5.3

$n_1 = 10^{18}\ cm^{-3}$, $W = 1\times10^{-4}\ cm$, $D_n = 7\ cm^2/sec$, $\mu_n = \frac{qD_n}{kT} = 271\ \frac{cm^2}{V\text{-}sec}$

(a) $\frac{d\mathcal{E}}{dx} = \frac{\rho}{\epsilon_s} = -\frac{q\,n(x)}{\epsilon_s} = -\frac{q n_1}{\epsilon_s}(1-\frac{x}{W})$ $\therefore \mathcal{E}(x) = -\frac{q n_1}{\epsilon_s}(x - \frac{x^2}{2W}) + C$

Boundary condition $\mathcal{E}(W) = 0$ $\therefore \mathcal{E}(x) = \frac{q n_1}{\epsilon_s}(\frac{x^2}{2W} - x + \frac{W}{2})$

$\mathcal{E}(0) = \frac{q n_1 W}{2\epsilon_s} = 7.726\times10^6\ V/cm$

$J_n(x) = q\mu_n n(x)\mathcal{E}(x) + qD_n\frac{dn}{dx}$, $n = n_1(1-\frac{x}{W})$, $n(0) = n_1$

$\frac{dn}{dx} = \frac{-n_1}{W}$ $\therefore J_n(0) = q\mu_n n_1 \mathcal{E}(0) - \frac{qD_n n_1}{W}$

$= \frac{q^2 n_1^2 \mu_n W}{2\epsilon_s} - \frac{qD_n n_1}{W} = 3.35\times10^8\ A/cm^2$

(b) Since from Table 1.3 the breakdown field of Si is $3\times10^5\ V/cm$ the charge configuration is not reasonable.

(c) If the current at $x=0$ can only be $10^5\ A/cm^2$, then $\mathcal{E}(0)$ should be $\mathcal{E}(0) = \frac{1}{q\mu_n n_1}\left[J_n(0) + \frac{qD_n n_1}{W}\right] = 2565\ V/cm$.

(d) $\rho = -q(n_1 - N_{d0})(1-\frac{x}{W})$. The result of part (a) can be used provided $n_1 \rightarrow n_1 - N_{d0}$ in the expression for $\mathcal{E}(x)$

$\mathcal{E}(x) = \frac{q(n_1 - N_{d0})}{\epsilon_s}(\frac{x^2}{2W} - x + \frac{W}{2})$; $\mathcal{E}(0) = \frac{q(n_1 - N_{d0})W}{2\epsilon_s}$

$J_n(0) = \frac{q^2\mu_n n_1(n_1 - N_{d0})W}{2\epsilon_s} - \frac{qD_n n_1}{W}$

We require $J_n(0) = 10^5\ A/cm^2$, then

$N_{d0} = n_1 - \frac{2\epsilon_s}{q^2\mu_n n_1}\left[J_n(0) + \frac{qD_n n_1}{W}\right] = 10^{18}\ cm^{-3} - 3.32\times10^{10}\ cm^{-3} \simeq 10^{18}\ cm^{-3}$

$\frac{n_1 - N_{d0}}{n_1} = \frac{3.32\times10^{10}\ cm^{-3}}{10^{18}\ cm^{-3}} = 3.32\times10^{-8}$

The relative deviation from electrical neutrality is extremely small.

5.5

For *very* high level injection $p, n \gg n_i$ and $p, n \gg n_i e^{|E_i - E_t|/kT}$

From Eq. (5.2.9a) with $p \simeq n$

$$U \simeq \frac{N_t V_{th} \sigma_n \sigma_p n^2}{\sigma_p n + \sigma_n n} = \frac{N_t V_{th} \sigma_n \sigma_p n}{\sigma_p + \sigma_n} \simeq \frac{n}{\tau_{eff}}$$

$$\tau_{eff} \simeq \frac{\sigma_p + \sigma_n}{N_t V_{th} \sigma_n \sigma_p} \;.\; \tau_{low} = \tau_o \;,\; \tau_{on} = \frac{1}{N_t V_{th} \sigma_n} \;,\; \tau_{op} = \frac{1}{N_t V_{th} \sigma_p}$$

$$\tau_{eff} \simeq \frac{1}{N_t V_{th} \sigma_n} + \frac{1}{N_t V_{th} \sigma_p} = \tau_{on} + \tau_{op} \quad \text{if } \sigma_n \neq \sigma_p$$

If $\sigma_n = \sigma_p$ $\tau_{on} = \underline{\tau_{op} = \tau_o \text{ and } \tau_{eff} = 2\tau_o}$

5.15

Using Eq. 5.3.20 in Eq. (5.2.10) (for the case $\sigma_n = \sigma_p$), we obtain

$$U = \frac{n_i^2 (e^{\frac{qV_a}{kT}} - 1)/\tau_o}{\left[p + \frac{n_i^2 e^{\frac{qV_a}{kT}}}{p} + 2n_i \cosh\left(\frac{E_t - E_i}{kT}\right)\right]} = \frac{n_i^2 (e^{\frac{qV_a}{kT}} - 1)/\tau_o}{\mathcal{D}(p)}$$

$$\frac{dU}{dp} = \frac{-n_i^2 (e^{\frac{qV_a}{kT}} - 1)/\tau_o}{[\mathcal{D}(p)]^2} \left[1 - \frac{n_i^2 e^{\frac{qV_a}{kT}}}{p^2}\right]$$

For U maximum $\frac{dU}{dp} = 0 = 1 - \frac{n_i^2 e^{\frac{qV_a}{kT}}}{p^2}$ or $p = n_i e^{qV_a/2kT}$

5.16 A similar calculation for n yields the same result; $\therefore n = p$