The University Of Sheffield.

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

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

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2007-2008 (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.** A certain silicon planar diffused bipolar transistor is fabricated using a silicon wafer doped with donors at an atomic concentration of 5 x 10^{20} m^{-3}. The first diffusion is of acceptors, giving an atomic dopant concentration of 1 x 10^{21} m^{-3}, the second diffusion is of donors, giving an atomic dopant concentration of 2 x 10^{21} m^{-3}.

Sketch and label clearly the cross section of this transistor, identifying the emitter, collector and base regions. Is this an *n-p-n* or *p-n-p* transistor? ***4***

b. Calculate the equilibrium majority carrier concentrations in each of the three active regions of the device at room temperature when the intrinsic carrier concentration n_i, is 1.3 x 10^{16} m^{-3}, justifying any assumptions you may make. (You may assume that all dopants are ionised at room temperature.) ***6***

c. The donor level is 2meV below the conduction band and the acceptor level is 10meV above the valence band. Calculate the equilibrium majority carrier concentrations in each of the three active regions of the device at a temperature of 500K where n_i =2 x 10^{20} m^{-3}. Comment on the results. ***7***

d. Comment on how this device would behave when placed in liquid nitrogen refrigerant at 77K? ***3***

2. **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. Show that this device operates in the unsaturated region of its output *I-V* characteristics provided that $V_{gs} - V_{ds} - V_T \geq 0$, where V_{gs} is the gate-source voltage, V_{ds} is the drain-source voltage, and V_T is the threshold voltage. You may assume that 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. ***4***

c. Show that:

$$I_d = \frac{\mu_e C_g}{2l^2}\left[V_{gs} - V_T\right]^2$$, when $V_{gs} - V_{ds} - V_T < 0$. ***4***

d. The source terminal of such a device is grounded and the drain terminal is connected directly to the gate terminal. In this situation, how does I_d depend on V_{ds} ? ***4***

e. Such a device connected as in part (d) of this question has $\mu_e C_g / l^2 = 6 \times 10^{-4}$ A V^{-2} and $V_T = 3.0$V. Find I_d when $V_{ds} = 2$V, 3V and 4V, commenting on your results and describing a possible use for this device. ***4***

3. **a.** Show that the wavelength, λ, and energy *E*, of a photon are related by:

$$\lambda = L/E,$$

and find the value of *L* if *E* is the photon energy in electron-volts. ***3***

b. Write down the de Broglie wave relation, defining carefully the symbols which you use. ***3***

c. Light from a 10mW, 633nm wavelength He-Ne laser falls on a metal electrode in a vacuum tube. The charge that is emitted travels to a second identical electrode and flows around an external circuit back to the first electrode. This current flow can be stopped by applying an external voltage of 0.5V between the electrodes.

(i) Draw a diagram of the experimental set-up, paying particular attention to the polarity of the external voltage and the direction of current flow.

(ii) Define what is meant by the work function energy of a material.

(iii) Calculate the apparent work function energy of the electrodes, expressing your final value in electron-volts.

(iv) Explain *briefly* what this experiment tells us about the quantum nature of light.

(v) Estimate the quantum efficiency if the full power of the laser causes a maximum current of 2mA to flow.

(vi) What current would flow if for the same optical power the wavelength of the laser was doubled? ***14***

4. **a.** Sketch how the light output varies with injected current in (i) a light emitting diode (LED), and (ii) a laser, making clearly the different regions of operation. ***3***

b. Sketch the shape of the emitted light intensity as a function of wavelength for the LED and the laser under normal operating conditions. If the devices emit light at 820nm, make clear the approximate scale of the wavelength axis in the sketches. ***3***

c. You wish to make a quantum well LED that is capable of emitting light at a centre wavelength of 1.55μm. You can choose between the following pairs of materials, with their band-gap energies given in parentheses:

i) GaAs (1.42eV) and AlGaAs (1.8eV)

ii) InGaAs (0.75eV) and InAlAs (1.5eV)

iii) GaN (3.4eV) and InGaN (2.48)

Which material pair would you choose and why? ***2***

d. Estimate the width of the quantum well that would enable you to reach this wavelength of 1.55μm using the material system chosen in part (c) above.

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, and that the electron and hole effective masses in the quantum well are $0.04m_0$ and $0.45m_0$, respectively. ***8***

e. What are the factors that would affect the shortest wavelength that could be achieved by a quantum well LED such as this? ***4***

JPRD / CHT