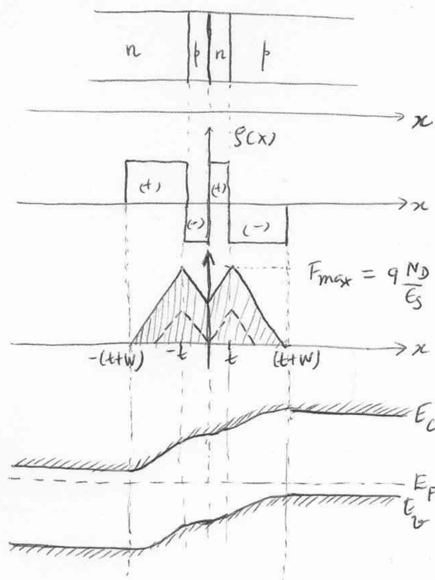
EE 566
SPR 2004
02/13/04

SOLID STATE DEVICES

ASSGN IV - SOLNS

PROBLEM 1

(a)



$N_A = N_D = 10^{17}/cm^3$.

$$V_{bi} = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right) = \underline{0.86\ \text{Volts}}.$$

(b) With Gummel correction,

V_{bi} = Area under $F(x) - x$ curve $+ 2\frac{kT}{q}$.

$$\underbrace{V_{bi} - 2\frac{kT}{q}}_{\text{Gummel correction.}} = \text{Area under curve}$$

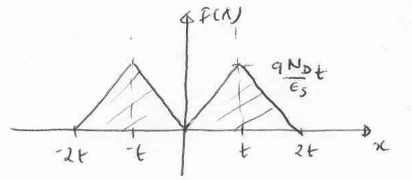
$$= \frac{qN_D W(t+W)}{\epsilon_S} - 2\times\frac{qN_D \cancel{2}t}{\cancel{2}\epsilon_S}$$

$$\therefore \quad W = \frac{1}{2}\left[\left\{t^2 + \frac{4\epsilon_S}{qN_D}\left(V_{bi} - 2\frac{kT}{q}\right)\right\}^{1/2} - t\right]$$

& Substituting $\begin{cases} V_{bi} = 0.86\text{ Volts}, & \epsilon_s = 11.7\,\epsilon_0\,,\ N_D = N_A = N_0 = 10^{17}/cm^3, \\ t = 40nm \end{cases}$ ②

$$\boxed{W = 52.3nm}$$

ⓒ Again, $F(x=0) = 0$ when the area under the $F(x) - x$ curve is



$$\underbrace{\left(V_{bi} - \frac{2kT}{q}\right)} - V_F = 2 * \frac{1}{2} * 2t * \frac{qN_D t}{\epsilon_s}$$

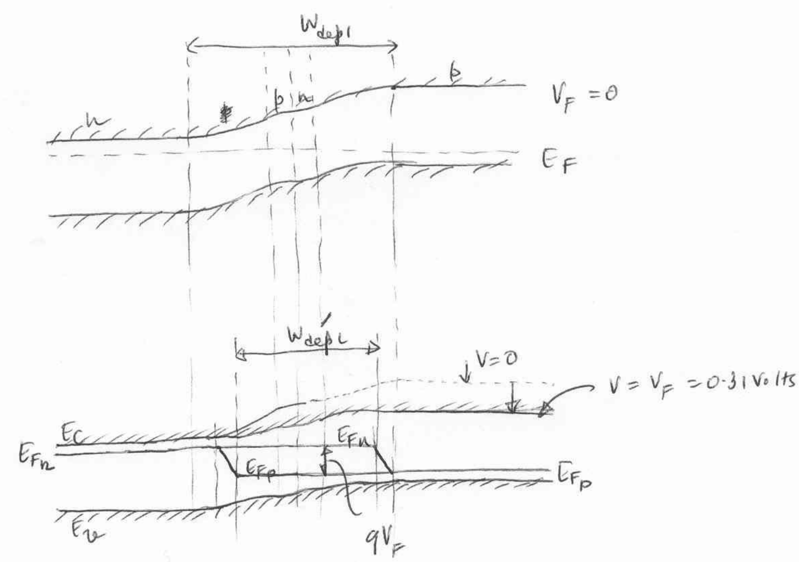
$$= \frac{2qN_D}{\epsilon_s} t^2$$

$$\approx 0.5V$$

$$\Rightarrow \boxed{V_F \approx 0.31\text{Volts}}$$

It is of course forward-bias, since area under the curve (total potential) decreases.

ⓓ



e

$$J = J_S\left(e^{qV/kT} - 1\right)$$

Remains the same as a p-n junction with dopings $N_A = N_D = N_0$

Since current in an ideal diode is completely determined by the currents @ the depletion edge!

$$\therefore \quad J_S = q\left(\frac{D_n\, \overbrace{n_{po}}^{n_i^2/N_A}}{\underbrace{L_n}_{\sqrt{D_n \tau_n}}} + \frac{D_p\, \overbrace{p_{no}}^{n_i^2/N_D}}{\underbrace{L_p}_{\sqrt{D_p \tau_p}}}\right)$$

Plug in all #s $\Rightarrow$ $\boxed{J \approx 33 \text{ nA/cm}^2}$

④

PROB 2

(a) $$J_o = q\left(\frac{D_n n_{po}}{L_n} + \frac{D_p p_{no}}{L_p}\right)$$

$\approx J_n$ since $N_D >> N_A$

$$\approx \frac{q D_n n_{po}}{L_n} = 30\,nA/cm^2.$$

$\therefore$ $\boxed{J_o \approx J_{no} = 0.30\,nA/cm^2}$

$D_n = 37.5\,cm^2/s$

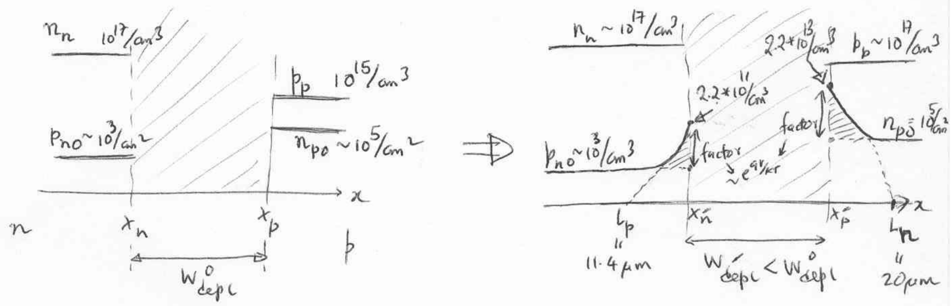
$L_n = \sqrt{D_n \tau_n} \approx 20\mu m$

$L_p = \sqrt{D_p \tau_p} \approx 11.4\mu m$

$D_p = 13\,cm^2/s$

$n_i \approx 10^{10}/cm^2$

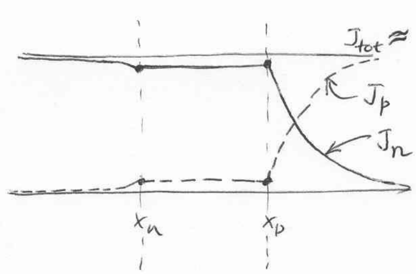
(b)



$\boxed{V = 0}$ $\qquad$ $\boxed{V = 0.5\,\text{Volt}}$

$$\left(e^{\frac{0.5\,\text{Volt}}{0.026\,\text{Volt}}} - 1\right) \approx 2.2 * 10^8 \approx e^{qV/kT}$$

(c)



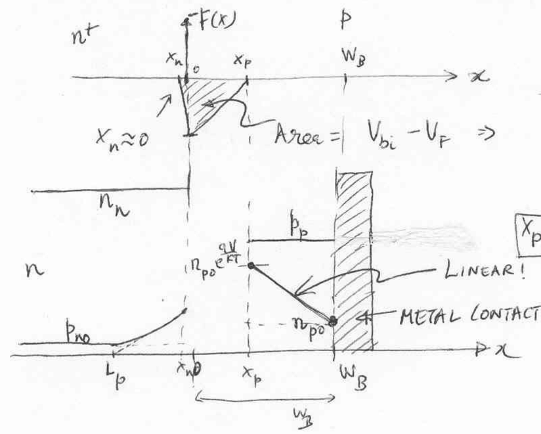
$$J_{tot} \approx \underbrace{q \frac{D_n}{L_n} n_{po}}_{J_o = 0.3\,nA/cm^2}(e^{qV/kT} - 1) \approx 65\,mA/cm^2$$

$$J_n \approx 65\frac{mA}{cm^2} * \exp\left(-\frac{|x - x_p|}{L_n}\right)$$

Electrons carry most of the current near depletion edges. $J_p \approx 0$!

$\therefore$ All current can be calc. from <u>MINORITY CARRIER DIFFUSION</u>

(d)



$$\Rightarrow \quad x_p \approx \left\{ \frac{2\varepsilon_s}{qN_A} (V_{bi} - V_F) \right\}^{1/2}$$

V_{bi}: 0.72V, V_F: 0.5V

$$\boxed{x_p = 0.53\,\mu m}$$

$$\boxed{W_B = 2\,\mu m}$$

$$W_B << L_n \approx 20\,\mu m$$

However, the ~~minorit~~ actual base-width of the neutral region is

$$\boxed{W' = W_B - |x_p| \approx 1.47\,\mu m}.$$

Therefore, current is $\quad J_{total} \approx J_n = q \frac{D_n}{W'} n_{p0} \left(e^{qV/kT} - 1\right)$

Since $\quad \frac{L_n}{W'} = \frac{20\,\mu m}{1.47\,\mu m} \approx 13.6$,

$$\frac{J_{tot}(\text{short-base})}{J_{tot}(\text{long-base})} \approx \frac{J_n(\text{short-base})}{J_n(\text{long-base})} = \frac{L_n}{W} = 13.6$$

(e) $\Rightarrow \quad J_{tot}(\text{short-base}) \approx 13.6 * \underbrace{J_{tot}(\text{long-base})}_{\text{Calculated before, } \approx 65\,mA/cm^2}$

$$\boxed{J_{tot}(\text{short-base}) = 0.9\ A/cm^2}$$

Of course, short-base current is larger, since the finite base width creates a large gradient → More diffusion current! Also, less recombination in short-base.