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NATIONAL UNIVERSITY OF IRELAND
GALWAY

SEMESTER 2 (SUMMER) EXAMINATIONS 2000

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

Experimental 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 (approx. one page each) on any two of the following:

(a) The transport and continuity equations in semiconductors.

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

(c) Metal-semiconductor contacts and their application in practical devices.

Q.2 Give a brief description , with an explanatory sketch, of a modern, high speed, drift, Bipolar Junction Transistor (BJT). What are the main factors determining the maximum switching speed for 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 in both equations.

$$b = 1 - \frac{W^2}{2D_n\tau_n} \qquad \gamma = \left[1 + \frac{D_p N_A W}{D_n N_D W_E}\right]^{-1}$$

For a particular BJT the value of *b* is indistinguishably close to unity; i.e., *b* may be taken as equal to 1. If $\gamma = 0.9973$, calculate the values of the common base and common emitter current gains, α and β, for the device.

Q.3 Define the terms in, and explain the physical significance of, the two semiconductor equations given below. What is the essential condition for these to be valid?

$$n = N_C e^{-\left(\frac{E-E_C}{kT}\right)} \qquad N_D^0 = 2N_D e^{-\left(\frac{E_D-E_F}{kT}\right)}$$

Silicon is doped with phosphorous impurity atoms at a concentration of 1.8×10^{22} atoms m^{-3}. Calculate the accurate percentage ionization 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.

Q.4 Define the threshold voltage, V_{TH}, of a MOSFET transistor. State the equation which determines V_{TH} and briefly indicate the physical origin of each term in it.

A NMOSFET aluminium gate transistor has a gate oxide of 55 nm grown on a p-type silicon substrate doped at a level of $N_A = 10^{22}$ atoms m^{-3}. For this substrate $\phi_{MS} = -0.97V$, $\phi_F = 0.35$ V, and the maximum depletion depth in the silicon is $W_M = 0.3$ μm. The value of V_{TH} for the device is experimentally determined to be 0.25 V. Calculate the density of positively charged surface states, N_{SS}, at the oxide-silicon interface.

What processing stage will raise the threshold voltage of this device to 1.2 V? Give a quantitative (i.e., numerical) answer to show how this can be done.

Continued......

Q.5 State the assumptions of the Feynman close coupling model of electron energy states in a 1-d crystal. Give a brief quantum mechanical derivation of how this model predicts the electron energy band formula of the form:

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

defining the physical significance of each term in the equation.

Show how this equation predicts the existence of electrons with a negative effective mass in a semiconductor crystal, and show how this leads to the concept of "holes".