of a conductor is proportional to current flowing through it
$V \propto I$
$V = IR$
The constant of proportionality, R, is called resistance of the conductor.
Resistivity: At a constant temperature, the resistance, R, of a conductor is (i) proportional to its length and (ii) inversely proportional to its area of cross-section,
$R = \rho\ L/A$
The constant of proportionality, ρ , is called resistivity of material of the conductor. Resistivity of a material is equal to the resistance offered by a wire of this material of unit length and unit cross-sectional area. Unit of resistance is ohm (Ω), and unit of resistivity is ohm-meter (Ω-m)



Temperature dependence of resistivity

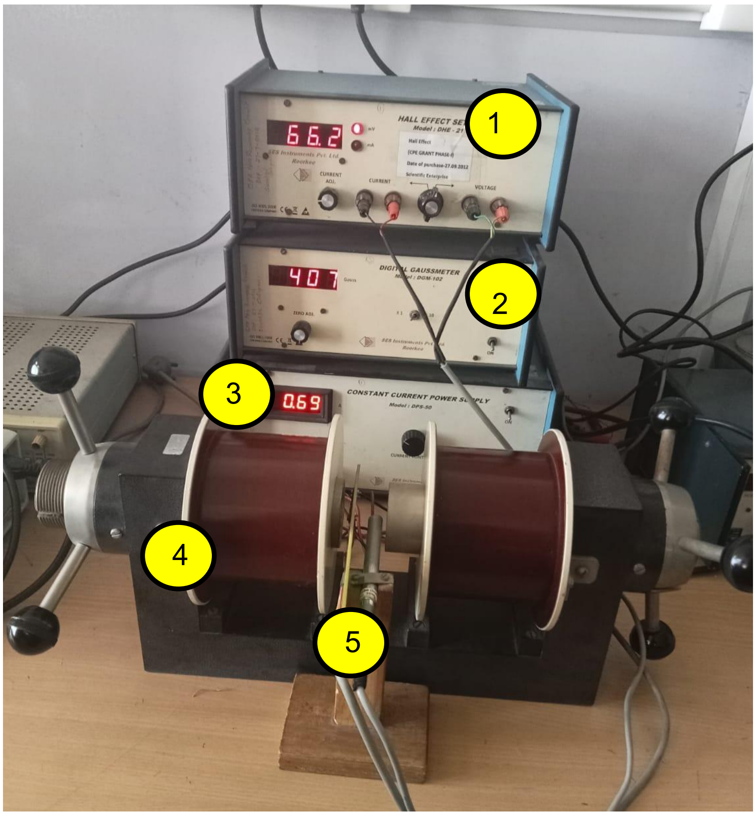
$\rho = A \exp (Eg/2k_BT)$ (7)
Where A is a constant Taking Log
$\ln \rho = \ln A + Eg/2k_BT$ (8)
or
$\log \rho = C + (1/2.3026)\times(Eg/2k_BT)$ (9)
where C is a constant . Rewriting eq (9)
$\log \rho = C + (1/2.3026\times10^3)\times(Eg/2k_B)\times(1000/T)$.
Therefore, if a graph is plotted log ρ vs (1000/T) it should be a straight line and band gap Eg can be determined from its slope as follows :

1. Slope = AC/BC=$(\text{Log } \rho/T^{-1}) = (1/2.3026)\times10^3\times(Eg/2kB)$,
2. Band gap Eg $= 2.3026\times10^3\times2\times k_B\times$slope eV, (Take Boltzmann constant $k_B=8.617\times10^{-5}$eVK-1

CHAPTER 3
APPARATUS AND PROCEDURE

3.1 HALL EFFECT

APPARATUS



1. Hall effect setup (Digital), **DHE-21**: It is a high performance instrument of outstanding flexibility. The set-up consists of an electronic digital millivoltmeter and a constant current power supply. The Hall Voltage and probe current can be read on the same digital panel meter through the selector switch.

2. Digital gaussmeter, Model **DGM-102**: The Hall effect Gaussmeter detects the magnetic field laterally across the tip of the probe. To measure the strength of residual magnetic fields, position the probe along the surface, perpendicular to the direction of the direction of the expected field.

3. Constant current power supply, **DPS-50**: The present constant current source is an inexpensive and high performance unit suitable for small and medium sized electromagnets. Although the equipment was designed for the electromagnet, model EMU-50, it can be used satisfactorily with any other electromagnet provided the coil resistance does not exceed 6 ohm. The current regulation circuit is IC controlled and hence results in the highest quality of performance. Matched power transistors are used to share the load current. The supply is protected against transients caused by the inductive load of the magnet.

4. Electromagnet: The current carrying conductor, the Hall plate, and the magnetic field all have an electrical charge and produce an electric field in the space surrounding them. The air-gap is continuously variable with a two way knobbed wheel screw adjusting system.

5. Hall probe: An Indium Arsenide probe. It is based on a thin film of semiconducting material in which a voltage perpendicular to an applied current and an applied magnetic field appears. The voltage is a direct measure of the magnetic field as the current is constant.

6. Samples: Unknown semiconductor material.

3.2 EXPERIMENTAL SET UP AND PROCEDURE

Sample in the form of a thin rectangular slab is mounted on a hall probe with four spring type pressure contacts. A pair of green color leads is provided for current and another pair of red for Hall voltage. Note the direction of current and voltage measurement carefully. Do not exceed current beyond 8 mA. The unit marked "Hall Effect Set-up" consists of a constant current source (CCS) for supplying current to the sample and a digital milli voltmeter to measure the Hall voltage. The unit has a single digital display used for both current and Hall voltage measurement. For applying the magnetic field, an electromagnet with a constant current supply is provided with a toggle switch to choose either. It is capable of generating a magnetic field of up to 0.75 tesla for a 10 mm gap between its pole pieces. The magnetic field can be measured using the gauss meter along with the given Hall probe.

PROCEDURE

1. Connect the leads from the sample to the "Hall effect Set-up" unit. Connect the electromagnet to constant current supply.

2. Switch on the electromagnet and check whether zero magnetic field is obtained for zero current, if not then adjust it accordingly. Then, set suitable magnetic field density by varying the current supplied to the electro-magnet. You can measure this magnetic field density using the Hall probe. Find out the direction of the magnetic field using the given bar magnet.

3. Insert the sample between the pole pieces of the electromagnet such that I, B and V are in the proper direction.

4. From the direction of current and magnetic field, determine the direction of accumulation of majority carriers. Connect the one of the Hall voltage probes into which charge carriers are expected to accumulate to the positive side of the milli voltmeter. Connect the other Hall voltage probe to the negative side of the milli voltmeter. Don't change this voltmeter connection throughout your experiment.

5. The magnetic field was then switched on and the Hall voltage was noted by varying the current flowing through the electromagnet slowly. We record Hall voltage as a function of the magnetic field. Note that field direction can be changed by changing the direction of current through the electron.

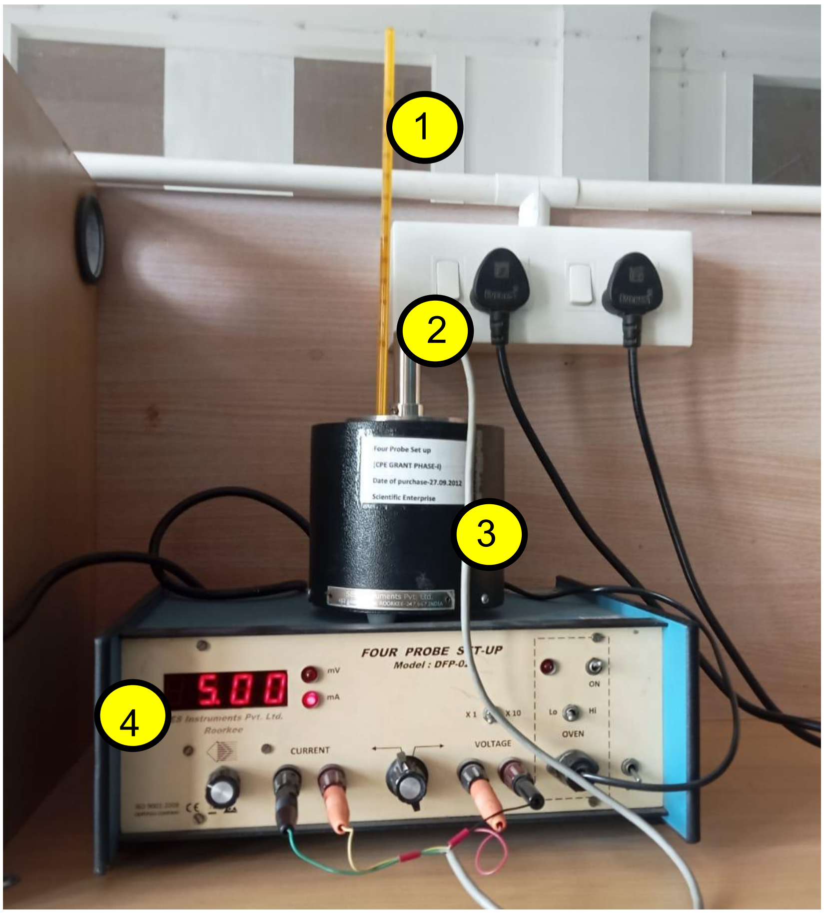
6. Above was repeated for 2 different probes and for 2 values of probe current for each of the two probes.

7. Plot V_H vs Magnetic field graph by least squares fitting. Calculate RH and majority charge carrier's density from this graph.

8. Determine the type of majority charge carriers.

3.3 FOUR PROBE EXPERIMENT

APPARATUS



1. <u>Thermometer:</u> It is a cool tool for checking the internal temperature of meat, liquids and Semi solid items. It comes with a pointed tip that you can insert to immerse it in liquid.

2. <u>Four probe :</u> It has four individually spring loaded probes, coated with Zn at the tips. The probes are collinear and equally spaced. The Zn coating & individual spring ensure good electrical contacts with the sample. The probes are mounted in a teflon bush which ensures good electrical insulation between the probes. A teflon spacer near the tips is also provided to keep the probes at equal distance. The whole arrangement is mounted on a suitable stand and leads are provided for current and voltage measurements.

3. Oven: It is a small oven for the variation of temperature of the crystal from room temperature to about 200 °C

4. Four probe set up: It has three subunits all enclosed in one cabinet.

   (i) Multi Range Digital Voltmeter: In this unit intersil 3½ digit single chip A/D converter ICL 7107 has been used. It has high accuracy, auto zero to less than 10 μV, zero drift-less than 1 μV/°C, input bias current of 10 pA and roll over error of less than one count. Since the use of internal reference causes the degradation in performance due to internal heating, an external reference has been used.

   (ii) Constant Current Generator: It is a IC regulated current generator to provide a constant current to the outer probes irrespective of the changing resistance of the sample due to change in temperatures. The basic scheme is to use the feedback principle to limit the load current of the supply to preset maximum value. Variations in the current are achieved by a potentiometer included for that purpose. The supply is a highly regulated and practically ripple free d.c. source. The current is measured by the digital panel meter.

   (iii) Oven Power Supply: Suitable voltage for the oven is obtained through a step down transformer with a provision for low and high rates of heating. A glowing LED indicates, when the oven power supply is 'ON'

5. sample (a Ge crystal in form of a chip)

Four probe:

The 4-point probe set up consists of four equally spaced tungsten metal tips with finite radius. Each tip is supported by springs on the end to minimize sample damage during probing. The four metal tips are part of an auto-mechanical stage which travels up and down during measurements. A high impedance current source is used to supply current through the outer two probes, a voltmeter measures the voltage across the inner two probes to determine the sample resistivity. Typical probe spacing ~ 2 mm. These inner probes draw no current because of the high input impedance voltmeter in the circuit. Thus unwanted voltage drop (I R drop) at point B and point C caused by contact resistance between probes and the sample is eliminated from the potential measurements. Since these contact resistances are very sensitive to pressure and to surface condition (such as oxidation of either surface).

3.4 PROCEDURE

1. Note the values of probe spacing (S) and the thickness (W) of the semiconductor chip. N(3) Make the circuit. Put the sample in the oven (normally already placed by the lab instructor) at room temperature.

2. Pass a milliampere range current (say 5 mA) in the sample using constant current power supply.

3. The reading of the current through the sample is measured using milliammeter provided for this purpose. The voltage is measured by a high impedance milli voltmeter connected to the inner probes. The readings can be taken alternately on a digital meter provided for this purpose.

4. Note the temperature of the sample (oven) using a thermometer inserted in the oven for this purpose.

5. The oven temperature is increased a little, and its temperature is noted after reaching steady state, say 110°c.

6. Switch off the oven, so that temperature starts to decrease.

7. Note the voltage for every 5°c decrease.

8. Repeat the procedure for different currents.. Note the data in the observation table.

9. For each temperature, calculate the resistivity

10. Compute log ρ and $10^3/T$ and write it in the observation table.

11. Plot a graph between log ρ and $10^3/T$. It is a straight line. Find its slope.

12. Calculate the band gap using formula $Eg = 2.3026 \times 10^3 \times 2 \times k_B \times$slope eV

CHAPTER 4

EXPERIMENTAL OBSERVATIONS AND CALCULATIONS

4.1 HALL EFFECT

Experiment using first sample

Observations

Current (mA)	Constant Current (mA)	Magnetic Field (T)	Voltage (mV)	Reverse Magnetic Field (T)	Reverse Voltage (mV)
2	0.1	122	32.9	-114	31.7
	0.3	237	33.7	-232	30.6
	0.5	350	34.6	-345	29.1
	0.7	479	35	-473	28.1
	0.9	600	36	-591	27.3
	1.1	724	37	-714	26.4
	1.3	852	38.4	-846	25.6
	1.5	980	38.9	-968	25.9
	1.7	1110	39.8	-1092	24.9
	1.9	1240	40.7	-1220	23.1

Current (mA)	Constant Current (mA)	Magnetic Field (T)	Voltage (mV)	Reverse Magnetic Field (T)	Reverse Voltage (mV)
4	0.1	123	62.9	-113	59.9
	0.3	264	64.6	-228	58.2
	0.5	392	66.8	-308	57.3
	0.7	518	68.7	-494	54.6
	0.9	609	69.5	-583	53
	1.1	693	70.8	-705	51.8
	1.3	934	74.6	-828	50.7
	1.5	1006	75.9	-974	47
	1.7	1208	78.8	-1078	45.2
	1.9	1327	79.3	-1200	44.2

Experiment using second sample
Observations

Current (mA)	Constant Current (mA)	Magnetic Field (T)	Voltage (mV)	Reverse Magnetic Field (T)	Reverse Voltage (mV)
2	0.1	116	-60.6	-118	-59.7
	0.3	232	-61.1	-232	-59.3
	0.5	355	-61.6	-356	-58.9
	0.7	480	-62.1	-480	-58.4
	0.9	611	-62.6	-600	-58
	1.1	742	-63.1	-731	-57.6
	1.3	861	-63.6	-859	-57.2
	1.5	992	-64.2	-985	-56.8
	1.7	1131	-64.7	-1114	-56.4
	1.9	1250	-65.3	-1244	-56

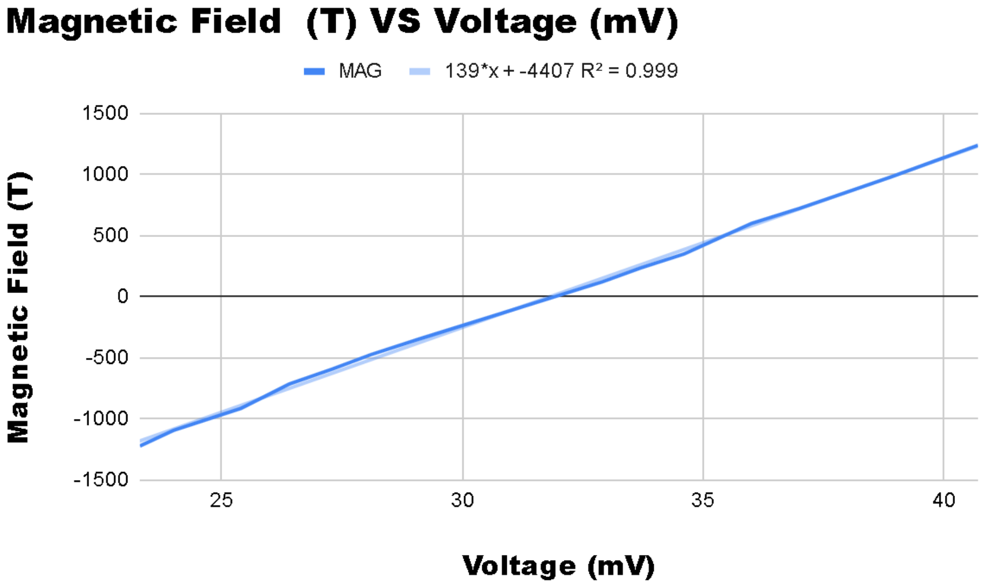
Current (mA)	Constant Current (mA)	Magnetic Field (T)	Voltage (mV)	Reverse Magnetic Field (T)	Reverse Voltage (mV)
4	0.1	114	-121.5	-112	-119.7
	0.3	231	-122.5	-231	-118.7
	0.5	356	-123.4	-352	-117.9
	0.7	482	-124.3	-475	-117
	0.9	602	-125.3	-601	-116.1
	1.1	737	-126.4	-723	-115.3
	1.3	862	-127.5	-860	-114.4
	1.5	987	-128.5	-990	-113.5
	1.7	1118	-129.6	-1112	-112.8
	1.9	1252	-130.7	-1244	-112.1

CALCULATIONS

First sample

I = 2mA

Graph



slope=139 $\times 10^3 \times 10^{-4}$ T/V=13.9 T/V

thickness,t=5$\times 10^{-4}$ m

R_H= ($V_H t/I_c B$) = t/$I_C \times$slope = (5$\times 10^{-4}$)/((2$\times 10^{-3}$)$\times$13.9) = 0.0179856 m^3C^{-1}

R_H is positive. This means, the given material is p type semiconductor.

Charge carrier density, n = 1/(R_Hq) = 1/(0.0179856$\times$1.6$\times 10^{-19}$)

= 3.475002 $\times$ 10^{20} m^{-3}

conductivity(given) σ = 0.1667 Ω^{-1}m

Resistivity = 1/ conductivity ≅ 6 Ωm^{-1}

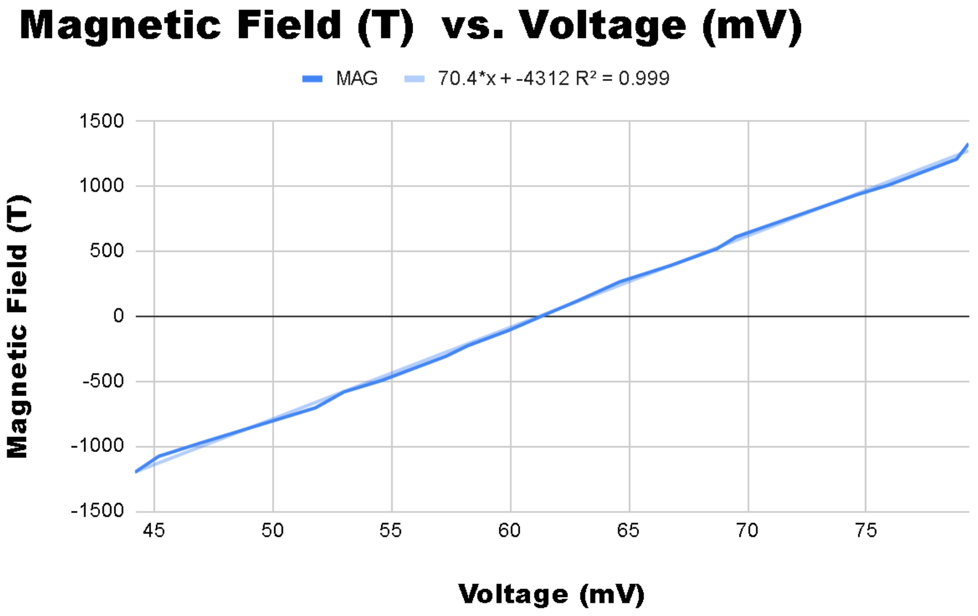
Therefore, mobility of charge carriers,

$\mu = R_H \sigma$ = (0.0179856 m^3C^{-1})$\times$(0.1667 Ω^{-1}m)

= 2.99819$\times 10^{-3}$ m^2/ Vs

I=4mA

Graph



Slope = $70.4 \times 10^{3} \times 10^{-4}$ T/V=7.04 T/V

Thickness,t = 5×10^{-4} m

$R_H = (V_H t/I_c B) = t/I_C \times \text{slope} = (5\times 10^{-4})/((4\times 10^{-3})\times 7.04) = 0.01775568\ m^3C^{-1}$

Charge carrier density, $n = 1/(R_H q)$

$= 1/(0.01775568 \times 1.6\times 10^{-19}) = 3.52 \times 10^{20}\ m^{-3}$

conductivity(given) $\sigma = 0.1667\ \Omega^{-1}m$

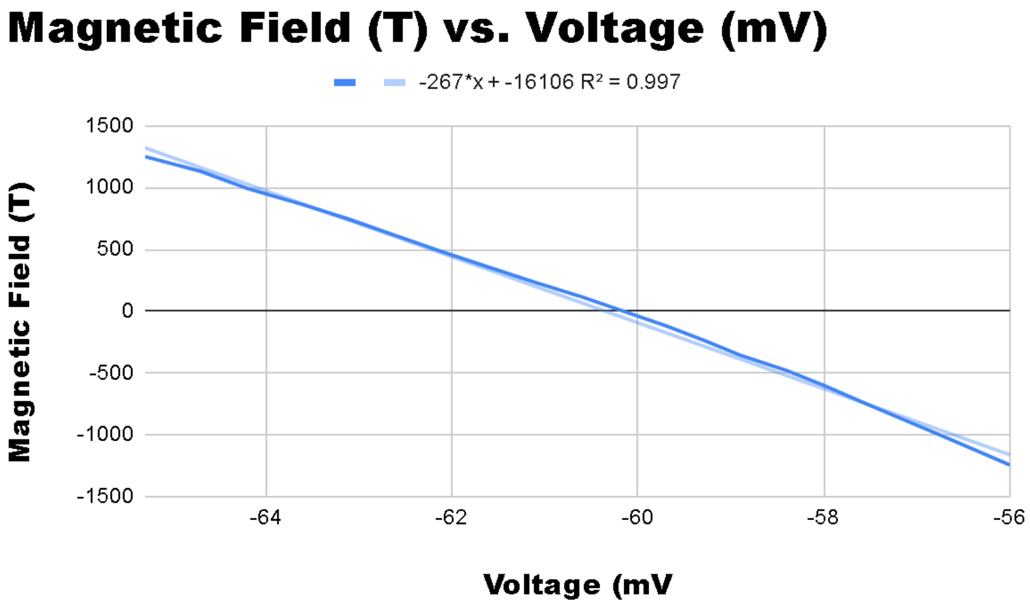
Resistivity = 1/ conductivity ≅ $6\ \Omega m^{-1}$

Therefore, mobility of charge carriers,

$\mu = R_H\ \sigma = (0.01775568 m^3C^{-1})\times(0.1667\ \Omega^{-1}m)$

$= 2.95987\times 10^{-3}\ m^2/\ Vs$

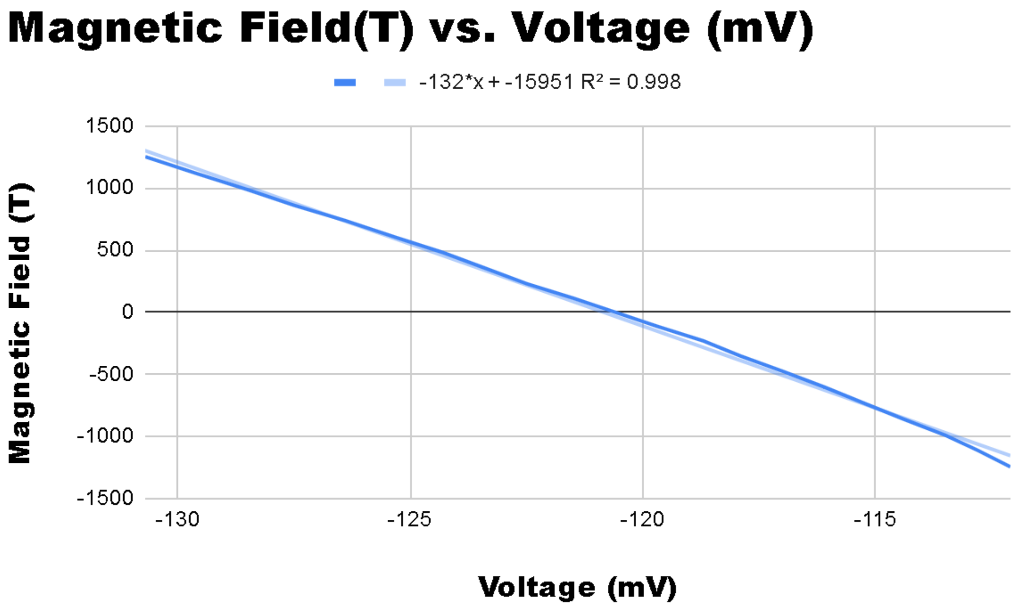
Second sample
I=2mA
Graph



slope= $-267 \times 10^{3} \times 10^{-4}$ T/V= -26.7 T/V
thickness,t=6.4×10^{-4} m
$R_H=(V_H t/I_c B) = t/I_C \times \text{slope} = (6.4 \times 10^{-4})/((2 \times 10^{-3}) \times -26.7) = -0.11985 m^3 C^{-1}$
Here R_H is negative, which means the given material is n type semiconductor.

Charge carrier density, $n= 1/(R_H q) = 1/(-0.11985 \times 1.6 \times 10^{-19})$
$= -5.214843 \times 10^{20} m^{-3}$

I=4mA
Graph



slope= $-132 \times 10^{3} \times 10^{-4}$ T/V= -13.2 T/V
thickness,t=6.4×10^{-4} m
$R_H=(V_Ht/I_cB) = t/I_C\times\text{slope} =(6.4 \times10^{-4})/((4\times10^{-3})\times -13.2) =-0.121212\text{m}^3\text{C}^{-1}$

Charge carrier density, n= $1/(R_Hq) = 1/(-0.1212121 \times1.6\times10^{-19})$
$= -5.15625 \times 10^{20}\ \text{m}^{-3}$

4.2FOUR PROBE EXPERIMENT

When current,I=5mA

Temperature °C	Temperature K	Voltage mV	$T^{-1}\times10^{-3}$ K^{-1}	ρ (Ωm)	Log ρ
35	308	45.1	3.246753247	1.92126	0.2835861
40	313	44.2	3.194888179	1.88292	0.2748318
45	318	42.2	3.144654088	1.79772	0.2547220
50	323	39.6	3.095975232	1.68696	0.2271047
55	328	36.5	3.048780488	1.5549	0.1917024
60	333	33.1	3.003003003	1.41006	0.1492375
65	338	29.7	2.958579882	1.26522	0.1021660
70	343	26.5	2.915451895	1.1289	0.0526554
75	348	23.2	2.873563218	0.98832	-0.0051024
80	353	20.1	2.83286119	0.85626	-0.0673943
85	358	17.4	2.793296089	0.74124	-0.1300411
90	363	14.8	2.754820937	0.63048	-0.2003286
95	368	12.1	2.717391304	0.51546	-0.2878050
100	373	9.7	2.680965147	0.41322	-0.3838186
105	378	7.9	2.645502646	0.33654	-0.4729633
110	383	6.5	2.610966057	0.2769	-0.5576770

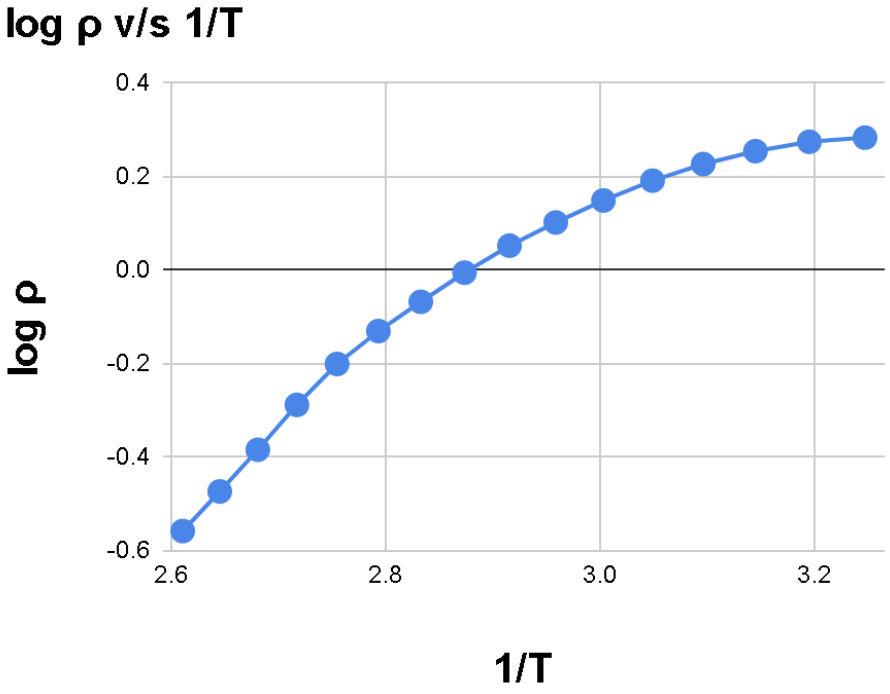
When current,I=4mA

Temperature °C	Temperature K	Voltage mV	$T^{-1} \times 10^{-3}$ K^{-1}	ρ (Ωm)	Log ρ
40	313	30.9	3.194888179	1.645425	0.2162780
45	318	29.7	3.144654088	1.581525	0.1990760
50	323	27.9	3.095975232	1.485675	0.1719238
55	328	25.8	3.048780488	1.37385	0.1379393
60	333	22.9	3.003003003	1.219425	0.0861550
65	338	20.3	2.958579882	1.080975	0.0338155
70	343	17.9	2.915451895	0.953175	-0.020827
75	348	15.6	2.873563218	0.8307	-0.080555
80	353	13.2	2.83286119	0.7029	-0.153106
85	358	11.1	2.793296089	0.591075	-0.228357
90	363	9.6	2.754820937	0.5112	-0.291409
95	368	7.7	2.717391304	0.410025	-0.387189
100	373	6	2.680965147	0.3195	-0.495529
105	378	4.5	2.645502646	0.239625	-0.620467
110	383	3.7	2.610966057	0.197025	-0.705478

CALCULATIONS

I = 5mA

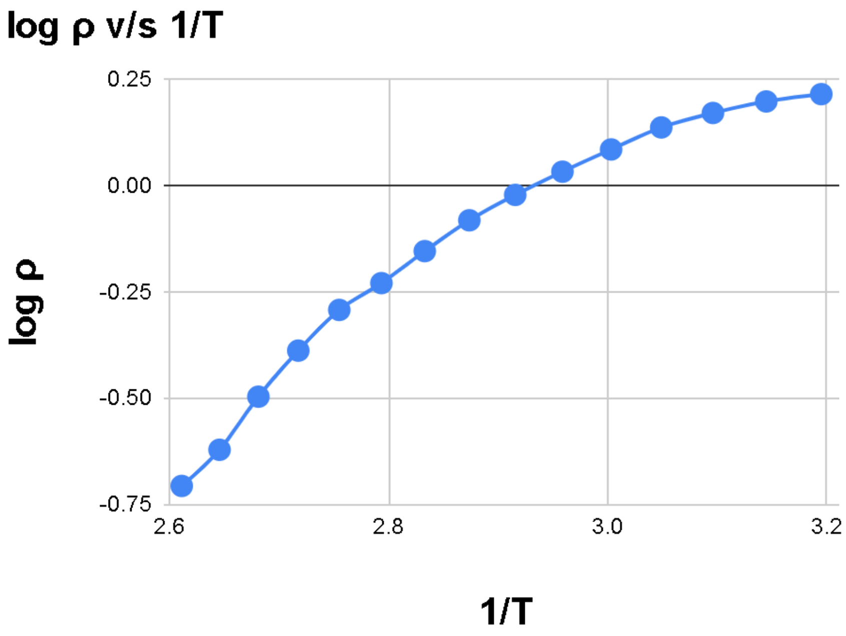
Graph



Slope = (**Log ρ/T^{-1}**) = (-0.06739434348 - -0.2003286855)⁄(2.83286119-2.754820937)
= 1.702840838

Band gap = $2\times k_B\times 2.303\times 10^3\times$Slope
= $2\times(8.617\times 10^{-5})\times 2.303\times 10^3\times 1.702840838$
= 0.67583 eV

I = 4mA
Graph



Slope = (**Log ρ/T^{-1}**) **=** (-0.02082735691- -0.2283574091)⁄(2.915451895 -2.793296089)
= 1.705883331

Band gap = $2\times k_B\times 2.303\times 10^3\times$Slope
= $2\times(8.617\times 10^{-5})\times 2.303\times 10^3\times 1.705883331$
= 0.67706 eV

CHAPTER 5
RESULTS AND CONCLUSION

5.1 HALL EFFECT

	First sample		**Second sample**	
Current (mA)	**I=2mA**	**I=4mA**	**I=2mA**	**I=4mA**
Hall Coefficient, R_H (m^3C^{-1})	**0.0179856**	**0.01775568**	**-0.11985**	**-0.121212**
Charge Carrier Density , n (× 10^{20} m^{-3})	**3.475002**	**3.52**	**-5.214843**	**-5.15625**

Type of Semiconductor	**P type**	**N type**
Mean Hall Coefficient, R_H (m^3C^{-1})	**0.01787064**	**-0.120531**
Mean Charge Carrier Density , n (× 10^{20} m^{-3})	**3.497501**	**-5.1855465**

The mean value of the Hall coefficient for the first sample is 0.01787064 m^3C^{-1} , which is a positive value. From this result we can assume that the first sample is a P type semiconductor with mean charge carrier density 3.497501× 10^{20} m^{-3} . Majority carriers in the first sample are holes.

The mean value of the Hall coefficient for the second sample is -0.120531 m^3C^{-1} , which is a negative value. From this result we can assume that the second sample is a N type semiconductor with mean charge carrier density -5.1855465 × 10^{20} m^{-3} . Majority carriers in the second sample are electrons.

5.2 FOUR PROBE METHOD

Current	**I=5mA**	**I=4mA**
Band gap (eV) of Ge	**0.67583**	**0.67706**

Actual value of the band gap of Germanium is in between 0.67 - 0.72 eV.
From four probe experiments, it is found that the band gap is 0.67583 for current I = 5mA and for current I = 4 mA.

Germanium is an intrinsic semiconductor. Energy difference between the highest valence band and lowest conduction band is the energy gap. From the experiment the mean band gap is 0.676445 eV. This amount of energy is required for an electron for excitation to the conduction band.

CHAPTER 6
APPLICATIONS AND FUTURE SCOPES

The initial use of this discovery was for the classification of chemical samples. The development of indium arsenide semiconductor compounds in the 1950's led to the first useful Hall-effect magnetic instruments. Hall effect sensors allowed the measurement of DC or static magnetic fields without requiring motion of the sensor. In the 1960's the popularization of silicon semiconductors led to the first combinations of Hall elements and integrated amplifiers. This resulted in the now classic digital output Hall switch.

The continuing evolution of Hall transducer technology saw a progression from single element devices to dual orthogonally arranged elements. This was done to minimize offsets at the Hall voltage terminals.

The next progression brought on the quadratic or four element transducers. These used four elements orthogonally arranged in a bridge configuration. All of the silicon sensors of this era were built from bipolar junction semiconductor processes.

HALL EFFECT SENSOR

Hall-effect sensors are integrated circuits that transduce magnetic fields to electrical signals with accuracy, consistency, and reliability. Some of the key benefits of using Hall-effect sensors include:

- Precision and accuracy: High-precision latches and switches offer very tight switching thresholds (as small as ±1 mT), while some single-axis and 3D linear sensors have accuracy levels as low as 2.6% to provide more headroom for mechanical tolerances.
- High sensitivity: Some Hall-effect sensors have the capability to detect magnetic fields as small as 2 mT allowing for the use of small magnets or low-cost magnets that do not produce large magnetic fields.
- High bandwidth: Hall-effect sensors are typically designed to meet low-power, low sampling requirements or high-bandwidth fast-changing magnetic field requirements of an application.
- Wide voltage range: Hall-effect sensors can provide wide voltage ranges, sometimes from 1.65 V to 5.5 V, allowing for low-power applications.

Hall-effect sensors offer real system-level benefits allowing for use in a wide variety of end products ranging from battery-powered portable electronics to high-precision factory automation systems. Some of the system benefits include:

- Real-time system monitoring and control

- Magnet field strength to position conversion
- Low-cost position switch
- High-speed rotary encoding
- Flexible mechanical placement

Three Common Hall-Effect Types

➢ Linear position

Output signal, either analog or digital, proportional to the magnetic flux density to detect absolute position or angular movements.

➢ Switch

Indicates the presence or absence of a magnetic flux density that exceeds a defined threshold for simple on and off or open and close applications.

➢ Latch

Determines the speed and direction for rotary encoding and position for motor commutation.\

CURRENT MEASUREMENT

The Hall effect can also be used to measure electric currents. By passing a current through a conductor and measuring the Hall voltage perpendicular to both the current and a magnetic field, the current can be determined.

PROXIMITY SENSING

The Hall effect can be used to detect the presence or absence of a magnet in proximity to a sensor. This is useful in applications such as automotive speedometers and door switches.

POSITION SENSING

By using an array of Hall effect sensors, the position and orientation of a magnet or magnetic field can be determined. This is useful in applications such as robotics and control systems.

MAGNETIC IMAGING

The Hall effect can be used to create images of magnetic fields, such as in magnetic resonance imaging (MRI) in medicine.

CURRENT REGULATION

The Hall effect can be used to regulate the current in electronic circuits. By using a Hall effect sensor to measure the current and a feedback loop to adjust the circuit, the current can be kept at a constant level.

The band gap is an important property of semiconductors that determines their electrical behavior. The size of the band gap determines whether a semiconductor is a conductor, an insulator, or a semiconductor. Here are some applications of the band gap in a semiconductor:

OPTOELECTRONICS

Semiconductors with narrow band gaps are used in optoelectronic devices such as light-emitting diodes (LEDs), lasers, and solar cells. In these devices, the band gap determines the energy required for electrons to move from the valence band to the conduction band, which in turn determines the wavelength of the emitted light or the efficiency of the solar cell.

TRANSISTOR

Semiconductors with wide band gaps are used in high-power electronic devices such as transistors. Wide-bandgap semiconductors can withstand high voltages and temperatures, making them ideal for power electronics.

QUANTUM COMPUTING

Semiconductors with small band gaps are being studied for use in quantum computing. In a quantum computer, the band gap determines the energy levels of the qubits, which are the basic units of quantum information.

SENSING

Semiconductors with specific band gaps are used in sensing applications such as gas sensors and temperature sensors. For example, semiconductors with a wide band gap are used in high-temperature sensors.

PHOTOVOLTAICS

The band gap of a semiconductor determines the energy required for electrons to be excited from the valence band to the conduction band. This energy can be harnessed to generate electricity in photovoltaic devices such as solar cells.

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