The University Of Sheffield.

Data Provided: Below

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2009-2010 (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, $q=1.6\times10^{-19}$ C

Boltzmann's constant, $k=1.38\times10^{-23}$ JK^{-1}

Speed of light, $c=3\times10^{8}$ m/s

Permittivity of free space, $\varepsilon_0 = 8.85\times10^{-12}$ Fm^{-1}

Planck's constant, $h=6.6\times10^{-34}$ Js

Mass of electron, $m_e = 9.11\times10^{-31}$ Kg

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

$$E = -\frac{dV}{dx} \qquad J = qD\frac{dn}{dx}$$

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

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

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

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

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

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

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

$$\alpha_B = \gamma_E\alpha$$

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 =0.7 V

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

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

Band-gap = 1.12 eV

Intrinsic carrier concentration at 300K $n_i = 1.45\times10^{16}$ m^{-3}

1. **a.** Describe the origin of the differences in conductivity between a metal and an insulator at room temperature. **(2)**

b. Explain, using diagrams if necessary;

i) The effect of a concentration gradient of charge carriers in a conductor.

ii) The effect of an electric field on charge carriers in a conductor.

iii) The effect of an electric field on a crystalline insulator. **(9)**

c. A rod of Si has a length of 1 cm, a cross sectional area of 2 mm^2. A voltage of 10 V is applied between the two ends of the rod giving a current of 2 mA. The rod is n-doped and known to have a uniform free electron concentration and uniform temperature along its length. Given that the effective mass $m^* = 0.98m_e$, calculate;

i) The average time between scattering events for the ensemble of electrons.

ii) The drift velocity.

iii) The electron concentration. **(9)**

(n.b. materials data for Si is given on the first page.)

2. **a.** Describe the origin of free carriers in an intrinsic semiconductor at room temperature. **(2)**

b. Derive an equation for the minority carrier concentration in terms of the intrinsic carrier concentration and the majority carrier concentration stating all assumptions made to derive the relationship. **(4)**

c. Explain, using diagrams if necessary, what is meant by doping in a semiconductor in terms of;

i) Choice of dopant atoms **(2)**

ii) Fraction of dopant atoms to host atoms **(1)**

iii) The position of donor and acceptor states with regard to the band edges and their occupancy at room temperature and low temperature (i.e. absolute zero = 0 K) **(3)**

d. The intrinsic carrier concentration, n_i, of a semiconductor is given by;

$$n_i = CT^{3/2} \exp\left(-\frac{W_g}{2k_B T}\right)$$

Where T= temperature, C=constant, W_g=band gap energy, and k_B= Boltzmann's constant. For a piece of silicon, calculate the free carrier density and conductivity at 350 K. **(8)**

(n.b. materials data for Si is given on the first page.)

3. **a.** A p-n junction isfabricated in silicon by doping two neighbouring regions. The donor doping density (N_a) is 1x10^{25} m^{-3}, whilst the doping density of acceptors (N_d) is 1x10^{23} m^{-3}.

i) Describe clearly the formation of the so-called “depletion region”. **(5)**

ii) Determine the total width of the depletion region at a reverse bias of 1 V. **(5)**

iii) Sketch the band diagram in the device at zero bias, marking clearly the n and p regions and the sign of the field. **(5)**

iv) Light of a particular wavelength is incident onto a Si photodiode. Sketch and label the I-V characteristics of the diode as a function of light intensity if the wavelength of light is;

1) 800 nm

2) 1550 nm **(5)**

4. **a.** For a bipolar junction transistor, briefly explain the terms “emitter efficiency” and “base transport factor”. **(2)**

b. Describe how such a bipolar junction transistor is designed to maximise these two factors. **(4)**

c. Derive the current amplification factor for a p-n-p bipolar junction transistor by defining the ratio of collector and base currents, describing all assumptions made. **(4)**

d. An n-p-n silicon bipolar junction transistor is doped as follows;

Emitter: 5x10^{25} m^{-3} , Base: 1x10^{23} m^{-3}, Collector: 9x10^{22} m^{-3},

The width of the base is 0.5 µm, and the minority carrier lifetimes of electrons in the base is 25 ns, for holes in the emitter is 0.15 ns, and for holes in the collector is 100 ns. For this device calculate the emitter efficiency assuming it is approximated to $\gamma_E = 1 - \frac{J_h}{J_e}$. **(10)**

(n.b. materials data for Si is given on the first page, and you will not necessarily need all of the structural information presented above.)

RAH