You can alternatively do this full-course exam. In that case, it replaces the two mid-term exams. Your homework points will affect the course grade with the same weighting. Clearly mark in your answer papers which exam you have given.

Answer all 5 questions. (Max. points from each question is 6; total 30).

1. Question

Answer the questions. 1 point each.

g) What is solar constant?
h) How can one measure direct, diffuse, and total solar irradiance components?
i) What is the annual total solar irradiation on a horizontal surface (kWh/m^2/a) in Helsinki (Finland), Vienna (Switzerland), Sevilla (Spain), and Cairo (Egypt)?
j) Write and explain the HWB equation.
k) What is a selective solar absorber?
l) Why does a vacuum tube (evacuated tube) solar thermal collector reach higher efficiency than a single-glazed planar solar collector?

2. Question

Answer the questions. 1 point each.

g) What is the most common N- and P-type dopants in silicon? Why and how do affect the conductivity of silicon?
h) What are minority carriers in N-type silicon? What determines their concentration at room temperature i) in the dark, ii) under illumination?
i) If the bandgap of a pn-junction solar cell decreases (conceptually), how does it affect the short circuit current and open circuit voltage of the cell (according to theory)?
j) Consider a solar module made of 72 identical solar cells that each have maximum power point (MPP) voltage V_{MPP} = 0.5 V and current I_{MPP} = 5 A. If the solar module has six parallel-connected strings of cells, each string consisting of 12 series-connected cells, what is the V_{MPP} and I_{MPP} of the solar module?
k) What are the two main challenges that development of perovskite solar cells need to overcome before they can become competitive with crystalline silicon solar cells?
l) Why do multi-junction solar cells reach higher efficiency than single junction cells?

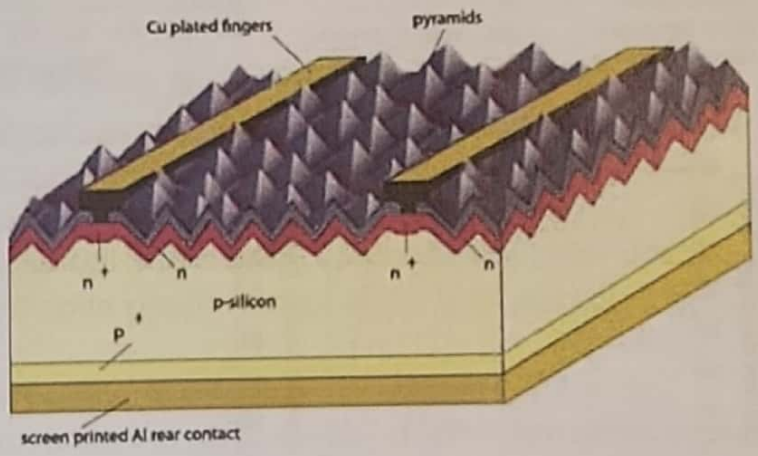
3. Question

The figures below show a photo and a schematic cross section of a crystalline silicon solar cell.

What are the main factors – related to the physical properties of the materials or structural properties of the solar cell or design – that determine the short-circuit current of the cell produced at 1000 W/m^2 AM1.5G solar illumination?

List the main factors, both gains or losses, of both optical and electrical by nature, and explain how and why they affect the current output of the cell. Try to be as thorough as you can but include only factors that you understand and can briefly (in few words) explain – mere long list of unexplained guesses does not count as valid answer.

Tip: Think about the sequence of processes in which light (flux of photons) is converted to electricity (current). (6 points total)



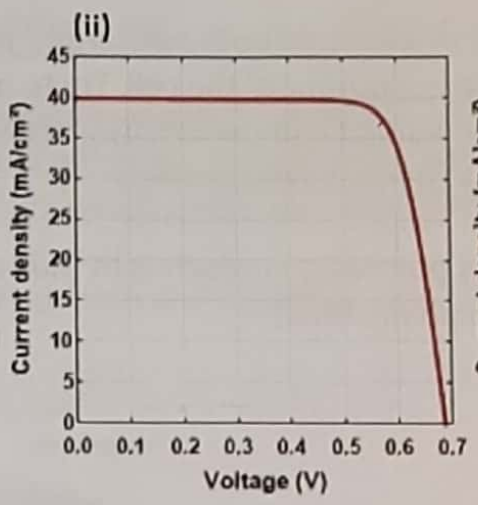
4. Question

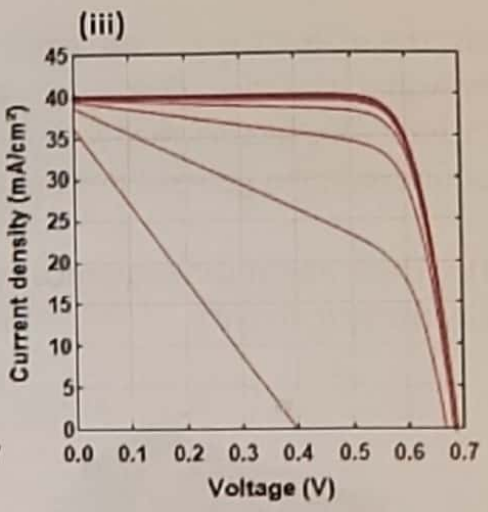
The figures (ii)-(vi) below show current–voltage (IV) curves of solar cells measured at the standard test conditions (STC). The IV curves can be represented with an equivalent circuit model which has five parameters: light-collected current J_L, saturation current density J_0, ideality factor m, shunt resistance R_{sh}, and series resistance R_s.

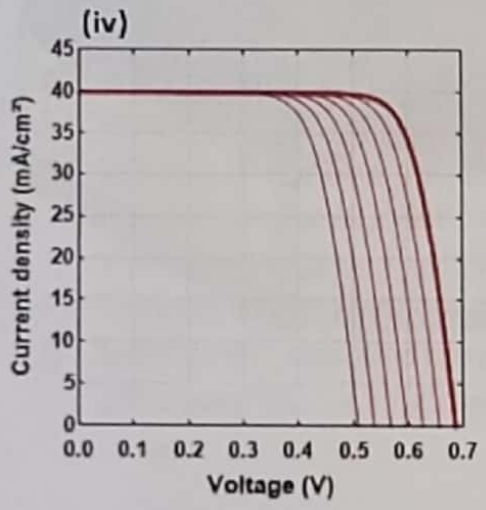
g) Draw the equivalent circuit corresponding to the IV curve and name its components. (0.5 p)
h) Using the five parameters, give the corresponding mathematical expression of the IV curve. (0.5 p)
i) Figure (ii) is the reference case, with the parameter values of the table in figure (i). Estimate approximately from figure (ii) the open circuit voltage (V_{OC}), short circuit current density (I_{SC}), fill factor (FF), and energy conversion efficiency (h). (0.5 p)
j) d) Figures (iii)-(vi) represent each variation of one of the parameters: J_L, J_0, R_{sh}, and R_s vs. the reference value. Which figure corresponds to variation of which parameter? (0.5 p)
k) Estimate the range of variation (lowest and highest value) of the parameter values corresponding to the curves. (2 p)
l) Explain which material or structural property could cause these variations in
    a. R_{sh} (0.5 p)
    b. R_s (0.5 p)
    c. J_0 (1 p)

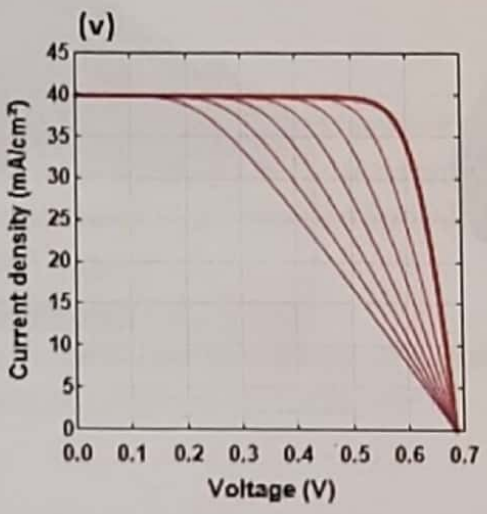
(i)

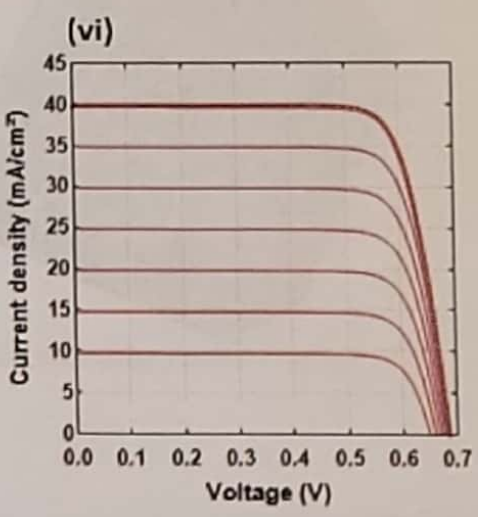
INPUTS			
Light-collected current	J_L	40	mA/cm²
Saturation current	J_0	1E-13	A/cm²
Ideality factor	m	1	
Shunt resistance	R_{sh}	10000	Ω·cm²
Series resistance	R_s	1	Ω·cm²











5. Question

a) The concentration ratio of a parabolic dish concentrator is C = 200. How much solar radiation is received on the absorber surface at the focal point of the concentrator if the solar radiation on a plane with surface normal pointing to the Sun is 200 W/m² direct radiation and 800 W/m² diffuse radiation? (2 p)

b) How much heat (W/m²) could the above concentrator (solar thermal collector) produce, if its optical efficiency is 0.8 and the heat loss factor is 5 W/m²K (per m² = per absorber area)? (2 p)

c) How high is the stagnation temperature in this solar collector? (1 p)

d) How accurately does the concentrator need to follow the movement of the sun in order to be able to concentrate the radiation to the absorber surface? Choose: the maximum misalignment error is about (1 p)

I. 5°
II. 2°
III. 1°
IV. 0.5°