**ELEC-3140 Semiconductor physics** **Mid-term exam 1, October 18, 2023**

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

1. Explain briefly, but exactly (with a couple of sentences):
   a) primitive vector,
   b) wurtzite lattice structure,
   c) indirect band gap,
   d) type II band alignment,
   e) interstitial site,
   f) modulation doping.

2. a) Describe how to determine the Miller indices for a crystal plane and for a crystal surface in a cubic crystal. (2p) b) Describe the quantum structures by dimensionality. Also sketch the density of states (DOS) function for each one of them along with the bulk DOS. Place all the DOS functions in the same graph and be careful where you start each of the curves on the energy scale. (4p)

3. a) 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? b) Describe the four main epitaxial growth methods and their operation principles. Compare the advantages and disadvantages of these methods.

4. 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?

5. a) Pseudomorphic $Ga_{0.25}In_{0.75}As_{0.5}P_{0.5}$ layer has been grown epitaxially on an InP substrate. Calculate the relative lattice mismatch of the layer on the InP substrate. b) Calculate the vertical component of the lattice constant of the layer material on the substrate. c) Pseudomorphic $Ga_{0.50}In_{0.50}P$ layer has been grown epitaxially on a GaAs substrate. Calculate the energy band gap of the layer material (no 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.

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  $\text{amu} = 1,6605 \times 10^{-27}$ kg

$e = 1,6021 \times 10^{-19}$ C  $c = 2,9979 \times 10^{8}$ m/s  $\hbar = 1,0545 \times 10^{-34}$ Js  $\mu_B = 9,2732 \times 10^{-24}$ JT$^{-1}$

$\varepsilon_0 = 8,8544 \times 10^{-12}$ C$^2$N$^{-1}$m$^{-2}$  $K_\varepsilon = 1 / 4\pi\varepsilon_0$  $\mu_0 = 1,2566 \times 10^{-6}$ 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 $\Delta_0$, 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).**

| | $a$ | $c_{11}$ | $c_{12}$ | $c_{44}$ | $E_{v,av}$ | $\Delta_0$ | $E_g(\Gamma)$ | $E_g(X)$ | $E_g(L)$ | $a_v$ | $a_c(\Gamma)$ | $b$ | $d$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | −8.0 |

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