REFERENCE BOOK: SEMICONDUCTOR DEVICES FUNDAMENTALS (1998)

HOMEWORK 2

Problem 1

(a) Draw the Fermi functions at room temperature 300 K for electrons and holes.
(b) Draw the Fermi functions for electrons at 0 K to 400 K in 100 K intervals.

Problem 2

Plot the density of states, Fermi functions for electrons and holes, and carrier (n and p) concentrations for Si at T = 300 K when

(a) $n > p$,
(b) $n = p$, and
(c) $n < p$.

Assume the corresponding locations of the Fermi levels for each case above.

Hint: Note that the Fermi level would not be exactly at the mid-gap for the case (b).

HOMEWORK 3

Problem 1

Plot the equilibrium carrier concentration with respect to Fermi level position (both for n-type and p-type) for Si using Fermi-Dirac distribution and considering Boltzmann approximation. (Reproduce the figure shown in the slides.)

Problem 2

(Problem 2.7 in the textbook.) The carrier distributions or numbers of carriers as a function of energy in the conduction and valence bands were noted to peak at an energy very close to the band edges. (See the carrier distribution sketches in Fig. 2.16.) Taking the semiconductor to be nondegenerate, show that the energy at which the carrier distributions peak is $E_C + kT/2$ and $E_V - kT/2$ for the conduction and valence bands, respectively.

Problem 3

Do the Exercise 2.4 worked out in the textbook. The effective masses and the bandgap have weak temperature dependence. Write the MATLAB code and generate the results by your own.

Problem 4

A silicon wafer is doped $2 \times 10^{18} cm^{-3}$ with B ($E_A = E_V + 0.045\, eV$). Calculate the hole concentration and Fermi level position relative to the valence band at 100-degree intervals from 100 K to 500 K. Repeat for a doping of $2 \times 10^{16} cm^{-3}$. Hints: You may neglect the temperature dependence of N_V. Assume $g_A = 4$.

Problem 5

A silicon wafer is doped $1 \times 10^{17} cm^{-3}$ with B. At what temperature will 90% of the acceptors be ionized?

HOMEWORK 4

Problem 1

Show that the general steady-state result valid for arbitrary injection levels and both carrier types in a nondegenerate semiconductor is

$$\left.\frac{\partial n}{\partial t}\right|_{R-G} = \left.\frac{\partial p}{\partial t}\right|_{R-G} = \frac{n_i^2 - np}{\tau_p(n+n_1)+\tau_n(p+p_1)}$$

where

$$n_1 = n_i e^{(E_T-E_i)/kT}$$

$$p_1 = n_i e^{(E_i-E_T)/kT}$$

E_T is the trap level energy, τ_P and τ_N are hole and electron minority carrier lifetimes. Observe that the generation rate decreases *exponentially* as the trap energy E_T moves away from *midgap*. This explains why *midgap* traps are the most effective $R-G$ centers, and why donors and acceptors play essentially no role in $R-G$.

Problem 2

A uniformly donor-doped silicon wafer maintained at room temperature is suddenly illuminated with light at time $t = 0$. Assuming $N_D = 10^{15} cm^{-3}$, $\tau_p = 1\ \mu S$, and a light-induced creation of 10^{17} electrons and holes per cm^3- sec throughout the semiconductor, determine and plot $\Delta p_n(t)$ for $t > 0$.

Problem 3

A uniformly doped ($N_D = 10^{15}\ cm^{-3}$) semi-infinite bar of Si is illuminated resulting in $\Delta p_{n0} = 10^{10}\ cm^{-3}$ excess holes at $x = 0$ at steady-state. No light penetrates beyond $x = 0$. Using $\tau_p = 1\ \mu S$, determine and plot $\Delta p_n(x)$. Also, determine and plot the quasi-Fermi levels F_N and F_P.

HOMEWORK 5

Problem 1

Determine the PN junction electrostatics (charge density, electric field, potential and band diagram) using *depletion approximation*. Also, determine the expressions of depletion layer widths in the P- and N-side, and the total depletion width.

Problem 2

Plot the Si PN junction electrostatics and calculate the built-in potential and peak electric field at the junction for the following cases.

a. $N_D = N_A = 10^{15} cm^{-3}$
b. $N_D = 10^{16} cm^{-3}, N_A = 10^{14} cm^{-3}$

HOMEWORK 6

Problem 1

Linearly graded PN junction: Determine the PN junction electrostatics (charge density, electric field, potential and band diagram) using *depletion approximation*. Also, determine the expressions of built-in potential and the depletion width.

Problem 2

Consider a Si PN junction at room temperature. Use $N_D = 10^{17} cm^{-3}, N_A = 10^{15} cm^{-3}, L_P = 3.47 \times 10^{-3} cm, L_n = 4.56 \times 10^{-3} cm$.

a. A *forward* bias of $V_A = 0.3\ V$ is applied.
b. A *negative* bias of $V_A = -0.3\ V$ is applied.

Do the following for the two cases above.

a. Determine the depletion layer widths x_p and x_n.
b. Plot $n_p(x)$ and $p_n(x)$ in the quasi-neutral regions.
c. Plot $J_p(x)$ and $J_n(x)$ throughout the device.
d. Plot the quasi-Fermi levels F_p and F_n throughout the device.

Problem 3

Plot the multiplication factor (M) versus $|V_A|/V_{BR}$ when $m = 3$ and $m = 6$ for a PN junction in reverse bias with *avalanching* mechanism in place. Orient the axes so that a plot like PN junction reverse-current is obtained.

HOMEWORK 7

Problem 1

Do the Exercise 6.6 from the textbook.

Problem 2

Determine the diffusion admittance $Y_D = G_D + j\omega C_D$ in PN junction diodes following the Section 7.3.2 in the textbook.

Problem 3

Determine the voltage-time response during the *turn-on* transient in PN diodes following the Section 8.2 in the textbook.

HOMEWORK 8

Problem 1

Draw the carrier activity and spatial visualization in an *npn* BJT under active mode biasing (similar to the Figures 10.8 and 10.9 in textbook for the case of a *pnp* BJT).

Considering $I_{En} = 100\,\mu A$, $I_{Ep} = 1\,\mu A$, $I_{Cn} = 99\,\mu A$, and $I_{Cp} = 0.1\,\mu A$,

calculate $\alpha_T, \gamma, I_E, I_C, I_B, \alpha_{dc}, \beta_{dc}, I_{CB0}$, and I_{CE0}.

Problem 2

Show that the expressions for the emitter and collector terminal currents reduce to the ideal diode equation when $W \gg L_B$.

Problem 3

Consider a *pnp* BJT at room temperature. Use $W_B = 2 \times 10^{-4} cm$, $A = 10^{-4} cm^{-2}$,

$N_E = 10^{18} cm^{-3}$, $N_B = 10^{16} cm^{-3}$, $N_C = 10^{15} cm^{-3}$,

$D_E = 6.81\ cm^2/sec$, $D_B = 11.3\ cm^2/sec$, $D_C = 34.8\ cm^2/sec$,

$L_E = 8.25 \times 10^{-4} cm$, $L_B = 3.36 \times 10^{-3} cm$, $L_C = 5.9 \times 10^{-3} cm$.

A *forward* bias of $V_{EB} = 0.7\ V$ and a *negative* bias of $V_{CB} = -5\ V$ are applied.

a. Determine the depletion layer widths in equilibrium and under bias for both the junctions.
b. Plot $n_E(x)$, $n_C(x)$, and $p_B(x)$ in the quasi-neutral regions.
c. Plot $I_{En}(x)$, $I_{Cn}(x)$, $I_{Ep}(x)$, $I_{Cp}(x)$ and the total current I throughout the device.
d. Plot the quasi-Fermi levels throughout the device.
e. How the performance matrices $\alpha_T, \gamma, \alpha_{dc}, \beta_{dc}$ change with base width modulation?

Problem 4

Consider the parameters in the Problem 3, and determine the Ebers-Moll model parameters for the *pnp* BJT, i.e., $I_{F0}, I_{R0}, \alpha_F, \alpha_R$.

Draw the Gummel plot and gain plot (I_C versus β_{dc}) considering the following non-idealities of $R-G$ current in the depletion region and high-level injection.

$I_{R-G} = I_{02}\left(e^{qV_{EB}/\eta_2 kT} - 1\right)$, where $I_{02} = 10^{-14} A$ and $\eta_2 = 1.5$.

$I_C = \Gamma I_C(ideal)$, where $\Gamma = 1/\left(1 + e^{q(V_{EB}-0.75)/2kT}\right)$.

Problem 5

In the low-frequency Hybrid-π equivalent circuit of BJT [Figure 12.2(b)], while including base-width modulation, show that the circuit parameters are given by the Equation (12.10).

HOMEWORK 9

Problem 1

For an M-S Schottky diode made of Cu-Si, with the parameters $\Phi_M = 4.65\, eV, \chi = 4.03\ eV, N_D = 10^{16}/cm^3, T = 300\ K$, and when no voltage is applied, determine $\Phi_{B,} V_{bi}, W$, and E_{max}.

Problem 2

Plot the equilibrium energy band diagram, charge density, electric field and potential using depletion approximation for metal-semiconductor (p-type, $N_A = 10^{16}/cm^3$) contact when

a. $\Phi_M = 4.65\ eV > \Phi_S = 4.03\ eV$.
b. $\Phi_M = 3.66\ eV < \Phi_S = 4.03\ eV$.

Problem 3

Do the Exercise 15.2 from the textbook.

HOMEWORK 10

Problem 1

Do exercise 16.2 in the textbook. You need to plot the Figure 16.8 using the exact solution of electrostatics.

Problem 2

Generate Fig. 16.10 using both delta-depletion approximation and exact solution of electrostatics.

Problem 3

Do exercise 16.5 in the textbook. You need to plot the Figures 16.14 and 16.15 using the exact solution of electrostatics.

HOMEWORK 11

Problem 1

Generate the Fig. 17.9 in the textbook.

Problem 2

Do Exercise 18.1 in the textbook.

Problem 3

Do exercise 18.6 in the textbook.