

5. Recombination

Problems

5.1. A semiconductor with an intrinsic carrier concentration of $n_i = 4.8 \times 10^8 \text{ cm}^{-3}$ is doped with an acceptor density of $N_A = 3.0 \times 10^{17} \text{ cm}^{-3}$:

a) In equilibrium, find:

- i) The density of holes (p_0) and electrons (n_0).
- ii) The separation of the Fermi level from the intrinsic energy ($E_i - E_F$).

b) The material is now uniformly illuminated, which generates carrier by band-to-band photoexcitation at a rate $G = 2.5 \times 10^{10} \text{ cm}^{-3} \cdot \text{s}^{-1}$. Assume the coefficient of radiative recombination is

$$B_{\text{rad}} = 6.2 \times 10^{-10} \text{ cm}^3 \cdot \text{s}^{-1}.$$

- i) Compute the radiative recombination lifetime for electrons $\tau_{n,\text{rad}}$.
- ii) In steady state, the radiative recombination rate U_{rad} equals the generation rate. Find the density of photogenerated carriers (the excess carrier density) in steady state $\Delta n = \Delta p$.
- iii) Find the Fermi-level splitting $\Delta\mu$.
- iv) Find the shift of the electron quasi-Fermi level ($E_{F_n} - E_F$).

c) Now a region of the material is illuminated that also contains traps with a density $N_t = 3.0 \times 10^{14} \text{ cm}^{-3}$, but with otherwise identical properties to the material analyzed in a) and b).

Assume $B_n = 2.8 \times 10^{-7} \text{ cm}^3 \cdot \text{s}^{-1}$, $B_p = 4.8 \times 10^{-7} \text{ cm}^3 \cdot \text{s}^{-1}$, and $E_t - E_i = 0.241 \text{ eV}$.

- i) Find the capture lifetime for electrons $\tau_{n,\text{SRH}}$ and holes $\tau_{p,\text{SRH}}$.
- ii) Find the carrier densities n_t and p_t when the Fermi level is at the trap level.
- iii) The net recombination rate $U = U_{\text{rad}} + U_{\text{SRH}}$ equals the generation rate in steady state. Estimate the excess carrier density Δn with both recombination mechanisms present.
- iv) Find the shift $E_{F_n} - E_F$ of the electron quasi-Fermi level.

d) Assume the Auger-recombination coefficient for electrons in p-type material is

$$A_n = 1.2 \times 10^{-27} \text{ cm}^6 \cdot \text{s}^{-1}. \text{ Find:}$$

- i) The Auger lifetime for electrons $\tau_{n,\text{Aug}}$.
- ii) The excess carrier density Δn with all three recombination mechanisms present.
- iii) The shift $E_{F_n} - E_F$ of the electron quasi-Fermi level.