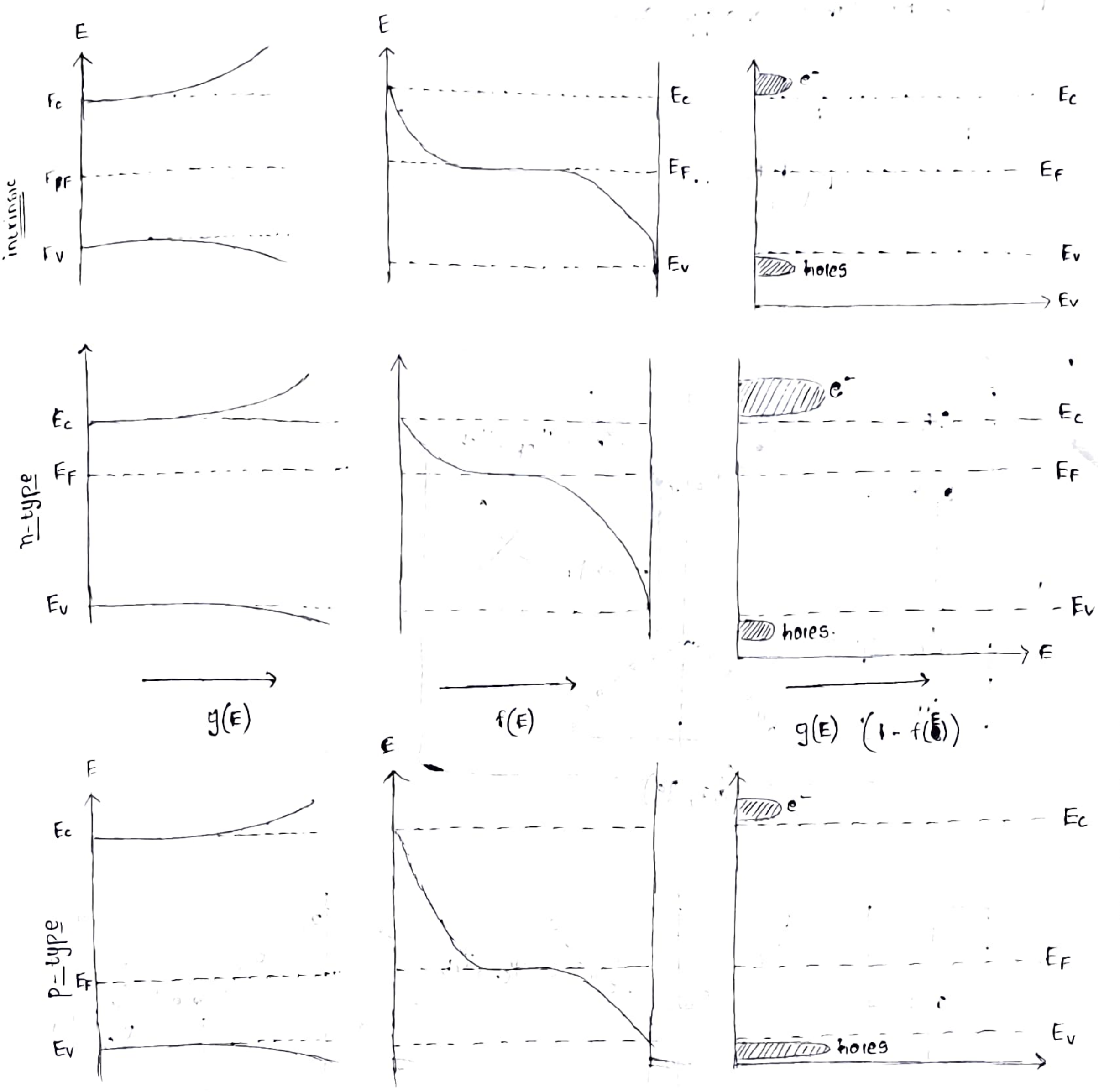
SEMI CONDUCTOR



$$n_i = N_c \exp\left[-\frac{(E_c - E_i)}{KT}\right]$$

$$p_i = N_v \exp\left[-\frac{(E_i - E_v)}{KT}\right]$$

$g(E) \rightarrow$ no. of states per unit vol. per unit energy

$f(E) \rightarrow$ Fermi-Dirac distribution.

$N_v \Rightarrow$ eff. DOS in valence band

∴ $N_c \Rightarrow$ effective density of states (DOS) in conduction band.

$N_c = 2.8 \times 10^{19}$ per cm^3 Si at 300 K.

$N_v = 1.02 \times 10^{19}$ per cm^3 Si at 300 K.

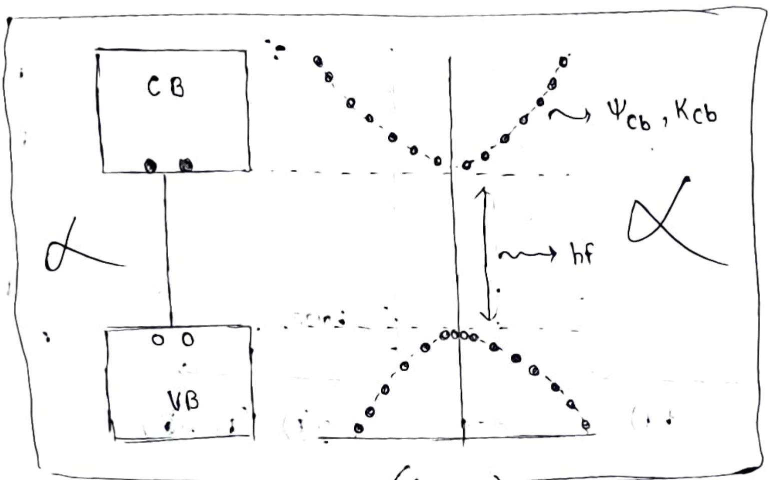
$$N_c = 2\left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2}, \quad N_v = 2\left[\frac{2\pi m_h^* KT}{h^2}\right]^{3/2}$$

$E_c \rightarrow$ bottom of conduction band level

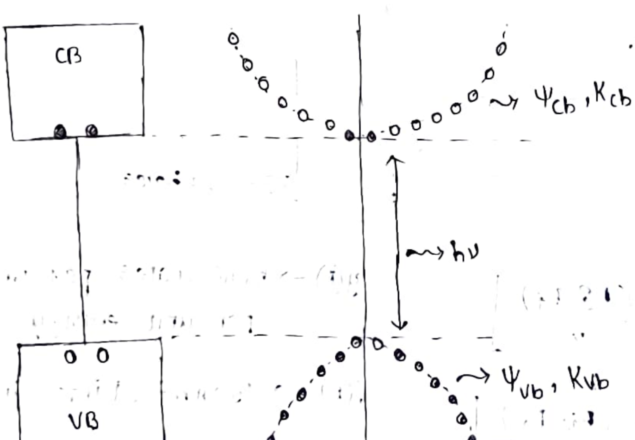
$E_v \rightarrow$ top of valence band level.

$E_F \rightarrow$ Fermi- Dirac energy level

$$f(E) = \frac{1}{\exp\left(\frac{E-E_F}{nT}\right)+1}$$

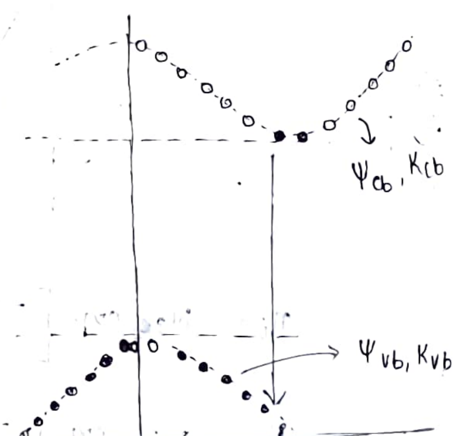


(Ga, As)



(Ga, As)

Direct bandgap.



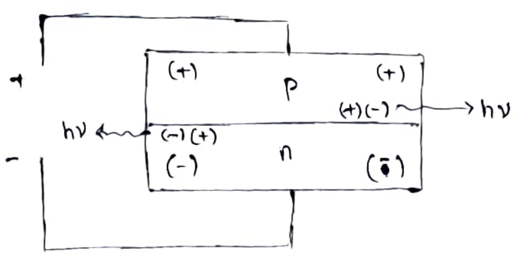
(Si)

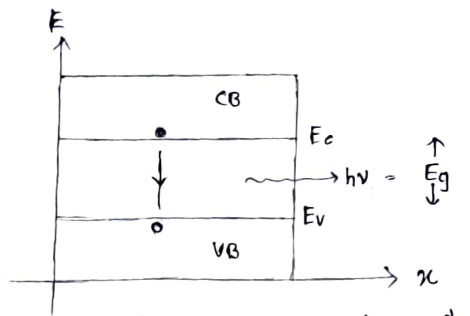
Indirect band gap.

LIGHT EMITTING DIODE. (LED).

A LED is a semi-conductor diode made by creation of a junc^n with n-type and p-type materials. When the diode is forward biased, e^- & holes enter the depletion region and recombine.

Unlike the case of regular diode these recombinations produce light. The recombination in the case of regular diode is called non-~~reactive~~ radiative.





Direct recombination in Ga, As.

When a free e^- wandering around in CB, if a crystal meets a hole, it falls into this low energy empty e^- state. This process is called recombination.

* Intuitatively, recombination corresponds to the free e^- finding an incomplete bond with a missing e^-. The e^- then enters and completes this bond. The free e^- in CB and free hole in VB are consequently aninihilants. On energy band diagram, the recombination process is represented by returning the e^- from CB (where it is free) into the hole in VB (where it is in a bond).

∴ RESPONSIVITY (R) and QUANTUM EFFICIENCY (η)

* This is regarding P-I-N photodiode.

* The input for a photodiode is light power. We denote it as P. The output current is known as photocurrent which is denoted by I_p.

* The photocurrent is proportional to the light power.

$$I_p \propto P$$

(or) $I_p = RP$

$R \rightarrow$ proportionality const known as responsivity.

* We know the photocurrent is the no. of e^- (N_e) times the charge of e^- (e) per unit time i.e.

$$I_p = \frac{N_e e}{t}$$

* On the otherhand, light power is light energy per unit time, where the light energy is equal to energy of photon (E_p) times the no. of photons (N_p) over time.

$$P = \frac{N_p E_p}{t}$$

* By substituting $E_p \left(= h\nu = \frac{hc}{\lambda}\right)$, we have following result:

$$R = \frac{I_p}{P} = \left(\frac{N_e}{N_p}\right)\left(\frac{e\lambda}{hc}\right) = \eta\left(\frac{e\lambda}{hc}\right)$$

$$\therefore \boxed{R = \eta \frac{e\lambda}{hc}} \ A/W.$$

⇒ A Si P-I-N photodiode has efficiency of 0.7 at wavelength 0.85 μm. Compute R.

Sol^n: $R = \eta \dfrac{e\lambda}{hc} = \dfrac{(0.7)\cdot(1.6\times10^{-19})\,(0.85\times10^{-6})}{(6.6\times10^{-34})\,(3\times10^{8})} = 0.479\ A/W$

⇒ When 2.5×10^{12} photons, generated by a laser source of wavelength 0.85 μm are incident on photodiode, 1.5×10^{12} e^- on average are collected at the output terminal. Compute Q-efficiency and Responsivity of photodiode at above wavelength.

Sol^n: $\therefore \eta = \dfrac{N_e}{N_p} = \dfrac{1.5\times10^{12}}{2.5\times10^{12}} = 0.6$

$\therefore R = (0.6)\,\dfrac{(1.6\times10^{-19})\,(0.85\times10^{-6})}{(6.6\times10^{-34})\,(3\times10^{8})} = 0.411\ A/W$

⇒ A PIN photodiode has quantum efficiency 70% for photons of energy 1.52×10^{-19} J. Calculate:

i) Calculate the wavelength at which the diode is operating.

ii) Calculate the optical power required to achieve a photocurrent of 3μA.

Sol^n: $\lambda = \dfrac{hc}{E} = 1.3\ \mu m.$

~~Responsivity~~ $R = \eta \dfrac{e\lambda}{hc} = 0.738\ A/W.$

$\therefore P = \dfrac{I_p}{R} = \dfrac{3\ \mu A}{0.738} = 4.07\ \mu W$

⇒ A PIN photodiode, on an avg generates one e^-- hole pair per two incident photons at $\lambda = 0.85\ \mu m$. Assuming the photogenerated e^- are collected, compute the following:

i) Q- efficiency of diode

ii) The maxm possible bandgap energy in eV of the semiconductor, assuming the incident wavelength to be long wavelength cutoff

iii) The mean output photocurrent when the incident optical power is $10 \mu W$.

Soln i) $\eta = \frac{1}{2} = 50\%$.

ii) $E = \frac{hc}{\lambda} = 1.46\ eV$.

λ ← $0.85\ \mu m$.

iii) $I_p = RP = 3.42\ \mu A$.

LASER : DIODE

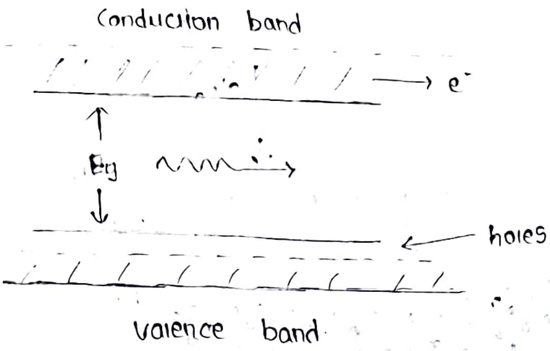


Fig-1

Light amplification mechanism in a p-N juncn diode.

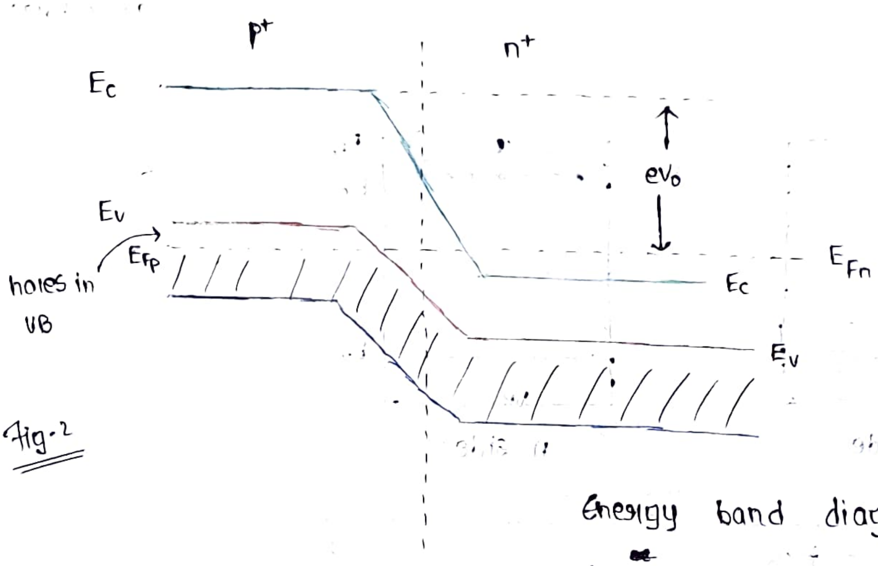


Fig-2

Energy band diagram of degenerately doped p-n juncn with no bias.

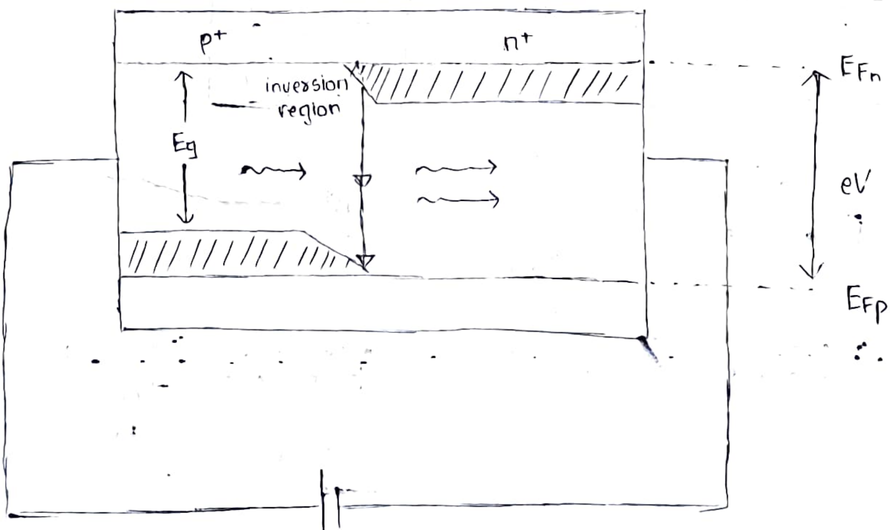


Fig-3

Band diagram with sufficiently large forward bias.

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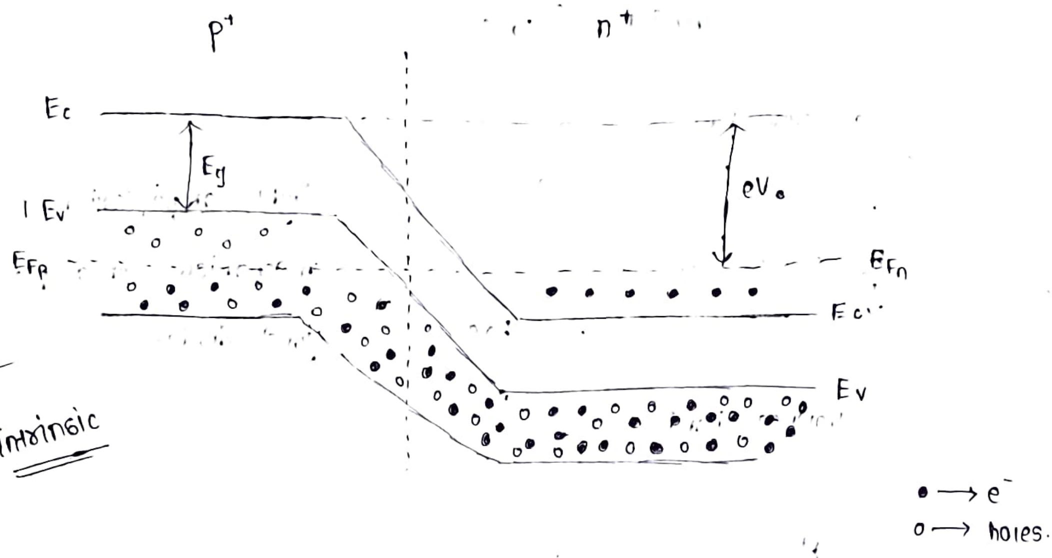

Fig. 4

intrinsic

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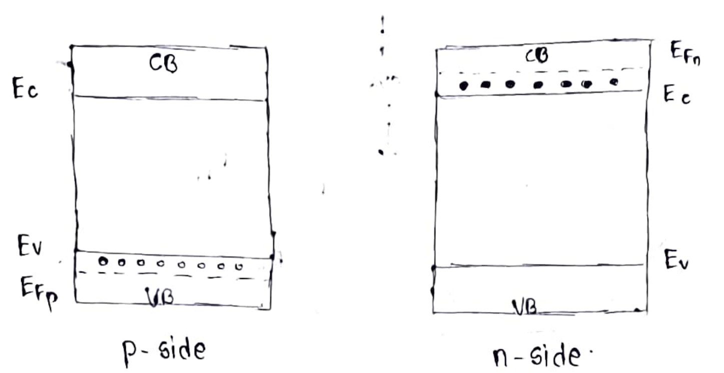
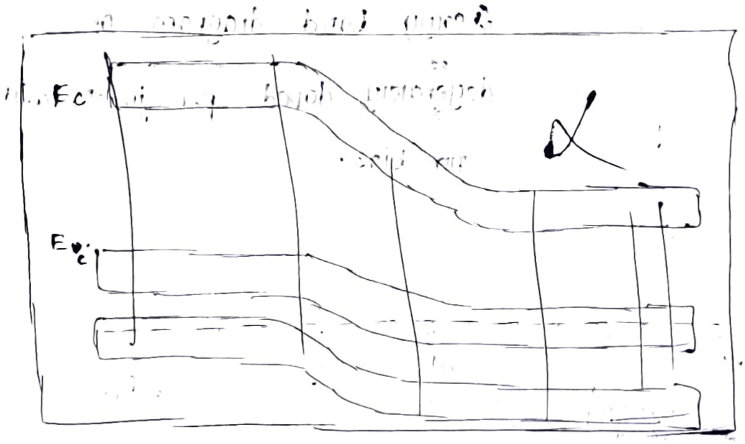


Fig. 5



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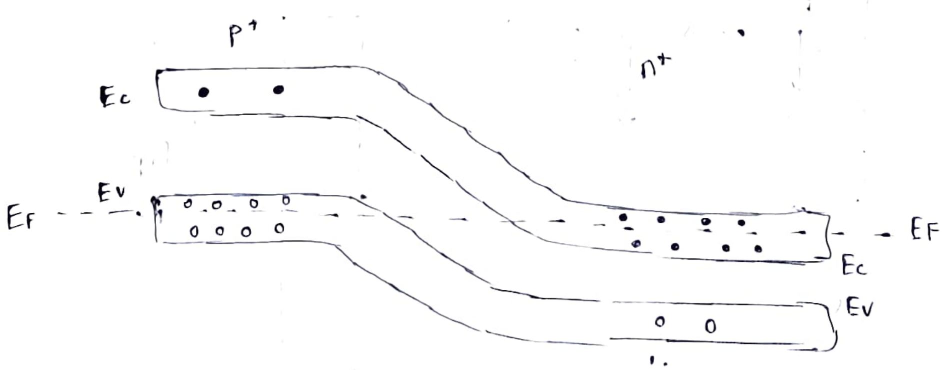


Energy bands of heavely doped PN Junc^n.

Stage-1 : In an intrinsic material, if

$$E_V + 3KT \le E_F \le E_C - 3KT$$

imp

$$n = N_{oc} \exp\left(\frac{E_F - E_C}{KT}\right)$$

use Fig-4

$$p = N_{ov} \exp\left(\frac{E_V - E_{oF}}{KT}\right)$$

* Substituting $n = p$, and set $E_{oF} = E_i$

$$N_{oc} \exp\left(\frac{E_i - E_c}{KT}\right) = N_v \exp\left(\frac{E_v - E_i}{KT}\right)$$

* Solving $E_i = \frac{E_v + E_c}{2} + \frac{KT}{2} \ln\left(\frac{N_v}{N_{oc}}\right)$

* But $\left(\frac{N_v}{N_{oc}}\right) = \left(\frac{m_p}{m_n}\right)^{3/2}$

* $$\boxed{E_i = \frac{E_c + E_v}{2} + \frac{3}{4} KT \ln\left(\frac{m_p}{m_n}\right)}$$

where $E_g = E_c - E_v$

Stage-2 : When a current is passed through PN junc^n under forward bias, the injected e^- and holes in VB will increase the density of e^- in CB and holes in VB. Further at some value of current the stimulated emission rate will exceed the absorption rate and amplification will begin. As the current is further increas at some threshold value of current the amplification will overcome the losses in the cavity and LASER will begin to emit coherent radiation

Use Fig-3

Stage-3 : Consider degenerately doped direct bandgap semiconductor PN junc^n, whose band diagram is given.

By degerate doping we mean that E_{Fp} (Fermi-level in p-side) is in VB and E_{Fpn} (Fermi-level in n-side) is in the CB. All energy levels upto Fermi level can be taken to be occupied by e^-.

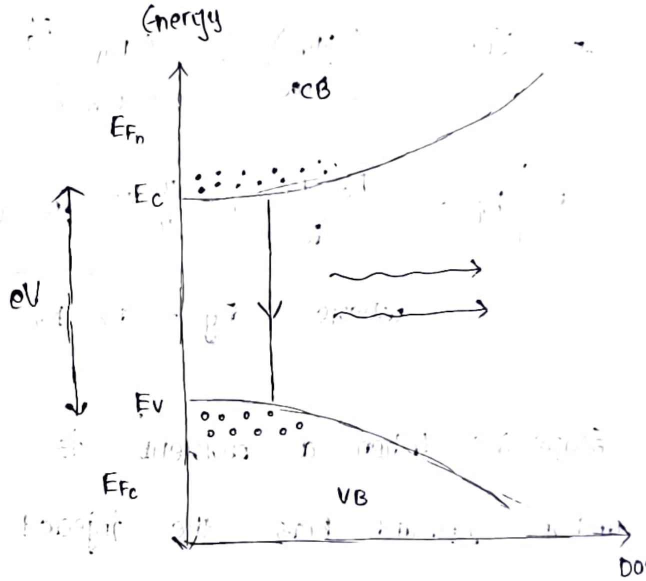
Fig-7

In the absence of appied voltage, the fermi level is continuous across the diode $E_{Fp} = E_{Fn}$.

Fig-5

Stage-4:

The DOS and energy distribution of e^- and holes in CB, VB resp. under forward bias of $E_{Fn} - E_{Fp} > E_g$



* Suppose PN Junc^n diode is forward biased by voltage V is greater than bandgap voltage eV > Eg.

* The seperation b/w E_{Fn} & E_{Fp} is now, the appied potential energy or eV. The applied voltage diminishesh the built in potential barrier to almost zero, which means that the e^- flow into SCL, ~~which means theat~~ the ~~e^- flow into~~ and flow over the p^+ side to consitute the diode current

* The final result is that e^- from n^+ side and holes from p^+ side flow into SCL region is no longer depletes.