04/08/2014

Junction Breakdown

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- In an ideal pn junction, a R.B voltage will result in a small current (I_0) through the device.
- However, at a critical R.B voltage ie breakdown voltage (V_{BR}), reverse current ↑ses sharply.

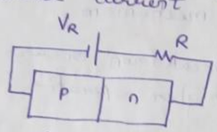
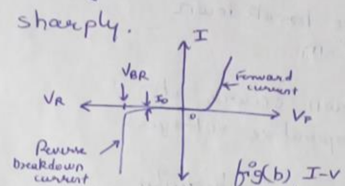


fig a) pn junction in R.B



fig(b) I-V curve of pn junction

- Now, maximum reverse current which can flow in the device is $\frac{(V_R - V_{BR})}{R}$; series resistor R is chosen to limit the current to a safe value.
- If the current is not limited externally, the junction can be damaged by excessive reverse current, which overheats the pn junction as the maximum power rating is exceeded.

Note: If this current is limited to a safe value by external circuit, the pn junction can be operated in reverse breakdown as safely as in F.B conditions (eg Zener diodes are designed to operate in Reverse breakdown regions)

- Breakdown puts limits on the amount of voltage that can be applied across a pn junction.
- Breakdown voltage (V_{BR}) is related to the peak or critical E-field at the depletion region of a R.B pn junction.

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- Junction breakdown / Reverse breakdown can occur by two mechanisms.

Zener breakdown mechanism

- Breakdown occurs at lower operative voltages
- It occurs in heavily doped pn junctions.
- It occurs due to tunneling mechanism
- These characteristics do not have a Knee point, hence Known as 'soft characteristics'
- Breakdown voltage (V_{BR})

$$V_{BR} < 4\left(\frac{E_g}{q}\right)$$

- Temperature co-efficient of breakdown $\left[\text{ie } \frac{1}{V_{BR}}\left(\frac{dV_{BR}}{dT}\right)\right]$ is negative.

ie $\frac{1}{V_{BR}}\left(\frac{dV_{BR}}{dT}\right) < 0$

Avalanche breakdown mechanism

- Breakdown occurs at higher operative voltages.
- It occurs mostly in pn diodes having low doping.
- It occurs due to impact ionization of energetic carriers.
- These characteristics (I-V) in reverse have Knee point, hence Known as 'hard' characteristics.
- $V_{BR} > 8\left(\frac{E_g}{q}\right)$
- Temperature co-efficient of breakdown is positive

ie $\frac{1}{V_{BR}}\left(\frac{dV_{BR}}{dT}\right) > 0$

• **Zener Breakdown:** (As per textbook):

• Zener breakdown occurs in highly doped pn junctions through a tunneling mechanism.

• In a highly doped junction, the CB and VB on opposite sides of the junction are sufficiently close during reverse-bias that e^-s may <u>tunnel</u> directly from the VB on pside into CB on the n-side.

• Thus tunneling of e^-s from pside of VB to nside CB constitute a reverse current from n to p. ⇒ Zener breakdown mechanism.

Reference:

> Note: In simple covalent bonding model, zener effect can be thought of as field ionization of host Si atoms at the junction, ie the R.B of heavily doped junction causes a large E-field within W, at critical field strength, e^- participating in covalent band may be torn from the bonds by E-field & accelerated to nside of the junction.

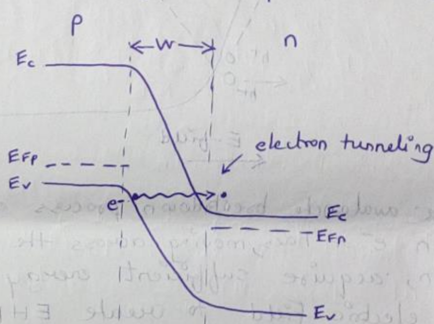

fig (1.a): Zener breakdown mechanism in a R.B pn junction showing electron tunneling from p to n.

• W → depletion region width.

Typical E-fields for Si & GaAs $\geq 10^6$ V/cm

Typical doping concentration (on both sides of the junction) $\geq 5 \times 10^{17}/cm^3$.

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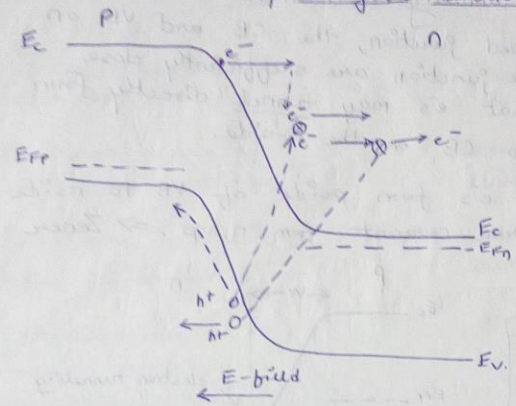
CB → Conduction band

VB → Valence band

· **Avalanche Breakdown** (As per textbook):

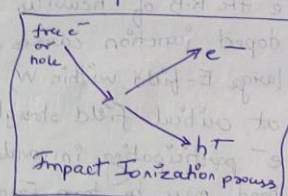
· Avalanche breakdown involves the impact ionization of host atoms by energetic carriers.



⊗ → host atoms (Si)

fig 2(a) Electron-hole pair (EHP) created by impact (II) ionization. Showing Avalanche breakdown mechanism.

→ Diagram shows energy Band of R.B pn junction having primary e^- gaining K.E in E-field of depletion region and creating a secondary EHP by II.



· The avalanche breakdown process occurs when e^- or holes, moving across the depletion region, acquire sufficient energy from the electric field to create EHP by colliding with host atoms within depletion region.

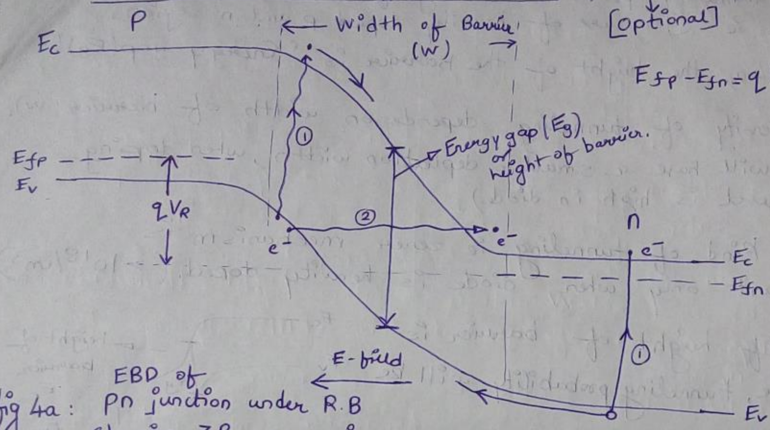
· The newly created e^- & holes move in opposite directions due to the E-field and thereby add to the existing R.B current.

In addition, the newly generated (secondary) e^- or holes may acquire sufficient energy to ionize with other atoms, leading to more such EHP and so forth.

This is an avalanche process, since each energetic carrier can initiate the creation of a large number of new carriers.

{ Energetic Carriers → Carriers which gains K.E from E-field)

∵ Zener Breakdown (ZB) mechanism (In depth): [optional] 15



$E_{fp} - E_{fn} = qV_R$ (Applied voltage)

fig 4a: EBD of pn junction under R.B showing ZB process via tunneling mechanism.

- When a pn junction is reverse biased (RB), small current still flows in the device. This current is due to generation of EHP's (Process ①), ie generation current.

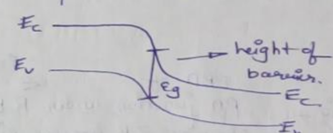
In process ①, e^- is jumping from VB to CB on <u>same side</u> of the material ie p-side ie (generation of EHP within p layer)
(Here, e^- is jumping from lower energy to higher energy).

- In process ②, there is also an EHP generation, but here e^- is jumping from VB of pside to CB of n-side.
(Here, e^- is jumping at same energy from 1side to the other side.
- This process → wherein e^- is pentrating a barrier at same energy is responsible for breakdown is known as "Tunneling process." (which is dominantly seen in heavily doped junction)
- Thus, tunneling process involves e^- going from one location to other location through a potential barrier, but the two locations are at the same energies.

- This tunneling process is significant when barrier is small ie in case of heavily doped p and n regions
- In Fig 4a, the hight of the barrier is 'Energy gap(E_g)'.
- The intensity of tunneling depends on width of barrier (w).
- (We will have a smaller depletion width, when doping level is high in diode)

∴ This kind of tunneling ie zener mechanism is dominant only when diode is heavily doped. ($>10^{18}/cm^3$)

Note: If hight of barrier is more, tunneling probability will be less.



* This means that, breakdown voltage (V_{BR}) becoz of zener mechanism is a function of Energy gap (E_g) of semiconductor.

Reference:

⊢ Practical estimation of Breakdown voltage (V_{BR}) of diode :-

- V_{BR} depends on 'peak' electric field.

$$V_{BR} = \frac{\epsilon_s E_{BR}^2}{2q N_B}$$

Valid for one-side junction (p^+-n junction)

when E_m reaches E_{BR}, then break-down occurs.

E_m - Peak E-field

E_{BR} - Breakdown field

N_B - Semiconding doping in low doping region

↦ Avalanche Breakdown (AB) (In-depth) only for understanding

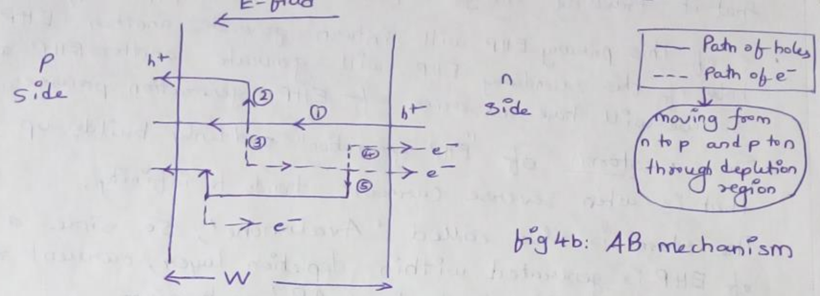


fig 4b: AB mechanism

- AB involves process of generation of EHPs by impact ionization. and it occurs in diodes having low doping (when doping levels are small in diodes, the depletion region's are wider).

- Let's consider a reverse bias pn junction having depletion width 'W' and having E-field directed as shown in fig(4b).

- Let's consider path of holes h^+ ① moving from n to p side through depletion layer. During its motion, if W is sufficiently wide, & E-field is sufficiently large, then what happen is →

1) The hole h^+ ① during its motion, can gain sufficient energy from E-field ie it gains K.E and if this K.E is large and high enough to break a covalent bond ie $K.E \approx E_g$, then h^+ moving in depletion region, it may collide with a Si atom, it can give rise to electron-hole pair (EHP) ie ② & ③.

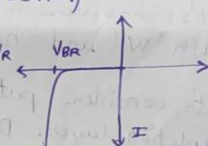
2) Now, hole ② moves to p side & e^- ③ generated will move towardes n-side. (via E-field)

3) If e^- ③ travels a sufficient distance within Depletion region, it may gain enough K.E to break covalent bond and generate an EHP ④ & ⑤., Thus e^- ④ moves to n side and hole ⑤ moves toward p side. & this process goes on.

- Thus if E-field and W are such that, for every hole that it travelling through depletion layer, an EHP is generated (primary).
- e⁻ of this primary EHP will inturn generate another EHP and holes of this secondary EHP will generate another EHP and so we will have a series of EHP generation processes.
- So, a <u>storm</u> of "EHP generation" suddenly builds up and that is when reverse current tends to infinity.
- The storm is also called 'Avalanche', so since a <u>storm</u> of EHP is generated within depletion layer, current rises rapidly. and this leads to '<u>AB' mechanism.</u>

<u>Note:</u> (AB mechanism occurs in diodes having low doping, becoz you must have a sufficiently large depletion width(w); otherwise e⁻ or holes which are travelling the depletion region cannot gain sufficient energy to break the bond.)

<u>Summary:</u> (Reverse Bias pn junction)



- For reverse currents below V_{BR}, mechanisms contributing to reverse current flow are

① Diffusion currents in neutral region and

② Thermal generation-recombination current within the depletⁿ layer.

- Near breakdown in reverse-bias, an additional generation mechanism is initiated, → either due to tunneling (zener breakdown) or due to impaction ionization (Avalanche breakdown).

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