**Chapter 1**
**Exercise Problems**

**EX1.1**

$$n_i = BT^{3/2} \exp\left(\frac{-E_g}{2kT}\right)$$

GaAs: $n_i = \left(2.1\times10^{14}\right)(300)^{3/2} \exp\left(\frac{-1.4}{2\left(86\times10^{-6}\right)(300)}\right)$ or $\underline{n_i = 1.8\times10^{6}\ cm^{-3}}$

Ge: $n_i = \left(1.66\times10^{13}\right)(300)^{3/2} \exp\left(\frac{-0.66}{2\left(86\times10^{-6}\right)(300)}\right)$ or $\underline{n_i = 2.40\times10^{13}\ cm^{-3}}$

**EX1.2**

(a) majority carrier: holes, $p_o = 10^{17}\ cm^{-3}$ minority carrier: electrons,

$$n_o = \frac{n_i^2}{p_o} = \frac{\left(1.5\times10^{10}\right)^2}{10^{17}} = 2.25\times10^{3}\ cm^{-3}$$

(b) majority carrier: electrons, $n_o = 5\times10^{15}\ cm^{-3}$ minority carrier: holes,

$$p_o = \frac{n_i^2}{n_o} = \frac{\left(1.5\times10^{10}\right)^2}{5\times10^{15}} = 4.5\times10^{4}\ cm^{-3}$$

**EX1.3**

For n-type, drift current density $J \cong e\mu_n n\mathrm{E}$ or $200 = \left(1.6\times10^{-19}\right)(7000)\left(10^{16}\right)\mathrm{E}$ which yields $\mathrm{E} = 17.9\ V/cm$

**EX1.4**

Diffusion current density due to holes:

$$J_p = -eD_p \frac{dp}{dx}$$

$$= -eD_p\left(10^{16}\right)\left(\frac{-1}{L_p}\right)\exp\left(\frac{-x}{L_p}\right)$$

(a) At $x = 0$

$$J_p = \frac{\left(1.6\times10^{-19}\right)(10)\left(10^{16}\right)}{10^{-3}} = 16\ A/cm^2$$

(b) At $x = 10^{-3}\ cm$

$$J_p = 16\exp\left(\frac{-10^{-3}}{10^{-3}}\right) = 5.89\ A/cm^2$$

**EX1.5**

$$V_{bi} = V_T \ln\left[\frac{N_a N_d}{n_i^2}\right] = (0.026)\ln\left[\frac{\left(10^{16}\right)\left(10^{17}\right)}{\left(1.8\times10^{6}\right)^2}\right]$$ or $V_{bi} = 1.23\ V$

**EX1.6**

$$C_j = C_{jo}\left(1 + \frac{V_R}{V_{bi}}\right)^{-1/2}$$

and

$$V_{bi} = V_T \ln\left[\frac{N_a N_d}{n_i^2}\right]$$

$$= (0.026)\ln\left[\frac{(10^{17})(10^{16})}{(1.5\times10^{10})^2}\right] = 0.757\ V$$

Then $0.8 = C_{jo}\left(1+\frac{5}{0.757}\right)^{-1/2} = C_{jo}(7.61)^{-1/2}$

or

$C_{jo} = 2.21\ pF$

**EX1.7**

$$i_D = I_S\left[\exp\left(\frac{v_D}{V_T}\right)-1\right]$$

so $10^{-3} = (10^{-13})\left[\exp\left(\frac{v_D}{0.026}\right)-1\right]$

Solving for the diode voltage, we find $v_D = (0.026)\ln\left[\frac{10^{-3}}{10^{-13}}+1\right]$

or

$v_D \cong (0.026)\ln(10^{10})$

which yields

$v_D = 0.599\ V$

**EX1.8**

$V_{PS} = I_D R + V_D$ and $I_D \cong I_S \exp\left(\frac{V_D}{V_T}\right)$

so $4 = I_D(4\times10^3)+V_D \Rightarrow I_D = \frac{(4-V_D)}{4\times10^3}$

and

$I_D = (10^{-12})\exp\left(\frac{V_D}{0.026}\right)$

By trial and error, we find $I_D \cong 0.864\ mA$ and $V_D \cong 0.535\ V$

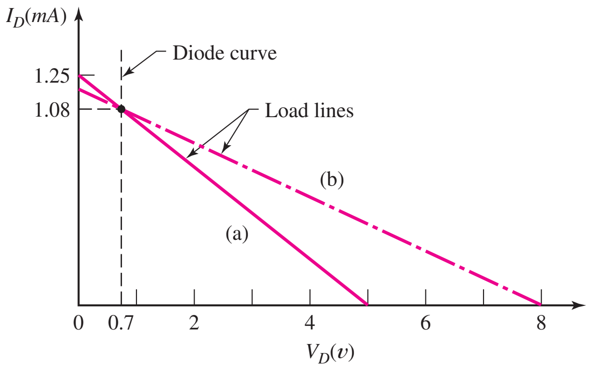
**EX1.9**

(a) $I_D = \frac{V_{PS}-V_\gamma}{R} = \frac{5-0.7}{4} \Rightarrow I_D = 1.08\ mA$

(b) $I_D = \frac{V_{PS}-V_\gamma}{R} \Rightarrow R = \frac{V_{PS}-V_\gamma}{I_D}$

Then $R = \frac{8-0.7}{1.075} = 6.79\ k\Omega$

(c)




**EX1.10**
PSpice analysis

**EX1.11**

Quiescent diode current $I_{DQ} = \dfrac{V_{PS} - V_\gamma}{R} = \dfrac{10 - 0.7}{20} = 0.465\ mA$

Time-varying diode current:

We find that $r_d = \dfrac{V_T}{I_{DQ}} = \dfrac{0.026}{0.465} = 0.0559\ k\Omega$

Then $i_d = \dfrac{v_I}{r_d + R} = \dfrac{0.2 \sin \omega t}{0.0559 + 20} \cdot \dfrac{(V)}{(k\Omega)}$ or $i_d = 9.97 \sin \omega t\,(\mu A)$

**EX1.12**

For the pn junction diode, $V_D \cong V_T \ln\left(\dfrac{I_D}{I_S}\right) = (0.026)\ln\left(\dfrac{1.2\times 10^{-3}}{4\times 10^{-15}}\right)$ or $V_D = 0.6871\ V$

The Schottky diode voltage will be smaller, so $V_D = 0.6871 - 0.265 = 0.4221\ V$

Now $I_D \cong I_S \exp\left(\dfrac{V_D}{V_T}\right)$

or

$$I_S = \frac{1.2\times 10^{-3}}{\exp\left(\dfrac{0.4221}{0.026}\right)} \Rightarrow I_S = 1.07\times 10^{-10}\ A$$

**EX1.13**

$P = I \cdot V_Z \Rightarrow 10 = I(5.6) \Rightarrow I = 1.79\ mA$

Also $I = \dfrac{10 - 5.6}{R} = 1.79 \Rightarrow R = 2.46\ k\Omega$

**Test Your Understanding Exercises**

**TYU1.1**
(a) $T = 400K$

Si: $n_i = BT^{3/2} \exp\left(\dfrac{-E_g}{2kT}\right)$

$$n_i = (5.23\times 10^{15})(400)^{3/2} \exp\left[\frac{-1.1}{2(86\times 10^{-6})(400)}\right]$$

or

$n_i = 4.76\times 10^{12}\ cm^{-3}$

Ge: $n_i = \left(1.66\times10^{15}\right)\left(400\right)^{3/2} \exp\left[\frac{-0.66}{2\left(86\times10^{-6}\right)\left(400\right)}\right]$

or

$n_i = 9.06\times10^{14}\ cm^{-3}$

GaAs:

$n_i = \left(2.1\times10^{14}\right)\left(400\right)^{3/2} \exp\left[\frac{-1.4}{2\left(86\times10^{-6}\right)\left(400\right)}\right]$

or

$n_i = 2.44\times10^{9}\ cm^{-3}$

(b) $T = 250\ K$

Si: $n_i = \left(5.23\times10^{15}\right)\left(250\right)^{3/2} \exp\left[\frac{-1.1}{2\left(86\times10^{-6}\right)\left(250\right)}\right]$

or

$n_i = 1.61\times10^{8}\ cm^{-3}$

Ge: $n_i = \left(1.66\times10^{15}\right)\left(250\right)^{3/2} \exp\left[\frac{-0.66}{2\left(86\times10^{-6}\right)\left(250\right)}\right]$

or

$n_i = 1.42\times10^{12}\ cm^{-3}$

GaAs: $n_i = \left(2.10\times10^{14}\right)\left(250\right)^{3/2} \exp\left[\frac{-1.4}{2\left(86\times10^{-6}\right)\left(250\right)}\right]$

or

$n_i = 6.02\times10^{3}\ cm^{-3}$

**TYU1.2**

(a) $n = 5\times10^{16}\ cm^{-3},\ p <<< n,$ so $\sigma \cong e\mu_n n = \left(1.6\times10^{-19}\right)\left(1350\right)\left(5\times10^{16}\right)$

or

$\sigma = 10.8\left(\Omega - cm\right)^{-1}$

(b) $p = 5\times10^{16}\ cm^{-3},\ n <<< p,$ so $\sigma \cong e\mu_p p = \left(1.6\times10^{-19}\right)\left(480\right)\left(5\times10^{16}\right)$

or

$\sigma = 3.84\left(\Omega - cm\right)^{-1}$

**TYU1.3**

$J = \sigma E = \left(10\right)\left(15\right)$ or $J = 150\ A/cm^2$

**TYU1.4**

(a) $J_n = eD_n \frac{dn}{dx} = eD_n \frac{\Delta n}{\Delta x}$ so $J_n = \left(1.6\times10^{-19}\right)\left(35\right)\left(\frac{10^{15} - 10^{16}}{0 - 2.5\times10^{-4}}\right)$

or

$J_n = 202\ A/cm^2$

(b) $J_p = -eD_p \frac{dp}{dx} = -eD_p \frac{\Delta p}{\Delta x}$ so $J_p = -\left(1.6\times10^{-19}\right)\left(12.5\right)\left(\frac{10^{14} - 5\times10^{15}}{0 - 4\times10^{-4}}\right)$

or

$J_p = -24.5\ A/cm^2$

**TYU1.5**

(a) $n_o = N_d = 8 \times 10^{15}\ cm^{-3}$

$$p_o = \frac{n_i^2}{n_o} = \frac{\left(1.5 \times 10^{10}\right)^2}{8 \times 10^{15}} = 2.81 \times 10^4\ cm^{-3}$$

(b) $n = n_o + \delta n = 8 \times 10^{15} + 0.1 \times 10^{15}$

or

$n = 8.1 \times 10^{15}\ cm^{-3}$

$p = p_o + \delta p = 2.81 \times 10^4 + 10^{14}$

or

$p \cong 10^{14}\ cm^{-3}$

**TYU1.6**

(a) $V_{bi} = V_T \ln\left[\frac{N_a N_d}{n_i^2}\right]$ so $V_{bi} = (0.026)\ln\left[\frac{\left(10^{15}\right)\left(10^{17}\right)}{\left(1.5 \times 10^{10}\right)^2}\right] = 0.697\ V$

(b) $V_{bi} = (0.026)\ln\left[\frac{\left(10^{17}\right)\left(10^{17}\right)}{\left(1.5 \times 10^{10}\right)^2}\right] = 0.817\ V$

**TYU1.7**

(a) $I_D = I_S\left[\exp\left(\frac{V_D}{V_T}\right) - 1\right]$

$I_D \cong 10^{-14} \exp\left(\frac{0.5}{0.026}\right)$

Then, for

$V_D = 0.5\ V,\ I_D = 2.25\ \mu A$

$V_D = 0.6\ V,\ I_D = 0.105\ mA$

$V_D = 0.7\ V,\ I_D = 4.93\ mA$

(b) $I_D \cong -I_S = -10^{-14}\ A$

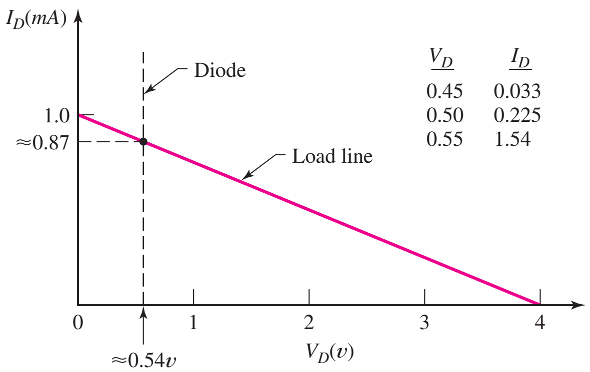
for both cases.

**TYU1.8**

$\Delta T = 100C$ so $\Delta V_D \cong 2 \times 100 = 200\ mV$

Then $V_D = 0.650 - 0.20 = 0.450\ V$

**TYU1.9**




**TYU1.10**

$P = I_D V_D \Rightarrow 1.05 = I_D(0.7)$ so $I_D = 1.5\ mA$

Now $R = \dfrac{V_{PS} - V_\gamma}{I_D} = \dfrac{10 - 0.7}{1.5} \Rightarrow R = 6.2\ k\Omega$

**TYU1.11**

$$g_d = \frac{I_D}{V_T} = \frac{0.8}{0.026} = 30.8\ mS$$

**TYU1.12**

$$r_d = \frac{V_T}{I_D} \Rightarrow 50 = \frac{0.026}{I_D} \Rightarrow I_D = \frac{0.026}{50}$$

or

$$I_D = 0.52\ mA$$

**TYU1.13**

For the pn junction diode,

$$I_D = \frac{4 - 0.7}{4} = 0.825\ mA$$

For the Schottky diode, $I_D = \dfrac{4 - 0.3}{4} = 0.925\ mA$

**TYU1.14**

$V_z = V_{zo} + I_z r_z \Rightarrow V_{zo} = V_z - I_z r_z$ so $V_{zo} = 5.20 - \left(10^{-3}\right)\left(20\right) = 5.18\ V$

Then $V_z = 5.18 + \left(10 \times 10^{-3}\right)\left(20\right) \Rightarrow V_z = 5.38\ V$