pn junction

balance between diffusion and drift currents for electrons and holes;
application of the forward or reverse external bias;

July 1, 2021

Doping

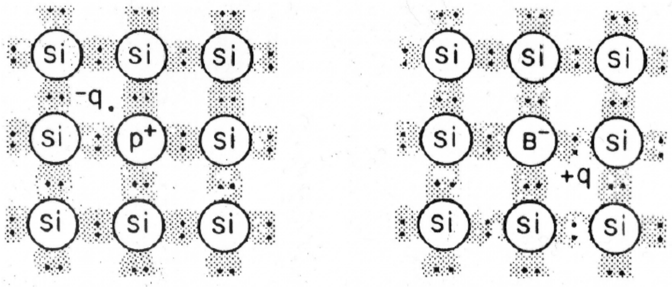
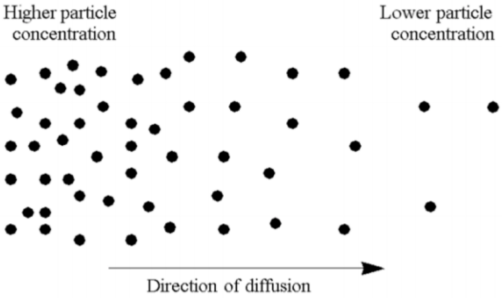


Figure 1: Doping of a Si-semiconductor

One region (P) is doped with B atoms (3 valence electrons)
The other region (N) is doped with P atoms (5 valence electrons)
The electrons in excess in the N region go to the P region leaving an excess of positive charge (P^*) apporting negative charge in the P region.

Diffusion process

- Particles will diffuse to equalize distribution.



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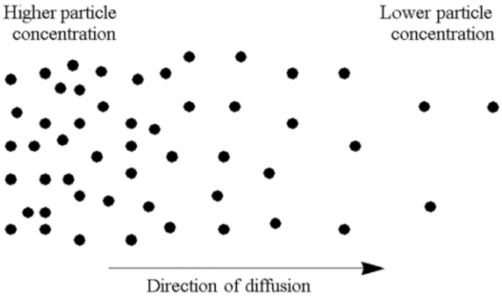
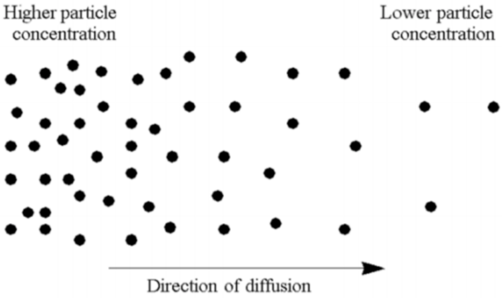
- Particles diffuse from regions with higher concentration to lower and vice versa.



Diffusion process

- Particles will diffuse to equalize distribution.
- Particles diffuse from regions with higher concentration to lower and vice versa.
- This is simply due to statistical properties.



An electric field starts forming and slows down the process of diffusion untill the elctrons have not enough energy to win the potential

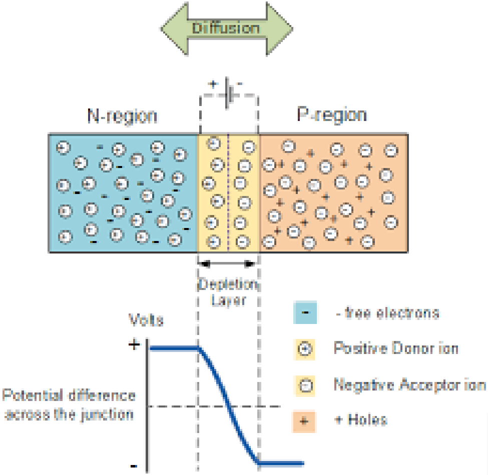


Figure 2: PN junction

Diffusion process

- The diffusion current consists in electrons moving from the N region to the P region (concentration gradient)

$$J_n = J_{n,\ \text{drift}} + J_{n,\ \text{diff}} = qn\mu_n\varepsilon + qD_n\frac{dn}{dx}$$
$$J_p = J_{p,\ \text{drift}} + J_{p,\ \text{diff}} = qp\mu_p\varepsilon - qD_p\frac{dp}{dx}$$

At equilibrium $J = J_n + J_p = 0$

Diffusion process

- The diffusion current consists in electrons moving from the N region to the P region (concentration gradient)
- The drift current is due to moving electrons as a consequence of the electric field and it is in the opposite direction of the diffusion current

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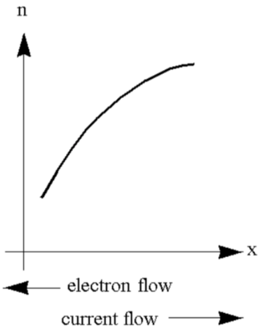
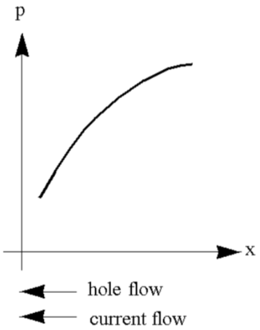
$$J_p = J_{p,\text{ drift}} + J_{p,\text{ diff}} = qp\mu_p\varepsilon - qD_p\frac{dp}{dx}$$

At equilibrium $J = J_n + J_p = 0$

$$J_{\text{n,diff}} = qD_n \frac{dn}{dx}$$

$$J_{\text{p,diff}} = -qD_p \frac{dp}{dx}$$





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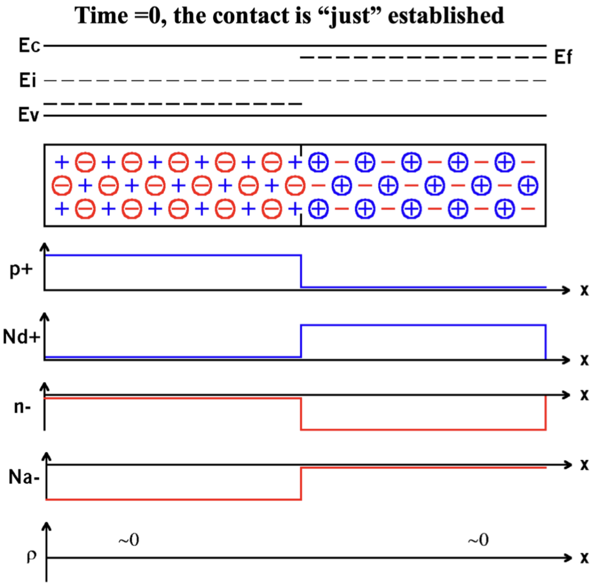
- The total charge flow is determined by a combination of drift and diffusion

$$\begin{gathered}J = J_n + J_p \\ J_n = J_{n,\mathrm{drift}} + J_{n,\mathrm{diff}} = qn\mu_n\varepsilon + qD_n\frac{dn}{dx} \\ J_p = J_{p,\mathrm{drift}} + J_{p,\mathrm{diff}} = qn\mu_p\varepsilon + qD_p\frac{dn}{dx}\end{gathered}$$

Contact bending



Band bending

At equilibrium the Fermi energy of the two parts are equal and the other levels bend in order to connect each other

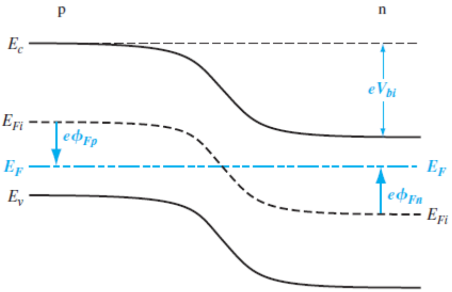


Figure 7.3 | Energy-band diagram of a pn junction in thermal equilibrium.

Figure 3: Energy levels in a PN junction

Biasing

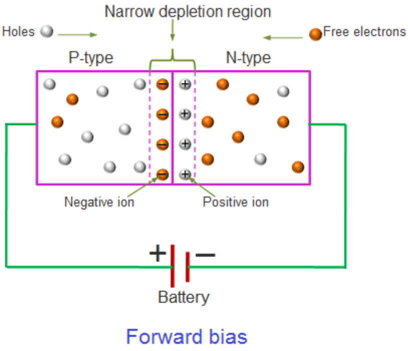
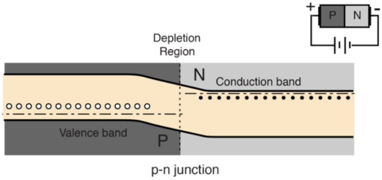
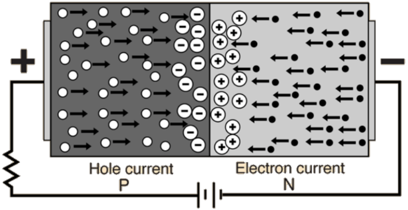


Figure 4: Forward biasing of a PN junction

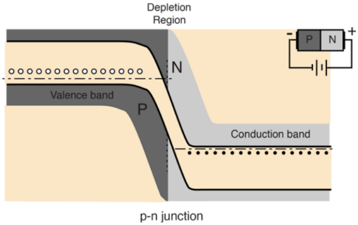
Biasing

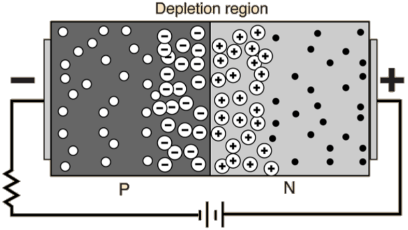
Forward bias





Reverse bias





Biasing

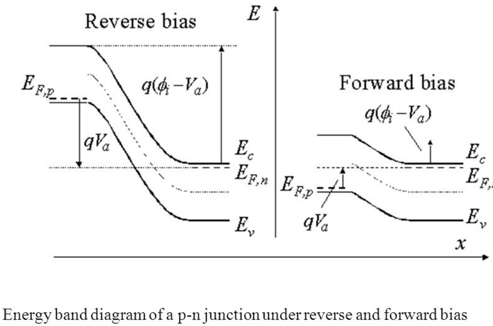


Figure 5: Biasing of a PN junction

Diode

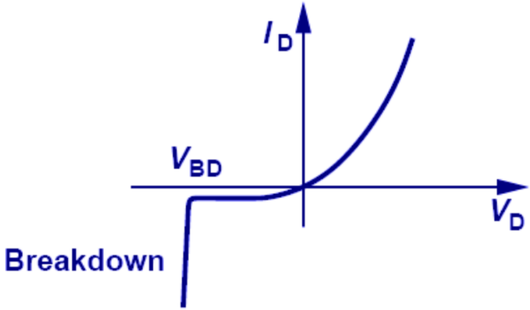


Figure 6: I-V curve of a diode. The exponential trend is due to the Boltzmann distribution. The breakdown occurs when we provide enough energy to break bonds forming electron-hole pairs that travel according to the applied field and counter the depletion region field.