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Problem set 1

$n_i = 1.5\times10^{10}$

1 P-type Si, $N_a = 2\times10^{17}\ cm^{-3}$, $t_{ox} = 10nm$, $Q_{ss}' = 5\times10^{10}\ C\,cm^{-2}$, $E_g = 1.12eV$

a) $E_{Fi} - E_F = \phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = 0.0259 \ln\left(\frac{2\times10^{17}}{1.5\times10^{10}}\right) = \boxed{0.4249\ V}$

b) Oxide capacitance, $C_{ox} = \frac{\varepsilon_{ox}\varepsilon_o}{t_{ox}} = \frac{\varepsilon_o(10^2)(3.9)}{10\times10^{-9}(10^2)} = \boxed{3.453\times10^{-7}\ F/cm^2}$

c) Max dep. reg. width, $x_{dt} = \left(\frac{4\varepsilon_s\phi_{fp}}{eN_a}\right)^{1/2} = \left[\frac{4(\varepsilon_o\times10^{-2})(11.7)(0.4249)}{e(2\times10^{17})}\right]^{1/2} = \boxed{7.413\times10^{-5}\ cm}$

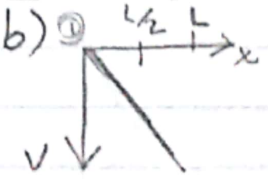
d) $\phi_{ms} = -\left[\frac{E_g}{2e} + \phi_{fp}\right] = -\left[\frac{1.12}{2} + 0.4249\right] = \boxed{-0.9849\ V}$

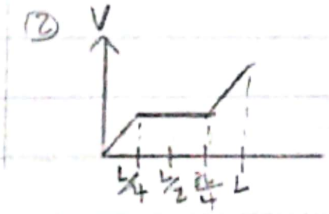
e) Flat band voltage, $V_{FB} = \phi_{ms} - \frac{Q_{ss}}{C_{ox}} = -0.9849 - \frac{5\times10^{10}e}{3.453\times10^{-7}} = \boxed{-1.008\ V}$

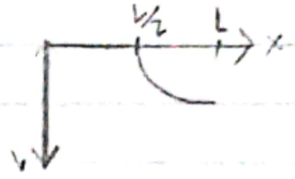
f) $|Q_{SD}'(max)| = eN_a x_{dt} = 2.3754\times10^{-7}\ C/cm^2$

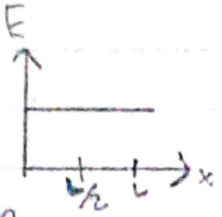
$V_{TP} = \frac{|Q_{SD}'(max)|}{C_{ox}} + V_{fp} + 2\phi_{fB} = \boxed{0.530\ V}$

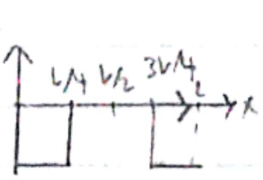
2 a) Yes, in equilibrium as Fermi level is constant.

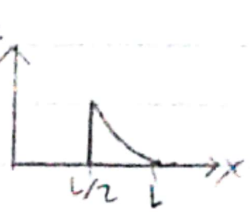
b) ① 

② 

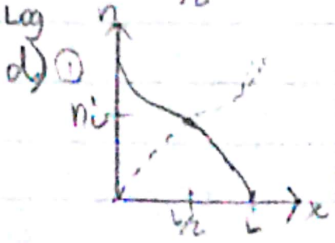
③ 

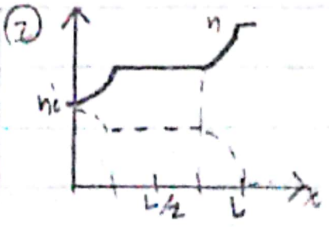
c) ① 

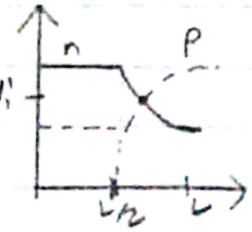
② 

③ 

$E = -\frac{dV}{dx}$

d) ① 

② 

③ 

$n = n_i \exp\left(\frac{E_i - E_f}{kT}\right)$

3 P-type, $K_p' = 0.1\ mA/V^2$, $\frac{W}{L} = 17$, $V_t = -0.5V$ I? a) $V_{SG} = 0.4$, $V_{SD} = 0.3$ b) $V_{SG} = 1.2$, $V_{SD} = 2\ V$

$I_{D_{Linear}} = \frac{W}{L}K_p'\left((V_{SG} - |V_{tp}|) - \frac{V_{SD}}{2}\right)V_{SD}$, $I_{DsaT} = \frac{1}{2}\frac{W}{L}K_p'(V_{SG} - |V_{tp}|)^2$

a) $V_{ov} = V_{SG} - |V_{tp}| = 0.4 - 0.5 = -0.1V$ ∴ Linear ∴ $\boxed{I_D = 0.1275\ mA}$

b) SAT ∴ $\boxed{I_D = 0.4165\ mA}$

P-type, $t_{ox}=25nm$, $N_a=6\times10^{15}cm^{-3}$

4) $\gamma=\frac{\sqrt{2\varepsilon_s qN_a}}{C_{ox}}$, $C_{ox}=\frac{3.9\varepsilon_0}{t_{ox}}=1.381\times10^{-7}\ F/cm^2$ $\therefore \boxed{\gamma=0.3231}$

$\Delta V_T=\frac{-\Delta Q'_D}{C_{ox}}=\gamma\left(\sqrt{2\phi_{fp}+V_{BS}}-\sqrt{2\phi_{fn}}\right)$ $\therefore \boxed{V_{BS}=-0.65}$ final answer

5) $\phi_{fp}=0.0259\ln\left(\frac{10^{16}}{1.5\times10^{10}}\right)=0.347V$ $V_{DSsat}=V_{GS}-V_T=1.5-0.5=1V$

$\Delta V_{DS}=V_{DS}-V_{DSsat}=2V$, $\Delta L=\sqrt{\frac{2\varepsilon_s}{eN_a}}\times\left(\sqrt{\phi_{fp}+V_{DS(sat)}+\Delta V_{DS}}-\sqrt{\phi_{fp}+V_{DSsat}}\right)$

$\therefore \Delta L=\sqrt{\frac{2(11.7\varepsilon_0)}{e(10^{16})}}\times\left(\sqrt{0.347+1+2}-\sqrt{0.347+1}\right)=\boxed{2.405\times10^{-5}cm}$

b) $\Delta L=\sqrt{\frac{2\varepsilon_s}{eN_a}}\left(\sqrt{Q_{sat}+(V_{DS}-V_{DSsat})}-\sqrt{Q_{sat}}\right)$, $Q_{sat}=\frac{2\varepsilon_s}{eN_a}\cdot\left(\frac{E_{sat}}{2}\right)^2$

$\because E_{sat}=30\ kV/cm$ $\therefore Q_{sat}=0.121$ $\therefore \boxed{\Delta L=3.505\times10^{-5}cm}$

b) $\because \Delta L=2.405\times10^{-5}cm$ $\therefore \frac{I_D'}{I_D}=\frac{L}{L-\Delta L}=1.25$

c) $\frac{L}{L-(2.405\times10^{-5}\times10^{-2})}=1.4$, solve for L $\therefore L=8.42\times10^{-7}m=\boxed{8.42\times10^{-5}cm}$

d) $\frac{\Delta L}{L}=0.1$ $\therefore L=10\Delta L=\boxed{2.405\times10^{-4}cm}$

f) $\frac{L}{L-\Delta L}=1+\lambda V_{DS}$ $\therefore \lambda=\frac{1}{3}\left[\frac{1.2\times10^{-4}}{1.2\times10^{-4}-2.405\times10^{-5}}\right]=\boxed{0.0836\ V^{-1}}$

6) $V_{TLong}=\frac{Q_{SD'max}-Q_{SS}'}{C_{ox}}+Q_{MS}+2\phi_{fp}$, $C_{ox}=\frac{\varepsilon_{ox}}{t_{ox}}=3.453\times10^{-7}F/cm^2$

a) $Q_{SS}'=10^{10}e=1.6\times10^{-9}$, $\phi_{fp}=0.0259\ln\left(\frac{2\times10^{16}}{n_i}\right)=0.4249V$

$Q_{MS}=-\left(\frac{E_g}{2}+\phi_{fp}\right)=-0.985V$, $Q_{SD'max}=eN_A x_{dT}=2.37\times10^{-7}C/cm^2$

$\therefore V_{TLong}=\frac{2.37\times10^{-7}-1.6\times10^{-9}}{3.453\times10^{-7}}+(-0.985V)+2(0.4249)=\boxed{0.547V}$

$\Delta V_T=\frac{-eN_A x_{dT}}{C_{ox}}\left(\frac{x_i}{L}\sqrt{1+\frac{2x_{dT}}{x_i}}-1\right)$, $x_{dT}=7.421\times10^{-6}$ $\therefore \Delta V_T=-0.085V$

$V_{Tshort}=V_{TLong}+\Delta V_T=\boxed{0.462V}$

b) $E_{lateral}=\frac{V_{DSsat}}{L-\Delta L}$ $\therefore V_{DSsat}=4.538V$ $\because V_{GS}=V_{DS}$ $\therefore \Delta V_{DS}=V_T=0.462V$

$\Delta L=\sqrt{\frac{2\varepsilon_s}{eN_a}}\left(\sqrt{\phi_{fp}+V_{DSsat}+\Delta V_{DS}}-\sqrt{\phi_{fp}+V_{DSsat}}\right)=8.15\times10^{-7}cm$, $\boxed{E_{lateral}=92.263\ eV/cm}$

c) $v=v_{sat}=\boxed{10^7\ cm/s}$ d) $E_{normal}=\frac{1}{\varepsilon_s}\left(|Q_{SD'max}|+\frac{1}{2}Q_n'\right)=\boxed{985.4\ kV/cm}$