Data Provided: None

EEE105

The University of Sheffield

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2003-2004 (2 hours)

Electronic 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.**

You may require the following:

Charge on the electron,	$q=1.6x10^{-19}$ C
Permittivity of free space,	$\varepsilon_0 = 8.85x10^{-12}$ F/m
Boltzmann constant,	$k=1.38x10^{-23}$ J/K
Planck's constant,	$h=6.6x10^{-34}$ Js
Speed of light in vacuum,	$c=3x10^{8}$ m/s

Poisson's Equation $\frac{d^2V}{dx^2} = -\frac{r}{e}$

$$E = -\frac{dV}{dx}$$

$$d_j = \left(2e_0 e_r V_j / qN_d\right)^{0.5}$$

$$J = qD\frac{dn}{dx}$$

$$J_0 = \frac{qL_e n_p}{t_e} + \frac{qL_h p_n}{t_h}$$

$$J = J_0\left[\exp\left(\frac{qV}{kT}\right) - 1\right]$$

$$D = \frac{kT}{q} m$$

$$ß = \frac{a_B}{1 - a_B}$$

$$a_B = g_E a$$

Energy of a photon =hc/λ

$$\P p = \P p_0 \exp\left(\frac{-x}{L_h}\right)$$

$$L = \sqrt{Dt}$$

$$R = \ ?\, {}^{L}\!/\!_{A}$$

For silicon(Si): relative permittivity ε_r =12
built-in voltage =0.7 V
electron mobility=0.07 m^2/Vs
hole mobility=0.045m^2/Vs

	Ge	Si	GaAs	InSb
n_i (m^{-3})	2.4×10^{19}	1.45×10^{16}	1.8×10^{12}	2.1×10^{22}

1a) For an LED explain in detail how electricity can conduct easily in only one direction, detailing what is meant by the terms electron, hole and saturation currents in your answer. Explain how light is produced in such an LED, and what determines the emission wavelength. **(10)**

b) Using the diode equation, estimate the voltage drop across the junction region of an LED operating at 20 mA if the saturation current is 10^{-12} A. **(3)**

c) The LED in part (b) has a cross-sectional area of 300 μm x 300 μm. The n-type material is 100 μm thick and the p-type layer is 0.5 μm thick. The n- and p-doping concentrations are 1×10^{24} m^{-3} and 1×10^{22} m^{-3}, respectively; and $\mu_e = 0.5\ m^2V^{-1}s^{-1}$ and $\mu_h = 0.03\ m^2V^{-1}s^{-1}$.
Calculate the total voltage drop across the device. **(7)**

2a) Using sketches where appropriate, explain how a MOSFET can be designed to operate in

i) enhancement mode
ii) depletion mode

making clear the differences between the devices and their mode of operation. **(10)**

b) An n-channel depletion mode MOSFET is to be used in a simple amplifier for an a.c. input signal with a peak-to-peak value of 40 mV. The transconductance of the device is 80 mS. Devise a circuit to give an output across the transistor with a voltage gain of 100 using a 12 V power supply. Show clearly your final circuit with component values in a diagram. **(10)**

3a) Explain what is meant by electron-hole pair generation and recombination in a semiconductor and give an equation for the recombination rate in an undoped semiconductor, qualitatively justifying it.
Hence, show that the minority carrier concentration in an n-type semiconductor can be given by:

$$p_n = \frac{n_i^{\,2}}{n}$$ **(8)**

b) An n-type doped block of Si has a thin p^+ region created along one end using ion implantation. A contact is attached to the p^+ region and a positive bias applied. The n-type semiconductor is earthed at the opposite end of the block.
Explain what will happen to the concentration of minority carriers in the n-type block as one travels into it from the p^+ end. **(3)**

c) It is proposed to use a layer of n-type Si with a carrier concentration 10^{22} m^{-3} as the base of a transistor, where the emitter carrier concentration is $5x10^{25}$ m^{-3}. If the minority carrier lifetime is 200 ns in the base, what is the maximum thickness the base can be if at least 98% of the holes must reach the collector. **(6)**

d) The base of the transistor is open circuited and light is irradiated on it such that it is absorbed in the base region while retaining normal bias conditions on the emitter and collector contacts. Briefly describe what will happen. **(3)**

4a) Briefly describe what causes the difference in electrical conductivity between metals, semiconductors and insulators **(6)**

b) Explain what semiconductor bands are, and using this concept of semiconductor bands, explain in detail how B and As atoms in Si can change the material's conductivity.
(Note: No marks will be awarded for an explanation that does not use a band description) **(7)**

c) A variable capacitor is fabricated using a reverse biased n^+-p Si junction. Calculate the doping required in order to obtain a maximum capacitance of 1 nF, stating clearly all the assumptions you make, if the device diameter is 800 μm. **(7)**

END OF QUESTION PAPER