PHYSICS OF SOLAR CELLS

There are two mechanismos for charge transport

Electric field

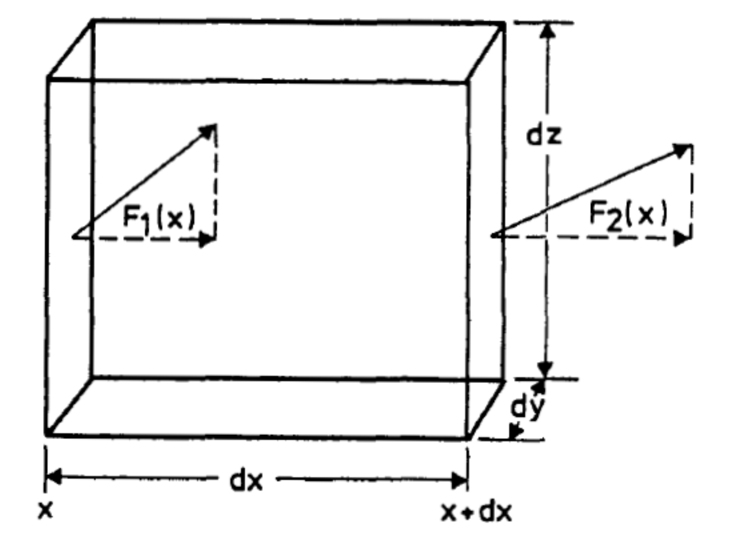
Diffusion

$$I_n = q\left(n\mu_n E + D_n \frac{\mathrm{d}n}{\mathrm{d}x}\right)$$

PHYSICS OF SOLAR CELLS

$$-\frac{d^2\varphi}{dx^2} = \frac{dE}{dx} = \frac{Q}{\varepsilon\varepsilon_0}$$

$$\frac{dE}{dx} = \frac{q}{\varepsilon\varepsilon_0}\left(p - n + N_D^+ - N_A^-\right)$$

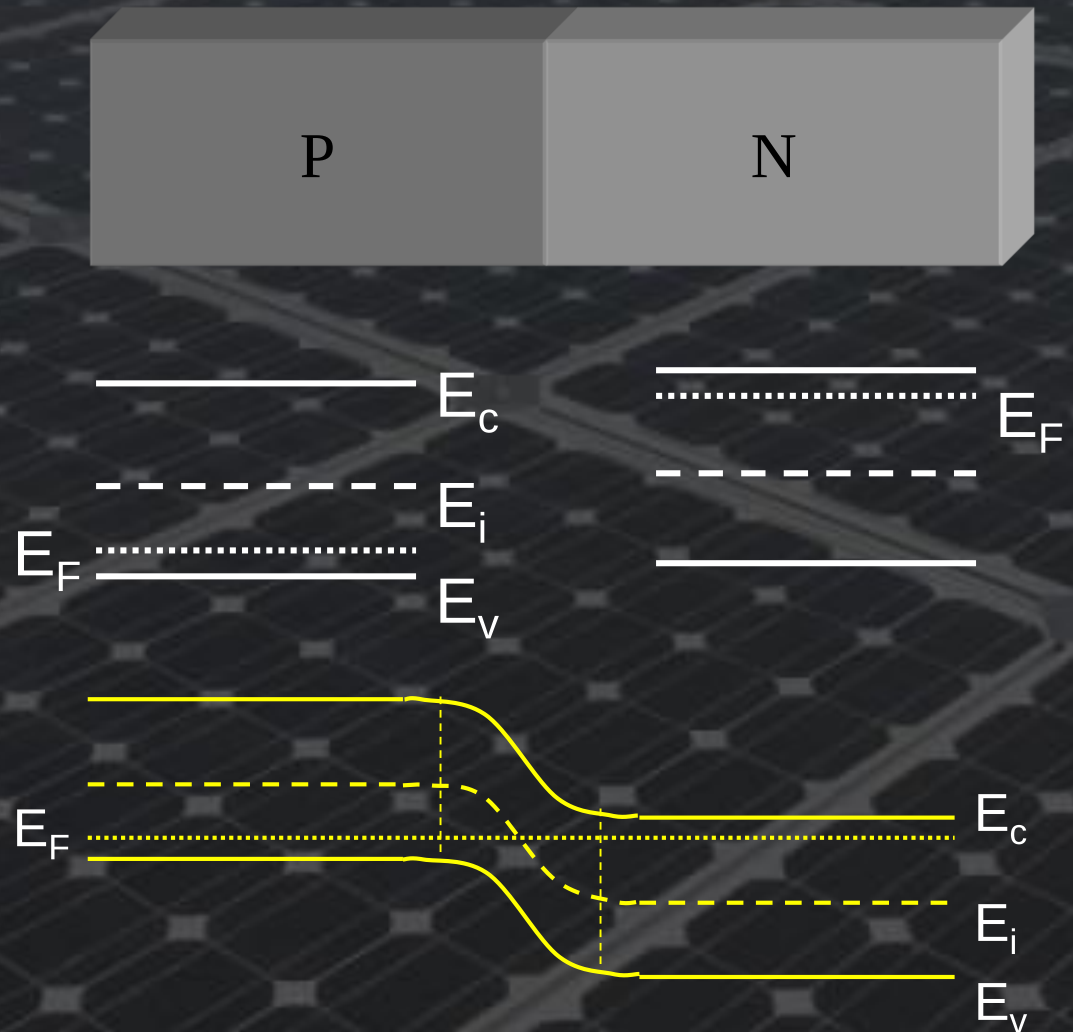


$$\Delta F = \frac{dF(x)}{dx}\delta x\ dy\ dz = (G - R)\delta x\ dy\ dz$$

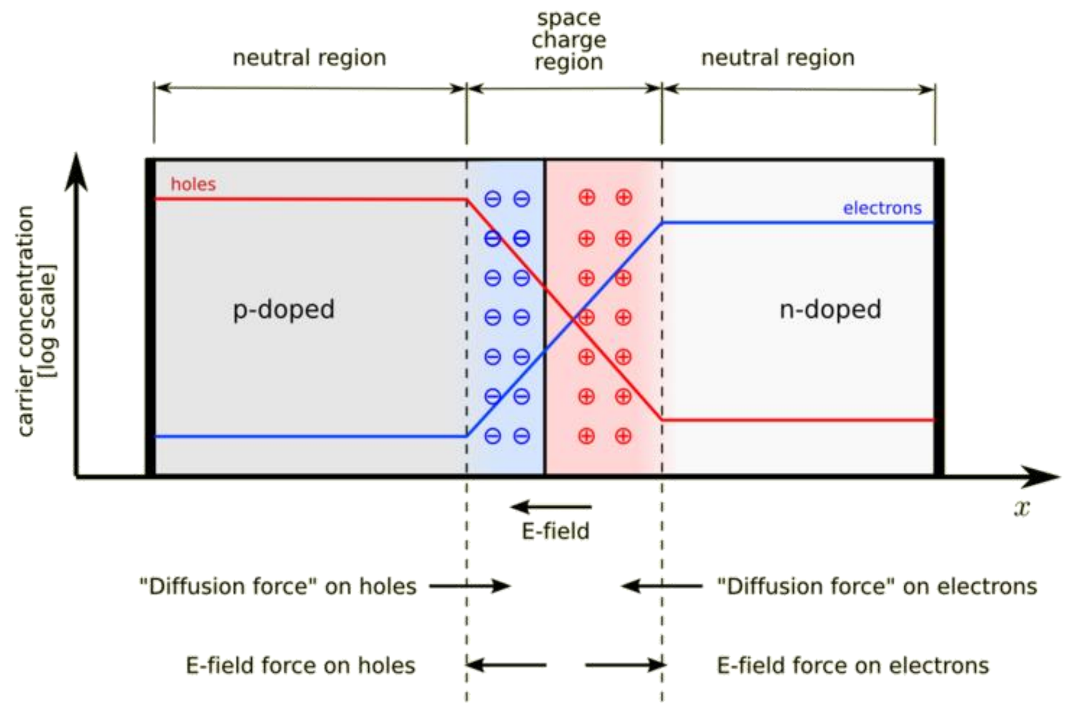
$$\frac{1}{q}\frac{dI_n(x)}{dx} = R - G$$

PHYSICS OF SOLAR CELLS

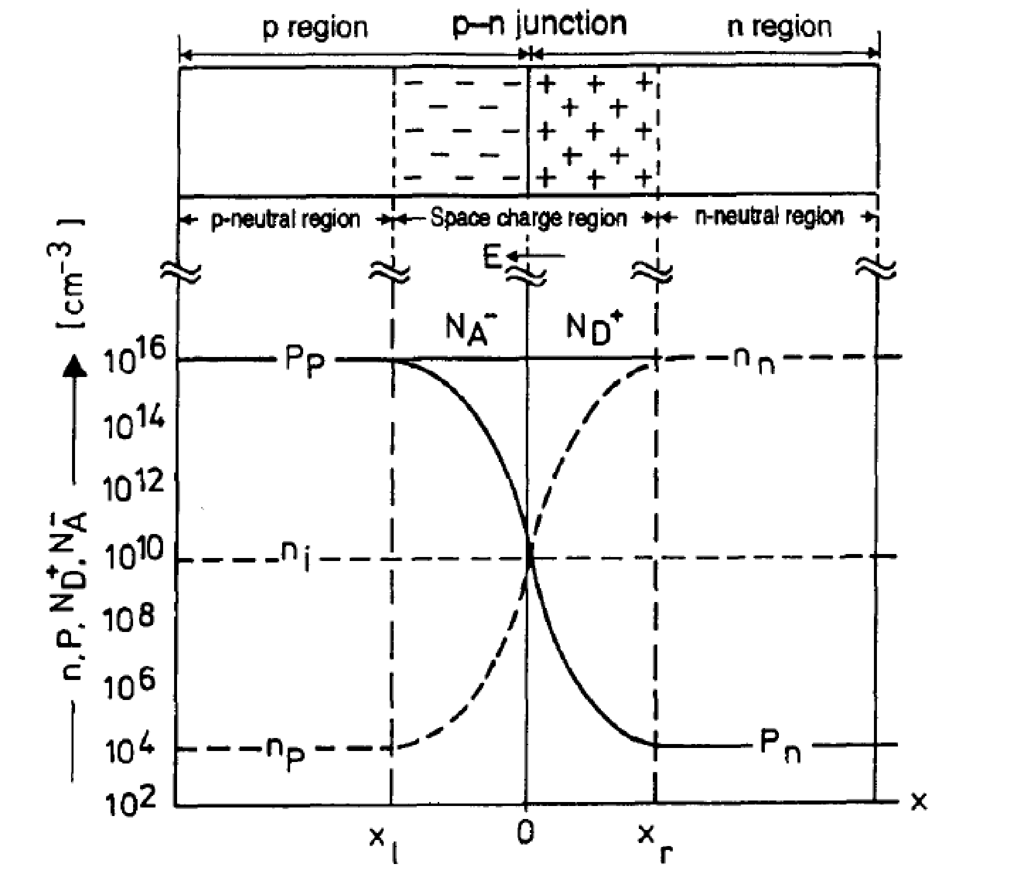
Junção PN



PHYSICS OF SOLAR CELLS



PHYSICS OF SOLAR CELLS



p_p is the hole concentration in the p-neutral area, and n_n is the electron concentration in the n-neutral area.

$$N_A^- \approx N_A \approx p_p \text{ and } N_D^+ \approx N_D \approx n_n$$

We assume that in this example $N_A = 10^{16}$ cm^{-3} and $N_D = 10^{16}$ cm^{-3}

In thermal equilibrium we continue to have

$$np = n_i^2$$

Therefore in the p neutral region $n_p = 10^4$ cm^{-3} and in the n region $p_n = 10^4$ cm^{-3}

PHYSICS OF SOLAR CELLS

Since in some parts of the junction there is no charge neutrality, we must have an associated electric field

$$q n \mu_n E = -q D_n \frac{dn}{dx}$$

Since In= 0

$$E = -\frac{d\varphi}{dx}$$

E= -grad V

$$D = \frac{kT}{q}\mu$$

$$\frac{d\varphi}{dx} = \frac{kT}{q}\frac{dn}{n}\frac{1}{dx}$$

$$\varphi_{(x,r)} - \varphi_{(x,l)} = -U_T \ln(n_p/n_n) = U_D$$

$$U_T = kT/q$$

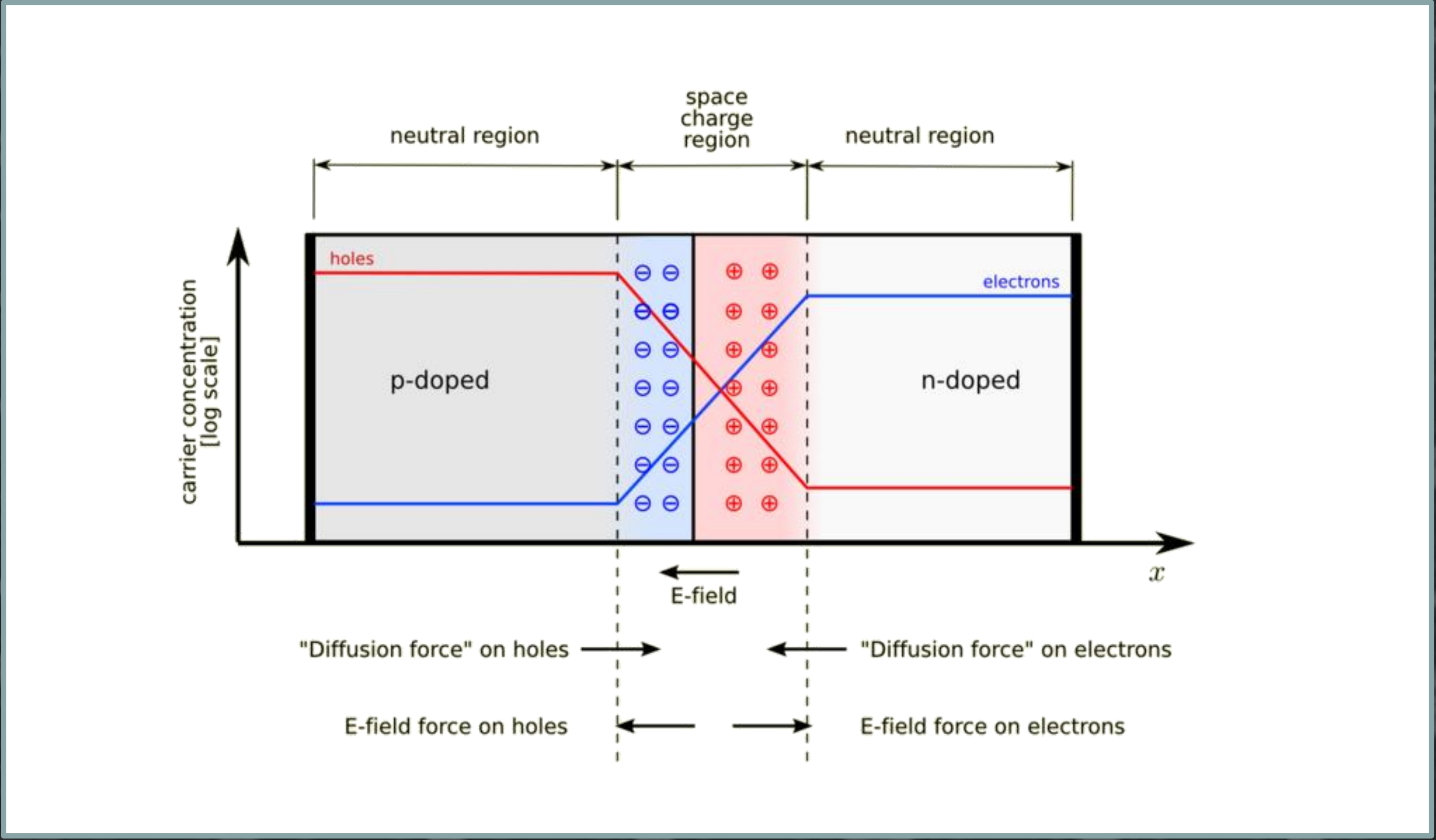
U_T= 25 mV at 300 K

$$n_p \approx n_i^2/N_A \text{ and } n_n \approx N_D$$

$$U_D = U_T \ln(N_D N_A/n_i^2)$$

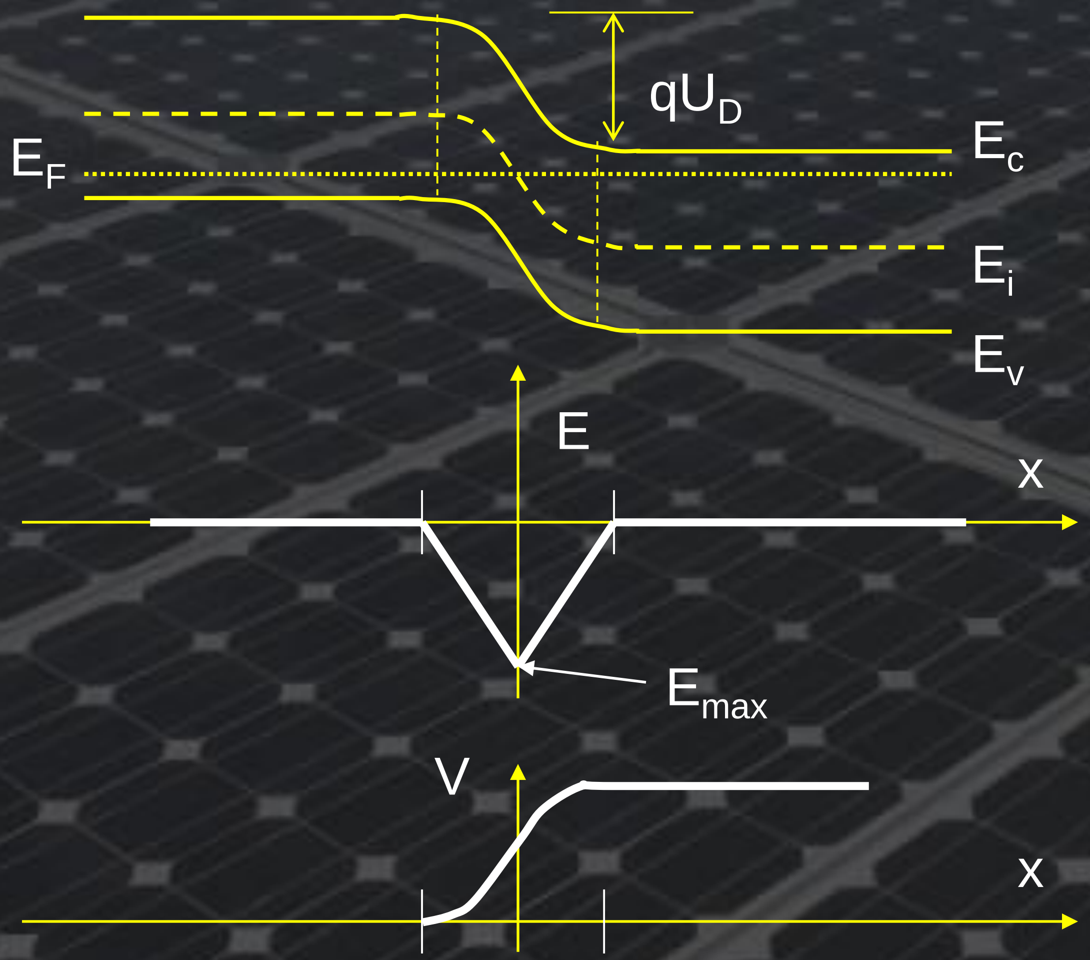
Since $N_A = 10^{16}$ cm^{-3} and $N_D = 10^{16}$ cm^{-3} we find U_D= 0.72 V for silicon at 300 K

PHYSICS OF SOLAR CELLS



PHYSICS OF SOLAR CELLS

PN junction

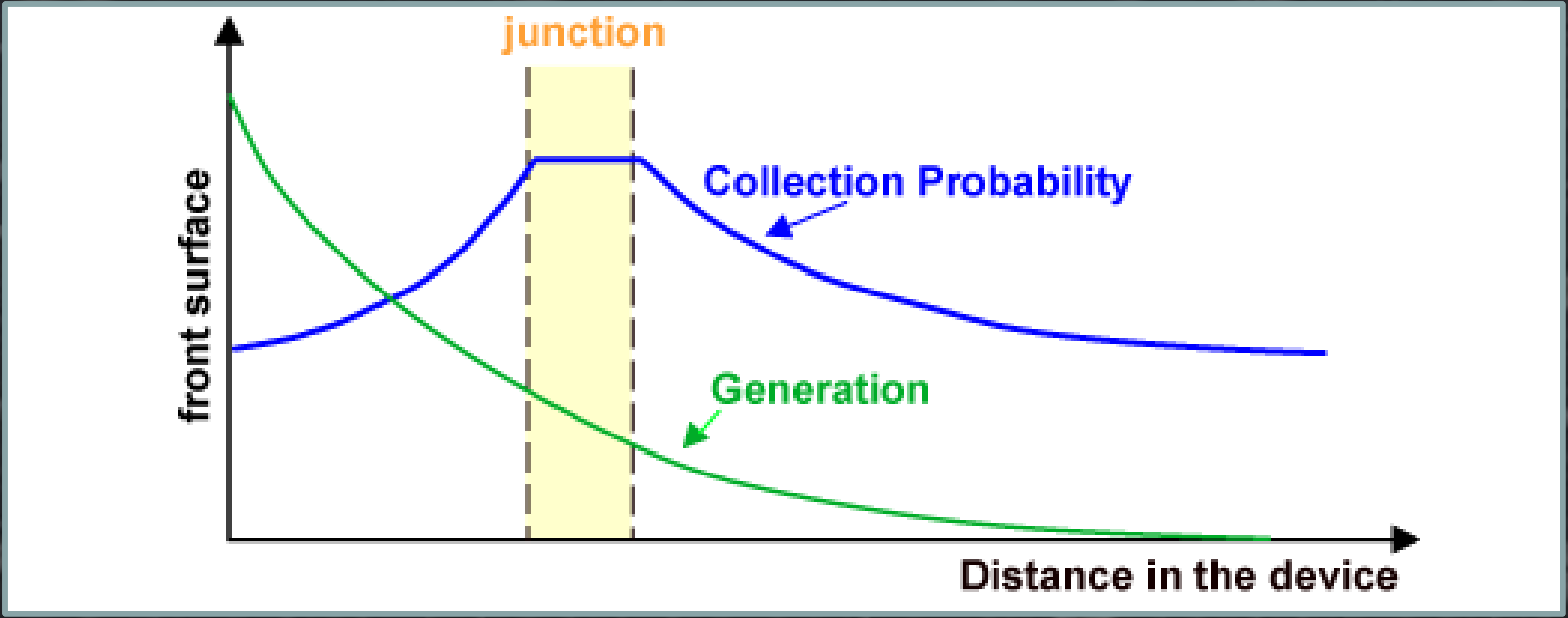


$$E = -\frac{dV}{dx}$$

$$V = \int E\,dx$$

PHYSICS OF SOLAR CELLS

$$L_p = \sqrt{D_p \tau_p}$$

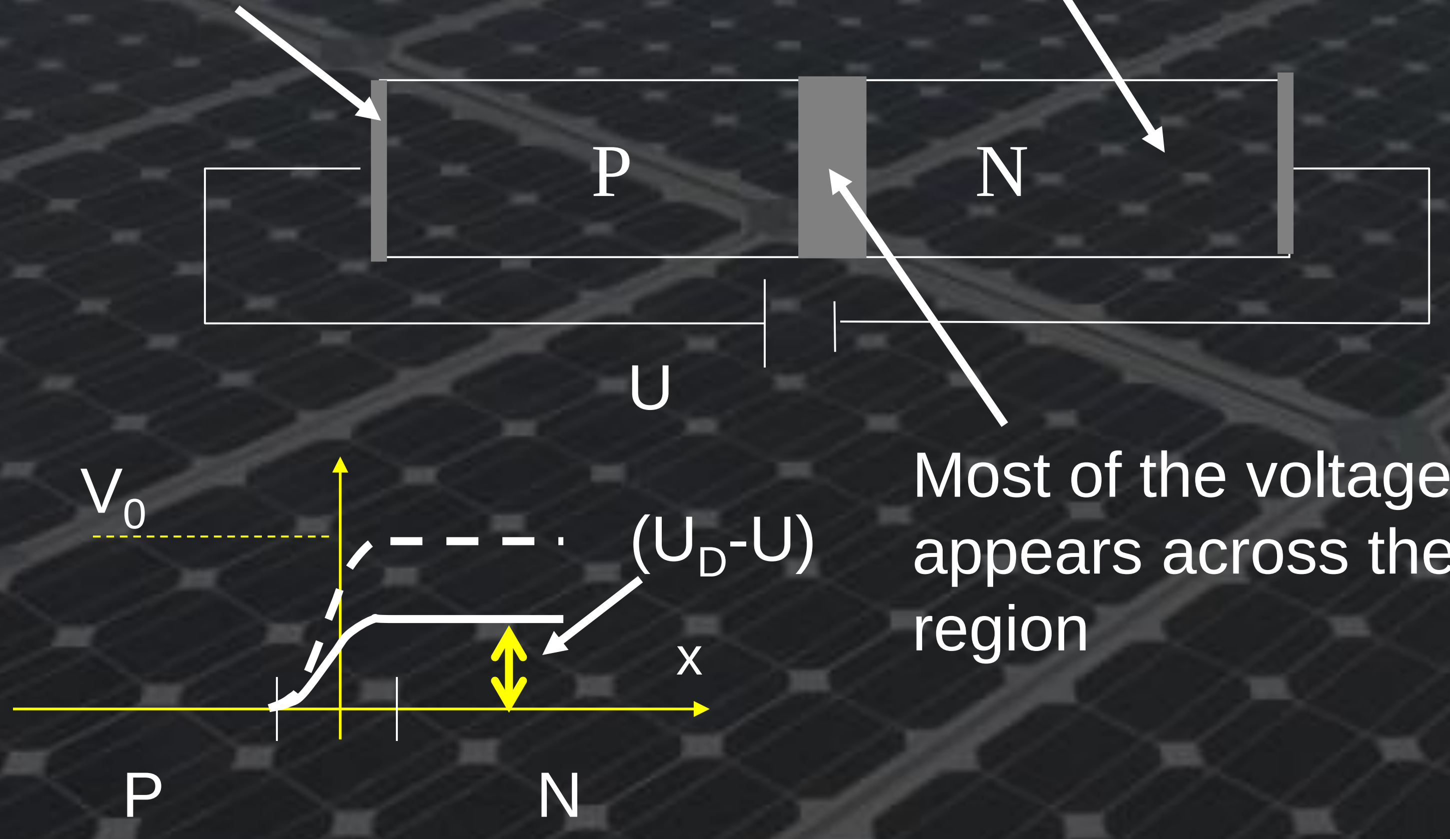


PHYSICS OF SOLAR CELLS

Junção PN

Negligible voltage drop (ohmic contact)

Negligible voltage drop (neutral region, high doping)



Most of the voltage applied appears across the depletion region

PHYSICS OF SOLAR CELLS

If we apply an external voltage UA

$$I_{total} = I_p + I_n$$

$$I_{total} = \left(\frac{q D_n n_{p0}}{L_n} + \frac{q D_p p_{n0}}{L_p} \right) (\exp(U_A / U_T) - 1)$$

$$p_{n0} = n_i^2 / N_D \quad \text{resp.} \quad n_{p0} = n_i^2 / N_A$$

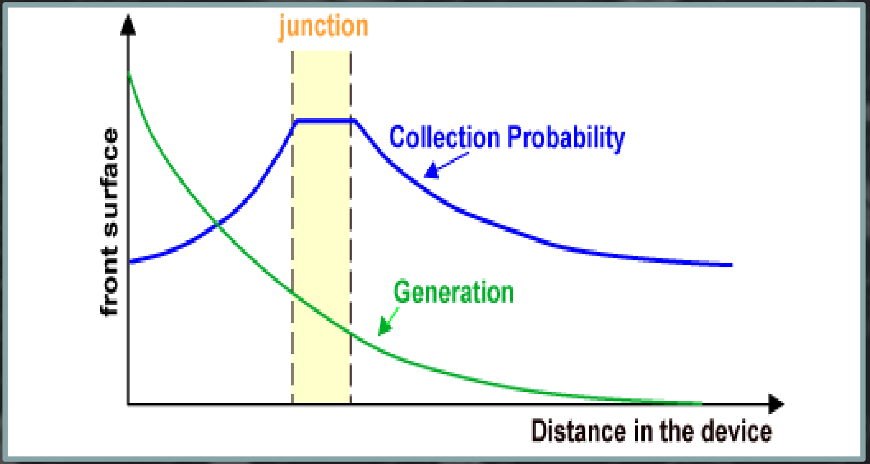
$$I_o = \left(\frac{q D_n n_i^2}{L_n N_A} + \frac{q D_p n_i^2}{L_p N_D} \right)$$

$$I = I_0 \left(\exp U_A / U_T - 1 \right)$$

PHYSICS OF SOLAR CELLS

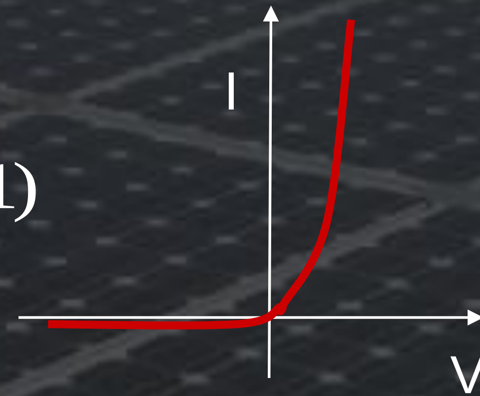
If we have now some ilumination on the cell

$$I = I_0 \left(\exp \left[U / U_T \right] - 1 \right) - I_L$$

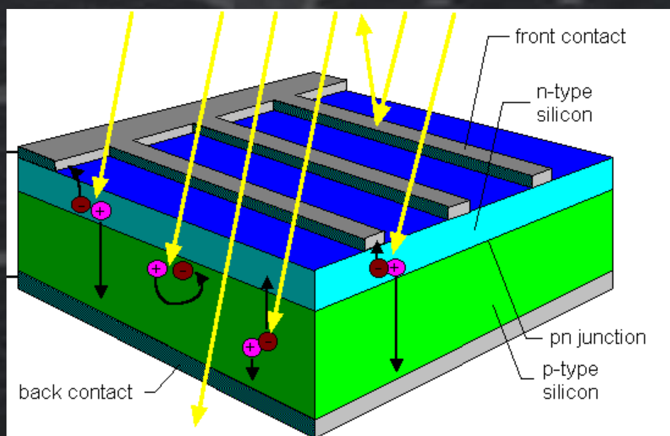


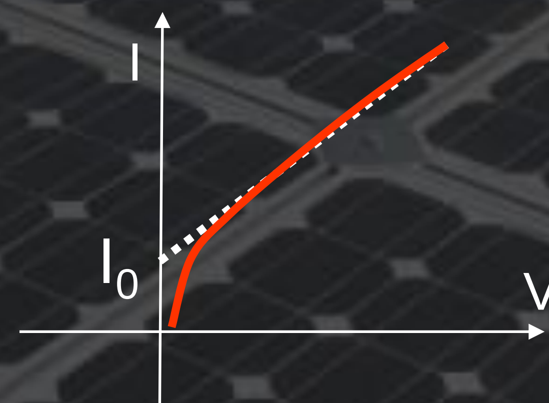
PHYSICS OF SOLAR CELLS

Solar cell I-V characteristics



$$I = I_0 (e^{qV/kT} - 1)$$

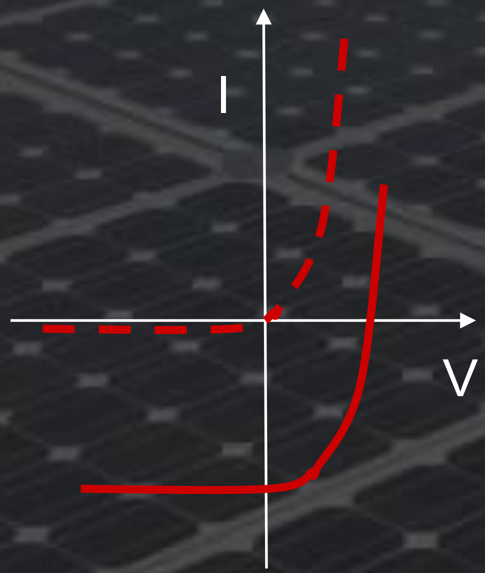


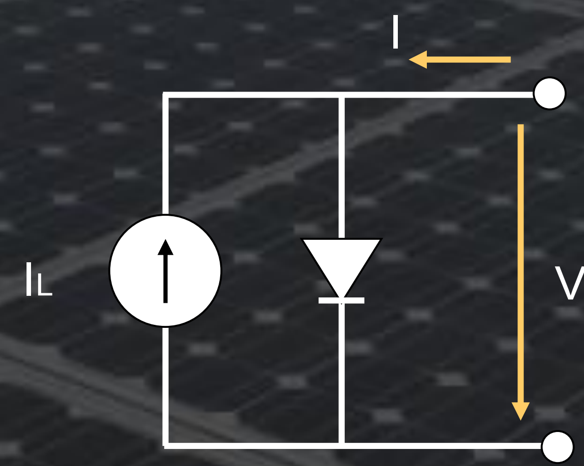


$$\ln I_{total} = \ln I_0 + \frac{q}{kT} V$$

PHYSICS OF SOLAR CELLS

Characteristics under ilumination

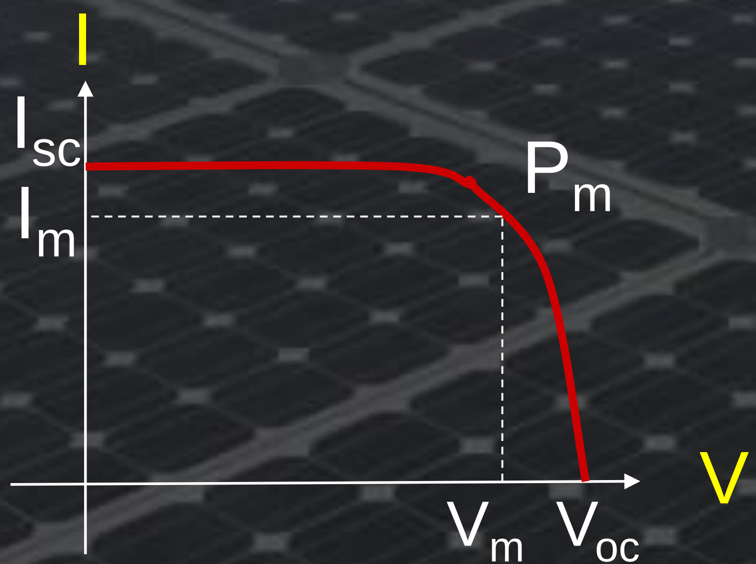




$$I_{total} = I_0(e^{qV/kT} - 1) - I_L$$

PHYSICS OF SOLAR CELLS

Important parameters

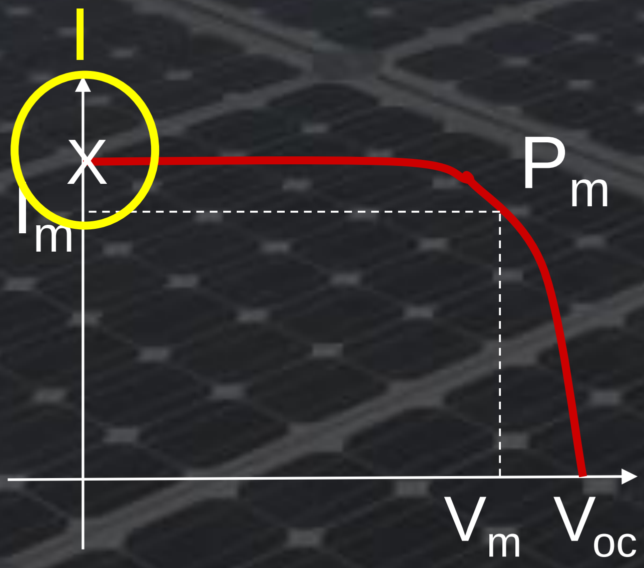


Solar cell parameters

- **V_{oc}** - open circuit voltage,
- **I_{sc}** - short circuit current,
- **P_m** - maximum power point
- **I_m, V_m** – current and voltage at maximum power point
- FF – Fill factor
- η – Efficiency
- R_s – series resistance
- R_{sh} – shunt resistance

PHYSICS OF SOLAR CELLS

Short circuit current



- The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited).

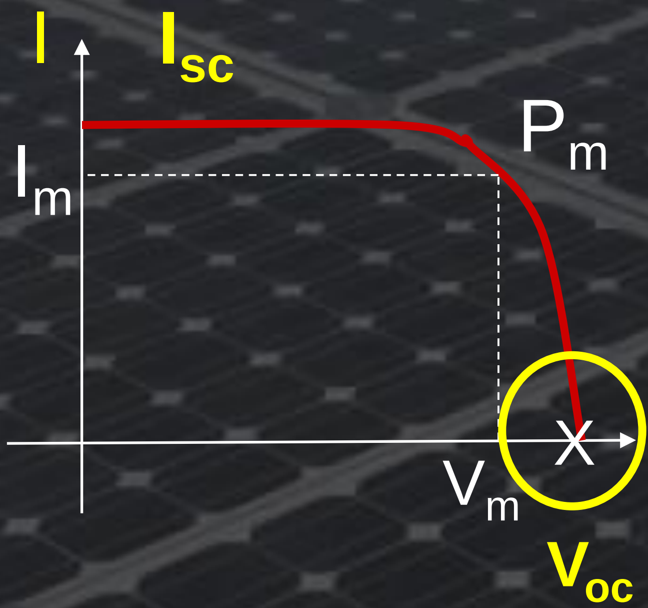
•The short-circuit current is due to the generation and collection of light-generated carriers.

• The short-circuit current is the largest current which may be drawn from the solar cell.

$$I_{total} = -I_L$$

PHYSICS OF SOLAR CELLS

Open circuit voltage

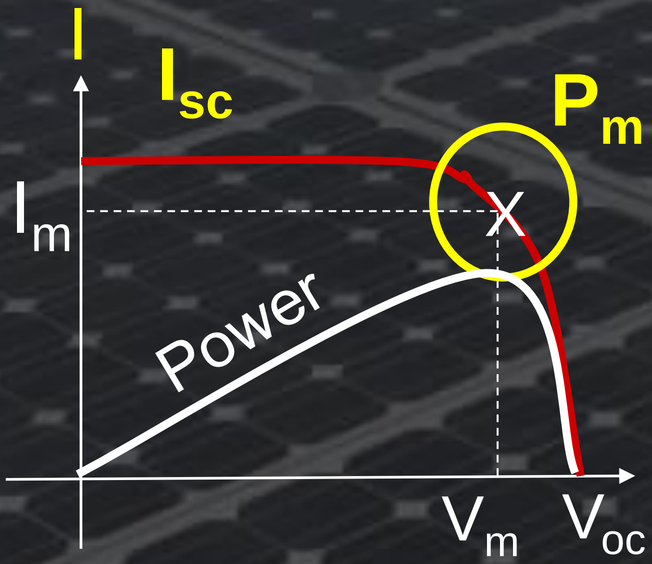


- The open-circuit voltage, V_{oc}, is the maximum voltage available from a solar cell, and this occurs at zero current.

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_L}{I_0}+1\right)$$

PHYSICS OF SOLAR CELLS

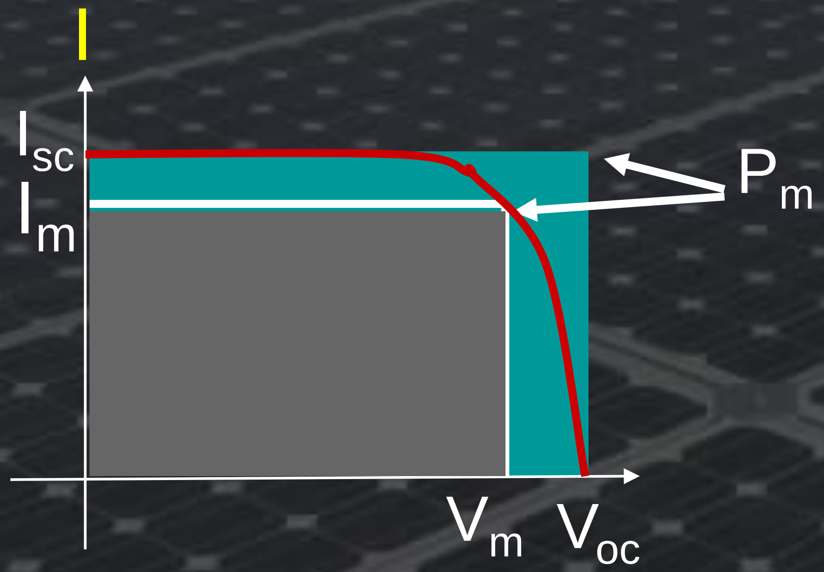
Generated Power



$$P_m = I_m \times V_m$$

PHYSICS OF SOLAR CELLS

Fill factor



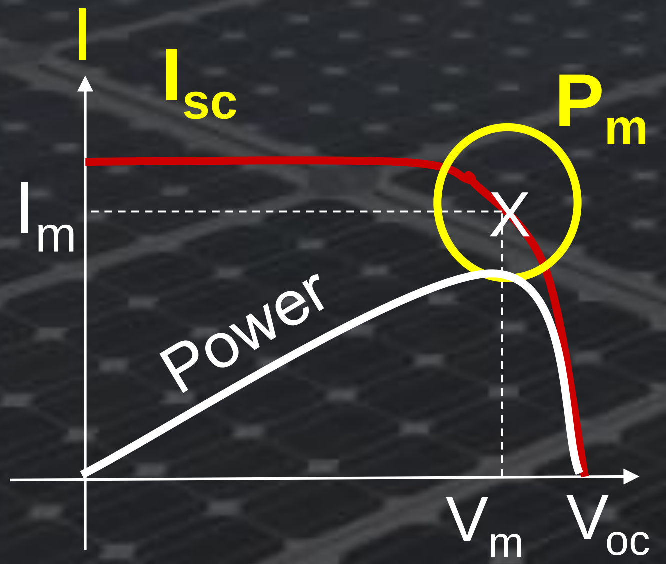
- The FF is defined as the ratio of the maximum power from the actual solar cell to the maximum power from a ideal solar cell

FF is a measure of the "squareness" of the solar cell

$$FF = \frac{Max\ power\ from\ real\ cell}{Max\ power\ from\ ideal\ cell} = \frac{V_m I_m}{V_{oc} I_{sc}}$$

PHYSICS OF SOLAR CELLS

Conversion efficiency



$$\eta = \frac{Max.\,Cell\ Power}{Incident\ light\ Intensity} = \frac{V_m I_m}{P_{in}}$$

- The efficiency is the most commonly used parameter to compare the performance of one solar cell to another.

- Efficiency of a cell also depends on the solar spectrum, intensity of sunlight and the temperature of the solar cell.

PHYSICS OF SOLAR CELLS