E3.18

$\phi_{n+} = .55V$

$\phi_n = .025 \ln\left(\frac{N_d}{n_i}\right) = .328\ V$

a) $V_{FB} = -(\phi_{n+} - \phi_n) = \boxed{-.222V}$

b) $\phi_s = -\phi_n = \boxed{-.328\ V}$

c) $x_{d\,max} = \sqrt{\frac{2\epsilon_s(2\phi_n)}{q N_d}} = \boxed{.411\ \mu m}$

d) $V_{TP} = V_{FB} - 2\phi_n - \frac{q N_d x_{d\,max}}{C_{ox}}$

$t_{ox} = 150 \times 10^{-8}\ cm$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 2.3 \times 10^{-7}\ F/cm$

$V_{TP} = \boxed{-1.021V}$

E3.19

a) $V_{Tn1} = V_{FB} - 2\phi_p + \frac{1}{C_{ox}}\sqrt{2q\epsilon_s N_a(-2\phi_p)}$

$\phi_{n+} = 550mV$

$\phi_p = -.025 \ln\left(\frac{N_a}{n_i}\right) = -386mV$

$V_{FB} = -(\phi_{n+} - \phi_p) = -.936mV$

$t_{ox} = 200 \times 10^{-8}$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 1.725\ F/cm$

$V_{TN1} = \boxed{.4914\ V}$

b) $V_{TN2} = V_{FB} - 2\phi_p + \frac{t_{ox2}}{\epsilon_{ox}}\sqrt{2q\epsilon_s N_a(-2\phi_p)}$

$5V_{TN1} = V_{TN2}$

$t_{ox_2} = \frac{(5V_{TN1} - V_{FB} + 2\phi_p)\epsilon_{ox}}{\sqrt{2q\epsilon_s N_a(-2\phi_p)}} = 8 \times 10^{-6} cm = \boxed{800 \mathring{A}}$

c) $N_a = 5 \times 10^{17}\ cm^{-3}$ $\quad t_{ox} = \boxed{253 \mathring{A}}$

E 3.23

a) $N_a = 10^{17}\ cm^{-3}$ $\quad \phi_p = -420\ mV$

$\phi_{n+} = 550\ mV$

$t_{ox} = 100 \times 10^{-8}\ cm$

$$V_{TN} = V_{FB} - 2\phi_p + \frac{1}{C_{ox}}\sqrt{2q\,\epsilon_s N_a(-2\phi_p)}$$

$V_{FB} = -(\phi_{n+} - \phi_p) = -970\ mV$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 3.45 \times 10^{-7}\ F/cm^2$

$V_{TN} = \boxed{.353\ V}$

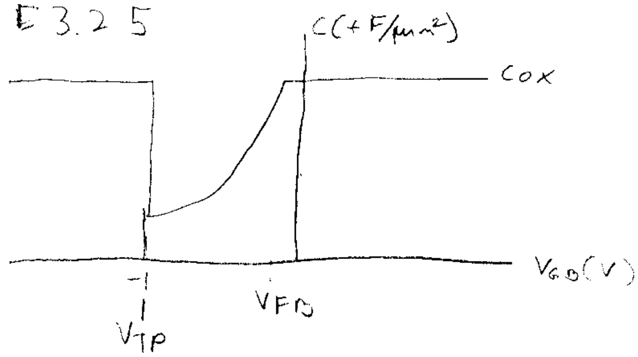
b) $Q_n = -C_{ox}(V_{GB} - V_{TN})$

$V_{GB} = 2.9\ V$

$Q_n = 8.79 \times 10^{-7}\ C/cm$

electron # $= Q_n/q \times W \times L = 2.75 \times 10^5$

E 3.25



a) $\boxed{V_T = -1\ V}$ The threshold voltage is the place where the C-V curve jumps from a minimum to Cox

b) $\boxed{V_{FB} = -.05\ V}$ At the flatband voltage the C-V curve starts to gradually fall from Cox

c) The substrate doping is n-type because you have to have $V_{GB} < V_T$ to reach inversion.

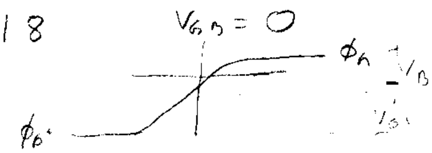
d) $V_{FB} = -(-\phi_{n+} - \phi_{sub})$

$\phi_{sub} = V_{FB} + \phi_{n^+} = .5V$

$\phi_{sub} = 60mV \cdot \log\left(\frac{N_d}{n_i}\right)$

$N_d = \boxed{2.15 \times 10^{18} cm^{-3}}$

P 3.18



a) $V_{FB} = -(\phi_{p+} - \phi_n)$

$\phi_{p+} = -550mV$

$N_d = 5 \times 10^{16} cm^{-3}$ $\phi_n = 386 mV$

$V_{FB} = \boxed{936 mV}$

b) $V_{TP} = V_{FB} - 2\phi_n - \frac{\sqrt{2q\epsilon_s N_d(2\phi_n)}}{C_{ox}}$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = 1.38 \times 10^{-7} F/cm$

$V_{Tp} = \boxed{-.688V}$

c)

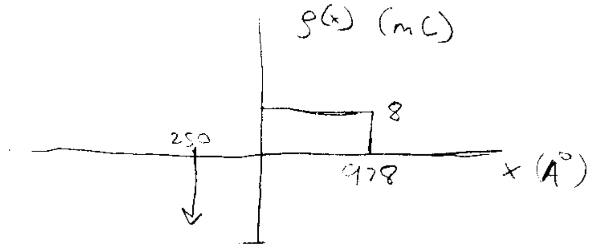
$\phi_n - \phi_{p^+} = V_0 + V_{ox}$

$\phi_n - \phi_{p^+} = \frac{q N_d X_{do}}{C_{ox}} + \frac{q N_d X_{do}^2}{2\epsilon_s}$

$X_{do} = t_{ox}\left(\frac{\epsilon_s}{\epsilon_{ox}}\right)\left(\sqrt{1 + \frac{2C_{ox}^2(\phi_n - \phi_{p^+})}{q\epsilon_s N_d}} - 1\right)$

$= .0978 \mu m$ 978 Å

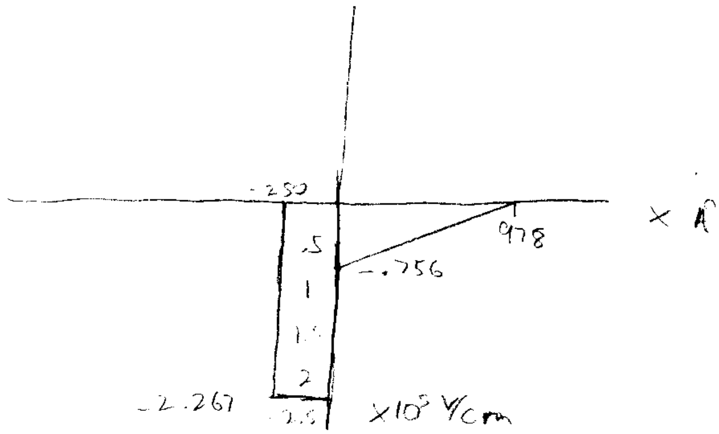
$\rho = qN_d = 8 \times 10^{-3} C/cm^3$



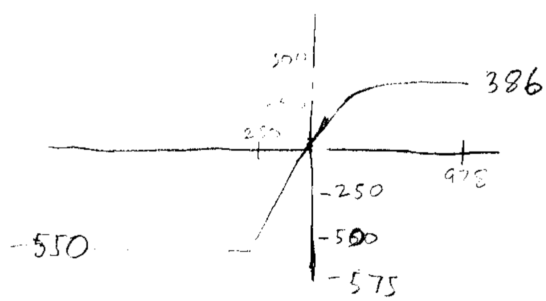
$E(0^-) = \frac{Q_G}{\epsilon_{ox}}$ $\qquad Q_G = -q N_a x_{do}$

$E(0^-) = -2.267 \times 10^5$ V/cm

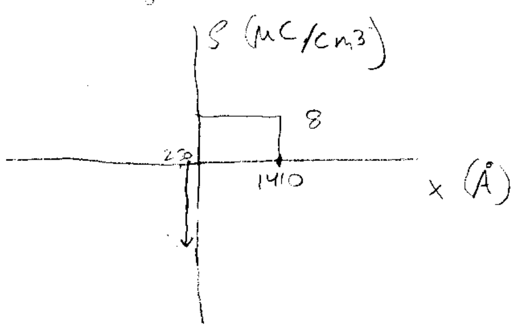
$E(0^+) = E(0^-)/3 = -7.56 \times 10^4$ V/cm



$\phi_s = \phi_{p+} + \frac{q N_d X_{do}}{C_{ox}} = .017$ V



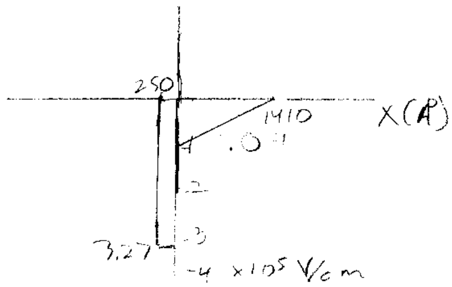
d) $X_{d\,max} = \sqrt{\frac{2\epsilon_s(2\phi_n)}{q N_a}} = .141\ \mu m$

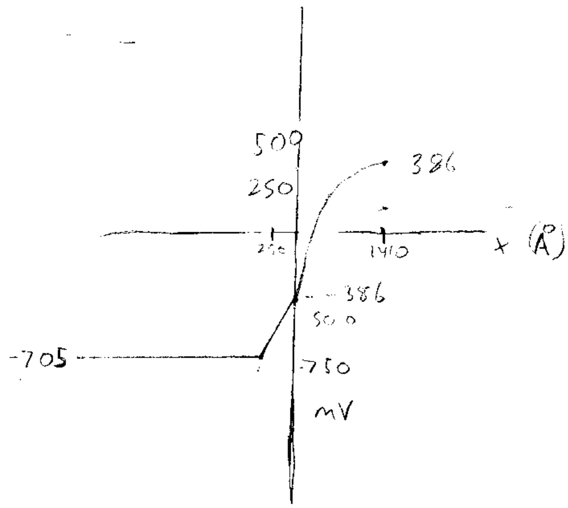


$E(0^-) = \frac{\ \ }{\varepsilon_{ox}}$ $\quad \psi_G = -qN_a x_{dmax}$

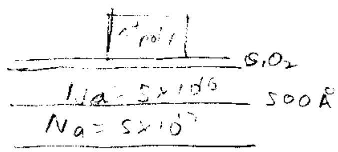
$E(0^-) = -3.27 \times 10^5$ V/cm

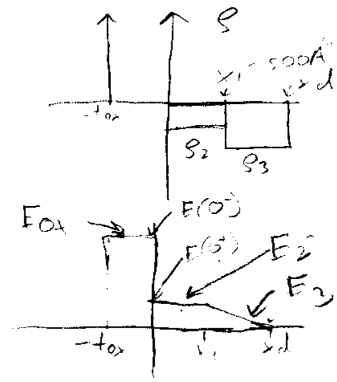
$E(0^+) = E(0^-)/3 = 1.09 \times 10^5$ V/cm



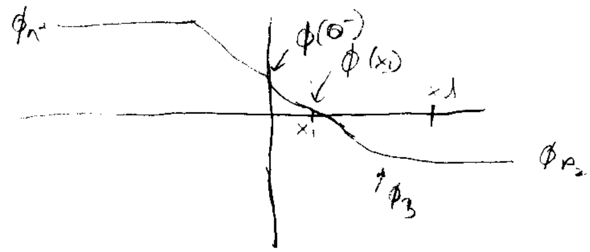


P 5-7





$x_1 = 500\text{Å} = 500\times10^{-8}\,cm$



$Q_B = -qN_{a1}x_1 - qN_{a2}(xd - x_1) \qquad Q_G = -Q_B$

$E_{ox} = \dfrac{qN_{a1}x_1}{\epsilon_{ox}} + \dfrac{qN_{a2}(xd - x_1)}{\epsilon_{ox}}$

solve for field in ea region $E = \frac{Q}{\epsilon}$

$E(0^+) = \dfrac{qN_{a1}x_1}{\epsilon_{si}} + \dfrac{qN_{a2}(xd - x_1)}{\epsilon_{si}}$

$E_2(x) = \dfrac{qN_{a1}x_1}{\epsilon_{si}} + \dfrac{qN_{a2}(xd - x_1)}{\epsilon_{si}} - \dfrac{qN_{a1}x}{\epsilon_{si}}$

$E_3(x) = \dfrac{qN_{a1}x_1}{\epsilon_{si}} + \dfrac{qN_{a2}(xd - x_1)}{\epsilon_{si}} - \dfrac{qN_{a1}(x_1)}{\epsilon_{si}} - \dfrac{qN_{a2}(x-}{\epsilon_{si}}$

$E_3(x) = \dfrac{qN_{a2}(xd - x)}{\epsilon_{si}}$

integrate th E field in each region find potentia

$\phi(0^-) - \phi(-t_{ox}) = -\int_{-t_{ox}}^{0} \dfrac{qN_{a1}x_1}{\epsilon_{ox}} + \dfrac{qN_{a2}(xd - x_1)}{\epsilon_{ox}}\,dx$

$(\phi_{n+} = \phi(-t_{ox}))$

1) $\phi(0^-) - \phi_{n+} = -\frac{q N_{a1} x_1}{\epsilon_{ox}} t_{ox} \quad - \frac{q N_{a2}(x_d - x_1)}{\epsilon_{ox}} t_{ox}$

(2) $\phi(x_1) - \phi(0^+) = -\int_0^{x_1} \frac{q N_{a1} x_1}{\epsilon_{si}} + q\frac{N_{a2}(x_d - x_1)}{\epsilon_{si}} - \frac{q N_{a1} x}{\epsilon_{si}} \, dx$

$$= -\frac{q N_{a1} x_1^2}{\epsilon_{si}} - \frac{q N_{a2}(x_d - x_1) x_1}{\epsilon_{si}} + \frac{q N_{a1} x_1^2}{2\epsilon_{si}}$$

$(\phi(0^-) = \phi(0^+))$

$\phi(x_1) - \phi(0^-) = -\frac{q N_{a1} x_1^2}{2\epsilon_{si}} - \frac{q N_{a2}(x_d - x_1) x_1}{\epsilon_{si}}$

3) $\phi(x_d) - \phi(x_1) = -\int_{x_1}^{x_d} \frac{q N_{a2}(x_d - x)}{\epsilon_{si}} = + \left.\frac{q N_{a2}(x_d - x)^2}{2\epsilon_{si}}\right|_{x_1}^{x_d}$

$\phi(x_d) = \phi_{p_2}$

$$= -\frac{q N_{a2}(x_d - x_1)^2}{2\epsilon_{si}}$$

add 1, 2 and 3

$$\phi_{p_2} - \phi_{n_+} = -\frac{q N_{a2}(x_d - x_1)^2}{2\epsilon_{si}} - \frac{q N_{a1} x_1^2}{2\epsilon_{si}} - \frac{q N_{a2}(x_d - x_1) x_1}{\epsilon_{si}}$$

$$- \frac{q N_{a1} x_1 t_{ox}}{\epsilon_{ox}} - \frac{q N_{a2}(x_d - x_1) t_{ox}}{\epsilon_{ox}}$$

Solve for X_d

$\phi_{p2} = -462$ mV

$\phi_{n^+} = 550$ mV

$x_1 = 6.31 \times 10^{-7}$ cm

$X_d = \boxed{563.1\ \text{Å}}$

b) $V_{FB} = -(\phi_{n+} - \phi_{p1})$

$\phi_{p1} = -402$

$V_{FB} = \boxed{-951\,mV}$

c) Threshold $\rightarrow$ when $\phi_S = -\phi_{p1}$

$V_{TN} - V_{FB} = V_B' + V_{ox}'$

$V_B' = \phi_S - \phi(x_{dmax})$

$= -(\phi(x_{dmax}) - \phi_S)$

$\phi(x_{dmax}) - \phi(x_1) = \dfrac{-q N_{a2}(x_{dmax} - x_1)^2}{2\epsilon_{si}}$ (from part a

$\phi(x_1) - \phi(0^-) = -\dfrac{q N_{a1} x_1^2}{2\epsilon_{si}} - \dfrac{q N_{a2}(x_{dmax} - x_1)x_1}{\epsilon_{si}}$

$(\phi_S = \phi(0^-))$

$\phi(x_{dmax}) - \phi_S = \dfrac{-q N_{a2}(X_{dmax} - X_1)^2}{2\epsilon_{si}} - \dfrac{q N_{a1} x_1^2}{2\epsilon_{si}} - \dfrac{q N_{a2}(x_{dmax}}{\epsilon_{si}}$

$V_B' = -\phi_{p1} - \phi_{p2}$ during inversion

$-\phi_{p1} - \phi_{p2} = \dfrac{q N_{a2}(x_{dmax} - x_1)^2}{2\epsilon_{si}} + \dfrac{q N_{a1} x_1^2}{2\epsilon_{si}} + \dfrac{q N_{a2}(x_{dmax} - x_1)x}{\epsilon_{si}}$

$x_{dmax} - x_1 = 1.697 \times 10^{-6}$

$x_{dmax} = 670\,\text{Å}$

$$V_{ox} = \frac{-Q_n\,max}{C_{ox}}$$

$$Q_n\,max = -q\,N_{a1}x_1 - q\,N_{a2}(x_{dmax} - x_1)$$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$ $\quad t_{ox} = 250\,Å$

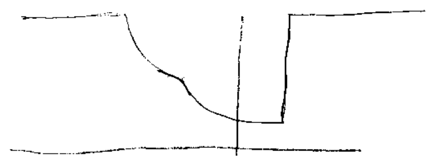
$V_{ox}' = 1.275\ V$

$V_{TN} = V_{FB} + V_B' + V_{ox}' \quad = \boxed{1.19V}$

P3.26

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} \quad t_{ox} = 250\,Å$

$C_{ox} = 1.38 \times 10^{-7}\ F/cm^2$



$C = \frac{C_{ox}C_b}{C_{ox}+C_b} \qquad V_{FB} < V_{GB} < V_{TN}$

$C_b = \frac{\epsilon_s}{x_d(V_{GB})}$

$C_{bmin} = \frac{\epsilon_s}{x_{dmax}} = 1.6 \times 10^{-7}\ F/cm^2$

the capacitance is lowest when $x_d = x_{dmax}$

$C_{min} = 7.4 \times 10^{-8}\ F/cm^2$

need to find V when $x_d = 500\,Å$
only need to consider N_{a1}

$E_{ox} = \frac{q\,N_a\,x_1}{\epsilon_{ox}}$

$$\phi_s - (\phi_n + V_{GB}) = -\int_{-t_{ox}}^{0} E_{ox} = \frac{-q\,N_a\,x_1\,t_{ox}}{\epsilon_{ox}}$$

$$E_2(x) = \frac{q N_{a1} (x_1 - x)}{\epsilon_{si}}$$

$$\phi_{p1} - \phi_s = -\int_0^{x_1} E_2(x)\, dx = \frac{q N_{a1}}{2\epsilon_{si}} (x_1 - x)^2 \Big|_0^{x_1}$$

$$= -\frac{q N_{a1} x_1^2}{2 \epsilon_{si}}$$

$$\phi_{p1} - \phi_n - V_{GB} = -\frac{q N_{a1} x_1^2}{2 \epsilon_{si}} - \frac{q N_{a1} x_1 t_{ox}}{\epsilon_{ox}}$$

$$V_{GB} = \phi_{p1} - \phi_n + \frac{q N_a x_1^2}{2 \epsilon_s} + \frac{q N_{a1} x_1 t_{ox}}{\epsilon_{ox}}$$

$$V_{GB} = -.5655\text{ V}$$

$$C_{b x_1} = \frac{\epsilon_s}{x_d} = 2.07 \times 10^{-7}$$

$$C_{x_1} = 8.28 \times 10^{-8}\ \text{F/cm}^2$$