ECE415/515 Assignment Model Answers Fall 2012

Assignment #8

15.7

(a) $n_{po} = \frac{n_i^2}{N_B} = \frac{(1.5\times10^{10})^2}{8\times10^{15}} = 2.8125\times10^4$ cm^{-3}

(i) $\delta n_p(0) \cong n_{po}\exp\left(\frac{V_{BE}}{V_t}\right)$

$$\Rightarrow V_{BE} = V_t \ln\left(\frac{\delta n_p(0)}{n_{po}}\right)$$

$$= (0.0259)\ln\left(\frac{10^{14}}{2.8125\times10^4}\right) = 0.5696\text{ V}$$

(ii) Neglecting any recombination in the base

$$I_C \cong \frac{eD_B n_{po} A}{x_B}\exp\left(\frac{V_{BE}}{V_t}\right)$$

$$= \frac{(1.6\times10^{-19})(20)(2.8125\times10^4)(0.4)}{2\times10^{-4}}$$

$$\times\exp\left(\frac{0.5696}{0.0259}\right)$$

$$I_C = 0.640\text{ A}$$

(b) $\delta n_p(0) = (0.1)N_B = 8\times10^{14}$ cm^{-3}

(i) $V_{BE} \cong (0.0259)\ln\left(\frac{8\times10^{14}}{2.8125\times10^4}\right) = 0.6234$ V

(ii) $I_C = \frac{(1.6\times10^{-19})(20)(2.8125\times10^4)(0.4)}{2\times10^{-4}}$

$$\times\exp\left(\frac{0.6234}{0.0259}\right)$$

$$I_C = 5.12\text{ A}$$

15.8

(a) From Figure 7.15, $BV_{BC} \cong 450$ V

(b) $V_{pt} = \frac{ex_B^2}{2\in_s}\cdot\frac{N_B(N_C+N_B)}{N_C}$

$$= \frac{(1.6\times10^{-19})(2\times10^{-4})^2}{2(11.7)(8.85\times10^{-14})}$$

$$\times\frac{(8\times10^{15})(6\times10^{14}+8\times10^{15})}{6\times10^{14}}$$

$$V_{pt} = 354.4\text{ V}$$

(c) From Figure 7.15, $BV_{BE} \cong 65$ V

15.17

(a) Let the n-drift region doping concentration be $N_d = 10^{14}$ cm^{-3}.

$$V_{bi} = (0.0259)\ln\left[\frac{(10^{14})(10^{15})}{(1.5\times10^{10})^2}\right]$$

$$= 0.516\text{ V}$$

For the base region,

$$x_p = \left\{\frac{2\in_s(V_{bi}+V_R)}{e}\left(\frac{N_d}{N_a}\right)\left(\frac{1}{N_a+N_d}\right)\right\}^{1/2}$$

$$= \left\{\frac{2(11.7)(8.85\times10^{-14})(0.516+200)}{1.6\times10^{-19}}\right.$$

$$\left.\times\left(\frac{10^{14}}{10^{15}}\right)\left(\frac{1}{10^{14}+10^{15}}\right)\right\}^{1/2}$$

$$x_p = 4.86\times10^{-4}\text{ cm} = 4.86\ \mu\text{m}$$

= channel length

$$x_n = \left\{ \frac{2(11.7)(8.85\times10^{-14})(0.516+200)}{1.6\times10^{-19}} \times \left(\frac{10^{15}}{10^{14}}\right)\left(\frac{1}{10^{14}+10^{15}}\right) \right\}^{1/2}$$

$x_n = 4.86\times10^{-3}$ cm $= 48.6\ \mu$m

= drift region width

(b) Assume $N_d = 10^{14}$ cm^{-3}
$V_{bi} = 0.516$ V

$$x_p = \left\{ \frac{2\in_s (V_{bi}+V_R)}{e}\left(\frac{N_d}{N_a}\right)\left(\frac{1}{N_a+N_d}\right) \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85\times10^{-14})(0.516+80)}{1.6\times10^{-19}} \times \left(\frac{10^{14}}{10^{15}}\right)\left(\frac{1}{10^{14}+10^{15}}\right) \right\}^{1/2}$$

$x_p = 3.08\times10^{-4}$ cm $= 3.08\ \mu$m

= channel length

$$x_n = \left\{ \frac{2(11.7)(8.85\times10^{-14})(0.516+80)}{1.6\times10^{-19}} \times \left(\frac{10^{15}}{10^{14}}\right)\left(\frac{1}{10^{14}+10^{15}}\right) \right\}^{1/2}$$

$x_n = 3.08\times10^{-3}$ cm $= 30.8\ \mu$m

= drift region width

15.19

(a) $P = \left(\frac{1}{2}\cdot V_{DD}\right)\left(\frac{1}{2}\cdot I_{D,\max}\right)$

$45 = \left(\frac{60}{2}\right)\left(\frac{I_D}{2}\right) \Rightarrow I_{D,\max} = 3$ A

$R_L = \frac{V_{DD}}{I_{D,\max}} = \frac{60}{3} = 20\ \Omega$

(b) $P = \left(\frac{V_{DD}}{2}\right)\cdot\left(\frac{I_{D,\max}}{2}\right)$

$R_L = \frac{V_{DD}}{I_{D,\max}} = 10 \Rightarrow I_{D,\max} = \frac{V_{DD}}{10}$

Then $P = \left(\frac{V_{DD}}{2}\right)\cdot\left(\frac{V_{DD}}{20}\right)$

Or $45 = \frac{V_{DD}^2}{40} \Rightarrow V_{DD} = 42.4$ V

14.4 $g' = \frac{\alpha I(x)}{h\nu}$

For $h\nu = 1.3$ eV, $\lambda = \frac{1.24}{1.3} = 0.95\ \mu$m

For silicon: $\alpha \cong 3\times10^2$ cm^{-1}

Then for $I(x) = 10^{-2}$ W/cm^2, we obtain

$$g' = \frac{(3\times10^2)(10^{-2})}{(1.6\times10^{-19})(1.3)}$$

or $g' = 1.44\times10^{19}$ cm^{-3} s^{-1}

The excess concentration is

$\delta n = g'\tau = (1.44\times10^{19})(10^{-6})$

or $\delta n = 1.44\times10^{13}$ cm^{-3}

14.11

From Problem 14.10, $I_S = 8.95\times10^{-10}$ A

(a) $V_{oc} = V_t \ln\left(1+\frac{I_L}{I_S}\right)$

$= (0.0259)\ln\left(1+\frac{120\times10^{-3}}{8.95\times10^{-10}}\right)$

$= 0.4847$ V

(b) $I = I_L - I_S\left[\exp\left(\frac{V}{V_t}\right)-1\right]$

$100\times10^{-3} = 120\times10^{-3}$

$-8.95\times10^{-10}\left[\exp\left(\frac{V}{V_t}\right)-1\right]$

$\Rightarrow V = 0.4383$ V

(c) $\left(1+\frac{V_m}{V_t}\right)\exp\left(\frac{V_m}{V_t}\right) = 1+\frac{I_L}{I_S}$

$= 1+\frac{120\times10^{-3}}{8.95\times10^{-10}} = 1.341\times10^{8}$

By trial and error, $V_m \cong 0.412$ V

Now $I_m = I_L - I_S\left[\exp\left(\frac{V_m}{V_t}\right)-1\right]$

$= 120\times10^{-3} - (8.95\times10^{-10})\left[\exp\left(\frac{0.412}{0.0259}\right)-1\right]$

$\Rightarrow I_m = 112.75\times10^{-3}$ A $= 112.75$ mA

$P_m = I_m V_m = (112.75)(0.412) = 46.5$ mW

(d) $V_m = I_m R_L \Rightarrow R_L = \frac{V_m}{I_m} = \frac{0.412}{0.11275}$

$R_L = 3.65\,\Omega$

14.16

(a) $V_{oc} = (0.0259)\ln\left(1+\frac{100\times10^{-3}}{10^{-10}}\right)$

$= 0.5367$ V

(b) $\left(1+\frac{V_m}{V_t}\right)\exp\left(\frac{V_m}{V_t}\right) = 1+\frac{I_L}{I_S}$

$= 1+\frac{100\times10^{-3}}{10^{-10}}$

$= 10^{9}$

By trial and error, $V_m \cong 0.461$ V

Then

$I_m = 100\times10^{-3} - (10^{-10})\exp\left(\frac{0.461}{0.0259}\right)$

$= 9.463\times10^{-2}$ A $= 94.63$ mA

$P_m = I_m V_m = (94.63)(0.461) = 43.62$ mW

(c) $n = \frac{10}{0.461} = 21.7 \to n = 22$ cells

(d) Now $V = (22)(0.461) = 10.14$ V

$P = IV$

$5.2 = I(10.14) \Rightarrow I = 0.5128$ A

Then $n' = \frac{0.5128}{0.09463} = 5.42 \to n' = 6$

(e) Then $I = (6)(0.09463) = 0.5678$ A

So $R_L = \frac{V}{I} = \frac{10.14}{0.5678} = 17.86\,\Omega$

14.19

(a) $n_o = N_d = 5\times10^{15}$ cm $^{-3}$

$I = e\mu_n n_o A\mathrm{E}$

$$= \left(1.6\times10^{-19}\right)(1200)\left(5\times10^{15}\right)$$

$$\times\left(5\times10^{-4}\right)\left(\frac{3}{120\times10^{-4}}\right)$$

$I = 0.12$ A $= 120$ mA

(b) $\delta p = G_L \tau_{p0} = \left(10^{21}\right)\left(10^{-7}\right) = 10^{14}$ cm $^{-3}$

(c) $\Delta\sigma = e(\delta p)\left(\mu_n + \mu_p\right)$

$$= \left(1.6\times10^{-19}\right)\left(10^{14}\right)(1200+400)$$

$$= 2.56\times10^{-2}\ (\Omega\text{-cm})^{-1}$$

(d) $I_L = (\Delta\sigma)A\mathrm{E}$

$$= \left(2.56\times10^{-2}\right)\left(5\times10^{-4}\right)\left(\frac{3}{120\times10^{-4}}\right)$$

$$= 3.2\times10^{-3}\ \text{A} = 3.2\ \text{mA}$$

(e) $\Gamma_{ph} = \dfrac{I_L}{eG_L AL}$

$$= \frac{3.2\times10^{-3}}{\left(1.6\times10^{-19}\right)\left(10^{21}\right)\left(5\times10^{-4}\right)\left(120\times10^{-4}\right)}$$

$\Gamma_{ph} = 3.33$