ISSN (ONLINE) : 2395-695X
ISSN (PRINT) : 2395-695X
Available online at www.ijarbest.com

International Journal of Advanced Research in Biology, Ecology, Science and Technology (IJARBEST)
Vol. 1, Issue 3, June 2015

Monograph On Semi Conductor Diodes

Christo Ananth,

Assistant Professor, Department of ECE, Francis Xavier Engineering College, Tirunelveli, India

PN junction diode, Current Equations, Diffusion and drift current densities, forward and reverse bias characteristics, Switching characteristics.

1.1 PN JUNCTION DIODE:

pn junction diode is formed by 2 blocks of semiconductor material : → p type material and n type material

p region	:	holes	→	majority carriers
		electrons	→	minority carriers
n region	:	electrons	→	majority carriers
		holes	→	minority carriers

* Holes from p-side diffuse across the junction and recombine with electrons in n- side.

* Free electrons that cross the junction create positive ions (because the atom loses one electron) on n-side.

* Diffusion of holes in p-material creates negative ions (because the atom gains one hole)

* Since negative ions are created on p-side of junction, region close to junction acquires negative charge.

* Similarly positive ions created on n-side gives positive charge near the junction.

Shape of Charge density(□) depends on doping level of diode.

* As these charges build up, a point is reached where total negative charge in p-region repels diffusion of electrons into p-region and diffusion stops. At this point, positive ions on n-side and negative ions on p-side are **immobile**.

* Region near the junction is called **Depletion region** or **space charge region** or **transition region** (Width of depletion region = 1 □ m)

* Since there are many positive charges and many negative charges on opposite sides of pn junction, an **electric field** is formed.

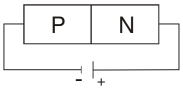
* External energy must be applied to move an electron through electric field.

External energy depends on Potential difference of electric field across depletion region.

* Potential difference required to move electrons through electric field is called "**Barrier potential (V_0)**"

[V_0= 0.3V for Ge and V_0 = 0.7V for Si]

* When negative terminal is connected to p-side and positive terminal is connected to n-side, the device is said to be "**REVERSE BIASED**"



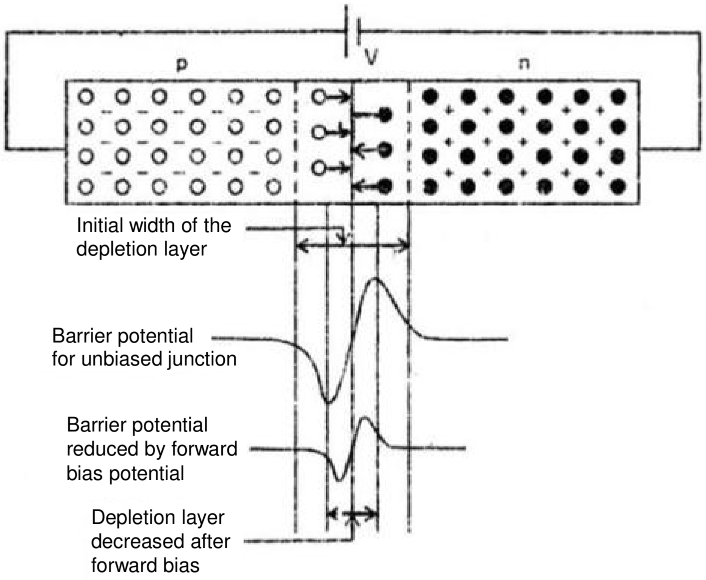


Fig 1.3 Forward Biased *pn* Junction

* When **FORWARD BIAS** is applied to *pn* Junction, holes in p-side are **repelled** by positive terminal of battery and flow **towards** junction.
* Similarly electrons in n-side are **repelled** by negative terminals of battery and move **towards** junction.
* These electrons and holes recombine with ions near boundary and reduce depletion layer width ⇒BARRIER POTENTIAL REDUCTION
* If applied voltage is further increased, barrier potential disappears and charge carriers can easily **flow across** junction.

* Collision and generation of carriers results in large amount of reverse current called as “**REVERSE BREAKDOWN**”. Reverse breakdown occurs at particular reverse voltage for pn-junction known as “**REVERSE BREAKDOWN VOLTAGE**”.

x

1.3 CHARACTERISTICS OF pn JUNCTION - DIODE
(V-I CHARACTERISTICS)
[FORWARD AND REVERSE CHARACTERISTICS]

(A) CIRCUIT DIAGRAM TO OBTAIN FORWARD CHARACTERISTICS OF DIODE:

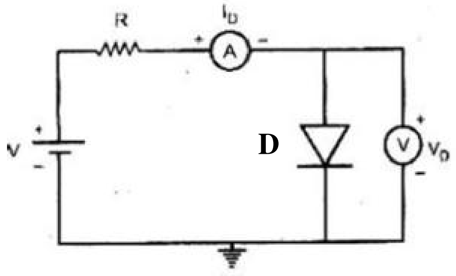


Fig 1.5.CIRCUIT DIAGRAM TO OBTAIN FORWARD CHARACTERISTICS OF DIODE

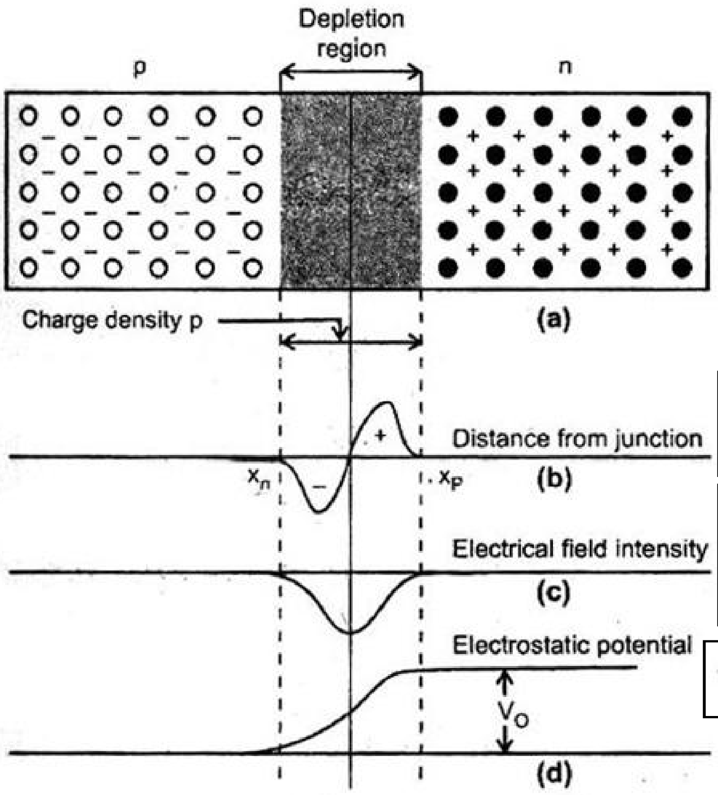
* Resistor →limits forward current to a value that will not heat the diode.

* Ammeter is connected to measure diode current I_D and voltmeter measures voltage across it.

* By varying dc Voltage source, voltage V_D and current I_D through diode can be measured.

* When applied voltage is 0, Voltage across diode remains 0 ⇒ no forward current. When applied voltage is increased gradually, forward current and voltage across diode gradually increases. Further more, Voltage across diode increases rapidly to barrier potential and forward current increases rapidly. Christo Ananth et al.[1] discussed about principles of Semiconductors which forms the basis of Electronic Devices and Components. Christo Ananth et al. [2] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing. The proposed system has a fuzzy filter which has the parallel fuzzy inference mechanism, fuzzy mean process, and a fuzzy composition process. In particular, by using no-reference Q metric, the particle swarm optimization learning is sufficient to optimize the parameter necessitated by the particle swarm optimization based fuzzy filter, therefore the proposed fuzzy filter can cope with particle situation where the assumption of existence of "ground-truth" reference does not hold. The merging of the particle swarm optimization with the fuzzy filter helps to build an auto tuning mechanism for the fuzzy filter without any prior knowledge regarding the noise and the true image. Thus the reference measures are not need for removing the noise and in restoring the image. The final output image (Restored image) confirm that the fuzzy filter based on particle swarm optimization attain the excellent quality of restored images in term of peak signal-to-noise ratio, mean absolute error and mean square error even when the noise rate is above 0.5 and without having any reference measures. Christo Ananth et al.[3] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.

(D)CALCULATION OF DEPLETION WIDTH:



$$\frac{d^2V}{dx^2} = \frac{-\square}{\square}$$

$$E = \frac{-dV}{dx}$$

$$E = \int + \frac{\sqcup}{\square} dx$$

$$V = \int - E\,dx$$

Fig 1.8

a) pn JUNCTION DIODE
b) CHARGE DENSITY IN DEPLETION REGION
c) ELECTRIC FIELD INTENSITY IN DEPLETION REGION
d) ELECTROSTATIC POTENTIAL IN DEPLETION REGION

* Charge density is **negative** to left of pn junction and **positive** to right of pn junction.

* Electric field in depletion region establishes potential barrier V which obstructs flow

of electrons and holes across junction.

No. of holes in p-side = No.of acceptor ions $\Rightarrow$ $\boxed{p = N_A}$

No.of electrons in n-side = No.of donor ions $\Rightarrow$ $\boxed{n = N_D}$

$$V = \frac{qN_A x^2}{2\varepsilon} + Cx + D; \rightarrow ④, \text{ C and D } \rightarrow \text{integration constants}$$

TO FIND C AND D :

Boundary conditions : $\boxed{\text{At } x = 0 \text{ ; V} = 0}$ and at $x \le x_p$, V= constant

$$\boxed{\Rightarrow \frac{dV}{dx} = 0 \qquad at\ x = x_p}$$

At $x = 0$,

$$V = \frac{qN_A x^2}{2\varepsilon} + Cx + D \Big|_{x=0}$$

$$V = 0 + 0 + D$$

$0 = 0 + D$ (∵ By boundary condition①, At $x = 0$, V= 0)

$$\boxed{D = 0}$$

$$\frac{dV}{dx} = \frac{qN_A}{2\varepsilon} 2x + C$$

$$= \frac{qN_A x}{\varepsilon} + C$$

$\boxed{\text{At } x = x_p, \quad \frac{dV}{dx} = 0}$ (By boundary condition②)

$$0 = \frac{qN_A x_P}{\varepsilon} + C$$

$$\boxed{C = \frac{-qN_A x_P}{\varepsilon}}$$

$$\therefore ④ \Rightarrow V = \frac{qN_A x^2}{2\varepsilon} - \frac{qN_A x_p x}{\varepsilon} + 0$$

$$V = \frac{qN_A x^2}{} - \frac{qN_A x_p}{\varepsilon} x$$

$$V = \frac{qN_A}{\varepsilon} \left(\frac{x^2}{2} - x x_p \right)$$

$$= \frac{q}{2\varepsilon}\left(N_D x_n^{\,2}\left(1+\frac{N_D}{N_A}\right)\right)$$

$$x_n^{\,2} = \frac{2\varepsilon V_O}{qN_D\left(1+\dfrac{N_D}{N_A}\right)} = \frac{2\varepsilon V_O N_A}{qN_D(N_A+N_D)}$$

Similarly $x_p^{\,2} = \dfrac{2\varepsilon V_o N_D}{qN_A(N_A+N_D)}$

Depletion width = $x_n + x_p$

$$= \left[\frac{2\varepsilon V_O N_A}{qN_D(N_A+N_D)}\right]^{1/2} + \left[\frac{2\varepsilon V_O N_D}{qN_A(N_A+N_D)}\right]^{1/2}$$

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

$$= \frac{(2\varepsilon V_O)^{1/2}\,(N_A+N_D)}{q^{1/2}(N_A+N_D)^{1/2}\,N_A^{1/2}N_D^{1/2}}$$

$$\boxed{\text{Depletion width } = \left[\frac{2\varepsilon V_0(N_A+N_D)}{qN_AN_D}\right]^{1/2}}$$

x

$$\boxed{V_0 = \frac{E_0}{q}}$$

In p region, position of Fermi level

$$E_{FP} = E_{ip} - KT \ln \frac{N_A}{n_i}$$

Similarly $E_{Fn} = E_{in} + KT \ln \frac{N_D}{n_i}$

Since Fermi level is constant,

$$E_{FP} = E_{Fn} = E_F$$

$$E_{ip} - KT \ln \frac{N_A}{n_i} = E_{in} + KT \ln \frac{N_D}{n_i}$$

$$E_0 = E_{ip} - E_{in}$$

$$= KT \left[\ln \frac{N_A}{n_i} + \ln \frac{N_D}{n_i} \right]$$

$$\boxed{E_0 = KT \ln \left(\frac{N_A N_D}{n_i^2} \right)}$$

$$V_0 = \frac{E_0}{q} = \frac{KT}{q} \ln \left(\frac{N_A N_D}{n_i^2} \right)$$

$$V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$$

Assuming complete ionization,

$$p_{p0} = N_A$$
$$n_{n0} = N_D$$

$$V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$$

$$V_0 = V_T \ln \frac{p_{p0} n_{n0}}{n_i^2}$$

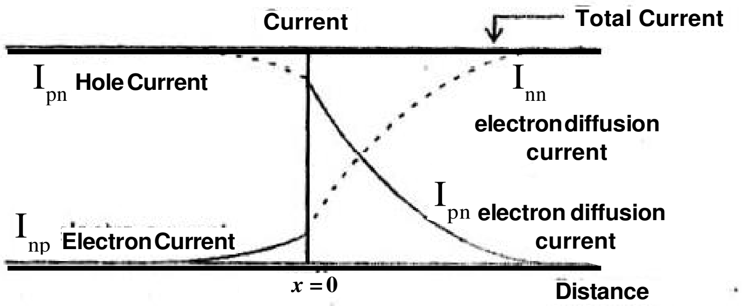


Fig .1.12. CURRENT COMPONENTS

✶ Consider forward biased pn junction. By applied voltage, holes are injected into n-side and electrons into p-side of diode.

Let $p_n'(x) \rightarrow$ increase in minority carrier concentration above equilibrium

$p_{n0} \rightarrow$ hole concentration in n-side at equilibrium

$p_n \rightarrow$ decrease in hole concentration due to recombination.

$$\boxed{p_n'(x) = p_n - p_{n0}}$$

Continuity Equation states that

Rate of change of hole concentration = Sum of all increase in hole concentration

$$\frac{dp}{dt} = \frac{p_{n0} - p_n}{\tau_p} - \frac{1}{q}\frac{dJ_p}{dx}$$

For steady state ,

$$\frac{dp}{dt} = 0$$

$$\therefore 0 = \frac{p_{n0} - p_n}{\tau_p} - \frac{1}{q}\frac{dJ_p}{dx}$$

$$\frac{1}{q}\frac{dJ_p}{dx} = \frac{(p_{n0} - p_n)}{\tau_p}$$

$$\frac{dJ_p}{dx} = \frac{q(p_{n0} - p_n)}{\tau_p} \rightarrow ①$$

$$k_2 = 0$$

At x =0

$$p_n'(0) = k_1 \Rightarrow \boxed{k_1 = p_n'(0)}$$

$$\therefore p_n'(x) = p_n'(0)\, e^{-x/L_P} + 0$$

$$= p_n'(0)\, e^{-x/L_P}$$

$$= (p_n(x) - p_{n0})\, e^{-x/L_P} \rightarrow \text{③}$$

Diffusion current,

$$I_{pn}(x) = AJ_p$$

$$= A\left(-q D_p \frac{dp_n}{dx}\right)$$

$$= -q AD_p \frac{d}{dx}(p_n) \rightarrow \text{④}$$

We have $p_n'(x) = p_n - p_{n0}$

$$p_n = p_n'(x) + p_{n0}$$

$$\frac{dp_n}{dx} = \frac{dp'_n(x)}{dx}$$

$$\therefore \text{④} \Rightarrow I_{pn}(x) = -q A D_p \frac{dp_n'(x)}{dx}$$

$$= -qAD_P \frac{d}{dx}\left[\left(p_n(x) - p_{n0}\right) e^{-x/L_p}\right]$$

$$(\because \text{from ③})$$

$$I_{pn}(x) = -\frac{qAD_p p_n'(0) e^{-x/L_p}}{-L_p}$$

$$I_{pn}(x) = \frac{qAD_p}{Lp} p'_n(0) e^{-x/L_p}$$

$$I_{pn}(x) = \frac{AqD_P}{L_P}(p_n(x) - p_{n0}) e^{-x/L_p} \quad (\because \textit{from} \text{ ③})$$

Minority diffusion current crossing junction at $x = 0$ is

$$\ln\left(\frac{p_n(0)}{p_{p0}}\right) = \frac{-1}{V_T}(V_0 - V)$$

$$\boxed{p_n(0) = p_{po}\ e^{-(V_0-V)/V_T}} \qquad \rightarrow ⑤$$

By **Law of Junction,**

$$V_0 = V_T \ln \frac{p_{p0}}{p_{n0}}$$

$$\frac{V_0}{V_T} = \ln \frac{p_{p0}}{p_{n0}}$$

$$e^{V_0/V_T} = \frac{p_{p0}}{p_{n0}}$$

$$\boxed{p_{p0} = p_{n0}\ e^{V_0/V_T}} \qquad \rightarrow ⑥$$

Subs ⑥ in ⑤,

$$p_n(0) = p_{n0}\, e^{V_0/V_T - (V_0-V)/V_T}$$

$$= p_{n0} e^{(V_0 - V_0 + V)/V_T}$$

$$\boxed{p_n(0) = p_{n0} e^{V/V_T}}$$

We know that

$$I_{pn}(0) = \frac{AqD_p}{L_p} p_n{}'(0)$$

$$= \frac{AqD_p}{L_p} (p_n(0) - p_{n0})$$

$$= \frac{AqD_p}{L_p} (p_{n0}\, e^{V/V_T} - p_{n0})$$

$$\boxed{I_{pn}(0) = \frac{AqD_p p_{n0}}{L_p} (e^{V/V_T} - 1)}$$

$$\boxed{I_{np}(0) = \frac{AqD_n n_{p0}}{L_n} (e^{V/V_T} - 1)}$$

□ =2 for silicon

For forward bias voltage,

Current equation is

$$\mathrm{I} = \mathrm{I}_o e^{V/\square V_T}$$

For reverse bias voltage,

Current equation is

$$\mathrm{I} = I_0 (e^{-V\square V_T} - 1)$$

Note:

$$I = I_0 \ (e^{V/V_T} - 1)$$

$$I = Aq\left(\frac{D_p}{L_P N_D} + \frac{D_n}{L_n N_A}\right) n_i^2 [e^{V/V_T} - 1]$$

$$J = \frac{I}{A} = qn_i^2 \left(\frac{D_p}{L_P N_D} + \frac{D_n}{L_n N_A}\right) [e^{V/V_T} - 1]$$

$$J = qn_i^2 \left(\frac{D_p}{\sqrt{D_p \square_p}\, N_D} + \frac{D_n}{\sqrt{D_n \square_n}\, N_A}\right) [e^{V/V_T} - 1]$$

$$J = qn_i^2 \left(\sqrt{\frac{D_P}{\square_p}} \frac{1}{N_D} + \sqrt{\frac{D_n}{\square_n}} \frac{1}{N_A}\right) [e^{V/V_T} - 1]$$

From this

$$\boxed{\begin{aligned} J_p &= \frac{qn_i^2}{N_D} \sqrt{\frac{D_p}{\square_p}} \left(e^{V/V_T} - 1\right) \\ J_p &= \frac{qn_i^2}{N_A} \sqrt{\frac{D_n}{\square_n}} \left(e^{V/} \quad - 1\right) \end{aligned}}$$

x

PROBLEMS:

1. Consider silicon *pn* junction at T= 300K so that n_i=1.5×10 ^{10}cm^{-3}.Assume n-type doping is 1×10^{16}cm^{-3}and assume forward bias of 0.60V is applied to pn junction. Calculate minority carrier hole concentration at the edge of space charge region.

Solution:

Given T = 300K

n_i = 1.5 ×10^{10}cm^{-3}

N_d= 1×10 ^{16}cm^{-3}

$D_p = 10\text{cm}^2/\text{s}$

$n_i = 1.5\times10^{10}\text{cm}^{-3}$

$□_{p0} = □_{n0} = 5\times10^{-7}$ s

$□_r = 11.7$

SOLUTION:

Given : $N_a=N_d=10^{16}\text{cm}^{-3}$, $D_n=25\times10^{-4}$m/s, $D_p=10\times10^{-4}$m/s

$n_i=1.5\times10^{10}\text{cm}^{-3}$, $□_{po}=□_{n0}=5\times10^{-7}$s, $□_r = 11.7$, T=300K

$$J_0 = \frac{qn_i^2}{N_D}\sqrt{\frac{D_p}{□_p}} + \frac{qn_i^2}{N_A}\sqrt{\frac{D_n}{□_n}}$$

$$= \left[\frac{1.6\times10^{-19}\times(1.5\times10^{10}\times10^{-6})^2}{10^{16}\times10^{-6}}\right]\sqrt{\frac{10\times10^{-4}}{5\times10^{-7}}} + \left[\frac{1.6\times10^{-19}\times(1.5\times10^{10}\times10^{-6})^2}{10^{16}\times10^{-6}}\right]\sqrt{\frac{25\times10^{-4}}{5\times10^{-7}}}$$

$$\boxed{J_0 = 4.15\times10^{-11} A/cm^2}$$

X

PROBLEM:3

Consider silicon pn junction diode at T =300K. Obtain Acceptor concentration and Donor concentration such that J_n=20A/cm ^{2} and J_p=5A/cm ^{2} at V_a=0.65V, D_n=25cm²/s, D_p=10cm²/s, $□_{p0}=□_{n0}=5\times10^{-7}$s, $n_i=1.5\times10^{10}\text{cm}^{-3}$

Solution:

Given : T = 300K, J_n =20 A/cm^2, J_p =5A/cm^2, V_a =0.65V, D_n =25cm^2/s, D_p =10cm^2/s,

$□_{po}=□_{no}=5\times10^{-7}$s , $n_i = 1.5\times10^{10}\text{cm}^{-3}$

Electron diffusion current density,

$$J_n = \frac{qn_i^2}{N_A}\sqrt{\frac{D_n}{□_n}}(e^{V/V_T}-1)$$

$$20 = \frac{(1.6\times10^{-19})(1.5\times10^{10})^2}{N_A}\sqrt{\frac{25}{5\times10^{-7}}}\left(\exp\left(\frac{0.65}{0.026}\right)-1\right)$$

Acceptor concentration $\boxed{N_A=1.01\times10^{15}\text{cm}^{-3}}$

Similarly hole diffusion current density,

$$J_p = \frac{qn_i^2}{N_D}\sqrt{\frac{D_p}{□_p}}(e^{V/V_T}-1)$$

By Diode current equation,

$$I = I_0\left(e^{V/\square V_T} - 1\right)$$

$$\frac{dI}{dV} = I_0 e^{V/\square V_T} \frac{1}{\square V_T}$$

$$\frac{dV}{dI} = \frac{\square V_T}{I_o\, e^{V/\square V_T}} \quad \rightarrow ①$$

We have $I = I_0(e^{V/\square V_T} - 1)$

$$I = I_0 e^{V/\square V_T} - I_0$$

$$I + I_0 = I_0 e^{V/\square V_T} \quad \rightarrow ②$$

Subs ② in①

$$\frac{dV}{dI} = \frac{\square V_T}{I + I_0}$$

For forward bias $I >> I_0$,

$$\boxed{r_f \approx \frac{\square V_T}{I}}$$

x

1.4 DRIFT CURRENT DENSITYAND DIFFUSION CURRENT DENSITIES

(May/June 2010 -8 Marks, May /June 2009 - 8 marks)

DRIFT CURRENT AND DRIFT CURRENT DENSITY:

(I_n&I_p) (J_n & J_p)

* When small electric field is applied across semiconductor bar, holes move in the direction of applied field whereas electrons move in direction opposite to that of applied field.

* Combined effect of movement of holes and electrons constitute electric current which is known as "**DRIFT CURRENT**".

Drift current for electrons $I_n = Aqn \square_n E$ Ampere

Drift current for holes $I_p = Aqp \square_p E$ Amperes

Drift current density due to free electrons $J_n = \frac{I_n}{A} = qn \square_n E$ A/cm^2

Drift current density due to holes $J_p = \frac{I_p}{A} = qp \square_p E$ A/cm^2

where n → no. of free electrons /cm^3

p → no. of free holes / cm^3

x

- * If vertical line y-y is drawn, density of holes on **left side of vertical line >Right side**
- * As $x \uparrow$, Concentration of impurities in semiconductor $\downarrow$.

DIFFUSION CURRENT DENSITY DUE TO HOLES , $J_p \propto \frac{dp}{dx}$

$$J_p = -qD_p \frac{dp}{dx}$$ ($\because$ Concentration gradient is negative as x increases)

D_p = diffusion constant for holes (m^2 /sec)

Similarly $J_n = -qD_n \frac{dn}{dx}$

D_n = diffusion constant for electrons (m^2/sec)

TOTAL CURRENT DENSITY IN SEMICONDUCTOR:

Total current density = Drift current density + Diffusion current density

For p- type,

$$J_p = q\mu_p pE + (-q D_p \frac{dp}{dx})$$

$$\boxed{J_p = q\mu_p pE - q D_p \frac{dp}{dx}}$$

Similarly for n-type semi conductor,

$$\boxed{J_n = q\mu_n nE - q D_n \frac{dn}{dx}}$$

x

TRANSITION OR SPACE CHARGE CAPACITANCE C_T

(Nov /Dec - 2009 - 8 Marks, May/June - 2009 - 2 Marks)

- * When diode is reverse biased, holes in p-side and electrons in n-side drift away from the junction $\Rightarrow$ Thickness of depletion region increases $\Rightarrow$ Capacitance effect is experienced across depletion region.
- * Width of depletion region increases with increasing reverse bias voltage, So Capacitare varies with reverse bias.
- * The Capacitance due to depletion layer is called **Depletion capacitance or Transition capacitance (C_T)**

- In step graded junction, concentration in p and n sides are **uniform** and transition from p to n side is abrupt at the junction
- W_p →Width of depletion region on p-side

  W_n →Width of depletion region on n-side

  $$N_A W_P = N_D W_n$$

  N_A → Acceptor concentration

  N_D → Donor concentration

  $N_A >> N_D$

  $W_p << W_n$

  $\therefore W \approx W_n$

Relation between potential and charge configuration

$$\frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon} \rightarrow ①$$

$$= -\frac{qN_D}{\varepsilon}$$

We know that $E = \frac{-dV}{dx}$

$$\frac{dV}{dx} = -\int \frac{\rho}{\varepsilon} dx \; (\because \text{ from } ①)$$

$$\boxed{\therefore E = \int_{x_0}^{x} \frac{\rho}{\varepsilon}\, dx} \rightarrow ②$$

$$E = \frac{\rho}{\varepsilon} x + C$$

At $x = W$, $E=0$ (Boundary condition)

$$\therefore 0 = \frac{\rho}{\varepsilon} W + C$$

$$\boxed{C = \frac{-\rho}{\varepsilon} W}$$

$$\therefore E = \frac{\rho}{\varepsilon} x - \frac{\rho}{\varepsilon} W$$

$$1 = \frac{qN_D}{2\varepsilon} 2W \frac{dW}{dV_j}$$

$$1 = \frac{qN_D W}{\varepsilon} \frac{dW}{dV_j}$$

$$\frac{dW}{dV_j} = \frac{\varepsilon}{qN_D W} \rightarrow ⑥$$

Subs ⑥ in ⑤,

$$\frac{dQ}{dV} = qN_D A \left(\frac{\varepsilon}{qN_D W} \right)$$

$$\frac{dQ}{dV} = \frac{\varepsilon A}{W}$$

$$\boxed{\therefore C_T = \frac{dQ}{dV} = \frac{\varepsilon A}{W}}$$

X

1.4.6 DIFFUSION CAPACITANCE: (Nov /Dec -2009 - 8 Marks, Nov /Dec - 2010 - 8 Marks, Nov /Dec - 2010 - 2 Marks, May /June - 2011 - 2 Marks, May / June - 2012 - 8 Marks, Nov /Dec -2012 - 2 Marks)

- Diffusion of minority carriers on both sides of junctions gives rise to **Diffusion Capacitance.**
- Carriers get accumulated near the junction before they get diffused and recombine with majority carriers. So holes in n-region and electrons in p-region are separated by thin depletion layer which leads to Capacitance called "**Diffusion Capacitance**".

Diffusion Capacitance, $C_D = \frac{dQ}{dV}$

$$dQ = \tau dI$$

where τ →mean lifetime of holes and electrons

$$\therefore C_D = \tau \frac{dI}{dV}$$

$$= \tau \ g \ (\because \text{conductance } g = \frac{dI}{dV})$$

$$= \frac{\tau}{r}$$

MINORITY CARRIER DENSITY DISTRIBUTION:

- When external voltage is applied to forward biased pn junction, density of minority carriers is large.
- When external voltage is applied to reverse biased pn junction, density of minority carrier diminishes to zero $\Rightarrow$ Reverse saturation current (I_0) is small
- Diode wll conduct only when minority carrier density (p_n-p_{n0} or n_p-n_{p0}) has dropped to zero and current will be determined by external resistance in the diode circuit.

STORAGE AND TRANSITION TIMES:

- Input voltage V_i=V_F is applied to the circuit below:

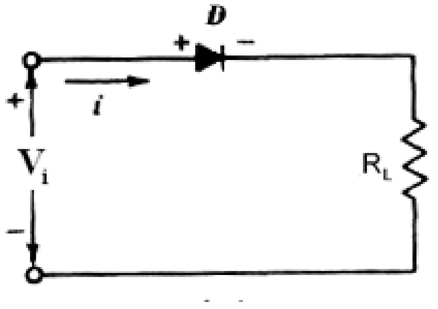


Fig 1.17 DIODE - CIRCUIT

- For a long time, voltage remains the same (upto t_1). R_L is assumed to be large

→Current $i \approx V_F / R_L \approx I_F$

- At time t=t_1, input voltage reverses abruptly and becomes V = -V_R . So current reverses and becomes $i \approx \frac{-V_R}{R_L} \approx -I_R$ until time t=t_2 (shown in (a))

* Time interval which elapses between t_2 and the time when diode has nominally recovered is called "**transition time** (t_t)"

* "**REVERSE RECOVERY TIME** (t_{rr})" is the time interval from current reversal at $t = t_1$ until diode has recovered to certain extent (as shown in(c))

pn DIODE APPLICATIONS:

1. Rectifiers in dc power supplies
2. Clippers in wave shaping circuits
3. Clampers in TV receivers
4. Voltage doublers in CRT
5. **5.** Comparators

x

PROBLEM : 4

Consider silicon pn junction at T=300 K, $N_a=N_d = 10^{16}cm^{-3}$, $n_i = 1.5\times10^{10}cm^{-3}$, $D_n = 25cm^2/s$, $\tau_{po}=\tau_{no} = 5\times10^{-7}s$, $D_p =10cm^2/s$, $\varepsilon_r =11.7$ with an applied forward bias voltage V_a=0.65V. Find electric field intensity required to produce given majority carrier drift current. Assume $\mu_n =1350cm^2/V\text{-}s$

GIVEN:

$N_a= N_d= 10^{16} cm^{-3}$, $D_n=25cm^2/s$, $D_p=10cm^2/s$, $n_i=1.5\times10^{10} cm^{-3}$, $\tau_{p0}=\tau_{n0}=5\times10^{-7}s$, $\varepsilon_r=11.7$,

T=300K, V_a=0.65V, $\mu_n=1350cm^2/V\text{-}s$

$$J_0 = \frac{qn_i^2}{N_D}\sqrt{\frac{D_p}{\tau_p}} + \frac{qn_i^2}{N_A}\sqrt{\frac{D_n}{\tau_n}}$$

$$= qn_i^2\left(\frac{1}{N_D}\sqrt{\frac{D_p}{\tau_p}} + \frac{1}{N_A}\sqrt{\frac{D_n}{\tau_n}}\right)$$

$$=1.6\times10^{-19} + \left(1.5\times10^{10}\right)^2\left(\frac{1}{10^{16}}\sqrt{\frac{10}{5\times10^{-7}}} + \frac{1}{10^{16}}\sqrt{\frac{25}{5\times10^{-7}}}\right)$$

$$\boxed{J_0 = 4.15\times10^{-11}\,A/cm^2}$$

Total current density,

$J = J_0$ (exp (V/V_T) -1)

$$= (4.15\times10^{-11})\left[\exp\left(\frac{0.65}{0.026}\right) -1\right]$$

$$\boxed{J = 3.29\ A/cm^2}$$

Since μ_n is given,

Reverse bias saturation current for pn Junction diode is 1 □ A at 300ºK. Determine its ac resistance at 250 mV forward bias.

SOLUTION:

GIVEN: η=1(Ge), V_T=26mV, $I_0 = 1\times10^{-6}$A, V= 250mV, T=300K

$$r = \frac{\Box\, V_T}{I}$$

$$= \frac{\Box V_T}{I_0\ e^{V/\Box V_T}} \qquad (\because I = I_0\ e^{V/\Box V_T} \text{ for forward bias})$$

$$= \frac{1\times 0.026}{1\times10^{-6}\times e^{250\times10^{-3}/26\times10^{-3}}}$$

a.c. resistance

$$\boxed{r = 1.734\ \Omega}$$

x

PROBLEM 7 :

If reverse saturation current in pn junction silicon diode is 1nA, find applied Voltage for forward current of 0.5 □ A.

SOLUTION:

GIVEN:

I_0=1nA. I = 0.5×10^{-6}A, □ =2 (Si)

$I = I_0 (e^{V/\Box V_T}$-1)

$$0.5\times10^{-6} = 1\times10^{-9}(e^{V/2\times26\times10^{3}} -1)$$

$$0.5\times10^{3} = (e^{V/52\times10^{3}} -1)$$

$$500+1 = (e^{V/52\times10^{3}})$$

$$\ln(501) = \frac{V}{52\times10^{-3}}$$

$$6.216 = \frac{V}{52\times10^{-3}}$$

Applied voltage,

$$\boxed{V = 0.3232V}$$

x

For what voltage will the reverse current in pn junction diode reach 80% of its saturation value at room temperature.

Solution :

For Si, □ =2 and room temperature =300K

$I = 80\%$ of I_0

$I = -0.8I_0$ (∵ it is reverse current)

$I = I_0 \ (e^{V/\square V_T} - 1)$

V_T= 26mV at T = 300K

$$-0.8\ I_0 = I_0 (e^{V/2\times26\times10^{-3}} - 1)$$

$$-0.8\ I_0 + I_0 = I_0 (e^{V/52\times10^{-3}})$$

$$0.2\ I_0 = I_0 \ (e^{V/52\times10^{-3}})$$

$$0.2 = (e^{V/52\times10^{-3}})$$

$$\ln 0.2 = \frac{V}{52\times10^{-3}}$$

$$-1.609 = \frac{V}{52\times10^{-3}}$$

Voltage $\boxed{V = -83.69\ \text{mV}}$ (As diode is reverse biased, voltage is negative)

x

PROBLEM :10

A specimen of metal p-type silicon has resistivity 0.02 Ωcm at 300ºK. Assume $\square_p = 475 m^2/V$- sec, $n_i = 1.45\times10^{10}$ per cm³ Find concentration of holes and electrons.

SOLUTION:

GIVEN

$\square_p = 475 m^2/V - \sec$

$\square = 0.02\ \Omega\ cm = 0.02\times10^{-2}\ \Omega - m$

$n_i = 1.45\times10^{10}/cm^3$
$= 1.45\times10^{16}/m^3$

For p-type silicon,

REFERENCES

[1] Christo Ananth, S.Esakki Rajavel, S.Allwin Devaraj, P.Kannan. "Electronic Devices.", ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-6-5, Volume 2,December 2014, pp:1-300.

[2] Christo Ananth, Vivek.T, Selvakumar.S., Sakthi Kannan.S., Sankara Narayanan.D, “Impulse Noise Removal using Improved Particle Swarm Optimization”, International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE), Volume 3, Issue 4, April 2014,pp 366-370

[3] Christo Ananth, W.Stalin Jacob, P.Jenifer Darling Rosita. "A Brief Outline On ELECTRONIC DEVICES & CIRCUITS.”, ACES Publishers, Tirunelveli, India, ISBN: 978-81-910-747-7-2, Volume 3,April 2016, pp:1-300.