Homework 4 Solutions

1.

a) Depletion charge (also called space charge or junction charge)

Under the reverse bias $v_R = 1\ V$

$$\varphi_j = V_T ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.89\ V$$

$$\varepsilon_s = \varepsilon_{r\_silicon} * \varepsilon_0 = 11.68 \times 8.854 \times 10^{-14}\ \ F/cm = 1.03 \times 10^{-12}\ F/cm$$

$$w_{d0} = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\varphi_j} = 15.4\ \mu m$$

$$Q_{dep} = q\left(\frac{N_A N_D}{N_A + N_D}\right) w_d A = q\left(\frac{N_A N_D}{N_A + N_D}\right) A w_{d0} \sqrt{1 + \frac{v_R}{\varphi_j}} = 3.5 \times 10^{-22}\ C$$

or

$$Q_{dep} = A\sqrt{2\varepsilon_s q\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(\varphi_j + v_R)} = 3.5 \times 10^{-22}\ C$$

Under forward bias $v_D = 0.6\ V$

$$Q_{dep} = A\sqrt{2\varepsilon_s q\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(\varphi_j - v_D)} = 1.37 \times 10^{-22}\ C$$

Under forward bias $v_D = 0.8\ V$

$$Q_{dep} = A\sqrt{2\varepsilon_s q\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(\varphi_j - v_D)} = 0.76 \times 10^{-22}\ C$$

b) Injection charge (or diffusion charge)

$$Q_D(v_d) = qAn_i^2\left(\frac{W_p{}'}{2N_A} + \frac{L_p}{N_D}\right)\left(e^{qv_d/kT} - 1\right)$$

$$Q_D(-1\ V) = 2.13 \times 10^{-53}\ C$$

$$Q_D(0.6\ V) = 1.58 \times 10^{-26}\ C$$

$$Q_D(0.8\ V) = 3.61 \times 10^{-23}\ C$$

c)

$$C_j = \frac{\varepsilon_s}{w_{d0}\sqrt{1 - \frac{v_D}{\varphi_j}}}$$

$$C_j(-1\ V) = 46.2\ \ nF/cm^2$$

$$C_j(0.6\ V) = 117\ \ nF/cm^2$$

$$C_j(0.8\ V) = 207\ \ nF/cm^2$$

$$C_D = \frac{dQ_D}{Adv_D} = \frac{q^2}{kT}n_i^2\left(\frac{W_p{}'}{2N_A} + \frac{L_p}{N_D}\right)e^{qv_d/kT}$$

$$C_D(-1\ V) = 1.16 \times 10^{-36}\ \ nF/cm^2$$

$$C_D(0.6\ V) = 0.81\ \ nF/cm^2$$

$$C_D(0.8\ V) = 1.83\ \mu F/cm^2$$

2. J&B P4.1

(a) $V_G = 2\ V > V_{TN} = 1\ V$, inversion region.

(b) $V_G = -2\ V \ll V_{TN} = 1\ V$, accumulation region.

(b) $V_G = 0.5\ V < V_{TN} = 1\ V$, depletion region.

3. J&B P4.4

$$K'_n = \mu_n C''_{ox} = \mu_n \frac{\varepsilon_{ox}}{T_{ox}}$$

$$\varepsilon_{ox} = 3.9 \times 8.854 \times 10^{-14}\ F/cm$$

(b) $T_{ox} = 20\ nm$

$$K'_n = \mu_n \frac{\varepsilon_{ox}}{T_{ox}} = 86.33\ \mu A/V^2$$

(d) $T_{ox} = 5\ nm$

$$K'_n = \mu_n \frac{\varepsilon_{ox}}{T_{ox}} = 345.31\ \mu A/V^2$$

4. J&B P4.7

The voltage at the pinch-off point in the channel is always equal to $V_{GS} - V_{TN}$, this voltage across the inverted potion of the channel, and electrons will be drifting down the channel from left to right. When the electrons reach the pinch-off point, they are injected into the depleted region between the end of the channel and the drain, and the electric field in the depletion region then sweeps these electrons on to the drain. Once the channel has reached pinch-off, the voltage drop across the inverted channel region is constant; hence, the drain current becomes constant and independent of drain-source voltage.

5. J&B P4.10

$V_{GS} = 0\ V < V_{TN} = 1\ V$, MOSFET is off, $i_D = 0$.

$V_{GS} = 1V = V_{TN} = 1\ V$, MOSFET is about to turn on, $i_D = 0$.

$V_{GS} = 2\ V > V_{TN} = 1\ V$, $V_{GS} - V_{TN} = 1\ V > V_{DS} = 0.1\ V$, MOSFET is in triode region. $i_D = K'_n \frac{W}{L}\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right) V_{DS} = 1.88\ mA$.

$V_{GS} = 3\ V > V_{TN} = 1\ V$, $V_{GS} - V_{TN} = 2\ V > V_{DS} = 0.1\ V$, MOSFET is in triode region. $i_D = K'_n \frac{W}{L}\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right) V_{DS} = 2.44\ mA$.

$$K_n = K'_n \frac{W}{L} = 12500\ \mu A/V^2$$

6. J&B P4.20

$V_{GS} = 0\ V < V_{TN} = 1\ V$, MOSFET is off, $i_D = 0$.

$V_{GS} = 1V = V_{TN} = 1\ V$, MOSFET is about to turn on, $i_D = 0$.

$V_{GS} = 2\ V > V_{TN} = 1\ V$, $V_{GS} - V_{TN} = 1\ V < V_{DS} = 3.3\ V$, MOSFET is in saturation region. $i_D = \frac{K'_n}{2} \frac{W}{L} (V_{GS} - V_{TN})^2 = 1.88\ mA$.

$V_{GS} = 3\ V > V_{TN} = 1\ V$, $V_{GS} - V_{TN} = 2\ V < V_{DS} = 3.3\ V$, MOSFET is in saturation region. $i_D = \frac{K'_n}{2} \frac{W}{L} (V_{GS} - V_{TN})^2 = 7.50\ mA$.

$$K_n = K'_n \frac{W}{L} = 3750\ \mu A/V^2$$