Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2008-2009 (2 hours)

Electronic Devices 1

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 electron, q = 1.60x10^{-19}C

Boltzmann constant, k = 1.38x10^{-23} JK^{-1}

Speed of light in vacuum, c = 3.00x10^{8} ms^{-1}

Permittivity of free space, ε_0 = 8.85x10^{-12} Fm^{-1}

Planck's constant, h = 6.63x10^{-34} Js

Mass of electron, m_e = 9.11x10^{-31} kg

$$E = -\frac{dV}{dx} \qquad \frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon} \qquad R = \rho L/A$$

$$J = qD\frac{dn}{dx} \qquad D = \frac{kT}{q}\mu \qquad E_{photon} = \frac{hc}{\lambda}$$

$$J = J_0\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \qquad J_0 = \frac{qL_e n_p}{\tau_e} + \frac{qL_h p_n}{\tau_h} \qquad d_j = \left(2\varepsilon_0\varepsilon_r V_j / qN_d\right)^{0.5}$$

$$\partial p = \partial p_0 \exp\left(\frac{-x}{L_h}\right) \qquad L = \sqrt{D\tau}$$

$$\beta = \frac{\alpha_B}{1-\alpha_B} \qquad \alpha_B = \gamma_E \alpha$$

For silicon:

relative permittivity = 12

electron mobility = 0.12 m^{2}V^{-1}s^{-1}

band gap = 1.12 eV

built-in voltage = 0.7 V

hole mobility = 0.045 m^{2}V^{-1}s^{-1}

intrinsic carrier concentration = 1.45x10^{16} m^{-3}

1. **a.** Briefly explain the reasons for the difference in conductivity between an intrinsic semiconductor and an insulator at room temperature. **(3)**

b. Explain what is meant by doping and how this can modify the conductivity of a semiconducting material. **(4)**

c. As the temperature is increased from room temperature a semiconductor's conductivity may also change. Carefully explain the change in conductivity expected for:

i) An EXTRINSIC semiconductor **(3)**

ii) An INTRINSIC semiconductor **(3)**

d. A resistor in an integrated circuit was fabricated from Al metal. It consists of a strip of the metal that is 100 µm long, 5 µm wide, and 10 nm thick. The resistance of the strip was found to be 97 Ω.

However, the desired resistance is 101 Ω. In order to obtain this a laser was used to remove a 12 µm segment of material to reduce the width in that segment by a controlled amount, as shown in Figure 1 below. For this example calculate the width, *x*, of the material to be removed, in order to obtain the desired resistance.

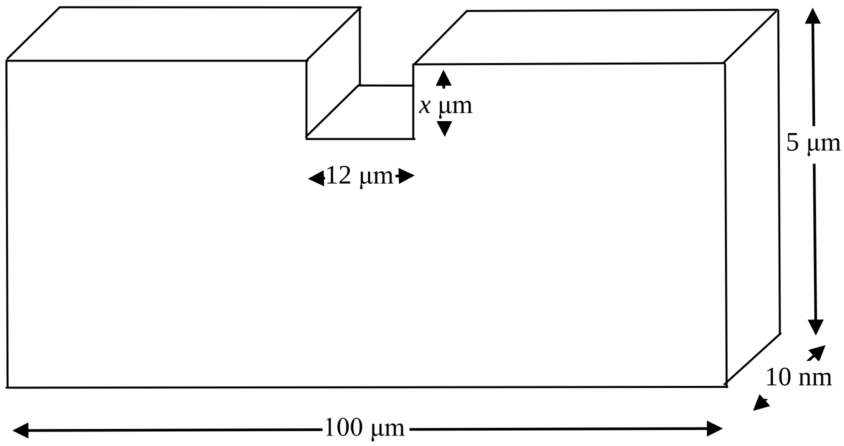

Figure 1

(7)

2. **a.** For a diode describe how a potential barrier forms at the junction between the p- and n-type materials, explaining clearly the formation of the so-called "depletion region". **(5)**

b. **i)** Briefly explain the mechanisms of light detection of a p-n junction used as a photodiode.

ii) Sketch I-V characteristics of the photodiode under dark and illuminated conditions, indicating clearly which is which.

iii) On the diagram, clearly mark the region in which the device could be used as a solar cell. **(7)**

c. A solar-cell is placed in series with a resistive load. Show this schematically as a circuit diagram, indicating clearly the expected direction of current flow. **(2)**

d. The overall efficiency of a solar cell can be described by the fraction of the optical power from the sun hitting the device which is converted to electrical power. The sun is a so-called "black body" source. This means it emits light at essentially all wavelengths from the ultra-violet through to the long wavelength infrared. For a Si photodiode

i) Explain in detail how photons of different wavelengths will have different efficiencies **(4)**

ii) Suggest and briefly explain at what wavelength, or wavelength region, the silicon based device will have the highest efficiency in conversion of optical power to electrical power. **(2)**

3. **a.** For a p-n junction in forward bias:

i) Explain what is meant by the term "electron current". **(2)**

ii) Starting from the diode equation show that the ratio of electron and hole currents in the junction can be given by $\frac{J_e}{J_h} = \frac{\sigma_n}{\sigma_p}\frac{L_h}{L_e}$ **(6)**

iii) By obtaining a relationship for the diffusion lengths in terms of the material conductivities, show that the ratio of electron and hole currents in the junction can be given by the square root of the ratio of the p-type and n-type conductivities. **(5)**

b. For a n-p-n bipolar junction transistor briefly explain the term "Base Transport Factor" and how it can be optimised. **(2)**

c. A n-p-n silicon bipolar junction transistor is doped as follows:

Emitter: $6\text{x}10^{25}$ m^{-3}, Base: $3\text{x}10^{23}$ m^{-3}, Collector: $7\text{x}10^{22}$ m^{-3}

The width of the base is 0.8 μm. The minority carrier lifetimes of electrons in the base is 30 ns, for holes in the emitter is 0.15 ns, and for holes in the collector is 130 ns. For this device calculate the base transport factor. State any assumptions you make. **(5)**

4. **a.** Using figures where necessary, give a description of an p-channel enhancement mode MOSFET. In your answer you should:

- **i)** Describe the physical structure of the device
- **ii)** Explain how the voltages applied to the device contacts lead to fields in the semiconductor and how these fields affect carrier motion.
- **iii)** Outline how transistor operation can be obtained.
- **iv)** Give a clear statement of what the "threshold voltage" of the device is. **(8)**

b. Explain what is meant by the "transconductance" of a field effect transistor, and give an equation for it for small signals being applied to the transistor. **(3)**

c. The transconductance of a p-channel enhancement mode MOSFET is 5 mS.

The MOSFET is required to be used to amplify the signal produced by an accelerometer, which can produce signals between +/-10 mV. The circuit is needed to feed the accelerometer signal to an analogue-to-digital converter which requires an input of +/-2.5 V.

Design a simple, common source amplifier circuit to achieve this, using a 12 V battery as a power supply.

In addition to having access to a wide range of resistors, you can also use any number of 1.5 V batteries should you need them. **(9)**

PJP