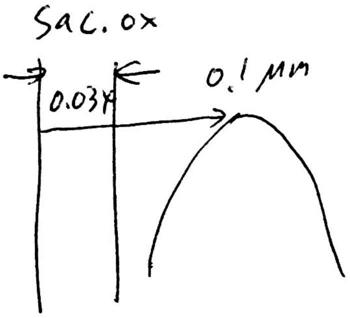
EE143 HW #11 Solutions

1 a) V_{tn} for NMOS

V_{tn} implants @ step 16 : $B11$, 30keV, $D_I = 9\times10^{11}/cm^2$

$\xrightarrow{\text{(Fig 5.3)}} R_p = 0.1\,\mu m,\ \Delta R_p = 0.035\,\mu m$



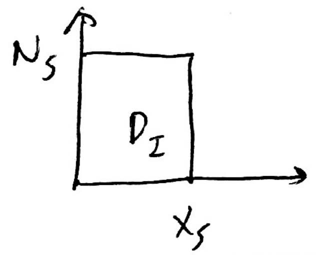
— implantation has an equivalent "Dt" as

$$Dt = \frac{1}{2}\Delta R_p^2 = 6.13\times10^{-12}\ cm^2$$

— high temp steps after step 16 (see HW#9)

$$\Sigma Dt = 1.1\times10^{-10}\ cm^2$$

$$\Rightarrow \text{total } Dt = 1.16\times10^{-10}\ cm^2$$



$$N_s = \frac{N_0}{2} = \frac{1}{2}\frac{D_I/2}{\sqrt{\pi Dt}} = 1.18\times10^{16}/cm^2$$

$$\therefore x_s = \frac{D_I}{N_s} = 0.76\,\mu m$$

need test Wdep w/ N_s :

$$x_{j,N_s} = \sqrt{\frac{2\varepsilon_{si}}{q}\frac{1}{N_s}2|\phi_{f,N_s}|}$$

approx. as 0.3

$$= \sqrt{\frac{2\times11.7\times8.854\times10^{-14}}{1.6\times10^{-19}}\cdot\frac{1}{1.18\times10^{16}}2\cdot0.3}$$

$$= \underline{0.26\,\mu m} < x_s$$

ok, the I/I (V_{th}) covers all depletion region, assumption is correct

$$V_{TH} = V_{FB} - 2\phi_{f,N_s} - \frac{Q_B}{C_{ox}}$$

$$V_{FB} = \phi_{f,N_s} - \phi_{f,n^+gate}$$

$$= -0.3 - 0.56$$

From page 209 Jaeger

$$= -0.86$$

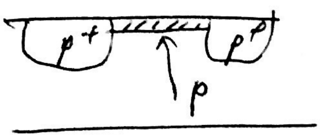
$$Q_B = -\sqrt{2\varepsilon_{si}\cdot qN_s\cdot 2|\phi_{f,N_s}|}$$

$$= -4.84\times10^{-8}\ C/cm^2$$

$$C_{ox} = \frac{\varepsilon_{SiO_2}\cdot\varepsilon_0}{t_{ox}} = \frac{3.9\times8.854\times10^{-14}}{59.53\times10^{-7}cm} = 5.8\times10^{-8}\ C/V\cdot cm^2$$

$$V_{tn} = -0.86-(-0.6)-(-0.834) = \boxed{0.574V}$$

b) <u>PMOS</u> V_{tp}



same Vth implants as NMOS (Boron)
so S/D are shorted (i.e., current flows)
when no bias is applied on gate
To operate, need to apply a "+" bias on gate
to create depletion region and thus to turn
device "off" ⇒ depletion-mode PMOS

$$V_{tp} = V_{FB} - 2\phi_f - \frac{Q_B}{C_{ox}}$$

Q_B ← the total implants (Boron) since you wanna deplete all the p-type implants

approx. 0.3

$$V_{tp} = (\underline{\phi_{s,N_s}} - \underbrace{\phi_{f\,n^+ gate})}_{\text{same as NMOS case}} - 2\underline{\phi_f} - \frac{D_I \cdot q}{C_{ox}}$$

$\boxed{N_S \text{ is same as that of NMOS}}$

$$= (-0.3 - 0.56) + 0.6 + \frac{9\times10^{11} \times 1.6\times10^{-19}}{5.8\times10^{-8}}$$

$$= \boxed{2.22\ V}$$

c) mobility vs. concentration chart

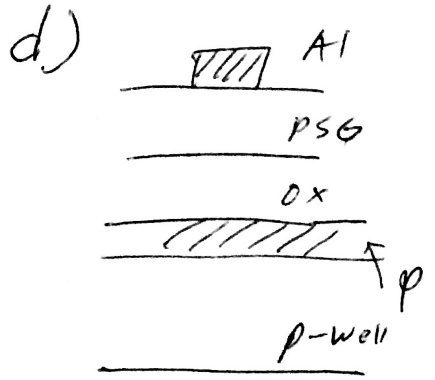
@ $1.18\times10^{16}/cm^3$ (N_S)

$\mu_p = 425\ cm^2/V\cdot s$ $\mu_n = 1250\ cm^2/V\cdot s$

$\therefore k_p = \mu_p C_{ox} = 2.47\times10^{-5}\ F/V\cdot s$

$K_n = \mu_n C_{ox} = 7.25\times10^{-5}\ F/V\cdot s$

d)



channel stop implants @ step 10

B11, 100keV, $D_I = 10^{13}/cm^2$ P-Field Channel Stop

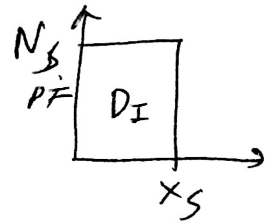
$\Rightarrow R_p = 0.32\mu m \quad \Delta R_p = 0.07\,\mu m$

$\Downarrow$

$Dt = 2.45\times10^{-11}\,cm^2$

ΣDt afterwards $= 2.43\times10^{-10}\,cm^2$

$\Rightarrow$ total $Dt = 2.68\times10^{-10}\,cm^2$



$x_S = \frac{D_I}{N_s} = 1.16\mu m$

$$N_{s,pF} = \frac{1}{2} N_0 = \frac{1}{2}\,\frac{D_I/2}{\sqrt{\pi Dt}} = 8.62\times10^{16}/cm^3$$

$$\underset{(test)}{x_{j,N_{S.pF}}} = \sqrt{\frac{2\varepsilon_{si}}{q}\,\frac{1}{N_{spF}}\,2|\phi_f|} = 0.1\mu m < x_S$$

$\underline{ok}$

$$V_{TH,pF} = V_{FB} - 2\phi_f - \frac{Q_B}{C_{ox}}$$

$$= -0.97 - (-0.6) - \frac{\overset{1.3\times10^{-7}\,C/cm^2}{\sqrt{2\cdot11.7\times8.854\times10^{-14}\cdot1.6\times10^{-19}\cdot8.62\times10^{16}\cdot2\cdot0.3}}}{\left.\frac{3.9\,(8.854\times10^{-14})}{0.7\times10^{-4}+0.7\times10^{-4}}\right\} = 2.46\times10^{-9}\,C/Vcm^2}$$

$V_{FB} = \phi_{f,N_{s.pF}} - \phi_{Al}$

$= -0.3 - (-0.56 - \underline{\underline{0.11}})$ page 203

$= -0.97\,V$

assume PSG has the same ε as SiO_2

$= \boxed{52.86\,V}$

e) $V_{th,N\text{-}field}$

implants @ step 12

P, $D_I = 5\times10^{12}/cm^2$, 40keV

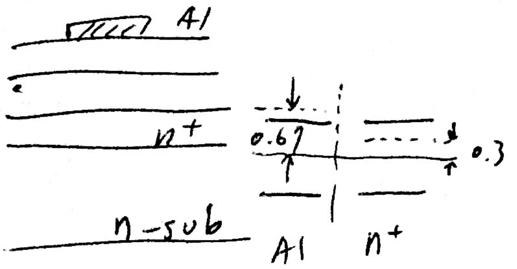
$\Rightarrow R_p = 0.05\,\mu m.\ \Delta R_p = 0.022\,\mu m \equiv Dt = 2.42\times10^{-12}\,cm^2$

total $Dt = 2.42\times10^{-12} + 2.43\times10^{-10} \cong 2.43\times10^{-10}\,cm^2$

$N_S = \frac{1}{2}N_0 = \frac{1}{2}\,\frac{D_I/2}{\sqrt{\pi Dt}} = 4.52\times10^{16}/cm^3$ $\boxed{x_j\ test < x_S}$ verify yourself

$$V_{TH} = V_{FB} - 2\phi_f - \frac{Q_B}{C_{ox}} = (0.3 - 0.56 - 0.11) - 0.6 - \frac{\sqrt{2\times11.7\times8.85\times10^{-14}\cdot1.6\times10^{-19}\cdot4.52\times10^{16}\cdot2\cdot0.3}}{2.46\times10^{-9}}$$

$9.48\times10^{-8}\,C/cm^2$



$= \boxed{-39.51\,V}$