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 2008-2009 (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 silicon photodiode is fabricated using a silicon wafer that is doped with donors at an atomic concentration of 1 x 10^{21}m^{-3} and a diffusion of acceptors that gives an atomic dopant concentration of 5 x 10^{22}m^{-3}.

Show the band structure of this photodiode when it is in the dark with no applied bias. Mark clearly the *p* and *n* regions, the band-gap, the Fermi-level and the built-in (or contact) potential. ***4***

b. Starting from the charge neutrality condition or otherwise, calculate the equilibrium majority and minority carrier concentrations in both sides of the active region 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.) ***4***

c. This photodiode is now required to operate at a temperature of 500K, where n_i =1.3 x 10^{20}m^{-3}.

(i) Will the device be able to operate as a photodiode at this temperature? Explain clearly how you came to your conclusion.

(ii) Estimate the maximum operating temperature for this photodiode.

[Assume that E_g=1.1eV and is independent of temperature, and that

$n_i \propto T^{3/2} exp(-E_g/2kT)$, where the terms have their usual meaning]. ***10***

d. Suggest modifications at the fabrication stage that would increase the maximum operating temperature of this device. ***2***

2. **a.** Sketch the schematic band diagram of rectifying metal-semiconductor junctions in equilibrium when the semiconductor is (i) n-type and (ii) p-type, identifying clearly the built-in (contact) potential. State clearly the relative work functions for the metal and semiconductor in both cases. ***4***

b. Show how the band diagram changes under forward bias for both these junctions in part (a) and the direction of majority current flow. ***4***

c. An n-type semiconductor with a work function of 1eV is sandwiched between two metal contacts, M1 with work function of 0.7eV and M2 with a work function of 0.5eV. When a voltage of +1V is applied to M1 with M2 held at 0V, a current of 100mA flows. M1 is now replaced with another metal contact M3, with a work function of 2eV. When a voltage of +5V is applied to M2 and M3 is held at 0V, a current of 1μA is found to flow.

(i) What is the resistance of the n-type semiconductor?

(ii) Estimate what current would flow when +1V is applied to M3 and M2 is held at 0V? (Assume that the metal resistance and metal-semiconductor contact resistance is negligible). ***10***

d. Give one advantage and one disadvantage of schottky diodes over p-n junction diodes. ***2***

3. **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. InGaAs has a direct band gap energy of 0.75eV 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 $0.045m_0$, give an expression for how the electron energy varies with the electron wavenumber, k. (Remember that momentum, $p=\hbar k$) ***7***

c. Light with a power of 1mW and a wavelength of 850nm falls on a Cs:GaAs electrode, with a work function of 1eV, in a vacuum tube. The charge that is emitted travels to a second electrode and flows around an external circuit back to the first electrode. This current flow can be stopped by applying an external voltage between the electrodes.

(i) What is the value of this external voltage?

(ii) What is the longest wavelength of light that would result in an emission of electrons from the electrode when the external voltage is zero?

(iii) The 850nm light in (i) is now doubled in optical intensity. Explain how the external voltage required to stop the current varies.

(iv) The wavelength of light used in (i) is now halved to 425nm with the power still at 1mW. What happens to the external stopping voltage? ***6***

d. The momentum of a classical object is given simply by the product of its velocity and mass. Photons have no mass, yet can have momentum. Give an expression for how the wavelength of a photon determines its momentum. ***3***

4. **a.** Semiconductor based photodiodes and photoconductors are capable of detecting light. Sketch the current voltage characteristics of both these types of detectors: (i) in the dark , and (ii) under illumination, and thereby explain briefly how they operate. ***6***

b. A certain GaAs photodiode has a reverse dark current of 10nA. What is the minimum optical power this photodiode can detect with light of wavelength (i) 633nm, (ii) 850nm and (iii) 1300nm. The band-gap of GaAs is 1.42eV. (Assume that the device is very thick and that the internal quantum efficiency is 100%. The minimum optical power can be assumed to be when the photocurrent exceeds the dark current). ***8***

c. The GaAs photodiode in part (b) is replaced by a structure where the GaAs is 5nm thick and is between barriers of AlGaAs with a band-gap energy of 2.2eV. How might this affect its ability to detect the three wavelengths given in part (b)?

(Assume that the quantum well has infinitely high barriers, and that 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 $0.063m_0$ and $0.48m_0$, respectively.) ***4***

d. If the thickness of the GaAs in part (c) could be varied, what would be the longest and shortest wavelengths that such a structure could detect and why? ***2***

JPRD / CHT