CMR
INSTITUTE OF
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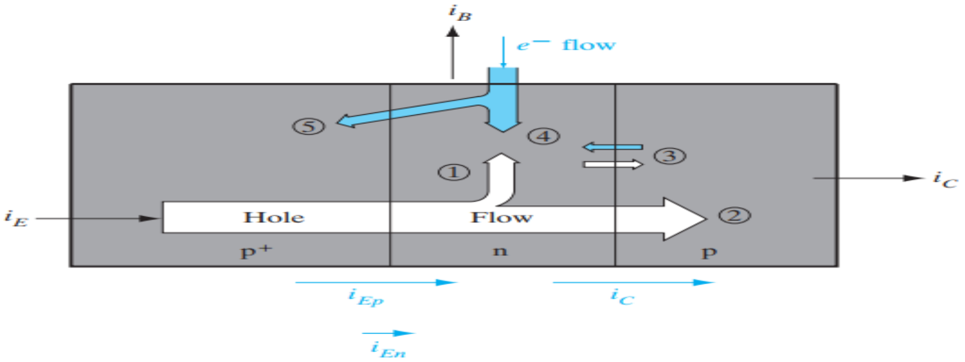
USN											

Internal Assesment Test - II

Sub:	Electronic Devices							Code:	18EC33
Date:	25/01/2022	Duration:	90 mins	Max Marks:	50	Sem:	III	Branch :	ECE-A,B,C,D

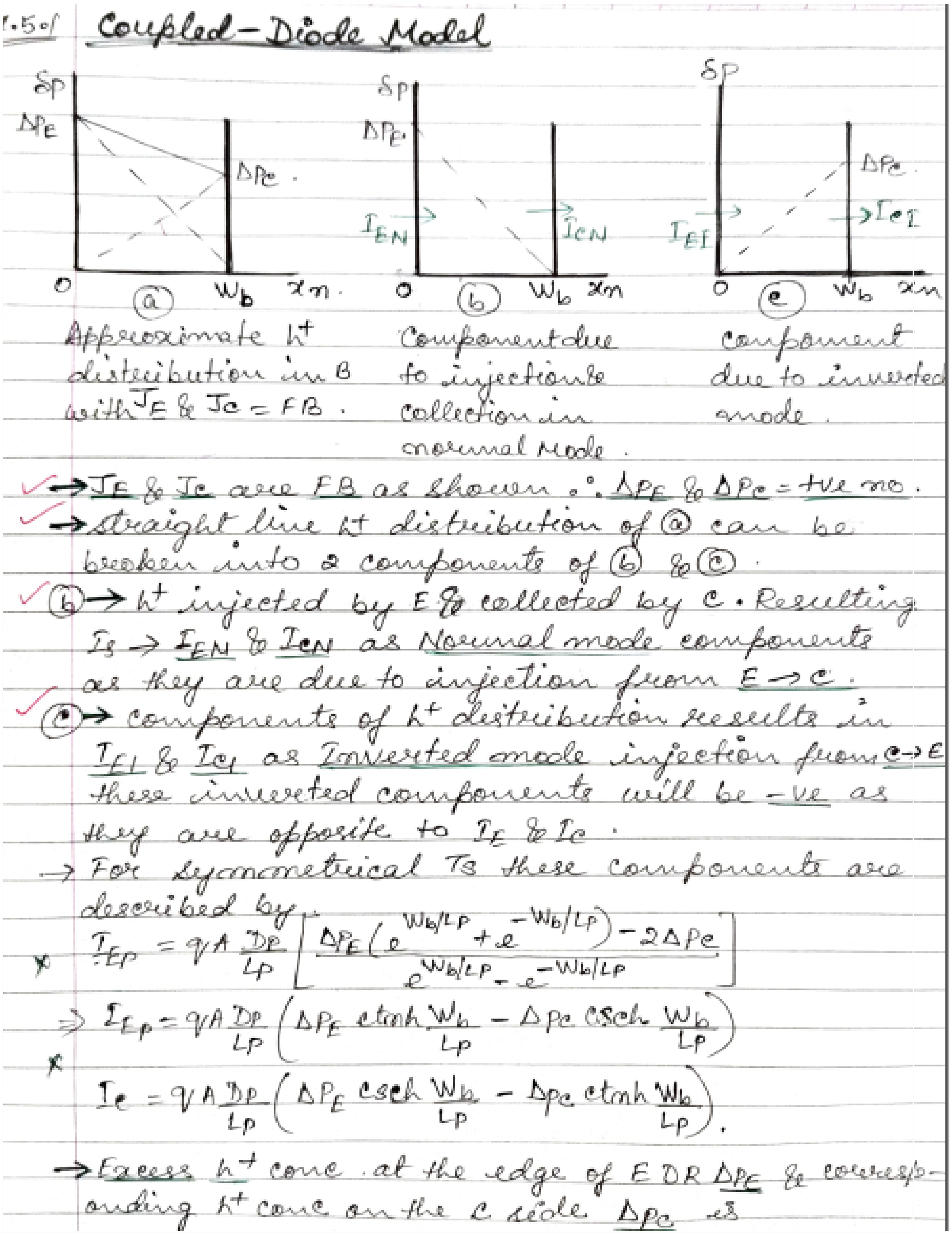
Answer Any FIVE FULL Questions

		Marks	OBE CO	OBE RBT
1.	With a neat diagram explain the hole and electron flow in P$^+$-N-P transistor with proper Biasing. What are the mechanisms (factors) which cause base current in a transistor?	[7+ 3]	CO2	L2



- *IB = small, as IE is emitted h+ I & IC is collected h+ I – IC~IE.*
    - *1.* injected h+ lost to recombination in B.
    - *2. h+ reaching RB Jc.*
    - *3. thermally generated e- & h+ making up reverse Isat of Jc.*
    - *4. e- supplied by B contact for recombination with h+.*
    - *5. e- injected at FB Je.*
- *Ib* can be accounted by three dominant mechanisms:
    - (a) There must be some recombination of injected *h+* with *e-* in the base, even with $Wb \ll Lp$. *e-* lost to recombination must be resupplied through the base contact.
    - (b) Some *e-* will be injected from n to p in the FB *Je*, even if the emitter is heavily doped compared with the base. These *e-* must also be supplied by *Ib*.
    - (c) Some *e-* are swept into the base at the RB *Jc* due to thermal generation in the collector. This small current reduces *Ib* by supplying *e-* to the base.
- Dominant sources of *Ib* are : (i) recombination in B (ii) injection into E region.

2. Derive the Ebers Moll equations of a PNP BJT and draw the Ebers Moll model (Diode coupled Model) diagram. Also explain the terms involved in it. [10] CO4 L3



1.5M

Coupled-Diode Model

ⓐ Approximate h^+ distribution in B with J_E & J_C = FB.

ⓑ Component due to injection & collection in normal Mode.

ⓒ component due to inverted mode.

✓ → J_E & J_C are FB as shown ∴ Δp_E & Δp_C = +ve no.

✓ → straight line h^+ distribution of ⓐ can be broken into 2 components of ⓑ & ⓒ.

✓ ⓑ → h^+ injected by E & collected by C. Resulting I's → I_{EN} & I_{CN} as Normal mode components as they are due to injection from E → C.

✓ ⓒ → components of h^+ distribution results in I_{EI} & I_{CI} as Inverted mode injection from C → E these inverted components will be −ve as they are opposite to I_E & I_C.

→ For symmetrical Ts these components are described by

× $$I_{Ep} = qA\frac{D_p}{L_p}\left[\frac{\Delta p_E\left(e^{W_b/L_p}+e^{-W_b/L_p}\right)-2\Delta p_C}{e^{W_b/L_p}-e^{-W_b/L_p}}\right]$$

$$\Rightarrow I_{Ep} = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{ctnh}\frac{W_b}{L_p} - \Delta p_C \operatorname{csch}\frac{W_b}{L_p}\right)$$

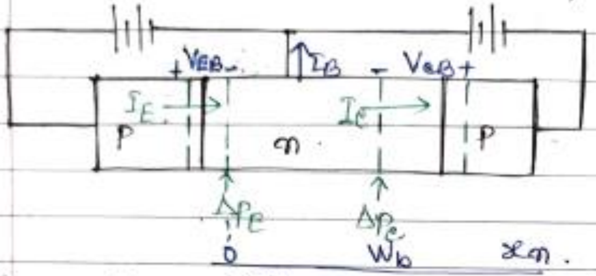
×

$$I_C = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{csch}\frac{W_b}{L_p} - \Delta p_C \operatorname{ctnh}\frac{W_b}{L_p}\right).$$

→ Excess h^+ conc at the edge of E DR Δp_E & corresponding h^+ conc on the C side Δp_C is

→ $\boxed{\Delta p_E = p_n\left(e^{qV_{EB}/kT}-1\right)}$ & $\boxed{\Delta p_c = p_n\left(e^{qV_{CB}/kT}-1\right)}$ —①.

→ If J_E is strongly FB → $V_{EB} \gg kT$ & if J_C is strongly RB then $V_{CB} \ll 0$. ∴ $\Delta p_E \propto p_n e^{qV_{EB}/kT}$ & $\Delta p_c \propto -p_n$



By Superposition Theorem.

→ $I_{EN} = a\Delta p_E$ & $I_{CN} = b\Delta p_E$ with $\Delta p_c = 0$.

$I_{EI} = -b\Delta p_c$ & $I_{CI} = -a\Delta p_c$ with $\Delta p_E = 0$.

→ 4 components are combined by linear superposition

$$I_E = I_{EN} + I_{EI} = a\Delta p_E - b\Delta p_c = A\left(e^{qV_{EB}/kT}-1\right) - B\left(e^{qV_{CB}/kT}-1\right).$$

$$I_C = I_{CN} + I_{CI} = b\Delta p_E - a\Delta p_c = B\left(e^{qV_{EB}/kT}-1\right) - A\left(e^{qV_{CB}/kT}-1\right)$$

where $A = ap_n$ & $B = bp_n$. —②

→ I_E in normal mode is given by

$$I_{EN} = I_{ES}\left(e^{qV_{EB}/kT}-1\right), \quad \Delta p_c = 0 \quad —③$$

I_{ES} = magnitude of I_{Esat} in normal mode, with J_C = SC ∵ $V_{CB} = 0$.

∵ $\Delta p_c = 0$ ∴ $V_{CB} = 0$.

→ I_C in inverted mode.

$$I_{CI} = -I_{CS}\left(e^{qV_{CB}/kT}-1\right), \quad \Delta p_E = 0. \quad —③.$$

I_{CS} = magnitude of I_{Csat} with $V_{EB} = 0$

→ −ve sign of I_{CS} ⇒ h^+ are injected opposite to the defined I_C for inverted mode.

→ Collected I for each mode of operation.

$$\left.\begin{aligned} I_{CN} &= \alpha_N I_{EN} = \alpha_N I_{ES}\left(e^{qV_{EB}/kT}-1\right) \\ I_{EI} &= \alpha_I I_{CI} = -\alpha_I I_{CS}\left(e^{qV_{CB}/kT}-1\right) \end{aligned}\right\} ④$$

where α_N & α_I = ratios of collected I to injected I in each mode.

→ In inverted mode → injected I = I_{CI} & collected I = I_{EI}.

→ Total I obtained by superposition of components

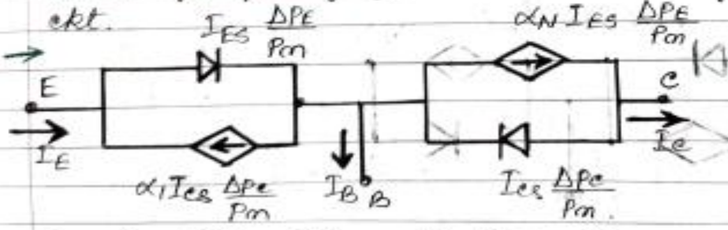
$$\boxed{\begin{aligned} I_E &= I_{EN} + I_{EI} = I_{ES}\left(e^{qV_{EB}/kT}-1\right) - \alpha_I I_{CS}\left(e^{qV_{CB}/kT}-1\right) \quad ⓐ \\ I_C &= I_{CN} + I_{CI} = \alpha_N I_{ES}\left(e^{qV_{EB}/kT}-1\right) - I_{CS}\left(e^{qV_{CB}/kT}-1\right) \quad ⓑ \end{aligned}} \; ⑤$$

→ These relations were derived by J. J. Ebers & J. L. Moll and are referred to as Eber-Moll equations.

→ Equa. ② is for symmetrical Ts, these equa. varies in I_{ES}, I_{CS}, α_I & α_N due to asymmetry b/w the junc.

→ $\boxed{\alpha_N I_{ES} = \alpha_I I_{CS}}$ ⑥ can be shown for non-symmetrical Ts.

→ Feature of Eber-Moll equa. → I_E & I_C are described by terms resembling diode relations (I_{EN} & I_{CI}) + terms that give coupling b/w the properties of E & C (I_{EI} & I_{CN}). This coupled-diode property is illustrated by the equivalent ckt.



An equivalent ckt synthesizing Ebers-Moll equa. ⑤

$$I_B = (1-\alpha_N) I_{ES}\frac{\Delta P_E}{P_n} + (1-\alpha_I) I_{CS}\frac{\Delta P_C}{P_n}$$

→ saturation I from the coupling term in each part of equa ⑤ can be removed by multiplying equa. (5a) by α_N & subtracting the result from (5b)

$$\left.\begin{aligned} I_C &= \alpha_N I_E - (1-\alpha_N\alpha_I) I_{CS}(e^{qV_{CB}/kT}-1) \\ &\& \\ I_E &= \alpha_I I_C + (1-\alpha_N\alpha_I) I_{ES}(e^{qV_{EB}/kT}-1) \end{aligned}\right\} ⑧$$

→ The term $(1-\alpha_N\alpha_I) I_{CS} = I_{CO}$ & $(1-\alpha_N\alpha_I) I_{ES} = I_{EO}$.

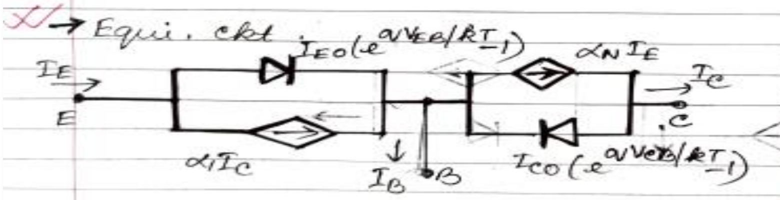
I_{CO} = mag. of I_{Csat} with J_E open ($I_E = 0$)

& I_{EO} = " " I_{Esat} " J_C open.

→ Eber-Moll equa. becomes (substituting in ⑧

$$\left.\begin{aligned} I_E &= \alpha_I I_C + I_{EO}(e^{qV_{EB}/kT}-1) \\ I_C &= \alpha_N I_E - I_{CO}(e^{qV_{CB}/kT}-1) \end{aligned}\right\} ⑨$$

→ Equi. ckt.



Equivalent ckt of Ts in terms of terminal I & O.C. sat. on equa. ⑨

3. a) Define and give expressions for [1+1+2+1] CO2 L1

i. Base transport factor ii. Emitter injection efficiency

iii. Current transfer ratio iv. Base to collector current amplification factor. [5] CO1 L2

Amplification with BJTs

→ BJT works as amplifier as ⇒ I_E & I_C are controlled by the relatively small I_B.

→ Neglecting, ac analysis, Isat at C, recombinations. I_C is made up of h^+ injected at E which are not lost to recombination in B.

∴ $I_C \propto h^+$ component of I_E.

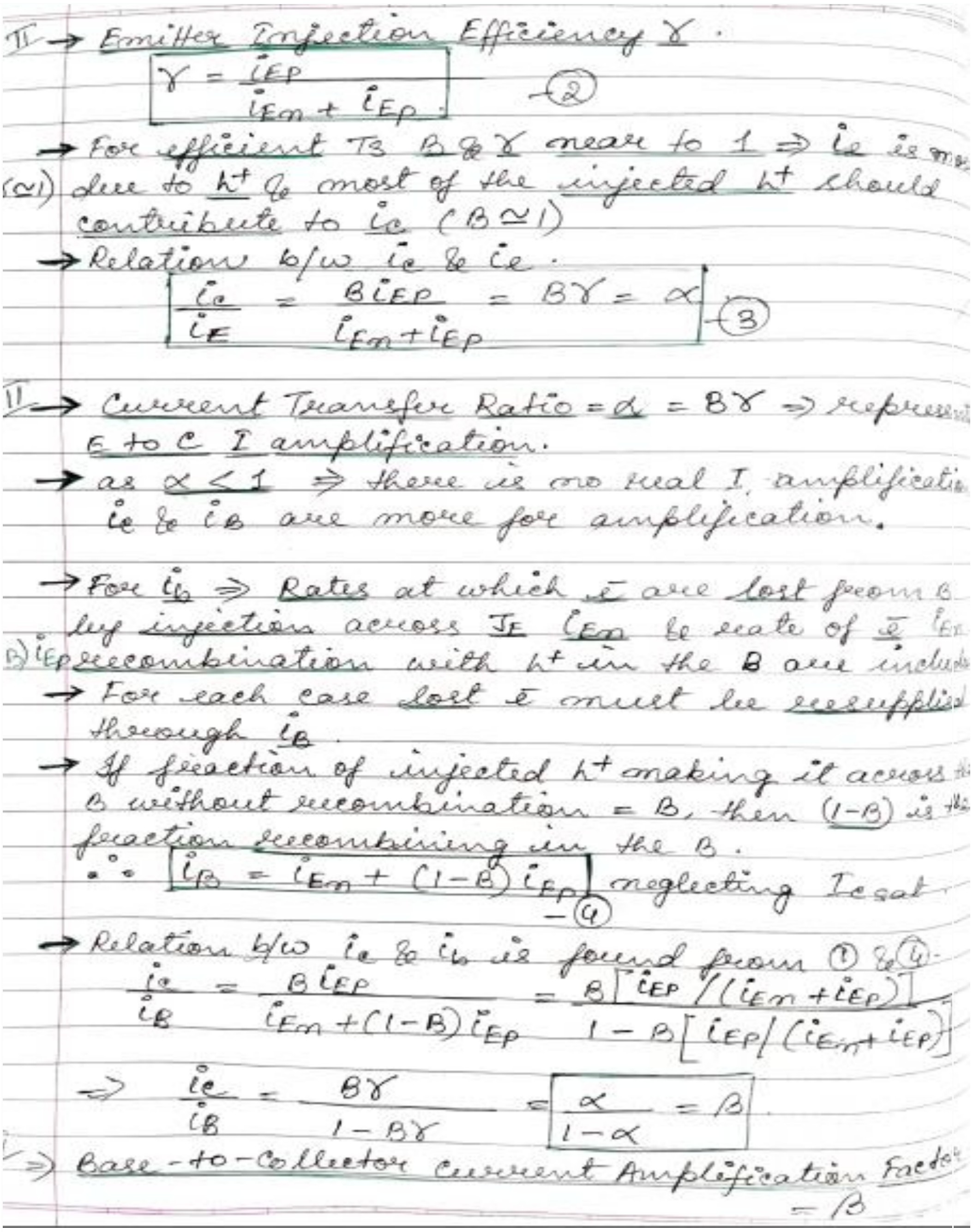
$$\boxed{i_C = B\, i_{Ep}} \quad ①$$

B = proportionality factor = fraction of injected h^+ which make it across the B to C.

B = Base transport factor.

→ Total i_E is made up of h^+ component i_{Ep} & $\bar{e}$ component i_{En} due to $\bar{e}$ injected from B → E.

$$\underset{}{i_{E_T}} = \underset{E\to B}{i_{Ep}} + \underset{B\to E}{i_{En}}$$



II → Emitter Injection Efficiency γ.

$$\boxed{\gamma = \frac{i_{Ep}}{i_{En} + i_{Ep}}} \quad -②$$

→ For efficient TB B & γ near to 1 ⇒ i_c is mo

(≃1) due to h^+ & most of the injected h^+ should contribute to i_c ($B \simeq 1$)

→ Relation b/w i_c & i_E.

$$\boxed{\frac{i_c}{i_E} = \frac{B i_{Ep}}{i_{En} + i_{Ep}} = B\gamma = \alpha} \quad -③$$

II → Current Transfer Ratio = α = $B\gamma$ ⇒ represe E to C I amplification.

→ as $\alpha < 1$ ⇒ there is no real I amplificati i_c & i_B are more for amplification.

→ For i_B ⇒ Rates at which $\bar{e}$ are lost from B by injection across J_E i_{En} & rate of $\bar{e}$ i_{En}

B) i_{Ep} recombination with h^+ in the B are includ

→ For each case lost $\bar{e}$ must be resupplie through i_B.

→ If fraction of injected h^+ making it across th B without recombination = B, then $(1-B)$ is th fraction recombining in the B.

$$\therefore \boxed{i_B = i_{En} + (1-B)\, i_{Ep}} \text{ neglecting } I_{csat} \quad -④$$

→ Relation b/w i_c & i_B is found from ① & ④.

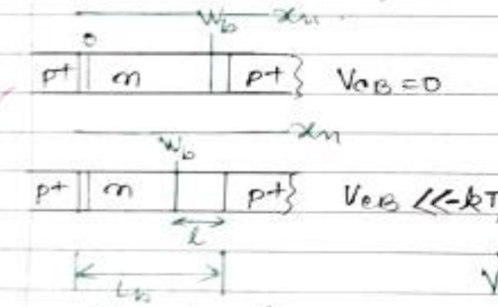
$$\frac{i_c}{i_B} = \frac{B i_{Ep}}{i_{En} + (1-B)\, i_{Ep}} = \frac{B\left[i_{Ep}/(i_{En} + i_{Ep})\right]}{1 - B\left[i_{Ep}/(i_{En} + i_{Ep})\right]}$$

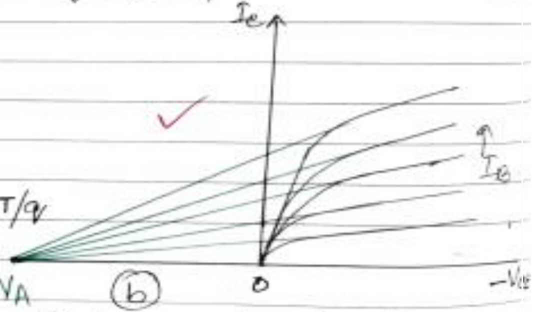
$$\Rightarrow \frac{i_c}{i_B} = \frac{B\gamma}{1 - B\gamma} = \boxed{\frac{\alpha}{1-\alpha} = \beta}.$$

⇒ Base-to-Collector Current Amplification Facto $= \beta$

b) Explain base narrowing effect (Early effect) in P^+-N-P^+ transistor.

1·2 Base Narrowing → Early Effect / Base width Modul





$W_b = L_b - l$

$l \propto \sqrt{V_{BC}}$

(a) B width decreases with increase in J_C = RB.

increase in I_C increases V_C. Extrapolation of curve to V_A.

→ If B is lightly doped, DR at J_C RB can extend into n type B.

→ As V_C increases, space charge layer takes up more of the B width L_b & decrease W_b.

→ This effect is called Base Narrowing / Early effect / Base-width Modulation. J.M. Early.

→ Effect of this is shown in C characteristics of CE config.

→ Decrease in W_b causes β to increase → I_C increases with V_C instead of remaining const.

→ Slope of Early effect is almost linear with I_C & CE graph extrapolate to an intersection with V axis V_A — called Early V.

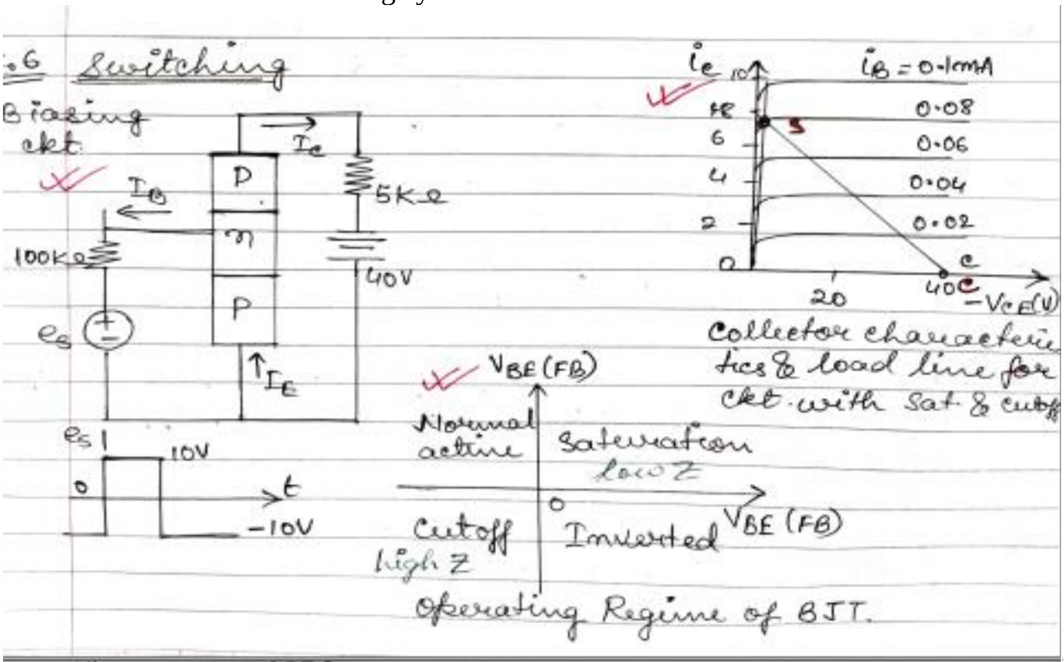
→ l = length of DR into n B.

$$l = \left(\frac{2\epsilon V_{BC}}{q N_d}\right)^{1/2}$$

→ If RB on J_C increases far enough, W_b reduces such that J_C DR fills the entire B region giving Punch through condition ⇒ where h^+ are swept directly from E → C & TS action is lost. Punch through is a breakdown effect & should be avoided.

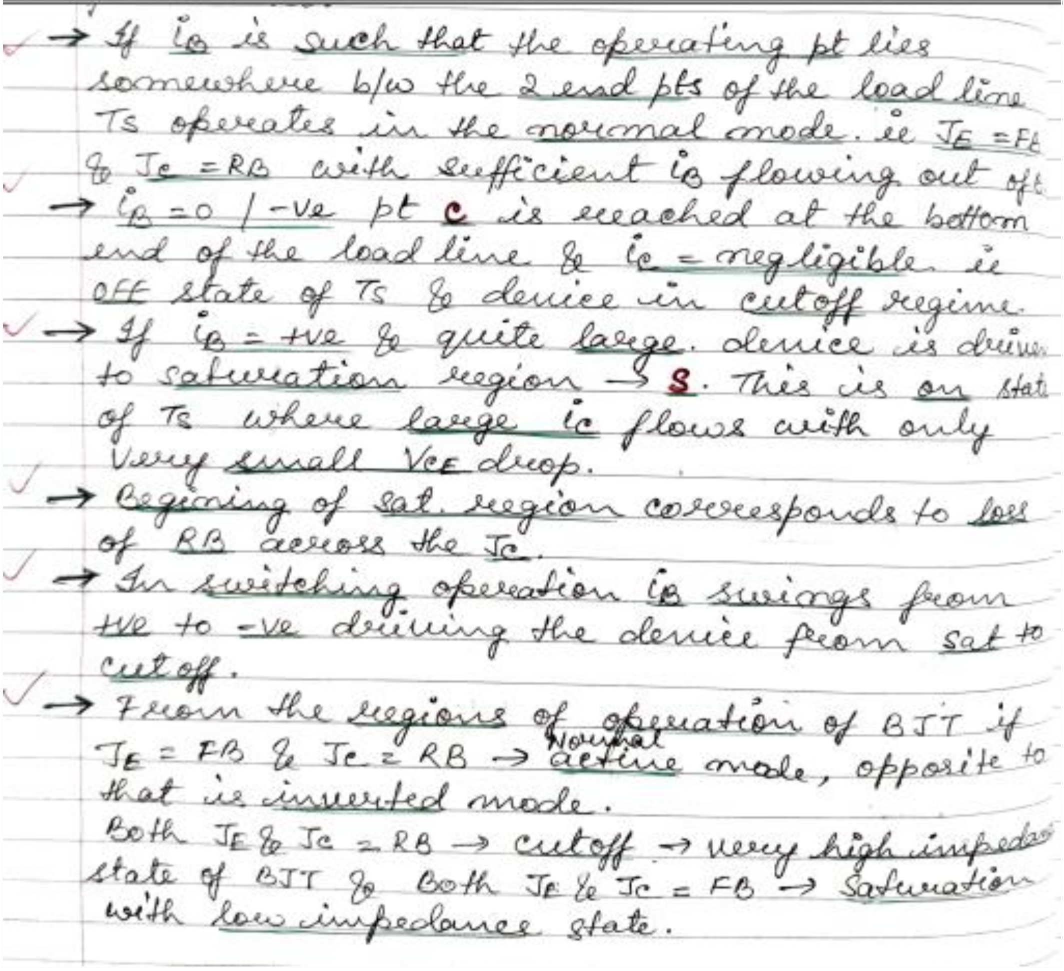
→ Avalanche breakdown of J_C occurs before Punch-through is reached.

4. Explain switching operation of a transistor in cut off and saturation region. What are the various mechanisms of switching cycle? [6+4] CO2 L2



Collector characteristics & load line for ckt with Sat & cutoff

Operating Regime of BJT.



→ If i_B is such that the operating pt lies somewhere b/w the 2 end pts of the load line Ts operates in the normal mode. ie J_E = F & J_C = RB with sufficient i_B flowing out of

→ i_B = 0 / −ve pt C is reached at the bottom end of the load line & i_C = negligible. ie OFF state of Ts & device in cutoff regime.

→ If i_B = +ve & quite large. device is drive to saturation region → S. This is on stat of Ts where large i_C flows with only very small V_{CE} drop.

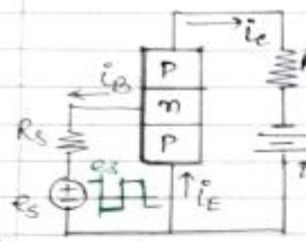
→ Begining of sat. region corresponds to loss of RB across the J_C.

→ In switching operation i_B swings from +ve to −ve driving the device from sat to cutoff.

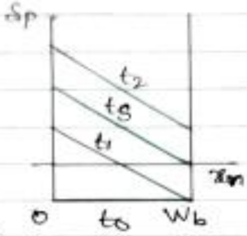
→ From the regions of operation of BJT if J_E = FB & J_C = RB → Normal active mode, opposite to that is inverted mode.
Both J_E & J_C = RB → cutoff → very high impeda state of BJT & Both J_E & J_C = FB → Saturation with low impedance state.

-6.3 Switching Cycle →

→ Various mechanisms of a switching cycle are shown

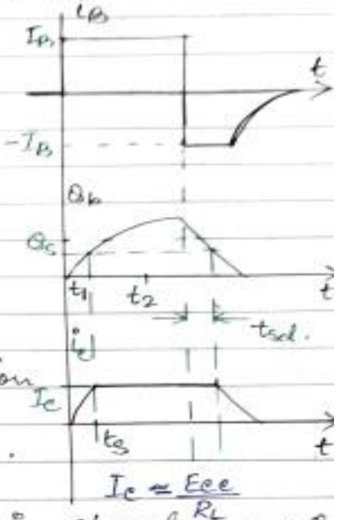


ⓐ switching effects in CE Ts



ⓑ h^+ distribution in B during switching from cutoff to saturation

t_0 = Cutoff.
t_1 = Normal active region.
t_S = Begining of Saturation Region.
t_2 = Final saturated state



ⓒ i_B, stored charge Q_B & i_C during turn on & turn off of Ts

→ If the device is originally in cutoff, a step increase of i_B to I_B causes the h^+ distribution to increase as shown in ⓑ

→ At t_S – device enters saturation & the h^+ distribution reaches its final state at t_2

→ As stored charge in B Q_b increases, i_C increases

→ i_C does not increase beyond its value at the begining of saturation t_S $I_C \approx E_{CC}/R_L \Rightarrow I_{C sat}$.
E_{CC} = value of c ckt battery & R_L = load R.
$I_C \simeq 8mA$.

→ i_C increases exponentially as Q_b rises to Q_s at t_S → this rise time serves as one of the limitations of the Ts in switching application.

→ when i_B is -ve to $-I_B$, stored charge Q_b must withdrawn from the B before cutoff is reached.

→ while Q_b is larger than Q_s i_C remains at I_C fixed by battery & R_L.

→ There is storage delay time t_{sd} after the i_B is switched & before i_C begins to fall towards 0

→ when $Q_b < Q_s$, i_C drops exponentially with characteristic fall time..

→ Once stored charge is withdrawn, i_B cannot x be maintained any longer at its large -ve value & must decay to small cutoff value.

$$i_B = -(1-\alpha_N) I_{ES} - (1-\alpha_I) I_{CS}.$$

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5a). Write the expression for current in photodiode resulting due to collection of optically generated carriers and open circuited voltage across the junction.

[6] CO2 L2

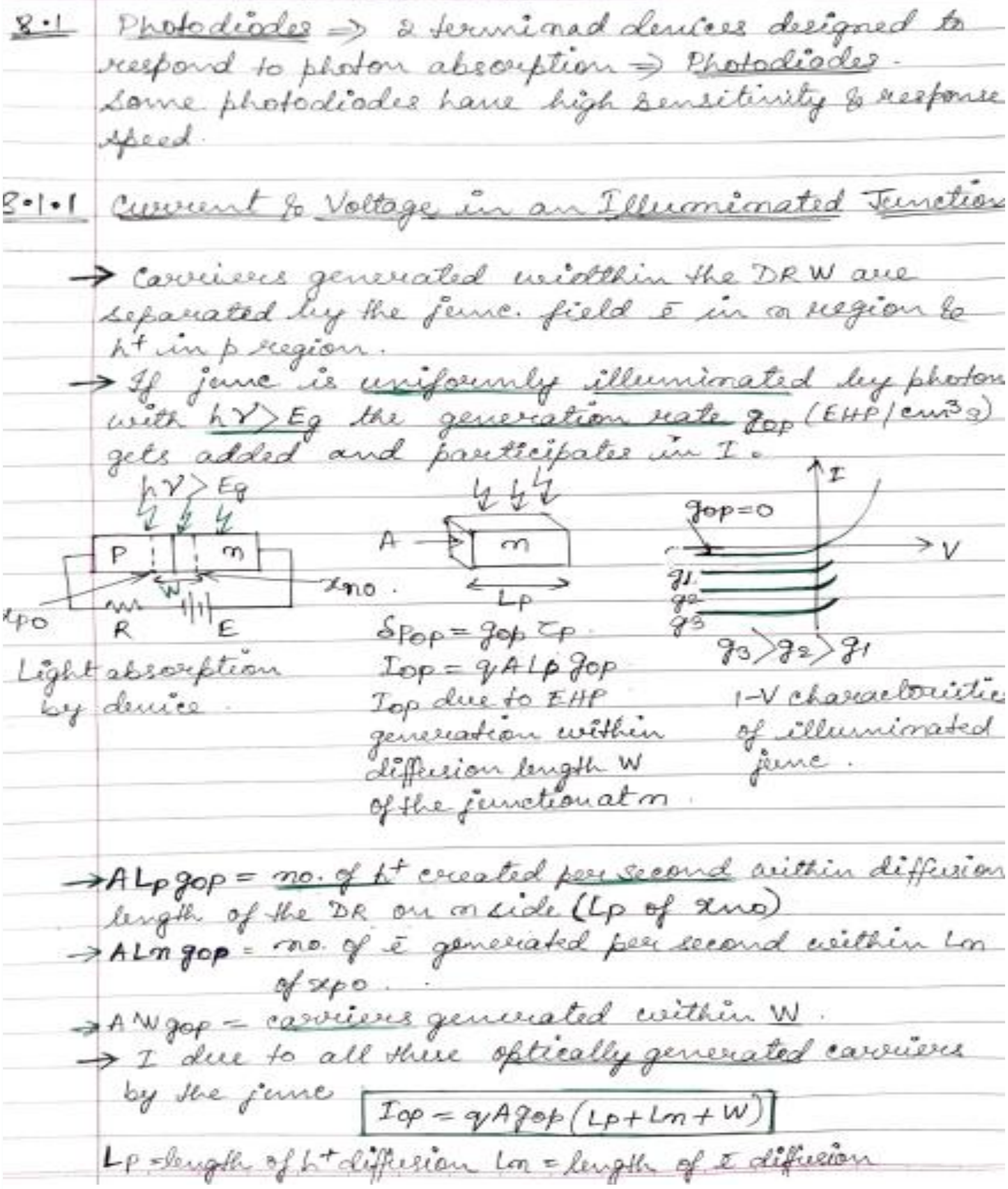
[4]

CO2 L1

[5]

[5]

[10] CO2 L2



8·1 Photodiodes ⇒ 2 terminal devices designed to respond to photon absorption ⇒ Photodiodes. Some photodiodes have high sensitivity & response speed.

8·1·1 Current & Voltage in an Illuminated Junction

→ Carriers generated within the DR W are separated by the junc. field $\bar{e}$ in n region & h^+ in p region.

→ If junc is uniformly illuminated by photon with $h\nu > E_g$ the generation rate g_{op} (EHP/cm^{3}s) gets added and participates in I.

$g_3 > g_2 > g_1$

Light absorption by device.

$\delta p_{op} = g_{op} \tau_p$

$I_{op} = qAL_p g_{op}$

I_{op} due to EHP generation within diffusion length W of the junction at n.

I-V characteristics of illuminated junc.

→ $AL_p g_{op}$ = no. of h^+ created per second within diffusion length of the DR on n side (L_p of x_{no})

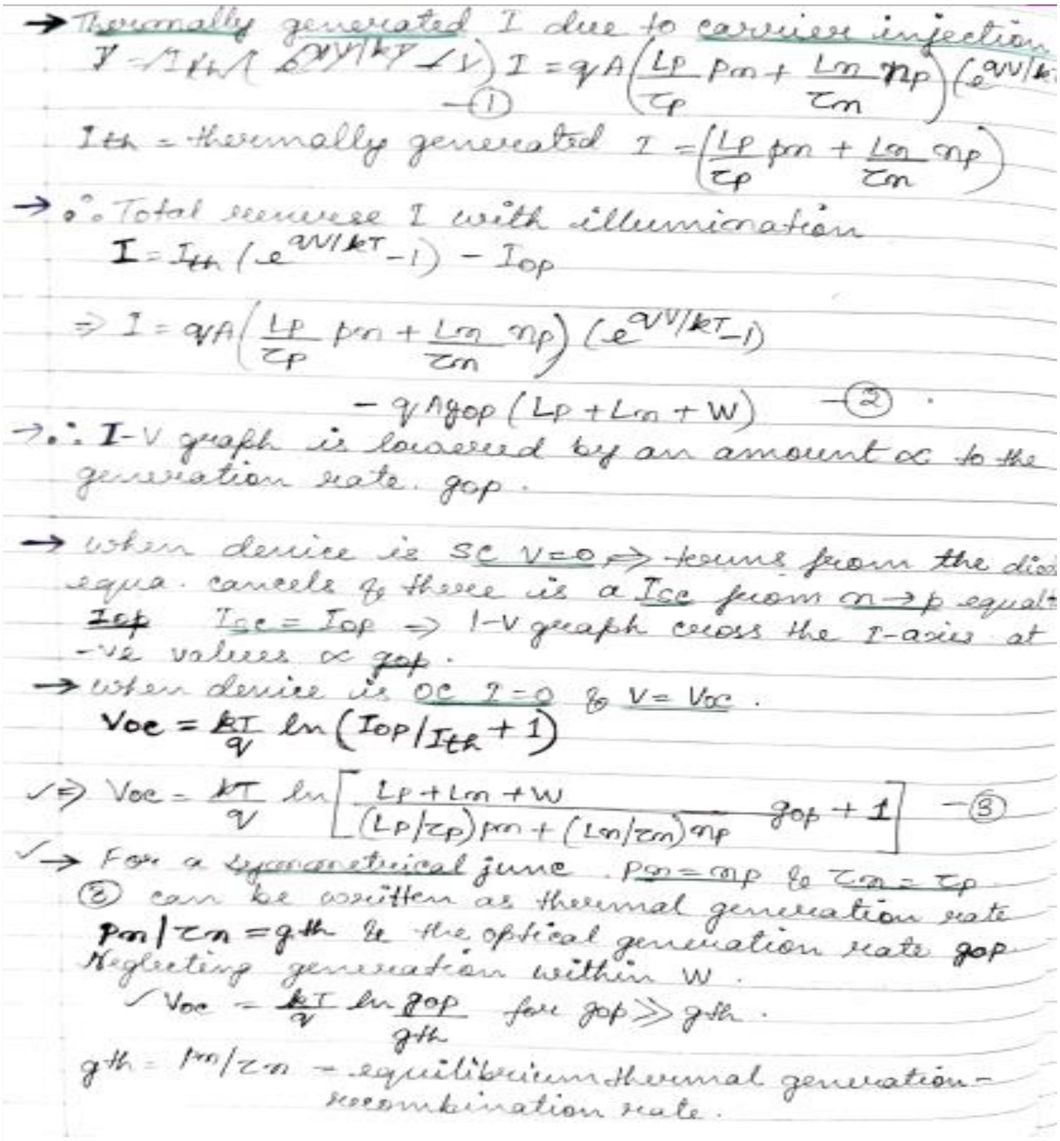
→ $AL_n g_{op}$ = no. of $\bar{e}$ generated per second within L_n of x_{po}.

→ $AW g_{op}$ = carriers generated within W.

→ I due to all these optically generated carriers by the junc

$$\boxed{I_{op} = qAg_{op}(L_p + L_n + W)}$$

L_p = length of h^+ diffusion L_n = length of $\bar{e}$ diffusion



→ Thermally generated I due to carrier injection

~~$I = I_{th}(e^{qV/kT} - 1)$~~ $I = qA\left(\frac{L_p}{\tau_p}p_n + \frac{L_n}{\tau_n}n_p\right)(e^{qV/k}$ —①

I_{th} = thermally generated $I = \left(\frac{L_p}{\tau_p}p_n + \frac{L_n}{\tau_n}n_p\right)$

→ ∴ Total reverse I with illumination

$I = I_{th}(e^{qV/kT} - 1) - I_{op}$

$\Rightarrow I = qA\left(\frac{L_p}{\tau_p}p_n + \frac{L_n}{\tau_n}n_p\right)(e^{qV/kT} - 1)$

$- qAg_{op}(L_p + L_n + W)$ —②.

→ ∴ I-V graph is lowered by an amount ∝ to the generation rate. g_{op}.

→ when device is SC $V=0$ ⇒ terms from the diod equa. cancels & there is a I_{sc} from $n \rightarrow p$ equal to I_{op} $I_{sc} = I_{op}$ ⇒ I-V graph cross the I-axis at -ve values ∝ g_{op}.

→ when device is OC $I=0$ & $V = V_{oc}$.

$V_{oc} = \frac{kT}{q}\ln(I_{op}/I_{th} + 1)$

✓⇒ $V_{oc} = \frac{kT}{q}\ln\left[\frac{L_p + L_n + W}{(L_p/\tau_p)p_n + (L_n/\tau_n)n_p}g_{op} + 1\right]$ —③

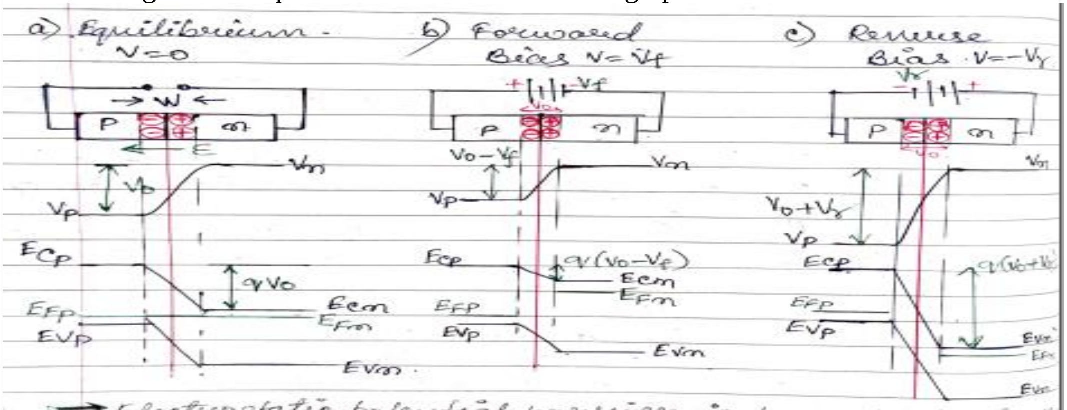
✓→ For a symmetrical junc. $p_n = n_p$ & $\tau_n = \tau_p$ ③ can be written as thermal generation rate $p_n/\tau_n = g_{th}$ & the optical generation rate g_{op} Neglecting generation within W.

✓ $V_{oc} = \frac{kT}{q}\ln\frac{g_{op}}{g_{th}}$ for $g_{op} \gg g_{th}$.

$g_{th} = p_n/\tau_n$ → equilibrium thermal generation-recombination rate.

Draw and explain the energy band diagram of a PN junction i) at equilibrium, ii) under forward bias and iii) under reverse bias. Explain qualitatively the effect of biasing on current using current equation and I-V characteristic graph.

b)



→ Electrostatic potential barrier is lower by V_f from the equilibrium contact potential V_o to a smaller value $V_o - V_f$. as FB ↑ the electrostatic potential on the p side relative to n side.

→ For RB, potential barrier ↑ by $+V_r$ as electrostatic potential is depressed on the p side relative to n side & barrier at the junc. becomes larger $(V_o + V_r)$

→ For FB → EF at the transition region ↓ as the applied field V_f opposes the built-in field $\mathcal{E}$
For RB → EF at the transition region ↑ as applied field V_r & built in field are in same direction

→ Changes in EF $\mathcal{E}$ changes width W. ∴ W↓ in FB & W↑ in RB.

→ $W = \left[\frac{2\epsilon V_0}{q}\left(\frac{N_a+N_d}{N_aN_d}\right)\right]^{1/2} = \left[\frac{2\epsilon V_0}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)\right]^{1/2}$ can be used to calculate width

→ Energy band separation in FB is given by $q(V_0-V_f)$ and in RB by $q(V_0+V_r)$

→ Under FB E_{Fn} is above E_{Fp} by the energy qV_f & for RB E_{Fp} is above E_{Fn} by qV_r.

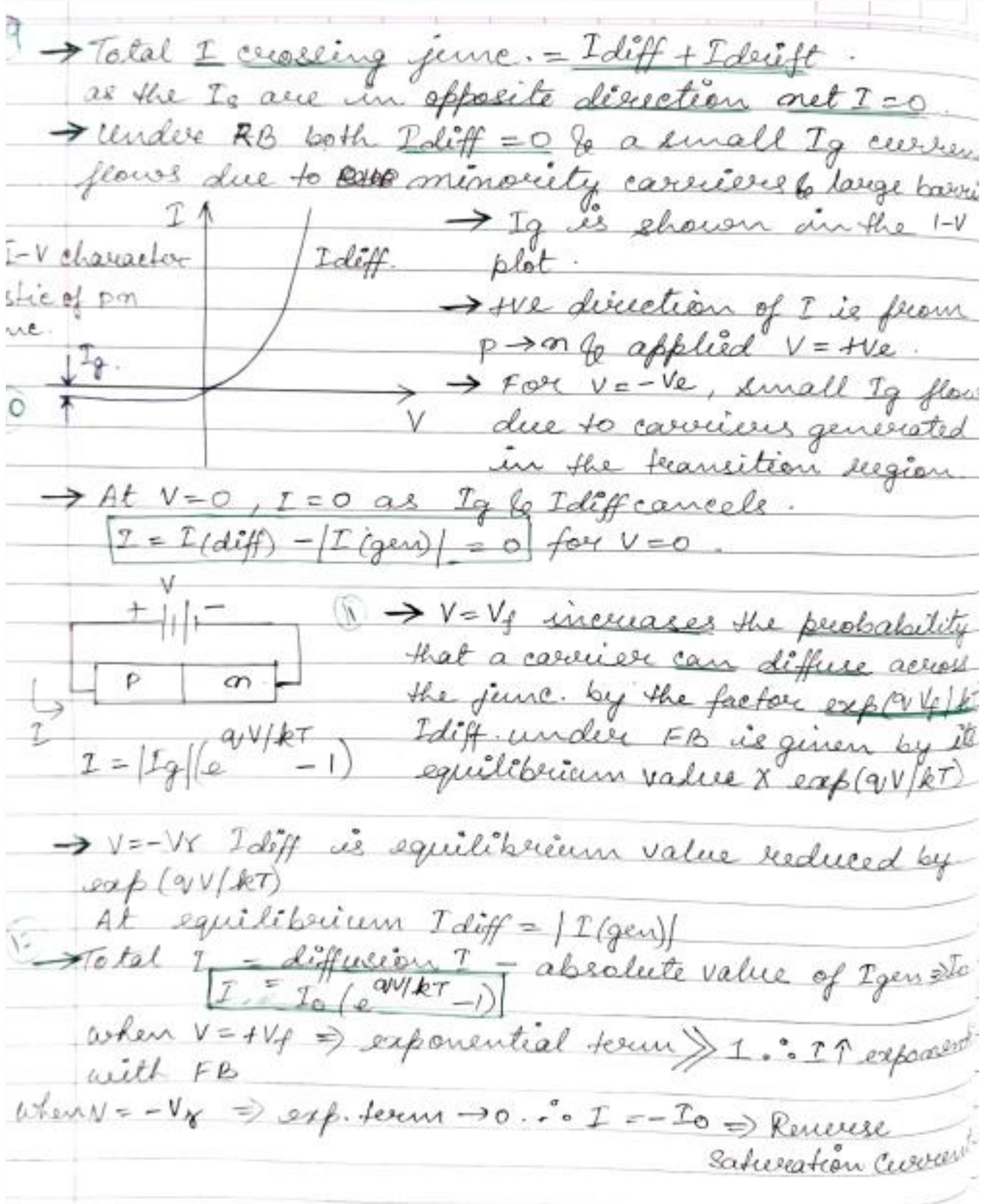
→ In FB ⇒ barrier is lowered to (V_0-V_f) → more $\bar{e}$ get sufficient energy to diffuse from n → p
∴ $I_{(\bar{e}\,diff)}$ or $I_{(n\,diff)}$ increases.
& also more h^+ can diffuse from p → n
∴ $I_{(h^+diff)}$ or $I_{(p\,diff)}$ increases.
} FB I_{diff} ↑

→ For RB ⇒ barrier is large to (V_0+V_r) & $\bar{e}$ & h^+ can't cross over ∴ Diffusion I is negligible I_{diff} ↓

→ Drift I is not related to barrier potential height

*

→ Minority carriers contributing to drift component are generated by thermal excitation of EHP. I due to drift of generated carriers across the junction is called Generation Current as its magnitude depends on rate of generation of EHP. I_g can be increased by optical excitation at the junc for photodiode.



→ Total I crossing junc. = Idiff + Idrift.
as the Is are in opposite direction net $I = 0$.

→ Under RB both $I_{diff} = 0$ & a small Ig curren
flows due to minority carriers & large barri

I-V character
stic of pn
ne.

→ Ig is shown in the I-V plot.

→ +ve direction of I is from $p \rightarrow n$ & applied $V = +Ve$.

→ For $V = -Ve$, small Ig flo
due to carriers generated
in the transition region

→ At $V = 0$, $I = 0$ as Ig & Idiff cancels.

$\boxed{I = I(diff) - |I(gen)| = 0}$ for $V = 0$.

Ⓘ → $V = V_f$ increases the probability that a carrier can diffuse across the junc. by the factor $exp(qV_f/k$
Idiff. under FB is given by it
equilibrium value X $exp(qV/kT)$

$I = |I_g|(e^{qV/kT} - 1)$

→ $V = -V_r$ Idiff is equilibrium value reduced by $exp(qV/kT)$
At equilibrium $I_{diff} = |I(gen)|$

→ Total I = diffusion I − absolute value of $I_{gen} \Rightarrow I_o$

$\boxed{I = I_o(e^{qV/kT} - 1)}$

when $V = +V_f \Rightarrow$ exponential term $\gg 1$ ∴ I ↑ exponent
with FB

when $V = -V_r \Rightarrow$ exp. term $\rightarrow 0$ ∴ $I = -I_o \Rightarrow$ Reverse Saturation Current

6. (a) What are the advantages of using PIN photodiode in photo-detector? What is the figure of merit of a photo-detector?

1.3 Photodetectors

→ When photodiode is operated in the 3rd quadrant of I-V characteristic, I is independent of V but $I \propto g_{op}$ optical generation rate.

→ This can be used to measure illumination or converting time-varying optical signal into electrical signal.

→ In optical detection operation, detector's speed of response or BW is important.

→ Eg → if a photodiode is to respond to a series of light pulses 1ns apart, the photogenerated minority carriers must diffuse ~~to~~ the junc. & be swept across the other side in a time much < 1ns.

→ DR width W should be large so that most of the photons are absorbed within W rather than in the neutral n & p region.

→ When EHP is created in the DR, the EF sweeps the $\bar{e}$ to n side & h^+ to p side. As this carrier drift occurs ~~very~~ in very short time, ∴ response of photodiode is quite fast.

→ When carriers are generated within the DR W, the detector is called depletion layer photodiode.

→ One side of the junc. is dopped lightly so that W can be made large.

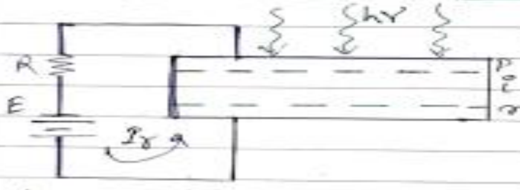
→ Appropriate width for W is choosen b/w sensitivity & speed of response

→ If W is wide most of the incident photo[n] will be absorbed in the DR giving high sensitivity.

→ wide W → small junc. capacitance $\boxed{C_j = \frac{\epsilon A}{W}}$ which reduces RC time const of the detector ckt

→ But W must not be so wide that the time needed for drift of photogenerated carriers out of the DR is more → low BW.

→ To control W → p-i-n photodetector.



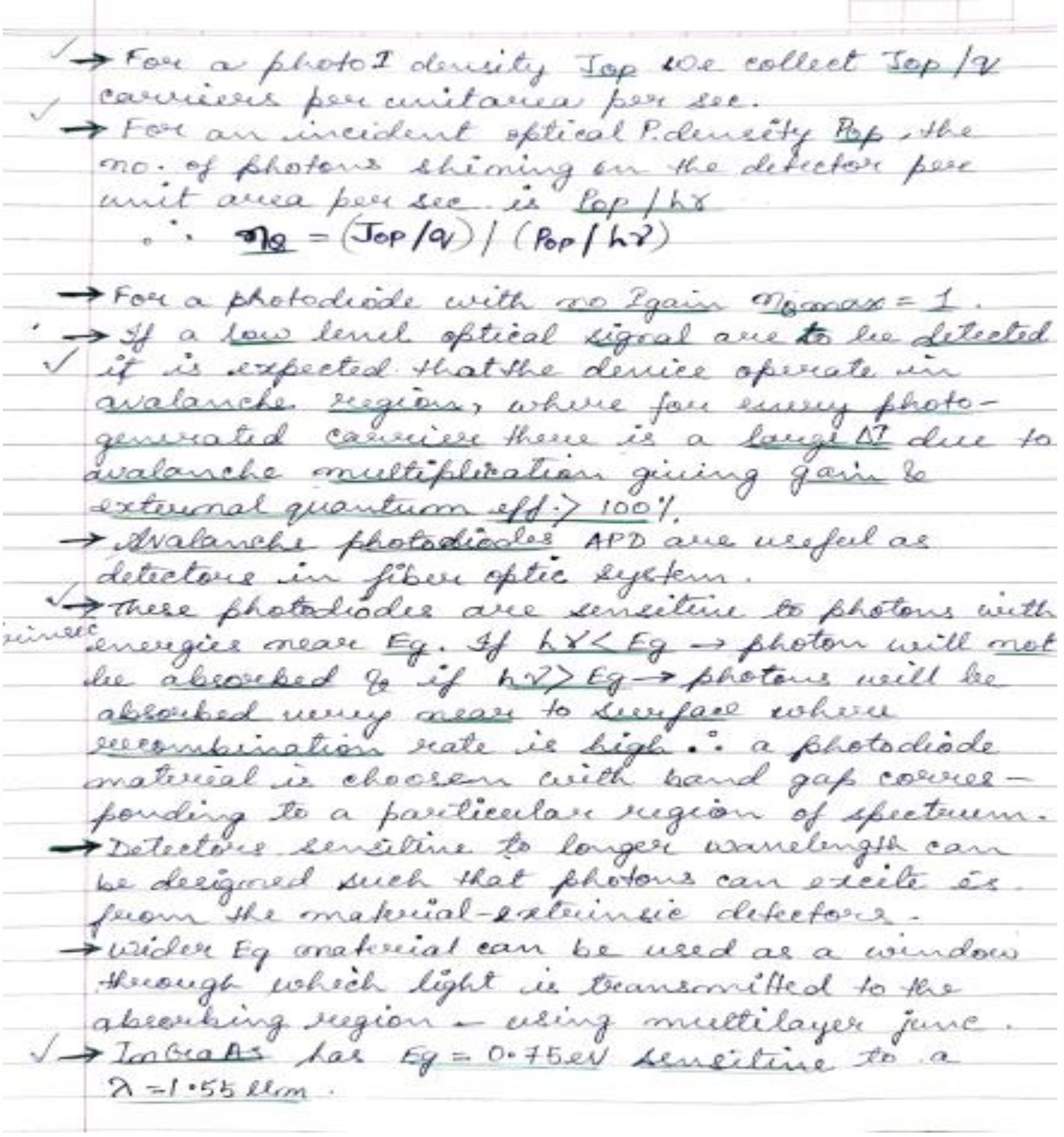
→ i region is intrinsic with high resistivity

→ i region can be grown epitaxially on the n type substrate & the p region can be obtained by implantation

→ When pin diode is RB the applied voltage appears almost entirely across the i region.

→ If carrier lifetime τ within the i region is long compared with the drift time, most of the photogenerated carriers will be collected by the n & p region.

→ Important figure of merit of the photodetector is the external quantum efficiency η defined as the no. of carriers that are collected for every photon impinging on the detector.



→ For a photo I density J_{op} we collect J_{op}/q carriers per unit area per sec.

→ For an incident optical P. density P_{op}, the no. of photons shining on the detector per unit area per sec. is $P_{op}/h\nu$

$\therefore \eta_Q = (J_{op}/q) / (P_{op}/h\nu)$

→ For a photodiode with no I gain $\eta_{Q\,max} = 1$.

→ If a low level optical signal are to be detected it is expected that the device operate in avalanche region, where for every photo-generated carrier there is a large ΔI due to avalanche multiplication giving gain & external quantum eff. > 100%.

→ Avalanche photodiodes APD are useful as detectors in fiber optic system.

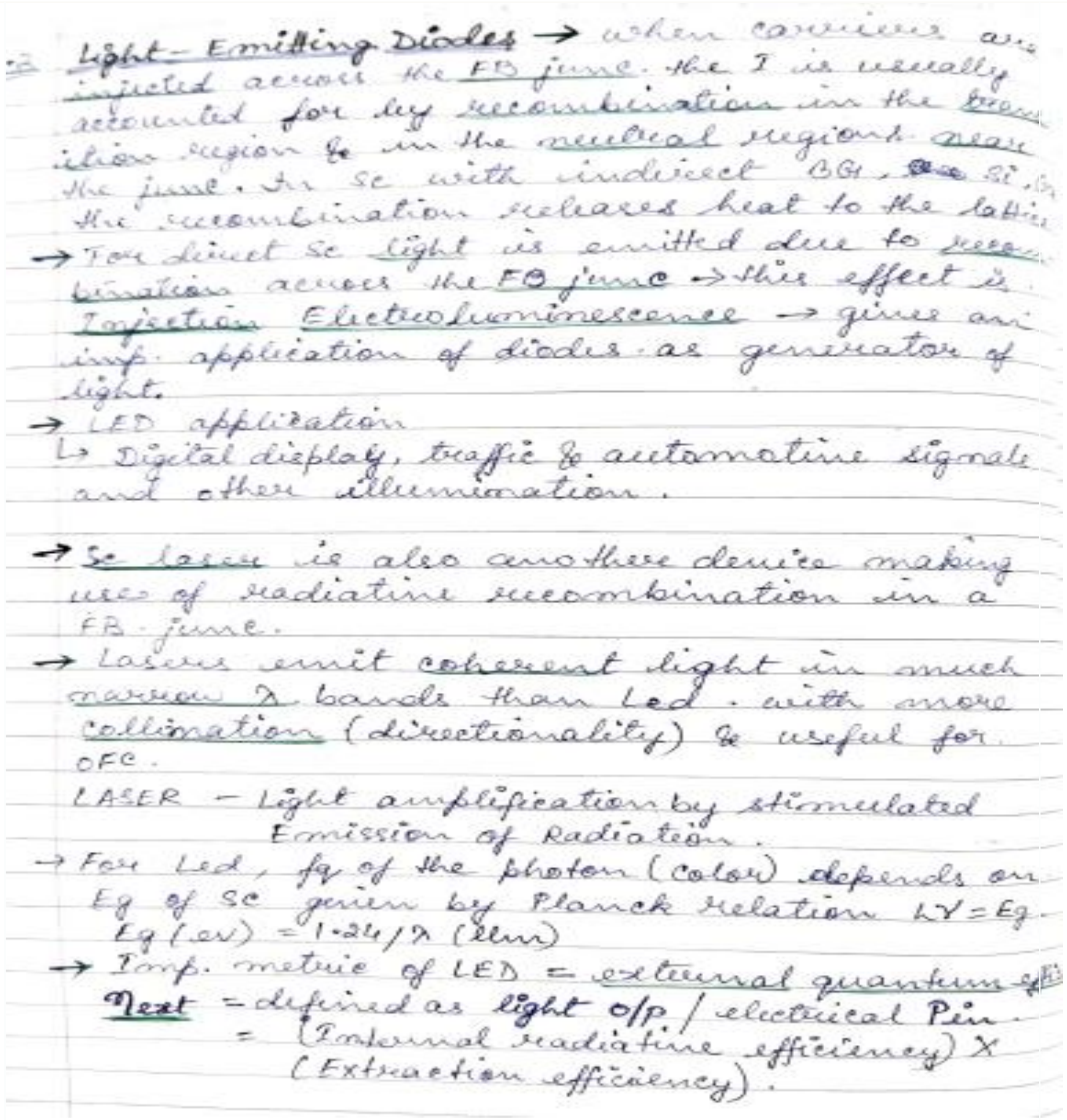
→ These photodiodes are sensitive to photons with energies near E_g. If $h\nu < E_g$ → photon will not be absorbed & if $h\nu > E_g$ → photons will be absorbed very near to surface where recombination rate is high ∴ a photodiode material is chosen with band gap corresponding to a particular region of spectrum.

→ Detectors sensitive to longer wavelength can be designed such that photons can excite e⁻s from the material - extrinsic detectors.

→ Wider E_g material can be used as a window through which light is transmitted to the absorbing region - using multilayer junc.

→ InGaAs has $E_g = 0.75\,eV$ sensitive to a $\lambda = 1.55\,\mu m$.

(b) Write a note on LED mentioning the applications of LED. What is external quantum efficiency of an LED?



3 Light-Emitting Diodes → when carriers ar injected across the FB junc. the I is usually accounted for by recombination in the transition region & in the neutral regions near the junc. In SC with indirect BG, Si, the recombination releases heat to the latti

→ For direct SC light is emitted due to recombination across the FB junc → this effect is Injection Electroluminescence → gives an imp. application of diodes as generator of light.

→ LED application

↳ Digital display, traffic & automotive signals and other illumination.

→ SC laser is also another device making uses of radiative recombination in a FB junc.

→ Lasers emit coherent light in much narrow λ bands than Led. with more collimation (directionality) & useful for OFC.

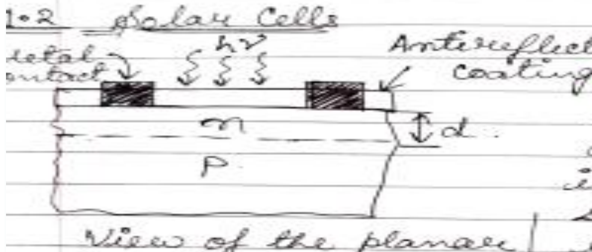
LASER – Light amplification by stimulated Emission of Radiation.

→ For Led, fq of the photon (color) depends on Eg of SC given by Planck relation $h\nu = E_g$.
$E_g(eV) = 1.24/\lambda\ (\mu m)$

→ Imp. metric of LED = external quantum effi
η_{ext} = defined as light o/p / electrical Pin.
= (Internal radiative efficiency) X (Extraction efficiency).

Explain the operation of a typical solar cell with a neat diagram. Define fill factor with diagram and describe efficiency of power generation of a solar cell.

1.2 Solar Cells



View of the planar junction.

→ ∴ power can be deli to an external ckt by an illuminated junc. it is possible to convert solar energy into electric energy. using 4th quad. But less Power is delivered by a Sing

→ V is < Vo for Si Voc < 1V & Iop = 10-100 mA for a junc. of area = $1cm^2$. Single junc. delivers less th

→ If many devices are used then power is significant.

→ Arrays of pn junc. are used to supply electric power for satellites, over a long period of time

→ Array of pn junc. can be placed on the satellite body / placed in solar cell paddles attached to the main body.

→ Eg → a solar wing. measuring 74m tip to t can each have 32,800 solar cells & can generate 62KW of power.

→ To utilize maximum amount of optical energy that is available, solar cells ar designed with large area junction located near device surface.

→ Planar junc is formed by diffusion or ion implantation & the surface is coated with appropriate materials to reduce reflection & to decrease surface recombination.

→ Many compromises are made in solar cell design.

→ Junc. depth d < Lp in the n material to allow hole generation near the surface. to diffuse to the junc. before they recombine ||ly p region thickness must be such that $\bar{e}$ generated in this region can diffuse to the junc. before they recombine.

→ Proper matching is needed b/w Ln, p region thickness & α absorption coeff.

$$I(x) = I_0 e^{-\alpha x}$$

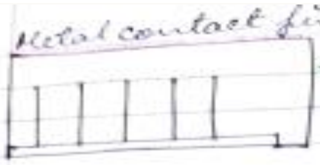
→ If contact potential Vo is large, photovoltage will be large. ∴ heavy doping is needed.

→ Series resistance of the device should be very small so that power is not lost to heat due to ohmic losses in the device. Series resistance of only few ohms can seriously reduce the Poutput of a solar cell.

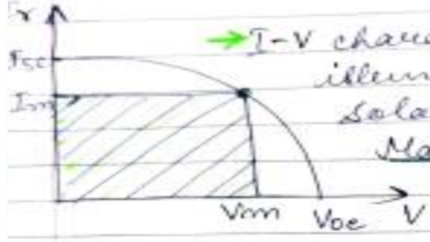
→ Since area is large, resistance of ptype body of the device can be made small.

→ Contacts to the thin n region requires special design. If this region is contacted at the edge, I must flow along the thin n region to the contact giving a large series resistance.

→ To prevent this the contact must be distributed over the n surface by providing by providing small contact fingers.



→ Narrow contacts reduce the series Resistance without interfering with the incoming light



→ I-V characteristics of illuminated solar cells. Max. power Rectangle.

→ 4th quadrant of solar cell characteristics Is plotted upward.

→ Voc & Isc are determined for a given light level by the cell properties.

→ Max Power is delivered to the load by the solar cell when product $VI_r = max$.

→ Max Power delivered is given by shaded rectangle $< I_{sc} V_{oc}$ $V_m I_m < V_{oc} I_{sc}$

→ Ratio $\frac{I_m V_m}{I_{sc} V_{oc}}$ = fill factor = figure of merit for solar cell design.
FoM.

→ Solar cell application
↳ Outer space
↳ Terrestrial application even though solar intensity is reduced by atmosphere.

→ Currently total power generation ~15TW & annual energy usage of ~500 quads (1 quad = 10^{15} or a quadrillion BTU) with an annual increase of 1-2%. From this 80% co
from fossil fuels.

→ Photovoltaic gives a I capacity of 100GW.