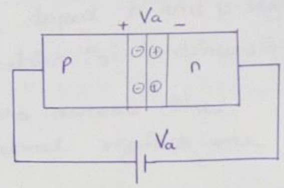
01

30/07/14

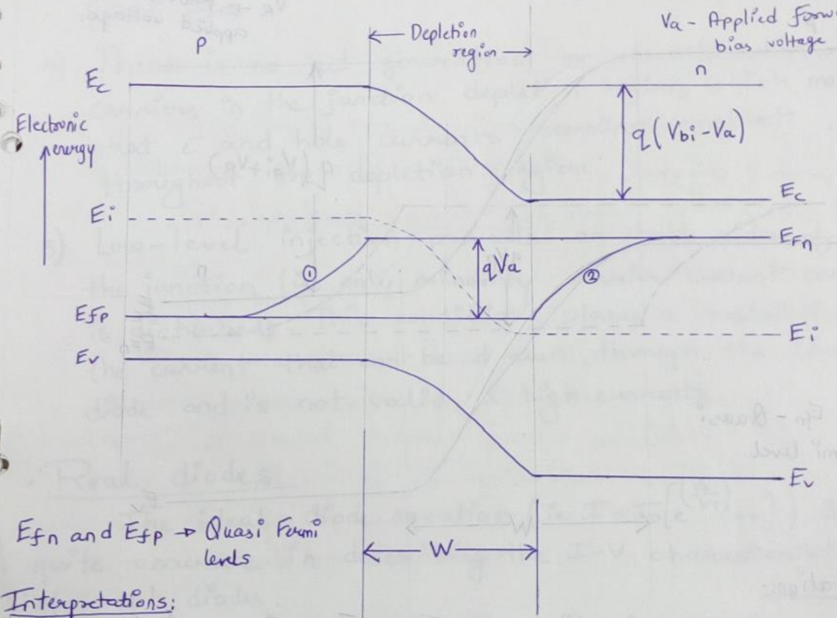
Energy band diagram of pn junction under forward bias:-

Assumptions:

1) No voltage drops in neutral p and n regions
2) Injection level in n and p sides is low, i.e (majority carrier concentration is not disturbed).



Va - Applied forward bias voltage



Efn and Efp → Quasi Fermi levels

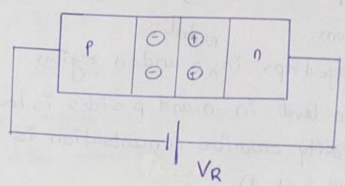
Interpretations:

① and ② ⇒ Indicates the presences of excess carriers

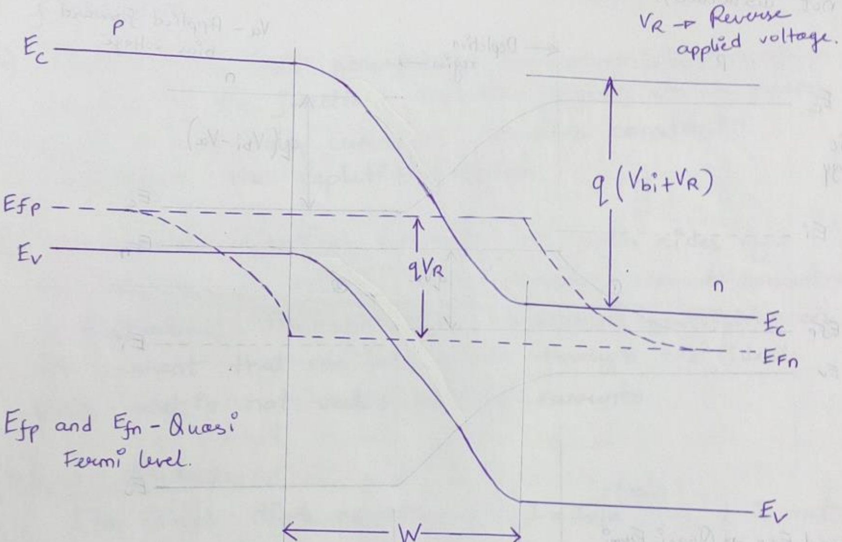
- $E_{Fn} - E_{Fp} = qV_a$
- E_{Fn} and E_{Fp} remains constant in the depletion region.
- Splitting of quasi fermi level in the neutral n and p regions indicates the presences of excess carriers in these regions.

INDERJIT SINGH

Energy band diagram of a pn junction under Reverse Bias.



$V_R \rightarrow$ Reverse applied voltage.



· E_{fp} and E_{fn} - Quasi Fermi level.

· **Interpretation:-**

· E_{Fn} in n-region is displaced from E_{Fp} in neutral p-region by qV_R.

· E_{Fn} and E_{Fp} are constant throughout the depletion region.

· Splitting of quasi-Fermi level in the neutral n and p regions indicates the extraction of minority carriers from their regions.

03 R

31/07/14

∴ Ideal pn junction diode assumptions: —

1) Abrupt junction between uniformly doped n and p regions.
2) Current flow across the pn junction is 1-dimensional.
3) All of the applied voltage appears across the space-charge region and the neutral regions are field free.
4) There is no net generation or recombination of carriers in the junction depletion region, which means that e^- and hole currents remains constant throughout the depletion region.
5) Low-level injection prevails on both sides of the junction. (ie only minority carrier current concentratn is disturbed). This condition places a restriction on the current that can be drawn through the ideal diode and is not valid at high currents.

· Real diodes:

The ideal diode equation (ie $I = I_0[e^{\left(\frac{V_a}{V_T}\right)} - 1]$) is not quite accurate in describing the I-V characteristics of real diodes.

Thus several deviations from ideal behavior are observed such as,

a) The generation and recombination of e^--hole pairs in the depletion region.
b) Voltage drop associated with E-field in neutral n and p regions.
c) Current arising from leakage across the surface of the junction.

04. R.

• When a semi-conductor is in non-equilibrium, then excess carriers may be generated.

• The rate at which these excess carriers (e^- or holes) recombine is "Recombination rate". (R)

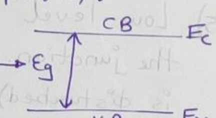
$$\boxed{R = \frac{\delta}{\tau}}$$

$\delta \rightarrow$ excess carriers

$\tau \rightarrow$ lifetime of excess carrier.

↦ Generation and Recombination of Currents:-

• In an ideal semiconductor (pure form) as it is a perfect crystal, the electronic energy states do not exist within the Forbidden-energy bandgap. (E_g).



• In real semiconductor material, however, defects or [deep impurities] are present within the crystal and these defects will create discrete electronic energy states within the forbidden energy band. known as "trap level" (E_t). This trap level depending on its location in the energy gap may acts as: an e^- trap or hole trap or as an "Recombination center". (As per Shockley-Read-Hall (SRH) theory of recombination)

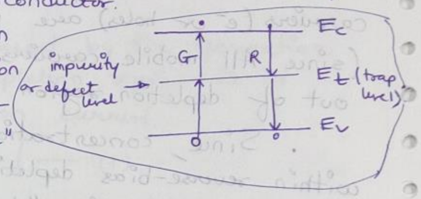
a) An e^- trap has a high probability of capturing a e^-, and setting it free after some time.

b) Similarly, a hole trap has a high probability of capturing a hole ie released in the valence band.

c) At a "Recombination center", the probability of capturing e^-s or holes are nearly equal.

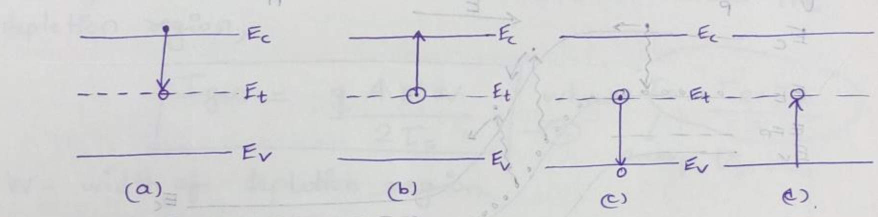
· SRH theory of recombination assumes that a single "recombination center" or trap, exists at a energy E_t within the bandgap of semiconductor. 05R

This type of mechanism is known as Indirect Generation/Recombination (Indirect G/R). ie here recombinatn or generation occurs via an "defect level" within the energy gap.



· There are 4 basic processes, that may occur at single trap level.

a) Electron capture b) Electron emission c) Hole capture
d) Hole emission.



a) Capture of an e^- from conduction band by trap level E_t.

b) Emission of e^- (ie intially occupying a trap level) from E_t level back into conduction band.

c) Capture of a hole from the valence band by trap level E_t.

d) Recombination center captures an e^- from valence band leaving behind a hole in the valence band.

INDERJIT SINGH

• Reverse bias generation current:-

• For a pn junction in reverse bias, no mobile carriers (e^- or holes) are present in the depletion region (since All mobile carriers have been essentially swept out of depletion region due to E-field).

• Since concentration of e^- and holes is zero within reverse-bias depletion region, e^- and holes are being generated via "trap level". These excess carriers generated are then recombined with carrier's which maintains thermal equilibrium (So Far)!
i.e e^-/holes generated via "trap level" are swept out of space charge region by E-field as shown below.

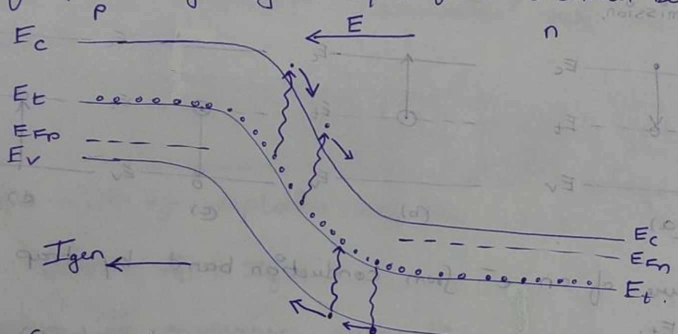


fig a: Current in a R.B pn junction due to thermal generation of carrier by (generation from a trap level 'E_t').

• Reverse current can be influenced by carrier's generated in depletion region.

• The generated minority carriers diffuse through depletion region, where they are swept to the other side of the junction by E-field as shown in fig(a).

- That is why, in the reverse-bias depletion region, generated carriers are swept out before recombination can occur and hence net "generation current" results in R.B.

- This reverse-bias current caused by the generation of e^-/holes via trap levels in depletion region is in addition to ideal R.B saturation current.

ie $$\boxed{I_R = I_0 + I_{gen}} \quad \text{— (1)}$$

ie Total current flowing through R.B pn junction is the sum of R.B generation current (I_{gen}) and I_0.

(Note: I_{gen} is the dominant current among the two in pn junction diode.)

Now for a constant 'Generation' rate across the depletion region,

$$\boxed{I_{gen} = \frac{q A n_i W}{2\tau_0}} \quad -(2) \qquad \text{where } \tau_0 = \frac{\tau_{p0} + \tau_{n0}}{2}$$

τ_0 → average life time.

W - width of depletion region.

ie $I_R = I_0 + I_{gen}$

where, I_0 → reverse saturation current
↳ It is independent of V_R

I_{gen} → Generation current in RB
↳ It is a function of depletion width (W)
ie it is a function of V_R

∴ I_R → Dependent on R.B voltage (V_R).
↓
Reverse-bias current