MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Department of Electrical Engineering and Computer Science

6.012 ELECTRONIC DEVICES AND CIRCUITS

Answers to Exam 1 - Fall 2003

Problem 1:

a) $p_o \quad N_A$. Thus: $N_A = 5 \times 10^{17}$ cm^{-3}
$N_A = N_a - N_d$, and so $N_a = N_A + N_d = 5 \times 10^{17} + 2 \times 10^{16} = 5.2 \times 10^{17}$ cm^{-3}

b) $n_o = n_i^2 / N_A = (10^7)^2 / (5\text{x}10^{17}) = 0.2 \times 10^{-3}$ cm^{-3}

c) $\phi = (kT/q) \ln (N_A / n_i) = 0.06 \log (5 \times 10^{17} / 10^7) = 0.06 \log (5 \times 10^{10})$
$= 0.06 \times (10 + \log 5) = 0.06 \times 10.7 = 0.642$ V

d) $\sigma_o \quad q\, \mu_h\, N_A = 1.6 \times 10^{-19} \times 3 \times 10^2 \times 5 \times 10^{17} = 24$ S/cm

e) $\sigma \quad q\, \mu_h\, N_A + q\mu_h n' + q\mu_e p' = q\, \mu_h\, N_A + q(\mu_h + \mu_e)n'$
Also $\sigma = 1.01\, \sigma_o = 1.01\, q\, \mu_h\, N_A$ is given.
Thus: $n' = (\sigma - q\, \mu_h\, N_A) / q(\mu_h + \mu_e) = 0.01\, q\, \mu_h\, N_A / q(\mu_h + \mu_e)$
$= (10^{-2} \times 2.4 \times 10^1) / [1.6 \times 10^{-19} \times (300 + 4000)]$
$= (10^{-2} \times 2.4 \times 10^1) / (1.6 \times 10^{-19} \times 4.3 \times 10^3) = 0.35 \times 10^{15}$ cm^{-3}

f) $n' \quad p' \quad G_L \tau_{min}$ so $G_L = p' / \tau_{min}$
Thus: $G_L = 3.5 \times 10^{23} =$ hole-electron pairs/cm^3-s

g) The excess portion decays with $\sigma(t) = \sigma_o [1 + 0.01 \exp(-t/\tau_{min})]$

h) $L_{min} = (D_{min} \tau_{min})^{1/2} = (100 \times 10^{-9})^{1/2} = 3.16 \times 10^{-4}$ cm $= 3.16$ µm

Problem 2:

a) i) $p(w_n) = p_{on} = n_i^2 / N_{Dn} = 10^{20} / 10^{16} = 10^4$ cm^{-3}

ii) $p(x_n) = p_{on} \exp(V_{AB}/kT) = 10^4 \times 10^{0.48/0.06} = 10^4 \times 10^8 = 10^{12}$ cm^{-3}

iii) $q_{QNR,n\text{-}side} = q\, A\, [p'(x_n) - p'(w_n)]\, w_n / 2 \quad q\, A\, p'(x_n)\, w_n / 2$
$= 1.6 \times 10^{-19} \times 10^{-4} \times 10^{12} \times 2 \times 10^{-4} / 2 = 1.6 \times 10^{-8}$ Coul

iv) $J_h(0) = J_h(w_n) \quad - q\, D_h\, dp'/dx \quad q\, D_h\, p'(x_n) / w_n$
$= 1.6 \times 10^{-19} \times 15 \times 10^{12} / (2 \times 10^{-4}) = 1.2 \times 10^{-2}$ A/cm^2

b) i) Given that $n(-x_p) = 0.1\, p(x_n)$, which should tell you $N_{Ap} = 10\, N_{Dn} = 10^{17}$ cm^{-3}, but if not, begin with:
$n(-x_p) = 0.1\, p(x_n) = 0.1\, (n_i^2 / N_{Dn})[\exp(q\, 0.48/kT) - 1]$
$= 0.1\, (10^{20} / 10^{16})\, 10^8 = 10^{11}$

Next: $n(-x_p) = (n_i^2 / N_{Ap})[\exp(qV_{AB} / kT) - 1]$

so $N_{Ap} = [n_i^2 / n(-x_p)][\exp(qV_{AB} / kT) - 1] = (10^{20} / 10^{11})\ 10^8 = 10^{17}\ cm^{-3}$

ii) Area under profile is proportional to peak. Thus $n(-x_p) = 0.1\ p(x_n)$ implies immediately that $|q_{QNR,p\text{-}side} / q_{QNR,n\text{-}side}| = 0.1$

iii) $J_e(0) / J_h(0) = [qD_e n'(-x_p) / w_p] / [qD_h p'(x_n) / w_n] = [D_e / D_h][n'(-x_p) / p'(x_n)][w_n / w_p]$

$= [16 / 6]\ 0.1 \times 1 = 4 / 15 = 0.2667$

iv) $\Delta\phi = \phi_b - V_{AB}$

$\phi_b = (kT / q) \ln [(N_{Dn} N_{Ap}) / n_i^2] = 0.06 \log[10^{13}] = 0.78$ V

$V_{AB} = 0.48$ V is given. Thus: $\Delta\phi = 0.78 - 0.48 = 0.3$ V

Problem 3:

a) i) $J_e(x) = qD_e\ dn' / dx$ and $D_e = \mu_e (kT / q) = 1600 \times 0.025 = 40\ cm^2 / s$

$-w_p < x < -w_p / 2$: $J_e(x) = 1.6 \times 10^{-19} \times 4 \times 10 \times 10^{14} / 10^{-4} = 6.4\ A / cm^2$

$-w_p / 2 < x < -x_p$: $J_e(x) = 0$

ii) $\Delta J_e(x)$ @ $x = -w_p / 2 = qM$

Thus $M = 6.4 / (1.6 \times 10^{-19}) = 4 \times 10^{19}$ hole-electron pairs / s-cm^2

b) i) At ohmic contact excess is zero. Thus: $p'(w_p) = 0$

ii) The doping on the n-side is half that on the p-side, thus the minority population will be twice as great, since $n'(x_p) \propto n_i^2 / N_{Ap}$ and $p'(-x_n) \propto n_i^2 / N_{Dn}$.
Thus: $p'(x_p) = 2 \times 10^{14}\ cm^{-3}$.

iii) $J_h(x) = qD_h\ dp' / dx$ and $D_h = 600 \times 0.025 = 15\ cm^2 / s$

$x_n < x < w_n$: $J_h(x) = 1.6 \times 10^{-19} \times 1.5 \times 10 \times 2 \times 10^{14} / 2 \times 10^{-4} = 2.8\ A / cm^2$

c) $I_D = A\ J_{TOT} = A\ [J_e(-x_p) + J_h(x_n)] = 10^{-4}\ [\ 0 + 2.8] = 2.8 \times 10^{-4}$ Amps

d) $n'(-x_n) = 10^{14} = (n_i^2 / N_{Ap})[\exp(qV_{AB} / kT) - 1]$ $(n_i^2 / N_{Ap}) \exp(qV_{AB} / kT)$

$= 10^3 \exp(qV_{AB} / kT)$

Thus: $V_{AB} = 0.06 \times \log\{10^{11}] = 0.06 \times 11 = 0.66$ V

Average/Standard deviation:

Problem 1	31.1	4.3
Problem 2	24.1	5.1
Problem 3	24.5	7.5
Total	79.7	13.9

Distribution to nearest 5: