Name: Matriculation number:

Mock exam for "Solar Energy" lecture, WS 2021/2022
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1. Solar spectrum

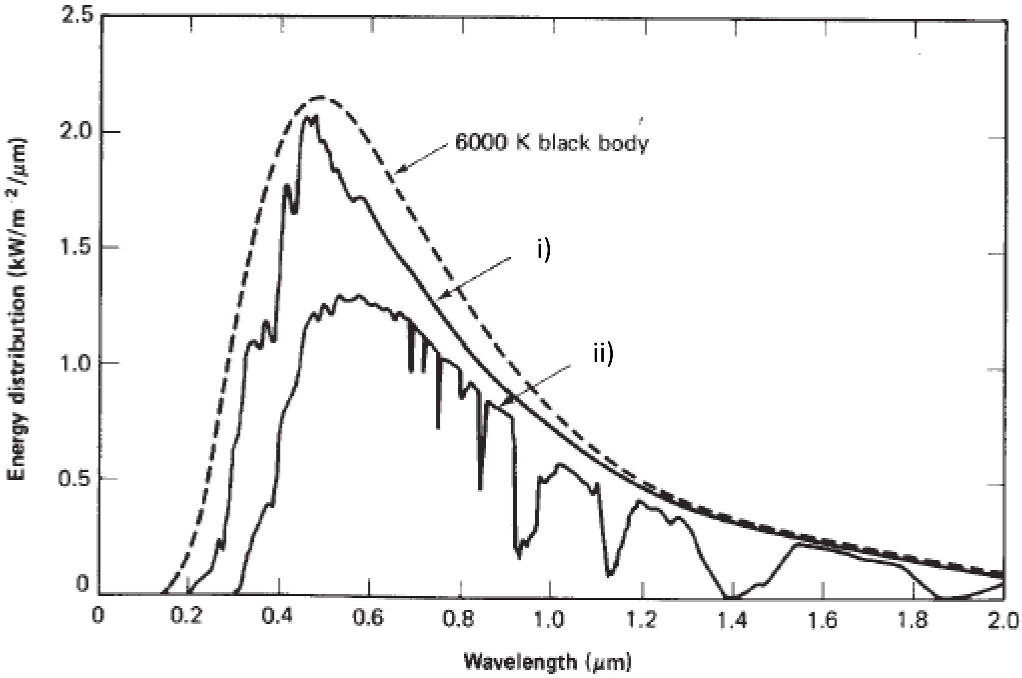

Figure 1: Depicted is a black body spectrum at 6000 K and two solar spectra.

a) Figure 1 shows three different spectra, one from a black body at 6000 K and two from the sun. Identify the solar spectra and label correctly i) and ii) with a suitable air mass. Please justify your decisions.

b) Explain the deviation of the solar spectra from the black body spectrum. What are the relevant processes in the ultraviolet, visible and infrared region of the spectrum?

c) It was measured that the sun has a radiation power of $2{,}4 \cdot 10^{45}$ eV per second. With this value calculate the Boltzmann constant $\boldsymbol{\sigma}$ in SI units.
(Temperature of the sun's surface: 5778 K, diameter of sun: 1.391$\cdot 10^{6}$km)

d) The photophysical properties of a solar cell are mostly determined by the band gap of the active layer. State one advantage and one disadvantage of using a very small and a very large band gap, respectively.

e) State two strategies to overcome the Shockley-Queisser limit.

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2. **Physics of Semiconductor**

a) Draw a simple energy band diagram of i) a metal, ii) a semiconductor and iii) an insulator, also indicate the Fermi Level.

b) What is the main electronic difference between crystalline silicon and gallium arsenide? Briefly state how is this affecting the absorption.

c) Identify these two equations for electronic currents and name the variables:

$$j_1 = -q \cdot D \cdot \frac{\partial n}{\partial x}$$
$$j_2 = q \cdot n \cdot \mu \cdot E$$

State which is dominant in crystalline silicon and which in an amorphous silicon solar cell. Justify your decision.

d) Referring to Figure 2 below, calculate the thickness of the active layer for

1. a crystalline silicon solar cell
2. an amorphous silicon solar cell

such that 80% of light with a wavelength λ=620 nm gets absorbed.

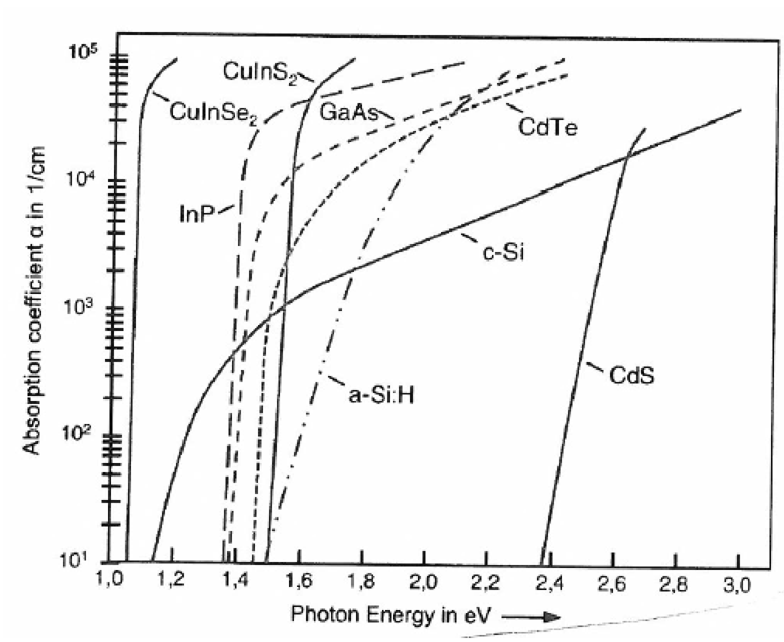

Figure 2: Absorption coefficient for different materials.

3. Solar cell

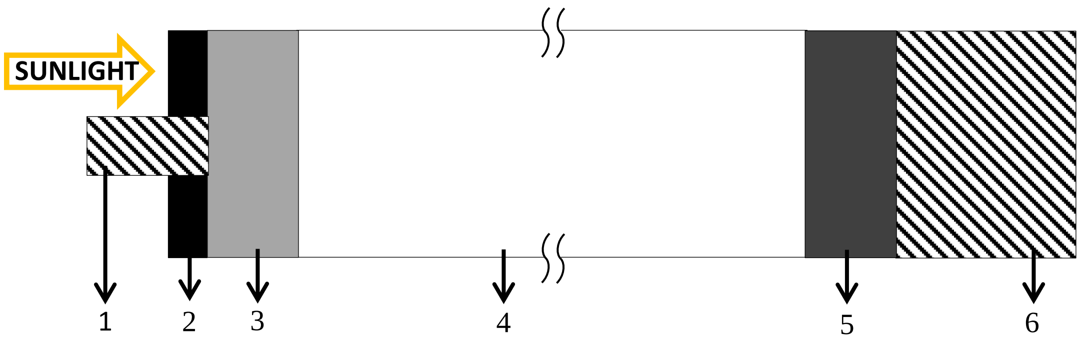

Figure 3: Layers of a monocrystalline silicon solar cell.

a) Figure 3 shows the cross section of a typical monocrystalline silicon solar cell. Label all the numbered layers above and describe the function of them.

b) Sunlight is concentrated with a lens on to a solar cell by a factor of X=10. Derive how this is affecting the short circuit current I_{SC}. Further derive an equation of V_{OC} depending on the concentration factor X, assume that $I_{SC} \gg I_0$. Calculate the efficiency of the solar module by using the following values (STC) under concentrated sun light. $\left(V_{OC,0} = 650mV, I_{SC,0} = 30mA, n_{ideality} = 1.0, T = 25°C, FF = 0.7, P_{sun} = 0.5W\right)$.

c) Concentrated sunlight will increase the heat of the solar cell. For the solar cell parameters given in b) how does the open circuit voltage depend on the solar cell temperature?

Calculate V_{OC} for a temperature increase of $\Delta T = 50K \left(\partial V_{OC}/\partial T = 2\frac{mV}{K}\right)$.

d) From the results in b) and c) find a conclusion about using concentrated sunlight for increasing the efficiency of solar cells.

4. Advanced optics and energy yield modelling

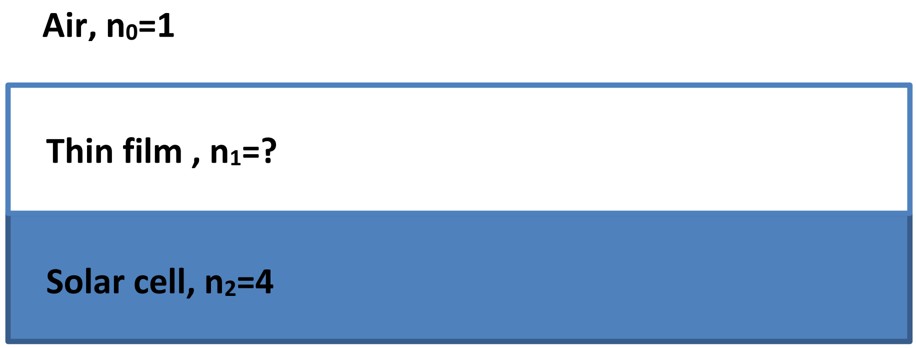

Figure 4: Schematic graph of the solar cell layer stack.

a.) Figure 4 shows a sketch of a solar cell and a thin film on top of it. The thin film should act as an anti-reflection coating. Which refractive index should the thin film have so that it can fulfill this function? State the thickness of the thin film for 530 nm.

b.) Figure 5 shows the external quantum efficiency (EQE) curve of a thin film solar cell and a curve of an ideal loss-free solar cell. Explain what can be learnt via these EQE measurements.

c.) Explain the deviation between the ideal and real spectra for the three sections (1, 2 and 3) indicated in Figure 5.

d.) Explain two methods of reducing the losses discussed in c.).

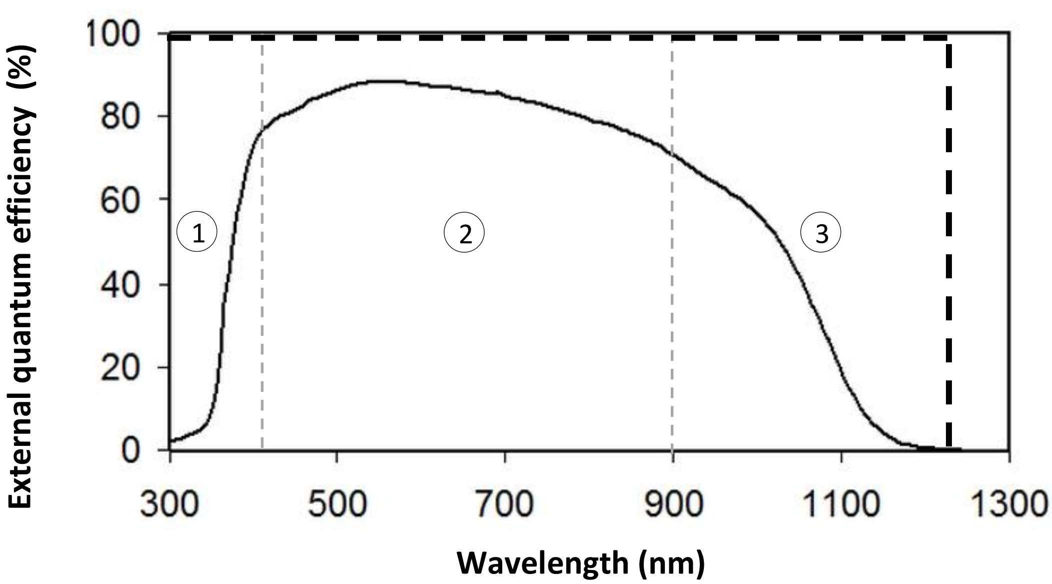

Figure 5: EQE spectra of a thin film solar cell (solid line) and the ideal curve (bold dashed line).

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Natural constants:

Absolute Zero	T_0	$-273{,}15$	$°C$
Atomic Mass Unit	u	$1{,}661 \cdot 10^{-27}$	kg
Avogadro Constant	N_A	$6{,}022 \cdot 10^{23}$	mol^{-1}
Bohr Radius	a_0	$0{,}529 \cdot 10^{-10}$	m
Boltzmann Constant	k_B	$1{,}381 \cdot 10^{-23}$	J/K
Vacuum Permittivity	ε_0	$8{,}854 \cdot 10^{-12}$	As/Vm
Electron Mass	m_e	$9{,}109 \cdot 10^{-31}$	kg
Elementary Charge	e	$1{,}602 \cdot 10^{-19}$	C
Euler's Number	e	$2{,}718$	
Pi	π	$3{,}142$	
Speed of Light in Vacuum	c_0	$2{,}998 \cdot 10^{8}$	m/s
Vacuum Permeability	μ_0	$1{,}257 \cdot 10^{-6}$	Vs/Am
Neutron Mass	m_n	$1{,}675 \cdot 10^{-27}$	kg
Planck Constant	h	$6{,}626 \cdot 10^{-34}$	Js
	$\hbar$	$1{,}055 \cdot 10^{-34}$	Js
Proton Mass	m_p	$1{,}673 \cdot 10^{-27}$	kg