S-104.3310 Optoelectronics **Second Exam** **05.09.2007**

1. Give **one** example of:
    a) a method to grow bulk semiconductor substrate
    b) a method to grow epitaxial layers
    c) a method to etch semiconductor materials

2. Explain **briefly** the operation of
    a) a photoconductor
    b) a PN photodiode

3. The rate equations of a laser diode above threshold are given by:

$$\frac{dn}{dt} = \frac{J}{qd} - \frac{n}{\tau_e} - \Omega(n - n_{trans})N_p$$

$$\frac{dN_p}{dt} = \Omega(n - n_{trans})N_p - \frac{N_p}{\tau_p}$$

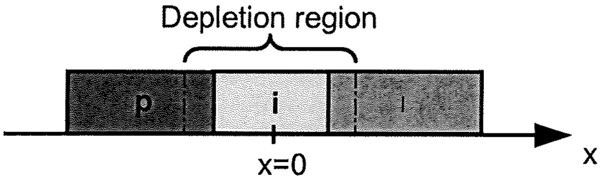
where N_p is the photon density, n the charge carrier density and J the injected current density. The other parameters have their usual meaning.

a) Show that at quasi-equilibrium the carrier concentration n is the same for any value J above threshold.

b) Supposing that the photon density is equal to zero at threshold, give an expression of the carrier concentration as a function of the threshold current density J_{th}.

4. Calculate the conductivity of Mg-doped GaN (acceptor concentration $N_a = 10^{17}\,\text{cm}^{-3}$) supposing that the fraction of ionized acceptors is equal to $\exp(-E_a/kT)$ where E_a is the ionization energy of the acceptor (E_a=160meV) and T the temperature (T= 300K).

5. Plot the density of charge, the electric field and the electrical potential in a PIN junction assuming that the p- and n-sides are equally doped and that the junction is abrupt.



6. We want to realize an infrared laser on a GaSb substrate. The active region is composed of $Ga_{0.78}In_{0.22}Sb$ quantum wells separated by AlGaAsSb barriers.
    a) Calculate x and y so that the alloy $Al_{1-x}Ga_xAs_{1-y}Sb_y$ is lattice matched to GaSb and has a bandgap of 1 eV (Hint: you may use approximations to solve the equations!)
    b) Calculate the width of the quantum wells so that the laser emits at a wavelength of 1690 nm (consider that radiative recombination takes place only between the *e1* and the *hh1* level of the QWs).

1,2,3,5 = 6 points each; 4 = 4 points; 6 = 8 points

Equations

Poisson equation: $\frac{d^2V}{dx^2} = -\frac{dE}{dx} = -\frac{Q(x)}{\varepsilon_0 \varepsilon_r}$

Energy levels in QWs (infinite barrier approximation): $E_{e\lambda} = \frac{\pi^2 \eta^2 \lambda^2}{2m_e^* L_z^2}$ $E_{hh\lambda} = \frac{\pi^2 \eta^2 \lambda^2}{2m_{hh}^* L_z^2}$ (Joules)

Material parameters

	GaSb	InSb	AlSb	GaAs	InAs	AlAs
Lattice constant *a (*Å*)*	6.0959	6.4794	6.1355	5.6533	6.0583	5.6611
Bandgap energy (eV)	0.726	0.174	2.3	1.423	0.354	3.003
m_{hh}/m_0	0.23	0.26	0.29	0.35	0.39	0.44
m_e/m_0	0.039	0.0135	0.14	0.067	0.026	0.15

GaN:
Electron mobility: 1000 $cm^2s^{-1}V^{-1}$
Hole mobility: 30 $cm^2s^{-1}V^{-1}$
Intrinsic carrier concentration: $< 1\times10^6$ cm^{-3}
Bandgap at 300K: 3.39 eV

Physical constants

Boltzmann constant: $1.380\,6504 \times 10^{-23}$ J K^{-1}
Planck constant: $6.626\,068\,96 \times 10^{-34}$ J s
Speed of light in vacuum: 299 792 458 m s^{-1}
Elementary charge: $1.602\,176\,487 \times 10^{-19}$ C
Electron mass (m_0): $9.10938188 \times 10^{-31}$ kg