ISD 2023 - Week 6 Assignment

There are 10 questions for a total of 20 marks.

1. (2 marks) Which of the following is defined as the work function (ϕ_m) of a material?

   A. The energy required to move an electron from E_c to the vacuum level.

   B. The energy required to move an electron from E_v to the vacuum level.

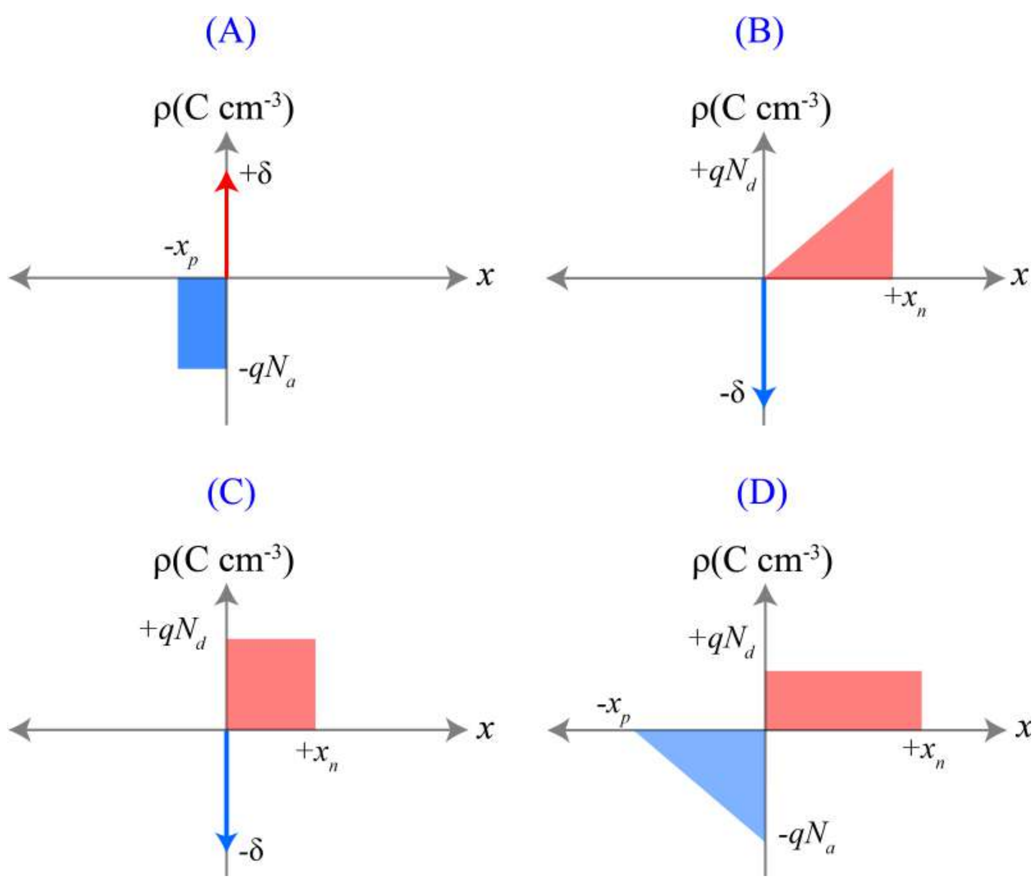
   C. The energy required to move an electron from E_F to the vacuum level.

   D. The energy required to move an electron from E_F to E_c.

   E. The energy required to move an electron from E_F to E_v.

For Q2-Q3: Answer the following questions regarding the charge configurations in a Schottky diode.

2. (2 marks) Consider a Schottky diode made from a metal and a n-type semiconductor. The doping of the semiconductor follows an abrupt profile, and the work function of metal (ϕ_M) is greater than that of the semiconductor (ϕ_S). The charge configuration of such a device is given in the figure ______.



   A. A

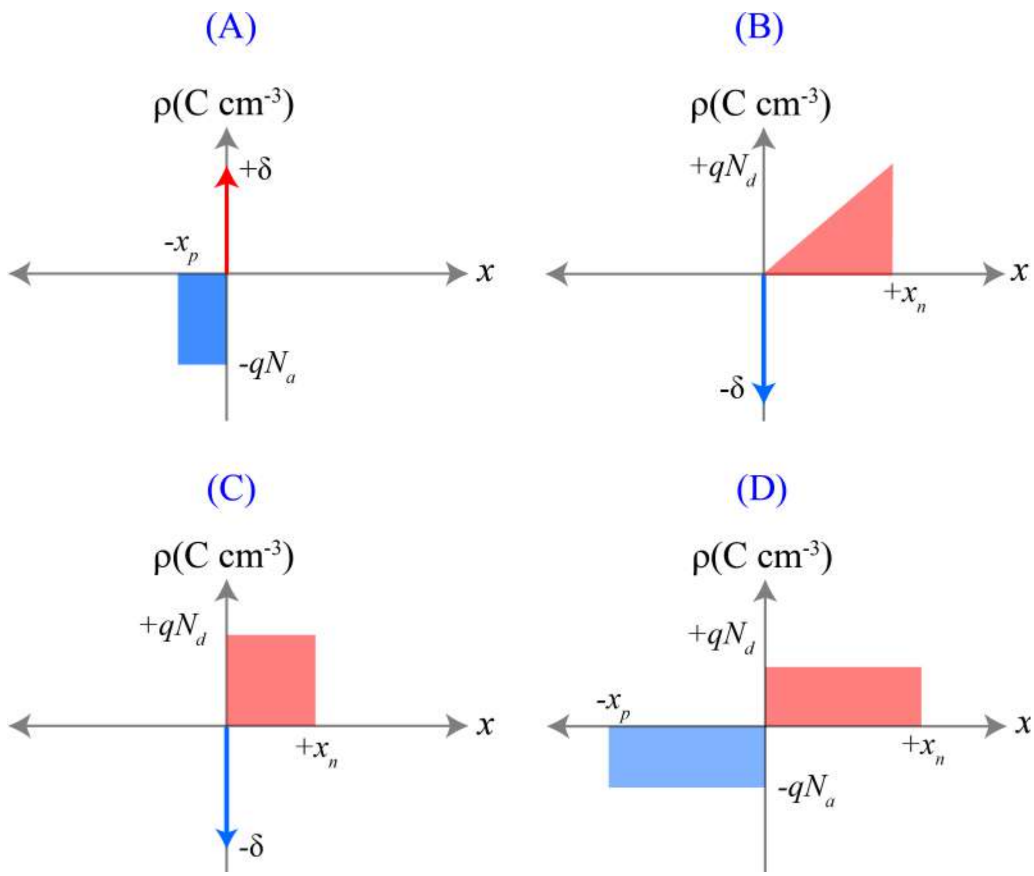
B. B

C. C

D. D

Reflect and remember: It is important to understand the distinction between a one-sided junction and a Schottky barrier, though they possess many similar properties. An important point is that there is no field inside the metal, so there is a discontinuity in the electric field at the interface. This implies that there is a delta charge accumulation at the metal-semiconductor junction.

3. (2 marks) Consider a Schottky diode made from a metal and a n-type semiconductor. The doping of the semiconductor follows a linearly graded profile, and the work function of metal (ϕ_M) is greater than that of the semiconductor (ϕ_S). The charge configuration of such a device is given in the figure ______.



A. A

B. B

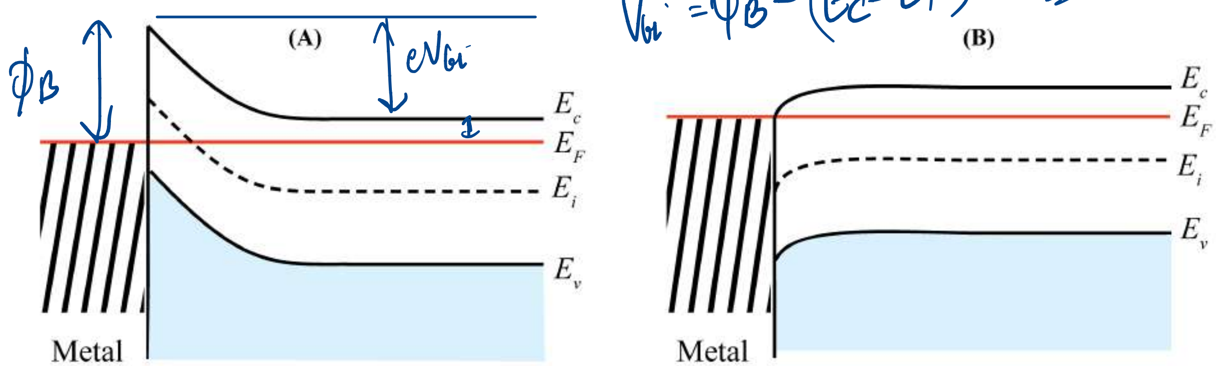
C. C

D. D

> **Reflect and remember:** The doping of the semiconductor need not always have an abrupt profile. The charge configuration, and hence the electric field, of the Schottky diode will change according to the doping profile of the semiconductor. An important point to remember is that the procedure to determine the charge and field profiles is the same as the PN junctions. Students are encouraged to use Poisson's equation to determine the field profiles for the Schottky barrier and verify from the standard textbooks.

For Q4-Q8: The equilibrium energy band diagram for an ideal metal-semiconductor contact is shown in the figure below. Answer the following questions based on the band diagrams

$V_{bi} = \phi_B - (E_C - E_F)$ & $E_C - E_F = \frac{E_g}{2} - (E_F - E_i)$



4. (2 marks) The relation between metal and semiconductor work function, and the type of contact formed, for the band diagram in Figure A is ______.

   A. $\Phi_M < \Phi_s$, rectifying

   B. $\Phi_M < \Phi_s$, ohmic

   C. $\Phi_M > \Phi_s$, rectifying

   D. $\Phi_M > \Phi_s$, ohmic

   E. $\Phi_M < \Phi_s$, flatband

5. (2 marks) The relation between metal and semiconductor work function and the type of contact formed for the band diagram in Figure B is ______.

   A. $\Phi_M < \Phi_s$, ohmic

   B. $\Phi_M > \Phi_s$, rectifying

   C. $\Phi_M > \Phi_s$, ohmic

   D. $\Phi_M < \Phi_s$, rectifying

E. $\Phi_M < \Phi_s$, flatband

6. (2 marks) Copper is deposited on n-type silicon substrate to form an ideal Schottky diode. The work function of copper is $\Phi_m = 4.65\ eV$ and the electron affinity of silicon is $\chi = 4.03\ eV$. The Schottky barrier height (Φ_B) is ______ eV.

A. 0.20

B. 0.62

C. 0.26

D. 4.65

E. 4.03

$$\phi_B = \phi_m - \chi = 4.65 - 4.03 = \underline{0.62 eV}$$

7. (2 marks) The built-in potential (V_{bi}) in the copper Schottky diode is ______ V.

(Take $N_D = 10^{16}\ cm^{-3}$, $E_g = 1.1\ eV$, $n_i = 10^{10}\ cm^{-3}$, $\epsilon_s = 11.8$ and $kT = 26\ meV$.)

A. 0.76

B. 0.62

C. 0.16

D. 4.65

E. 0.43

$$V_{bi} = \phi_B - (E_c - E_F) = \phi_B - \left[E_g/_2 - (E_F - E_i)\right]$$
$$= 0.62 - \left[\frac{1.1}{2} - \frac{kT}{q} \ln\left(\frac{N_D}{n_i}\right)\right]$$
$$= 0.62 - \left[0.55 - 0.026 \ln\left(\frac{10^{16}}{10^{10}}\right)\right] = \underline{0.429 V}$$
$$\therefore V_{bi} \simeq \underline{0.43V}$$

8. (2 marks) For a zero applied voltage, the depletion width in the semiconductor due to the formation of a copper-Si Schottky junction is ______ μm.

A. 0.237

B. 23.7

C. 46.4

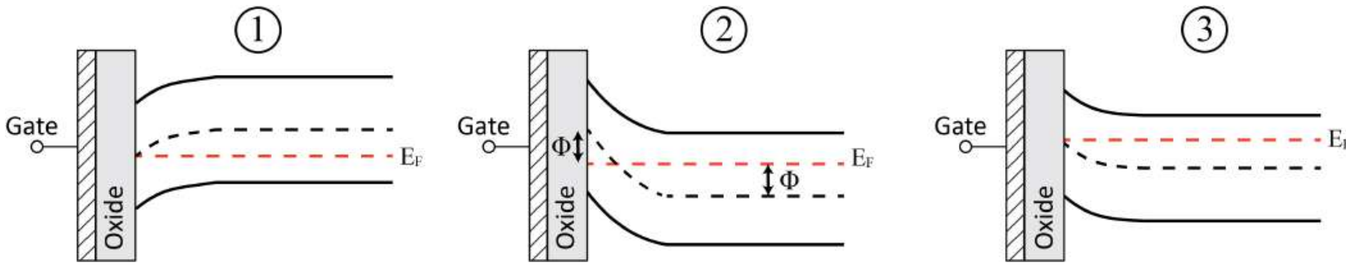
D. 0.464

E. 0.361

$$W = \sqrt{\frac{2\epsilon_{si} V_{bi}}{qN_D}} = \sqrt{\frac{2 \times 11.8 \times 8.85 \times 10^{-14}}{1.6 \times 10^{-19} \times 10^{16}} \times 0.43}$$
$$= 2.369 \times 10^{-5}\ cm$$
$$\therefore W \simeq \underline{0.237 \mu m}$$

> **Reflect and remember:** The depletion width in a Schottky barrier will lie completely inside the semiconductor and has an inverse square root dependency on the carrier density.

For Q9-Q10: Simplified band diagrams for a MOSCAP are shown in the figure below. Match the energy band diagrams labelled from $1 \to 3$, with the corresponding substrate type, applied gate voltage V_g, and the bias condition.



9. (2 marks) For each of the band diagrams given in the figure, identify the type of MOSCAP (PMOS or NMOS) and the substrate used (p-type or n-type) for the MOSCAP.

   A. ①→ p-type, PMOS ②→ p-type, PMOS ③→ p-type, PMOS

   B. ①→ n-type, NMOS ②→ n-type, NMOS ③→ n-type, NMOS

   C. ①→ n-type, NMOS ③→ n-type, PMOS ③→ p-type, PMOS

   D. ①→ p-type, NMOS ②→ n-type, PMOS ③→ n-type, PMOS

   E. ①→ p-type, NMOS ②→ n-type, PMOS ③→ p-type, NMOS

> **Reflect and remember:** An important point to note is that the type MOS capactor (PMOS or NMOS) determined by the type of inversion charge present at the interface. Another point to remember here is that we have drawn the band diagrams considering an ideal scenario with no defect or trap states in the oxide region.
> In the upcoming week, we will relax a few of these assumptions and show how they will impact the band diagrams and the basic parameters of a MOSCAP.

10. (2 marks) Identify the sign of applied gate voltage (V_g) and the bias condition for each of the band diagram.

   A. ① → -ve, inversion ②→ -ve, accumulation ③→ +ve, accumulation

   B. ①→ -ve, accumulation ②→ +ve, accumulation ③→ +ve, inversion

   C. ①→ -ve, inversion ②→ +ve, accumulation ③→ +ve, inversion

   D. ① → +ve, accumulation ②→ -ve, accumulation ③→ +ve, accumulation

   E. ① → +ve, depletion ②→ -ve, inversion ③→ -ve, depletion