UNIT-I

1. Explain V-I characteristics of PN Junction diode in Forward bias & Reverse bias With Neat circuit diagrams.
2. Explain about diode capacitances?
3. Explain static & dynamic Resistances & derive the derivation of a dynamic resistance?
4. Derive the Expression for current diode Equation?
5. Calculate the dynamic forward & Reverse Resistances of a PN Junction diode when the applied voltage is 0.25V at T=300K given $I_o = 2\mu A$?
6. If the saturation current is 10mA for silicon diodes calculate the forward currents for the Voltage of 0.2 & 0.3V respectively.

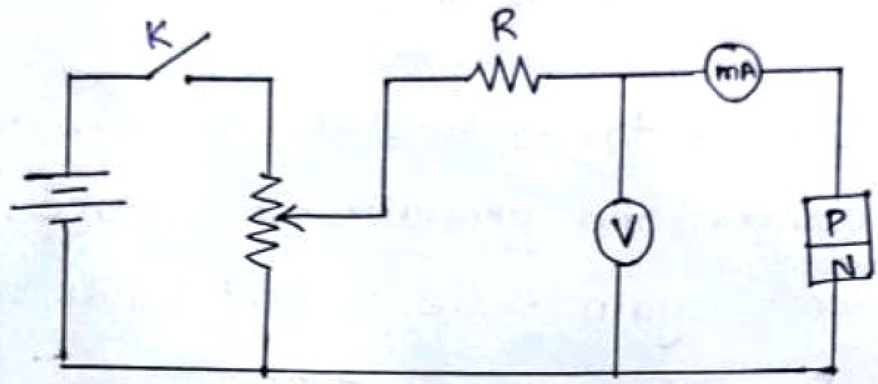
UNIT-II

1. Explain the working of SCR With Neat sketches.
2. Explain the Function of Zener diode as simple Regulator.
3. Explain different Breakdown Mechanisms
4. Explain the operation of Varactor Diode.
5. Explain the V-I characteristics of Tunnel diode With Enegry Band diagrams
6. Explain the V-I characteristics of Zener diode.

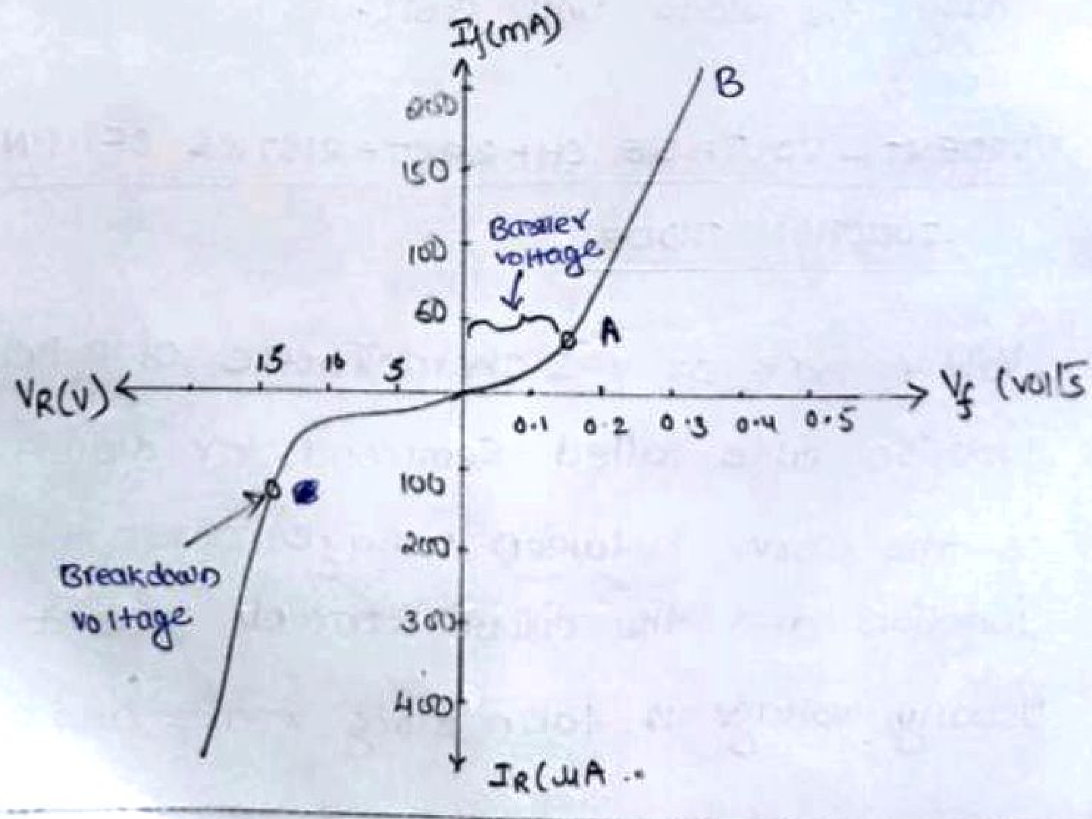
CURRENT - VOLTAGE CHARACTERISTICS OF PN JUNCTION DIODE.

Volt Ampere or V-I characteristic of a Pn junction also called semiconductor diode is the curve between voltage across the junction and the circuit current. Usually voltage is taken along x axis and current along Y axis.

Fig 1·2, shows the circuit arrangement for determining the V-I characteristics of a pn junction. The characteristics is studied under three heads : 1) zero external voltage 2) Forward bias 3) Reverse bias



(i) ZERO External voltage - When the external voltage is zero, i.e circuit is open at K, the circuit current is zero as indicated by point O in Fig 1-3.



ii] **FORWARD BIAS** :- With forward bias to the pn junction the potential barrier is reduced. At some forward voltage (0.7V for Si and 0.3V for Ge), the, potential barrier is altogether eliminated and current starts flowing in the circuit. From now onwards the current increases with the increase in forward voltage. Thus a rising curve OB is obtained with forward bias as shown.

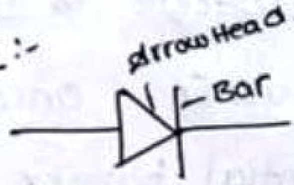
From the forward characteristic ; it is seen that at first (region OA), the current increases very slowly and the curve is non linear. It is because the external applied voltage is used up in overcoming the potential barrier. once, the external voltage exceeds the potential barrier voltage, the pn junction behaves like an ~~ogg~~ ordinary conductor. Therefore, the current rises very sharply with increase in external voltage (region AB on the curve). The curve is almost linear.

(iii) **REVERSE BIAS** :- With reverse bias to the pn junction, potential barrier at the junction is increased. There fore, the junction resistance becomes very high and practically no current flows through the circuit.

However in practice a very small flows in the circuit with reverse bias as shown in the reverse characteristic. This is called reverse Sat Current and is due to minority carriers.

If reverse voltage is increased continously, the kinetic energy of electrons may become high enough to knock out electrons from the semiconductor atoms. At this stage break down of the junction occurs, characterised by a sudden rise of reverse current and a sudden fall of the resistance of barrier region this may destroy the junction permently.

DIODE AS A SWITCH :-



A Pn junction is known as semi conductor diode. When it is connected in a circuit, If the external circuit is trying to push the conventional current in the direction of arrow, the diode is Forward biased and then it is said to be ON.

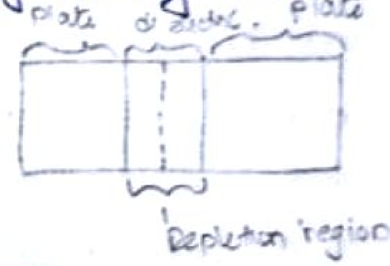
If the conventional current is trying to flow opposite to arrow head, the diode is reverse biased, and it is said to be OFF.

Hence a Diode acts as a switch.

TRANSITION CAPACITANCE (C_T) (Space Charge capacitance)

When a P-N junction is reverse biased, the depletion region acts like an insulator or dielectric material while P and N type regions on either side have low resistance and act as the plate. In this way a P-N junction may be regarded as parallel plate Capacitor. The junction capacitance is called the space charge capacitance or transition Capacitance and is denoted by C_T. This capacitance is voltage dependent and is given by the relation,

$$C_T = \frac{K}{(V_K + V_R)^n}$$



where V_K = Knee voltage

V_R = applied reverse voltage

K = Constant depending on Semiconductor material.

$n = (1/2)$ for alloy junction

$n = 1/3$ for diffused junction.

Fig below shows the variation of space charge capacitance with applied reverse voltage

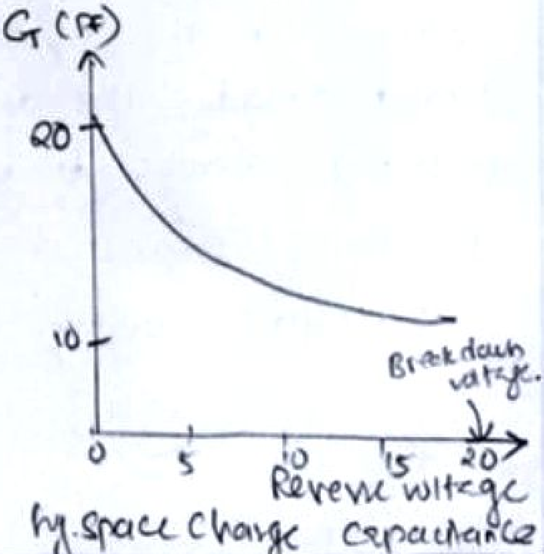
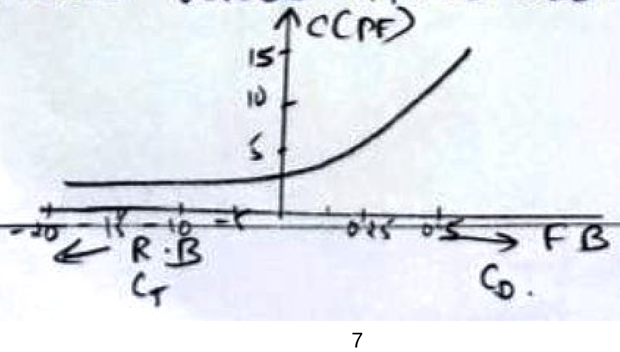


fig. space Charge capacitance variation

DIFFUSION CAPACITANCE (C_D):-

When a P-N junction is forward biased, a capacitance which is much larger than space charge capacitance comes into play. we know that for a forward biased PN junction, the potential barrier is reduced. Now the holes from P-side enter into N-side and similarly electrons from N-side enter the P-side. These carriers diffuse away from the junction and progressively recombine. The density of carriers is high near the junction and decays exponentially with distance. Thus a charge is stored on both sides of the junction when a forward bias voltage is applied. It is observed that the amount of stored charge varies with the applied potential as for a true Capacitor. It is convenient to introduce an incremental capacitance called capo diffusion or Storage capacitance ~~to introduce an incremental capacitance called diffusion~~ expressed by the equation $C_D = dq/dv$, where dq represents the change in the number of minority carriers stored outside the depletion region when a change in voltage across diode, dV is applied.

Fig below shows a depletion layer and diffusion capacitance versus applied bias for a silicon diode.



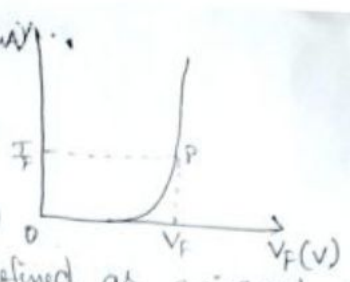
Ideal Versus practical - Resistance levels (Static and dynamic):→

Static Resistance:→

An ideal diode should offer zero resistance in forward bias and infinite resistance in the reverse bias. But in practice no diode can act as an ideal diode. So the real diode doesnot offer zero resistance when it is forward biased and an infinite resistance when reverse biased. This shows that when a real diode is forward biased has a definite resistance. This resistance is known as static or forward resistance of diode.

"Static resistance is defined as the ratio of d.c. voltage across the diode to the d.c current flowing through it". If V_F and I_F be the d.c voltage across diode to the d.c current flowing through it respectively, then the Static Resistance R_F is given by

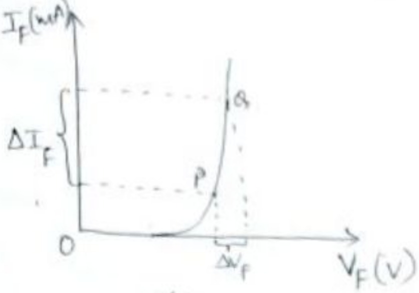
$$R_F = \frac{V_F}{I_F}$$



Dynamic Resistance:→

The dynamic resistance (or) ac resistance of a diode is defined as reciprocal of the slope of forward characteristic (or) the ratio of change in forward voltage to change in forward current. It is denoted by r_{ac}.

$$r_{ac} = \frac{\Delta V_F}{\Delta I_F}$$



$$I = I_0 e^{V/\eta V_T} \quad ; \text{ for FB.}$$

$$\frac{dI}{dV} = \frac{d}{dV}\left(I_0 e^{V/\eta V_T}\right) = \frac{d}{dV}\left(I_0 e^{V/\eta KT}\right)$$

$$= I_0 e^{V/\eta KT} \times \frac{1}{\eta KT} = \frac{I}{\eta KT}$$

$$\rightarrow \boxed{r_{ac} = \frac{dV}{dI} = \frac{\eta KT}{I}}$$

Capacitive effects in P-N Junction diode:-

The depletion layer width decreases when the P-N junction is forward biased while increases when P-N junction is reverse biased. The depletion layer acts as a dielectric medium (Non-conductive) between P and N regions. Therefore these regions may be regarded as the plates of a capacitor. Thus a P-N junction may be regarded as a capacitor with P and N regions as the plates of the capacitor and depletion layer as dielectric medium. The capacitance formed in junction area is called as depletion layer capacitance. For a parallel plate capacitor

$$C = \epsilon\left(\frac{A}{d}\right)$$

where ϵ = permitivity of dielectric

A = area of plates

d = seperation between the plates

→ As the value of d increases in reverse bias, hence depletion layer capacitance decreases. Depletion layer capacitance increases in forward bias because d decreases

① Space charge (or) Transition capacitance (C_T):-

In reverse bias, the depletion layer capacitance is called as transition capacitance and dinoted by C_T. This capacitance is voltage dependent and is given by

$$C_T = \frac{K}{(V_0+V_R)^n}$$

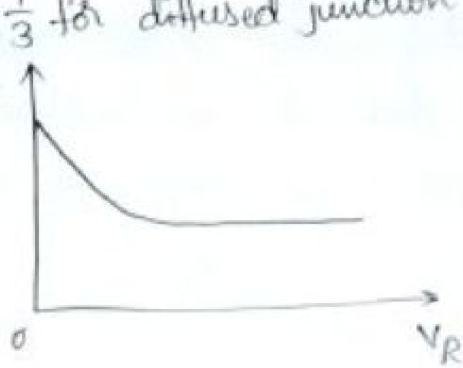
where V_0 = cut in voltage

V_R = applied reverse voltage

ν - constant depends on material (η)

$n = \frac{1}{2}$ for alloy junction and $\frac{1}{3}$ for diffused junction.

→ The space charge capacitance C_T decreases with increase in applied reverse voltage (V_R).



a) Step graded junction :-

In this case, there is an abrupt change from acceptor ion concentration on P-side to donor ion concentration on N-side. This type of junction is alloy junction. In this junction, usually the acceptor density N_a and donor density N_d are kept unequal.

$$C_T = \frac{\epsilon A}{x}$$

for alloyed junction, $x = \sqrt{\frac{2\epsilon V_B}{e N_d}}$

Subst x in C_T

$$\Rightarrow C_T = \epsilon A \left[\frac{e N_d}{2\epsilon V_B}\right]^{1/2} = A\left[\left(\frac{e\epsilon}{2}\right)\left(\frac{N_d}{V_B}\right)\right]^{1/2}$$

ⓑ Linearly graded junction :-

In this type of junction, the charge densities varies linearly with distance. So $N_a = N_d$, hence x is given by

$$x = \left[\frac{6\epsilon V_B}{e N_d}\right]^{1/2}$$

$$C_T = \epsilon A \left[\frac{e N_d}{6\epsilon V_B}\right]^{1/2} = A\left[\left(\frac{e\epsilon}{6}\right)\left(\frac{N_d}{V_B}\right)\right]^{1/2}$$

(2) Diffusion capacitance (C_D):- 17

When the P-N junction is forward biased, the depletion layer capacitance is called as diffusion capacitance and denoted by C_D. The charge is stored on both sides of junction when forward bias is applied. Thus the amount of stored charge varies with applied voltage. hence this capacitance is also called as storage capacitance. and is given by

$$C_D = \frac{dq}{dV}$$

The current $I = \frac{q}{\tau}$

where q = charge.

τ = mean life time of carriers

$$I = I_0\left[e^{V/\eta V_T} - 1\right]$$

$$q = I_0\tau\left[e^{V/\eta V_T} - 1\right] = I_0\tau e^{V/\eta V_T} \quad [\because \text{Forward bias}]$$

$$C_D = \frac{dq}{dV} = \frac{d}{dV}\left[\tau I_0 e^{V/\eta V_T}\right] = \frac{\tau I_0}{\eta V_T} e^{V/\eta V_T}$$

$$\boxed{C_D = \frac{\tau I}{\eta V_T}} \quad \left(\because I = I_0 e^{V/\eta V_T}\right)$$

Diode Equation:→

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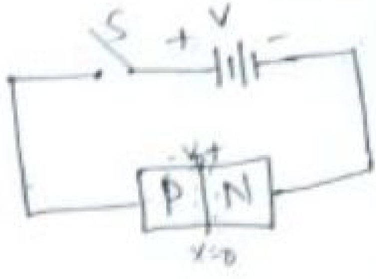
Let us consider an open circuit P-N junction as shown in fig: with Switch S open. Let hole and electron densities in p-region are P_p and n_p respectively. Similarly, electron and hole densities in N-region are n_n and P_n respectively.

The density of holes in p-region and density of holes in N-region are related by Boltzmann relation as



$$P_p = P_n e^{V_B/V_T}$$

where V_B is barrier potential across depletion layer

V_T is Volt equivalent of temperature

$$V_T = \frac{KT}{e} = \frac{T}{11,600}$$

where K is Boltzmann Constant = 1.381×10^{-23} J/K

→ For open circuited P-N junction, $V_B = V_0$, hence

$$P_p = P_n e^{V_0/V_T} \quad \text{——— } (1)$$

Consider that the junction is biased in the forward direction by applying a voltage V i.e. by closing Switch S. Now the barrier voltage V_B is decreased from its equilibrium value V_0 by an amount V or $V_B = V_0 - V$. With forward bias, the hole density in p-region remains Constant upto depletion region while in N-region just at the junction it increases from P_n to $P_n + \Delta P_n$ due to diffusion of holes across the junction. As the holes diffuse further in

N-region they combine with electrons and their density decreases with increase of distance from the junction. Ultimately at large distance it becomes the same as P_n. Now the hole density in N-region can be expressed by Boltzmann relation as

$$P_p = (P_n + \Delta P_n) \cdot e^{(V_0 - V)/V_T}$$

$$= (P_n + \Delta P_n)\, e^{V_0/V_T}\, e^{-V/V_T} \quad \text{——— (2)}$$

Substituting the value of P_p in eqn (1) we get

$$P_n e^{V_0/V_T} = (P_n + \Delta P_n) \cdot e^{V_0/V_T}\, e^{-V/V_T}$$

$$P_n = (P_n + \Delta P_n)\, e^{-V/V_T}$$

$$P_n e^{V/V_T} = (P_n + \Delta P_n)$$

$$\Delta P_n = P_n (e^{V/V_T} - 1) \quad \text{——— (3)}$$

From eqn (1) $\quad P_n = P_p e^{-V_0/V_T} \quad$ ——— (4)

Subst the value of P_n from eqn (4) in eqn (3) we get

$$\Delta P_n = P_p e^{-V_0/V_T} (e^{V/V_T} - 1) \quad \text{——— (5)}$$

The diffusion of holes constitute the hole current. The hole current I_p is proportional to ΔP_n. So

N-region they combine with electrons and their density decreases with increase of distance from the junction. Ultimately at large distance it becomes the same as P_n. Now the hole density in N-region can be expressed by Boltzmann relation as

$$P_p = (P_n + \Delta P_n).e^{(V_0 - V)/V_T}$$

$$= (P_n + \Delta P_n)\, e^{V_0/V_T}\, e^{-V/V_T} \quad \text{—— (2)}$$

Substituting the value of P_p in eqn (1) we get

$$P_n e^{V_0/V_T} = (P_n + \Delta P_n).e^{V_0/V_T}\, e^{-V/V_T}$$

$$P_n = (P_n + \Delta P_n)\, e^{-V/V_T}$$

$$P_n e^{V/V_T} = (P_n + \Delta P_n)$$

$$\Delta P_n = P_n (e^{V/V_T} - 1) \quad \text{—— (3)}$$

From eqn (1) $P_n = P_p e^{-V_0/V_T}$ —— (4)

Subst the value of P_n from eqn (4) in eqn (3) we get

$$\Delta P_n = P_p e^{-V_0/V_T} (e^{V/V_T} - 1) \quad \text{—— (5)}$$

The diffusion of holes constitute the hole current. The hole current I_p is proportional to ΔP_n. So

$I_p \propto \Delta p_n$ or $I_p \propto p_p e^{-V_0/V_T}(e^{V/V_T}-1)$

$$I_p = I_{sp}(e^{V/V_T}-1) \quad \text{——— (6)}$$

where I_{sp} represents the constant of proportionality.

→ In a similar way, an expression for electron current due to diffusion of electrons from N-region to P-region may be obtained. This is given by

$$I_n = I_{sn}(e^{V/V_T}-1) \quad \text{——— (7)}$$

The total current I is given by

$$I = I_p + I_n$$

$$= I_{sp}(e^{V/V_T}-1) + I_{sn}(e^{V/V_T}-1)$$

$$\boxed{I = I_0(e^{V/V_T}-1)} \quad \text{——— (8)}$$

where I_0 is called the saturation current.

Eqn (8) is called diode current equation

In general $\boxed{I = I_0(e^{V/\eta V_T}-1)}$ ——— (9)

where I = forward or reverse diode current

I_0 = Reverse saturation current

V = External voltage, which is +ve for forward bia[s] and -ve for reverse bias

η = constant, which depends upon the material

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property and have a value one for Ge and 2 for Si.

V_T = Volt equivalent of temperature.

For forward biased junction:

The value of V will be +ve. For large forward biased voltage $e^{V/nV_T} >> 1$. In this case

$$I_f = I_0 e^{V/nV_T} \qquad (10)$$

This eqn shows that for a given temperature the forward current increases exponentially with voltage V except for a small value of V.

For reverse biased junction:

In this we have

$$I_r = I_0 (e^{-V/nV_T} - 1)$$

for a reverse bias whose magnitude is large compared with V_T, we have

$$(e^{-V/nV_T} \to 0)$$

$$\Rightarrow I_r \to -I_0$$

Hence I_0 is called reverse saturation current. This is constant independent of applied reverse bias.

(5)

$T = 300K$

$I_0 = 2\mu A$

$V = 0.25$

$$V_T = \frac{T}{11600} = \frac{300}{11600} = 26\,mV$$

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

$$= 2\times10^{-6}\,A\left(e^{0.25/1\times26\times10^{-3}} - 1\right)$$

$$= 2\times10^{-6}\left(e^{9.615} - 1\right)$$

$$= 2\times10^{-6}\left(14987.92266 - 1\right)$$

$$= 2\times10^{-6}\left(14986.92266\right)$$

$$= 29973.84532\times10^{-6}\,A$$

$$I = 0.029\,A$$

Static Resistance

$$R_{ac} = \frac{V}{I} = \frac{0.25\ V}{0.029\ A} = 8.6\ \Omega$$

Dynamic Resistance

$$R_{dc} = \frac{\eta V_T}{I + I_0} = \frac{1 \times 0.026\ V}{(29.973 + 0.002) \times 10^{-3}}$$

$$= 0.86\ \Omega$$