Solutions to Chapter 5:

Exercise 5.1: Production of c-Si Solar Cells

a) See Section 5.1

b)
1. Texturizing,
2. n^+-doping of the emitter
3. Anti-reflection coating
4. Screen printing of contacts (front and rear side)
5. Contact firing
6. Edge insulation
7. Measurement and classification of cell

Exercise 5.2: a-Si Thin Film Cells

a) The drift cell is built up of a very thin pin-layer with inbuilt electrical field. The generated charge carriers are separated by the field and moved to the contacts. On the contrary the diffusion cell is a (e.g.) p-doped wafer with a thickness larger than 100 µm in which uppermost layer an n-emitter has been doped. The light absorption mainly takes place in the field-free base so that the generated particles must first diffuse to the p-n junction to be afterwards transported to their home regions by the field of the space charge region.

b) See Section 5.2.3

c) See Section 5.2.4
Moderation of the effect: - Passivate with hydrogen
- Use thinner layers (in tandem or triple cells)
- Temper to heal the degradation

Exercise 5.3: CIS Cells

a) See Figure 5.22

b) It serves on the one hand as an n-layer of the p-n junction and on the other hand as a window layer. This means that it has a large bandgap and will therefore absorb almost no photons.

c) The standard buildup is the superstrate configuration (*super*: Latin for *above*): Here the glass pane lies above and the cell is illuminated through the glass. Advantageous to this solution is the fact that the glass pane can be the cover of the whole solar module.
For the substrate configuration (*sub*: Latin for *under*) the glass pane - in a manner of speaking - lies under the cell; light incidence comes from the other cell side. This structure is necessary when the absorber only can be deposited on a lightproof material (e.g. molybdenum in CIS cells). In this case an additional module front glass pane has to be used on the other side.

Exercise 5.4: Concentrator Systems

a) See Figure 5.25

b) The short circuit rises linearly with an increase of the incident irradiance.
Simultaneously V_{MPP} rises so that P_{MPP} increases over-proportional.

c) $$V'_{\mathrm{OC}} = m \cdot V_{\mathrm{T}} \cdot \ln \frac{X \cdot I_{\mathrm{SC}}}{I_{\mathrm{S}}} = m \cdot V_{\mathrm{T}} \cdot \ln \frac{I_{\mathrm{SC}}}{I_{\mathrm{S}}} + m \cdot V_{\mathrm{T}} \cdot \ln X = V_{\mathrm{OC}} + m \cdot V_{\mathrm{T}} \cdot \ln X$$

$$\frac{\Delta V_{\mathrm{OC}}}{V_{\mathrm{OC}}} = \frac{V'_{\mathrm{OC}} - V_{\mathrm{OC}}}{V_{\mathrm{OC}}} = \frac{m \cdot V_{\mathrm{T}} \cdot \ln X}{V_{\mathrm{OC}}}$$

i) $X_1 = 100$: $\frac{\Delta V_{\mathrm{OC}}}{V_{\mathrm{OC}}} = \frac{15 \cdot 26\ \mathrm{mV} \cdot \ln 100}{600\ \mathrm{mV}} = 0.3 \Rightarrow \eta_1 = \eta \cdot (1 + 0.3) = \underline{23.4\ \%}$

ii) $X_2 = 400$: $\frac{\Delta V_{\mathrm{OC}}}{V_{\mathrm{OC}}} = \frac{1.5 \cdot 26\ \mathrm{mV} \cdot \ln 400}{600\ \mathrm{mV}} = 0.389 \Rightarrow \eta_1 = \eta \cdot (1 + 0.389) = \underline{25.0\ \%}$

d) Heating up of the cell, rising losses at series resistances

Exercise 5.5: Ecology Questions

a)

c-Si:	no problems
CdTe:	upper limit through restricted availability of tellurium; about 10 GWp/a possible
CIS:	upper limit through restricted availability of indium; about 5 GWp/a possible

b) i) $w_{\mathrm{Year}} = 900$ kWh/(kWp·a), $T_{\mathrm{A}} = \frac{w_{\mathrm{Prod}}}{w_{\mathrm{Year}} \cdot F_{\mathrm{PE}}} = \frac{5500\ \mathrm{kWh/kWp}}{900\ \frac{\mathrm{kWh}}{\mathrm{kWp} \cdot \mathrm{a}} \cdot 3} = \underline{2.04\ \mathrm{a}}$;

$$ERoEI = \frac{T_{\mathrm{L}}}{T_{\mathrm{A}}} = \frac{25\ \mathrm{a}}{2.04\ \mathrm{a}} = \underline{12.3}$$

ii) With Table 2.4: $w_{\mathrm{Year}} = 900$ kWh/(kWp·a) · 81.9 % = 737 kWh/(kWp·a)

$$T_{\mathrm{A}} = \frac{w_{\mathrm{Prod}}}{w_{\mathrm{Year}} \cdot F_{\mathrm{PE}}} = \frac{5500\ \mathrm{kWh/kWp}}{737\ \frac{\mathrm{kWh}}{\mathrm{kWp} \cdot \mathrm{a}} \cdot 3} = \underline{2.49\ \mathrm{a}}\ ;\ ERoEI = \frac{T_{\mathrm{L}}}{T_{\mathrm{A}}} = \frac{25\ \mathrm{a}}{2.49\ \mathrm{a}} = \underline{10.0}$$