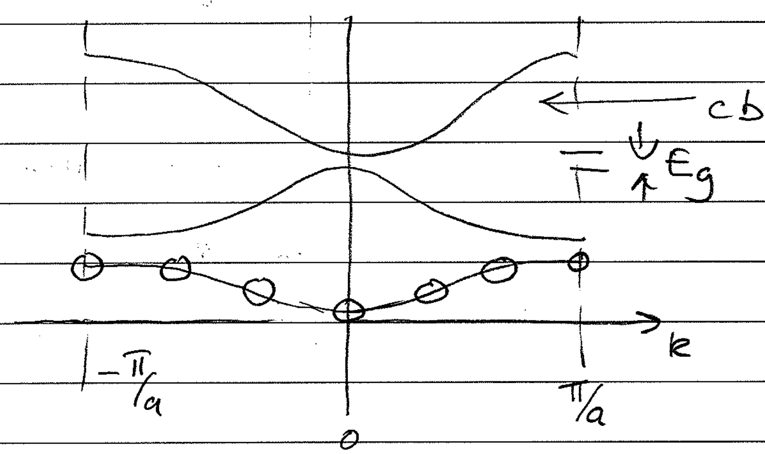
EECE 480 FINAL 2007

1a) Allowed $k = \frac{2\pi n}{Na} = \frac{\pi n}{6a}$ $n = 0, \pm 1, \pm 2, \pm 3$

$\therefore$ N momentum states / band

2N electron states / band (spin)

We have $N \times 4$ electrons $\therefore$ 1st 2 bands filled

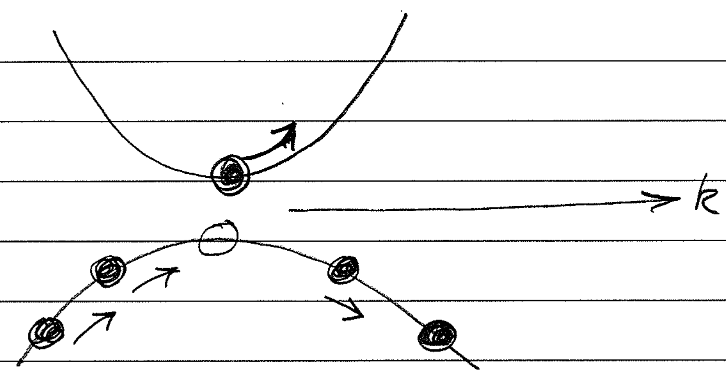


b) $$E - E_c = \frac{\hbar^2 k^2}{2m^*}$$

Bottom (top) of bands are approximately parabolic.

Electrons (holes) reside near minima (maxima) due to the restoring action of scattering (collisions).

1(c)



$(\hbar)k$ is $+ve \rightarrow$ i.e. v is $+ve \rightarrow$ for CB electrons

v is $-ve \rightarrow$ for VB "

i.e. $\hbar k \equiv m^* v$

(d) $$\vec{J} = \frac{1}{\Omega}\sum_{\text{filled states}} -q\vec{v}_k \equiv \frac{1}{\Omega}\sum_{\text{full band}} - \frac{1}{\Omega}\sum_{\text{empty states}} -qv_k$$

$$= \frac{1}{\Omega}\left[0 + qv_k\right]$$

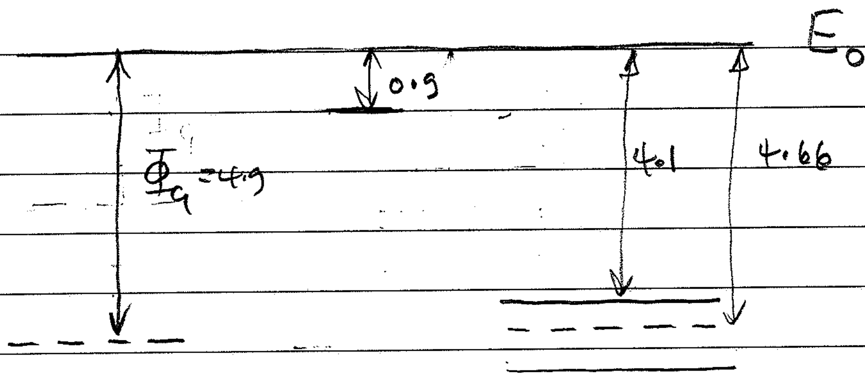
$$= \frac{1}{10^{-2}} \times 1.6\times10^{-19} \times v_k\,(m/s).$$

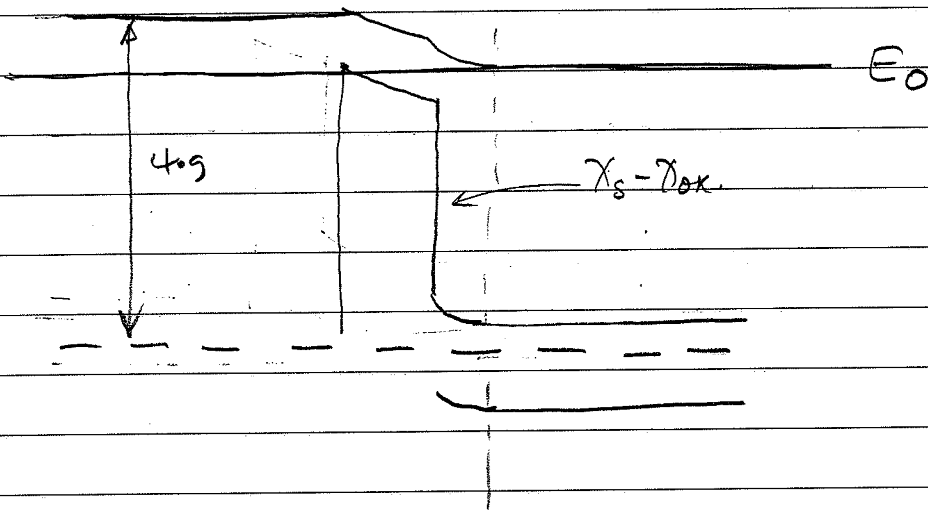
$$E = \frac{\hbar^2 k^2}{2m} \qquad mv = \hbar k \qquad \therefore v = \frac{4.55\times10^{-26}}{0.5\times9.1\times10^{-31}} = 10^5\ m/s$$

$$\therefore J = \frac{1.6\times10^{-19}}{10^{-2}} \times 10^5 \quad A \quad = \underline{\underline{1.6\ pA}}$$

2a) Volume of channel is now so small that statistical variations of N_A are now significant.

b)





c) $\phi_B = \frac{kT}{q} \ln \frac{N_A}{n_i} = 0$

$\therefore V_T = V_{fb} = \frac{\Phi_g - \Phi_s}{q} = 4.9 - (4.1 + 0.56) = 4.9 - 4.66$

$= \underline{\underline{0.24\,V}}$

3 $$T(E) = \exp\left[-2k'(E)t\right]$$

From Eqn sheet

$$T(E) \approx \exp -\frac{4\pi}{h}\int_0^{t_{ox}} \left\{2m\left[U(x)-E\right]\right\}^{1/2} dx$$

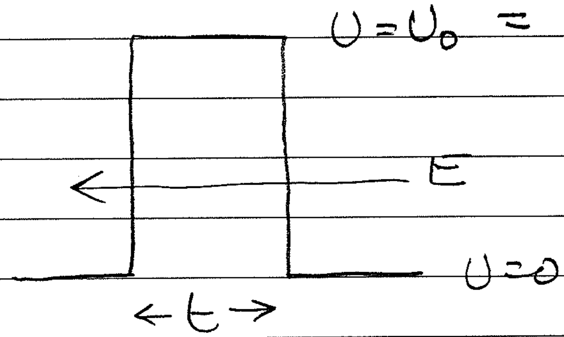
For $U(x) = U_0 = \text{constant}$

$$T(E) = \exp -\frac{4\pi}{h}\cdot\sqrt{2m(U_0-E)}\quad t$$

$$= \exp\left\{-\frac{2}{\hbar}\sqrt{2m(U_0-E)}\cdot t\right\}$$

$$\therefore\ k' = \frac{1}{\hbar}\sqrt{2m(U_0-E)}$$

$$U = U_0 = \chi_{Si} - \chi_{ox}$$



(a) For silica $U_0 = 4.1 - 0.9 = 3.2\,eV$
For hafnia $U_0 = 4.1 - 2.9 = 1.2\,eV$

For silica $U_0 - E = 3\,eV$ For hafnia $U_0 - E = 1\,eV$

$$T_{silica}(2nm) = \exp\left\{-\frac{2}{\hbar}\sqrt{2m}\,(3)^{1/2}\cdot 2\times10^{-9}\right)$$

$$T_{hafnia}(t_{haf}) = \exp\left\{-\frac{2}{\hbar}\sqrt{2m\,1}\cdot t_{haf}\right)$$

for equal $T(E=0.2eV)$

$$t_{haf} = \sqrt{3} \times 2\times10^{-9} \quad m$$
$$= 3.46 \text{ nm}$$

b) $$I_{Dsat} = \frac{Z}{L}\mu\frac{C_{ox}}{2}\left[V_{GS}-V_T\right]^2$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \qquad V_T = V_{fb} + 2\phi_B + \frac{1}{C_{ox}}\sqrt{}$$

$$C_{ox}(\text{silica}) = \frac{3.9\varepsilon_0}{2} \qquad C_{ox}(\text{haf}) = \frac{4\times3.9\varepsilon_0}{3.46}$$

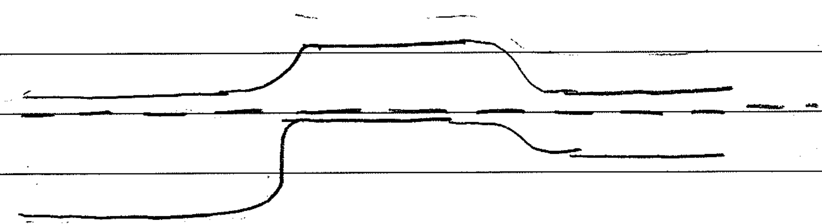
$$\therefore \frac{C_{ox}(\text{haf})}{C_{ox}(\text{Si})} = \frac{4}{3.46}\times2 = \frac{8}{3.46} \approx 2$$

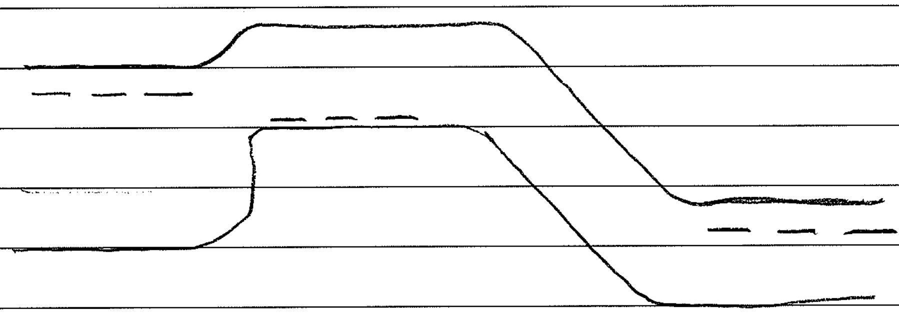
$\therefore$ $I_{Dsat}\uparrow$ due to $C_{ox}\uparrow$ directly

$I_{Dsat}\uparrow$ due to $V_T\downarrow$

4a) $\chi_{InGaP} = \chi_{GaAs} = 4.07eV$

$E_g = 1.9$ $\quad$ $E_g(GaAs) = 1.42$





b) - To reduce R_B, increase f_{max}, decrease NF at HF.

- Because β would go down due to back-injection.

c) $BDV \propto \left(\frac{1}{N_D} + \frac{1}{N_A}\right)$

$C'_{CB} \propto \frac{1}{d} \propto \frac{1}{\sqrt{1/N_A + 1/N_D}}$

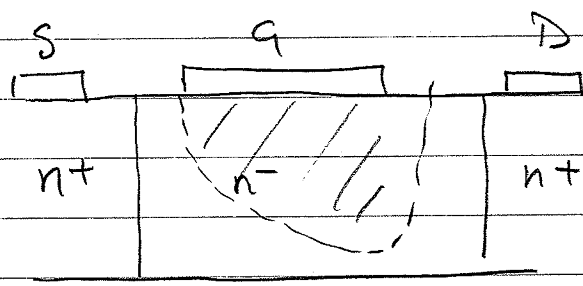
$C'_{BE,F} \propto d \propto \sqrt{\frac{1}{N_A} + \frac{1}{N_D}}$

For high power: need high BDV $\therefore N_D$ low

For HF need C's low d large for CBC $\therefore N_D$ low

BUT d small for $C'_{BE,t}$ i.e. N_D high.

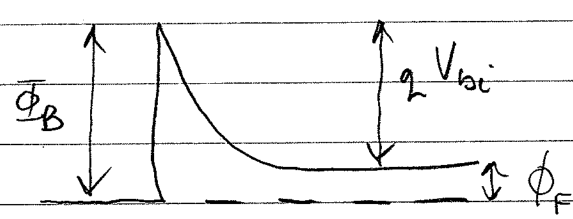
5 a)



b) High mobility semic → high g_m

c) Need W @ $V_{GS} = V_{DS} = 0$

$$W_0 = \sqrt{\frac{2\varepsilon}{q} V_{bi} \frac{1}{N_D}}$$



$$qV_{bi} = \Phi_B - q\phi_F$$

$$n = N_c \exp\left(\frac{E_F - E_C}{kT}\right) = N_c \exp \frac{-q\phi_F}{kT}$$

$$-\phi_F = \frac{kT}{q} \ln \frac{N_D}{N_C}$$

$$\therefore \phi_F = \frac{kT}{q} \ln \frac{N_C}{N_D}$$

$$= 0.0259 \ln \frac{4.21 \times 10^{17}}{10^{16}} = 0.097$$

$$\therefore V_{bi} = 0.8 - 0.097 = 0.703 \text{ V}$$

$$W = \left(\frac{2 \times 13.1 \times 8.85 \times 10^{-12}}{1.6 \times 10^{-19}} \times 0.703 \times \frac{1}{10^{22}} \right)^{1/2}$$

$$W = 3.19 \times 10^{-7} \text{ m}$$
$$= \underline{\underline{319 \text{ nm}}}$$

$\therefore$ it is depletion device.

Generally $\quad W = \sqrt{\frac{2\varepsilon}{q}\left(V_{bi} - V_{GS}\right)\frac{1}{N_D}}$

At threshold $W = a \quad \therefore \quad \frac{a^2 q N_D}{2\varepsilon} = V_{bi} - V_T$

$$V_T = V_{bi} - \frac{\left(500 \times 10^{-9}\right)^2 \times 1.6 \times 10^{-19} \times 10^{22}}{2 \times 13.1 \times 8.85 \times 10^{-12}}$$
$$= 0.7 - 1.73$$
$$= \underline{\underline{-1.03 \text{V}}}$$

6 ZERO is strong inversion

$$\psi_s = 2\phi_B = \frac{kT}{q} \ln \frac{N_A}{n_i} = 0.0259 \times \ln \frac{10^{17}}{10^{10}} \times 2$$

$$= \underline{\underline{0.835V}}$$

$$\therefore W_{inv} = \sqrt{\frac{2\varepsilon}{q} \; 0.835 \times \frac{1}{N_D}}$$

$$= \left(\frac{2 \times 11.9 \times 8.85 \times 10^{-12} \times 0.835}{1.6 \times 10^{-19} \times 10^{23}} \right)^{1/2} = 1.05 \times 10^{-7} \text{ m}$$

$$= \underline{\underline{105 \text{ nm}}}$$

$$\therefore \Delta W = 145 - 105 = 40 \text{ nm.} = 40 \times 10^{-7} \text{ cm}$$

$$\Delta Q = +q N_A \Delta W \; A$$

$$= \Delta(It) = I \Delta t$$

$$\therefore \Delta t = \frac{q N_A \Delta W}{J} = \frac{1.6 \times 10^{-19} \times 10^{17} \times 40 \times 10^{-7}}{6.4 \times 10^{-6}}$$

$$= \frac{64 \times 10^{-19+17-7+6}}{6.4} = 10 \times 10^{-3} \text{ s}$$

$$= \underline{\underline{10 \text{ msec}}}$$