Similarly for holes:-

$$J_p = -e D_p \frac{dp}{dx}$$

Diffusion coefficient for holes.

Equilibrium vs. Steady-State:-

Equilibrium is the condition when ~~no voltage or~~ ~~to~~ the material doesn't have any source of excitation that is applied externally. This is also known as thermal equilibrium.

On the other hand when there is a source of excitation and ~~to~~ after the application of the excitation you have waited long enough so, that every thing, for eg n and p within the material, has reached a constant distribution, then the state of the material is known as steady state.

~~Read See 1.1.4~~

Einstein's relation:

$$\frac{D}{\mu} = \frac{kT}{e}.$$

Excess carriers

Some external sources of excitation may cause valence electrons to break bonds. and create electron hole pair. The electron resides in CB while the hole reside in VB. ~~The~~

For eg: let us say when light impinges on a semiconductor, if the photons have energy $> E_g$, then the electrons can absorb the photons to break the bond. This result in creation of excess electron in the ~~valence~~ CB and excess holes in the VB. The electrons and holes thus created donot stay there indefinitely, but recombine with a characteristic life span called minority carrier life-time or excess carrier life-time. At steady state the generation rate must be equal to recombination rate.

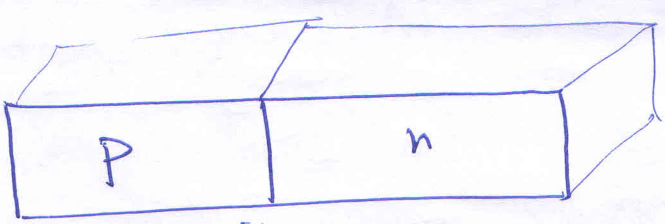
since this is not an equilibrium situation, $np \neq n_i^2$.

Majority and minority carriers:

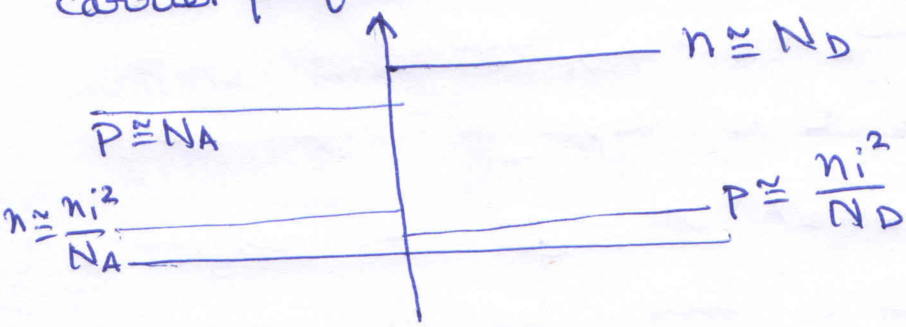
Carriers which dominate current conduction within a semiconductor are called majority carriers. For example in a ~~semicondu~~. n-type semiconductor, electrons are the majority carriers. Holes are majority carriers for p-type semiconductors. The other type of carriers are called minority carriers. Electron and holes are minority carriers in p-type and n-type semiconductors respectively.

The p-n junction or metallurgical junction:

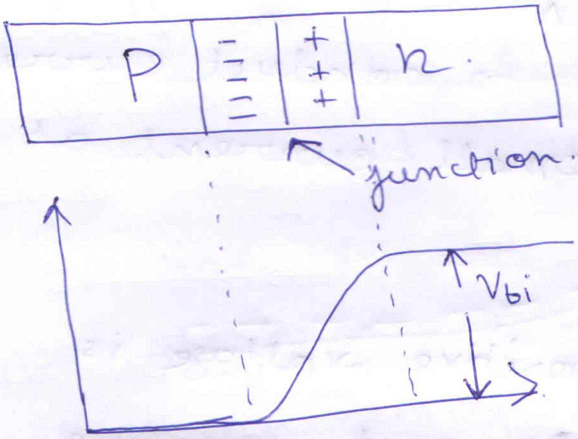
This is a device formed by the junction of a p-type semiconductor and an n-type semiconductor. p-type semiconductor contains lot of holes and n-type semiconductor contains lot of electrons. When they are joined, (dont assume they are joined with adhesive. There are proper chemical and growth methods to form a junction), electron from n-type semiconductor flow or diffuse towards the p-type semiconductor. Holes diffuse towards the n-type semiconductor. This results in exposing immobile charge near the junction.



Carrier profile;-



When such immobile charges are exposed, an electric field develops across the junction. This electric field prevents further diffusion of electrons and holes.



Due to this electric field, a potential develops across the junction. This potential is called built-in potential barrier and is given by $V_{bi} = \frac{kT}{e} \ln \frac{N_A N_D}{n_i^2}$

$$= V_T \ln \frac{N_A N_D}{n_i^2}$$

$V_T = \frac{kT}{e}$ is called the thermal voltage.

$V_T \cong 26$ meV at room temp.

The region containing immobile charge near the junction is called the depletion or the space-charge region.

Reverse Biased junction: Negative voltage applied to the p-side and positive voltage applied to the n side. Note that it increases the potential barrier at the junction. and also increases the peak electric field. This repels holes and electrons near the junction from the p-type and n-type material respectively and the junction becomes depleted of carriers. Here at the junction The diffusion component of the current decreases there are no or little carrier to conduct current and we get a very small current at reverse bias.

Forward Bias: When positive voltage is applied to the p-side and negative voltage is applied to the n-side. This increases the diffusion current compared to the drift current by decreasing the built in potential at the junction. (The drift and diffusion currents are equal but opposite when no voltage is applied). In this case, the current increases exponentially with the applied voltage.

The current both in reverse and forward bias is given by the relation:-

$$i_D = I_s \left[\exp\left(\frac{v_d}{nV_T} \right) - 1 \right].$$

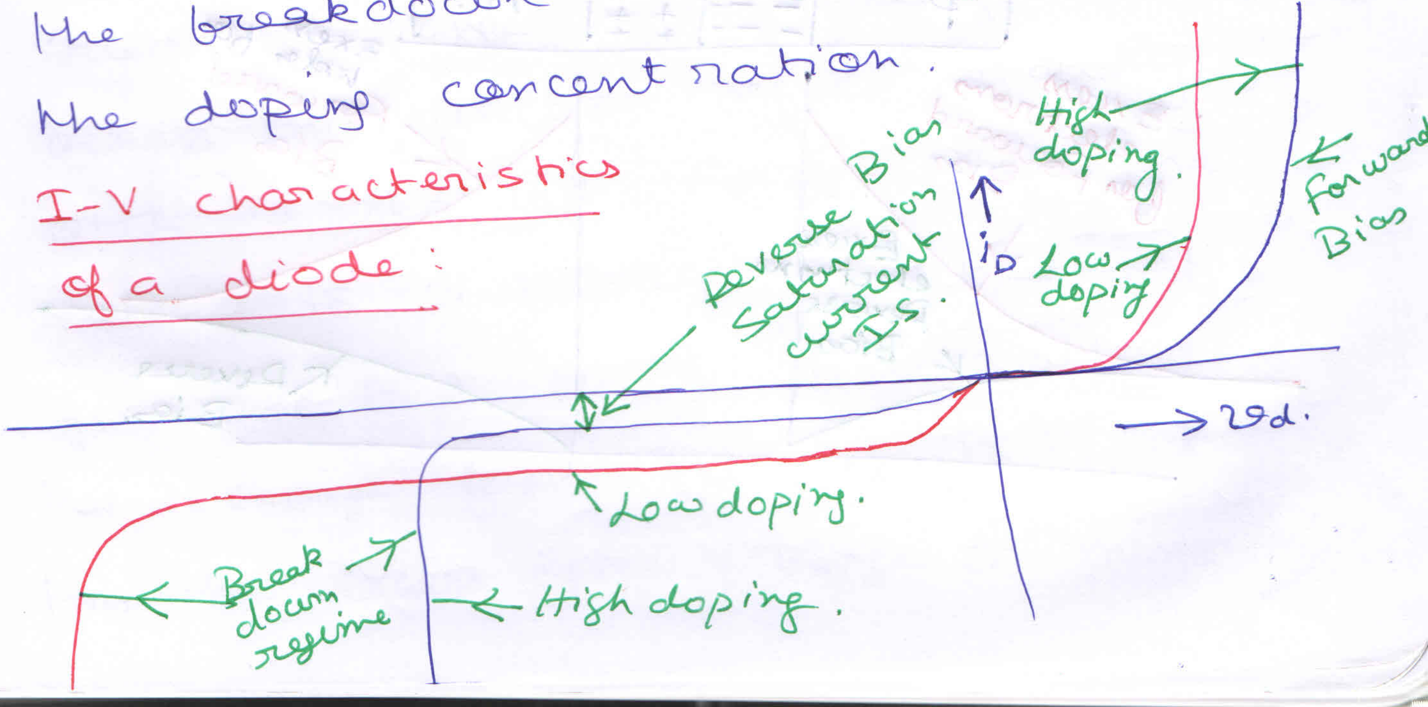
I_s is called the reverse-bias saturation current. [When ~~v_d~~ $v_d \ll -V_T$, $i_D \simeq I_s$]

Higher is ~~the~~ the doping concentration, lower is the value of I_s

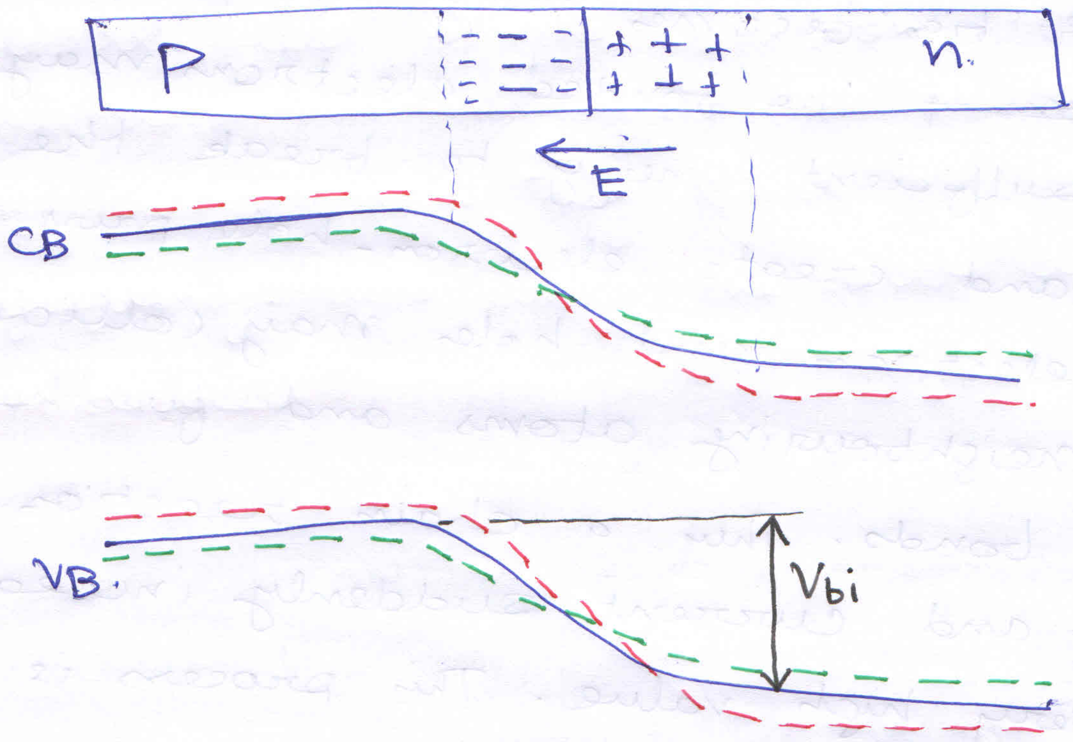
Breakdown regime: If the magnitude of reverse bias becomes very high then ~~electrons~~ the bonded electrons may gain sufficient energy to break the bond, and create electron-hole pairs. These electrons and holes may collide with neighbouring atoms and further break bonds. Thus a chain reaction starts and current suddenly increases to a very high value. This process is known as avalanche breakdown.

In very highly doped junction, electron-hole pairs may tunnel through the barrier easily if the voltage is increased to a very high value. This is known as Zener Breakdown mechanism. One can control the breakdown voltage by controlling the doping concentration.

I-V characteristics of a diode:



Band Diagram of a p-n junction:



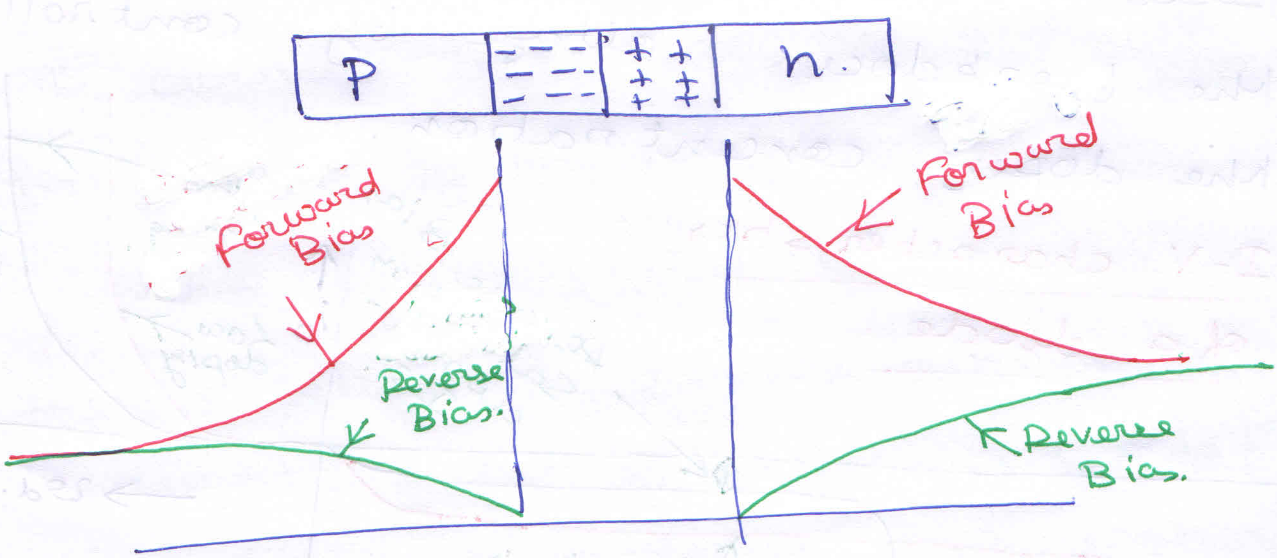
Blue: Junction in equilibrium with no applied voltage.

Red: Reverse Bias

Green: Forward Bias

~~Minority Carrier distribution~~

Excess minority carrier distribution:



Effects of temp on diode current:

The diode current generally increases with increase in temperature. This occurs due to the change in energy distribution of electrons. As a general rule the diode current generally increases 2 times per 10°c rise in temp.

Junction Capacitance

Depletion capacitance:- Capacitance due to change in depletion layer width (depletion charges) with change of voltage.

Diffusion Capacitance: Capacitance due to change in minority carrier conc with applied voltage.

Both these capacitances affect the steady state operation (when ac is applied) since the charge conc. needs to change as the voltage is changed across the junction before steady state is reached. For eg: When the voltage is suddenly switched off, from V_R to 0, the junction voltage has to change from $V_{bi} + V_R$ to V_{bi}. For this the excess space-charge or minority carriers have to flow out before the electric field at the junction changes. So, the capacitances affect the ac behaviour of the circuit. They limit the upper frequency upto which the diode works as desired.

Excess minority carriers: In forward bias the diffusion component of the current increases and hence more electrons are injected from the n-side to the p-side and more holes are injected from the p-side towards the n-side. Hence, some excess minority carriers build up in the n and p-side due to excess injection of holes and electrons respectively. ~~These carriers are knou~~

In reverse bias electrons and holes are depleted in the p and n side respectively.

~~This can be vieo~~