Solutions to Chapter 3 Exercises

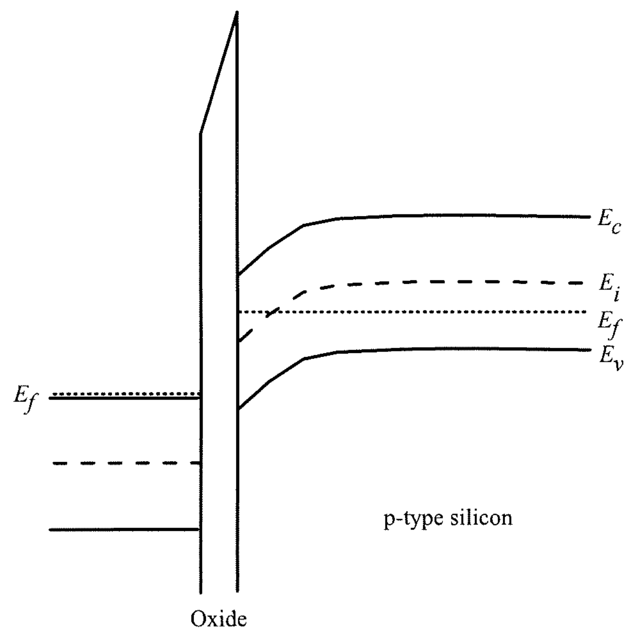
3.1.

(a)

$$\psi_B = \frac{kT}{q}\ln\frac{N_a}{n_i} = 0.42 \text{ V}$$

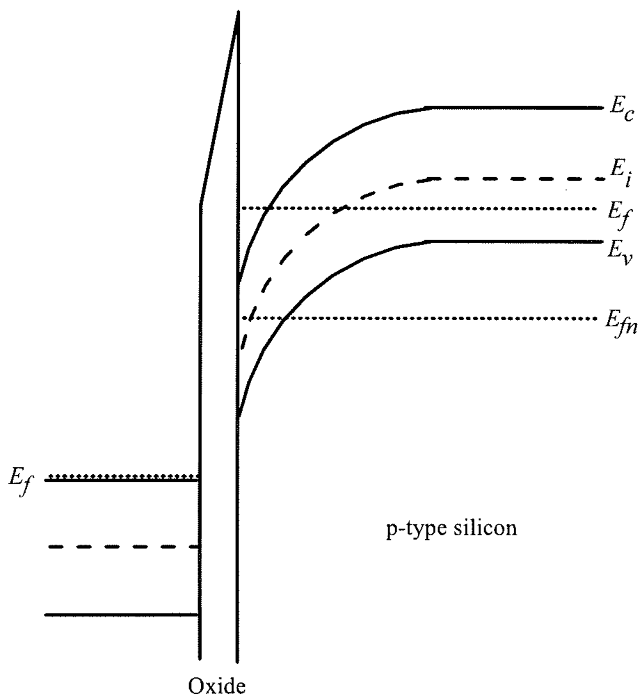
$$V_{fb} = -\frac{E_g}{2q} - \psi_B = -0.98 \text{ V}$$

$$V_t = V_{fb} + 2\psi_B + \frac{\sqrt{2\varepsilon_{si} q N_a (2\psi_B)}}{C_{ox}} = -0.98 + 0.84 + 0.97 = 0.83 \text{ V.}$$



(b)

$$V_t = V_{fb} + 2\psi_B + \frac{\sqrt{2\varepsilon_{si} q N_a (2\psi_B + V_{bs})}}{C_{ox}} = -0.98 + 0.84 + 1.44 = 1.30 \quad \text{V}$$



(c)

$$W_{dm} = \sqrt{\frac{2\varepsilon_{si}(2\psi_B)}{qN_a}} = 0.104\ \mu\text{m}$$

$$\lambda = W_{dm} + 3t_{ox} = 0.164\ \ \mu\text{m}$$

$$L_{\min} \approx 2\lambda = 0.33\ \ \mu\text{m}$$

Problem #2

Subthreshold

$C_{gs} \sim 0$

$$C_{gb} \approx \sqrt{\frac{\epsilon_{si} q N_a}{2\psi_s}} \, WL$$

$$\cong \sqrt{\frac{\epsilon_{si} q N_a}{2\psi_B}} \, WL$$

depends on bias
approximate
$\psi_s = \psi_B$

$= 14 \cancel{8}$ FF

Linear

$C_{gb} \sim 0$

$C_{g\text{-}ch} = WL\, C_{ox}$

$C_{ox} = \frac{\epsilon}{d}$

$C_{g\text{-}ch} = 17$ FF

Sat

$C_{g\text{-}ch} = \frac{2}{3} WL\, C_{ox} = 11$ FF

PROBLEM # 3

3.40

$$I_{ds} = \mu_{eff} C_{ox} \frac{W}{L}(m-1)\left(\frac{kT}{q}\right)^2 e^{q(V_{gs}-V_t)/mkT}$$

$$\mu = 600 \frac{cm^2}{V-s} = 6\,10^{-2} \frac{m^2}{V-s}$$

$$C_{ox} = \frac{\epsilon}{d} = 1.7\ 10^{-3} \frac{F}{m^2}$$

$$I_{ds} = 689\ nA\ e^{-q(V_{gs}-V_t)/mkT}$$

$-(V_{gs} - V_t) = 2V$

$\Rightarrow I_{ds} = 0.7\ \mu A \times 10^{-17}\ 1.9 =$

$10^{-23} A$

Negligible

$P_{TOTAL} = 10^{-14} W$

$V_{gs} - V_t = 1V$

$\Rightarrow I_{ds} = 0.7\ \mu A \times 4.5\ 10^{-9} = 3\ 10^{-15} A$

$\Rightarrow P_{TOTAL} = 12\ \mu W$

Still too small to be noticeable.

Problem 4

Long Channel

$$g_m = \mu_{eff} C_{ox} \frac{W}{L} \frac{(V_{gs} - V_t)}{\cancel{2}}$$

Short Channel

$$g_m = C_{ox} W V_{sat}$$

Equate

$$\Rightarrow \mu (V_{gs} - V_t) \frac{1}{L} = V_{sat}$$

$$\Rightarrow \boxed{L = \frac{\mu (V_{gs} - V_t)}{V_{sat}}}$$

Problem 5

$$I_{ds} = \mu C \frac{W}{L} \frac{1}{2} (V_{gs} - V_t)^2 (1 + \lambda V_{ds})$$

$$g_{ds} \equiv \frac{d I_{ds}}{d V_{ds}} = \lambda I_{ds}$$

$$g_m \equiv \frac{d I_{ds}}{d V_{gs}} = \mu C \frac{W}{L} (V_{gs} - V_t)$$

gain: $$\frac{g_m}{g_{ds}} = \frac{\cancel{\mu C \frac{W}{L} (V_{gs} - V_t)}}{\lambda \cancel{\mu C} \cancel{\frac{W}{L}} \frac{1}{2} (V_{gs} - V_t)^{\cancel{2}}}$$

$$= \frac{1}{\lambda} 2 \frac{1}{V_{gs} - V_t}$$

$$= \frac{\cancel{2}\,1}{0.1} \frac{1}{\cancel{4}\,2} = \frac{1}{0.2} = 5 \checkmark$$