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NATIONAL UNIVERSITY OF IRELAND
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SEMESTER 2 (SUMMER) EXAMINATIONS 1998-99

Applied Physics & Electronics, Experimental Physics, Physics & Computing – Paper 3

EP326: Solid State Physics

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Answer THREE questions	Time allowed: TWO hours

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, 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
e	=	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) SPICE models and parameters for *either* the p-n diode *or* bipolar junction transistor.

(b) The transport and continuity equations in semiconductors.

(c) Switching speeds and minority charge storage in bipolar junction transistors.

Q.2 State the assumptions of the Feynman close coupling model for electrons in a 1-d crystal. The result of a Quantum Mechanical analysis using this model gives rise to the following energy band equation:

$$E(k) = E_0 - 2A\cos(ka)$$

Explain the physical significance of this equation, defining all the terms used in it. Show quantitatively how the equation predicts the existence of positive charge, positive mass, *holes* in semiconductors. Describe briefly how a general energy band theory for electrons accounts for the main qualitative features of conduction observed in metals, insulators, and semiconductors.

p.t.o.

Q.3 Given (a) the Fermi-Dirac distribution equation: $F(E) = \frac{1}{\exp\left(E/E_F\right)+1}$, and,

(b) the formula for the density of available quantum states in the conduction band of a semiconductor: $N(E) = \frac{4\pi}{h^3}\left(2m_e^*\right)^3\left(E-E_C\right)^{0.5}$, show that the total number of free electrons n in a semiconductor conduction band at temperature T, is given by: $n = N_C \exp\left(-\frac{(E_C - E_F)}{kT}\right)$. State and carefully explain any assumptions made in your derivation. Say what N_C is, and give the algebraic expression for it.

Silicon is doped with phosphorous impurities at a concentration of 4×10^{22} atoms m^{-3}. Assuming 100% impurity ionisation, estimate the resultant shift in the Fermi energy, E_F, as measured from its intrinsic position, E_i.

Q.4 Give a labelled diagram, to help you to explain the fabrication and structure of a modern, high speed, drift, Bipolar Junction Transistor (BJT). How does the doping profile set up in the base help in improving the switching speed of such a device ?

Define the *base transport factor*, *b*, and the *emitter injection efficiency*, γ, for a BJT. Equations for these two quantities are given below. Define all the terms used.

$$b = 1 - \frac{W^2}{2D_n\tau_n} \quad : \quad \gamma = \left[1 + \frac{WN_AL_n}{L_EN_DL_p}\right]^{-1}$$

A particular npn BJT has a base width of 0.8 μm, and the minority carrier lifetime in the base is 800 ns. If the emitter injection efficiency $\gamma = 0.9975$, calculate the values of the common base and common emitter current gains, α and β, for the device.

Q.5 Identify the following MOSFET equation, defining all the terms used in it, and explaining their physical origin.

$$V_{TH} = \phi_{MS} - \frac{Q_{OX}}{C_{OX}} - \frac{Q_{BO}}{C_{OX}} + 2\phi_F$$

A NMOSFET transistor is fabricated with a gate oxide thickness $t_{OX} = 60$ nm on a p type silicon substrate with doping level $N_A = 9\times10^{21}$ m^{-3}. The device parameters are measured or calculated as: $\phi_{MS} = -0.95$ V, $\phi_S(inv) = 0.71$ V, maximum depletion depth $W_M = 0.33$ μm, $V_{TH} = 0.35$ V. Calculate the gate capacitance C_{OX}, the maximum semiconductor depletion charge density Q_D, and the density of surface states N_{OX} at the oxide-semiconductor interface.

Estimate (quantitatively) the ion implant dose required to raise the threshold voltage of this device to 1.5 V. What element would be used for the implant?