Exercise Series 10

Exercise 1: Real solar cell

Consider a solar cell based on a simple p-n junction with the same emitter as described in Ex. 2 of Serie 6 and a p-doped base ($N_A = 10^{16}\,\mathrm{cm}^{-3}$) but this time with a finite thickness of $d = 180\,\mu\mathrm{m}$. The total thickness of the wafer is denoted by H. We assume that under AM1.5G illumination, the fill factor (FF) is 75 % and the short circuit current density (J_{sc}) is $44\,\mathrm{mA\,cm}^{-2}$. The purpose of this exercise is to get a feeling for the impact that the surface recombination velocities S_n and S_p, the lifetime τ and the saturation current density J_0 have on the cell efficiency.

a) Write down the V_{oc} as a function of J_0 with the help of the diode equation (one diode model) under illumination.

b) Explain why J_{0E} increases with the doping (starting from approx. $10^{19}\,\mathrm{cm}^{-3}$) for a constant S_p using Fig. 1.

c) Explain why J_{0E} increases strongly for S_p higher than $10^3\,\mathrm{cm\,s}^{-1}$, if the doping is decreased below 10^{19}.

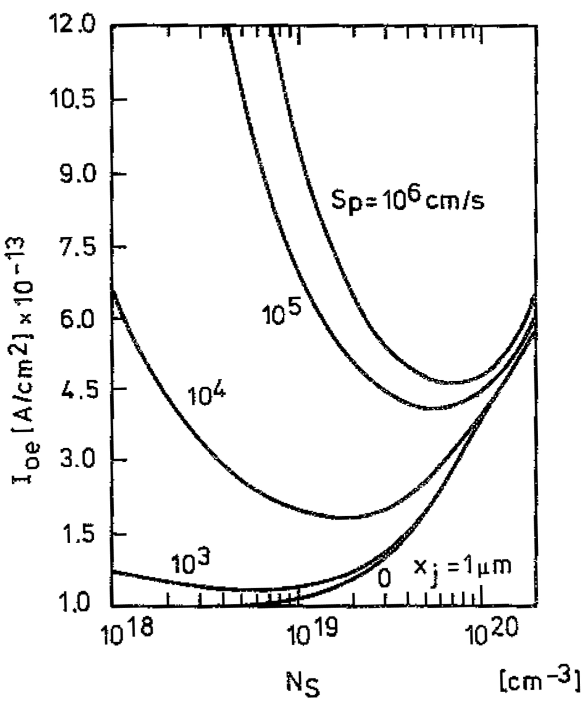

Figure 1: Saturation current of an emitter as a function of surface concentration, with S_p being parameter. Taken from *Crystalline silicon solar cells* by A. Goetzberger, J. Knobloch, and B. Voss.

Exercise 2: Geometry factor

The following exercise will treat the so-called geometry factor G_F which influences the base saturation current J_0B given by:

$$J_\mathrm{0B} = \frac{q \cdot n_i^2 \cdot D_n}{N_\mathrm{A} \cdot L_n} \cdot G_\mathrm{F} \tag{1}$$

G_F is determined by the two variables S_n/S_∞ and H/L_n, where S_∞ is the bulk recombination velocity defined as D_n/L_n. The relationship between those parameters is shown in Fig. 2.

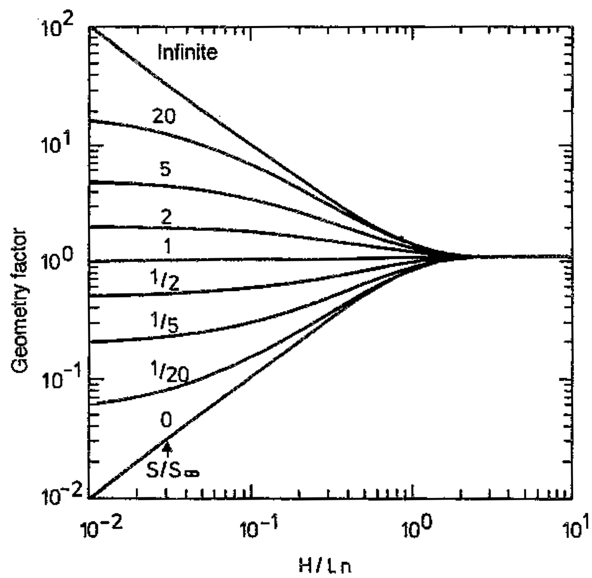

Figure 2: Geometry factor as function of the ratio base thickness H / diffusion length L_n. Taken from *Crystalline silicon solar cells* by A. Götzberger, J. Knoblauch, and B. Voss.

a) Explain Fig. 2 in your own words.

The rest of this exercise is OPTIONAL but we recommend to you to at least have a look at the solutions posted on the Moodle.

b) Extract the value of the G_F for $\tau = 1\,\mathrm{ms}$ from the graph and three different values of surface recombination velocity $S_n = 10^1$, 10^3, $10^7\ \mathrm{cm\,s^{-1}}$. Use $H = 180\,\mathrm{\mu m}$ and $D_n = 28\,\mathrm{cm^2\,s^{-1}}$.

c) With the values obtained in part b) calculate the corresponding base saturation current values, the total saturation current density $J_0 = J_\mathrm{0E} + J_\mathrm{0B}$, the V_oc and eventually the efficiency η. Use the following values: $D_n = 28\,\mathrm{cm^2\,s^{-1}}$, $n_i^2 = 10^{20}\,\mathrm{cm^{-6}}$, $J_\mathrm{0E} = 2 \times 10^{-13}\,\mathrm{A\,cm^{-2}}$, $J_\mathrm{sc} = 44\,\mathrm{mA\,cm^{-2}}$ and $FF = 75\,\%$.

d) Change the lifetime to $\tau_n = 1\,\mathrm{\mu s}$ and calculate again.

e) Is the efficiency realistic?

f) Imagine $S_n \to 0$ and $\tau_n \to \infty$. Calculate J_0B. Which part of the saturation current dominates and limits the efficiency? What is the maximum achievable efficiency?