ELEC-3140 Semiconductor physics **Mid-term exam 1, Oct 19, 2022**

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

1. Explain briefly and exactly (with a couple of sentences) the following terms/definitions:
   a) wurtzite lattice structure,
   b) reciprocal lattice,
   c) type II band alignment,
   d) quantum dot,
   e) reactive ion etching,
   f) law of mass action.

2. a) Describe the division of crystal defects by their dimensionality. Give at least one example in each category. (2p.) b) Draw and describe the four band model for semiconductor band structure. What are the four bands, what are their functional shapes and how the curvature of the band has an effect on the semiconductor parameters? If the semiconductor has an indirect band gap, what changes in this model? (4p.)

3. a) Describe shortly the four main epitaxial growth methods. In addition, mention at least two techniques to fabricate semiconductor single crystals and ingots. b) Describe what methods or phenomena can be used to engineer the value of the semiconductor band gap energy and other band properties.

4. a) What are the two close-packing crystal structures? How do they differ from each other and why are they called close-packing structures? b) Pseudomorphic $Ga_{0.55}In_{0.45}P$ layer has been grown epitaxially on a GaAs (100) substrate. Calculate the relative lattice mismatch and the vertical component of the lattice constant of the layer on the GaAs substrate. c) Using the layer material in part b, calculate the energy band gap of the layer (you don't need to take strain effects into account) and use that to find the emission wavelength of the compound. The bowing parameter of GaInP is 0.79.

5. A hypothetical semiconductor has a density of states function approximated by

$$D(E) \propto C \cdot (E - E_C)^{3/2},$$

where C is an arbitrary constant. Calculate the energy at which the electron occupation has its maximum in a non-degenerate (not highly doped) semiconductor crystal. You can use the Maxwell-Boltzmann distribution instead of the Fermi-Dirac distribution.

Constants and material parameters on the other side!

Constants:

$m_e = 9.1091 \times 10^{-31}$ kg $\quad m_p = 1.6725 \times 10^{-27}$ kg $\quad m_n = 1.6748 \times 10^{-27}$ kg $\quad \text{amu} = 1.6605 \times 10^{-27}$ kg

$e = 1.6021 \times 10^{-19}$ C $\quad c = 2.9979 \times 10^{8}$ m/s $\quad \hbar = 1.0545 \times 10^{-34}$ Js $\quad \mu_B = 9.2732 \times 10^{-24}$ JT^{-1}

$\varepsilon_0 = 8.8544 \times 10^{-12}$ C^{2}N^{-1}m^{-2} $\quad K_e = 1/4\pi\varepsilon_0$ $\quad \mu_0 = 1.2566 \times 10^{-6}$ mkgC^{-2} $\quad K_m = \mu_0/4\pi$

$\gamma = 6.670 \times 10^{-11}$ Nm^{2}kg^{-2} $\quad N_A = 6.0225 \times 10^{23}$ mol^{-1} $\quad R = 8.3143$ JK^{-1}mol^{-1} $\quad k = 1.3805 \times 10^{-23}$ 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	−8.09	0.07[a]	3.56	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	−4.8
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	−4.6
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	−5.0

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