Ghousia College of Engineering
Department of Electronics and Communication

EC 56: Solid State Devices and Technology

Internal Exam-Solutions #1

*Problem **I**.*

1. For a germanium sample, at 300^oK has a concentration of free electrons as $5.8 \times 10^{18}\ /cm^3$, and holes as $10.58 \times 10^{19}\ /cm^3$, with applied electric field of $2\ V/cm$. Take $n_i = 2.5 \times 10^{13}\ /cm^3$ at 300^oK, $\mu_n = 3,800\ cm^2/V\text{-}s$, $\mu_p = 1,800\ cm^2/V\text{-}s$, $D_n = 99\ cm^2/s$, $D_p = 47\ cm^2/s$.
   (a) Find the drift current due to electrons and holes. (4 Marks)
   A: $J_n = qn\mu_n\varepsilon = 1.6 \times 10^{-19} \times 5.8 \times 10^{18} \times 3800 \times 2 = 7052.8\ A/cm^2$
   $J_p = qp\mu_p\varepsilon = 1.6 \times 10^{-19} \times 10.58 \times 10^{19} \times 1800 \times 2 = 60940.8\ A/cm^2$
   (b) If there exists a gradient of concentration of holes and electrons with $|dp/dx| = 2 \times 10^{18}\ /cm^4$ and $|dn/dx| = 5 \times 10^{17}\ /cm^4$ respectively, then find diffusion current densities due to holes and electrons. (4 Marks)
   A: $J_p = -qD_pdp/dx = -1.6 \times 10^{-19} \times 47 \times 2 \times 10^{18} = -15.04\ A/cm^2$
   $J_n = qD_ndn/dx = 1.6 \times 10^{-19} \times 99 \times 5 \times 10^{17} = 7.92\ A/cm^2$
   (c) Using the results obtained in (a) and (b) find the total current densities due to holes and electrons. (2 Marks)
   A: Total current density due to electrons $= qn\mu_n\varepsilon + qD_ndn/dx = 7052.8 + 7.92 = 7060.72\ A/cm^2$
   Total current density due to holes $= qp\mu_p\varepsilon - qD_pdp/dx = 60940.8 - 15.04 = 60925.76\ A/cm^2$

2. An abrupt (or step-graded) p-n junction is formed with $N_A = 10^{16}\ /cm^3$ and $N_D = 4 \times 10^{18}\ /cm^3$ of circular cross-section, with diameter of $0.02\ cm$. Calculate the following, (i) $V_0 =$ Contact potential at open-circuited junction, (ii) depletion width W (iii) $x_{p_0} =$ depletion width on the p-side (iv) $Q^+ =$ total positive charge in the depletion region (v) $\varepsilon_0 =$ Electric field present at the junction. (vi) Draw the graph for $\rho_v =$ volume charge density. (vii) Draw the graph for electric field intensity ε. (viii) $x_{n_0} =$ depletion width on the n-side. Take $n_i = 1.5 \times 10^{10}\ /cm^3$, and $\epsilon_r = 11.8$. (2+2+2+2+2+2+2+1 Marks)
   A: (i) $V_0 = V_T\ ln\frac{N_AN_D}{n_i^2} = 26 \times 10^{-3}\ ln\frac{10^{16} \times 4 \times 10^{18}}{(1.5 \times 10^{10})^2} = 0.85\ V$ (ii) $W = \left(\frac{2\epsilon_r\epsilon_0V_0}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\right)^{\frac{1}{2}} = 3.34 \times 10^{-5}\ cm$. (iii) $x_{p_0} = \frac{N_DW}{N_A+N_D} = 3.331 \times 10^{-5}\ cm$ (iv) $Q^+ = qx_{p_0}N_A \times \pi(0.02/2)^2 = 6.655 \times 10^{-9}\ C$ (v) $\varepsilon_0 = -\frac{qN_Ax_{p_0}}{\epsilon_r\epsilon_0} = -5.06 \times 10^4\ V/cm$ (vi) and (vii) graphs are shown in the Fig.1(a) and (b). (viii) $x_{n_0} = W - x_{p_0} = 3 \times 10^{-8}\ cm = 3^oA$

*Problem **II**.*

1. (a) Define different modes of operation for BJT. (3 Marks)
   A: Refer to the lecture notes-6, (LN-6) table-1.
   (b) For an *npn* transistor operated with collector base junction reverse-biased by at least few volts, with emitter open circuited. Determine the following, (i) Mode of operation, (ii) V_{EB}, (iii) collector and base currents, take $I_{C0} = 10^{-15}\ A$, $I_{E0} = 2 \times 10^{-15}\ A$, $\alpha_F = 0.99$. (*Hint:* Use reciprocity condition) (iv) Find β_F. (4+4+3+1 Marks).
   A: Refer to the LN-6 example problem. (iv) $\beta_F = \frac{\alpha_F}{1-\alpha_F} = 49.74$

2. (a) Write Continuity equation for holes. (1.5 Marks)
   A: Refer to LN-2, Eqn.(33)

(b) Define Reverse saturation current (I_0). (1.5 Marks)
A: Refer to LN-4, Eqn.(17)

(c) Draw Ebers-Moll equivalent of *npn* transistor and write the equations for I_E and I_C in terms of V_{BE} and V_{CE}. (3 Marks)
A: Refer to LN-5, Fig.9, Eqns.(14) and (15)

(d) Draw the equivalent DC model for the *npn* BJT with CE configuration, operating in the forward-active region. (1 Mark)
A: Refer to LN-7,Fig.5(a)

(e) Draw the *I*-*V* characteristics of the *p*-*n* junction and explain each region (forward and reverse bias) in the graph using diode equation. (3 Marks)
A: Refer to LN-4, The Volt-Ampere Characteristics of Diode.

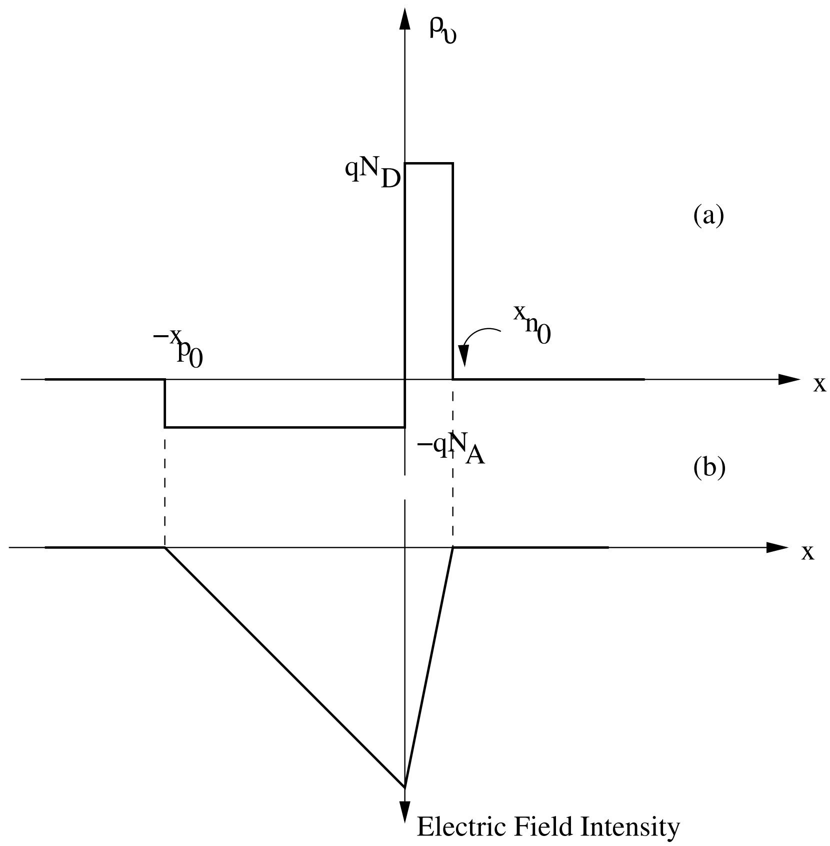

Figure 1: (a) Charge Density ρ_v (b) Electric Field Intensity (ε)