# Exercise Series 8

## Exercise 1: P-N junction

a) Consider a p-n-junction with equal doping concentrations in both the p-doped and n-doped part and no bias voltage applied. Sketch the *charge densities*, the *electrical field* and *electrical potential* within the space charge region and explain how they are related to one another. Sketch also the *band diagram* for the same region.

b) Consider now a junction with a bias voltage applied.

   (a) Sketch the carrier concentration for electrons and holes that will arise throughout the junction for forward and reverse bias (direct or reverse polarization).

   (b) What will happen to the electric field across the junction, the width of the depletion region and the energy bands (CB and VB) for each case?

c) Explain in your own words how the current flows across the junction in equilibrium, forward bias, and reverse bias. *Hint:* Consider drift and diffusion currents.

## Exercise 2: Lifetime, surface recombination velocity and saturation current

In this exercise we will consider a solar cell with an infinite base and determine the dominating contribution to the saturation current density $J_0$. It is the sum of two parts: the base $J_{0\mathrm{B}}$ and the emitter $J_{0\mathrm{E}}$ saturation current density. $J_0$ is detrimental to the cell performance as it influences the $V_{\mathrm{oc}}$ and thus the overall cell efficiency.

We consider a solar cell based on p-type crystalline silicon wafer with an infinite base, i.e the thickness of the latter is much higher than the diffusion length of the electrons. The emitter is $1\,\mu$m thick ($x_j$=1 $\mu$m) and homogeneously $n^{++}$ doped ($N_\mathrm{S} = 2 \cdot 10^{19}\,\mathrm{cm}^{-3}$). After passivation of the emitter, the surface recombination velocity at the front surface $S_\mathrm{p}$ is $10^4\,\mathrm{cm\,s}^{-1}$. The doping concentration in the base is $N_\mathrm{A} = 1 \cdot 10^{16}\,\mathrm{cm}^{-3}$. Fig. 1 shows the relationship between $J_{0\mathrm{E}}$, the surface recombination velocity $S_\mathrm{p}$ and the surface concentration $N_\mathrm{S}$.

a) Is the saturation current density in the base $J_{0\mathrm{B}}$ influenced by the surface recombination velocity in this specific case? Considering Fig. 1 and assuming a lifetime in the base of $\tau_n = 4\,\mathrm{ms}$, which saturation current governs the solar cell efficiency? Is it the same if $\tau_n$ is equal to $10\,\mu\mathrm{s}$?

b) With the results of part a) in mind explain why the temperature coefficient for a-Si ($0.2\,\%/^\circ\mathrm{C}$) is lower than for c-Si ($0.5\,\%/^\circ\mathrm{C}$).

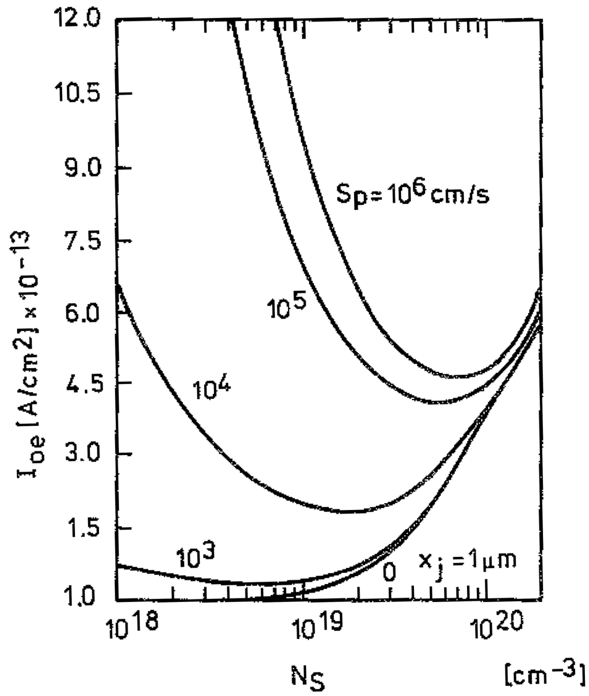


Figure 1: Saturation current of an emitter as a function of surface concentration, with $S_{\mathrm{p}}$ being parameter. Taken from *Crystalline silicon solar cells* by A. Goetzberger, J. Knobloch, and B. Voss.