Monday, October 23, 2023 2:34 PM

Problems 7.1, 2, 4, 6, 7, 8, 10, 11, 13, 15, 16, 18

7.1: a)

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$N_a = 2\times10^{15}\ cm^{-3}$, $N_d = 2\times10^{15}\ cm^{-3}$
$n_i = 1.5\times10^{10}\ cm^{-3}$

$V_t = \frac{kT}{e}$

i) $V_{bi} = .611\ V$

ii) $V_{bi} = .671\ V$

iii) $V_{bi} = .731\ V$

b) Now, $N_a = 2\times10^{17}\ cm^{-3}$

i) $V_{bi} = .731\ V$

ii) $V_{bi} = .790\ V$

iii) $V_{bi} = .85\ V$

7.2:

Si : $n_i = 1.5\times10^{10}\ cm^{-3}$
Ge : $n_i = 2.4\times10^{13}\ cm^{-3}$
GaAs : $n_i = 1.8\times10^{6}\ cm^{-3}$

a) $N_d = 10^{14}\ cm^{-3}$, $N_a = 10^{17}\ cm^{-3}$

Si: $V_{bi} = .635\ V$
Ge: $V_{bi} = .253\ V$
GaAs: $V_{bi} = 1.10\ V$

b) $N_d = 5\times10^{16}\ cm^{-3}$, $N_a = 5\times10^{16}\ cm^{-3}$

Si: $V_{bi} = .778\ V$
Ge: $V_{bi} = .396\ V$
GaAs: $V_{bi} = 1.25\ V$

c) $N_d = 10^{17}\ cm^{-3}$, $N_a = 10^{17}\ cm^{-3}$

Si: $V_{bi} = .814\ V$
Ge: $V_{bi} = .432\ V$
GaAs: $V_{bi} = 1.28\ V$

7.4: Si: $N_a = 10^{17}\ cm^{-3}$, $N_d = 5\times10^{15}\ cm^{-3}$, $T = 300K$

a) n-side:

$$E_F - E_{Fi} = kT \ln\left(\frac{N_d}{n_i}\right) = .3294\ eV$$

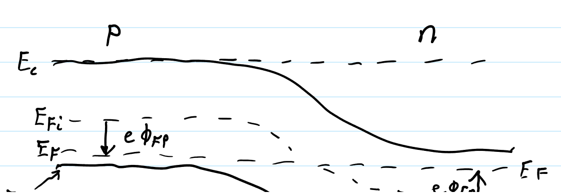
$$e\phi_{Fn} = E_{Fi} - E_F = -\frac{kT}{e}\ln\left(\frac{N_d}{n_i}\right)$$

p-side:

$$E_F - E_{Fi} = kT \ln\left(\frac{N_a}{n_i}\right) = .4070\ eV$$

$$E_F - E_{Fi} = \frac{kT}{e}\ln\left(\frac{N_d}{n_i}\right)$$

b)



$$V_{bi} = |\phi_{Fp}| + |\phi_{Fn}| = .407\ eV + .3294\ eV$$

$$\rightarrow V_{bi} = .7364\ eV$$

$V_{bi} = |\phi_{Fp}| + |\phi_{Fn}| = .407\,eV + .3294\,eV$

$\rightarrow$ $V_{bi} = .7364\,eV$

$E_F > E_{Fi}$

c)

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right) = .7363\,eV$$

d)

$$x_n = \left\{\frac{2\varepsilon_s V_{bi}}{e}\left(\frac{N_a}{N_d}\right)\left(\frac{1}{N_a + N_d}\right)\right\}^{1/2} \qquad \varepsilon_s = 11.7 \cdot \varepsilon_0$$

$\Rightarrow$ $x_n = .426\,\mu m$

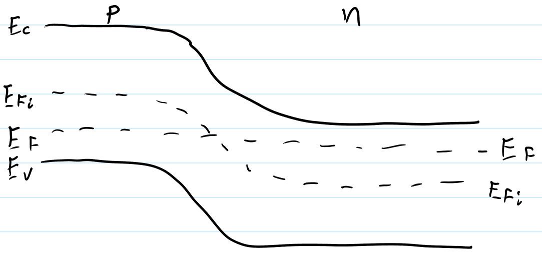
$$x_p = \frac{N_d}{N_a} x_n = 2.13\,\mu m$$

and

$$|E_{max}| = \frac{e N_d x_n}{\varepsilon_s} = 3.29 \times 10^4 \ \frac{V}{cm}$$

7.6:

a)



b)

$$N_d = n_i \exp\left[\frac{E_F - E_{Fi}}{kT}\right] = (1.5 \times 10^{10}\,cm^{-3}) \exp\left[\frac{.365\,eV}{.02590\,eV}\right] = 1.98 \times 10^{16}\,cm^{-3}$$

$$N_a = n_i \exp\left[\frac{E_{Fi} - E_F}{kT}\right] = (1.5 \times 10^{10}\,cm^{-3}) \exp\left[\frac{.33\,eV}{.02590\,eV}\right] = 5.12 \times 10^{15}\,cm^{-3}$$

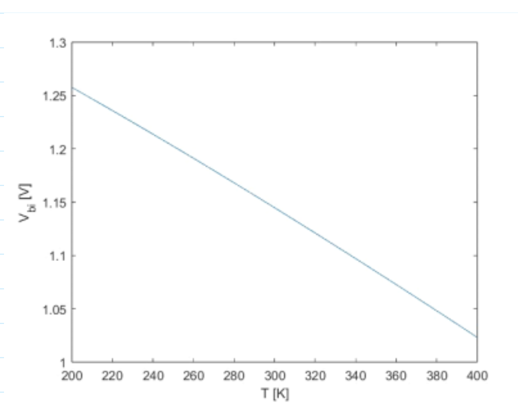
c) $V_{bi} = V_t \exp\left[\frac{N_a N_d}{n_i^2}\right] = .695\ V$

7.7:

Plot V_{bi} for GaAs pn junction, $N_a = 2 \times 10^{15}\,cm^{-3}$, $N_d = 4 \times 10^{16}\,cm^{-3}$ for $200K \le T \le 400K$

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$n_i^2(T) = N_{c0} N_{v0} \left(\frac{T}{300}\right)^3 \exp\left[\frac{-E_g}{kT}\right]$$



7.8: a) $x_n = .25W = .25(x_n + x_p)$

$\Rightarrow .75 x_p = .25 x_n \rightarrow \frac{x_p}{x_n} = 3$

$x_n N_d = x_p N_a \Rightarrow \frac{N_d}{N_a} = \frac{x_p}{x_n} = 3 \rightarrow N_d = 3 N_a$

$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right) = V_t \ln\left(\frac{3 N_a^2}{n_i^2}\right)$, $V_t = .0259\ V$, $n_i = 1.5 \times 10^{10}\ cm^{-3}$

$n_i^2 \exp\left[\frac{V_{bi}}{V_t}\right] = 3 N_a^2 \rightarrow N_a^2 = \frac{1}{3} n_i^2 \exp\left[\frac{V_{bi}}{V_t}\right]$

i) $N_a = \frac{n_i}{\sqrt{3}} \exp\left[\frac{V_{bi}}{2 V_t}\right] = 7.766 \times 10^{15}\ cm^{-3}$

ii) $\Rightarrow N_d = 2.33 \times 10^{16}\ cm^{-3}$

iii) $x_n = \left\{\frac{2 \varepsilon_s V_{bi}}{e}\left(\frac{N_a}{N_d}\right)\left(\frac{1}{N_a + N_d}\right)\right\}^{1/2} = 9.924 \times 10^{-6}\ cm = .0992\ \mu m$

iv) $x_p = 3 x_n = 2.977 \times 10^{-5}\ cm = .2977\ \mu m$

v) $|E_{max}| = \frac{e N_d x_n}{\varepsilon_s} = 35774.7\ \frac{V}{cm}$

b) repeat for GaAs, $V_{bi} = 1.18\ V$

i) $N_a = \frac{n_i}{\sqrt{3}} \exp\left[\frac{V_{bi}}{2 V_t}\right] = 8.127 \times 10^{15}\ cm^{-3}$

ii) $N_d = 2.438 \times 10^{16}\ cm^{-3}$

iii) $x_n = 1.324 \times 10^{-5}\ cm = .1324\ \mu m$

iv) $x_p = .3972\ \mu m$

v) $|E_{max}| = 4.45 \times 10^4\ \frac{V}{cm}$

7.10: $N_a = 2 \times 10^{17}\ cm^{-3}$, $N_d = 4 \times 10^{16}\ cm^{-3}$

a) $V_{bi}(T = 300K) = \frac{kT}{e} \exp\left[\frac{N_a N_d}{n_i^2}\right] = .8484\ V$ (using $n_i^2(T=300) = N_{co} N_{vo}\left(\frac{T}{300}\right)^3 e^{\frac{-E_g}{.0259(T/300)}}$ instead of $1.5 \times 10^{10}\ cm^{-3}$)

b) $n_i^2(T) = N_{co} N_{vo}\left(\frac{T}{300}\right)^3 \exp\left[\frac{-E_g}{.0259\left(\frac{T}{300}\right)}\right]$

$V_{bi}(T) = .0259\left(\frac{T}{300}\right) \exp\left[\frac{N_a N_d}{n_i^2(T)}\right]$

Want to find T at which $V_{bi} = 0.8654\ V$

graphically, I found $V_{bi} = .8654\ V$ @ $T \simeq 310\ K$

7.11:

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$0.550 = (0.0259)\left(\frac{T}{300}\right)\ln\left[\frac{(4\times10^{16})(2\times10^{15})}{n_i^2}\right]$$

Using the procedure from Problem 7.10, we can write, for $T = 300$ K,

$$n_i^2 = (1.5\times10^{10})^2$$

$$= K(2.8\times10^{19})(1.04\times10^{19})\exp\left(\frac{-1.12}{0.0259}\right)$$

$\Rightarrow K = 4.659$

At $T = 300$ K,

$$V_{bi} = (0.0259)\ln\left[\frac{(4\times10^{16})(2\times10^{15})}{(1.5\times10^{10})^2}\right]$$

$= 0.68886$ V

For $V_{bi} = 0.550$ V, $\Rightarrow T > 300$ K

At $T = 380$ K, $kT = 0.032807$ eV

Also

$$n_i^2 = (4.659)(2.8\times10^{19})(1.04\times10^{19})\left(\frac{380}{300}\right)^3 \times \exp\left(\frac{-1.12}{0.032807}\right)$$

$= 4.112\times10^{24}$

Then

$$V_{bi} = (0.032807)\ln\left[\frac{(4\times10^{16})(2\times10^{15})}{4.112\times10^{24}}\right]$$

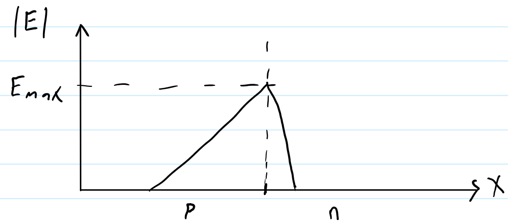
$= 0.5506$ V ≈ 0.550 V

7.13: a) $V_{bi} = .456$ V

b) $x_n = 2.43\times10^{-7}$ cm

c) $x_p = 2.43\times10^{-3}$ cm

d) $|E_{max}| = 375\ \frac{V}{cm}$



7.15:

7.15

$$|E_{max}| = \left\{\frac{2eV_{bi}}{\epsilon_s}\left(\frac{N_a N_d}{N_a + N_d}\right)\right\}^{1/2}$$

We find

$$\frac{2e}{\epsilon_s} = \frac{2(1.6\times10^{-19})}{(11.7)(8.85\times10^{-14})} = 3.0904\times10^{-7}$$

(a)

(i) For $N_a = 10^{17}$, $N_d = 10^{14}$; $V_{bi} = 0.6350$ V

(ii) $= 10^{15}$; $= 0.6946$ V

(iii) $= 10^{16}$; $= 0.7543$ V

(iv) $= 10^{17}$; $= 0.8139$ V

(i) For $N_a = 10^{17}$,
$N_d = 10^{14}$; $|E_{max}| = 0.443\times10^4$ V/cm

(ii) $= 10^{15}$; $= 1.46\times10^4$ V/cm

(iii) $= 10^{16}$; $= 4.60\times10^4$ V/cm

(iv) $= 10^{17}$; $= 11.2\times10^4$ V/cm

(b)

(i) For $N_a = 10^{14}$, $N_d = 10^{14}$; $V_{bi} = 0.4561$ V

(ii) $= 10^{15}$; $= 0.5157$ V

(iii) $= 10^{16}$; $= 0.5754$ V

(iv) $= 10^{17}$; $= 0.6350$ V

(i) For $N_a = 10^{14}$,
$N_d = 10^{14}$; $|E_{max}| = 0.265\times10^4$ V/cm

(ii) $= 10^{15}$; $= 0.381\times10^4$ V/cm

(iii) $= 10^{16}$; $= 0.420\times10^4$ V/cm

(iv) $= 10^{17}$; $= 0.443\times10^4$ V/cm

(c) $|E_{max}|$ increases as the doping increases, and the electric field extends further into the low-doped side of the pn junction.

7.16:

a) $V_{bi} = .6767$ V

b) $$W = \left[\frac{2\epsilon_s(V_{bi}+V_R)}{e}\left(\frac{N_a+N_d}{N_a N_d}\right)\right]^{1/2}$$

i) $V_R = 0$: $W = 9.452\times10^{-5}$ cm $= .9452\ \mu m$

ii) $V_R = 5$ V; $W = 2.738\times10^{-4}$ cm $= 2.738\ \mu m$

c) $$|E_{max}| = \frac{2(V_{bi}+V_R)}{W}$$

i) $V_R = 0$: $|E_{max}| = 1.43\times10^4\ \frac{V}{cm}$

ii) $V_R = 5$ V: $|E_{max}| = 4.15\times10^4\ \frac{V}{cm}$

7.18:

$N_a = 80 N_d$, $V_{bi} = .74\,V$, $V_R = 10\,V$

a) $V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right) = V_t \ln\left(\frac{80 N_d^2}{n_i^2}\right)$

$\Rightarrow n_i^2 \exp\left[\frac{V_{bi}}{V_t}\right] = 80 N_d^2 \Rightarrow N_d^2 = \frac{n_i^2}{80} \exp\left[\frac{V_{bi}}{V_t}\right]$

$\Rightarrow N_d = \frac{n_i}{4\sqrt{5}} \exp\left[\frac{V_{bi}}{2V_t}\right] = 2.684 \times 10^{15}\ cm^{-3}$

$\therefore N_a = 2.147 \times 10^{17}\ cm^{-3}$

b) $\frac{N_a}{N_d} = \frac{x_n}{x_p} = 80 \Rightarrow x_n = 80 x_p$

$W \simeq x_n = \left[\frac{2\epsilon_s (V_{bi} + V_R)}{e\,N_d}\right]^{1/2} = 2.27 \times 10^{-4}\ cm = 2.27\,\mu m$

$x_p = 2.843 \times 10^{-6}\ cm = .02843\,\mu m$

c) $|E_{max}| = \frac{2(V_{bi} + V_R)}{W} = 94625.55\ \frac{V}{cm}$

d) $C' = \left[\frac{e\epsilon_s N_d}{2(V_{bi} + V_R)}\right]^{1/2} = 4.55 \times 10^{-9}\ \frac{F}{cm^2}$