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°C = 273.2 K
Permittivity of free space:	$\varepsilon_0 = 8.854\times10^{-12}\,\mathrm{Fm}^{-1}$
Permeability of free space:	$\mu_0 = 4\pi\times10^{-7}\,\mathrm{Hm}^{-1}$

The University of Sheffield

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2004-2005 (2 hours)

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.** Describe briefly the concept of compensation doping of a semiconductor. Starting with the charge neutrality condition or otherwise, derive expressions for the carrier densities in such a semiconductor in terms of the doping densities and intrinsic carrier density. 5

b. A uniformly doped silicon semiconductor is found to have an electron density of $10^{12}\mathrm{m}^{-3}$ and an acceptor density, N_a, of $10^{21}\mathrm{m}^{-3}$. Assuming that the intrinsic carrier density at room temperature is $2 \times 10^{16}\mathrm{m}^{-3}$, and that $\mu_e=0.13\mathrm{m}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$, $\mu_h=0.05\mathrm{m}^2\,\mathrm{V}^{-1}\,\mathrm{s}^{-1}$, find:

i) the hole concentration in the semiconductor

ii) the donor concentration

iii) the conductivity of the semiconductor 6

c. Another silicon semiconductor has a donor density, N_d, of $5.02 \times 10^{19}\mathrm{m}^{-3}$ and an acceptor density, N_a, of $5.01 \times 10^{19}\mathrm{m}^{-3}$. Assuming the same intrinsic carrier density and mobilities as in (b), find:

i) the majority carrier density

ii) the minority carrier density

iii) the conductivity of the sample 6

d. Comment briefly on the main differences between the two doped silicon semiconductors. 3

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

Draw a typical light output versus junction current characteristic and describe the different regions. 8

b. The active region of a telecommunications laser comprises InGaAs quantum wells and InP barriers. If the gap energy of the InGaAs and InP is 0.75eV and 1.35eV respectively, calculate the maximum and minimum wavelengths we could theoretically obtain from such a material combination. 4

c. Estimate the width of quantum well, L, required to obtain a laser capable of operating at the 1.55μm attenuation minimum in optical fibre based systems.

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 InGaAs are $0.04m_o$ and $0.45m_o$ respectively. 5

d. What in reality limits the operation of such a quantum well laser at the shorter wavelengths? 3

3. a. Draw the band diagram for an ideal metal- n-type semiconductor junction in equilibrium for the cases when:

i) the junction rectifies

ii) the junction is ohmic

Make clear the relative work functions for the metal and semiconductor in both cases, the position of the fermi level and the magnitude of any potential barrier. 6

b. Explain what happens when the junctions above are forward and reverse biased. Make clear the direction of majority and minority current flow. 6

c. An n-type semiconductor with work function 1eV is sandwiched between two metal contacts, M1 with work function 2eV, and M2 with work function 0.5eV. The resistance of the bulk semiconductor between the contacts is 1Ω. *(Assume that the current in ideal metal-semiconductor Schottky junction is given by: $I=I_0[exp(eV/kT)-1]$, where the terms have their usual meanings.)*

When a DC potential of +1V is applied across the two metal contacts, a large current of 350mA flows. When the polarity of the potential is reversed, the current that flows is reduced significantly. Calculate the magnitude of the current in this case. 8

4. **a.** State and describe what is meant by the Heisenberg Uncertainty Principle. **4**

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

Determine the accelerating potential electrons have to undergo to enable them to resolve 0.2nm scale features. **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) at the zone centre, *i.e.* where $k=0$

ii) at the edge of the first Brillouin zone, *i.e.* where the electron velocity is zero **10**

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END OF PAPER