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INSTITUTE OF SCIENCE & TECHNOLOGY
(Deemed to be University u/s 3 of UGC Act, 1956)

Program: B. Tech. (CSE & All Specialization and Nano Technology)

21PYB102J - Semiconductor Physics and Computational Methods

Instructional Manual

EX. NO.	NAME OF THE EXPERIMENTS	PAGE NO.

1. Determination of Hall Coefficient and carrier type for a Semi-conducting Material

Aim

To determine the hall coefficient of the given n type or p-type semiconductor

Apparatus Required

Hall probe (n type or p type), Hall effect setup, Electromagnet, constant current power supply, gauss meter etc.,

Principle

Hall effect: When a current carrying conductor is placed in a transverse magnetic field, a potential difference is developed across the conductor in a direction perpendicular to both the current and the magnetic field.

Formula

i) Hall coefficient (R_H) = $\frac{V_H . t}{IH} \times 10^{8}\ \text{cm}^3\ \text{C}^{-1}$

where
V_H = Hall voltage (volt)
t = Thickness of the sample (cm)
I = Current (ampere)
H = Magnetic field (Gauss)

ii) Carrier density (n)= $\frac{1}{R_H\ q}$ carriers / cm^{-3}

where
R_H = Hall coefficient ($\text{cm}^3\ \text{C}^{-1}$)
q = Charge of the electron or hole (C)

iii) Carrier mobility (μ)= $R_H \sigma\ \text{cm}^2 \text{V}^{-1}\ \text{s}^{-1}$

where
R_H = Hall coefficient ($\text{cm}^3 \text{C}^{-1}$)
σ = Conductivity ($\text{C V}^{-1} \text{s}^{-1} \text{cm}^{-1}$)

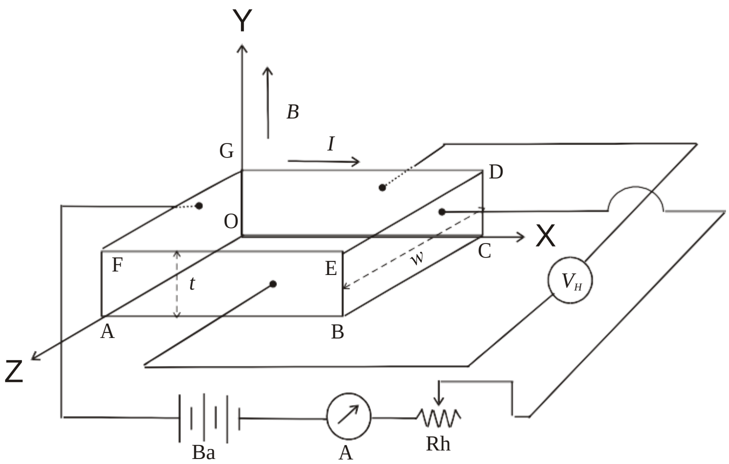


Fig.1.1 Hall Effect Setup

Procedure

1. Connect the widthwise contacts of the hall probe to the terminals marked as „voltage" (i.e. potential difference should be measured along the width) and lengthwise contacts to the terminals marked (i.e. current should be measured along the length) as shown in fig 1.1.
2. Switch on the Hall Effect setup and adjust the current say 0.2 mA.
3. Switch over the display in the Hall Effect setup to the voltage side.
4. Now place the probe in the magnetic field as shown in fig and switch on the electromagnetic power supply and adjust the current to any desired value.Rotate the Hall probe until it become perpendicular to magnetic field. Hall voltage will be maximum in this adjustment.
5. Measure the hall voltage and tabulate the readings.
6. Measure the Hall voltage for different magnetic fields and tabulate the readings.
7. Measure the magnetic field using Gauss meter
8. From the data, calculate the Hall coefficient, carrier mobility and current density.

Table 1.1 Measurement of Hall coefficient

Current in the Hall effect setup = 2 mA

Current in the constant current power supply (A)	Magnetic field (H) (Gauss)	Hall Voltage (V_H) (volts)	Hall coefficient (R_H) $cm^3\ C^{-1}$

Observations and calculations

1. Thickness of the sample (t) = ...cm
2. Resistivity of the sample (ρ) = ...$V\ C^{-1}\ s\ cm$
3. Conductivity of the sample (σ) = ...$CV^{-1}\ s^{-1}\ cm^{-1}$

4. The hall coefficient of the sample = $R_H = V_H t / IH \times 10^8$ =...........$cm^3 C^{-1}$
5. The carrier density of the sample (n) = ... / cm^{-3}
6. The carrier mobility of the sample (μ) = $R_H\sigma$= ....$cm^2V^{-1} s^{-1}$

Result

The Hall coefficient of the given semi conducting material	≈ ....$cm^3 C^{-1}$
The carrier density	≈ ....carriers/cm^3
The carrier mobility	≈ ....cm^2/Vs

References

1. Ramsden and Edward Ramsden. Hall- effect Sensors. Amsterdam: Elsevier / Newnes. 2006
2. Fundamentals of solid state engineering by Manijeh Razeghi.
3. Materials handbook. Berlin:Springer, 2008.

2. Band Gap Determination using Post Office Box

Aim

To find the band gap of the material of the given thermistor using post office box.

Apparatus required

Thermistor, thermometer, post office box, power supply, galvanometer, insulating coil and glass beakers.

Principle

Wheatstone‟s Principle for balancing a network $\frac{P}{Q} = \frac{R}{S}$

Of the four resistances, if three resistances are known and one is unknown, the unknown resistance can be calculated.

Formula

The band gap for semiconductors is given by $E_g = 2k \left(\frac{2.303 log_e R_T}{1/T} \right) eV$

where k = Boltzmann constant = 1.38×10^{-23} J /K

R_T = Resistance at T K

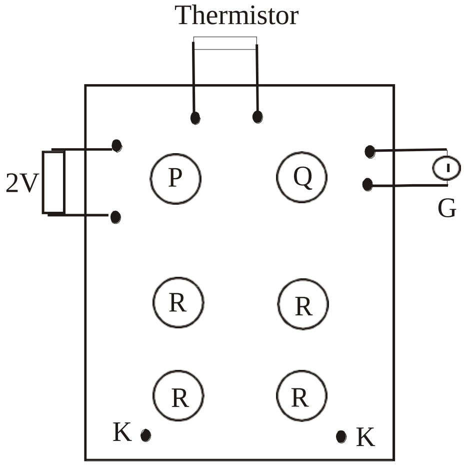


Fig.2.1Post Office Box - Circuit diagram

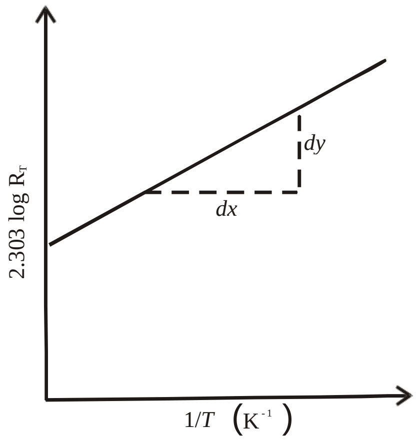


Fig.2.2 Model Graph

Procedure

1. The connections are given as in the Fig. 6.1(a).1. Ten ohm resistances are taken in P and Q.
2. Then the resistance in R is adjusted by pressing the tap key, until the deflection in the galvanometer crosses zero reading of the galvanometer, say from left to right.
3. After finding an approximate resistance for this, two resistances in R, which differ by 1 ohm, are to be found out such that the deflections in the galvanometer for these resistances will be on either side of zero reading of galvanometer.

4. We know $R_T = \frac{Q}{P} \times R = \frac{10}{10} \times R_1$ *or* $(R_1 + 1)$.This means that the resistance of the thermistor lies between R_1 and (R_1+1). Then keeping the resistance in Q the same, the resistance in P is changed to 100 ohm.
5. Again two resistances, which differ by one ohm are found out such that the deflections in the galvanometer are on the either side of zero. Therefore the actual resistance of thermistor will be between $\frac{R_2}{10}$ and $\frac{R_2 + 1}{10}$.
6. Then the resistance in P is made 1000 ohms keeping same 10 ohms in Q. Again, two resistances R and (R+1) are found out such that the deflection in galvanometer changes its direction. Then the correct resistance = $R_T = \frac{10}{1000}(R)$ (or)$R+1 = 0.01R$ *(or)* $0.01(R+1$. Thus, the resistance of the thermistor is found out accurately to two decimals, at room temperature. The lower value may be assumed to be R_T (0.01R).
7. Then the thermistor is heated, by keeping it immersed in insulating oil. For every 10 K rise in temperature, the resistance of the thermistor is found out, (i.e) R_T"s are found out. The reading is entered in the tabular column.

Table 2.1To find the resistance of the thermistor at different temperatures

Temp. of thermistor T = t+273	$\frac{1}{T}$	Resistance in P	Resistance in Q	Resistance in R	Resistance of the thermistor $R_T = \frac{P}{Q} \times R$	2.303 $\log_{10} R_T$
K	K^{-1}	ohm	ohm	Ohm	ohm	ohm

Observation

From graph, slope = (dy / dx) = …………..…

Graph

A graph is drawn between $\frac{1}{T}$ in X axis and 2.303 log R_T in Y axis where T is the temperature in K and R_T is the resistance of the thermistor at TK. The graph is shown in the Fig 2.2

Band gap (E_g)=2k × slope of the graph = $2k \times \left(\frac{dy}{dx}\right)$

wherek = Boltzmann‟s constant.

Calculation

Band gap, E_g = $2k(dy / dx)$=**...................................**eV

Result

The approximate band gap value of given thermistor is E_g = ...eV

References

1. B.L.Theraja, Basic Electronics Solid State, Fifth edition: S.Chand and company Ltd.
2. R.S.Sedha, A Textbook of Applied Electronics, Third edition: S.Chand and company Ltd.

3. RESISTIVITY DETERMINATION FOR A SEMICONDUCTOR WAFER USING FOUR PROBE METHOD

Aim:

To determine the energy band gap of a semiconductor (Germanium) using four probe method.

Apparatus required

Probes arrangement (it should have four probes, coated with zinc at the tips). The probes should be equally spaced and must be in good electrical contact with the sample), Sample (Germanium or silicon crystal chip with non-conducting base), Oven (for the variation of temperature of the crystal from room temperature to about 200°C), A constant current generator (open circuit voltage about 20V, current range 0 to 10mA), Milli-voltmeter (range from 100mV to 3V), Power supply for oven Thermometer.

Formula

The energy band gapof semi-conductor is given by $E_g = 2k_B \dfrac{2.3026 \times log_{10}\rho}{1/T}$ *in eV*

where k_B is Boltzmann constant equal to 8.6×10^{-5} eV / kelvin

ρ is the resistivity of the semi-conductor crystal given by

$$\rho = \frac{\rho_0}{f(W/S)} \quad where\ \rho_0 = \frac{V}{I} \times 2\pi s \ ; \ \rho = \frac{V}{I}(0.213)$$

Here S is distance between probes

W is the thickness of semi-conducting crystal.

V and I are the voltage and current across and through the crystal chip.

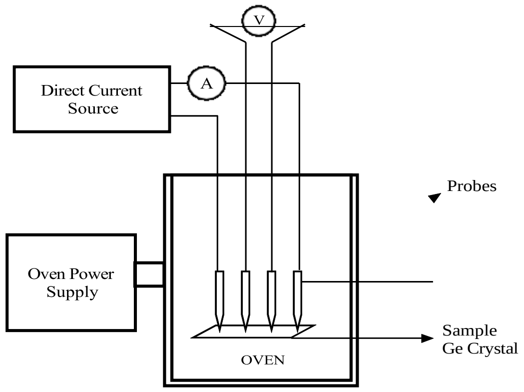


Fig 4.1 Four Probe experimental setup

Procedure

1. Connect one pair of probes to direct current source through milliammeter and other pair to millivoltmeter.
2. Switch on the constant current source and adjust current I, to a described value, say 2 mA.
3. Connect the oven power supply and start heating.
4. Measure the inner probe voltage V, for various temperatures.

Table 4.1 To determine the resistivity of the semi-conductor for various temperatures

Current (I) = ... mA

S.No.	Temperature		Voltage (V)	Resistivity ρ (ohm. cm)	1/T (10^{-3})	$\mathrm{Log}_{10}\rho$
	in $^\circ$C	in K	(mV)		(K)	

Observations

Distance between probes(s) = ...mm

Thickness of the crystal chip (W) = ...mm

Current (I) = ...mA

Graph

Plot a graph in $\left(\frac{10^3}{T}\right)$ and $\log_{10}\rho$ as shown in Fig.4.2. Find the slope of the curve $\frac{AB}{BC} = \frac{\log_{10}\rho}{10^3 / T}$. So the energy band gap of semiconductor (Germanium) is given by

$$E_g = 2k \times \frac{2.3026 \times \log_{10}\rho}{1/T} = 2 \times 8.6 \times 10^{-5} \times 2.3026 \times \frac{AB}{BC} \times 1000\,eV = 0.396 \times \frac{AB}{BC}\,eV$$

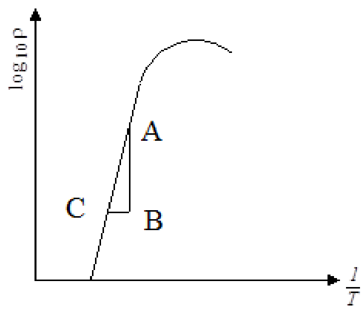


Fig. 4.2.Model Graph of (10^3/T)and $\log_{10}\rho$

Source of error and precautions

1. The resistivity of the material should be uniform in the area of measurement.
2. The surface on which the probes rest should be flat with no surface leakage.
3. The diameter of the contact between the metallic probes and the semiconductor crystal chip should be small compared to the distance between the probes.

Result

The energy band gap for given semiconductor is estimated to be E_g =......................eV

References

1. Introduction To Semiconductor Materials And Devices, M.S Thyagi, Publisher John Wiley& Sons,2008
2. Physics of Semiconductor Devices, 3rd Ed, S.M.Sze, Kwok K .Ng, Publisher John Wiley& Sons,2008

4. To study V-I Characteristics of a Light Dependent Resistor (LDR)

Aim

To measure the photoconductive nature and the dark resistance of the given light dependent resistor (LDR) and to plot the characteristics of the LDR.

Apparatus required

LDR, Resistor (1 kΩ), ammeter (0 – 10 mA), voltmeter (0 – 10 V), light source, regulated power supply.

Principle

The photoconductive device is based on the decrease in the resistance of certain semiconductor materials when they are exposed to both infrared and visible radiation.

The photoconductivity is the result of carrier excitation due to light absorption and the figure of merit depends on the light absorption efficiency. The increase in conductivity is due to an increase in the number of mobile charge carriers in the material.

Formula

By ohm"s law, $V = IR$ (or) $R = \frac{V}{I}$ ohm

where R is the resistance of the LDR (i.e.) the resistance when the LDR is closed.
V and I represents the corresponding voltage and current respectively.

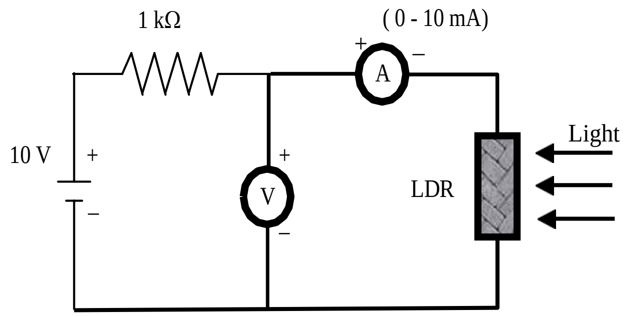


Fig. 3.1 Circuit diagram

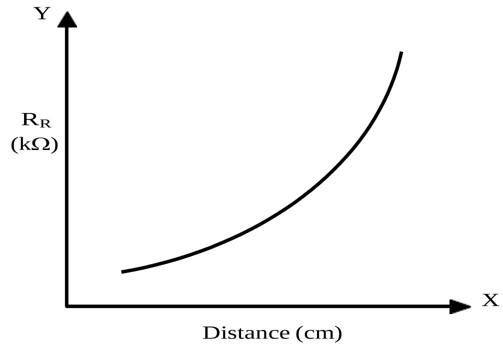


Fig.3.2 Model graph for photoconductivity of LDR

Procedure

1. The connections are given in as shown in Fig. 3.1
2. The light source is switched on and made to fall on the LDR.
3. The corresponding voltmeter and ammeter readings are noted.
4. The procedure is repeated by keeping the light source at different distances from the LDR.
5. A graph is plotted between resistance and distance of LDR from the light source.
6. The LDR is closed and the corresponding voltmeter and ammeter readings are noted. The value of the dark resistance can be calculated by Ohm‟s law.

Observation and calculation

Voltmeter reading when the LDR is closed = ...V

Ammeter reading when the LDR is closed = ...A

Dark resistance = $R = \frac{V}{I}$ = **.................**ohm

Table 3.1 To determine the resistances of LDR at different distances

S.No	Distance (cm)	Voltmeter reading (V) volt	Ammeter reading (I) mA	R kΩ

Result

The characteristics of LDR were studied and plotted.

The dark resistance of the given LDR = ... ohm.

References

1. U.A Bakshi, A.P Godse, “Electronic Devices. Technical Publications”, India, 2008.
2. Robert Diffenderfer,“Electronic Devices: Systems and Applications”, Thomas Delmer Learning, USA, 2005.

5. Study of V-I & V-R Characteristics and Efficiency of a Solar Cell

Aim

To study the V-I and V-R characteristics of a solar cell also to calculate the efficiency of the Solar Cell.

Apparatus Required

Solar cell, voltmeter, milliammeter, a dial type resistance box, keys, illuminating lamps, connecting wires etc.

Formula

Efficiency of solar cell is measured as $\eta = [P_{max} / AI_o] \times 100$

where P_{max} = Maximum power = $I_{mp} \times V_{mp}$ watt

A = Area of the solar panel (7.2 cm x 4.5 cm)

I_o = Intensity of light = Power of the bulb/$4\pi d^2$ W/m^2

d = Distance between solar panel and bulb

Power of bulb = 75 watt

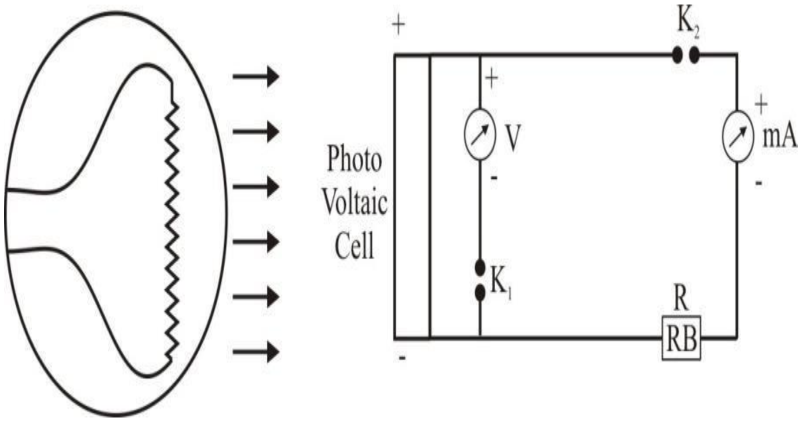


Fig.5.1 Schematic representation and circuit of Solar Cell

Procedure

A solar cell (photovoltaic cell) essentially consists of a p-n junction diode, in which electrons and holes are generated by the incident photons. When an external circuit is connected through the p-n junction device, a current passes through the circuit. Therefore, the device generates power when the electromagnetic radiation is incident on it. The schematic representation of a solar cell and the circuit connections are as shown in Fig. 5.1.

The voltmeter is connected in parallel with the given solar cell through a plug key. A milli-ammeter and a variable resistor are connected in series to the solar cell through a key as shown in the Fig.5.1.The solar cell can be irradiated by sun"s radiation. Instead, it can also be irradiated by a filament bulb (60 W or 100 W).The resistance value is adjusted by a resistance box and the variation of V-I and V-R are plotted.

Efficiency of Solar Cell

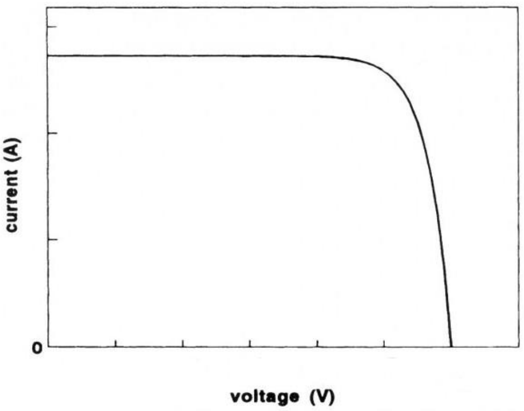
1. Measure the length and width of the solar cell with a vernier caliper and find its surface area
2. Place the desk lamp in front of solar panel
3. Measure the distance from solar cell to the desk lamp with the ruler. Adjust the distance to 0.05m and , turn on the desk lamp
4. Find the intensity of bulb as I_o= Power of the bulb/$4\pi d^2$
5. Connect the circuit as shown in the figure 11.1. A solar cell, variable resistance and a DMM (for measuring current) is connected in series. A second DMM (for measuring voltage) is connected to the solar cell in parallel.
6. Record the voltage and current values for different resistance values in table 11.1
7. Adjust the distance from solar cell to the desk lamp as 0.10cm and record the voltage and current for different resistance
8. Plot the graph with voltage along X-axis and current along Y-axis and find maximum power as $P_{max} = I_{mp} \times V_{mp}$ watt

Table 5.1 V-I and V-R characteristics

Intensity	Resistance	Voltmeter Reading	Ammeter Reading
Maximum			

Table 5.2 V-I and V-R characteristics

Intensity	Resistance	Voltmeter Reading	Ammeter Reading
Minimum			



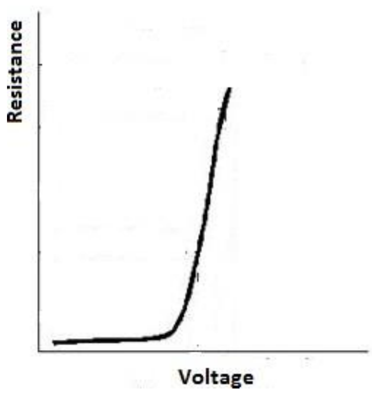
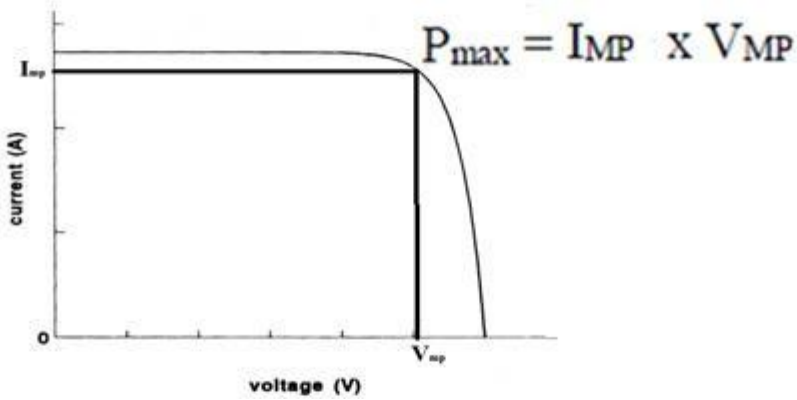


Fig. 5.2 Model Graph for V-I & V-R Characteristic



Observation

Intensity of light I_o when d = 5 cm = ...W / m^2

Intensity of light Io when d = 10 cm = ...W/m^2

When d = 5cm, Power maximum = ………………

When d = 10cm, Power maximum = ……………..

Result:

1. The V-I and V-R Characteristics of the solar cell is studied.
2. Efficiency of solar cell is calculated as, η (minimum intensity) = ...%

   η (maximum intensity) =..................%

Reference

1. Introduction To Semiconductor Materials And Devices, M.S Thyagi, Publisher John Wiley& Sons,2008
2. Physics of Semiconductor Devices, 3rd Ed, S.M.Sze, Kwok K .Ng, Publisher John Wiley& Sons,2008

6. Characteristic of PN junction diode under Forward & Reverse bias

Aim

To plot the characteristics curve of PN junction diode in Forward bias and Reverse bias.

Apparatus

A diode, DC voltage supplier, Bread board, 100Ω resistor, two multi-meters for measuring current and voltage and connecting wires

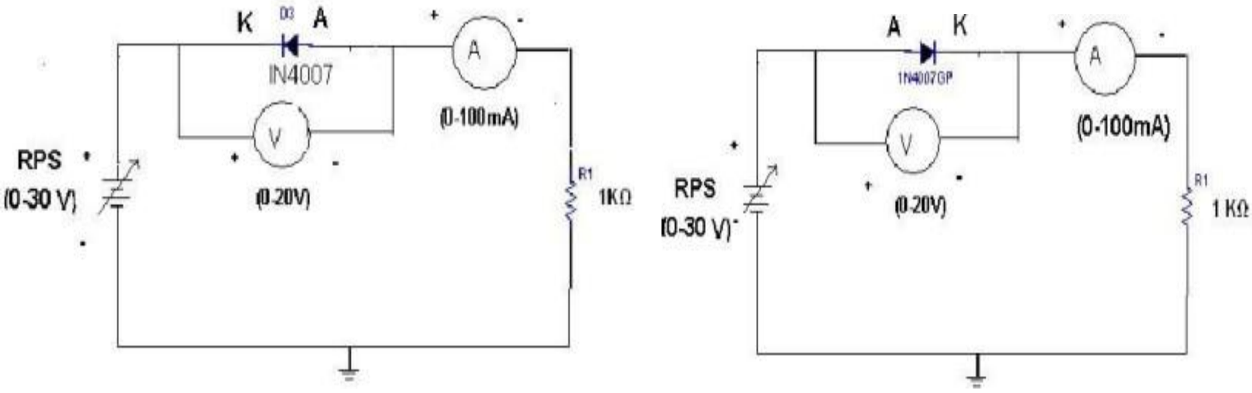
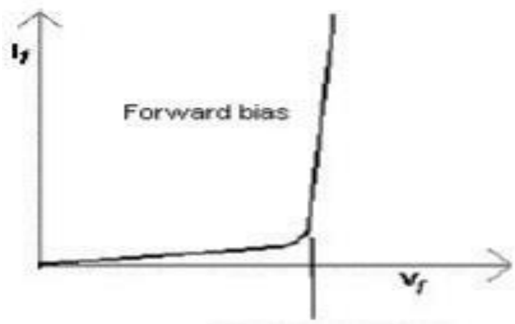


Fig. 6.1 PN Junction Forward and Reverse Bias

Procedure:

For the forward bias of a P-N junction, P-type is connected to the positive terminal while the N-type is connected to the negative terminal of a battery. The potential at P-N junction can be varied with the help of potential divider. At some forward voltage (0.3 V for Ge and 0.7V for Si) the potential barrier is altogether eliminated and current starts flowing. This voltage is known as threshold voltage (V_{th}) or cut in voltage or knee voltage .It is practically same as barrier voltage V_B. For $V<V_{th}$, the current is negligible. As the forward applied voltage increase beyond threshold voltage, the forward current rises exponentially.

For the reverse bias of p-n junction, P-type is connected to the negative terminal while N-type is connected to the positive terminal of a battery. Under normal reverse voltage, a very little reverse current flows through a P-N junction. But when the reverse voltage is increased, a point is reached when the junction break down with sudden rise in reverse current. The critical value of the voltage is known as break down (VBR). The break down voltage is defined as the reverse voltage at which P-N junction breakdown with sudden rise in reverse current.



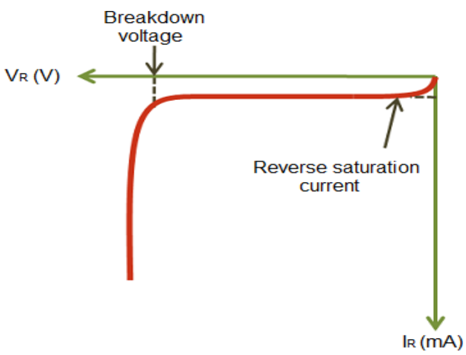


Table 6.1 V-I Characteristics of PN junction diode under forward bias

S. No	**Forward Voltage (V_f) Volt**	**Forward Current (I_f)μA**

Table 6.2 Characteristics of PN junction diode under reverse bias

S. No	**Reverse Voltage V_RVolt**	**Reverse Current I_R mA**

Result

The PN junction characteristic is studied and curve is drawn.

Reference

1. B.L.Theraja, Basic Electronics Solid State, Fifth edition: S.Chand and company Ltd.
2. R.S.Sedha, A Textbook of Applied Electronics, Third edition: S.Chand and company Ltd.

7. To study V-I characteristics a photo cell

Aim

To study the illumination and V-I characteristic of photocell

Apparatus

Photo cell Apparatus and connecting wires.

Theory

Solid-state device with a photosensitive cathode that emits electrons when illuminated and an anode for collecting the emitted electrons. Illumination excites electrons, which are attracted to the anode, producing current proportional to the intensity of the illumination. In a photovoltaic cell, light is used to produce voltage. In a photoconductive cell, light is used to regulate the flow of current. Photocells are used in control systems, where interrupting a beam of light opens a circuit, actuating a relay that supplies power to a mechanism to bring about a desired operation, such as opening a door or setting off a burglar alarm.

Fig. 7.1 Experimental setup for Photo cell

Procedure

1. **Illumination characteristics:**
   1. Connect the voltmeter and ammeter as per circuit diagram shown on the apparatus and set RL to minimum position.
   2. A 100 W lamp is arranged over the solar panel such that light falls on it at normal. Initially, the lamp is placed at maximum distance and is switched on.
   3. The voltage and the current is noted.
   4. The intensity of the lamp is varied in steps by changing the distance of lamp. The readings are noted in Observation Table 7.1

2. **Voltage – Current characteristics**
   1. The intensity of the lamp is kept at Medium (I_1).
   2. The voltage and current are switched on.
   3. The load dial is set at 470 ohms. The voltage and current are noted down. The loads is set to 1 k, 2.2 k, 3.3 k, 4.7 k and 10 k ohms and at each setting the voltage and current are recorded. The readings are recorded in Observation Table 7.2

4. The intensity of the lamp is increased (I_2).At this setting, step 3 is repeated.
5. The intensity of the lamp is set to its maximum (I_3). At this setting step 3 is again repeated.

Table 7.1 Illumination characteristics

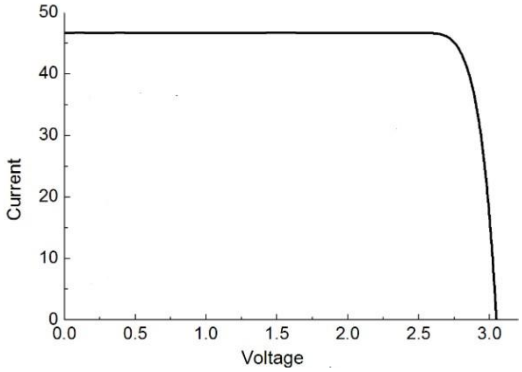
Intensity Variation (distance cm)	At Minimum R_L (kΩ)	
	Voltage (V)	Current (μA)

Table 7.2 V-I Characteristics of Photo cell

R_L (kΩ)	Minimum Intensity I_1 (at longest distance X_1)		Medium Intensity I_2 (at mid distance X_2)		Maximum Intensity I_3 (at shortest distance X_3)	
	Voltage (V)	Current (μA)	Voltage (V)	Current (μA)	Voltage (V)	Current (μA)

Graph

For V-I characteristics, a graph is plotted between the current and voltage



Result

Illumination andV-I characteristics of Photo cell has been studied.

Reference

1. BrijeshTripathi, Manoj Kumar,"Solar Energy: From Cells to Grid", CSFML Publications, India, 2018.
2. R.C. NevilleAngeleReinders, Pierre Verlinden, Wilfried van Sark, AlexandreFreundlich, "Photovoltaic Solar Energy: From Fundamentals to Applications", John Wiley & Sons Publication, UK, 2017.
3. R.C. Neville, "Solar Energy Conversion: The Solar Cell", Elsevier Science Publications, Netherlands, 1995.
4. Alan Fahrenbruch, Richard Bube, "Fundamentals of Solar Cells: Photovoltaic Solar Energy Conversion" Academic Press INC, UK, 1983.

8.Determination of electron and hole mobility versus doping concentration using GNU Octave

Aim: To plot the electron and hole mobility of a semiconductor with respect to different doping concentrations using GNU octave.

Tool Required: GNU Octave or MATLAB software.

Theory:

Extrinsic semiconductors are formed by adding specific amounts of impurity atoms to the silicon crystal.
An n-type semiconductor is formed by doping the silicon crystal with elements of group V of the periodic table (antimony, arsenic, and phosphorus). The impurity atom is called a donor. The majority carriers are electrons and the minority carriers are holes.
A p-type semiconductor is formed by doping the silicon crystal with elements of group III of the periodic table (aluminum, boron, gallium, and indium). The impurity atoms are called acceptor atoms. The majority carriers are holes and minority carriers are electrons.

In a semiconductor material (intrinsic or extrinsic), the law of mass action states that,

pn =constant
p is the hole concentration
n is the electron concentration. For intrinsic semiconductors,
$p = n = n_i$
Hence, $pn = n^2$ (where, n is the electron concentration in intrinsic semiconductor
and n_i is given by Equation
$\mathbf{n_i = AT^{3/2}\exp[-E_g/(kT)]}$

The law of mass action enables us to calculate the majority and minority carrier density in an extrinsic semiconductor material.
The charge neutrality condition of a semiconductor implies that,
$p+N_D = n+N_A$

Where, N_D is the donor concentration, N_A is the acceptor concentration p is the hole concentration and n is the electron concentration.

In an n-type semiconductor, the donor concentration is greater than the intrinsic electron concentration, i.e., N_D is typically 10^{17} cm^{-3} and $n_i = 1.5 \times 10^{10}$ cm^{-3} in Si at room temperature. Thus, the majority and minority concentrations

are given by, $n_n \cong N_D$ and $p \cong n^2/N_D$
In a p-type semiconductor, the majority and minority concentrations are given

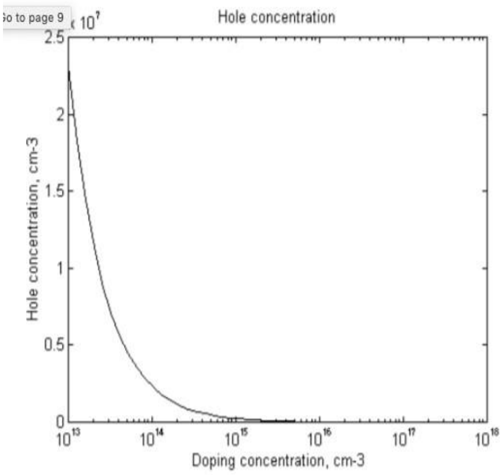
by, $p_p \cong N_A$ and $n \cong n\ ^2/N_A$

Problem 1: For an n-type semiconductor at 300^o K, if the doping concentration is varied from 10^{13} to 10^{18} atoms/cm^3, determine the minority carriers in the doped semiconductors.

MATLAB Code:

```
% hole concentration in a n-type semiconductor
nd = logspace(13,18);
n = nd;
ni = 1.52e10;
ni_sq = ni*ni;
p = ni_sq./nd;
semilogx(nd,p,'b')
title('Hole concentration') xlabel('Doping concentration, cm-3')
ylabel('Hole concentration, cm-3')
```

Typical output:



Problem 2:

From measured data, an empirical relationship between electron (μ_n) and hole (μ_p) mobilities versus doping concentration at 300°K is given as [2]

$$\mu_n(N_D) = \frac{5.1x10^{18} + 92N_D^{0.91}}{3.75x10^{15} + N_D^{0.91}} \qquad (10.24)$$

$$\mu_{pn}(N_A) = \frac{2.9x10^{15} + 47.7N_A^{0.76}}{5.86x10^{12} + N_A^{0.76}} \qquad (10.25)$$

where

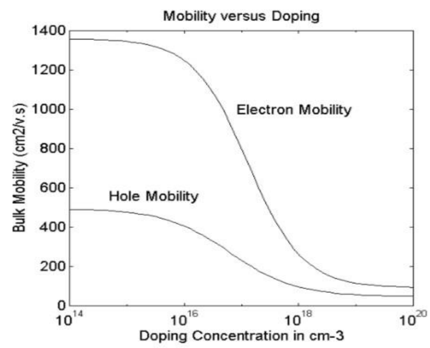
N_D and N_A are donor and acceptor concentration per cm^3, respectively.

Plot the μ_n (N_D) and μ_p (N_A) for the doping concentrations from 10^{14} to 10^{20} cm^{-3}.

MATLAB Code:

```
% nc - is doping concentration
%
nc = logspace(14,20);
un = (5.1e18 + 92*nc.^0.91)./(3.75e15 + nc.^0.91);
up = (2.90e15 + 47.7*nc.^0.76)./(5.86e12 + nc.^0.76);
semilogx(nc,un,'w',nc,up,'w')
text(8.0e16,1000,'Electron Mobility')
text(5.0e14,560,'Hole Mobility')
title('Mobility versus Doping')
xlabel('Doping Concentration in cm-3')
ylabel('Bulk Mobility (cm2/v.s)')
```

Typical output:



Result:

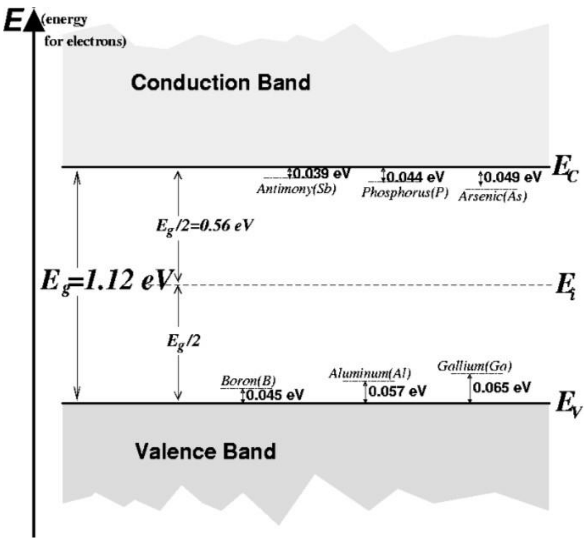
The electron and hole carrier densities in a semiconductor with different doping concentrations have been simulated using GNU octave.

9. Determination of Fermi function for different temperature using GNU Octave

Aim: To study the Fermi function distribution in a semiconductor under different temperatures using CNU octave.

Tool Required : GNU octave or MATLAB

Theory:



The conduction band in a piece of semiconductor consists of many available, allowed, empty energy levels. When calculating how many electrons will fill these levels contributing to conductivity, we consider two factors:

- How many energy levels are there within a given range of energy, in our case the conduction band, and
- How likely is it that each level will be populated by an electron.

The likelihood in the second item is given by a probability function called the Fermi-Dirac distribution function. f(E) is the probability that a level with energy E will be filled by an electron, and the expression
is:

$$f(E) = \frac{1}{1 + \exp((E - E_F)/(k_B T))}$$

Since $f(E_1)$ is the probability that the energy level E_1 will be filled by an electron, $(1- f(E_1))$ is the probability that the energy level E will be empty. Or, equivalently, if E_1 is in the valence band, $(1 - f(E_1))$ is the probability that the energy level E_1 will have a hole.

In an n-type semiconductor, if we know the doping level ND, we know we can say n0 = ND; therefore, using the Boltzmann approximation:

$\mathbf{n_0 = N_D = N_C \exp(-(E_C - E_F)/(k_B T))}$

Where, $E_c = E_i + k_B T \log(n/n_i)$ and E_i can be taken as E_F. Similarly, for the holes, p-type semiconductor, in the valence band considering the effective density of states (NV) and multiply it with the
probability that a state at that level will be empty ((1 − f (EV))), again using Boltzmann approximation: we can write,

$\mathbf{p_0 = N_V(1-f(E_V)) = N_V \exp(-(E_F - E_V)/(k_B T))}$

Where, $E_v = E_i - k_B T \log(p/n_i)$ and E_i can be taken as E_F
.
Problem 1:

Plot Fermi-Dirac Distribution function using the following equation and given parameters

$$f(E) = \frac{1}{1 + \exp((E - E_F)/(k_B T))}$$

k_B = 8.617e-5; % in eV/K
E_F = 0.56; % Fermi level in eV
E = -0.2 eV to 1.4eV; % Energy range

MATLAB Code:

1. Evaluation of the expression

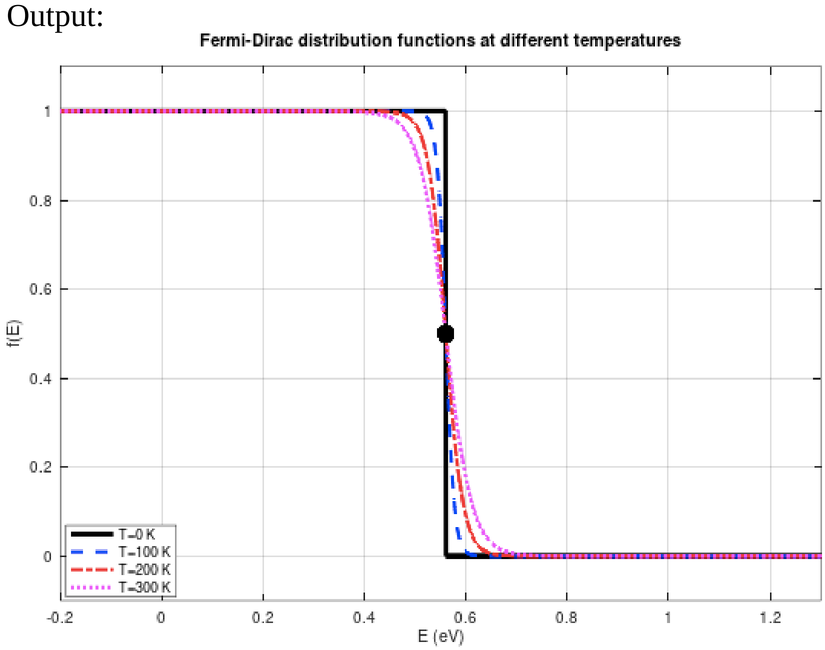
```
% Fermi distribution function calculation
kB = 8.617e-5; % in eV/K
Ef = 0.56;     % Fermi level in eV
E = -0.2:0.0005:1.4; % Energy levels
% "Calculate" f(E) at T=0 K as fTo
fTo = zeros(size(E));
for k=1:length(E)
   if E(k)<Ef fTo(k)=1;
   elseif E(k)==Ef fTo(k)=0.5;
   end
end

% Calculate f(E) at three different temperatures
T1 = 100; % in K
T2 = 200;
T3 = 300;
fT1 = 1 ./ (1 + exp( (E-Ef*ones(size(E)))/(kB*T1) ));
fT2 = 1 ./ (1 + exp( (E-Ef*ones(size(E)))/(kB*T2) ));
fT3 = 1 ./ (1 + exp( (E-Ef*ones(size(E)))/(kB*T3) ));
```

2. plotting the graph

```
figure(1); clf
plot(E,fTo,'k','LineWidth',3);
grid on; hold on
plot(E,fT1,'b--','LineWidth',2)
plot(E,fT2,'r-.','LineWidth',2)
plot(E,fT3,'m:','LineWidth',2)
axis([-0.2 1.3 -0.1 1.1])
set(1,'Position',[34 88 634 538]);
xlabel('E (eV)'); ylabel('f(E)');
title('Fermi-Dirac distribution functions at different temperatures')
legend('T=0 K','T=100 K','T=200 K','T=300 K','Location','SouthWest')
plot(Ef,0.5,'k.','MarkerSize',36)
```

Output:



Result:

The Fermi function distribution of a semiconductor under different temperatures have been studied using GNU octave.

10.Study of Attenuation and Propagation Characteristics ofOptical Fiber Cable

10 (a) Attenuation in fibers

Aim

1. To determine the attenuation for the given optical fiber.
2. To measure the numerical aperture and hence the acceptance angle of the given fiber cables.

Apparatus Required

Fiber optic light source, optic power meter and fiber cables (1m and 5m), Numerical aperture measurement JIG, optical fiber cable with source, screen.

Principle

The propagation of light down dielectric waveguides bears some similarity to the propagation of microwaves down metal waveguides. If a beam of power P_i is launched into one end of an optical fiber and if P_f is the power remaining after a length L km has been traversed , then the attenuation is given by,

$$\text{Attenuation} = \frac{10\log\left(P_i / P_f\right)}{L} \text{ dB / km}$$

Formula

$$\text{Attenuation} = \frac{10\log\left(P_i / P_f\right)}{L} \text{ in dB / km}$$

where P_i = Power output for minimum light intensity (dB)
P_f = Power output for maximum light intensity (dB)

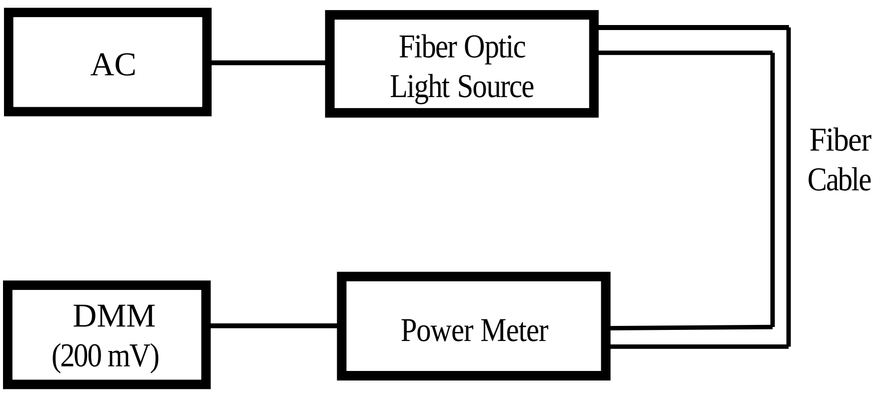


Fig. 9.1 Setup for loss measurement

Procedure

1. One end of the one metre fiber cable is connected to source and other end to the optical power metre.
2. Digital power meter is set to 200mV range (- 200 dB) and the power meter is switched on
3. The ac main of the optic source is switched on and the fiber patch cord knob in the source is set at one level (A).
4. The digital power meter reading is noted (P_i)
5. The procedure is repeated for 5m cable (P_f).
6. The experiment is repeated for different source levels.

Table 10.1 Determination of Attenuation for optical fiber cables

$L = 4 \text{ m} = 4 \times 10^{-3}$ km

Source Level	Power output for 1m cable (P_i)	Power output for 5m cable (P_f)	Attenuation = $\frac{10\log\left(P_i / P_f\right)}{L}$ dB / km
Min			
Max			

Result

1. Attenuation at source level A = ...(dB/km)
2. Attenuation at source level B =.......................... (dB/km)

10 (b) Numerical Aperture and Acceptance angle

Principle

Numerical aperture refers to the maximum angle at which the light incident on the fiber end is totally internally reflected and transmitted properly along the fiber. The cone formed by the rotation of this angle along the axis of the fiber is the cone of acceptance of the fiber.

Formula

$$\text{Numerical aperture (NA)} = \frac{W}{\sqrt{4L^2 + W^2}} = \sin\theta_{max}$$

Acceptance angle = 2 θ_{max} (deg)

where L = distance of the screen from the fiber end in metre

W =diameter of the spot in metre.

ϴ = Half of acceptance angle (degree)

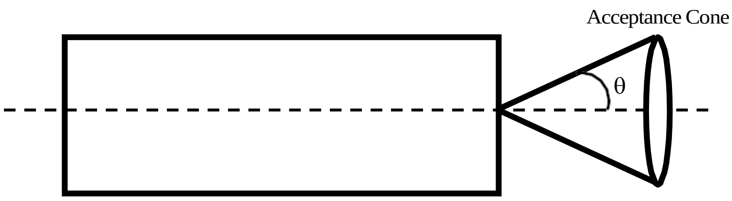


Fig. 9.2 Measurement of Numerical aperture

Procedure

1. One end of the 1 metre fiber cable is connected to the source and the other end to the NA jig.
2. The AC mains are plugged. Light must appear at the end of the fiber on the NA jig. The set knob in source is turned clockwise to set to a maximum output.
3. The white screen with the four concentric circles (10, 15, 20 and 25mm diameters) is held vertically at a suitable distance to make the red spot from the emitting fiber coincide with the 10mm circle.
4. The distance of the screen from the fiber end L is recorded and the diameter of the spot W is noted. The diameter of the circle can be accurately measured with the scale. The procedure is repeated for 15mm, 20mm and 25mm diameter circles.
5. The readings are tabulated and the mean numerical aperture and acceptance angle are determined.

Table 10.2 To find Numerical aperture and acceptance angle of optical fiber

Circle	Distance between source and screen (L) (mm)	Diameter of the spot W (mm)	NA = $\frac{W}{\sqrt{4L^2 + W^2}}$	θ
5m				
1m				

Result

1. The Numerical aperture of fiber is measured as 1m = ... (No unit)

   5m = ... (No unit)

2. The acceptance angle is calculated as 1m = ... (deg)

   5m = ... (deg)

Reference

1. Introduction to Fiber Optics, Ajay Ghatak and K. Thyagarajan, Cambridge University Press, 1998.
2. Fiber Optic Communications, Downing, James N., Clifton Park: Thomson Delmar Learning, 2004

11. Plotting and interpretation of I-V characteristics of Diode GNU Octave

Aim:

To simulate the Current – Voltage (I-V) characteristics of a PN junction diode using GNU Octave.

Tool Required : GNU octave or MATLAB

Theory:

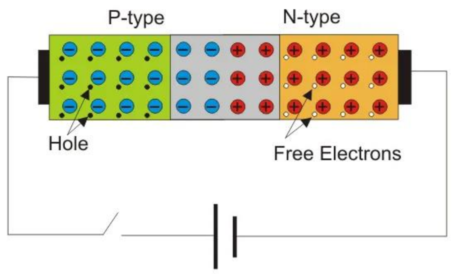
A diode is defined as a two-terminal electronic component that only conducts current in one direction (so long as it is operated within a specified voltage level). An ideal diode will have zero resistance in one direction, and infinite resistance in the reverse direction.

Diode Equation

$$I = Io(e^{(qv/kt) - 1})$$

I_0 is directly related to recombination, and thus, inversely related to material quality. Non-ideal diodes include an "n" term in the denominator of the exponent. N is the ideality factor, ranging from 1-2, that increases with decreasing current.

Working Principle of Diode



- A diode's working principle depends on the interaction of n-type and p-type semiconductors. An n-type semiconductor has plenty of free electrons and a very few numbers of holes.

- The free electrons diffusing into the p-type region from the n-type region would recombine with holes available there and create uncovered negative ions in the p-type region. In the same way, the holes diffusing into the n-type region from the p-type region would recombine with free electrons available there and create uncovered positive ions in the n-type region. Due to the lack of charge carriers, this region is called the depletion region.

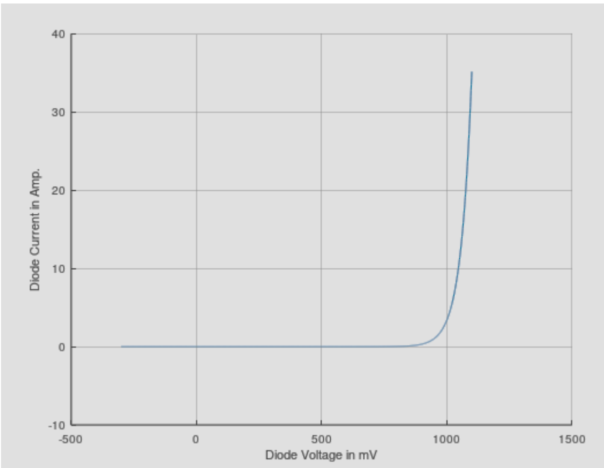
- After the formation of the depletion region, there is no more diffusion of charge carriers from one side to another in the diode. This is due to the electric field appeared across the depletion region will prevent further migration of charge carriers from one side to another.

The diode equation is plotted on the interactive graph below. Change the saturation current and watch the changing of IV curve.

MATLAB Code:

```
clear all
n = 1.65;    %Ideality factor
Is = 220*10^-12;  % diode reverse saturated current
q = 1.602*10^-19;    % electron charge
K = 1.38*10^-23; %Boltzmann constant
T = 300;    % Absolute temperature
fs=1000;
dv=1/fs;
v0=-0.3 ; % change as you want
vend=1.1 ; % change as you want
Vd=v0:dv:vend;
Id = Is*(exp((q*Vd)./(1.65*K*T))-1);
plot(1000*Vd,Id) ; grid ; xlabel(' Diode Voltage in mV ' ) ;
ylabel(' Diode Current in Amp. ‘)
```

Output:



Result:

The current -voltage (I-V) relationship of a PN junction diode have benn theoretically simulated using GNU octave.

12.Calculation of Lattice Cell Parameters – X-ray Diffraction

Aim

Tocalculate the lattice cell parameters from the powder X-ray diffraction data.

Apparatus required

Powder X-ray diffraction diagram

Principle

Bragg‟s law is the theoretical basis for X-ray diffraction.

$$(\sin^2\theta)_{hkl} = (\lambda^2 / 4a^2)\ (h^2 + k^2 + l^2)$$

Each of the Miller indices can take values 0, 1, 2, 3……. Thus, the factor $(h^2 + k^2 + l^2)$ takes the values given in Table 12.1

Formula

For a cubic crystal

$$\frac{1}{d^2} = \frac{(h^2 + k^2 + l^2)}{a^2}$$

For a tetragonal crystal

$$\frac{1}{d^2} = \left\{\frac{(h^2 + k^2)}{a^2} + \frac{l^2}{c^2}\right\}$$

For a orthorhombic crystal

$$\frac{1}{d^2} = \left(\frac{h^2}{a^2}\right) + \left(\frac{k^2}{b^2}\right) + \left(\frac{l^2}{c^2}\right)$$

The lattice parameter and interplanar distance are given for a cubic crystal as,

$$a = \frac{\lambda}{2\sin\theta}\sqrt{h^2 + k^2 + l^2}\ \text{Å}$$

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}\ \text{Å}$$

where, a = Lattice parameter
d = Interplaner distance
λ = Wavelength of the CuKα radiation (1.5405)
h, k, l = Miller integers

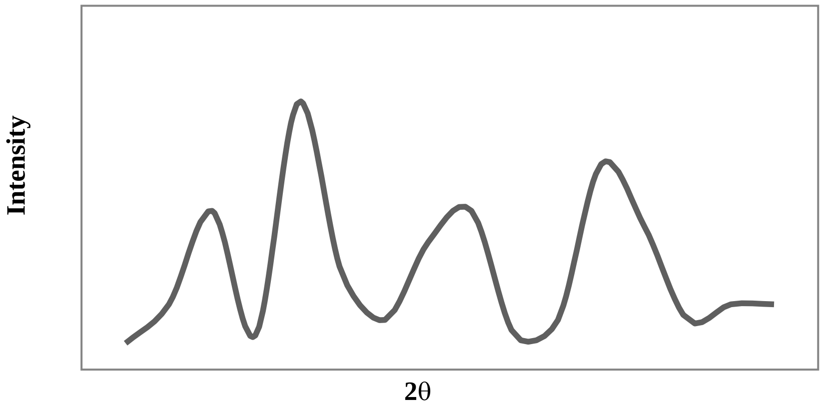


Fig. 12.1. Model X-ray diffraction pattern

The problem of indexing lies in fixing the correct value of a by inspection of the $\sin^2\theta$ values.

Procedure:

From the 2θ values on a powder photograph, the θ values are obtained. The $\sin^2\theta$ values are tabulated. From that the values of $1 \times \frac{\sin^2\theta}{\sin^2\theta_{min}}, 2 \times \frac{\sin^2\theta}{\sin^2\theta_{min}}, 3 \times \frac{\sin^2\theta}{\sin^2\theta_{min}}$ are determined and are tabulated. The values of $3 \times \frac{\sin^2\theta}{\sin^2\theta_{min}}$ are rounded to the nearest integer. This gives the value of $\boldsymbol{h^2+k^2+l}$.From these the values of h,k,l are determined from the Table 12.1

From the h,k,l values, the lattice parameters are calculated using the relation

$$a = \frac{\lambda}{2\sin\theta}\sqrt{h^2+k^2+l^2}\ \text{Å}$$

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}}\ \text{Å}$$

Table 12.1 Value of $h^2 + k^2 + l^2$ for different planes

h, k, l	$h^2 + k^2 + l^2$	***h, k, l***	$h^2 + k^2 + l^2$
100	1	300	9
110	2	310	10
111	3	311	11
200	4	322	12
210	5	320	13
211	6	321	14
220	8	400	16
221	9	410	17

Table 12.2 Lattice parameter (a) and Interplanar distance (d) for different planes

S. No	2θ	$sin^2\theta$	$1 \times \frac{sin^2 \theta}{sin^2 \theta_{min}}$	$2 \times \frac{sin^2 \theta}{sin^2 \theta_{min}}$	$3 \times \frac{sin^2 \theta}{sin^2 \theta_{min}}$	$h^2+k^2+l^2$	***hkl***	**a Å**	**d** Å

Table 3 Lattice determination

Lattice type	**Rule for reflection to be observed**
Primitive P	None
Body centered I	*hkl*: $h + k + l = 2n$
Face centered F	*hkl*: *h, k, l* either all odd or all even

Depending on the nature of the *h,k,l* values the lattice type can be determined.

Result:

The lattice parameters are calculated theoretically from the powder x-ray diffraction pattern.

Reference

1. Dann, S.E. Reactions and Characterization of SOLIDS. Royal Society of Chemistry,USA (2002).
2. Skoog, D.A.; Holler, F.J.; Crouch, S.R. Principles of Instrumental Analysis. SixthEdition, Thomson Brooks/Cole, USA (2007).

13. Mini Project – Concept based Demonstration

Aim:

To construct the working model based on principles of physics, the opportunity to develop a range of skills and knowledge already learnt to an unseen problem.

Objectives:

On successful completion of the mini project, the student will have developed skills in the following areas:

1. Design of experiments.
2. Experimental or computational techniques.
3. Searching the physical and related literature.
4. Communication of results in an oral presentation and in a report.
5. Working as part of a team.
6. Assessment of team members.

Assessment and Evaluation:

1. Each Class should have at least **eight groups**. Each group should have a **minimum of 5 members** or above and Maximum of **9 members**.
2. Mini Project should be a **working model**. One page write-up about the project should be submitted as per the template provided by the class subject teacher.
3. **Department of Physics & Nanotechnology** will be organizing an event **TechKnow** to showcase these Mini Projects. All groups should present the working model along with the poster at the TechKnow.
4. Expert Committee will evaluate and select the best project from each class.
5. Certificates will be awarded for the best project during the event TechKnow.
6. Marks for the project will be awarded under the following criteria.

S. No	Criteria	Marks
1.	Working model / Design	**5**
2.	Idea/ Concept / Novelty	**5**
3.	Presentation / Viva	**5**
4.	Usefulness / Application	**5**
	Total	**20**