Exercise 8.1-5

IV Characteristics of Real Solar Cells

We take the diode equation, including generation and recombination in the space charge region part, as given. We will now try to see what we can do with this equation with respect to solar cells. We have

$$j = \underbrace{\left(\frac{e \cdot L \cdot n_i^{\,2}}{\tau \cdot N_A} + \frac{e \cdot L \cdot n_i^{\,2}}{\tau \cdot N_D}\right)}_{(j_1)} \cdot \left(\exp\frac{eU}{kT} - 1\right) + \underbrace{\left(\frac{e \cdot n_i \cdot d(U)}{\tau}\right)}_{(j_2)} \cdot \left(\exp\frac{eU}{2kT} - 1\right) - j_{Ph}$$

- We must first look at the important parameters (all others have their usual meaning) and find numerical values:
  - L = **diffusion length** = $(D\tau)^{1/2}$ average distance a minority carrier travels between its birth by a generation event (mostly by light in a "working" solar cell) and its death by recombination. A good values for bulk Si that we take for simple calculation is $L = 100\ \mu m$
  - D is the diffusion coefficient and τ the (minority carrier) life time. A good enough value for the life time going with a diffusion length of **100 µm** is $\tau = 1\ ms$
  - n_i is the intrinsic carrier concentration. It increases exponentially with temperature T. A good values for **Si** at room temperature (**RT**) is $n_i(RT) = 10^{10}\ cm^{-3}$.
  - N_A and N_D are the acceptor and donor concentrations in the **p**-part (called **base**; the usually several **100 µm** thick part of a bulk **Si** solar cell) and the **n**- part (called **emitter**, the thin "layer" on top) of the solar cell. The base is lightly doped (otherwise the diffusion length suffers) whereas the emitter is heavily doped (good conductivity is important). $N_A = 10^{16}\ cm^{-3}$ and $N_D = 10^{18}\ cm^{-3}$ are good round numbers for the purpose here.
  - The width of the space charge region we take as $d(U) = 1\ \mu m$
- Now we consider a *real* good solar cell under "standard" illumination. This gives us the following (simplified) second set of numbers:
  - Area of the **Si** bulk solar cell = $100\ cm^2$. It's actually more like $200\ cm^2$ in **2008** but let's stay with easy numbers.
  - Photo current density $j_{Ph} = 30\ mA/cm^2$ for a very good solar cell, less for a not-so-good one.
  - The photo current here is thus $j_{Ph} = 3\ A$.

Question 1:

- **1a:** Using only the first term in the bracket for j_1 as a sufficient approximation, give an equation for the relation of j_2/j_1 and some numbers for these current densities
- **1b:** Does the result imply that you can neglect one of the j_i terms in the equation above in the *forward* direction? How about the *reverse* direction?

If we now *measure* the actual ***UI*** characteristics of a good *real* solar cell and fit the curve obtained to our equation from above, we find values for the current densities j_1 and j_2 like

- $j_1 = 10^{-9}\ A/cm^2$.
- $j_2 = 10^{-7}\ A/cm^2$

Question 2:

- **2a:** Do these values and their relation meet your expectations based on your results from **question 1**?
- **2b:** If not, what could be reasons for the discrepancy?

Given the measured j_i values from above and the j_{Ph} value given, we now can consider the short circuit current I_{SC} and the open circuit voltage U_{OC}

Question 3:

- **3a:** What do you get for $\boldsymbol{I_{SC}}$? Does it depend on $\boldsymbol{j_i}$ and $\boldsymbol{j_2}$? If not, what determines its value?
- **3b:** What can you say about the open circuit voltage $\boldsymbol{U_{OC}}$?

Solution