# Exercise 3.1 – The efficiency limit of c-Si solar cells

In c-Si solar cells the efficiency is limited by non-radiative recombination effects such as Auger recombination. Outline the main idea of the derivation and point out the differences to the derivation of Shockley and Queisser which is based on radiative recombination (c.f. Ex 1.2)

Literature (suggestions only, please find other sources):

Tiedje et al., https://ieeexplore.ieee.org/abstract/document/1483879

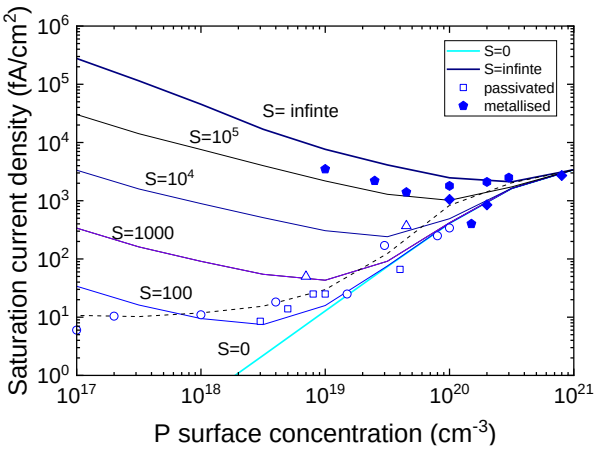
Richter et al., https://ieeexplore.ieee.org/abstract/document/6557081

# Exercise 3.2 - Selective emitter

In the development of c-Si solar cells, much of effort was devoted to the front contact. The phosphorous diffusion profiles shown in the course was initially passivated by $SiO_2$ later by $SiN_x$, and was eventually further improved on by introducing *selective emitters*.

a) Design a sketch of the front region of a c-Si solar cell, showing the *pn*-junction between wafer and the diffused region, the local contacts to the silver finger metallization, and the passivated region between the fingers.

b) Assume a *passivated emitter* with uniform surface concentration of $N_D = 10^{19}\ \mathrm{cm}^{-3}$. Using the diagram below,[1] project the $j_0$ by using an area weighted sum of $j_{0,met}$ and $j_{0,pass}$, assuming that the silver fingers cover an area of 5%.




c) Explain the working principle of a *selective emitter* that combines highly doped regions below the fingers and lowly doped regions in between. Using again the diagram, estimate the additional improvement that is possible.

[1] The symbols refer to experimental data digitized from King, TED (1980) and from Kerr, JAP (2001). The lines refer to a simple model with the geometry factor $G_F$, assuming constant donor density $N_D$ equal to the surface concentration and an emitter thickness of 150 nm.

# Exercise 3.3 – Wafer size

Present a historic overview on the wafer size used in c-Si manufacturing and the underlying driving forces. Discuss the utilization ratio between wafers and ingots, consequences to module design and shipping.

Literature (suggestions only, please find other sources):

Zhang et al, section 21.2 in https://onlinelibrary.wiley.com/doi/epdf/10.1002/9781119578826.ch21

Mittag et al. https://www.epj-pv.org/articles/epjpv/pdf/2024/01/pv20240050.pdf

Chen et al., section 5.1 in https://onlinelibrary.wiley.com/doi/full/10.1002/pip.3626

# Exercise 3.4 – Cost of Ag metallization

The aspect of Ag consumption w.r. to the global supply of the raw material is investigated in Ex. 1.4. In this exercise. Please estimate the cost that the Ag metallization contributes to typical cell configurations. Show the historical development of Ag utilization and compare to the cost of the raw material. Point out recent development towards reducing the use of Ag.

Literature (suggestions only, please find other sources):

Cost of silver, e.g. https://tradingeconomics.com/commodity/silver

Pingel et al., https://www.sciencedirect.com/science/article/pii/S0927024823004415

Schube et al., https://doi.org/10.1063/1.5125872

Zhang et al., https://www.sciencedirect.com/science/article/pii/S0927024825002557

# Exercise 3.5 – Lifecycle Assessment of photovoltaics

Outline the main aspects to estimate the energy that are needed to produce solar modules and the energy that a solar module supplies during its lifetime. Present important outcomes like the energy payback time (EBT) and the $CO_2$ footprint.

Literature (suggestions only, please find other sources):

Fthenakis et al., https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119578826.ch33

Fthenakis et al., https://onlinelibrary.wiley.com/doi/full/10.1002/pip.3441

# Exercise 3.6 – Alpine PV installations

Lifecycle assessments include an average value for the energy that required for the deployment of photovoltaic systems. This may not be adequate for particular scenarios like Alpine installations in Switzerland. For example, the project in Grengiols anticipates to lift construction materials either by cableway and partially by helicopter. Try to find numbers for the fuel consumption, assuming that you had to lift standard modules of a 1 GW installation by freight helicopter. Compare to the expected energy that such a system will supply during its lifetime.

https://www.grengiols-solar.ch