Data Provided: None

The University of Sheffield

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2004-2005   (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, $k = 1.38\text{x}10^{-23}$ J/K

Speed of light in vacuum, $c = 3.00\text{x}10^{8}$ m/s

Permittivity of free space, $\varepsilon_0 = 8.85\text{x}10^{-12}$ F/m

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 = 0.07 m^2/Vs

band gap = 1.12 eV

built in voltage = 0.7 V

hole mobility = 0.045 m^2/Vs

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

1. **a.** For a standard pn junction diode, use the diode equation as a starting point to show that the ratio of electron and hole currents will be approximately given by the ratio of the conductivity of the n-type and p-type materials. State all the assumptions you make. **(8)**

b. A gallium phosphide diode is found to have an ideal reverse bias leakage current of 1×10^{-24} A. Estimate the forward bias voltage across the junction of the diode if a 20 mA current is flowing. **(3)**

c. The device in part (b) is a surface emitting light emitting diode which forms a square with sides of length 0.3 mm. The electron and hole mobilities are $0.20\ m^2\ V^{-1}s^{-1}$ and $0.05\ m^2\ V^{-1}s^{-1}$, respectively and the thickness of the n- and p-regions are 250 μm and 1 μm, respectively.

Assuming that the current remains at 20 mA, estimate the total voltage drop across the device if the density of donors and acceptors on each side of the junction are $3 \times 10^{22}\ m^{-3}$ and $8 \times 10^{24}\ m^{-3}$, respectively. **(4)**

d. Gallium phosphide does not normally emit light as it is a so-called indirect bandgap semiconductor. However, it can emit green light if it is doped with nitrogen in the region of the device where the electrons and holes recombine (the nitrogen acts as a sort of luminescence centre). It is normal to dope only one side of the junction.

For the device in part (c) above, which side of the p-n junction should be doped with nitrogen in order to get maximum light output? Estimate what proportion of the current will be able to interact with the nitrogen doped region. **(5)**

2. **a.** Using diagrams as appropriate, give a physical explanation of how an insulator inserted between two parallel metal plates can modify the capacitance between them. **(5)**

b. Give three examples of issues that a manufacturer of a capacitor would consider when choosing an insulating material as the dielectric in the device. **(3)**

c. For a silicon p-n junction, where the p-type free hole concentration is much greater than the n-type free electron concentration, briefly explain how the device can form a capacitor, and sketch a diagram clearly indicating which parts of the diode form the conducting and insulating regions. **(6)**

d. A 1 mm diameter silicon diode with acceptor and donor concentrations of $1 \times 10^{25}\ m^{-3}$ and $3 \times 10^{21}\ m^{-3}$, respectively, has a reverse bias breakdown voltage of 100 V. Calculate the possible maximum and minimum practical capacitance values of the device. **(6)**

3. **a.** Qualitatively derive a relationship between the recombination rate, and the electron and hole carrier concentrations in an intrinsic semiconductor. **(3)**

b. Give a definition of a "minority carrier" and derive an equation for the minority carrier concentration in terms of the intrinsic and majority carrier concentrations. **(3)**

c. Using light absorption as an example, briefly explain what is meant by the minority carrier lifetime and diffusion length in a piece of uniformly extrinsically doped semiconductor. **(4)**

d. Briefly describe how a p-n junction can be used as a photodiode. **(3)**

e. A Si photodiode consists of a 1 μm thick p-type layer on a thick n-type layer. The minority carrier lifetime of the electrons in the p-type material is 1 μs

Light is irradiated on the top, p-type surface of the device. Assuming that the photons are absorbed essentially at the surface, estimate the likely fraction of absorbed photons that will lead to a photo-induced current in the device.

(You may assume the thickness of the depletion region is negligible on the p-side of the junction for this example) **(7)**

4. **a.** Using figures as appropriate, give a description of an n-channel enhancement mode MOSFET, describing in detail how it can be used as a transistor. Your explanation should include a clear statement of what the "threshold voltage" of the device is. **(6)**

b. Explain what is meant by the "transconductance" of a field effect transistor, and give an equation for it with reference to the small signals in the transistor. **(3)**

c. The transconductance of an n-channel enhancement mode MOSFET is 2 mS, at a gate voltage of 4.5 V. Design a simple, common source amplifier circuit to amplify a sensor output of maximum peak-to-peak range 20 mV to give an input to a analogue-to-digital converter with maximum allowed peak-to-peak input of 4 V. The circuit is to be powered by a 9 V battery.

In addition to having access to a wide range of resistors, you can also use three 1.5 V batteries should you need them. **(7)**

d. Sketch the small signal equivalent circuit for a MOSFET, showing clearly the resistor which models the output resistance. Sketch the output characteristic for a suitable value of the gate voltage showing clearly the effect of the output resistance on the curve. **(4)**

PJP / PAH