PHYS-E6570 Solar Energy Engineering (5 cr) **2nd mid-term exam** **3.4.2018**

Answer all five (5) questions.

1.

Explain briefly each concept (bolded) and answer one related question (6 p)

a) **N- and P-type silicon.** If the donor atom density is increased, how does it affect the Fermi energy of electrons (in the dark, at equilibrium)?

b) **Semiconductor band gap**. If the band-gap of a pn-junction solar cell is decreased, how does it affect the short circuit current and open circuit voltage of the cell?

c) **Equivalent circuit model of a solar cell**. Why do all well-performing solar cells exhibit diode-like current-voltage characteristics, even if they are not necessarily based on pn-junctions?

d) **Multi-junction solar cell**. Why can they reach higher efficiency than single junction solar cells?

e) **Perovskite solar cells**. What are the two main hurdles that they need to overcome before they can enter the main commercial PV market?

f) **Levelized cost of electricity (LCOE)**. When is residential solar electricity expected to become economically competitive to typical homeowners in Finland?

2.

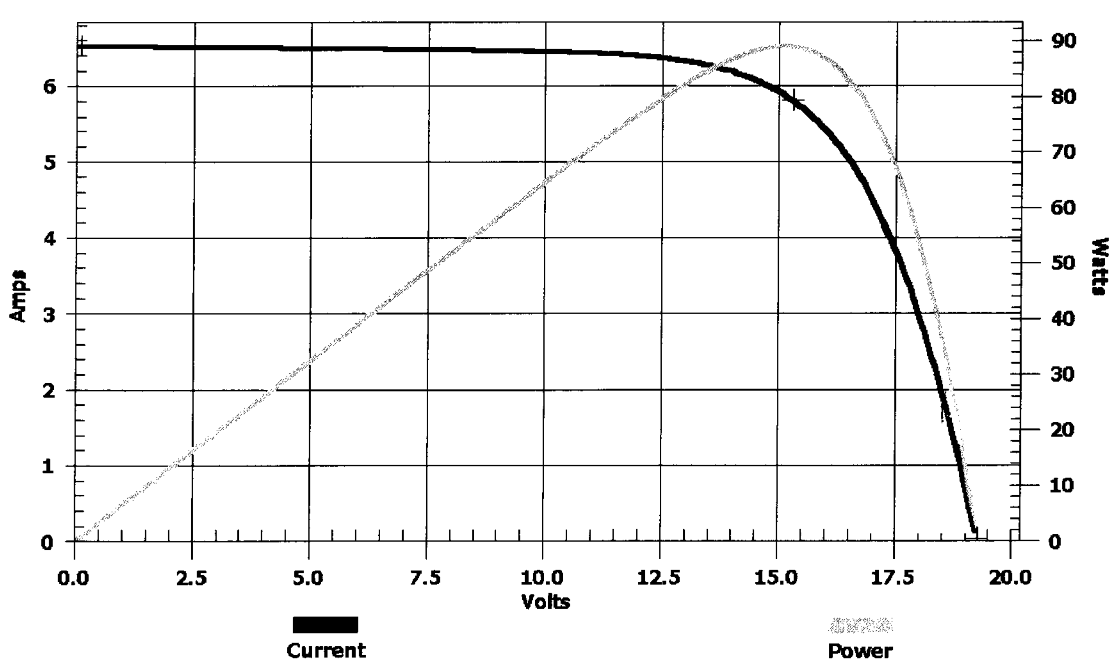
The figure below shows the current – voltage (IV) curve of a solar module (black curve) and corresponding power curves (power as the function of voltage, gray curve), measured at the standard test conditions (STC, radiation intensity 1000 W/m^2, temperature 25°C). The dimensions of the module are 600 x 1000 mm. Estimate approximately from the graph the open circuit voltage (V_{OC}), short circuit current (I_{SC}), fill factor (FF), and energy conversion efficiency (η) of the module in the following cases a) and b)

a) The initial case, as shown in the figure (2 p),

b) Otherwise the same, but an additional series resistance (R_S) of 1 Ω due to a bad external electrical contact is affecting the performance of the module (2 p)

c) What is the operating point (current, voltage, power) when a load resistance of 10 Ω is connected to the solar module in case a)? (1 p)

d) What value of the load resistance would draw the maximum power from the solar cell? (1 p)



3.

Crystalline silicon solar cells, as well as many other solar cells that are based in inorganic semiconductors, are often called pn-junction solar cells.

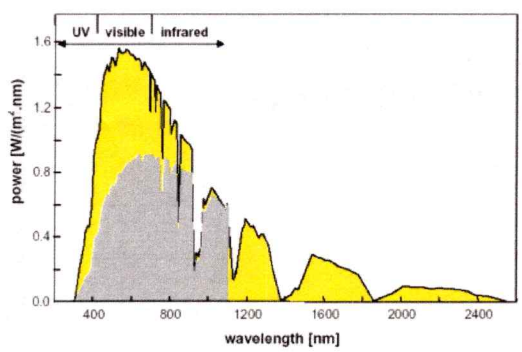
a) Explain briefly the role of pn-junctions in typical semiconductor solar cells (2 p)
b) The width W of the depletion zone of a pn-junction is 10 µm, dopant density in n-side (N_D) is $2.3\cdot10^{23}/m^3$ and in p-side (N_A) $8.6\cdot10^{21}/m^3$. Assume that the net charge density inside the depletion zone is constant and outside it zero. How far the depletion zone reaches to n-side and how far to the p-side? (2 p)
c) Coordinate x is defined perpendicular to the plane of pn-junction. Deduce the equation for the electric field of the junction as a function of x, when the dopant densities are known. Again, the net charge density inside the depletion zone is constant and zero outside the zone. (2 p)

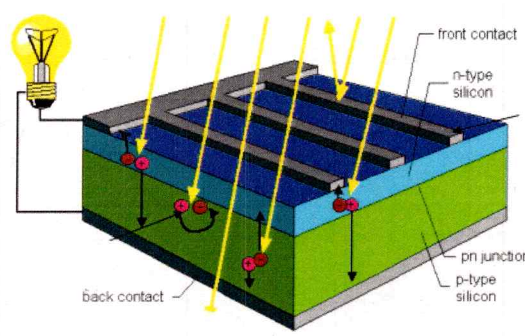
4.

Consider the theoretical and practical efficiency of a single-junction solar cell and module at standard reporting conditions (AM1.5G 1000 W/m², 25 °C).

a. Which two fundamental loss mechanisms already together limit the theoretical efficiency to ca. 45 %?
b. What additional fundamental physical process limits the theoretical efficiency to ca. 33 %?
c. What additional practical loss mechanisms limit the efficiency of real silicon solar cells to the current record of 27.6 %, and commercial silicon solar cells to 18 - 22 %?
d. What additional loss mechanisms are the reason why silicon solar modules have somewhat lower efficiency that the solar cells that they are built from?

Name and briefly explain these loss mechanisms and identify the key material properties that determine them. The figures below are given as a hint. (6 p)





5.

Design and sketch a stand-alone a PV system for a village electrification application in Africa. The daily average solar radiation is 6 kWh/m² and the daily average demand of electricity is 5000 Wh. The photovoltaic modules available for the project have rated power of 120 W, and their maximum power point voltage and current are V_{MPP} = 34.2 V and I_{MPP} = 3.5 A, respectively. You can choose between 12 V and 24 V batteries. The required reserve time (operation without PV) is 3 days. (6p)

$P = UI$

$I = \frac{P}{U}$