Module / Unit -1

p - n Diode

Review Questions:

1. In a n-semiconductor, hole concentration is less than its intrinsic value. Discuss.
2. How is depletion region formed across a p-n junction? What type of charges are present in the depletion region when junction is not biased?
3. Draw potential energy diagrams for a forward as well as a reverse biased p-n junction and explain the flow of currents in both the cases.
4. The width of depletion region varies with applied voltage. Explain.
5. Explain the zener and avalanche processes of p-n junction break down. How does a zener diode stabilize voltage in a circuit? Draw the circuit and explain.

Problems:

1.1 p-silicon has resistivity of 100 Ωcm. The other parameters for silicon are:
Intrinsic carrier density, $n_i = 10^{10}$ cm^{-3},
Hole mobility, $\mu_p = 500$ $cm^2/v.s.$
Electron mobility, $\mu_n = 1200$ $cm^2/v.s.$
Calculate the number of electrons for every 5000 million holes in the semiconductor.

Solutions: The hole density in p-semiconductor is related to resistivity as

$$\frac{1}{\rho} = p.q.\mu_p$$

Therefore,

$$\frac{1}{100} = p \times 1.6 \times 10^{-19} \times 500$$

Or p = 1.25 X 10^{14} / cm^3

The electron density can be obtained from the relation,

$n.p = n_i^2$

or $$n = \frac{n_i^{\,2}}{p} = \frac{10^{20}}{1.25 \times 10^{14}} = 8 \times 10^5 / cm^3$$

Since for every 1.25 X 10^{14} holes, there are 8 X 10^5 electrons, therefore 5000 million (= 5 X 10^9) holes will have

$$\frac{8 \times 10^5 \times 5 \times 10^9}{1.25 \times 10^{14}} = \frac{40}{1.25} = 32 \text{ electrons}$$

1.2 The resistivity of a silicon sample is 100 Ω cm. Calculate the hole density if silicon is p-type and electron density if it is is n-type.

Charge mobilities are :

μ_p = 500 cm^2/v.s

μ_n = 1300 cm^2/v.s

Solution:

In case the silicon is p-type, its conductivity σ , or resistivity ρ is,

$$\sigma = \frac{1}{\rho} = p.q.\mu_p$$

Where p is the hole concentration (same as hole density)

Then

$$p = \frac{1}{\rho.q.\mu_p} = \frac{1}{100 \times 1.6 \times 10^{-19} \times 500}$$

Or , p = 1.25 X 10^{14} cm^{-3}

And in the case, the silicon is n-type, the resistivity is

$$\frac{1}{\rho} = n.q.\mu_n$$

Then the electron density n is,

$$n = \frac{1}{\rho.q.\mu_n} = \frac{1}{100 \times 1.6 \times 10^{-19} \times 1300}$$

Or, n = 4.8 10^{13} cm^{-3}

1.3 A germanium p-n step junction has donor density $N_D = 10^{15}$/ cm^3 on n-side and acceptor density $N_A = 10^{17}/cm^3$ on p-side. Calculate the height of the potential barrier at the junction if intrinsic carrier density n_i, equals 2.5 X 10^{13} /cm^3. Assume kT/q = 0.026V.

Solution:

The value of barrier potential is expressed as,

$$V_B = \left(\frac{kT}{q}\right) \ln \left(\frac{N_A N_D}{n_i^{\,2}}\right)$$

Where N_A and N_D are respectively acceptor and donor densities on p and n-sides and n_i is intrinsic carrier density.

Then,

$$\begin{aligned} V_B &= 0.026 \ln \left[\frac{10^{17} \times 10^{15}}{\left(2.5 \times 10^{13}\right)^2}\right] \\ &= 0.026 \ln \left(1.6 \times 10^5\right) \\ &= 0.026 \times 11.98 \end{aligned}$$

Or, V_B = 0.311 volt

1.4 A silicon p-n diode has abrupt junction formed with acceptor ion density of $3X10^{15} cm^{-3}$ on p-side and donor density of $2X10^{14}\ cm^{-3}$ on n-side of the junction. Calculate the barrier potential height and width of the depletion region. Other data for silicon is intrinsic carrier density = $2X10^{10}\ cm^{-3}$, voltage equivalent of thermal energy, kT/q = 0.026 V, permittivity of silicon, Є (=$Є_r$, $Є_o$) = 10^{-12} farad/cm.

Solution:

The barrier potential is expresses as,

$$V_B = \frac{kT}{q}\ \ln\left(\frac{N_A\,N_D}{n_i^{\,2}}\right)$$

Therefore,

$$V_B = 0.026\ \ln\left[\frac{3\times10^{15}\ \times\ 2\times10^{14}}{\left(2\ \times10^{10}\right)^2}\right]$$
$$= 0.026\ \ln\left(1.5\ \times10^{9}\right)$$
$$= 0.026\ \times 21.021$$

Or, V_B = 0.54 volt

The depletion width for an unbiased p-n junction is given by

$$W = \left[\left(\frac{2\in}{q}\right)\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\right]^{1/2}\ V_B^{\ 1/2}$$

On substituting values of various parameters,

$$W = \left[\left(\frac{2\times10^{-12}}{1.6\times10^{-19}}\right)\left(\frac{1}{3\times10^{15}} + \frac{1}{2\times10^{14}}\right)\right]^{1/2}\ (0.54)^{1/2}$$

0r W = 1.89 X 10^{-4} Cm.

1.5 A germanium diode is formed with donor density, N_D=10^{15}cm$^{-3,}$ and acceptor density N_A 1.5 X 10^{16} . Avalanche breakdown occurs in the diode when the field reaches 2.20 kV/cm. Calculate the breakdown voltage. The permittivity of the semiconductor Є (=$Є_r$, $Є_o$) = 10^{-12} farad/cm.

Solution:

The externally applied voltage, V, gives rise to maximum electric field, E_{max}, at the junction. And E_{max} is expressed as,

$$E_{\max} = \left[\frac{2qN_A N_D}{\in (N_A + N_D)} \right]^{1/2} (V_B - V)^{1/2}$$

Here V_B is built-in-voltage (same as barrier height) and Є is permittivity of the semiconductor.

Now, V_B << V, and junction breakdown occurs at reverse bias therefore, taking applied voltage as negative and neglecting V_B, we have

$$E_{\max} = \left[\frac{2qN_A N_D}{\in (N_A + N_D)} V \right]^{1/2}$$

Now, Є (=$Є_0$, $Є_r$) is the permittivity

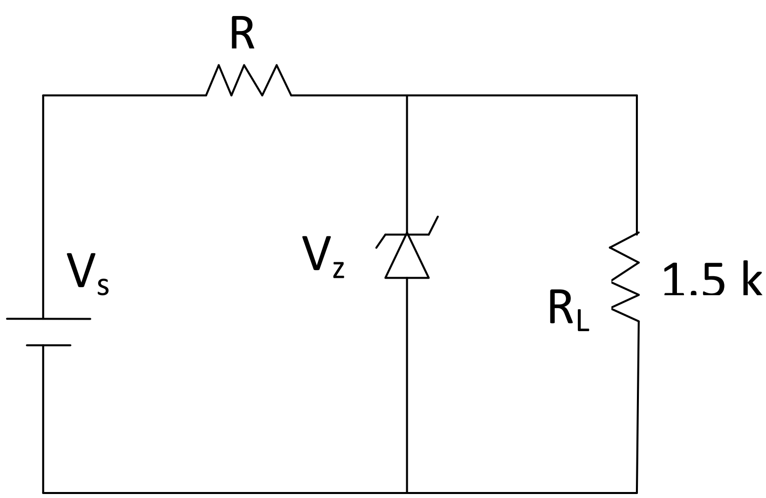
From the above equation

$$V = \frac{E_{\max}{}^2 \in (N_A + N_D)}{2qN_A N_D}$$

$$or\, V = \frac{(2.2 \times 10^5)^2 \times 10^{-12} (1.5 \times 10^{16} + 10^{15})}{2 \times 1.6 \times 10^{-19} \times 1.5 \times 10^{16} \times 10^{15}}$$

Or, V = 161.33 volts

1.6 The circuit shown uses a 9.0V zener diode. If the load resistance R_L is equal to 1.5 kΩ, and the dc source equals 24V, find the maximum value of resistor R required to maintain a constant voltage of 9V across the load.



Solution:

The voltage drop across load R_L will be constant and equal to zener voltage V_Z as long as zener diode works in reverse bias with a voltage equal to or larger than V_Z,

The voltage drop across resistor R is,

$R.I = V_S - V_Z$

Where, I is the current through R. The minimum current required through load R_L to maintain a voltage of V_Z is equal to V_Z/R_L.

In the limit this is also the current through resistor R. Then

$$R = (V_S - V_Z)\frac{R_L}{V_Z}$$

$$or, \ R = \frac{(24-9)\times 1.5\times 10^3}{9}$$

$$or, \ R = 2.5\,k\Omega$$