Data Provided: None

EEE105/176

The University of Sheffield

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2001-2002 (2 hours)

EEE105 Electronic Devices
EEE172 Fields and Devices

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:

$q=1.6\text{x}10^{-19}$C
Permittivity of free space $\varepsilon_0 = 8.85\text{x}10^{-12}$ F/m
Boltzmann's constant $k=1.38\text{x}10^{-23}$ J/K
Plank's constant $h=6.6\text{x}10^{-34}$ Js
speed of light $c=3\text{x}10^{8}$ m/s

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

$$E = -\frac{dV}{dx}$$

$$d_j = \left(2e_0 e_r V_j \,/\, qN_d\right)^{0.5}$$

$$J = qD\frac{dn}{dx}$$

$$J_0 = \frac{qL_e n_p}{t_e} + \frac{qL_h p_n}{t_h}$$

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

$$D = \frac{kT}{q} m$$

$$ß = \frac{a_B}{1 - a_B}$$

$$a_B = \alpha\gamma_E$$

Energy of a photon $=hc/\lambda$

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

$$L = \sqrt{Dt}$$

For silicon: Relative permittivity $\varepsilon_r = 12$
Built in voltage =0.7V
electron mobility=0.07m^2/Vs
hole mobility=0.045m^2/Vs

For germanium: Relative permittivity $e_r = 15.8$

	Ge	Si	GaAs	InSb
n_i (m^{-3})	2.4x10^{19}	1.45x10^{16}	1.8x10^{12}	2.1x10^{22}

1. Describe in a few sentences how electron diffusion takes place in a semiconductor which has a non-uniform electron distribution. Hence, from your knowledge of this process, outline the arguments leading to the expression for the diffusion current, J_{Diff}, in terms of the electronic charge, the diffusion coefficient for electrons and the slope of the electron concentration with distance. **(9)**

The Einstein relation shows that diffusion coefficient depends on electron mobility and temperature. Discuss the physical basis of this dependence. **(3)**

In the normal operation of an npn bipolar transistor electrons are injected from the emitter into the base. Describe the process of diffusion and recombination that takes place in the base, emphasising the requirements for good current gain. **(4)**

Such a transistor has a base width of 3μm and an emitter doping level of 2×10^{23}m^{-3}. It is biased such that the density of electrons injected into the emitter side of the base is 10% of the concentration in the emitter. Calculate the collector current density assuming negligible recombination in the base and a diffusion coefficient for electrons of 0.008 m^{2}s^{-1}. **(4)**

2. By comparison with a parallel plate type of capacitor, discuss the physical reasons why the depletion regions in a p-n junction diode behave as an effective capacitance. You should include an equation relating the capacitance to the device geometry. **(6)**

Explain qualitatively why the capacitance is inversely proportional to the square root of applied voltage assuming the built-in voltage is negligible. **(2)**

Calculate the junction capacitance of a germanium p-n diode with an area of $0.5\times 0.5\text{mm}^2$ and a space charge thickness of $3\mu\text{m}$. **(4)**

Varactors are electrically controlled capacitors using reverse biased p-n diodes. For a reverse bias of 4V a certain varactor has a capacitance of 10pF. Assuming a negligible built-in voltage, estimate the change in capacitance for a 0.5V increase in the reverse bias voltage. **(6)**

Without changing the area or the reverse bias, how might the capacitance be increased? **(2)**

3. Using sketches where appropriate, first explain the operation of the junction field effect transistor (JFET) and then the metal-oxide FET (MOSFET), bringing out the main differences between the two. **(10)**

The fraction of conducting channel width to total channel width in a JFET is given by

$$\frac{b}{a} = 1 - \left(\frac{V_g}{V_p}\right)^{\frac{1}{2}}$$

where V_g and V_p are the gate voltage and pinch-off voltage respectively. Using simple arguments relating the ratio of the channel conductivities to the channel widths with and without a gate bias, derive an expression for the drain current versus drain voltage at low drain voltages. **(5)**

A JFET has a zero gate-voltage resistance of 500Ω which rises to 1000Ω with a gate voltage of 2V. Calculate the drain current at a gate and drain bias of 3V and 10V respectively. Assume that the built-in voltage is negligible. **(5)**

4.(a) The diode current density equation can be written as:

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

where J_0 is given by

$$J_0 = qn_i^2\left[\frac{D_h}{L_h N_d} + \frac{D_e}{L_e N_a}\right] \quad ②$$ **(2)**

with the usual notation.

From these equations, derive the ratio of electron to hole current across the junction. In what device is this ratio important and why? **(8)**

(b) The current flowing in a certain p-n junction at room temperature is 10μA when a reasonably large reverse bias voltage (not exceeding breakdown) is applied. Find the applied junction voltage corresponding to a forward current of 50mA. The diode is constructed with p-type material of conductivity 2000Sm^{-1} and n-type of 500Sm^{-1}. Each region is 1mm long and 0.5mm^2 in cross-section. Calculate the total voltage drop across the terminals of the diode when 50mA flows. **(10)**

(c) Identify the term in equation ② that signifies the importance of the bond strength of the crystal lattice for controlling the reverse saturation current density, J_0. **(2)**