VE320 Intro to Semiconductor Devices
Summer 2022 — Problem Set 4

June 26, 2022

Revised June 20

Deleted Ex 4.1(b)

Revised June 26

Deleted Ex 4.5(a)

Exercise 4.1

GaAs, at $T = 300$ K, is uniformly doped with acceptor impurity atoms to a concentration of $N_a = 2 \times 10^{16}$ cm^{-3}. Assume an excess carrier lifetime of 5×10^{-7} s.

Determine the electron-hole recombination rate if the excess electron concentration is $\delta n = 5 \times 10^{14}$ cm^{-3}.

Exercise 4.2

Consider an infinitely large, homogeneous n-type semiconductor with a zero applied electric field. Assume that, for $t < 0$, the semiconductor is in thermal equilibrium and that, for $t \geq 0$, a uniform generation rate exists in the crystal.

(a) Calculate the excess carrier concentration as a function of time assuming the condition of low injection.

(b) Consider n-type silicon at $T = 300$ K doped to $N_d = 5 \times 10^{16}$ cm^{-3}. Assume that $g' = 5 \times 10^{21}$ cm^{-3} s^{-1} and let $\tau_{p0} = 10^{-7}$ s.

Determine $\delta p(t)$ at (i) $t = 0$, (ii) $t = 10^{-7}$ s, (iii) $t = 5 \times 10^{-7}$ s, and (iv) $t \to \infty$.

Exercise 4.3

Consider a silicon sample at $T = 300$ K that is uniformly doped with acceptor impurity atoms at a concentration of $N_a = 10^{16}$ cm^{-3}. At $t = 0$, a light source is turned on generating excess carriers uniformly throughout the sample at a rate of $g' = 8\times\ 10^{20}$ cm^{-3} s^{-1}. Assume the minority carrier lifetime is $\tau_{n0} = 5 \times 10^{-7}$ s, and assume mobility values of $\mu_n = 900$ cm^2/V $\cdot$ s and $\mu_p = 380$ cm^2/V $\cdot$ s.

(a) Determine the conductivity of the silicon as a function of time for $t \geq 0$.

(b) What is the value of conductivity at $(i) t = 0$ and (ii) $t = \infty$?

Exercise 4.4

A p-type gallium arsenide semiconductor at $T = 300$ K is doped at $N_a = 10^{16}$ cm^{-3}. The excess carrier concentration varies linearly from 10^{14} cm^{-3} to zero over a distance of 50μm. Plot the position of the quasi-Fermi levels with respect to the intrinsic Fermi level versus distance.

Exercise 4.5

In a GaAs material at $T = 300$ K, the doping concentrations are $N_d = 8\times10^{15}$ cm^{-3} and $N_a = 2\times10^{15}$ cm^{-3}. The thermal equilibrium recombination rate is $R_o = 4\times 10^4$ cm^{-3} s^{-1}.

1. A uniform generation rate for excess carriers results in an excess carrier recombination rate of $R' = 2\times 10^{21}$ cm^{-3} s^{-1}. What is the steady-state excess carrier concentration?

2. What in the excess carrier lifetime?

Exercise 4.6

Consider a bar of n-type silicon that is uniformly doped to a value of $N_\mathrm{d} = 2 \times 10^{16}$ cm^{-3} at $T = 300$ K.

The applied electric field is zero.

A light source is incident on the end of the semiconductor ($x = 0$).

The steady-state concentration of excess carriers generated at $x = 0$ is $\Delta n(0) = \Delta p(0) = 3 \times 10^{14}$ cm^{-3}.

Assume the following parameters: $\mu_\mathrm{n} = 1100$ cm^2/Vs, $\mu_\mathrm{p} = 500$ cm^2/Vs, $\tau_{\mathrm{n}0} = 2 \times 10^{-6}$ s, and $\tau_{\mathrm{p}0} = 8 \times 10^{-7}$ s.

Neglecting surface effects

(a) Determine the steady-state excess electron and hole concentrations as a function of distance into the semiconductor from the surface ($x = 0$).

(b) Calculate the steady-state hole diffusion current density as a function of distance into the surface from the surface ($x = 0$).

Reference

1. Neamen, Donald A. Semiconductor physics and devices: basic principles. McGraw-hill, 2003.