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: $\varepsilon_0 = 8.854\times10^{-12}\,\mathrm{Fm}^{-1}$
Planck's constant: $h = 6.626\times10^{-34}$ Js	Permeability of free space: $\mu_0 = 4\pi\times10^{-7}\,\mathrm{Hm}^{-1}$

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2011-12 (2.0 hours)

EEE207 Semiconductors for Electronics and Devices

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 condition and assuming that the acceptor and donor doping densities in a semiconductor are known, derive expressions from which the equilibrium majority and minority carrier concentrations can be estimated for,

i) a p-type extrinsic doped semiconductor, and

ii) a compensated near-intrinsic doped structure.

(State any assumptions that you make.) **(4)**

b. A certain silicon bipolar junction transistor is fabricated using a silicon wafer doped with acceptors at an atomic concentration of 5×10^{20} m^{-3}. To make the transistor, you need to make two further diffusions. You can choose between diffusing acceptors or donors for these two diffusions and you can choose the atomic dopant concentration to be 1×10^{20} m^{-3}, 1×10^{21} m^{-3} or 2×10^{21} m^{-3}. Specify which dopant type and doping level you would diffuse first and the dopant type and doping level you would diffuse second to make the transistor. Give a brief explanation for your choice.

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? **(6)**

1. **c.** i) Calculate the equilibrium majority carrier concentrations in each of the three active regions of the device in part (b) at room temperature when the intrinsic carrier concentration n_i, is 1.3×10^{16} m^{-3}, justifying any assumptions you may make.

ii) Determine also the minority carrier concentration in the emitter.

(You may assume that all dopants are ionised at room temperature.) **(7)**

d. i) As the ambient operating temperature of the device increases, the performance of the device degrades. Give two reasons why this might happen.

ii) Suggest modifications at the fabrication stage that would increase the maximum operating temperature of this device. **(3)**

2. **a.** i) Explain with the aid of an energy band diagram how a semiconductor p-n junction laser works. Show clearly the fermi level position under lasing conditions.

ii) Draw a typical light output versus junction current characteristic and describe the different regions. **(6)**

b. The active region of a red laser diode comprises two semiconductor materials; InGaP and InAlP. If the gap energy of the InGaP and InAlP is 1.8 eV and 2.4 eV respectively, calculate the range of emission wavelengths we could theoretically obtain from such a material combination if they were used to form quantum wells and barriers. Make clear which material would be used for the quantum well. **(4)**

c. i) If we wanted the laser to emit at 650 nm, estimate the width of quantum well, L, that would be required to obtain this wavelength using the material system in the previous section.

ii) If there is an error of ±0.5 nm in the width of the quantum wells, explain qualitatively how this error will affect the accuracy of the wavelength that could be achieved as the nominal quantum well dimension reduces.

(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 both semiconductor materials are $0.09m_o$ and $0.7m_o$ respectively.) **(8)**

d. What would limit the operation of such a quantum well laser at the shorter wavelengths? **(2)**

3. **a.** Draw and annotate the cross-sectional diagram of a metal-oxide-silicon-transistor (MOST). **(3)**

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

$$I_d = \frac{\mu_e C_g}{l^2}\left[V_g - V_T - \frac{V_d}{2}\right]V_d$$

where the symbols have their usual meaning.

i) Under what voltage conditions does saturation of the drain current happen?

ii) What is the transconductance in the saturation region?

iii) Show that the transconductance is simply given by twice the ratio of the saturated drain current to drain voltage **(5)**

c. A particular n-channel MOST is fabricated in silicon, which has a relative permittivity of 11.8 and an electron mobility of 0.13 $m^2V^{-1}s^{-1}$, with a gate aspect ratio (length/width) of 0.1.

The device is operated as an amplifier in common-source mode, with a DC supply voltage (V_{dd}) of 100 V, a standing drain current of 30 mA and a resistive load. Find the resistance of a load resistor that would ensure a stage voltage gain of 30. **(7)**

d. The gate capacitance, C_g, is measured to be 1 pF. Estimate the thickness of the gate oxide in this MOST. **(5)**

4. **a.** Starting from the description of an electron travelling in a vacuum, obtain an expression for the effective mass of an electron in a semiconductor, in terms of its energy and momentum. **(4)**

b. i) InGaP has a direct band gap energy of 1.80 eV and at the centre of the first Brillouin zone, the conduction band can be assumed to be parabolic. Assuming that the effective mass of an electron at the zone centre is $0.09m_o$, give an expression for how the electron energy varies with the electron wavenumber, k. (Remember that momentum, $p=\hbar k$)

ii) The hole effective mass is approximately 8 times that of the electron electron mass. Sketch the conduction and valence band structures around the Brillouin zone centre. Show how the masses affect the shape of the band structure and mark clearly the band gap.

iii) What happens to the electron effective mass in reality as you approach the Brillouin zone edge, and what effect does this have on the conduction band energy? **(6)**

c. State and describe what is meant by the Heisenberg Uncertainty Principle. **(4)**

d. Write down the de Broglie wave relation, defining carefully the symbols which you use.

An electron microscope with an accelerating potential for electrons of 50 V is used to inspect a CMOS device. By calculating the resolution with this potential, determine the minimum feature size you can measure. **(6)**

JPRD/CHT