Exercise Series 5

Exercise 1: EQE, spectral response, ideal solar cell efficiency under illumination

Three single junction solar cells are made of three different semiconductors materials, characterized by different band gap energies E_g (at 273 K):

- Germanium $E_g = 0.8\,\text{eV}$
- Crystalline silicon $E_g = 1.12\,\text{eV}$
- Gallium Arsenide $E_g = 1.43\,\text{eV}$

Let's assume two hypotheses for this exercise:

- Each solar cell behaves like an ideal solar cell (one diode model), i.e. reflection at the front layers, recombination and other loss mechanisms are neglected.
- Photons with $h\nu < E_g$ are not absorbed, whereas photons with $h\nu \geq E_g$ are absorbed and create one electron-hole pair. These free carriers are collected with a quantum efficiency of one.

a) Draw a sketch of the EQE curve of each cell between 300 - 1600 nm

b) Define the Spectral Response (SR) and sketch the SR of a typical solar cell. Does it depend on the solar spectrum? Based on the EQE sketches in part a) and on the the solar irradiance spectrum, explain how you can obtain the short-circuit current density of the cells. The solar irradiance sprectrum outside the atmosphere and on the earth are shown in Fig. 1.
(data: http://pveducation.org/pvcdrom/appendices/standard-solar-spectra

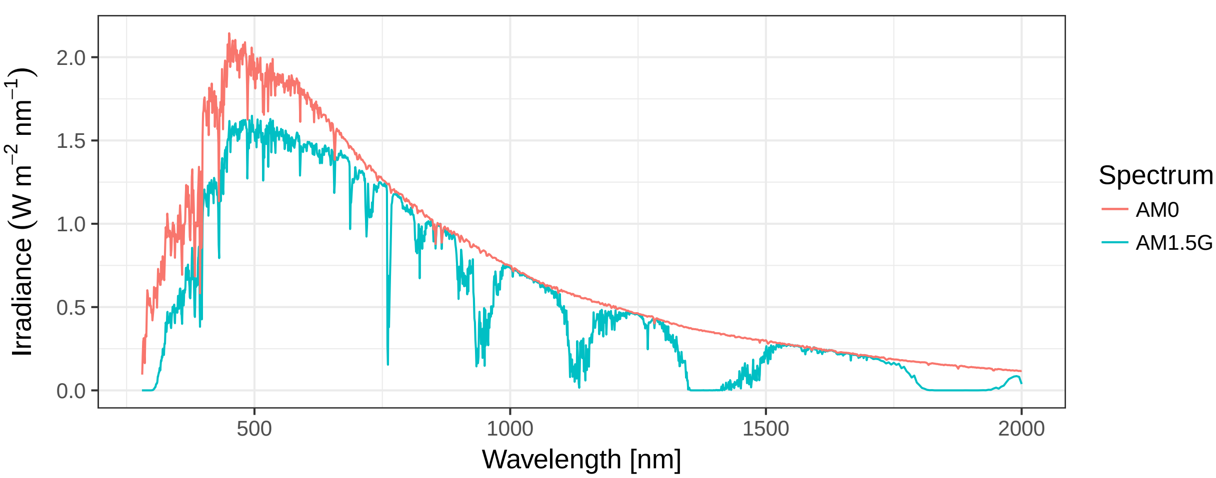

Figure 1: AM0 and AM1.5G spectrum.

c) Compare the results obtained in part b) and given in Table 1. with the data provided in the Solar cells efficiency table - Version 58, available on Moodle. Explain the differences.

semiconducting bulk material	Ge	c-Si	GaAs
$J_{\text{sc, AM0}}$ (mA cm^{-2})	71.7	52.9	38.6
$J_{\text{sc, AM1.5g}}$ (mA cm^{-2})	54.5	43.8	31.9

Table 1: Short-circuit current of ideal single junctions solar cells

d) Calculate the open-circuit voltage V_{oc}, the fill factor FF and the efficiency η of each of the cells for the AM0 and AM1.5g spectrum (use the information given in Table 1). Keep in mind that the first approximation of the solar cell working point under illumination is based on the superposition principle of the generated current: See the 'Chapter I. General introduction to photovoltaics.

e) Compute the values of J_{sc}, V_{oc}, FF and η in the case of a 1000 suns concentrated illumination for AM1.5g.

Hints: Use the following information for the calculations.

- Assume a temperature of $T = 273\,\text{K}$.
- The dark saturation current density of the one diode model is given by:

$$J_0\ (\text{mA/cm}^{-2}) = 1.5 \cdot 10^8 \exp \frac{-E_\text{g}}{k_\text{B}T} \tag{1}$$

- The fill factor FF dependence on the open-circuit voltage V_{oc} is given by:

$$FF = \frac{v_{\text{oc}} - ln(v_{\text{oc}} + 0.72)}{v_{\text{oc}} + 1} \text{ with } v_{\text{oc}} = \frac{V_{\text{oc}}}{k_\text{B}T/q} \tag{2}$$

We assume that this approximation is valid for the AM1.5g spectrum as well as for the AM0 spectrum. In the case of the concentrated illumination of 1000 suns, we use the same FF value under the AM1.5g illumination because we assume that the conductivity of TCO is optimized so that no resistive losses occur.