Photonics in Semiconductors, Spring 2017

Exercise 9, 20.4.2017

1. Si pn-junction

An abrupt Si pn-junction has $N_a = 10^{18} cm^{-3}$ on one side and $N_d = 5 \times 10^{15} cm^{-3}$ on the other side.
a) Calculate the Fermi level positions at room temperature in the p and n regions.
b) Draw an equilibrium energy band diagram for the junction and determine the contact potential V_0 from the diagram.
c) Compare the result with the potential calculated from $V_0 = \frac{k_B T}{q} \frac{N_a N_d}{n_i^2}$.

2. Si pn-junction bias

An abrupt Si pn-junction ($A = 10^{-4} cm^{-2}$) has the following properties at 300 K.

p	n
$N_a = 10^{17} cm^{-3}$	$N_d = 10^{15} cm^{-3}$
$\tau_n = 0.1\ \mu s$	$\tau_p = 10\ \mu s$
$\mu_p = 200\ cm^2 V^{-1} s^{-1}$	$\mu_n = 1300\ cm^2 V^{-1} s^{-1}$
$\mu_n = 700$	$\mu_p = 4500$

Calculate the current over the junction when it is forward (0.5 V) or reverse (-0.5 V) biased.

3. Electrons in GaAs

Given that the electron effective mass m_e^* for the GaAs is $0.067 m_e$, calculate the thermal velocity of the electrons in the CB of a nondegenerately doped GaAs at room temperature (300 K). If μ_e is the drift mobility of the electrons and τ_e the mean free time between electron scattering events (between electrons and lattice vibrations) and if $\mu_e = e\tau_e / m_e^*$, calculate τ_e, given $\mu_e = 8500\ cm^2 V^{-1} s^{-1}$. Calculate the drift velocity $v_d = \mu_e E$ of the CB electrons in an applied field E of $10^5 V\ m^{-1}$. What is your conclusion?

4. LED output spectrum

The typical width of LED output spectrum in units of energy is $\sim 3k_B T$. Show that the linewidth $\Delta\lambda$ is approximately:

$$\Delta\lambda \approx \lambda^2 \frac{3k_B T}{hc}$$

5. LED output spectrum vs. T

The bandgap of a GaAs LED is 1.42 eV at 300K. The bandgap energy decreases with temperature as $dE_g/dT \approx -4.5 \times 10^{-4} eV\, K^{-1}$. Compute the change in the emitted wavelength, if the temperature changes $10°C$.

6. LED linewidth

Suppose, that the width of the output spectrum is given by $\Delta E_{ph} = m k_B T$, where m is a numerical constant.
a) Compute $\Delta\lambda$ as a function of m.
b) The table below shows peak wavelengths and linewidths for various LED junction materials. Plot the data in the table and compute m.

λ / nm	650	810	820	890	950	1150	1270	1500
$\Delta\lambda_{1/2}$ / nm	22	36	40	50	55	90	110	150
Material	AlGaAs	AlGaAs	AlGaAs	GaAs	GaAs	InGaAsP	InGaAsP	InGaAsP

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