**Data Provided: None**

The University Of Sheffield.

**DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING**

**Autumn Semester 2007-2008 (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

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

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

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

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

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

*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.** **i)** Describe what is meant by generation rate and recombination rate in a semiconductor. **(4)**

**ii)** Using generation and recombination rates as a starting point, derive an equation for the minority carrier concentration in terms of the intrinsic and majority carrier concentrations for an n-type semiconductor. **(5)**

**b.** The intrinsic carrier concentration in a semiconductor can be given by:

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

Where the symbols have their usual meanings. Assuming that $n_i = 1.45\times10^{16}$ m$^{-3}$ in Si at a temperature of 20$^{o}$C, calculate the intrinsic carrier concentration if the temperature is reduced by 60 $^{o}$C. **(5)**

**c.** A p$^{+}$-n Si diode is to be operated on a Peltier cooler at a temperature of -40 $^{o}$C. At 20 $^{o}$C the reverse leakage current was measured to be 1 nA. What is the expected leakage current once the device has been cooled? State any assumptions you make. **(6)**

**2.** **a.** Explain how a diode may be used to detect light. In your explanation clearly describe the physical mechanism by which the light can be detected and any constraints there are on the energy of the light that can be detected by a particular semiconductor. Also, state the diode bias conditions you think would be appropriate. **(7)**

**b.** A series of tests is carried out using a Si photodiode. In the initial test a red laser (with a wavelength of 630 nm) producing 1 mW of light was found to give a photocurrent of 100 μA.

Given this information calculate the expected photocurrent in each of the following tests. You should *clearly* justify the basis of your calculation in each case.

**i)** The power of the red laser is increased to 4 mW

**ii)** The red laser is replaced with a 1 mW blue laser operating at a wavelength of 405 nm.

**iii)** The red laser is replaced with a 1 mW infrared laser operating at a wavelength of 1.5 μm. **(8)**

*[Reminder: the definition of "photocurrent" is that it is the current in the diode produced as a result of the photons (or light) shining on it.]*

**c.** The quantum efficiency of a photodiode can be defined as:

The ratio of the total number of electrons being created due to light absorption per unit time in the device (forming the photocurrent), divided by the total number of photons shining on the device per unit time.

For the initial test result on the Si photodiode described above in part b what is the device's quantum efficiency. **(5)**

**3.** **a.** **i)** Using diagrams as appropriate, explain how the capacitance between two metal plates can be changed through the insertion of an insulator between them. Include in your explanation an outline of how the material in the insulator can behave when an electric field is applied across the plates. **(5)**

**ii)** Other than having a high relative permittivity, suggest two properties that a capacitor manufacturer would consider in choosing an insulator for his components. **(2)**

**b.** Describe in detail how a p-channel JFET can be used at a transistor. **(7)**

**c.** A Si planar p-channel JFET is fabricated with a gate length of 2 μm and a device width of 500 μm. The channel majority carrier concentration is $2 \times 10^{23}\,\mathrm{m}^{-3}$.

A bias of 12 V is applied across the gate. If the device is not pinched off and the drain voltage is small, relative to the gate bias, estimate the capacitance between the gate and the channel. State any assumptions you make. **(6)**

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

**i)** A detailed description of the device design, and how current gain can be obtained

**ii)** 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.

**iii)** A definition of the term “base transport factor” and description of how the value of this parameter can be changed through the device design.

**iv)** A description of the appropriate bias conditions for the terminals of the device when it is to be used as an amplifier in a common-emitter configuration. **(11)**

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

Emitter: $N_a = 1 \times 10^{26}\,\mathrm{m}^{-3}$

Base: $N_d = 1 \times 10^{24}\,\mathrm{m}^{-3}$ Base Thickness: $W_B = 1\ \mu\mathrm{m}$

Collector: $N_a = 7 \times 10^{22}\,\mathrm{m}^{-3}$

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 **(4)**

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

**PJP / PAH**