ELEC-E3140 Semiconductor physics **Full exam, 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) hexagonal close packed struture,
   b) quantum wire,
   c) RIE,
   d) bound exciton,
   e) Auger recombination, and
   f) attenuation (damping) factor.

2. a) Describe how the actual carrier density *n(E)* (as a function of energy) in an intrinsic semiconductor is determined. Which are the two important functions, that affect the carrier density at different energies? And how the total carrier density *n* is derived from that? b) What is done in practice to set the type and conductivity of an extrinsic semiconductor? And how do you then determine the majority and minority carrier concentrations?

3. a) Calculate the packing fraction of body-centered cubic (BCC) crystal structure by assuming that the atoms are hard spheres with a radius of R (all the same size). Then calculate what is the relative volume that the spheres take for themselves, if the nearest neighbour spheres are touching each other. b) Calculate the primitive vectors of the reciprocal lattice for the BCC lattice. What type of lattice is that?

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 ($n_i = 1.45 \cdot 10^{10}\ \mathrm{cm}^{-3}$) with doping concentrations of $N_A = 1 \cdot 10^{16}\ \mathrm{cm}^{-3}$ and $N_D = 5 \cdot 10^{16}\ \mathrm{cm}^{-3}$. 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	amu $= 1,6605 \times 10^{-27}$ kg
$e = 1,6021 \times 10^{-19}$ C	$c = 2,9979 \times 10^{8}$ m/s	$h = 1,0545 \times 10^{-31}$ Js	$\mu_B = 9,2732 \times 10^{-24}$ JT^{-1}
$\varepsilon_0 = 8,8544 \times 10^{-12}$ C^{2}N^{-1}m^{-2}	$K_c = 1 / 4\pi\varepsilon_0$	$\mu_0 = 1,2566 \times 10^{-6}$ mkgC^{-2}	$K_m = \mu_0 / 4\pi$
$\gamma = 6,670 \times 10^{-11}$ Nm^{2}kg^{-2}	$N_A = 6,0225 \times 10^{23}$ mol^{-1}	$R = 8,3143$ JK^{-1}mol^{-1}	$k = 1,3805 \times 10^{-23}$ 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	−6.09	0.07[a]	3.58	2.45	3.11[a]	3.15	−5.54	−1.6[c]	
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[c]	
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	−6.65	−2.0	−4.6
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	−8.0

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