Numericals: Electronic Devices

1. A Si abrupt junction in thermal equilibrium at $T = 300K$ is doped such that $E_C - E_F = 0.21eV$ in the n region and $E_F - E_V = 0.18eV$ in the p region. (Given: $N_C = 2.8 \times 10^{19}/cm^3$, $N_V = 1.04 \times 10^{19}/cm^3$)
(a) Draw the EBD of pn junction in equilibrium
(b) Determine impurity doping concentrations in each region
(c) Find V_{bi}

[Ans: $N_d = 8.69 \times 10^{15}/cm^3$ (n-region), $N_a = 1.02 \times 10^{16}/cm^3$ (p-region)
$V_{bi} = 0.694V$]

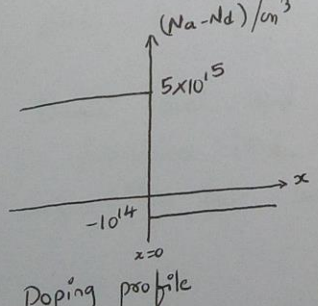
2. An abrupt Si pn junction has dopant concentration of $N_a = 2 \times 10^{16}/cm^3$ and $N_d = 2 \times 10^{15}/cm^3$ at $T = 300K$.
Calculate i) V_{bi} ii) W at $V_R = 0$ and $V_R = 8V$ and iii) the maximum E-field in the space-charge region at $V_R = 0$ and $V_R = 8V$.
Comment on result obtained for $V_R = 0$ & $V_R = 8V$

[Ans: For $V_R = 0$; $W = 0.68 \times 10^{-4} cm$, $V_{bi} = 0.673V$
For $V_R = 8V$; $W = 2.44 \times 10^{-4} cm$
For $V_R = 0$, $E_m = 19.79 \times 10^4 V/cm$
For $V_R = 8V$, $E_m = 71.09 \times 10^4 V/cm$]

3. Consider a uniformly doped Si pn junction with $N_a = 5 \times 10^{17}/cm^3$ and $N_d = 10^{17}/cm^3$. The junction has a cross-sectional area of $10^{-4} cm^2$ and has an applied reverse-bias voltage of $V_R = 5V$.
Find a) V_{bi} b) x_n, x_p, W c) E_m and d) total junction capacitance.

[Ans: $V_{bi} = 0.858V$
$W = 29.64 \times 10^{-6} cm$
$x_n = 24.7 \times 10^{-6} cm$, $x_p = 4.94 \times 10^{-6} cm$
$E_m = 3.95 \times 10^5 V/cm$, $C_j = 3.37 \times 10^{-12} F = 3.37 pF$]

4.



Doping profile

A Si pn junction at $T = 300K$ has the doping profile shown here.
Calculate a) V_{bi} b) x_n and x_p at zero bias

[Ans: $V_{bi} = 0.559V$
$x_n = 261.72 \times 10^{-6} cm$
$x_p = 5.23 \times 10^{-6} cm$]

[5.] Consider an ideal pn junction diode at $T = 300K$ operating in the forward-bias region. Calculate the change in diode voltage that will cause a factor of 10 increase in current.

[Ans: Change in diode voltage $(V_1 - V_2)$ = 59.86mV]

[6.] Consider a p^+n Si diode at $T = 300K$ with $N_a = 10^{18}/cm^3$ and $N_d = 10^{16}/cm^3$, $D_p = 12 cm^2/s$, $\tau_{po} = 10^{-7} sec$, $A = 10^{-4} cm^2$. Calculate the reverse saturation current and the diode current at a forward-bias voltage of 0.5V

[Ans: $I_s = 3.94 \times 10^{-15} A$; Hint: For a p^+n Si diode $I_s = Aqn_i^2 \left[\frac{1}{N_d} \sqrt{\frac{D_p}{\tau_{po}}} \right]$

$I_D = 8.85 \times 10^{-7} A$]

[7.] A Si pn junction diode at $T = 300K$ has $A = 10^{-2} cm^2$. The length of the p-region is 0.2cm and the length of n-region is 0.1cm. $N_d = 10^{15}/cm^3$, $N_a = 10^{16}/cm^3$. Given: $\mu_p = 480 \, cm^2/V\text{-}s$, $\mu_n = 1350 \, cm^2/V\text{-}s$. Find a) approximately the series resistance of the diode.

[Ans: $R_s = R_n + R_p$, $R_n = 46.3\Omega$, $R_p = 26\Omega$, $R_s = 72.3\Omega$

R_s: Total series resistance

Hint: Use $R = \frac{\rho L}{A} = \frac{L}{\sigma A}$]

[8.] An ideal Si pn junction diode at $T = 300K$ is forward-biased at $V_a = 20mV$. The reverse saturation current is $I_s = 10^{-13} A$. Calculate the small-slg diffusion resistance.

[Ans: $r_d = 1.2 \times 10^{11} \Omega$ Hint: $\frac{1}{r_d} = \frac{dI_D}{dV_a}$]

9 The critical E-field for breakdown is Si is $E_{crit} = 4\times10^5$ V/cm. 03
Determine the max n type doping conc^n in an abrupt p+n junction such that the breakdown voltage is 30V.

[Ans: $N_B = N_d = 1.73\times10^{16}/cm^3$, Hint: $V_B = \frac{\epsilon_s E_{crit}^2}{2q N_B}$]

10. Find cut-off freq^n of a BJT and beta-cut-off freq^n if $\beta = 100$, emitter to-collector transist time is $104 \pi \times 10^{-12}$ sec.

[Ans: $f_T = 1.53$ GHz , $f_\beta = 15.3$ MHz]

11. A Si npn BJT is uniformly doped & biased in forward-active region. Given: $W_B = 0.8\mu m$, $N_E = 5\times10^{17}/cm^3$, $N_B = 10^{16}/cm^3$, $N_C = 10^{15}/cm^3$

i) Calculate the values of p_{E0} , n_{B0} and p_{C0}
ii) For $V_{BE} = 0.625V$, determine n_B at $x = 0$

[Ans: $p_{E0} = 4.5\times10^2/cm^3$; $n_B(0) = 6.2\times10^{14}/cm^3$
$n_{B0} = 2.25\times10^4/cm^3$
$p_{C0} = 2.25\times10^5/cm^3$]

12. The following currents are measured in a uniformly doped npn BJT:

$I_{nE} = 1.2mA$ $I_{pE} = 0.1mA$
$I_{nC} = 1.18mA$ $I_R = 0.2mA$
$I_G = 0.001mA$ $I_{pc0} = 0.001mA$

Find a) Emitter injection efficiency (γ) b) Base transport factor (b or α_T)
c) Recombination factor (δ) d) α e) β

[Ans: $\gamma = 0.923$, $b = 0.983$, $\delta = 0.867$
$\alpha = 0.7867$, $\beta = 3.68$]

13. In a BJT, base transit time is 20% of total delay time. The base width is $0.5\mu m$ & $D_B = 20 cm^2/s$. Find cut-off freq^n of transistor

[Ans: $f_T = 509$ MHz]

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