The University Of Sheffield.

Data Provided: You may need to use the following physical constants:

Charge on electron: -1.602×10^{-19} C	Boltzmann's constant: $k = 1.381\times10^{-23}$ JK^{-1}
Free electron rest mass: $m_0 = 9.110\times10^{-31}$ kg	Melting point of ice: 0^{o}C = 273.2 K
Speed of light in vacuum $c = 2.998\times10^{8}$ m s^{-1}	Permittivity of free space: $\varepsilon_0 = 8.854\times10^{-12}\,\text{Fm}^{-1}$
Planck's constant: $h = 6.626\times10^{-34}$ Js	Permeability of free space: $\mu_0 = 4\pi\times10^{-7}\,\text{Hm}^{-1}$

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2009-2010 (2 hours)

Semiconductors for Electronics and Devices 2

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a** Starting from the charge neutrality equation and assuming that the acceptor and donor doping densities in a semiconductor are known, derive expressions from which the majority and minority carrier densities can be estimated for ,

(i) an n-type extrinsic doped structure, and
(ii) a compensated near-intrinsic doped structure
(State clearly all assumptions that are made.)

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b. An intrinsic layer of silicon is initially doped with acceptors such that its conductivity increases 10,000 times. It is then further doped with donors and it is now found to be p-type with a resistivity of 7.61×10^{2} Ω-m.

Given that the resistivity of intrinsic silicon at room temperature is 5×10^{3} Ω-m, and that μ_e=0.12m^2 V^{-1} s^{-1}, μ_h=0.05m^2 V^{-1} s^{-1} and E_g=1.1eV, estimate the final donor and acceptor concentrations in the compensated semiconductor. (Note: all the symbols have their usual meaning and not all the information given may be needed).

10

c. How could the original intrinsic resistivity be achieved and how practical is this in reality?

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2. **a.** Sketch how the light output varies with injected current in (i) a light emitting diode (LED), and (ii) a laser, marking clearly the different regions of operation. ***4***

b. Sketch the shape of the emitted light intensity as a function of wavelength for the laser when (i) the injected current is below the threshold current density, and (ii) when the injected current density is above the threshold current density. If the device is designed to operate at a wavelength of 1300nm, make clear the approximate scale of the wavelength axis in the sketches. ***4***

c. A quantum well laser structure made using InGaAs (Eg=0.75eV) and InP (Eg=1.35eV) was found to emit light at 1550nm when the well width was 14.5nm. Use this information to estimate the well width we would require with these materials for light emission at 1300nm.

Assume that in a quantum well with infinitely high and wide barriers the bound energy levels are given by $E_n = n^2h^2/8mL^2$, where the terms have their usual meaning. ***10***

d. What are the maximum and minimum wavelengths you can achieve with these materials, briefly justifying your answer. ***2***

3. **a.** Draw and annotate the cross-sectional diagram of an induced channel enhancement mode metal-oxide-silicon-transistor (MOST). Identify all the significant parts of the device and make clear the polarities of the applied voltages necessary for channel conduction. ***4***

b. The unsaturated drain characteristic of such a device can be represented by:

$$I_d = \frac{\mu_e C_g}{l^2}\left[V_{gs} - V_T - \frac{V_{ds}}{2}\right]V_{ds}$$, where the symbols have their usual meaning

The device is biased at a fixed gate-source voltage, $V_{gs.}$ As the drain-source voltage, V_{ds}, is increased beyond a certain value, the drain current saturates.

i) Using this fact and the expression above, determine the value of this saturation current and the critical value of V_{ds} .

ii) What is the transconductance of the device when operated in this saturated region?

Give two possible reasons why the actual transconductance of a device might be lower than the value calculated. ***10***

c. A MOST operating in the saturated region has its drain and gate terminals connected directly to each other. No drain current flows in this device until V_{ds} exceeds 2.5V. When V_{ds} is increased to 4V the drain current is found to be 1mA. By first determining V_T and $\mu_e C_g/l^2$, calculate what the drain current will be when V_{ds} is increased to 5V. ***6***

4. **a.** In a certain semiconductor, the electron energy in the conduction band is given, at all points in the first Brillouin zone by:

$$E = E_g + Ak^2 - Bk^4$$

where k is the electron wavenumber, and A and B are constants. The effective mass $m_e{}^*$ of electrons at the zone centre is found to be $0.12m_o$:

i) What is the value of the constant A?

ii) What is the wavenumber at the edge of the first Brillouin zone, (i.e. where the electron velocity is zero) expressed in terms of the constants?

iii) Is this a direct or indirect band-gap semiconductor? Justify your answer.

(Hint: Remember that $p = \hbar k$ and $v_g = dE/dp$) ***10***

b. State the Heisenberg Uncertainty Principle in terms of the momentum and position of a particle, explaining what it means. ***4***

c. A proton with mass 1.67 x 10^{-27} kg, is accelerated to a velocity about a tenth of the speed of light. If the velocity measurement has an uncertainly of 1%, how accurately can you measure the position of the proton. ***6***

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