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NATIONAL UNIVERSITY OF IRELAND
GALWAY

AUTUMN EXAMINATIONS 1999

3rd year B.Sc.Unit EP326: Solid State Physics

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Time allowed: TWO hours.	Answer THREE questions

Physical data for silicon at 300 K, and other constants

(a) Silicon at 300 K:

N_C	=	2.8×10^{25} m^{-3}	N_V	=	1.04×10^{25} m^{-3}
μ_n	=	0.14 m^2 V^{-1} s^{-1}	μ_p	=	0.05 m^2 V^{-1} s^{-1}
D_n	=	36×10^{-4} m^2 s^{-1}	D_p	=	13×10^{-4} m^2 s^{-1}
n_i	=	1.45×10^{16} m^{-3}	E_G	=	1.12 eV

Relative dielectric constant of Si, ε_S = 11.9
Density of Si atoms (crystalline) = 5.0×10^{28} atoms m^{-3}
Resistivity of intrinsic Si = 2300 Ω m

(b) Other constants:

			kT	=	0.0259 eV at T = 300K
q	=	1.602×10^{-19} C	m_e	=	9.11×10^{-31} kg
h	=	6.626×10^{-34} J s	ε_0	=	8.85×10^{-12} F m^{-1}

Relative dielectric constant of SiO_2, ε_{OX} = 3.9

Q.1 Write full notes on any *two* of the following topics.

(a) The concepts of electron energy bands and holes in semiconductors.

(b) The variations, with temperature T, of the carrier concentrations in a doped semiconductor.

(c) The transport and continuity equations in semiconductors.

Q.2 Define the terms in, and explain the physical significance of, the two semiconductor equations given below. What is the essential condition for these equations to be valid?

$$n = N_C \exp\left[\frac{-(E - E_c)}{kT}\right] \qquad N_D^0 = 2N_D \exp\left[\frac{-(E_D - E_F)}{kT}\right]$$

Silicon is doped with phosphorous impurity atoms at a concentration of 1.5 10^{22} atoms m^{-3}. Calculate the accurate percentage ionisation of the phosphorous atoms, the conductivity μ of the doped silicon, and the position of the Fermi level, $E_C - E_F$, in the silicon. Is the doped silicon degenerate or non-degenerate?

Note: $E_C - E_D = 0.049$ eV for P doping in Si.

p.t.o.

Q.3 By estimating the minority drift current, J_{PF}, of holes across a semiconductor p-n junction, show that the term J_o in the ideal diode equation, $J = J_o[exp(qV/kT) - 1]$, can be written as:

$$J_o = \frac{q D_p p_{no}}{L_p} + \frac{q D_n n_{po}}{L_n} \approx \frac{q D_p n_i^2}{L_p N_D} + \frac{q D_n n_i^2}{L_n N_A}$$

Explain the meanings of all the terms used in this equation. Under what assumptions is the approximation used in the second half of the equation valid?

The minority carrier lifetimes in the p and n regions of a p-n junction diode are 120 μs and 50 μs, respectively. The respective doping levels are $N_A = 2.5 \times 10^{23}$ m^{-3} and $N_D = 1.5 \times 10^{21}$ m^{-3}. Calculate the minority diffusion lengths in both regions, and estimate the percentage of hole current to total current across the junction. Why, and where, is it important to be able to control this ratio in the fabrication of a bipolar junction transistor?

Q.4 Briefly describe, and sketch, the modern day (planar epitaxial) fabrication method for an npn Bipolar Junction Transistor (BJT). Explain how this fabrication technique produces a *drift transistor* with built in electric field in the base. What is the main BJT operational benefit of this electric field? Define the *grading factor* η for such a device.

An npn BJT has a base width W = 1.2 μm, and a base grading factor η = 2.5. Calculate the drift velocity of electrons across the base, due to the built in field. Hence calculate the electron base transit times due to drift alone, and also due to diffusion alone. Define and estimate the *transition frequency*, f_T, for this transistor.

Q.5 Define the *threshold voltage*, V_{TH}, of a MOSFET device. State the equation, which is used to determine V_{TH}, explaining the origin and physical significance of each of the four terms that go to make up the equation. In addition, state briefly how the *surface states* arise.

A silicon NMOSFET device, with an oxide thickness of 60 nm, has its threshold voltage measured as 0.25 V. The theoretical threshold voltage in the absence of any surface states is calculated as being 0.95 V. Calculate the surface charge, Q_{OX}, and numerical density, N_{OX}, of the surface states. Say clearly whether this is a positive or negative charge density. The threshold voltage is to be adjusted to $V_{TH} = 1.2$ V, during fabrication, by a boron ion implant in the channel. Estimate the ion implant dose, N_I, required.