Electronic Devices

Tutorial-4: Metal-semiconductor junctions and MOS Devices

Q.1

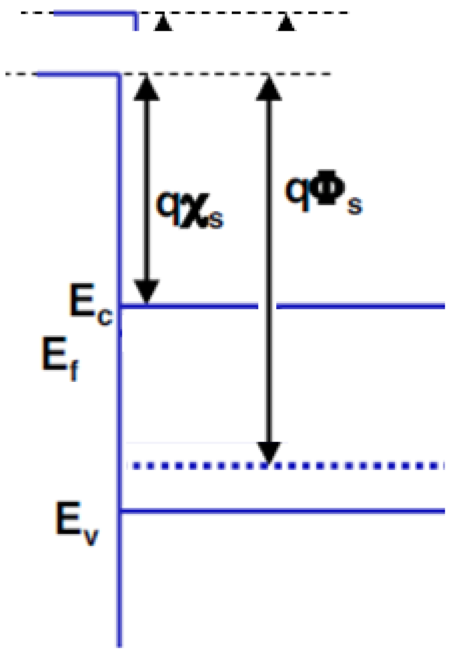
Consider a chrome-silicon metal-semiconductor junction with N_d = 10^{17} cm^{-3} . Draw the energy band diagram and calculate the barrier height and the built-in potential at room temperature if the work function of chrome is 4.5 V and electron affinity of silicon is 4.05 V. What will be the built-in potential if the semiconductor is p-type with the same doping concentration. Given that $N_c = 2.82 \times 10^{19}$ cm^{-3} and $N_v = 1.83 \times 10^{19}$ cm^{-3}

Sol.

$$\phi_B = \Phi_M - \chi = 4.5 - 4.05 = 0.45\text{ V}$$

$$V_o = \Phi_M - \chi - \frac{E_c - E_{F,n}}{q} \quad , \quad \text{n - type}$$

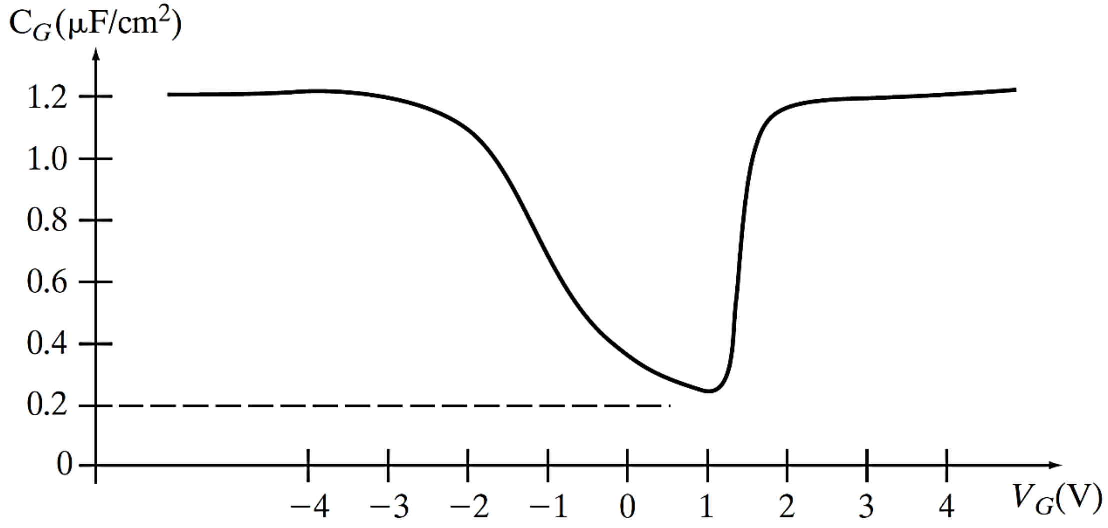
$$V_o = \phi_B - kT \frac{N_c}{N_d} = 0.45 - 0.0259\ln\frac{2.82\times10^{19}}{10^{17}} = 0.30\text{ V}$$



$$V_o = \chi + \frac{E_g}{q} - kT \frac{N_v}{N_a} - \Phi_M = 4.05 + 1.12 - 0.0259\ln\frac{1.83\times10^{19}}{10^{17}} - 4.5 \quad = 0.53\text{ V}$$

Q. 2

Consider the given C-V characteristics of a MOS Capacitor at room temperature



Find out:

(a) Type of MOSFET

(b) Thickness of the oxide layer, given ε_{SiO2}=3.9

(c) The maximum depletion width

Sol.

(a) Since the threshold voltage is +ve i.e. +1V, the CV characteristics is that of an ***n-channel*** *MOSFET*

(b) $$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} \rightarrow t_{ox} = \frac{\varepsilon_{ox}}{C_{ox}} = \frac{3.9 \times 8.85 \times 10^{-14}}{1.2 \times 10^{-6}} = \mathbf{28.76 \times 10^{-8} cm}$$

(c) For finding maximum width of depletion region, we have to find the C_{dmin}

$$C_{min} = \frac{C_{ox}.C_{dmin}}{C_{ox} + C_{dmin}}$$

$$Given, C_{min} = 0.2\ \mu F/\text{cm}^2 \rightarrow C_{dmin} = 0.24\ \mu F/\text{cm}^2$$

$$W_{max} = \frac{\varepsilon_{Si}}{C_{dmin}} = \frac{11.8 \times 8.85 \times 10^{-14}}{0.24 \times 10^{-6}} = \mathbf{4.35 \times 10^{-6} cm}$$

Q. 3

Consider a non-ideal MOS device with a n-type silicon substrate doping concentration of $N_d = 1.5 \text{ X } 10^{16}\ cm^{-3}$. Given that the metal work function is 4.1 eV and electron affinity of silicon is $q\chi = 4.05$ eV. The thickness of the gate oxide is to be taken as 15 nm. Find:

(a) Find the work function of the semiconductor.

(b) The surface potential of the semiconductor at threshold

(c) The charge density in the depletion region at threshold voltage

(d) Threshold voltage

Sol.

$$V_{Th} = \Phi_{ms} - \frac{Q_d}{C_{ox}} - V_s$$

$$\Phi_{ms} = \Phi_m - \Phi_s \qquad \Phi_s = \frac{E_g}{2q} + \chi - \frac{kT}{q}\ln(\frac{N_d}{n_i}) \quad = 4.19V$$

$$\Phi_{ms} = 4.1 - 4.25 = -0.15V \qquad V_s = 2\frac{kT}{q}\ln(\frac{N_d}{n_i}) = 0.718V$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.85 \times 10^{-14}}{15 \times 10^{-7}} = 2.31 \times 10^{-7} F/cm^2$$

$$W = \sqrt{\frac{2\varepsilon_s V_s}{qN_d}} = \sqrt{\frac{2 \times 11.8 \times 8.85 \times 10^{-14} \times 0.718}{1.6 \times 10^{-19} \times 1.5 \times 10^{16}}} = 2.449 \times 10^{-5} cm$$

$$Q_d = qN_dW = 1.6 \times 10^{-19} \times 1.5 \times 10^{16} \times 2.449 \times 10^{-5} \quad = 5.878 \times 10^{-8} C/cm^2$$

$$V_{Th} = -0.15 - \frac{5.878 \times 10^{-8}}{2.31 \times 10^{-7}} - 0.718 \quad = -1.122V$$

Q. 4

Consider a MOSFET fabricated using a p-type silicon substrate with doping concentration of $N_a = 10^{16}\ cm^{-3}$. The thickness of the gate oxide is 10 nm, Z=200μm and L=10μm. Calculate the threshold voltage of the MOSFET taking it as an ideal device. Also, find out the drain current for the four given conditions:

(a) $V_{GS} = 0.7$ V and $V_{DS} = 0.5$V
(b) $V_{GS} = 2$ V and $V_{DS} = 0.5$V
(c) $V_{GS} = 2$ V and $V_{DS} = 1.5$V
(d) $V_{GS} = 2$ V and $V_{DS} = 5$V

Assume the surface electron mobility is 200 $cm^2/V\text{-}s$

Sol.

$$V_{TH} = -\frac{Q_d}{C_{ox}} + V_s$$

$$V_s = 2V_T \ln\left(\frac{N_a}{n_i}\right) = 0.694\ V$$

$$W = \sqrt{\frac{2\epsilon V_s}{qN_a}} = 0.3 \times 10^{-4}\ cm$$

$$Q_d = -qN_aW \ = -4.82 \times 10^{-8} C/cm^2$$

$$C_{ox} = \epsilon_{ox}/t_{ox} \quad = \frac{3.9 \times 8.854 \times 10^{-14}}{10 \cdot 10^{-7}\ cm} = 3.45 \times 10^{-7}\ F/cm^2$$

$$V_{TH} = -\frac{Q_d}{C_{ox}} + \phi_s = \frac{4.82 \times 10^{-8}}{3.45 \times 10^{-7}} + 0.694 \quad = 0.14 + 0.694 = 0.834\ V$$

(a) $V_{GS} = 0.7V$, $V_{DS} = 0.5V$

Since $V_{GS} < V_{Th,}$ so the MOSFET is in Cut-Off, $\mathbf{I_D = 0\ A}$

(b) $V_{GS} = 2V$, $V_{DS} = 0.5\ V$

Since $V_{DS} < V_{GS} - V_{Th,}$ so the MOSFET is operating in linear region

$$I_D = \frac{\bar{\mu}_n Z C_i}{L}\left[(V_G - V_{Th})V_D - \tfrac{1}{2}V_D^2\right] = 138 \times 10^{-5} \times .458 = .632 \times 10^{-3} A$$

(c) $V_{GS} = 2V$, $V_{DS} = 1.5V$ Since $V_{DS} > V_{GS} - V_{Th,}$ MOSFET is in saturation

$$I_D(\text{sat.}) \cong \tfrac{1}{2}\bar{\mu}_n C_i \frac{Z}{L}(V_G - V_{Th})^2 = 69 \times 10^{-5} \times 1.36 = 0.938 \times 10^{-3} A$$

(d) $V_G = 2\ V$, $V_D = 5V$

Since $V_D > V_G - V_{Th,}$ MOSFET is in saturation, current is not going to increase