SOLUTIONS TO TEST 1

Q1(a).

(1) $n_i = 2.5 \times 10^{13}/cm^3$ (at 300K)

$\mu_n = 3800\, cm^2/Vs$

$\mu_p = 1800\, cm^2/Vs$

(i) Prove that $\rho_i = 45\, \Omega cm$ (at 300K)

$\sigma = ne\mu_n + pe\mu_p$

$= e(n\mu_n + p\mu_p)$

For intrinsic semiconductor, $n = p = n_i$

$\therefore \sigma = n_i e(\mu_n + \mu_p) = 2.5 \times 10^{13}/\cancel{cm^3} \times 1.6 \times 10^{-19} C \times (3800 + 1800)\cancel{cm^2}/Vs$

$= 0.0224 \frac{C}{cmVs}$

$= 0.0224 \frac{A\cancel{s}}{cmV\cancel{s}}$

$= 0.0224 \frac{1}{cm\Omega}$

$\rho_i = \frac{1}{0.0224} \Omega cm$

$= 44.64\, \Omega cm$

$\simeq 45\, \Omega cm$ # proven

Q1 (b) and (c).

(ii) Donor Dopant = 1 atom for every 10^8 Ge atom.

There are $4.4 \times 10^{22}/cm^3$ of Ge atoms

$\therefore$ Dopant density $= 4.4 \times 10^{14}/cm^3$

$N_D = 4.4 \times 10^{14}/cm^3$

$n \simeq 4.4 \times 10^{14}/cm^3$

$$p = \frac{n_i^2}{N_D} = \frac{(2.5 \times 10^{13}/cm^3)^2}{4.4 \times 10^{14}/cm^3} = 1.42 \times 10^{12}/cm^3$$

$$\sigma_{ex} = e(n\mu_n + p\mu_p) = 1.6 \times 10^{-19} C(4.4 \times 10^{14}/cm^3 \times 3800\, cm^2/Vs + 1.42 \times 10^{12}/cm^3 \times 1800\, cm^2/Vs)$$

$$= 0.2679\, C/cmVs$$

$$= 0.2679 \frac{As}{cmVs} = 0.2679/cm\Omega$$

$\rho_{ex} = 3.7327\, \Omega cm \simeq 3.7\, \Omega cm$ # proven

or $\sigma_{ex} = N_D e \mu_n = 4.4 \times 10^{14}/cm^3 \times 1.6 \times 10^{-19} C \times 3800\, cm^2/Vs = 0.2675\, C/cmVs$

$= 0.2675 \frac{As}{cmVs}$

$= 0.2675/\Omega cm$

(iii) $\sigma = e(n\mu_n + p\mu_p) = 100/\Omega cm$

$$\frac{\sigma}{e} = n\mu_n + p\mu_p$$

$$= \frac{n_i^2}{N_A}\mu_n + N_A\mu_p$$

$$= \frac{1}{N_A}(n_i^2\mu_n + N_A^2\mu_p)$$

$$\frac{N_A\sigma}{e} = n_i^2\mu_n + N_A^2\mu_p$$

$$\underbrace{N_A^2\mu_p}_{a} - \underbrace{\frac{\sigma}{e}N_A}_{b} + \underbrace{n_i^2\mu_n}_{c} = 0$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{+\frac{\sigma}{e} \pm \sqrt{\left(\frac{\sigma}{e}\right)^2 - 4(\mu_p) n_i^2 \mu_n}}{2(\mu_p)}$$

$$N_A = \frac{\frac{\sigma}{e} + \sqrt{\left(\frac{\sigma}{e}\right)^2 - 4(\mu_p) n_i^2 \mu_n}}{2\mu_p}$$

or $$\frac{\frac{\sigma}{e} - \sqrt{\left(\frac{\sigma}{e}\right)^2 - 4(\mu_p) n_i^2 \mu_n}}{2\mu_p}$$

$$\sqrt{\left(\frac{\sigma}{e}\right)^2 - 4(\mu_p) n_i^2 \mu_n} = \sqrt{\left(\frac{100/\Omega cm}{1.6\times10^{-19}C}\right)^2 - 4\left(1800 cm^2/Vs\right)\left(2.5\times10^{13}/cm^3\right)^2 \times 3800 cm^2/Vs}$$

$$= \sqrt{3.9062\times10^{41}/(\Omega cm C)^2 - 1.71\times10^{34}\left(\frac{cm^2}{Vs}\right)^2\left(\frac{1}{cm^3}\right)^2}$$

$$= \sqrt{3.9062\times10^{41}/(\Omega cm C)^2}$$

$$= 6.25\times10^{20}/\Omega cm C$$

$$\frac{\sigma}{e} = \frac{100/\Omega cm}{1.6\times10^{-19}C} = 6.25\times10^{20}/\Omega cm C$$

$$N_A \neq \frac{\frac{\sigma}{e} - \sqrt{\left(\frac{\sigma}{e}\right)^2 - 4(\mu_p) n_i^2 \mu_n}}{2\mu_p}$$ as the answer will be 0.

$$\frac{cm^4}{(Vs)^2} \times \frac{1}{cm^6} = \frac{1}{(Vs\,cm)^2} = \frac{1}{\left(\frac{VC}{A} cm\right)^2} = \frac{1}{(\Omega cm C)^2}$$

$C = As$

$s = \frac{C}{A}$

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$$\therefore N_A = p = \frac{\frac{I}{e} + \sqrt{\left(\frac{I}{e}\right)^2 - 4\mu_p n_i^2 \mu_n}}{2\mu_p}$$

$$= \frac{\cancel{2} \times 6.25 \times 10^{20} / \Omega\,cm\,C}{\cancel{2} \times 1800\ cm^2/Vs}$$

$$= 3.4722 \times 10^{17} \frac{Vs}{\Omega\,cm\,C\,cm^2} \rightarrow \frac{V\cancel{s}}{\Omega\,cm^3\,A\cancel{s}} = \frac{\cancel{\Omega}}{\cancel{\Omega}\,cm^3}$$

$$= 3.4722 \times 10^{17} / cm^3 \;\#$$

$$n = \frac{n_i^2}{N_A} = \frac{(2.5 \times 10^{13} / cm^3)^2}{3.4722 \times 10^{17} / cm^3} = 1{,}800{,}011{,}520 / cm^3$$

$\#$

If we're assuming $p \simeq N_A$ and $\sigma_{ext} = pe\mu_p$

$$100 / \Omega\,cm = p \times 1.6 \times 10^{-19}\,C \times 1800\,cm^2/Vs$$

$$\therefore p = \frac{100 / \Omega\,cm}{1.6 \times 10^{-19}\,C \times 1800\,cm^2/Vs}$$

$$= 3.4722 \times 10^{17} \left(\frac{1 \times Vs}{\Omega\,cm\,C\,cm^2}\right) \rightarrow \frac{V\cancel{s}}{\Omega\,cm^3\,A\cancel{s}} = \frac{\cancel{\Omega}}{\cancel{\Omega}\,cm^3}$$

$$= 3.4722 \times 10^{17} / cm^3 \;\#$$

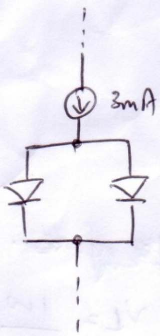
$$n = \frac{n_i^2}{N_A} = \frac{(2.5 \times 10^{13} / cm^3)^2}{3.4722 \times 10^{17} / cm^3} = 1{,}800{,}011{,}520 / cm^3$$

$\#$

(4)

The purpose of showing the long way of deriving the answer in Q1 (b) and (c) is to prove that the results from both the long way as well as when the assumptions are made are very close. If the question states that assumptions can be made, then use the short way to answer.

Q2 (a) and (b).



$$\frac{A_{D2}}{A_{D1}} = 5$$

$$I = I_S\left(e^{V/V_T} - 1\right)$$

$$I = Aq\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)\left(e^{V/V_T} - 1\right)$$

$$D_p = \mu_p V_T,\ D_n = \mu_n V_T,\ p_n = \frac{n_i^2}{N_D},\ n_p = \frac{n_i^2}{N_A}$$

$$L_p = \sqrt{D_p \tau_p},\ L_n = \sqrt{D_n \tau_n}$$

Hence, if the doping level and the fabrication are the same for both diodes, all the parameter above are equivalent.

$$I_{D2} = A_{D2}\, q\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)\left(e^{V/V_T} - 1\right)$$

$$I_{D1} = A_{D1}\, q\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)\left(e^{V/V_T} - 1\right)$$

$$\frac{I_{D1}}{I_{D2}} = \frac{A_{D1}\, \cancel{q\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)\left(e^{V/V_T} - 1\right)}}{A_{D2}\, \cancel{q\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)\left(e^{V/V_T} - 1\right)}} = \frac{1}{5} \ \#$$

$$T = 300^\circ K,\ V_T = \frac{kT}{q} = \frac{1.381 \times 10^{-23}\ J/^\circ K \times 300^\circ K}{1.6 \times 10^{-19} C} = 0.02589\ J/C$$

$$= 0.02589 \text{ Volt}. \qquad = 0.02589 \frac{J}{As} = 0.02589 \frac{J\Omega}{VS}$$

$$I_{D1} = \underbrace{A_{D1}\, q\left(\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right)}_{I_{SD1}}\left(e^{V/V_T} - 1\right)$$

$$0.6m = 10^{-15}\left(e^{V/V_T} - 1\right) \qquad \text{since } I_{D1} = \frac{1}{5}(3m) = 0.6mA$$

$$e^{V/V_T} = 6 \times 10^{11}$$

$$V = 0.7021 \text{ Volt} \ \#$$

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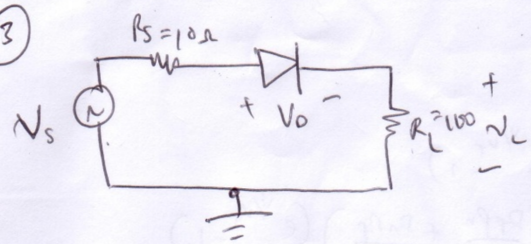
(C)The diodes are Silicon based on the 0.7021 V across them when they are forward biased.

Q3.

(3)



diod will be fb if $v_s > 0$.

If diod is fb (s/c), $v_s = \underbrace{iR_s}_{v_{RS}} + \underbrace{iR_L}_{v_L}$

$= i(10 + 100)$

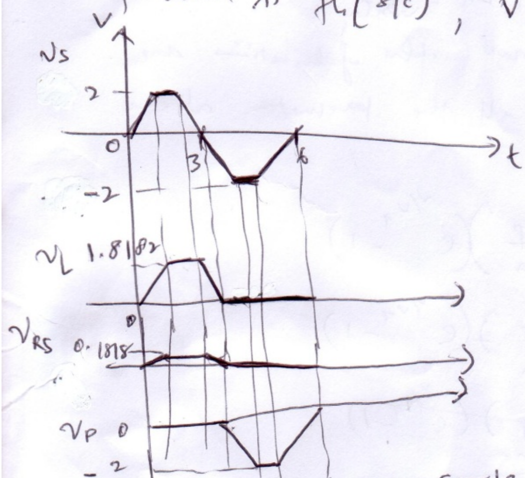
$= 110i$

$v_L = \frac{100}{110} \times v_s$

$= 0.9091\, v_s$

$v_{RS} = \frac{10}{110} \times v_s$

$= 0.0909 v_s$



At the peak value,

$2 = 110i$

$i = 18.1818\,mA$

$v_L = 1.8182V$.

or $v_L = 0.9091(2) = 1.8182\,V$.

$V_{RS} = 0.0909(2) = 0.1818\,V$

If v_s is at −ve cycle, diod rb (o/c). $v_L = 0$.

When $v_L = 0$, katod is 0 v and anode is v_s.

(6)