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

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2006-2007 (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 condition and assuming that the acceptor and donor doping densities in a semiconductor are known, derive expressions for the majority and minority carrier densities for the following cases:

(i) an n-type extrinsically doped structure, and

(ii) a compensated near-intrinsically doped structure

(State clearly all assumptions made.) **(6)**

b. An intrinsic layer of silicon was initially doped with donors, causing the resistance to change by a factor of 10,000 from its original value. The layer was then further doped with acceptors such that it was finally found to be n-type with a resistivity of 7.61×10^{2} Ωm.

Given that the resistivity of intrinsic silicon at room temperature is 5×10^{3} Ωm, 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 **(10)** needed).

c. What would we have to do to regain the original intrinsic resistivity and comment of the practicality of this in reality? **(4)**

2. a. Draw a schematic cross-section of a semiconductor p-n junction light emitting diode (LED), identifying the various regions of the device.

Show how the conduction band, valence band and Fermi level are positioned in the junction when it is biased such that light is emitted.

Draw a typical light output versus junction current characteristic and comment on how this differs from that of a laser. **(8)**

b. A short range telecommunications LED comprises GaAs quantum wells and AlGaAs barriers. The gap energy of the GaAs and AlGaAs is 1.42eV and 1.85eV respectively. What is the range of wavelengths we could theoretically obtain from such a material combination? **(3)**

c. Such a telecommunication LED is required to operate at a wavelength of 850nm. Estimate the width of the quantum well, *L*, that would be required to achieve this.

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 GaAs are $0.063m_0$ and $0.48m_0$, respectively . **(6)**

d. What in reality limits the operation of such a quantum well LED at the shorter wavelengths? **(3)**

3. a. Draw and annotate a cross-sectional diagram of a metal-oxide-silicon-transistor (MOST). **(4)**

b. The unsaturated drain characteristic of such a MOST is given 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.

Hence derive an expression for the transconductance (g_m) of a MOST in terms of the drain voltage and saturated drain current. **(5)**

c. A particular n-channel MOST is fabricated in silicon, which has a relative permittivity of 11.8 and an electron mobility of $0.13m^2V^{-1}s^{-1}$, 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 100V, a standing drain current of 30mA and a resistive load. Find the resistance of a load resistor that would ensure a stage voltage gain of 30. **(7)**

d. When the transconductance is 9.6mS and the drain voltage is 6.25V, the gate capacitance, C_g, is measured to be 1pF. Estimate the thickness of the gate oxide in this MOST. **(4)**

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

$$\lambda = L/E$$

and find the value of L, stating it using units suitable for energies expressed in electron-volts. **(4)**

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

Use the de Broglie relationship to determine the minimum size an accelerating potential of 36 volts is theoretically capable of resolving in an electron microscope. (State any assumptions you make.) **(6)**

c. 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, the value of A is 1 x 10^{-38}Jm^{-2}, and B is a negative constant. Evaluate the effective mass m_e* of electrons at:

i) the zone centre, i.e. where $k=0$

ii) the edge of the first Brillouin zone, i.e. where the electron velocity is zero

(Hint: Remember that $p=\hbar k$) **(10)**

JPRD / CHT