VE320
Intro to Semiconductor Devices

HOMEWORK 8

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1. (a) (a) The semiconductor is p type.
(b) The semiconductor is p type.
(c) The semiconductor is p type.
(d) The semiconductor is n type.
(b) (a) The device is biased in the inversion region.
(b) The device is biased in the depletion region.
(c) The device is biased in the accumulation region.
(d) The device is biased in the strong inversion region.
(c) (a)

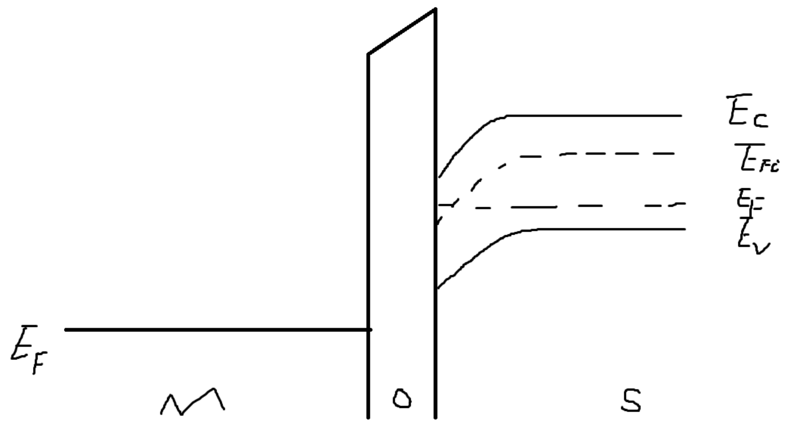

Figure 1. 1(c)(a).

(b)

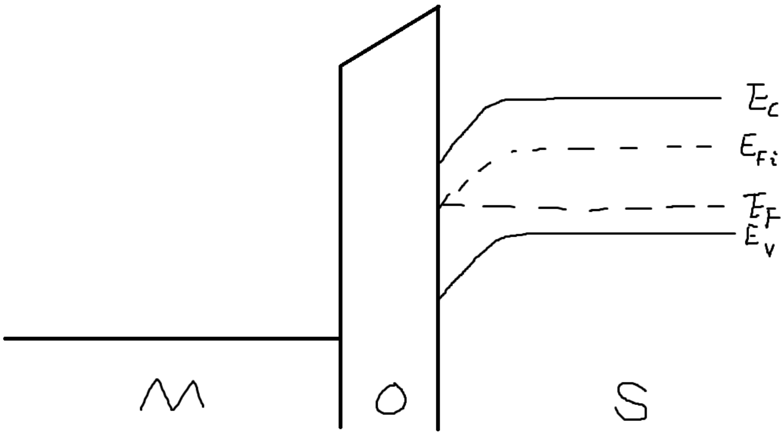

Figure 2. 1(c)(b).

(c)

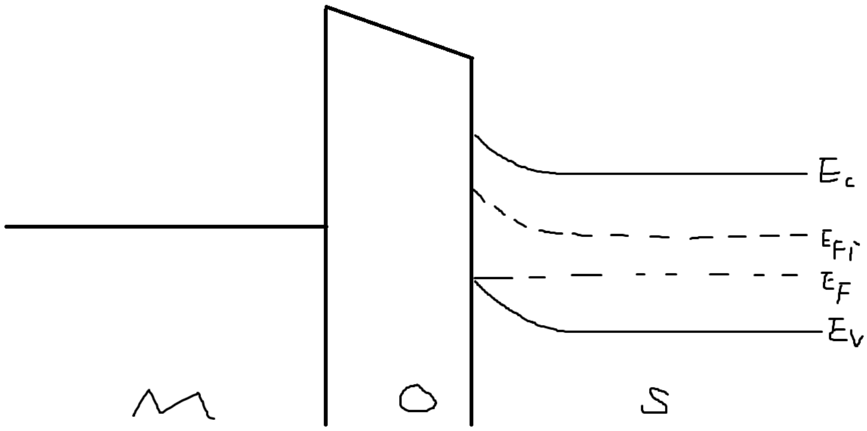

Figure 3. 1(c)(c).

(d)

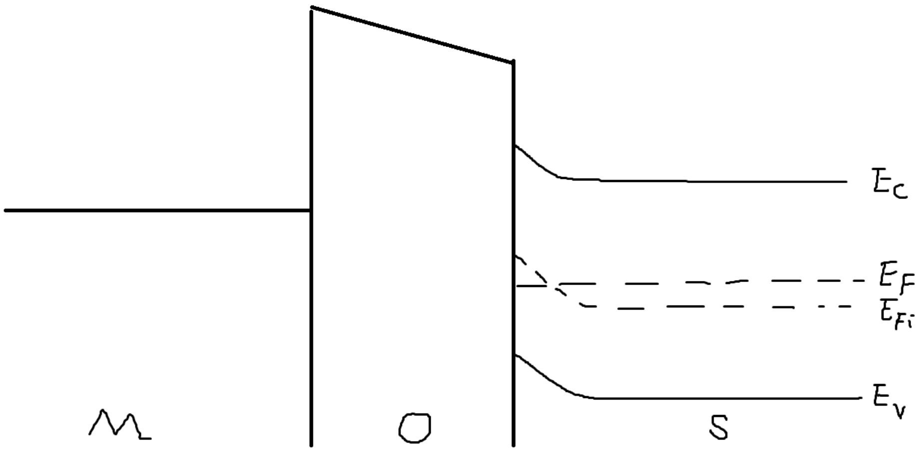

Figure 4. 1(c)(d).

2. (a) The ideal flat-band voltage is

$$V_{FB} = \phi_{ms} = -0.4\,\text{V}.$$

(b) (i) The shift in flat-band voltage is

$$\Delta V_{FB} = -\frac{Q'_{ss}}{C_{\text{ox}}} = -\frac{4 \times 10^{10} e}{\frac{3.9 \times 0.01 \epsilon_0}{200 \times 10^{-8}}} = -0.0371\,\text{V}.$$

(ii) The shift in flat-band voltage is

$$\Delta V_{FB} = -\frac{Q'_{ss}}{C_{\text{ox}}} = -\frac{10^{11} e}{\frac{3.9 \times 0.01 \epsilon_0}{200 \times 10^{-8}}} = -0.0928\,\text{V}.$$

(c) The ideal flat-band voltage is

$$V_{FB} = \phi_{ms} = -0.4\,\text{V}.$$

(i) The shift in flat-band voltage is

$$\Delta V_{FB} = -\frac{Q'_{ss}}{C_{\text{ox}}} = -\frac{4 \times 10^{10} e}{\frac{3.9 \times 0.01 \epsilon_0}{120 \times 10^{-8}}} = -0.0223\,\text{V}.$$

(ii) The shift in flat-band voltage is

$$\Delta V_{FB} = -\frac{Q'_{ss}}{C_{\text{ox}}} = -\frac{10^{11} e}{\frac{3.9 \times 0.01 \epsilon_0}{120 \times 10^{-8}}} = -0.0557\,\text{V}.$$

3. The threshold voltage is

$$V_{TN} = \left(|Q'_{SD}(\max)| - Q'_{ss}\right)\left(\frac{t_{\text{ox}}}{\epsilon_{\text{ox}}}\right) + \phi_{ms} + 2\phi_{fp}$$

$$|Q'_{SD}(\max)| = eN_a x_{dT} = \sqrt{4eN_a\epsilon_s\phi_{fp}}$$

The difference between E_{Fi} and E_F is

$$\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = \frac{kT}{e}\ln\left(\frac{N_a}{n_i}\right)$$

The metal-semiconductor work function difference is

$$\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} + \phi_{fp}\right).$$

For an aluminium-silicon dioxide junction, $\phi'_m = 3.20$ V and, for a silicon-silicon dioxide junction, $\chi' = 3.25$ V. We may assume that $E_g = 1.12$ V. Then, the metal-semiconductor work function difference is

$$\phi_{ms} = 2.30 - \left(3.25 + \frac{1.12e}{2e} + \phi_{fp}\right) = -0.61 - \phi_{fp}.$$

Thus, the threshold voltage is

$$V_{TN} = (\sqrt{4eN_a\epsilon_s\phi_{fp}} - Q'_{ss})\left(\frac{t_{\text{ox}}}{\epsilon_{\text{ox}}}\right) - 0.61 + \phi_{fp} = +0.45\,\text{V}.$$

Solving the equation, the p-type doping concentration is

$$N_a = 4.870 \times 10^{16}\,\text{cm}^{-3}.$$

4. (a) The flat-band voltage is

$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{\text{ox}}} = -1.1 - \frac{6 \times 10^{10}e}{\frac{3.9\times 0.01\epsilon_0}{180\times 10^{-8}}} = -1.150\,\text{V}.$$

(b) The difference between E_{Fi} and E_F is

$$\phi_{fp} = \frac{kT}{e}\ln\left(\frac{N_a}{n_i}\right) = \frac{300k}{e}\ln\left(\frac{10^{15}}{1.5\times 10^{10}}\right) = 0.287\,\text{V}.$$

The threshold voltage is

$$\begin{aligned} V_{TN} &= (\sqrt{4eN_a\epsilon_s\phi_{fp}} - Q'_{ss})\left(\frac{t_{\text{ox}}}{\epsilon_{\text{ox}}}\right) + \phi_{ms} + 2\phi_{fp} \\ &= (\sqrt{4e\times 10^{15}\times 11.7\times 0.01\epsilon_0\phi_{fp}} - 6\times 10^{10}e)\left(\frac{180\times 10^{-8}}{3.9\times 0.01\epsilon_0}\right) - 1.1 + 2\phi_{fp} \\ &= -0.504\,\text{V}. \end{aligned}$$

5. (a) The semiconductor is n type.
(b) The capacitance per unit area is

$$C_{\text{ox}} = \frac{C}{A} = \frac{200\times 10^{-12}}{2\times 10^{-3}} = 10^{-7}\,\text{F/cm}^2.$$

The oxide thickness is

$$t_{\text{ox}} = \frac{\epsilon_{\text{ox}}}{C_{\text{ox}}} = \frac{3.9\times 0.01\epsilon_0}{10^{-7}} = 3.453\times 10^{-6}\,\text{cm}.$$

(c) We have

$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{\text{ox}}}.$$

The equivalent trapped oxide charge density is

$$Q'_{ss} = (\phi_{ms} - V_{FB})C_{\text{ox}} = (-0.50 + 0.8)\times 10^{-7} = 3\times 10^{-8}\,\text{C/cm}^2.$$

(d) The flat-band capacitance is

$$
\begin{aligned}
C'_{FB} &= \frac{\epsilon_{\text{ox}}}{t_{\text{ox}} + \left(\dfrac{\epsilon_{\text{ox}}}{\epsilon_s}\right)\sqrt{\left(\dfrac{kT}{e}\right)\left(\dfrac{\epsilon_s}{eN_a}\right)}} \\
&= \frac{3.9 \times 0.01\epsilon_0}{\dfrac{3.9 \times 0.01\epsilon_0}{10^{-7}} + \dfrac{3.9 \times 0.01\epsilon_0}{11.7 \times 0.01\epsilon_0}\sqrt{\left(\dfrac{300k}{e}\right)\left(\dfrac{11.7 \times 0.01\epsilon_0}{2 \times 10^{16} e}\right)}} \\
&= 7.818 \times 10^{-8}\,\text{F/cm}^2.
\end{aligned}
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