Quiz - 3 Solutions

EE 207: Electronic Devices and Circuits — **Quiz 3 08/11/2018**

Maximum marks: 11, Time: 1 hr 15 min

Make reasonable assumptions and state them clearly.

Important constants: $k=8.62\times10^{-5}$ eV/K, $q=1.602\times10^{-19}$ Coulomb, $k_{silicon\text{-}dioxide}=3.9$, $\epsilon_0=8.85\times10^{-14}$ F/cm, $k_{silicon}=11.9$

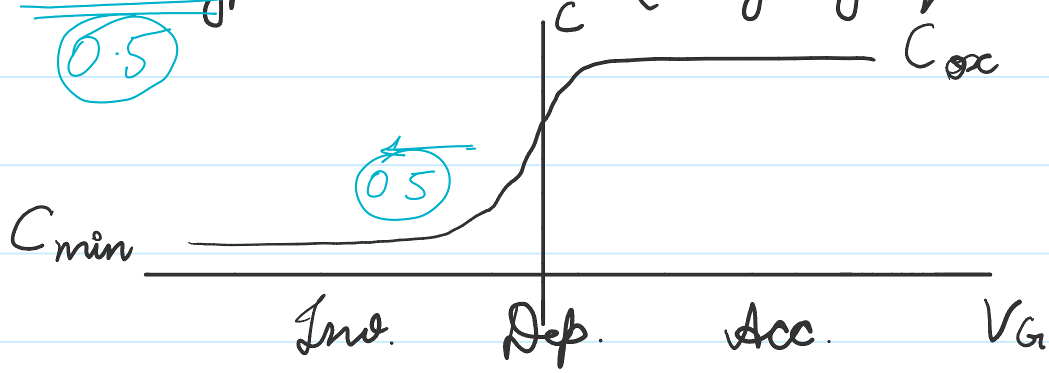
1. (1+1+2+1+2+1+1=9 Marks) An ideal metal-SiO_2-Si MOS capacitor is operated at T=300 K, $x_o=0.1$ um, $N_D=2\times10^{15}$ cm^{-3} and gate area $A_G=10^{-3}$ cm^{-2}.

(a) Sketch the general shape of the high frequency C-V characteristic of this device.
(b) Determine the maximum high-frequency capacitance of this device.
(c) Determine the minimum high-frequency capacitance of this device employing the delta-depletion approximation.
(d) If $V_G=V_T$, determine ϕ_S.
(e) Compute V_T.
(f) Draw the energy band diagram corresponding to gate bias such that $\phi_s=3\phi_F/2$.
(g) Draw the block charge diagram corresponding to gate bias such that $\phi_s=5\phi_F/2$.

2. (1+1=2 Marks) Consider an MOS capacitor on a p-type silicon substrate. The oxide capacitance is 2×10^{-7} F/cm^2, the metal-semiconductor work function difference is -1 V and a positive charge $Q_F=8\times10^{-8}$ C/cm^2 resides at the interface. There is no charge in interface states.
(a) Calculate the flat-band voltage
(b) Is there an electric field in the oxide? If yes, what is its magnitude?

1\. (a) N - type substrate (High freq. C-V)

0.5



(b) C_{max} in accumulation

$$C_{max} = C_{ox} \times A_G$$

$$= \frac{\varepsilon_{ox}}{t_{ox}} \times A_G \quad 0.5$$

$$= \frac{8.85 \times 10^{-14} \, F/cm \times 3.9}{0.1 \times 10^{-4} \, cm} \times 10^{-3} \, cm^2$$

$$= 34.5 \, pF \quad 0.5$$

c) Under Δ-dep approximation, the semiconductor depletion width is maximum at the onset of inversion $\phi_s = 2\phi_F$

$$\phi_F = \frac{kT}{q} \ln\left(\frac{N_D}{n_i}\right)$$

At room temperature, $\frac{kT}{q} \cong 26 \text{ mV}$

$$\phi_F = 26 \ln\left(\frac{2 \times 10^{15}}{10^{10}}\right) \text{mV} \cong 0.32 \, V$$

$$C_{min} = \frac{C_{ox} A_G}{1 + \frac{k_{ox}}{k_S} \frac{W_{dep}}{t_{ox}}}$$ — 0.5

$$W_{dep} = \sqrt{\frac{2 \varepsilon_s (2\phi_F)}{q N_D}}$$ 0.5

$$= \sqrt{\frac{2 \times 11.9 \times 8.85 \times 10^{-12} \times 0.64}{1.6 \times 10^{-19} \times 2 \times 10^{21}}} \text{ m}$$

$$= 0.65 \ \mu m$$ 0.5

$$C_{min} = \frac{34.5}{1 + \frac{3.9}{11.9} \times \frac{0.65}{0.1}} \text{ pF} \cong 11 \text{ pF}$$ 0.5

(d) If $V_G = V_T$; $|\phi_s| = |2\phi_F| = 0.64$ V 0.5

ϕ_s will be negative. 0.5

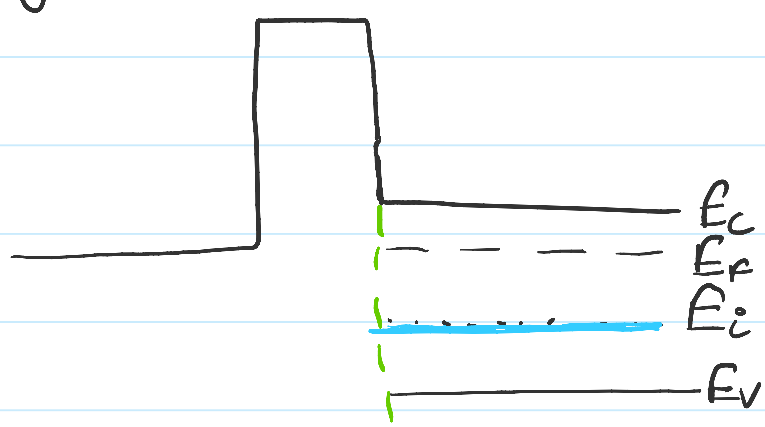
(e) Assuming $\phi_{MS} = 0$,

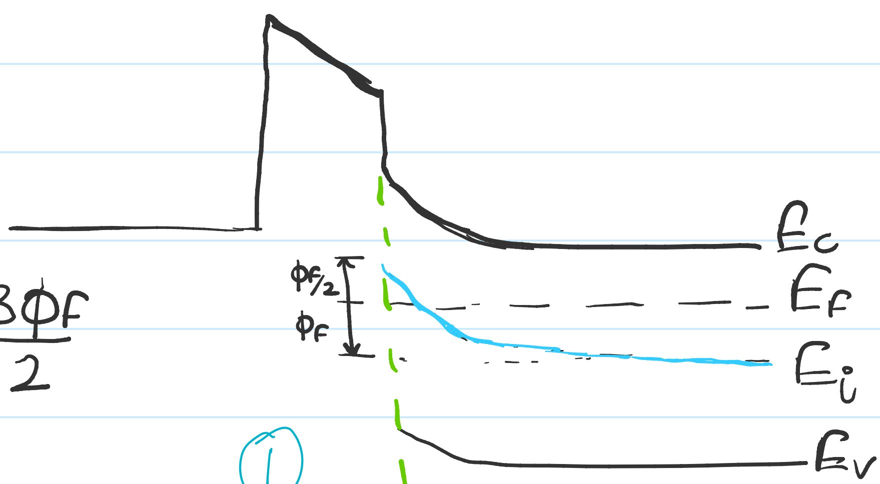
$$V_T = -\left(2\phi_F + \frac{q N_D W_{dep}}{C_{ox}}\right) \quad \text{—— } 1$$

$$= -\left(0.64 + \frac{1.6\times10^{-19} \times 2\times10^{15} \times 0.65\times10^{-4}}{34.5\times10^{-12} \times 10^{3}}\right) V$$

$$= -1.24\ V \quad \text{—— } 1$$

(f) Starting from $\phi_s = 0$,





$$\phi_s = \frac{3\phi_F}{2}$$

1

(g) $\phi_S = 5\phi_F/2$

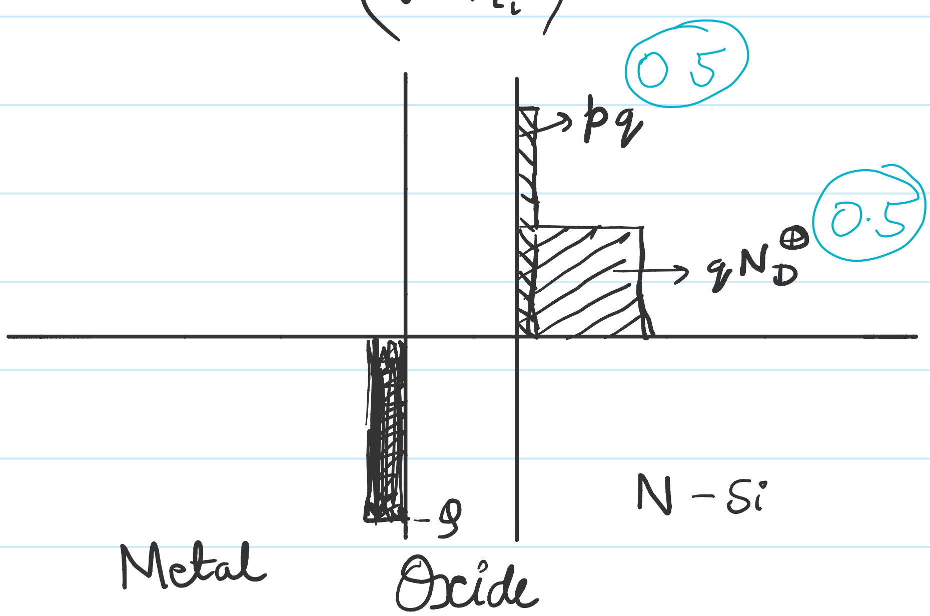
Inversion hole charge density

$$p = n_i e^{\left(\left(5\phi_F/2 - \phi_F\right)/kT/q\right)}$$

$$= n_i e^{\left(\frac{3\phi_F}{2kT/q}\right)}$$

$$e^{\phi_F/kT/q} \Rightarrow N_D/n_i \quad \text{(known)}$$

$$p = n_i\left(\sqrt{\frac{N_D}{n_i}}\right)^3 = 9 \times 10^{17}/cm^3$$



Solution 2:

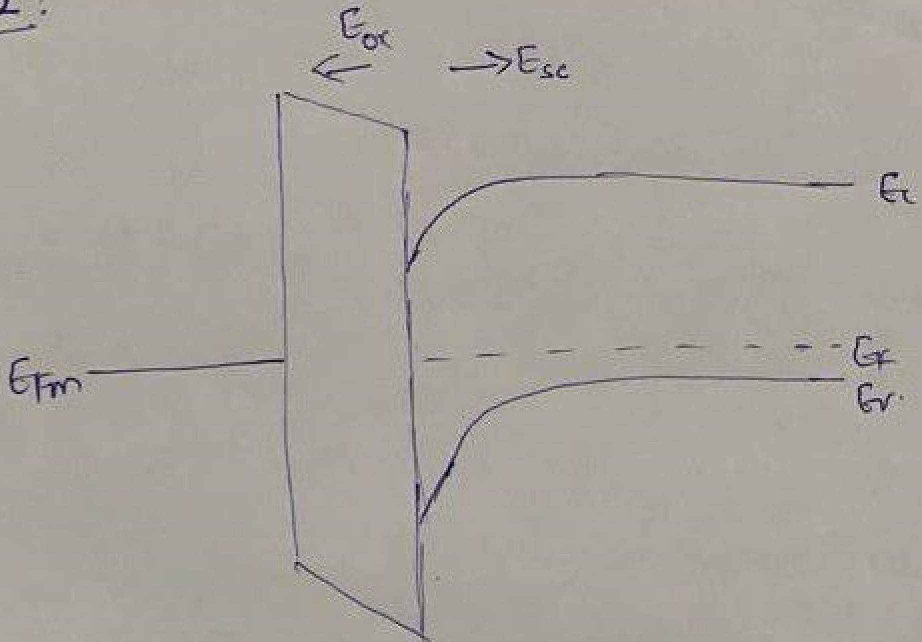


Fig.: Band diagram in Equilibrium.

Note that due to presence of $Q_F = 8\times10^{-8}\,c/cm^2$ @ interface, the E-field is in opposite directions @round the interface.

(a) $\phi_{ms} = \phi_m - \phi_s = -1\,eV$

$C_{ox} = 2\times10^{-7}\ F/cm^2$

$V_{FB} \Rightarrow V_G$ at which bands in semiconductor are flat.

0.5

Now, $V_{FB} = \dfrac{\phi_{ms}}{q} - \dfrac{Q_F}{C_{ox}} = \left(-1 - \dfrac{8\times10^{-8}}{2\times10^{-7}}\right) V$

$\Rightarrow V_{FB} = -1.4\,V$ 0.5

0.5

(b) @ interface $D_{ox} - D_{si} = Q_F$; D: normal Dielectric displacement

at Flat band $D_{Si} = \varepsilon_{si} E_{si} = 0 \ \because E_{si} = 0$

$\Rightarrow D_{ox} = \varepsilon_{ox} E_{ox} = Q_F \Rightarrow E_{ox} = \dfrac{Q_F}{\varepsilon_{ox}}$ Direction: (towards gate) 0.5

$\Rightarrow E_{ox} = 2.317\times10^{5}\ V\,cm^{-1}$