Serie 05

Preamble

Diffusion of minority carriers in the quasi-neutral regions

As we saw in Lecture 5, two opposite approximations may hold when calculating the distributions of minority carrier concentrations in the QNRs, depending on the dimensions of the PN junction.

1. **Short neutral sides**: if $W_p - x_p << L_n$, recombination occurs mainly at the interface with the QNR and bulk recombination can be neglected. The excess minority electrons concentration $n'(x)$ is **approximately linear with** x, in this case. The same applies to excess minority holes $p'(x)$ when $W_n - x_n << L_p$.

2. **Long neutral sides**: if $W_p - x_p >> L_n$, recombination in the bulk cannot be neglected. The excess minority electrons concentration $n'(x)$ follows an **exponential decay with** x, in this case. The same applies to excess minority holes $p'(x)$ when $W_n - x_n >> L_p$.

We remind here the formulas for the carriers diffusion lengths: $L_n = \sqrt{D_n \tau_{n0}}$, $L_p = \sqrt{D_p \tau_{p0}}$.

Given constants

$n_i(Si) = 1.5 \cdot 10^{10}\,[cm^{-3}] \quad @ \quad T = 300\,[K]$
$k = 8.62 \cdot 10^{-5}\,[eV/K]$
$q = 1.60 \cdot 10^{-19}\,[C]$
$\epsilon_0 = 8.85 \cdot 10^{-14}\,[F/cm]$
$\epsilon_{Si} = 11.7 \cdot \epsilon_0$

Exercise 01

Consider an ideal abrupt PN juntion with short neutral sides compared to the diffusion lengths of both electrons and holes: $W_n = W_p = 2\,[um]$, while we neglect the width of the depleted regions. Draw the ideal current-voltage characteristic and calculate the reverse saturation current I_S for a cross sectional area $A = 2 \cdot 10^{-4}\,\left[cm^2\right]$ and $T = 300\,[K]$. Evaluate the current through the junction with a forward bias $V_D = 0.75\,[V]$. Comment on the results.
The semiconductor parameters are: $N_A = 5 \cdot 10^{16}\,\left[cm^{-3}\right]$, $N_D = 1 \cdot 10^{16}\,\left[cm^{-3}\right]$, $D_n = 21\,\left[cm^2/s\right]$, $D_p = 10\,\left[cm^2/s\right]$.

Exercise 02

Design the doping concentrations N_A and N_D of a PN diode such that its diffusion current densities for electrons and holes are respectively $J_n = 20\left[A/cm^2\right]$ and $J_p = 5\left[A/cm^2\right]$ at an applied forward bias $V_D = 0.65\,[V]$ ($T = 300\,[K]$). The diode has fixed dimensions $W_n = W_p = 300\,[um]$ and the semiconductor parameters are: $\tau_{n0} = \tau_{p0} = 5 \cdot 10^{-7}\,[s]$, $D_n = 25\left[cm^2/s\right]$, $D_p = 10\left[cm^2/s\right]$.

Exercise 03

Consider a Si PN junction initially biased at $V_D = 0.6\,[V]$ at $T = 300\,[K]$. The temperature later increases to $T = 310\,[K]$. Calculate the change in the forward-bias voltage V_D required to maintain a constant current through the junction. We assume dopants are completely ionized at $T = 300\,[K]$.
Reminder: $n_i^2 \propto exp\left(\frac{-E_g}{kT}\right)$ with $E_g = 1.12\,[eV]$ for silicon.

Exercise 04

Calculate the small-signal admittance, small-signal resistance and the diffusion capacitance of a PN junction diode. Assume $N_A >> N_D$, so that $p_{n0} >> n_{p0}$ and therefore $I_{p0} >> I_{n0}$. Let $T = 300\,[K]$, $\tau_{p0} = 1 \cdot 10^{-7}\,[s]$ and $I_{p0} = 1\,[mA]$. The transit time can be approximated to $\tau_T \approx \tau_{p0}/2$.