ELEC-3140 Semiconductor physics **Mid-term exam 2, Dec 7, 2022**

Write your name, student number, degree programme, course code, and date of the exam on each separate answer paper.

1. Explain briefly and exactly (with a couple of sentences):
   a) Einstein relation,
   b) bound exciton,
   c) Auger recombination,
   d) attenuation (damping) factor,
   e) Stokes shift and
   f) quasi-Fermi level.

2. a) Describe the two main scattering mechanisms of charge carriers moving in a semiconductor. What is their temperature dependence qualitatively? Additionally, give at least one example of other scattering mechanisms. b) Describe what a phonon is. List different kinds of phonons you know. Describe qualitatively how the dispersion curves of different phonons behave.

3. A piece of semiconductor is illuminated continuously so that generation G_L is constant throughout the piece. If there is surface recombination rate of S at one end of the piece, what is the hole concentration as a function of position (away from that surface) at the steady state?

4. Describe a schematic absorption spectrum of a semiconductor: what wavelength areas absorb strongly, what areas are almost transparent, and if there are any weakly absorbing areas. Attach an appropriate absorption process to the different areas of the spectrum. Try to include at least five different absorption processes.

5. a) Describe the formation of depletion region in a pn-junction. List the assumptions made in the abrupt depletion region approximation. Especially discuss how the built-in potential is determined. b) Let us consider an abrupt pn-junction in silicon ($n_i = 1.45\cdot 10^{10}$ cm^{-3}) with doping concentrations of $N_A = 1\cdot 10^{16}$ cm^{-3} and $N_D = 5\cdot 10^{16}$ cm^{-3}. Calculate the built-in voltage of the junction.

Constants and material parameters on the other side!

Constants:

$m_e = 9,1091 \times 10^{-31}$ kg	$m_p = 1,6725 \times 10^{-27}$ kg	$m_n = 1,6748 \times 10^{-27}$ kg	$\mathrm{amu} = 1,6605 \times 10^{-27}$ kg
$e = 1,6021 \times 10^{-19}$ C	$c = 2,9979 \times 10^{8}$ m/s	$\hbar = 1,0545 \times 10^{-34}$ Js	$\mu_B = 9,2732 \times 10^{-24}\,\mathrm{JT}^{-1}$
$\varepsilon_0 = 8,8544 \times 10^{-12}\,\mathrm{C^2N^{-1}m^{-2}}$	$K_e = 1 / 4\pi\varepsilon_0$	$\mu_0 = 1,2566 \times 10^{-6}\,\mathrm{mkgC^{-2}}$	$K_m = \mu_0 / 4\pi$
$\gamma = 6,670 \times 10^{-11}\,\mathrm{Nm^2kg^{-2}}$	$N_A = 6,0225 \times 10^{23}\,\mathrm{mol^{-1}}$	$R = 8,3143\,\mathrm{JK^{-1}mol^{-1}}$	$k = 1,3805 \times 10^{-23}\,\mathrm{JK^{-1}}$

Material parameters:

Table 1. Material parameters for various zincblende-type semiconductors. Lattice constant a (in Å) at room temperature and elastic constants c_{11}, c_{12} and c_{44} (in 10^{12} dyn cm^{-2}; [15]). Valence-band average $E_{v,av}$ and hydrostatic deformation potentials a_v and $a_c(\Gamma)$ as calculated within Van de Walle's model-solid approach (in eV; [5]). Spin-orbit splittings Δ_0, band gaps $E_g(\Gamma)$, $E_g(X)$, $E_g(L)$ (at room temperature) and shear deformation potentials b and d (in eV; [15] and [22], except where indicated).

	a	c_{11}	c_{12}	c_{44}	$E_{v,av}$	Δ_0	$E_g(\Gamma)$	$E_g(X)$	$E_g(L)$	a_v	$a_c(\Gamma)$	b	d
AlP	5.451	1.32	0.63	0.62	−8.09	0.07[a]	3.58	2.45	3.11[a]	3.15	−5.54	−1.6[a]	
AlAs	5.660	1.25	0.53	0.54	−7.49	0.28	2.95	2.16[b]	2.80[a]	2.47	−5.64	−1.5[a]	
AlSb	6.136	0.88	0.43	0.41	−6.66	0.65	2.22	1.61[c]	2.21[c]	1.38	−6.97	−1.4	−4.3
GaP	5.451	1.41	0.62	0.70	−7.40	0.08	2.74	2.26	2.63	1.70	−7.14	−1.5	−4.6
GaAs	5.653	1.18	0.54	0.59	−6.92	0.34	1.42	1.91[b]	1.73[b]	1.16	−7.17	−1.7	−4.6
GaSb	6.096	0.88	0.40	0.43	−6.25	0.82	0.72	1.05[c]	0.76[c]	0.79	−6.85	−2.0	−4.8
InP	5.869	1.02	0.58	0.46	−7.04	0.11	1.35	2.21[d]	2.05[d]	1.27	−5.04	−1.6	−4.2
InAs	6.058	0.83	0.45	0.40	−6.67	0.38	0.36	1.37[d]	1.07[d]	1.00	−5.08	−1.8	−3.6
InSb	6.479	0.66	0.36	0.30	−6.09	0.81	0.17	1.63[d]	0.93[d]	0.36	−6.17	−2.1	−5.0

[a] Present work [16].
[b] [17].
[c] [21].