Data Provided: None

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2010-2011 (2 hours)

EEE105 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, $q=1.6\text{x}10^{-19}$ C

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

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

Planck's constant, $h=6.6\text{x}10^{-34}$ Js

Speed of light, $c=3\text{x}10^{8}$ m/s

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

$$\langle v_d \rangle = -\mu E \qquad \mu = \frac{q\tau}{m^*}$$

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

$$E = -\frac{dV}{dx} \qquad J_e^{diffusion} = qD\frac{dn}{dx}$$

$$W = \left(\frac{2\varepsilon_0\varepsilon_r V_0}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)\right)^{0.5}$$

$$R = \rho L/A \qquad D = \frac{kT}{q}\mu$$

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

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

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

$$\beta = \frac{\alpha_B}{1-\alpha_B} \qquad J_e^{drift} = q\mu En$$

$$p_{(p)} = p_{n0}\exp\left[\frac{q(V_0 - V_f)}{k_B T}\right]$$

$$\alpha_B = \gamma_E \alpha$$

Energy of a photon $=hc/\lambda$

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

For silicon;

Relative Permittivity = 12

Built-in Voltage, V_0 =0.7 V

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

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

Band-gap = 1.12 eV

Intrinsic carrier concentration at 300K $n_i = 1.45\text{x}10^{16}$ 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. Calculate the conductivity of intrinsic silicon at room temperature. **(4)**

d. Calculate the electron and hole concentration at room temperature for silicon doped with arsenic to $1\text{x}10^{21}$ m^{-3}, describing all assumptions. **(4)**

e. Calculate the average time between scattering events for an n-doped silicon sample. Describe how you expect this parameter to change with;

i) Increasing doping concentration

ii) Increasing temperature **(5)**

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. Starting from Poisson's equation show that the depletion region thickness, W of a p-n junction can be given by

$$W = \left(\frac{2\varepsilon_0 \varepsilon_r \left(V_0 - V_f\right)}{q} \left(\frac{N_a + N_d}{N_a N_d} \right) \right)^{0.5}$$

where V_0 is the built in voltage, V_f is the applied forward voltage, N_a is the acceptor concentration of the p-doped region, N_d is the donor concentration of the n-doped region, q is the charge on the electron, and ε_0 and ε_r are the permittivity of free space and relative permittivity, respectively.

(10)

c. Carefully sketch and label a schematic diagram of the p-n diode under zero, forward (0.5V), and reverse bias (2V) showing the conduction and valence bands, and any indication as to a change in depletion region width with applied bias. **(5)**

3. **a.** At a time $t=0$ the profile of free carriers in an intrinsic semiconducting material at a distance, x is illustrated in Figure Q3 below:

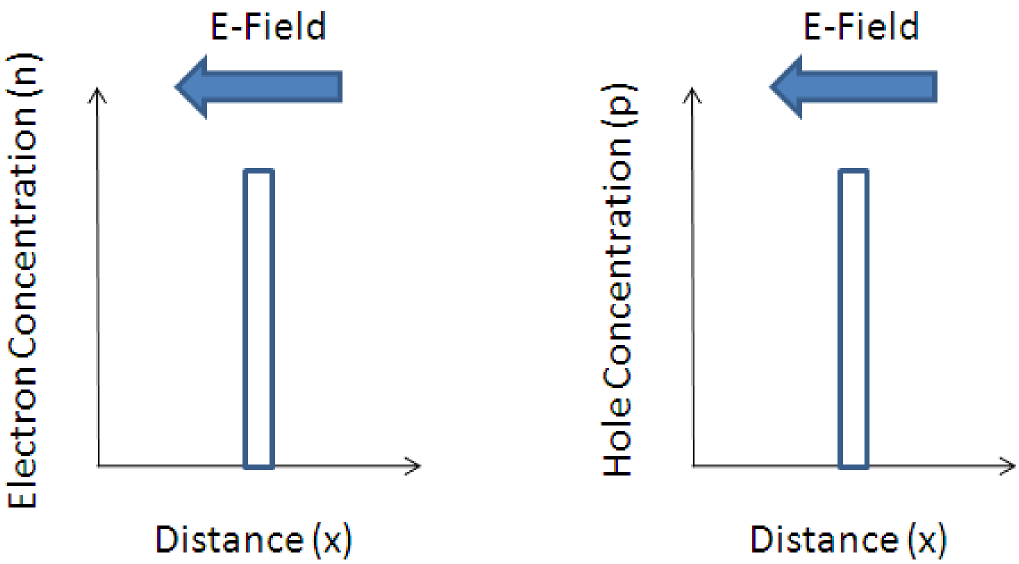

Figure Q3

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] **(12)**

b. A germanium bar is doped to have a non-uniform donor distribution along its length. The donor density in our region of interest is described by $N_d(x)=10^{20}(1+Ax)\ m^{-3}$, where A is a constant.

Considering that there is no net current under zero applied voltage, derive an equation to describe the electric field as a function of x.

Describe the physical origin of this electric field. **(8)**

4 **a.** Using figures where appropriate, describe the principles of operation of a p-n-p bipolar junction transistor. Your answer should include

i) An explanation of why the doping in the emitter must be much higher than that in the base for the device to operate as a transistor.

ii) A definition of the term "base transport factor".

iii) Description of how the value of the base transport factor parameter can be changed through the device design.

iv) How current gain can be obtained.

v) Briefly describe the Early effect at high base-collector voltages.

(10)

b. The carrier concentrations in a Si p-n-p bipolar junction transistor are as follows:

Emitter: $N_a = 1.2 \times 10^{26}\,\text{m}^{-3}$

Base: $N_d = 1 \times 10^{24}\,\text{m}^{-3}$ Base Thickness: $W_B = 0.7$ μm

Collector: $N_a = 8 \times 10^{22}\,\text{m}^{-3}$

The minority carrier diffusion length in the base material is 15 μm

i) Estimate the base transport factor in this device, clearly justifying your working **(5)**

ii) Estimate the emitter injection efficiency (the fraction of the total junction current that is due to hole current) **(5)**

RAH