



# POSTAL BOOK PACKAGE 2025

## ELECTRONICS ENGINEERING

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### CONVENTIONAL Practice Sets

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#### ELECTRONIC DEVICES AND CIRCUITS

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# 1

## CHAPTER

# Basic Semiconductor Physics

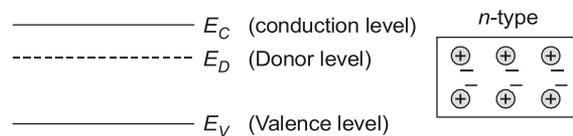
**Q1** What is doping? Give the advantage of doping.

**Solution:**

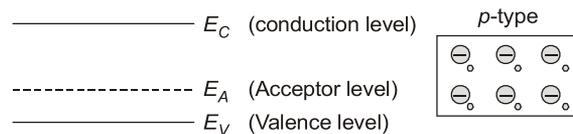
Addition of impurities to the pure semiconductor and making it impure is called doping.

Adding pentavalent impurity can cause 4 covalent bonds with the semiconductor and 1 electron is left free.

Adding this donor causes a new energy level, below the conduction band.



Adding trivalent impurity causes 3 covalent bonds and there is absence of 1 electron which will get occupied in acceptor level just above valence band.



Doping increases the conductance of semiconductor.

**Q2** A semiconductor has a bandgap of 0.62 eV. Find the maximum wavelength for resistance change in the material by photon absorption. (Note: 1 eV =  $1.6 \times 10^{-19}$  Joules)

**Solution:**

We know that 
$$E = \frac{hc}{\lambda}$$

Where,  $E =$  Energy bandgap = 0.62 eV (given)

$h =$  Planck constant =  $6.626 \times 10^{-34}$  Joule-sec

$c =$  Velocity of light in free space =  $3 \times 10^8$  m/sec

$\lambda =$  Wavelength

So, 
$$\lambda = \frac{hc}{E} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{0.62 \times 1.6 \times 10^{-19}}$$

$$\lambda = 2.004 \times 10^{-6} = 2.004 \mu\text{m}$$

**Q3** (a) Describe the 'Einstein Relationship'?

(b) Find the probability of finding an electron 0.2 eV above the Fermi level at 300°K?

**Solution:**

(a) Since both diffusion and mobility are statistical thermodynamic phenomena so diffusion constant ( $D$ ) and mobility ( $\mu$ ) are not independent. The relationship between the  $D$  and  $\mu$  is given by the 'Einstein Relationship', which is mathematically given as,

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T \quad \dots(i)$$

where,  $V_T$  is the 'Volt-equivalent of temperature' and is defined by,

$$V_T = \frac{\bar{k}T}{q} = \frac{T}{11600} \quad \dots(ii)$$

where,  $\bar{k}$  is the Boltzmann constant in J/°K

At room temperature i.e.  $T = 300^\circ\text{K}$ ,

$$V_T = 0.026 \text{ V} = 26 \text{ mV}$$

and

$$\mu = 39 D$$

$\therefore$

$$D_n \text{ for Ge} = \mu_n V_T = 99 \text{ cm}^2/\text{sec}$$

and

$$D_p = \mu_p V_T = 13 \text{ cm}^2/\text{sec}$$

(b) Given that,

$$T = 300^\circ\text{K}$$

and

$$E - E_F = 0.2 \text{ eV}$$

i.e.

$$E = E_F + 0.2 \text{ eV}$$

also,

$$V_T = K \cdot T = 0.026 \text{ V}$$

$\therefore$  Probability of finding an electron 0.2 eV above the Fermi level is given by,

$$f(E = E_F + 0.2 \text{ eV}) = \frac{1}{1 + \exp\left(\frac{0.2}{0.026}\right)} = \frac{1}{1 + \exp(7.692)} = 4.561 \times 10^{-4} \approx 0.0004561$$

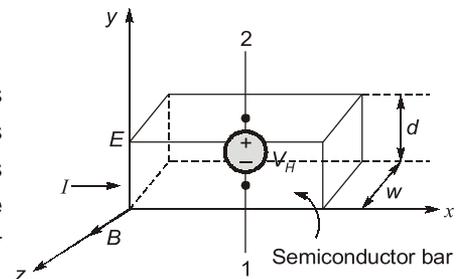
**Q4 Explain Hall effect.**

An n-type germanium sample is 2 mm wide and 0.2 mm thick. A current of 10 mA is passed through the sample (x-direction) and a field of 0.1 Weber/m<sup>2</sup> is directed perpendicular to the current flow (z-direction). The developed Hall voltage is -1.0 mV. Calculate the Hall constant and the number of electrons/m<sup>3</sup>.

**Solution:**

**Hall effect:**

- If a specimen (metal or semiconductor) carrying a current ' $I$ ' is placed in a transverse magnetic field ' $B$ ', an electric field ' $E$ ' is induced in the direction perpendicular to both  $I$  and  $B$ . This phenomenon known as the Hall effect. It is used to determine whether a semiconductor is n-type or p-type and to find the carrier concentration.
- As shown in the figure above, if ' $I$ ' is in the positive x-direction and ' $B$ ' is in the positive z-direction, a force will be exerted in the negative y-direction on the current carriers. The current  $I$  may be due to holes moving from left to right or to free electrons travelling from right to left in the semiconductor specimen. Hence, independently of whether the carriers are holes or electrons, they will be forced downward towards side 1 in the figure. Hence a potential, called the Hall voltage,  $V_H$  appears between surface 1 and 2. If the polarity of  $V_H$  is positive at terminal 2 with respect to terminal 1, then the carriers must be electrons. If terminal 1 becomes charged positively with respect to terminal 2, the semiconductor must be p-type. Given that,  $w = 2 \text{ mm}$ ;  $d = 0.2 \text{ mm}$ ;  $I = 10 \text{ mA}$ ;  $B = 0.1 \text{ Weber/m}^2$ ;  $V_H = -1.0 \text{ mV}$



$$\therefore |V_H| = \frac{BI}{\rho w} = 1.0 \text{ mV}$$

where,

$$\rho = \text{change density (C/m}^3\text{)}$$

$$\Rightarrow \rho = \frac{BI}{V_H w} = \frac{0.1 \times 10 \times 10^{-3}}{1 \times 10^{-3} \times 2 \times 10^{-3}} = 0.5 \times 10^3 \text{ C/m}^3$$

Hall constant  $R_H$  is defined by

$$\begin{aligned} R_H &\equiv 1/\rho \\ \therefore R_H &= 1/0.5 = 2 \times 10^3 \text{ m}^3/\text{C} \\ \text{since } \rho &= nq \\ \text{where } n &= \text{number of electrons /m}^3 \\ \text{and } q &= \text{charge of electron} = 1.6 \times 10^{-19} \text{ Coulomb} \\ \Rightarrow n &= \frac{0.5 \times 10^3}{1.6 \times 10^{-19}} = 3.125 \times 10^{21} \end{aligned}$$

Therefore, Hall constant,  $R_H = 2 \times 10^3 \text{ m}^3/\text{C}$   
and number of electrons per  $\text{m}^3$ ,  $n = 3.125 \times 10^{21}$ .

**Q5** A sample of Germanium is doped to the extent of  $10^{14}$  donor atoms/ $\text{cm}^3$  and  $5 \times 10^{13}$  acceptor atoms/ $\text{cm}^3$ . At  $300^\circ\text{K}$ , the resistivity of the intrinsic Germanium is  $60 \Omega\text{-cm}$ . If the applied electric field is  $2 \text{ V/cm}$ . Find the total conduction current density? (Assume  $\mu_p/\mu_n = 1/2$  and  $n_i = 2.5 \times 10^{13}/\text{cm}^3$  at  $300^\circ\text{K}$ )

**Solution:**

Given that,  $n_i = 2.5 \times 10^{13}/\text{cm}^3$  at  $300^\circ\text{K}$  and  $\mu_n = 2 \mu_p$  and  $E = 2 \text{ V/cm}$

$$N_D = 10^{14} \text{ atoms/cm}^3 \quad \Rightarrow \quad N_D > N_A$$

$$N_A = 5 \times 10^{13} \text{ atoms/cm}^3$$

and also,  $\rho_i = 60 \Omega\text{-cm}$

$$\therefore \sigma_i = \frac{1}{\rho_i} = \frac{1}{60} = 0.0166 (\Omega\text{-cm})^{-1}$$

For an intrinsic "Ge" semiconductor,

$$\begin{aligned} \sigma_i &= n_i q [\mu_n + \mu_p] \\ \text{or } 0.0166 &= 2.5 \times 10^{13} \times 1.6 \times 10^{-19} \times 3\mu_p \\ \text{or } \mu_p &= 1388.8 \text{ cm}^2/\text{V-sec} \approx 1389 \text{ cm}^2/\text{V-sec} \\ \therefore \mu_n &\approx 2 \mu_p \approx 2778 \text{ cm}^2/\text{V-sec} \end{aligned}$$

As we know that when semiconductor is simultaneously doped with donor and acceptor impurities then the type of semiconductor it is can be determined as:

$\Rightarrow$  If  $N_D > N_A$  then this semiconductor turns into the  $n$ -type semiconductor and in this case conductivity ( $\sigma_n$ ) is equal to,

$$\begin{aligned} \sigma_n &= q \mu_n [N_D - N_A] = 1.6 \times 10^{-19} \times 2778 [10^{14} - 5 \times 10^{13}] \\ \therefore \sigma_n &= 0.02215 (\Omega\text{-cm})^{-1} \end{aligned}$$

So, the total current density (here assume only  $n$ -type semiconductor, so only electrons are majority carriers) is,

$$\begin{aligned} J &= \sigma_n |E| = 0.02215 \times 2 = 0.0443 \text{ A/cm}^2 \\ \therefore J &= 44.3 \text{ mA/cm}^2 \end{aligned}$$

**Q6** Consider the intrinsic germanium and silicon at room temperature i.e. at  $300^\circ\text{K}$ . By what percentage does the conductivity increases per degree rise in temperature?

**Solution:**

The conductivity of an intrinsic semiconductor is given by the relation,

$$\begin{aligned} \sigma_{\text{int.}} &= n_i (\mu_n + \mu_p) q && \dots(i) \\ \text{where, } n_i &= \text{intrinsic concentration} \\ \mu_n &= \text{mobility of electrons} \\ \mu_p &= \text{mobility of holes} \\ q &= \text{electronic charge in Coulomb} \end{aligned}$$

As we know that with increasing the temperature, the density of hole-electron pairs increases and correspondingly, the conductivity increases.

From equation (i) it is clear that ' $\sigma_{int}$ ' depends upon ' $n_i$ ' as well as  $\mu_n$  and  $\mu_p$ . For finding the percentage change in conductivity per degree change in temperature, we take an assumption that mobility ( $\mu$ ) does not vary with temperature i.e. it is more or less constant. In this situation, the conductivity ( $\sigma_{int}$ ) varies as ' $n_i$ '

$$\therefore n_i^2 = A_0 T^3 e^{-E_{G_0}/kT} \quad \dots(ii)$$

where,

$$A_0 = \text{Constant independent of } T$$

$$E_{G_0} = \text{Energy gap at } 0^\circ K$$

$$k = \text{Boltzmann constant}$$

Now, from equation (ii),

$$n_i = A_0^{1/2} T^{3/2} e^{-E_{G_0}/2kT}$$

Taking ' $\ln$ ' both sides we get,

$$\ln n_i = \frac{1}{2} \ln A_0 + \frac{3}{2} \ln T - \frac{E_{G_0}}{2kT}$$

$$\Rightarrow \left( \frac{dn_i}{n_i} \right) = \frac{3}{2} \cdot \frac{dT}{T} + \frac{E_{G_0}}{2kT^2} \cdot dT = \left( \frac{3}{2} + \frac{E_{G_0}}{2kT} \right) \cdot \frac{dT}{T}$$

$$\therefore \frac{dn_i}{n_i} = \left( 1.5 + \frac{E_{G_0}}{2kT} \right) \cdot \frac{dT}{T} \quad \dots(iii)$$

At  $T = 300^\circ K$ ,  $kT = V_T = 26 \text{ mV} = 0.026 \text{ V}$

**Case-I: For Germanium (Ge):**

$$\left( \frac{dn_i}{n_i} \right) = \left[ 1.5 + \frac{0.785}{0.052} \right] \left( \frac{1}{300} \right) \times 100\%$$

$\therefore \sigma_{int}$  increases = 5.53% per degree rise in temperature

**Case-II: For Silicon (Si):**

From equation (iii) we have,

$$\left( \frac{dn_i}{n_i} \right) = \left[ 1.5 + \frac{1.21}{0.052} \right] \left( \frac{1}{300} \right) \times 100\%$$

$\therefore \sigma_{int}$  increases = 8.25% per degree rise in temperature.

**Q7** Derive the expression for the Fermi-Energy level ( $E_F$ ) in an intrinsic semiconductor. For the same effective masses of holes and electrons, show that ' $E_F$ ' lies in the centre of the forbidden energy band. Draw the appropriate diagram for this.

**Solution:**

Fermi level is the energy level where probability of finding electrons is 50% (when temperature is not  $0^\circ K$ ).

As we know that the concentration of electrons in C.B is given by,

$$n = N_c e^{-(E_c - E_F)/kT} \quad \dots(i)$$

where,

$N_c$  = a material constant

$$\therefore N_c = 2 \left[ \frac{2\pi m_n \bar{k} T}{h^2} \right]^{3/2} \quad \dots(ii)$$

and similarly the concentration of holes in the V.B is given by,

$$p = N_v e^{-(E_F - E_v)/kT} \quad \dots(iii)$$

where,

$N_v$  = a material constant

$$\therefore N_v = 2 \left[ \frac{2\pi m_p \bar{k} T}{h^2} \right]^{3/2} \quad \dots(iv)$$