POSTAL Book Package 2023

ESE

Electronics Engineering

Conventional Practice Sets

Electronic Devices and Circuits

Contents

MADE EASY Publications

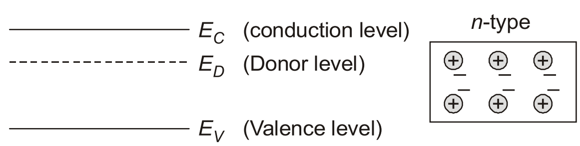
1 CHAPTER Basic Semiconductor Physics

Q.1 What is doping? Give the advantage of doping.

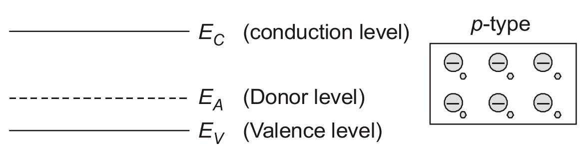
Solution:

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.

Q.2 Two scattering i.e. impurity and lattice are existing in a semiconductor and if only one mechanism is present, the mobility will be 250 cm^2/V-sec and if other scattering mechanism only present then the mobility is 500 cm^2/V-sec. Find the resultant mobility.

Solution:

$$\frac{1}{\mu} = \frac{1}{\mu_1} + \frac{1}{\mu_2} = \frac{1}{250} + \frac{1}{500}$$

$$\mu = 166.67 \text{ cm}^2/\text{V-sec}$$

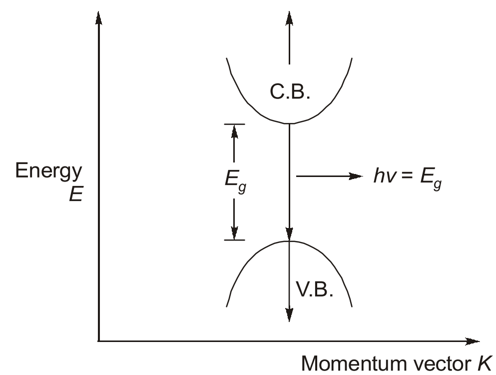
Q.3 Distinguish between direct and indirect bandgap materials with suitable *r-k* diagrams.
How would you make an intrinsic GaAs sample *n*-type or *p*-type? What happens when GaAs is doped with Si? What is the nature of bonding in GaAs?

Solution:

Direct Band Gap Material:

In a direct band gap semiconductor such as GaAs, an electron in the conduction band can fall to an empty state in the valance band, giving off the energy difference E_g as a photon of light.

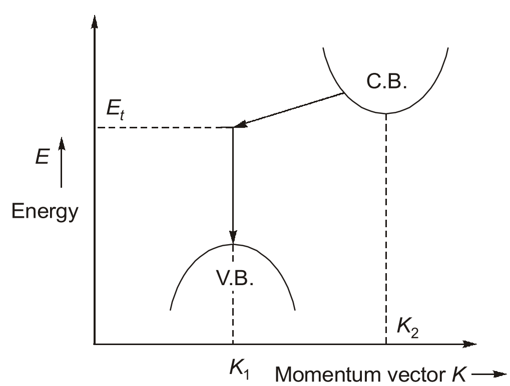
- This property of direct band gap material can be used in designing devices requiring light output. *r-k* diagram for direct band gap material is as.



- These are the materials for which lowest energy state of conduction band and higher energy state of valance band occurs for **"same value of momentum"**.
- In these type of materials the recombination occurs without the help of an external agent.
  No second particle is emitted.

Indirect Band Gap Material:

An electron in lowest energy conduction band of an indirect semiconductor can not fall directly to the valance band of maximum energy but also **"undergo a momentum change"** as well as **changing its energy**.
r-*k* diagram for indirect band gap material is



- These are the materials in which higher most energy state of valance band and lower most energy state of conduction band occurs for different values of momentum.
- The probability of recombination is very less.
- So an external agent (Au) is required.
- In these materials recombination occurs in following steps:
  1. Gold create trap levels (energy state which has momentum value K_1).
  2. As soon as any electron jumps from C.B. to trap level it's momentum value becomes K_1.
  3. Now it falls and recombine with hole having same value of momentum K_1 in opposite direction.
- Energy is released mainly in the form of heat.
- A second particle phonon is emitted when electron falls from C.B. to trap energy state E_t and this phonon collides with lattice crystal and loss it's energy in the form of heat.
- In GaAs $\rightarrow$ Ga is from III group and As is from V group.
- So in order to make GaAs *n*-type we will increase the concentration As(V group) in GaAs compare to Ga.
- In order to make GaAs *p*-type, we will increase the concentration (doping) of Ga compare to As in GaAs.
- In GaAs $\rightarrow$ bonding is mixed bonding covalent as well as ionic character.
- Ionic bonding is due to difference in placement of Ga and As atoms in the periodic table.

Q4 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 × 10^{-19} Joules)

Solution:

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

Where,
E = Energy bandgap = 0.62 eV (given)
h = Planck constant = 6.626 × 10^{-34} Joule-sec
c = Velocity of light in free space = 3 × 10^{8} m/sec
λ = Wavelength

So,
$$\lambda = \frac{hc}{E} = \frac{6.626\times10^{-34}\times3\times10^{8}}{0.62\times1.6\times10^{-19}}$$
$$\lambda = 2.004 \times 10^{-6} = 2.004\ \mu\text{m}$$

Q5 (a) Explain "The Mass-Action Law"?
(b) What is the Law of electrical neutrality of a semiconductor?
(c) A small number of readily ionized donors N_D are added to an intrinsic semiconductor, such that $N_D << n_i$, where n_i is the intrinsic carrier concentration. Then by using the concept involved in part (a) and (b); find the free electron and hole concentration in the semiconductor. What is the type of material?

Solution:

(a) Mass-Action Law:
In an extrinsic semiconductor, under thermal equilibrium, the product of the free negative and positive concentrations is a constant and is independent of the amount of donor and acceptor impurity doping. This relationship is called **"Mass-Action Law"** and is given by:

$$\boxed{np = n_i^2} \quad \text{...(i)}$$

where, n_i is the intrinsic concentration and is a function of temperature.
⇒ This law is used to determine the concentration of minority carriers in a semiconductor.

(b) Since, the semiconductor is electrically neutral, so according to the Law of electrical neutrality – "the magnitude of the positive charge density i.e. $(N_D + p)$ must equal that of the negative charge concentration i.e. $(N_A + n)$. So,

$$\boxed{N_D + p = N_A + n} \quad \text{...(ii)}$$

where,
N_D = Positive charges/m^3 and is contributed by donor ions.
N_A = Negative charges/m^3 and is contributed by acceptor ions.

(c) Here, let us assume that free electron and free hole concentration is 'n_0' and 'p_0' respectively.
So, from equation (i) and (ii) as in part (a) and (b) we have,

$$n_0 p_0 = n_i^2 \quad \text{...(iii)}$$

and
$$n_0 + N_A = p_0 + N_D \quad \text{...(iv)}$$

Substituting the value of 'p_0' from equation (iii) into equation (iv) yields,

$$n_0 + N_A = \frac{n_i^2}{n_0} + N_D$$

$$\Rightarrow \quad n_0^2 - (N_D - N_A)n_0 - n_i^2 = 0 \quad \text{...(v)}$$

$$\therefore \quad n_0 = \left(\frac{N_D - N_A}{2}\right) + \frac{1}{2}\sqrt{(N_D - N_A)^2 + 4n_i^2} \quad \text{...(vi)}$$

Neglecting the negative terms of n_0 as 'n_0' has the positive value.

Similarly, 'p_0' is obtained by putting the value of 'n_0' from equation (iii) into equation (iv) and thus we get 'p_0' as:

$$p_0 = -\left(\frac{N_D - N_A}{2}\right) + \frac{1}{2}\sqrt{(N_D - N_A)^2 + 4n_i^2} \quad \text{...(vii)}$$

Neglecting the negative term of 'p_0' as 'p_0' has +ve values.

Also given that,

$$N_D << n_i$$

and since donors are added so,

$$N_D > N_A$$

So, we have, $N_A < N_D << n_i$ ...(viii)

By using expression (viii) in the equation (vi) and (vii) then we may get,

$$n_0 = n_i + \left(\frac{N_D - N_A}{2}\right)$$

and
$$p_0 = n_i - \left(\frac{N_D - N_A}{2}\right)$$

This type is called Intrinsic compensated material. This state can also occur at high temperature when, $n_i >> (N_D - N_A)$.

Q.6 **(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 (μ) are not independent. The relationship between the D and μ is given by the **'Einstein Relationship'**, which is mathematically given as,

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

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

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

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

At room temperature i.e. $T = 300°K$,

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

and $\mu = 39\,D$

∴ D_n 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,

$$T = 300°K$$

and $E - E_F = 0.2$ eV

i.e. $E = E_F + 0.2$ eV

also, $V_T = K \cdot T = 0.026$ V

∴ Probability of finding an electron 0.2 eV above the Fermi level is given by,

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

$$\approx 0.0004561$$