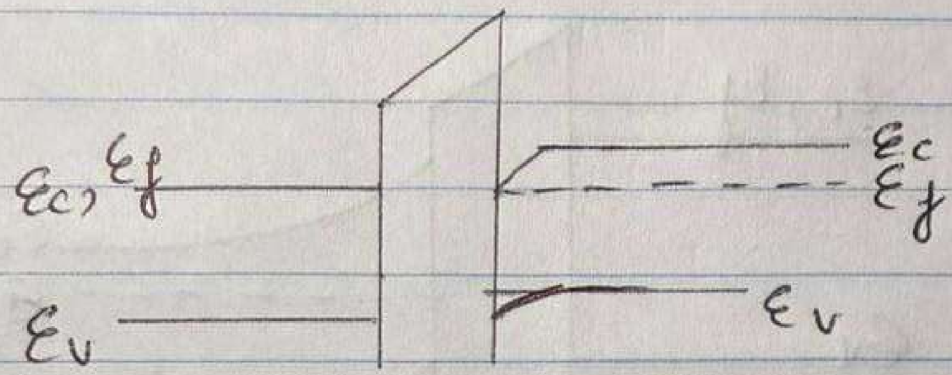
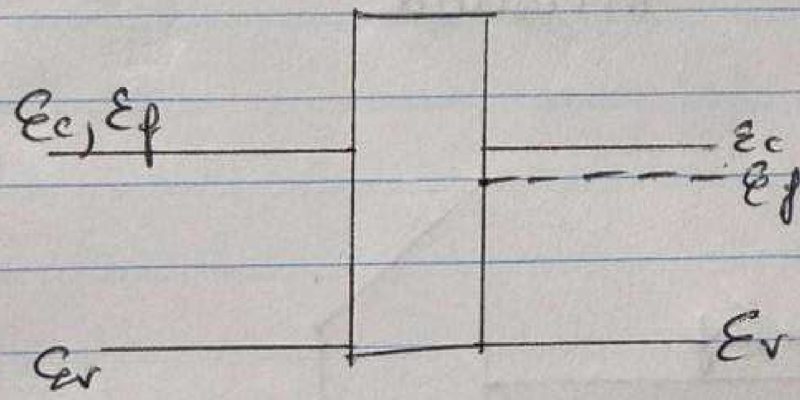
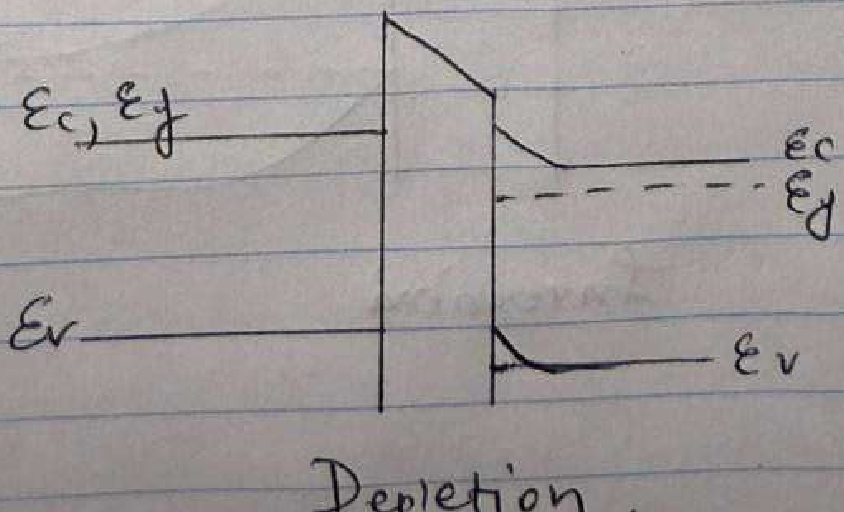
P1)



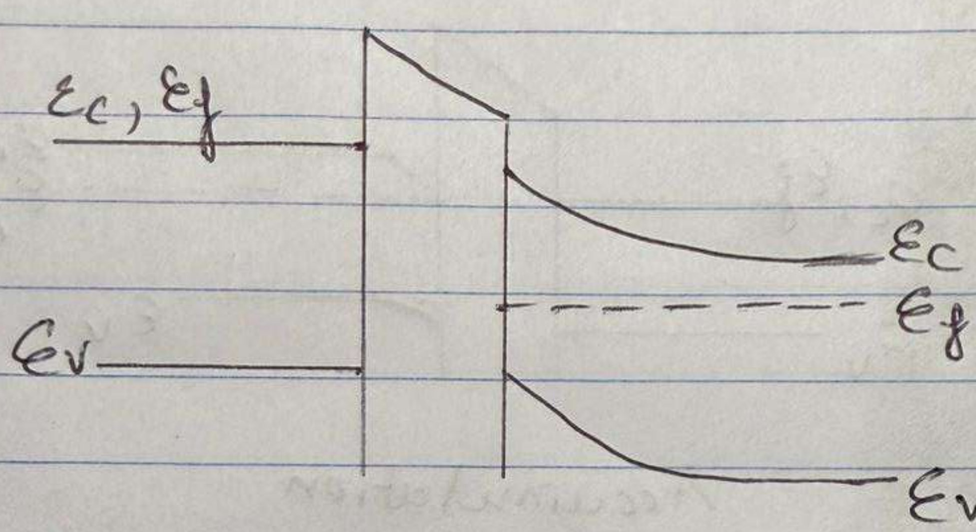
Accumulation



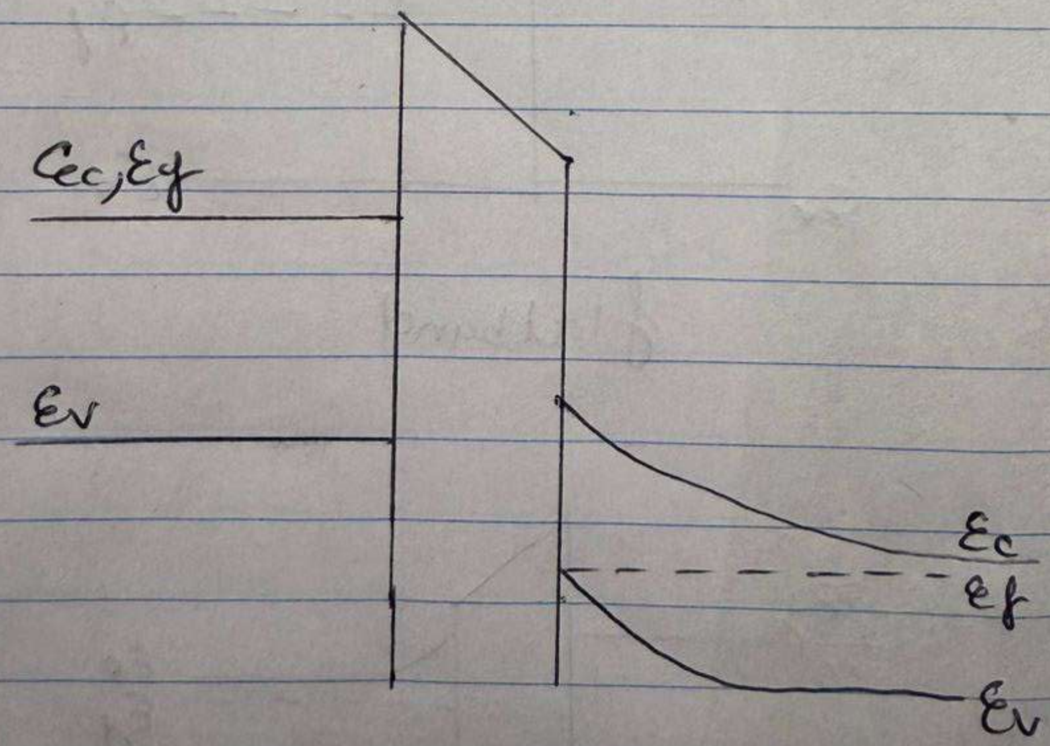
flatband



Depletion.



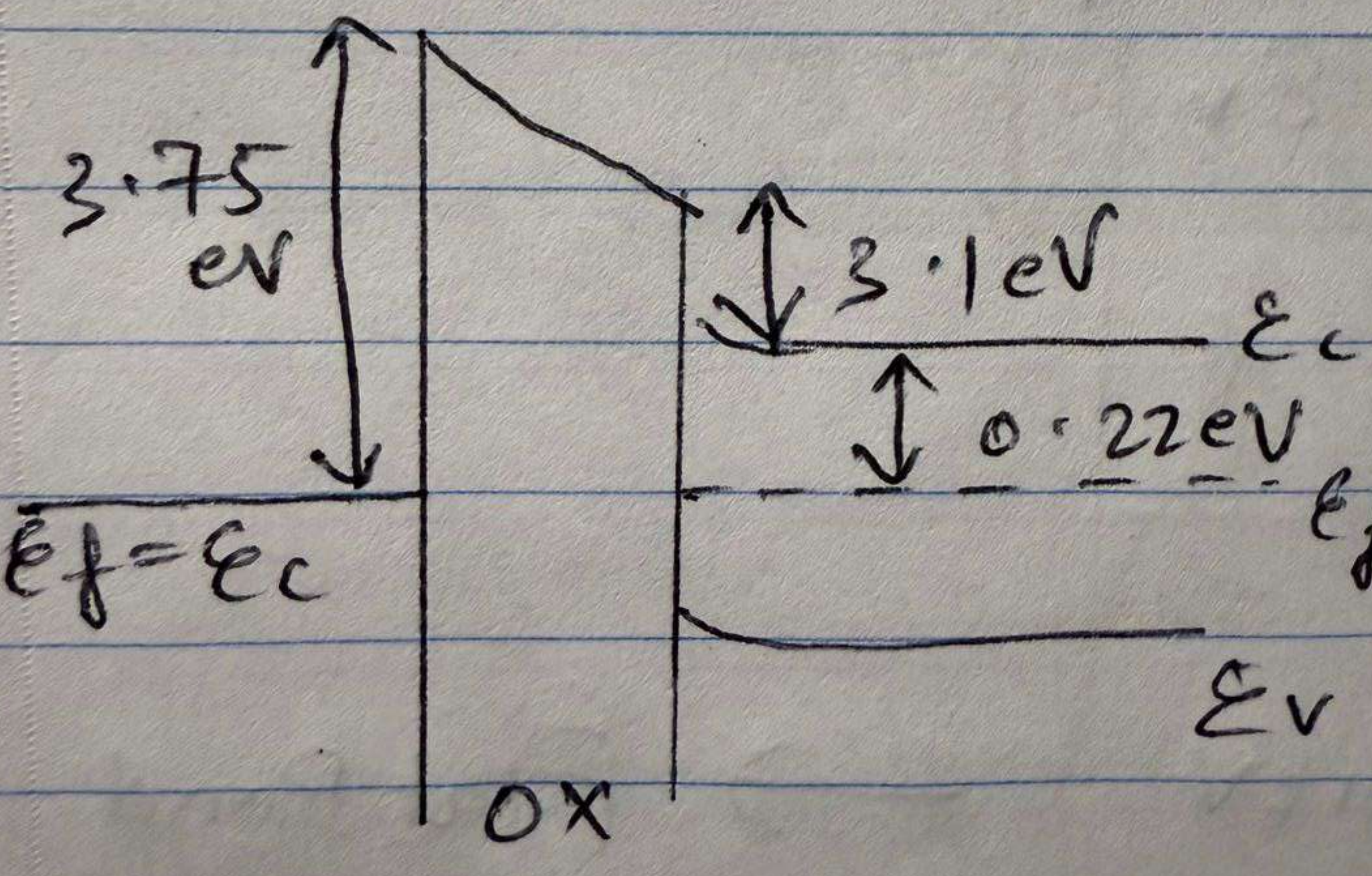
Threshold



Inversion

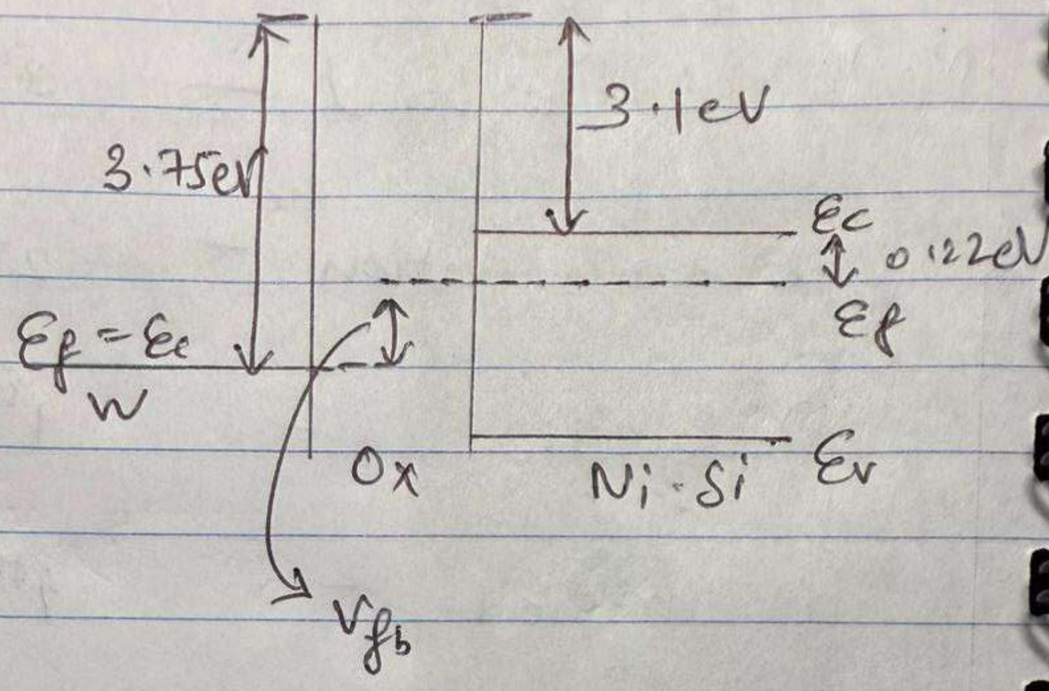
Q2)

a) i)

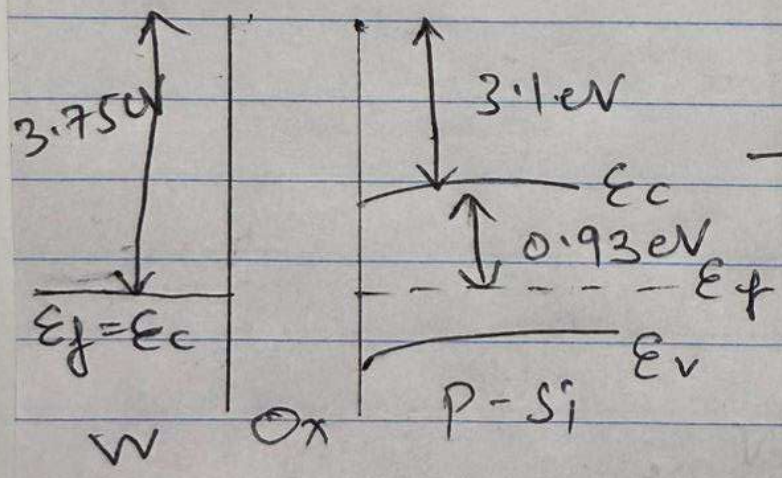


3.75 eV
3.1eV
$\mathcal{E}_c$
0.22eV
$\mathcal{E}_f$
$\mathcal{E}_f = \mathcal{E}_c$
$\mathcal{E}_v$
OX

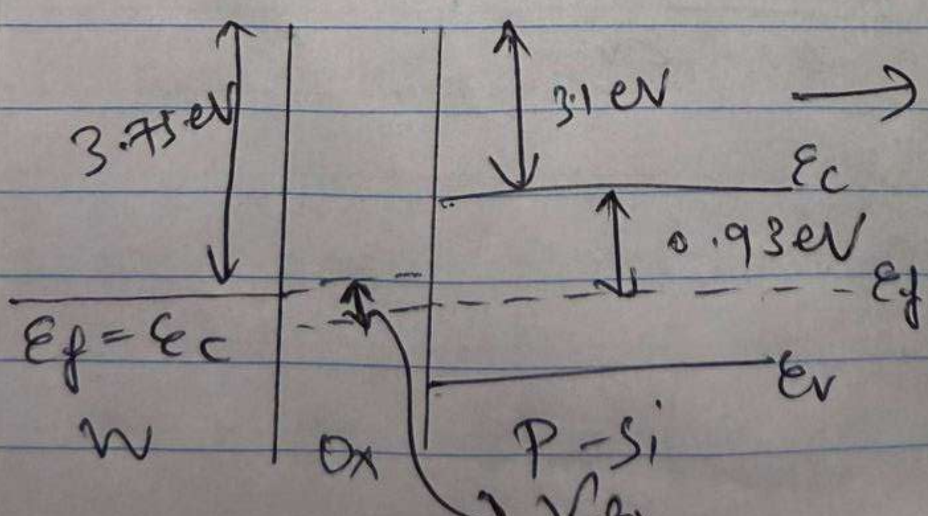
ii



b)

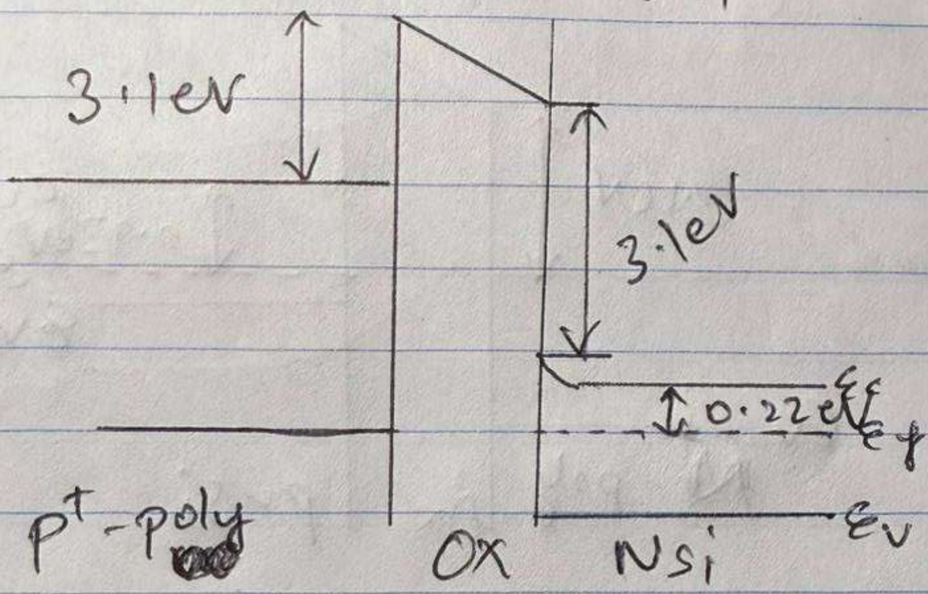


→ Thermal Equil

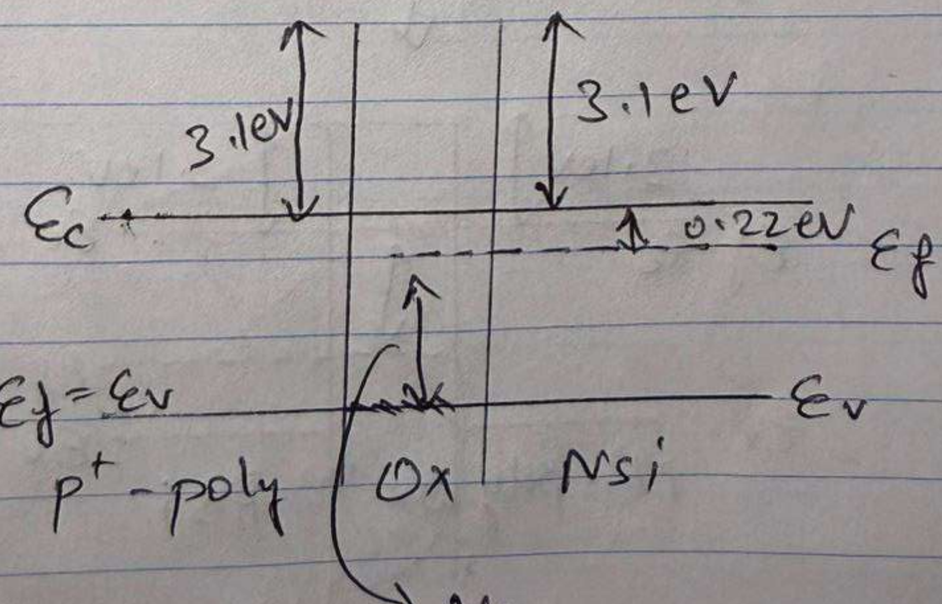


→ Flat Band

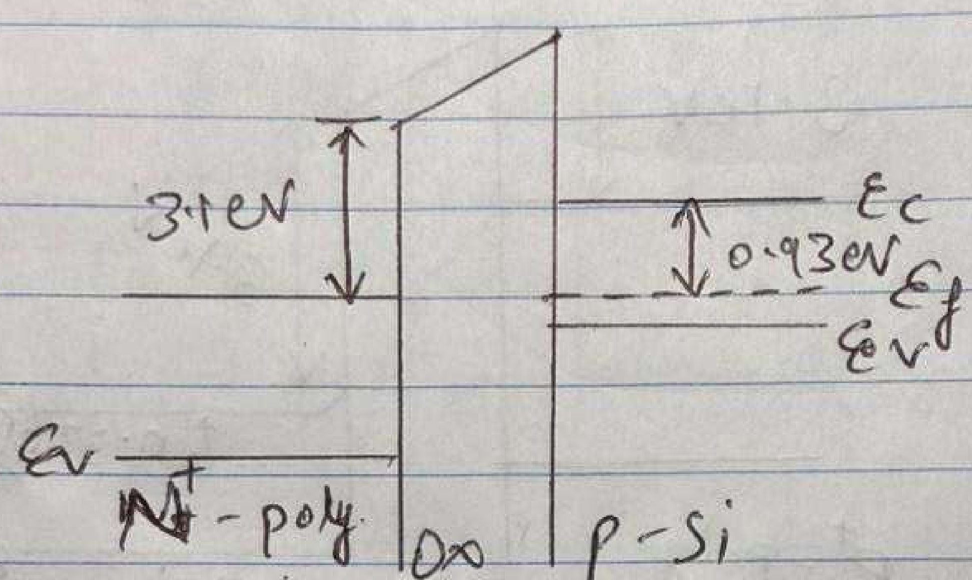
c) Thermal Equil



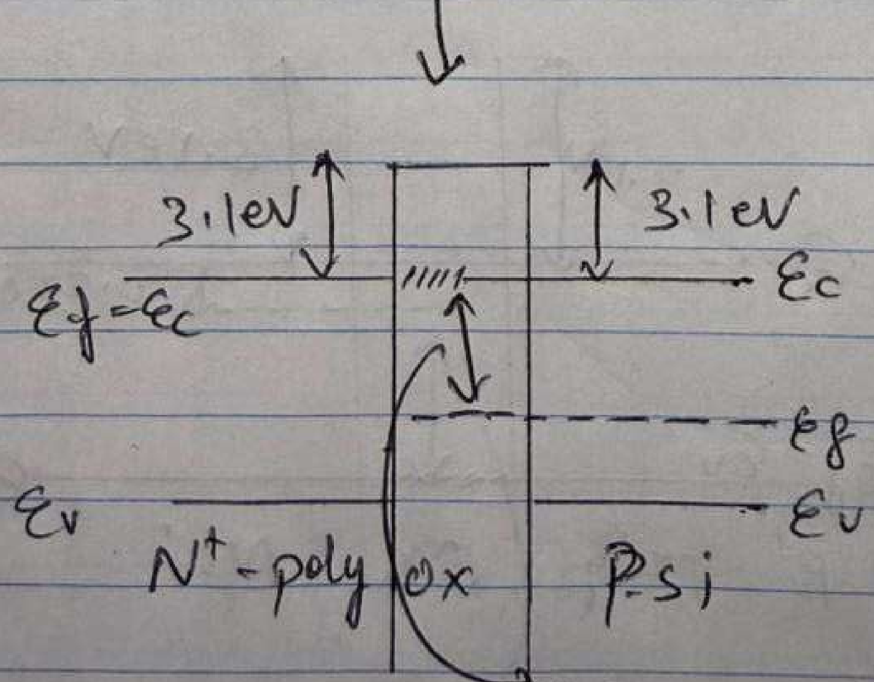
Flat band



d) Thermal Equil



Flatband



Q3) a) flat band — 3^{rd} figure

b) accumulation — 2^{nd} figure

c) depletion — 1^{st} figure

d) threshold — 4^{th} figure

e) inversion — 5^{th} figure

Q4)

a) $\phi_B = \left(\frac{kT}{q}\right) \ln\left(\frac{N_a}{N_i}\right)$

$(0.026V) \times \ln\left(\frac{10^{18} cm^{-3}}{10^{10} cm^{-3}}\right)$

$= 0.479V$

$\therefore V_{fb} =$

$\left(\frac{\chi_{si}}{q}\right) - \left[\left(\frac{\chi_{si}}{q}\right) + \frac{1}{2}\left(\frac{\mathcal{E}_g}{q}\right) + \phi_B\right]$

$= -\left[\frac{1}{2}\left(\frac{\mathcal{E}_g}{q}\right) + \phi_B\right]$

$= -\frac{1.12V}{2} - 0.479V$

$= \boxed{-1.039V}$

b) $W_{d\,max} = \sqrt{\dfrac{2\varepsilon_{si} \times 2\phi_B}{q N_a}}$

$= \sqrt{\dfrac{2 \times 11.7 \times 8.84 \times 10^{-14} \times 2 \times 0.479}{1.6 \times 10^{-19} \times 10^{18}}}$

$= 3.521 \times 10^{-6}\ \text{cm}$

c) $V_t = V_{fb} + 2\phi_B + \dfrac{\sqrt{2\varepsilon_{si} q N_a \times 2\phi_B}}{C_{ox}}$

$= (-1.039) + 2 \times (0.479) +$

$\dfrac{1 \times 2 \times 11.7 \times 8.85 \times 10^{-14} \times 1.6 \times 10^{-19} \times 10^{-18} \times 2 \times 0.479}{\sqrt{}(2 \times 10^{-7})\ 3.9 \times 8.85 \times 10^{-14}}$

$= \boxed{0.2455\ \text{V}}$

d) Only the flatband Voltages change.

$$V_{fb} = \left[\frac{\chi_{si}^{*}}{q} + \frac{E_g}{q}\right] - \left[\frac{\chi_{si}}{q} + \frac{1}{2}\left(\frac{E_g}{q}\right) + \phi_B\right]$$

$$= \frac{1}{2}\left(\frac{E_g}{q}\right) - \phi_B$$

$$= \frac{1.12}{2} - 0.479 = 0.081\,V$$

$$\therefore V_t = (0.081V) + 2\times(0.479V)$$

$$+ \frac{\sqrt{2\times 11.7\times 8.85\times10^{-14}\times1.6\times10^{-19}\times10^{18}\times2\times0.479}}{\left(\frac{3.9\times 8.85\times10^{-14}}{(2\times10^{-7}cm)}\right)}$$

$$= 1.3655V$$

	Parameters	Increase	Decrease	Unchange
a	Accumulation Regn Capacⁿ			X
b	Flatband Voltage, V_{fb}	X		
c	Depletion Regn Capacitance		X	
d	Threshold Voltage, V_t		X	
e	Inversion region Capace		X	

5) a) At accumulation : Accumulation capacitance

$$C = C_{ox} = \varepsilon_{ox} / T_{ox}$$

b) At flat band : Flat band Voltage

$$V_{fb} = \phi_g - \left(4.05 + 0.56 + 0.026 \ln\left(\frac{N_a}{N_i}\right)\right)$$

$N_a \downarrow$, $|\phi_B| \downarrow$

c) At depletion : depletion capacitance

$$1/C = 1/C_{ox} + W_{dep}/\varepsilon_s$$

$N_a \downarrow$, $W_{dep} \uparrow$, $C \downarrow$

d) At threshold Voltage : threshold Voltage

$$V_t = V_{fb} + |2\phi_B| + Q_d / C_{ox}$$

$N_a \downarrow$, $|\phi_B| \downarrow$, $Q_d \downarrow$, $V_t \downarrow$

e) At inversion : inversion capacitance

$$\frac{1}{C} = \frac{1}{C_{ox}} + \frac{W_{dmax}}{\varepsilon_s} \rightarrow N_a \downarrow, W_{dmax} \uparrow, C \downarrow$$

6) a) $V_{fb} = \Phi_{Al} - \phi_{Si} = 4.1V - \left(\chi_{Si} + E_g/2q + \frac{E_i - \mathcal{E}_f}{q}\right)$

$= 4.1V - \left(4.05V + (1.12/2)V + \left(\frac{kT}{q}\right) \cdot \ln\left(\frac{N_a}{n_i}\right)\right) = -0.80V$

b) $\Phi_B = \frac{E_i - \mathcal{E}_f}{q} = \frac{kT}{q} \cdot \ln\left(\frac{N_a}{n_i}\right)$

$= 0.290V$

$W_{dmax} = \sqrt{\frac{2\varepsilon_s 2\Phi_B}{qN_a}} = 0.866\,\mu m$

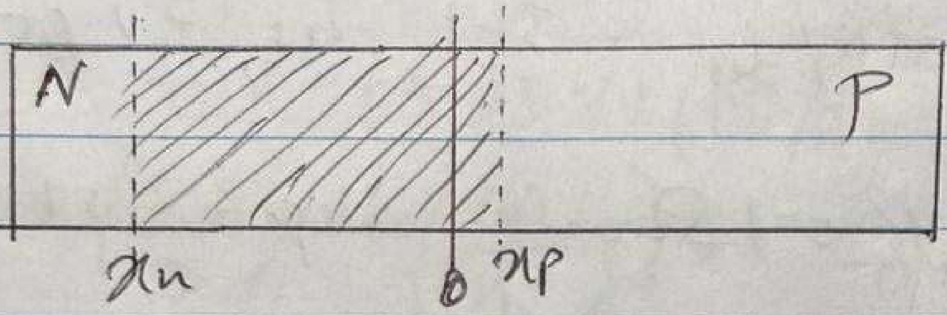
$V_t = V_{fb} + 2\Phi_B + \frac{qN_aW_{dmax}}{C_{ox}} \geq 5V$

$C_{ox} \leq 2.65 \times 10^{-9} F/cm^2$

c) $C_{ox} = \frac{\varepsilon}{T_{ox}} = \frac{K\varepsilon_0}{1\mu m} = 2.65 \times 10^{-9}$

$K = 2.99$

7) 99% of depletion region on n-Si



p^+N

$$W_{dep} = \sqrt{\frac{2\varepsilon_s \phi_b}{qN_d}} \approx x_N$$

$$|x_p| = (x)\left(\frac{N_d}{N_a}\right)$$

$$x_p = 0.01\, W_{dep}$$

$$x_n = 0.99\, W_{dep}$$

$$0.01 = 0.99 \frac{N_d}{N_a}$$

$$N_d = \frac{N_a}{99}$$

$$N_d = \frac{1}{q\mu_p} = \frac{1}{q\mu_n} \left(\rho = 1\right)$$

$q \rightarrow$ charge

μ = mobility

ρ = resistivity.

$$N_a = \frac{99}{q\mu_n} \quad \rho = \frac{1}{q\mu_p}$$

$$\rho = \frac{1}{99}\frac{\mu_n}{\mu_p}$$

8) from previous problem (room temp)

$$N_a = \frac{99}{q\mu_n} = 4.4\times10^{17} \quad N_d = \frac{1}{q\mu_n} = 4.6\times10^{15}$$

$$W = \sqrt{\frac{2\epsilon_s(\phi_{bi}-V)}{q}\left(\frac{1}{N_d}+\frac{1}{N_a}\right)}$$

$$\phi_{bi} = \frac{kT}{q}\ln\left(\frac{N_d \times N_a}{n_i^2}\right)$$

$$0.026\ln\left(\frac{4.6\times10^{15}\times4.4\times10^{17}}{10^{20}}\right)$$

$$0.796V = 0.8.$$

9) $\mu_n = 1400\ cm^2\ V^{-1} s^{-1}$

$\mu_n / \mu_p = 3.1 \quad n_i = 1.05 \times 10^{10}\ cm^{-3}$

$\rho = 1\ \Omega cm \quad \mu_p = 451.6 \approx 452$

$N = \frac{1}{q \mu_p} \longrightarrow N_a = 1.38 \times 10^{16}$

$N_d = 4.46 \times 10^{15}$

$\phi_b = \frac{kT}{q} \ln\left(\frac{N_a N_d}{(N_i)^2}\right)$

$0.026 \ln\left(\frac{1.38 \times 10^{16} \times 4.46 \times 10^{15}}{1.05 \times 1.05 \times 10^{20}}\right)$

$= \boxed{0.70V}$