Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2006-2007 (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

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

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

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

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

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

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

1. **a.** Briefly explain how a light emitting diode (LED) operates. Your answer should include discussion of the relationship between light output power and voltage and current. It should also explain where the energy being carried away in the form of emitted light came from. **(6)**

b. A very high brightness green LED using an InGaN active region is forward biased to give a current of 350 mA with a drive voltage of 3.4V. Using a so-called integrating sphere all the light emitted can be detected and in this case a power of 40 mW at a wavelength of 530 nm was measured.

i) The external efficiency of an LED is defined as the ratio of the number of photons emitted by the device per unit time to the number of the electron-hole pairs recombining per unit time. Given this definition calculate the external efficiency of the LED. **(6)**

ii) The wall plug efficiency is simply the ratio of useful power out to the power in. Calculate the LED wall plug efficiency **(2)**

iii) Explain why there is a difference between the external and wall plug efficiencies and suggest a source for the difference. **(3)**

c. The semiconducting layers used to inject the current into the green LED are made of gallium nitride. The dopants used to make it p- and n- type are magnesium (a group II element) and silicon (a group IV element), respectively. Explain clearly how these dopants lead to the formation of acceptors and donors in the material. **(3)**

2. **a.** Explain the differences in conductivity between a metal, a semiconductor and an insulator. **(5)**

b. **i)** Briefly explain what is meant an intrinsic semiconductor and extrinsic semiconductor.

ii) Make suggestions as to the relative densities of free carriers of both types in each case.

iii) Comment on the relative overall density of carriers in intrinsic and extrinsic material. **(5)**

c. It is found that the resistivity of a piece of n-type Si, with a free electron concentration of $1x10^{18}$ cm^{-3} increases as the temperature is raised from room temperature, Briefly explain why this is the case. **(2)**

d. It is found that the increase in resistivity with temperature for the silicon described in part c) can defined by an amount α, where $\alpha = 5.2\times10^{-7}\,\Omega\text{mK}^{-1}$. If the resistivity $\rho = 1.563\times10^{-4}\,\Omega\text{m}$ at 20°C, what is the resistivity at 50°C? **(2)**

e. A 0.1 m silicon rod, with a 1 mm^2 cross-sectional area, is placed in a non-uniform thermal environment. The temperature (in °C) at a distance x (in metres) along the rod is found to be given by:

$$T(x) = 20 + 400x - 1000x^2 .$$

Assuming the rod is made of the material described in parts c) and d), what is overall resistance of the rod?

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

3. **a.** At a time t=0 the profile of free carriers in an undoped semiconducting material with distance, x is given by:

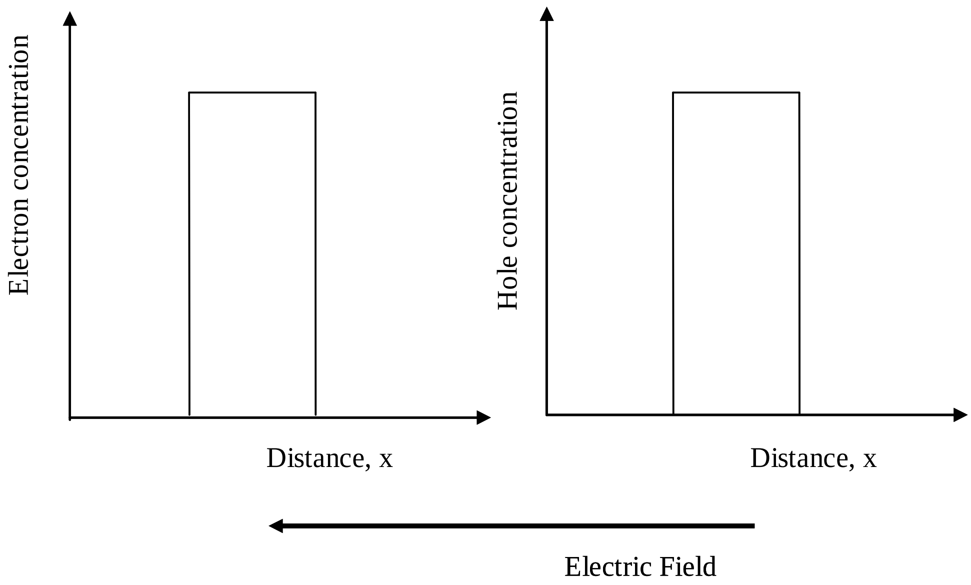

Figure Q3

The indicated electric field applies both to the electrons and holes where appropriate. Indicate how the concentration profiles of excess electrons and holes will evolve with time under the following assumptions, using diagrams and brief notes as appropriate:

i) Only diffusion occurs

ii) Only drift occurs

iii) Only recombination occurs

In each case your answer should highlight any similarities and differences between the behaviour of electrons and holes.

[Note: It is recognised that the three processes could not occur separately in practice. However, it does allow understanding of the properties of each process to be assessed in isolation] **(10)**

b. What is meant by the "base transport factor" in a bipolar junction transistor and explain how this effects the concentration profile of minority carriers in the base of the device. **(3)**

c. A Si bipolar transistor is biased in the normal operating region of its characteristic (that is such that it operates as an amplifier). The excess electron concentration at the emitter end of the base is $1 \times 10^{21} m^{-3}$ that the base length is $2\mu m$. Stating clearly any assumption you make about the value of the base transport factor in making the calculation, estimate the collector current density. **(7)**

4. **a.** A n^+p junction is created in silicon by doping. The density of donors (N_d) is $3\times10^{25}\,\mathrm{m}^{-3}$ and the density of acceptors (N_a) is $3\times10^{22}\,\mathrm{m}^{-3}$.

What is the width of the depletion region in this case, assuming zero bias is applied across the device. **(4)**

b. For this n^+p junction sketch the form of the electric field in the device, marking clearly the location n and p regions and the sign of the field where appropriate. **(4)**

c. The junction described above is found to breakdown by an avalanche mechanism at a voltage of 60 V. Briefly explain what is meant by avalanche breakdown **(3)**

d. This n^+p junction is to be used as a JFET, by preparing it on a piece of insulating Si.

i) Sketch the expected physical form of this JFET described showing clearly all the key features of the device. **(4)**

ii) Assuming that the JFET breakdown voltage is also 60 V calculate the maximum channel thickness that can be used assuming device pinch-off is required. Explain clearly your reasoning behind the calculation made. **(5)**

PJP / PAH