Data Provided: None

The University of Sheffield

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2005-2006 (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, $q = 1.60\text{x}10^{-19}$C

Boltzmann constant, $k = 1.38\text{x}10^{-23}$ JK^{-1}

Speed of light in vacuum, $c = 3.00\text{x}10^{8}$ ms^{-1}

Permittivity of free space, $\varepsilon_0 = 8.85\text{x}10^{-12}$ Fm^{-1}

Planck's constant, $h = 6.63\text{x}10^{-34}$ Js

Mass of electron, $m_e = 9.11\text{x}10^{-31}$ kg

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

$$\frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon}$$

$$R = \rho L/A$$

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

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

Energy of a photon = hc/λ

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

$$J_0 = \frac{qL_e n_p}{\tau_e} + \frac{qL_h p_n}{\tau_h}$$

$$d_j = \left(2\varepsilon_0\varepsilon_r V_j / qN_d\right)^{0.5}$$

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

$$L = \sqrt{D\tau}$$

$$\beta = \frac{\alpha_B}{1-\alpha_B}$$

$$\alpha_B = \gamma_E \alpha$$

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 = $1.45\text{x}10^{16}$ m^{-3}

1. **a.** For a p-n junction diode use the diode equation to show that, assuming $L_e \approx L_h$, the ratio of electron and hole currents can be given approximately by the ratio of the p-type and n-type conductivities. **(6)**

b. For a p-n-p bipolar junction transistor briefly explain what is meant by the terms "Emitter Injection Efficiency" and "Base Transport Factor". **(4)**

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

Emitter: $7x10^{25}$ m^{-3}, Base: $7x10^{23}$ m^{-3}, Collector: $1x10^{23}$ m^{-3}

The width of the base is 0.3 μm. For this device calculate the emitter injection efficiency. **(5)**

d. Find a relationship between the ratio of the minority carrier diffusion lengths and the ratio of p-type and n-type conductivities. Hence derive a more accurate equation for the ratio of electron and hole currents in a p-n junction. **(5)**

2. **a.** Describe the behaviour of individual electrons in a uniform conductor and in an insulator at room temperature, with no electric field present. **(4)**

b. Explain briefly what is meant by "drift" and "diffusion" of charge carriers in a conductor. **(4)**

c. A wire of length 1 m is made from copper, which has a resistivity of $1.73x10^{-8}$ Ωm at room temperature (20^oC). The cross-sectional area of the wire is 1 mm^2. What is the resistance? **(2)**

d. It is found that the resistivity of copper increases with temperature. Briefly explain why this is the case. **(2)**

e. It is found that the increase in resistivity with temperature for copper is defined by an amount α, where $\alpha = 3.9\times10^{-11}\Omega\text{mK}^{-1}$. Calculate the resistivity of the copper used in the wire described in part (c) if the temperature is increased to 320^oC. **(2)**

f. One end of the 1 m copper wire described above in parts (c) and (e) is attached to an oven operating at 320 ^oC. The temperature of the other end is held at 20 ^oC. Assuming that the variation in the temperature of the copper wire is linear along its length, calculate the resistance of the wire.

(You may assume that any increase in the length or cross-sectional area of the copper wire due to the thermal expansion can be neglected in this case) **(6)**

3. **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. Using Poisson's equation for a n^+-p junction show that the depletion region thickness, d_j can be given by $d_j = \left(\frac{2\varepsilon V_0}{qN_a}\right)^{1/2}$ **(6)**

c. Explain briefly how the above equation can be modified to give the depletion region width of a p-n junction under forward or reverse bias. **(2)**

d. A p-channel planar Junction Field Effect Transistor (JFET) fabricated from Si has the following parameters:

n-type gate doping, n=1x10^{26} m^{-3}
p-type channel doping, p=1x10^{23} m^{-3}
channel thickness, a= 0.8 µm
gate width, w=10 µm
gate length, l=1 µm

Calculate the gate bias required in order pinch-off the channel completely, allowing no current flow though the device. State all assumptions you make. **(4)**

e. For applications requiring very high frequencies so-called III-V semiconductors, such as gallium arsenide (GaAs), can be preferred to Si for transistor manufacture. For gallium arsenide explain how the Ga and As atoms are arranged in the semiconductor and suggest how the material can be doped n-type and p-type. **(3)**

4. **a.** Describe briefly how a p-n junction can be used as a photodiode and sketch the I-V characteristics of the device under dark and illuminated conditions. Indicate clearly the normal regions of operation of the photodiode and also the region where the device can be used as a solar cell. **(6)**

b. A solar-cell is placed in series with a low power resistive heater. Sketch this arrangement and indicate clearly the direction of current flow through the heater. **(2)**

c. For the above arrangement, explain, using "load lines" if necessary, how the choice of the heater resistance should be made in order to maximise the efficiency of the circuit for a particular intensity of sunlight falling on the solar-cell. **(5)**

d. Explain what is meant by the term "minority carrier" in a semiconductor, and what is meant by "minority carrier lifetime" and "minority carrier diffusion length". **(3)**

e. In a particular solar-cell the light irradiated on the semiconductor is absorbed in the top p-type material. Explain whether the cell will produce any power, and if so what factors in the design of the solar-cell will be important in determining the device efficiency. **(4)**

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