Tutorial problems for “Solar Energy“ lecture (23745), WS 2021/2022

Ulrich Paetzold & Bryce Richards

Tutorial Questions #6: PV System Design, Absorber thickness, PV economics, Triple junction cell, Solar cell configurations

1. PV System Design (adapted from: exercise 10.1 of textbook ‘Solar Energy’)

Consider two solar cells: solar cell *A* has a bandgap energy of 1 eV and solar cell *B* has a bandgap energy of 1.7eV. From all kind of possible losses, assume only optical losses. Which of the following statements is true?

a. Non-absorption losses are higher in solar cell *A* than in solar cell *B*.
b. Heating losses are higher in solar cell *A* than in solar cell *B*.
c. According to the Shockley–Queisser analysis, radiative recombination is more important in solar cell *B* than in solar cell *A*.
d. According to the Shockley–Queisser analysis, solar cell *A* can have an efficiency up to 50%.

2. Absorber thickness (adapted from: exercise 10.5 of textbook ‘Solar Energy’)

In Figure 1 we can see the absorption coefficient as a function of the wavelength for several semiconductor materials. Let us consider monochromatic light of photons with energy E_{ph} = 1.55 eV that is incident in a film with thickness *d*. If we ignore possible reflection losses at the rear and front interfaces of the film, what thickness is required to achieve a light absorption of 90% for the four materials?

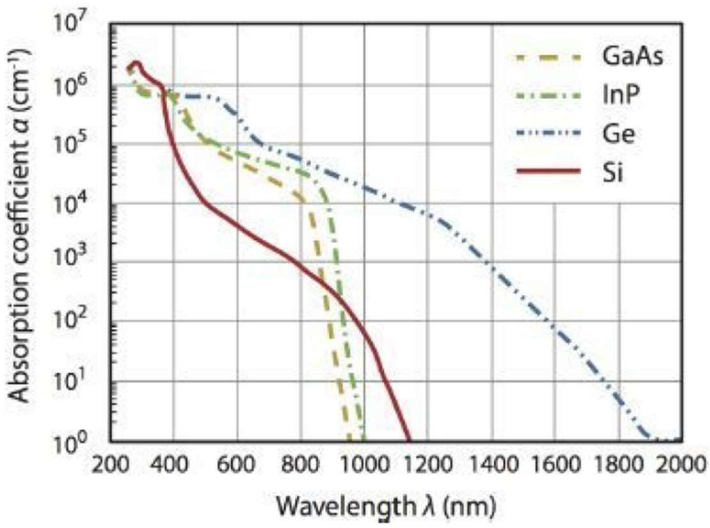

Figure 1: Absorption coefficients of different materials

3. Triple junction cell (adapted from: exercise 16.1 of textbook ‘Solar Energy’)

Figure 2 shows the EQE of a triple-junction cell with junctions A, B and C under short circuited (*V* = 0 V) condition.

a) What is the bandgap of the absorber layer of junction A?
b) What is the bandgap of the absorber layer of junction B?
c) What is the bandgap of the absorber layer of junction C?

d) Which of the following statements is true?

I. Junction C acts as the top cell, junction B as the middle cell, and junction A as the bottom cell.

II. Junction B acts as the top cell, junction C as the middle cell, and junction A as the bottom cell.

III. Junction A acts as the top cell, junction B as the middle cell, and junction C as the bottom cell.

e) Each junction is illuminated under standard test conditions. Given the photon fluxes below, calculate the short circuit current density of each (separate) junction.

I. $\Phi_{ph} = 9.3 \times 10^{20}\ m^{-2}s^{-1}$ for 300 nm < λ < 650 nm,

II. $\Phi_{ph} = 8.4 \times 10^{20}\ m^{-2}\ s^{-1}$ for 650 nm < λ < 850 nm,

III. $\Phi_{ph} = 1.4 \times 10^{20}\ m^{-2}\ s^{-1}$ for 850 nm < λ < 1250 nm.

f) The V_{OC} of each junction can be roughly estimated by the equation:

$$V_{OC} = \frac{E_g(eV)}{2q}$$

where the bandgap energy Eg is given in eV. Assuming a fill factor of 75%, calculate the efficiency of the triple-junction solar cell.

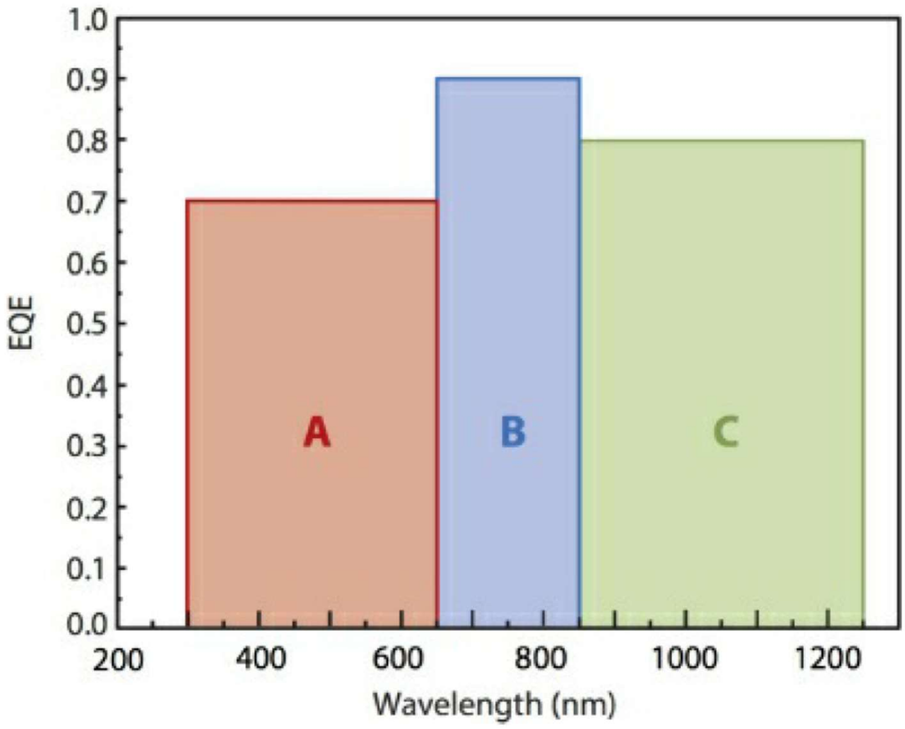

Figure 2: EQE of a triple junction cell

4. Solar cell configurations (adapted from: exercise 16.4 of textbook 'Solar Energy')

Figure 3 shows a simplified AM1.5 solar spectrum with a total irradiance of 1000 W/m^2. The spectrum is divided into three spectral ranges,

A	0 nm < λ < 620 nm,
B	620 nm < λ < 1240 nm,
C	1240 nm < λ < 1860 nm.

In the figure, also the photon flux in each spectral range is shown.

Hydrogenated silicon carbide (a-SiC:H) is a type of amorphous semiconductor material that has been recently studied for PV applications. This material has a relatively large bandgap of 2.0 eV. Imagine we integrate this material in a single junction *p-i-n* solar cell as shown in Figure 4 (a).

a) In which spectral range does this solar cell convert light into charge carriers?

b) What is the J_{SC} of the solar cell if only 65% of the absorbed photons result in a current?

c) The V_{OC} of each junction can be roughly estimated by the equation

$$V_{OC} = \frac{E_g(eV)}{2q}$$

where the bandgap energy E_g is given in eV. Assuming a fill factor of 80%, calculate the efficiency of the solar cell.

d) An upconverter is a material that can convert two low energy photons into a higher energy photon. Placing an upconverter in our solar cell can help to reduce the spectral mismatch, since it can convert some photons with energy lower than 2 eV, which are not absorbed by the a-SiC:H cell, into photons with energy higher than 2 eV. Figure 4 (b) depicts this possibility. In the upconverter 1, two photons are converted into one photon with 100% conversion efficiency. If all photons with energy above that of the bandgap of a-SiC:H are absorbed in the a-SiC:H layer, in which spectral range from Figure 3 can the photons be upconverted so that they contribute to the current in the cell as well? A, B, or C?

e) In that case what would be the short-circuit current density and the efficiency of the solar cell illustrated in Figure 4(b)? Assume again that 65% of the absorbed photons result in a current.

f) Now imagine that in upconverter 2, three photons are converted into one photon with 100% conversion efficiency, as illustrated in Figure 4 (c). If all photons with energy above that of the bandgap of a-SiC:H are absorbed in the p-i-n cell, and converter 1 absorbs only the photons in the spectral range determined above, in which spectral part can the photons be upconverted by converter 2 so that they contribute to the current in the cell as well? A, B, or C?

g) In that case what would be the short circuit current density and the efficiency of the solar cell illustrated in Figure 4 (c)? Assume that 65% of the absorbed photons result in a current.

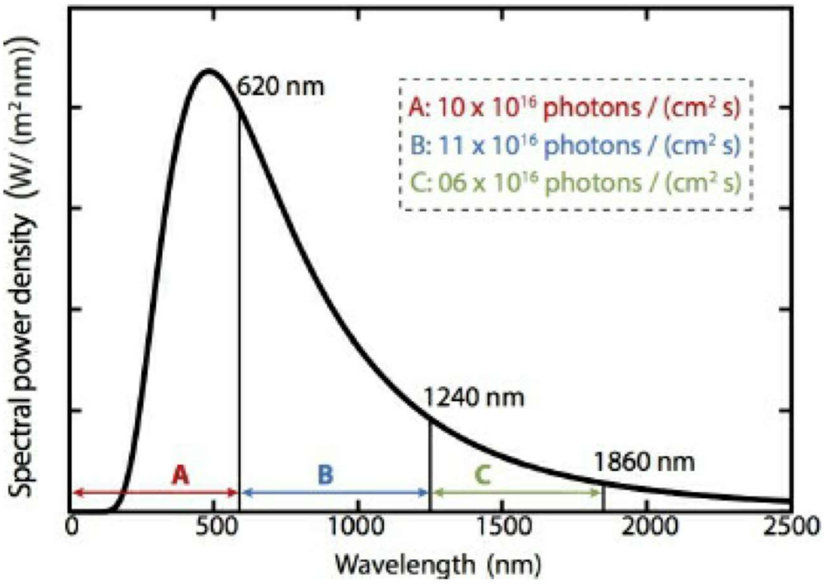

Figure 3: Solar spectrum

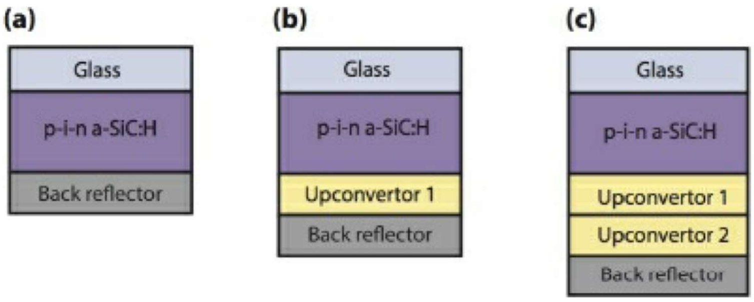

Figure 4: Solar cell configurations