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NATIONAL UNIVERSITY OF IRELAND
GALWAY

SEMESTER II (SUMMER) EXAMINATIONS 2001

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, 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 *TWO* of the following:

(a) The characteristics and behaviour of metal to semiconductor contacts. [5 marks]

(b) Minority carrier storage in pn junctions, and its effect on the switching speeds of diodes and bipolar junction transistors. [5 marks]

(c) The Haynes-Shockley experiment. [5 marks]

p.t.o.

Q.2 Briefly describe the contemporary fabrication of an npn Bipolar Junction Transistor (BJT). Use a sketch to illustrate your answer. Explain how these fabrication techniques produce a built-in electric field in the base which speeds the electron transit time across the base. Define the *grading factor* η for such a device. [5 marks]

An npn BJT has a base width W = 1.1 μm, and a base grading factor $\eta = 2.4$. Calculate the drift velocity of electrons across the base, due to the electric 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 the transistor. [5 marks]

Q.3 State the assumptions made, define the terms used in, and hence outline the derivation of the following semiconductor equation.

$$n = 2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{\frac{3}{2}} e^{-\left(\frac{E_C - E_F}{kT}\right)}$$

[5 marks]

For what types of semiconductors is this equation valid (i.e., intrinsic, p-type, n-type)? With reference to the equation define the effective density of electron states at the conduction band edge. [2 marks]

Sketch and briefly explain the variation of the concentration of electrons in the conduction band of an n-type doped semiconductor as a function of temperature, T. [3 marks]

Q.4 By analogy with Bragg scattering of X-rays in a 1-d crystal, show that travelling wave functions for electrons in a 1-d crystal cannot exist with wavenumbers $k = n\pi/a$, where n is an integer, and a is the interatomic spacing. By considering the only two possible electron standing wave functions in such a 1-d crystal show that the electron energy E versus k relationship exhibits discontinuities at these k values. [5 marks]

Sketch the general form of the *E-k* curves in this crystal, and indicate how they confirm the band theory of electron energy. Explain briefly how this energy band theory accounts for the main qualitative features of conduction in insulators, metals and semiconductors. [5 marks]

Q.5 Identify the following equation and explain the terms in it and their physical significance:

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

[5 marks]

An NMOSFET aluminium gate device has a gate oxide thickness of 50 nm on p-type silicon doped at $N_A = 10^{22}$ atoms m^{-3}. The maximum depletion depth, W_M, in the silicon is 0.3 μm and the values of ϕ_{MS} and ϕ_F are -0.97 V and 0.35 V, respectively. If its threshold voltage is measured as 0.1 V, calculate the density and nature of the charged surface states at the oxide interface. [5 marks]