SCHOOL OF ENGINEERING
MECHANICAL ENGINEERING
LRESE - Laboratory of Renewable Energy Sciences and Engineering

Solar Energy Conversion Devices and Plants: Exercise 5

Crystalline Silicon solar cell

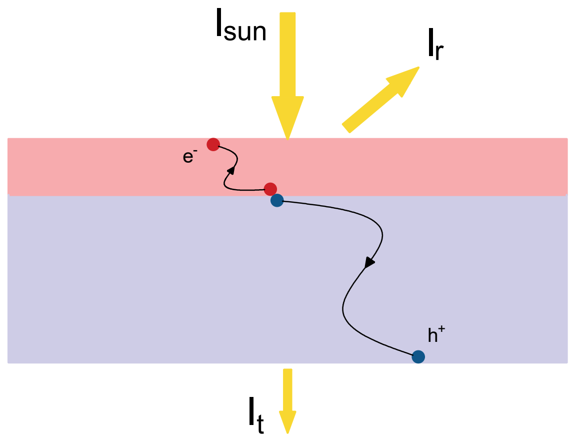

Figure 1: Scheme of the c-Si solar cell showing the input solar irradiation, and its reflected and transmitted portions.

Assumptions

a) Normal incident irradiation of 1000 Wm^{-2}.

b) The thickness of the c-Si layer is 300 μm.

c) The refractive index and extinction coefficients at a wavelength of 500 nm are $n = 4.293$ and $k = 0.045$.

Questions

1. Compute and plot at 300 K:

   a) the density of states in the conduction and valence band.

   The density of states can be computed with the following expressions:

$$g_c = 4\pi \left(\frac{2m_n^*}{h^2} \right)^{3/2} \sqrt{E - E_c}$$

$$g_v = 4\pi \left(\frac{2m_p^*}{h^2} \right)^{3/2} \sqrt{E_v - E}$$

   Replacing the good values shown in table 1 in the previous expressions:

T, K	0	273	300	353
m_n^*, kg	2.98e-31	3.06e-31	3.07e-31	3.08e-31
m_p^*, kg	5.01e-31	9.23e-31	9.56e-31	1.02e-30
E_g, eV	1.17	1.13	1.12	1.11
E_c, eV	-4.05	-4.05	-4.05	-4.05
N_c, cm^{-3}	0	4.25e18	4.91e18	6.31e18
N_v, cm^{-3}	0	2.22e19	2.70e19	3.78e19
n, cm^{-3}	0	3.55e8	4.16e9	1.84e11
p, cm^{-3}	0	3.55e8	4.16e9	1.84e11
n_i, cm^{-3}	0	3.55e8	4.16e9	1.84e11
E_f, eV	-	-4.14	-4.15	-4.18

Table 1: Material properties for c-Si.

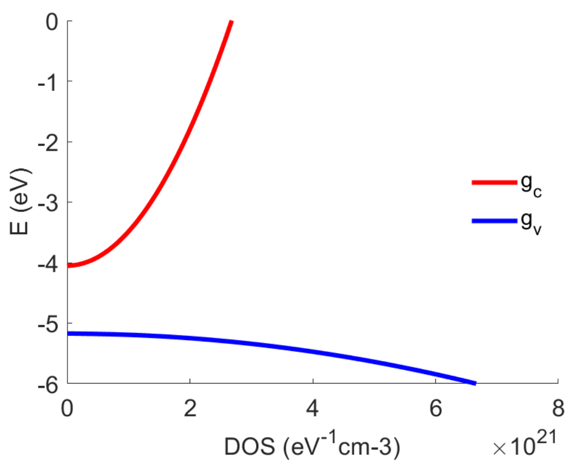

Figure 2: Density of states for c-Si at 300 K.

b) the Fermi level of the intrinsic material.

$$E_{fi} = \frac{E_c + E_v}{2} + \frac{k_B T}{2} \log\left(\frac{N_v}{N_c}\right)$$

Replacing the right values for 300 K should result in $E_{fi} = -4.59$ eV, which is in the middle of E_c and E_v.

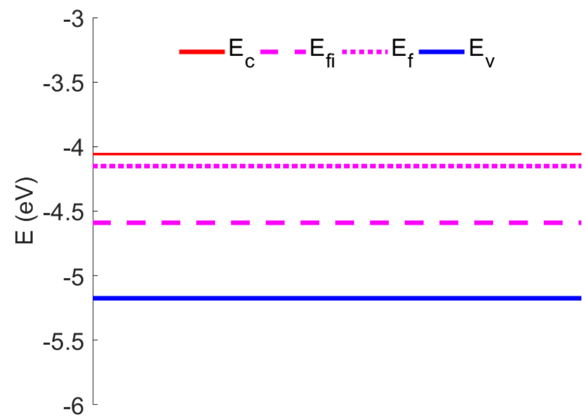

Figure 3: Energy levels for c-Si at 300 K.

c) the Fermi-Dirac distribution for different temperatures ($T = 0$, 273, 300, 353 K).

The Fermi-Dirac is given by

$$f(E) = \frac{1}{1 + \exp\left(\frac{E - E_\mathrm{f}}{k_\mathrm{B}T}\right)}$$

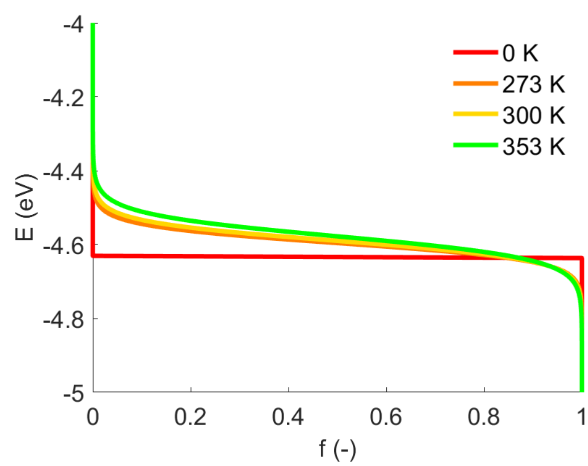

Figure 4: Fermi-Dirac distribution at different temperatures.

d) the density of electron and holes in the conduction and valence band.

The concentration of electrons and holes in the conduction and valence band are obtained by multiplying the density of states function with the distribution function:

$$n(E) = g_c(E)f(E)$$
$$p(E) = g_v(E)[1 - f(E)]$$

Then the result should look like the figure below:

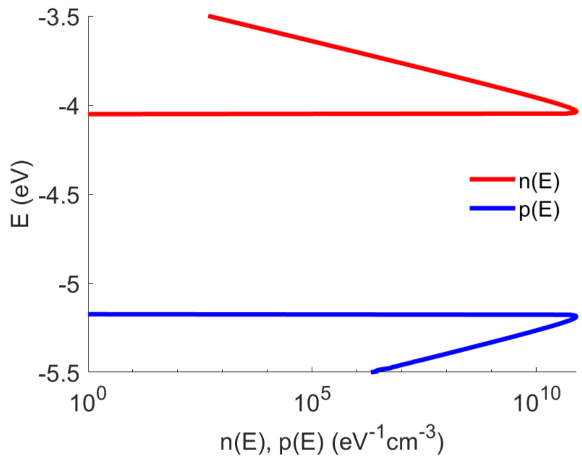

Figure 5: Electron and hole densities in the conduction and valence band at 300 K.

e) the total number of electrons and holes in the conduction and valence band.

$$n = N_c \exp\left(\frac{E_f - E_c}{k_B T}\right)$$
$$p = N_v \exp\left(\frac{E_v - E_f}{k_B T}\right)$$

Where N_c and N_v are the effective densities of the conduction band states and the valence band states, respectively. They are defined as:

$$N_c = 2\left(\frac{2\pi m_n^* k_B T}{h^2}\right)^{3/2}$$
$$N_v = 2\left(\frac{2\pi m_p^* k_B T}{h^2}\right)^{3/2}$$

The results are shown in table 1

f) the intrinsic carrier concentration for $T = 0$, 273, 300, 353 K.

$$n_\mathrm{i}^2 = N_\mathrm{c} N_\mathrm{v} \exp\left(\frac{E_\mathrm{v} - E_\mathrm{c}}{k_\mathrm{B} T}\right)$$

The results are shown in table 1

g) the Fermi level considering now a doping level $N_\mathrm{D} = 10^{17}$ cm^{-3}.

$n = N_\mathrm{D}$, then

$$E_\mathrm{f} = E_\mathrm{c} + k_\mathrm{B} T \log\left(\frac{N_\mathrm{D}}{N_\mathrm{c}}\right)$$

The results are shown in table 1 and figure 3 (dot lines).

2. Assuming that the electron and hole mobilities for c-Si are 1360 and 450 cm^{2}V^{-1}s^{-1}, respectively. Calculate the diffusion coefficient at room temperature and estimate order of magnitude of the expected diffusion and drift fluxes as function of the electron-hole gradients, and the electric field.

   Drift and diffusion current densities are computed according to the following expressions:

$$\begin{aligned} J_\mathrm{drift,n} &= q\mu_\mathrm{n} pE \\ J_\mathrm{diff,n} &= qD_\mathrm{n}\frac{dn}{dx} \\ J_\mathrm{drift,p} &= q\mu_\mathrm{p} pE \\ J_\mathrm{diff,p} &= qD_\mathrm{p}\frac{dp}{dx} \\ D_\mathrm{n,p} &= \mu_\mathrm{n,p} k_\mathrm{B} T \end{aligned}$$

   At room temperature $D_\mathrm{n} = 35.16$ cm^{2}s^{-1} and $D_\mathrm{p} = 11.63$ cm^{2}s^{-1}.

3. Calculate the total absorption. For simplicity, assume all light arrives at only one wavelength (500 nm).

   The absorption in the c-Si solar cell is the difference between the photon flux at the top

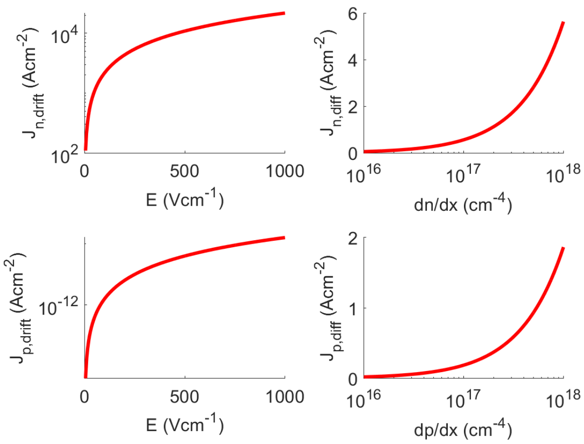

Figure 6: Drift and diffusion current densities at 300 K.

and at the bottom of the cell.

$$A = \Phi_{\mathrm{x=0}}(1-R) - \Phi_{\mathrm{x=L}}$$
$$\Phi_{\mathrm{x=0}} = I_{\mathrm{sun}}\frac{\lambda}{hc}$$
$$R = \left|\frac{n_{\mathrm{air}} - (n - ik)}{n_{\mathrm{air}} + (n - ik)}\right|^2$$
$$\Phi_x = \Phi_{\mathrm{x=0}}(1-R)\exp(-\alpha x)$$
$$\alpha = \frac{4\pi k}{\lambda}$$

Replacing the right values $\Phi_{\mathrm{x}} = 2.52\mathrm{e}21\ \mathrm{m}^{-2}\mathrm{s}^{-1}$, $R = 0.387$, $\Phi_{\mathrm{L}} = 0\ \mathrm{m}^{-2}\mathrm{s}^{-1}$, $\alpha = 1.131\mathrm{e}6\ \mathrm{m}^{-1}$, then $A = 1.54\mathrm{e}21\ \mathrm{m}^{-2}\mathrm{s}^{-1}$.