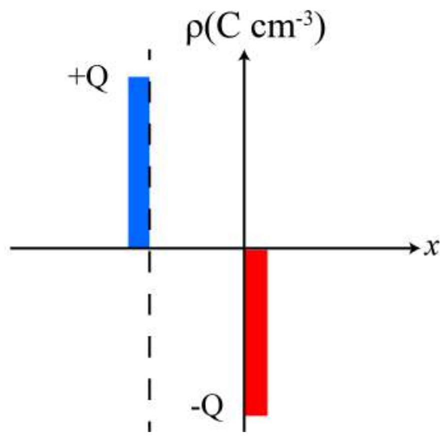
ISD 2023 - Week 7 Assignment

There are 10 questions for a total of 20 marks.

For Q1-Q2: The charge configuration of an ideal MOSCAP for an applied gate voltage (V_G) is given below. Answer the questions that follow. Note that free carriers are represented in red and blue, whereas bound charges are represented in magenta colour.



1. (2 marks) The type of substrate and the biasing condition of the MOSCAP is -

   A. $n-$type, Depletion

   B. $p-$type, Depletion

   C. $n-$type, Accumulation

   D. $p-$type, Accumulation

   E. $p-$type, Inversion

> **Reflect and remember:** An important distinction to be made is the type of carriers (free or bound charges) present at the interface, and their representation in the charge block diagram, when a voltage is applied at the gate.

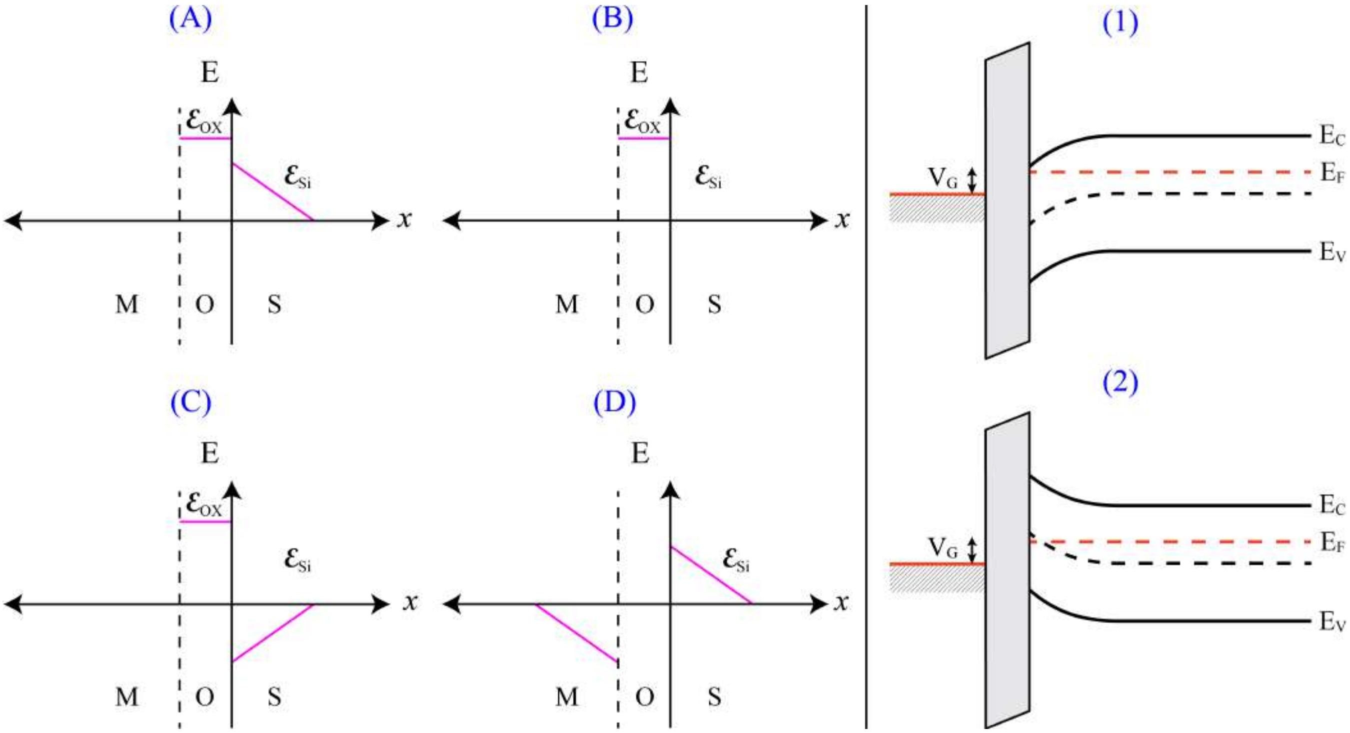
2. (2 marks) The field profile resulting from the above charge configuration and the corresponding band diagram are given by _______ and _______, respectively.

   A. A, 2

   B. B, 1

   C. C, 2

   D. D, 1



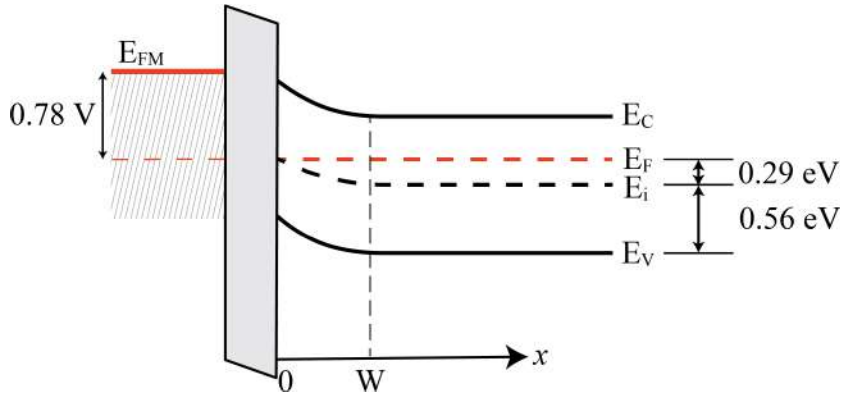
E. B, 2

F. D, 2

Reflect and remember: The procedure to draw the band diagrams and find the electric field profile is similar to that of a pn junction. It is always beneficial to use Poisson's equation to determine the electric field profile in various regions. An important point to remember is that no electric field penetrates the metal beyond the skin depth.

For Q3-Q10: A student experiments with the above MOSCAP by applying a different gate bias. The band diagram for the same is shown below. Note that the $E_F = E_i$ at the Si-SiO$_2$ interface. Also, the free carriers are represented in red and blue, whereas bound charges are represented in magenta colour.

(Assume $kT/q = 25\ mV$, $n_i = 10^{10}\ cm^{-3}$, and $\epsilon_{Si} = 11.8$, $\epsilon_{SiO_2} = 3.9$)



3. (2 marks) The MOSCAP is biased in ______ region.

   A. Accumulation

   B. Inversion

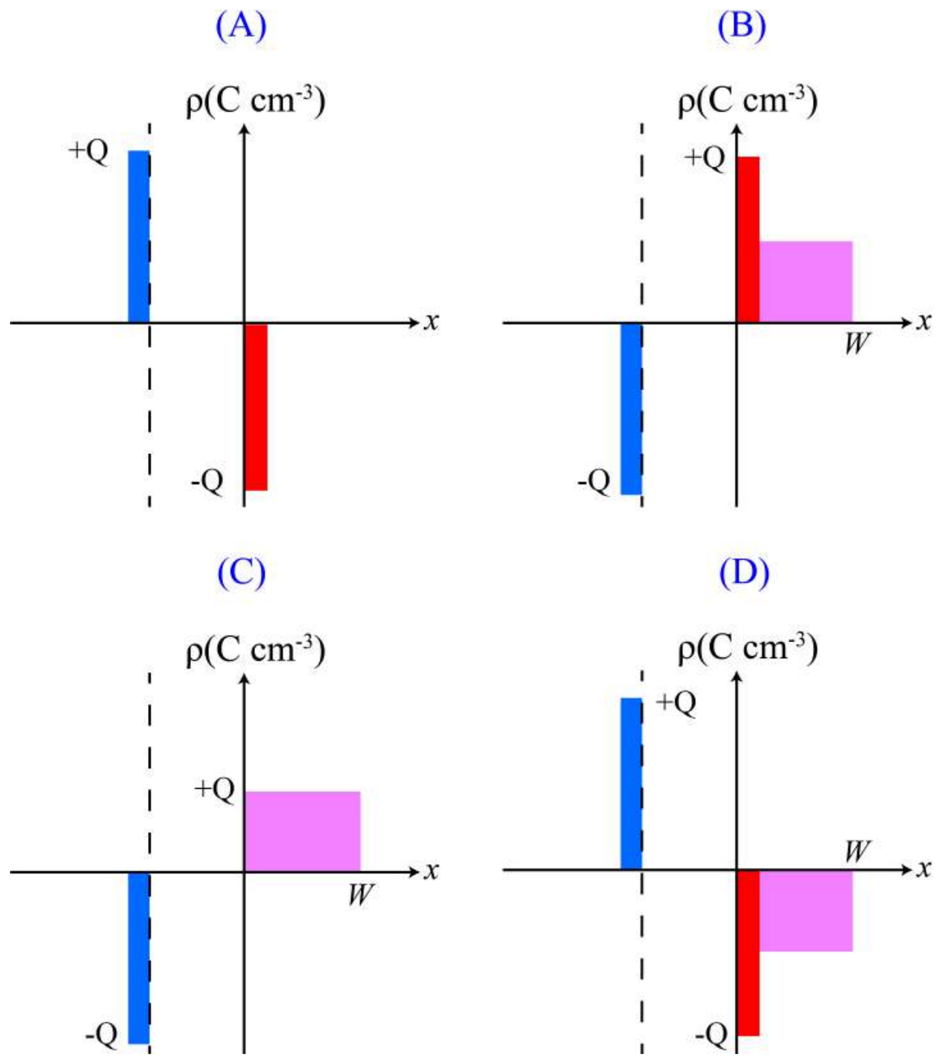
   C. Deep Depletion

   D. Depletion

   E. Flatband

Reflect and remember: $\phi_F = \frac{1}{q}[E_{i,bulk} - E_F]$ relates to the doping in the semiconductor. The sign of ϕ_F indicates whether the semiconductor is $p-$type ($\phi_F > 0$) or $n-$type ($\phi_F < 0$). ϕ_S and ϕ_F together specify the biasing condition of a MOSCAP.

4. (2 marks) The charge configuration that appropriately represents the MOSCAP biasing is shown in figure ______.



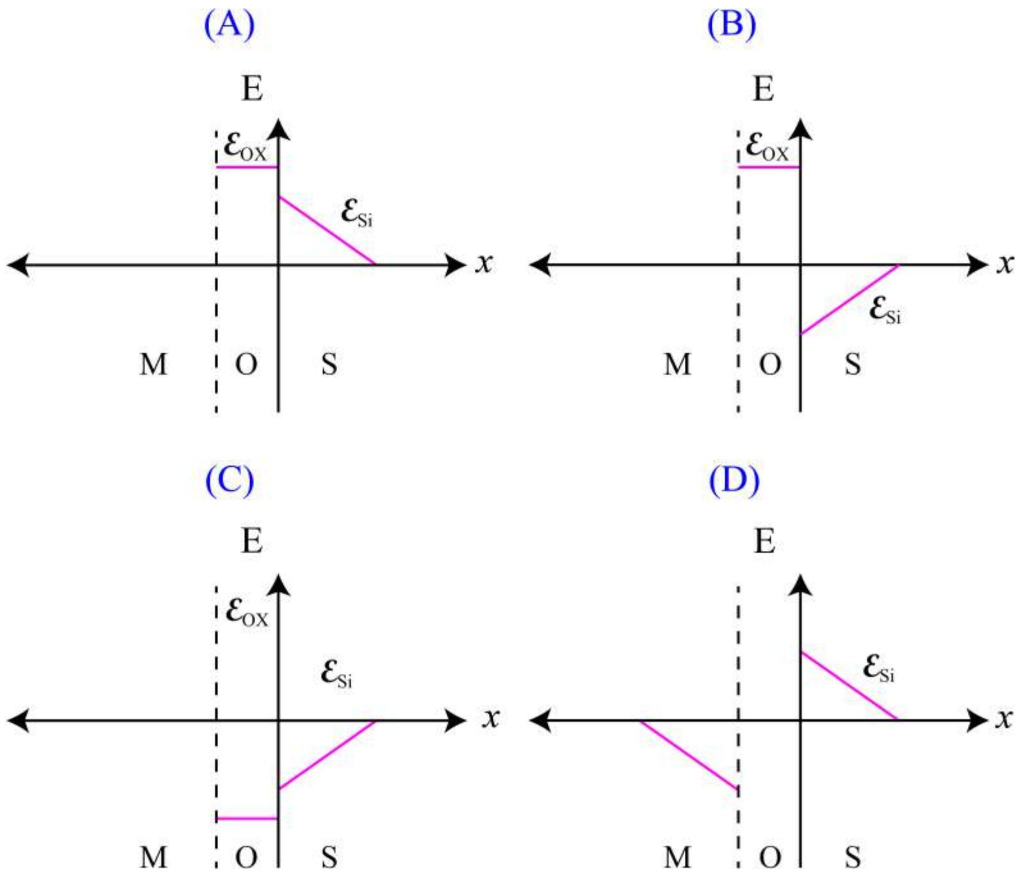
A. A

B. B

C. C

D. D

5. (2 marks) The field profile for the applied voltage is represented in figure ______.



A. A

B. B

C. C

D. D

6. (2 marks) The field in the oxide region (E_{ox}) is ______ at the Si-SiO$_2$ interface.

A. $3 \times E_{Si}$

B. $0.33 \times E_{Si}$

C. $4 \times E_{Si}$

D. equal to E_{Si}

E. $11.8 \times E_{Si}$

The displacement field across the Ox-semiC interface should be continuous.

$\therefore \epsilon_{ox} E_{ox} = \epsilon_{Si} E_{Si}$

$E_{ox} = \frac{\epsilon_{Si} E_{Si}}{\epsilon_{ox}} = \frac{11.8}{3.9} E_{Si}$

$\therefore E_{ox} \simeq 3 E_{Si}$

Reflect and remember: The discontinuity in the electric field at the Si-SiO_2 interface can be easily explained using the boundary conditions, i.e. the normal component of the displacement field is continuous across the interface.

7. (2 marks) The doping concentration (N_D) in the semiconductor, and the electron concentration at the Si-SiO_2 interface are given by ______ and ______ cm^{-3}, respectively.

   A. 1.1×10^{15}, 1.1×10^{15}

   B. 1.1×10^{15}, 1×10^{10}

   C. 7.2×10^{10}, 1.1×10^{15}

   D. 1.1×10^{15}, 0

   E. 4×10^{16}, 7.2×10^{10}

The electron concentration @ the Si-SiO_2 interface is equal to the intrinsic conc. ($10^{10}/cm^3$), as E_i intersects E_F @ the interface.

& $[E_F - E_i]_{bulk} = \frac{kT}{q} \ln\left(\frac{N_D}{n_i}\right)$

$\Rightarrow \frac{0.29}{0.025} = \ln\left(\frac{N_D}{n_i}\right) \Rightarrow N_D = n_i e^{0.29/0.025}$

$\therefore N_D = 1.09 \times 10^{15} /cm^3$

8. (2 marks) The surface potential (ϕ_s) is ______ eV.

   A. 0.56

   B. 0.29

   C. -0.56

   D. 0.85

   E. -0.29

$\phi_s = E_{i,bulk} - E_{i,interface} = -0.29\,eV$

Reflect and remember: A point to remember is that the threshold voltage ($V_G = V_T$) is the voltage where the MOSCAP transitions from depletion to inversion region. The condition for this to occur is that the surface potential $(\phi_S) = 2 \times \phi_F$. Similarly, $V_G = 0$ differentiates the accumulation and depletion region.

9. (2 marks) The applied voltage (V_G) and the drop across the oxide region ($\Delta\phi$) is ______ V.

   A. -0.78 and -0.49

   B. 0.78 and -0.49

   C. -1.07 and 0.78

   D. 0.78 and -0.78

   E. -0.49 and 1.07

Applied voltage is -ve $\Rightarrow -0.78V$

& $V_G = \Delta\phi + \phi_s$

$\Rightarrow -0.78 = \Delta\phi - 0.29$

$\Rightarrow \Delta\phi = -0.49\,V$

> **Reflect and remember:** The applied voltage (V_G) in a MOSCAP is equal to the separation of the Fermi energy levels at the two ends of the structure. V_G is equal to the voltage drop across the oxide and the surface potential.

10. (2 marks) The width of the depletion region (W) is ______ μm.

    A. 3.95

    B. 5.86

    C. 0.586

    D. 3.4

    E. 0.25

$$W = \sqrt{\frac{2\varepsilon_{si}}{qN_D}\phi_s} = \sqrt{\frac{2\times 11.8\times 8.85\times 10^{-14}}{1.6\times 10^{-19}\times 1.1\times 10^{15}}\times 0.29}$$

$$\therefore W = 5.86\times 10^{-5}\ cm$$

$$\underline{W = 0.586\ \mu m}$$