Photonics in Semiconductors, Spring 2017

Exercise 8, 23.3.2017

1. Electrons in the CB of a nondegenerate semiconductor

(a) Consider the energy distribution of electrons $n_E(E)$ in the conduction band (CB). Assuming that the density of state $g_{CB}(E) \propto (E - E_c)^{1/2}$ and using Boltzmann statistics $f(E) \approx \exp[-(E - E_F)/k_B T]$, show that the energy distribution of the electrons in the CB can be written as $n_x(x) = Cx^{1/2}\exp(-x)$ where $x = (E - E_c)/k_B T$, is the electron energy in terms of $k_B T$ measured from E_C and C is a constant at a given temperature (independent of E).
(b) Setting arbitrarily $C = 1$, plot $n(x)$ vs. x. Where is the maximum and what is the FWHM of the curve?
(c) Show that the average electron energy in the CB is $3/2 k_B T$, by using numerical integration.
(d) Show that the maximum in the energy distribution is at $x = 1/2$ or at $E_{max} = 1/2 k_B T$.

2. Extrinsic n-Si

A Si crystal has been doped n-type with 1×10^{17} cm^{-3} phosphorus (P) donors. The electron drift mobility μ_e depends on the total concentration of ionized dopants N_{dopant}, as it is described in Table 1. What is the conductivity of the crystal? Where is the Fermi level with the respect to the intrinsic crystal?

3. Compensation doping in n-type Si

An n-type Si sample has been doped with 10^{16} phosphorus (P) atoms per cm^{-3}.
(a) What are the electron and hole concentrations? (b) Calculate the room temperature conductivity of the sample. (c) Where is the Fermi level with respect to E_{Fi}? (d) If we now dope the crystal with 10^{17} boron acceptors per cm^{-3}, what will be the electron and hole concentrations? (e) Where is the Fermi level with respect to E_{Fi}?

4. Si pn junction

Consider a long pn junction diode with an acceptor doping, N_a, of 1×10^{18} cm^{-3} on the p-side and donor concentration of N_d on the n-side. The diode is forward biased with a voltage of 0.6 V across it. The diode cross-sectional area is 1 mm^2. The minority carrier recombination time, τ, depends on the dopant concentration, N_{dopant} (cm^{-3}), through the following approximate empirical relation $\tau \approx (5 \times 10^{-7}) / (1 + 2 \times 10^{-17} N_{dopant})$ in seconds
(a) Suppose that $N_d = 1 \times 10^{15}$ cm^{-3}. Then the depletion layer extends essentially into the n-side and we have to consider minority carrier recombination time, τ_h, in this region. Calculate the diffusion and recombination contributions to the total diode current with $N_a = 1 \times 10^{18}$ cm^{-3} What is your conclusion?
(b) Suppose that $N_d = N_a$. Then W extends equally to both sides and, further, $\tau_e = \tau_h$. Calculate the diffusion and recombination contributions to the diode current given $N_a = N_d = 1 \times 10^{18}$ cm^{-3} What is your conclusion?

Dopant concentration (cm^{-3})	0	10^{14}	10^{15}	10^{16}	10^{17}	10^{18}
GaAs, μ_e (cm^2 V^{-1} s^{-1})	8500		8000	7000	5000	2400
GaAs, μ_h (cm^2 V^{-1} s^{-1})	400		380	310	250	160
Si, μ_e (cm^2 V^{-1} s^{-1})	1450	1420	1370	1200	730	280
Si, μ_h (cm^2 V^{-1} s^{-1})	490	485	478	444	328	157

Table 1