VE320
Intro to Semiconductor Devices

HOMEWORK 7

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1. (a) Substituting $N_c = 2.8 \times 10^{19}$ cm^{-3} for N_c, 5×10^{15} cm^{-3} for N_d,

$$\phi_n = \frac{kT}{e} \ln\left(\frac{N_c}{N_d}\right) = 0.2231 \text{ V}.$$

The built-in potential barrier V_{bi} is

$$V_{bi} = \phi_{B0} - \phi_n = 0.4269 \text{ V}.$$

(b) When $N_d = 10^{16}$ cm^{-3}, since the value of the Schottky barrier height ϕ_{B0} has no relation to the doping concentration N_d, it will remain the same as

$$\phi_{B0} = 0.65 \text{ V}.$$

$$\phi_n = \frac{kT}{e} \ln\left(\frac{N_c}{N_d}\right) = 0.2052 \text{ V}.$$

The built-in potential barrier V_{bi} is

$$V_{bi} = \phi_{B0} - \phi_n = 0.4448 \text{ V}.$$

The value of ϕ_{B0} remains the same, while the value of V_{bi} increases.

(c) When $N_d = 10^{15}$ cm^{-3}, for the same reason,

$$\phi_{B0} = 0.65 \text{ V}.$$

$$\phi_n = \frac{kT}{e} \ln\left(\frac{N_c}{N_d}\right) = 0.2647 \text{ V}.$$

The built-in potential barrier V_{bi} is

$$V_{bi} = \phi_{B0} - \phi_n = 0.3853 \text{ V}.$$

The value of ϕ_{B0} remains the same, while the value of V_{bi} decreases.

2. (a) From Figure 9.5 we read that $\phi_m = 4.65$ V and the Schottky barrier is

$$\phi_{B0} = 0.63 \text{ V}.$$

The reverse-saturation current density J_{sT} is

$$J_{sT} = A^* T^2 \exp\left(\frac{-e\phi_{B0}}{kT}\right) = 120 \times 300^2 \times \mathrm{e}^{\frac{-0.63e}{300k}} = 2.818 \times 10^{-4} \text{ A/cm}^2.$$

The reverse-saturation current I_{sT} is

$$I_{sT} = AJ_{sT} = 2.818 \times 10^{-8} \text{ A}.$$

When $I = 10\ \mu\text{A} = 10^{-5}$ A, the forward-bias voltage is

$$V_a = \frac{kT}{e} \ln\left(\frac{I}{I_{sT}} + 1\right) = 0.1519 \text{ V}.$$

When $I = 100\ \mu\text{A} = 10^{-4}$ A, the forward-bias voltage is

$$V_a = \frac{kT}{e} \ln\left(\frac{I}{I_{sT}} + 1\right) = 0.2113 \text{ V}.$$

When $I = 1$ mA $= 10^{-3}$ A, the forward-bias voltage is

$$V_a = \frac{kT}{e} \ln\left(\frac{I}{I_{sT}} + 1\right) = 0.2709 \text{ V}.$$

(b) Assuming $T = 350$ K, the reverse-saturation current I_{sT} is

$$I_{sT} = AJ_{sT} = AA^*T^2 \exp\left(\frac{-e\phi_{B0}}{kT}\right) = 1.247 \times 10^{-6} \text{ A}.$$

When $I = 10\ \mu\text{A} = 10^{-5}$ A, the forward-bias voltage is

$$V_a = \frac{kT}{e} \ln\left(\frac{I}{I_{sT}} + 1\right) = 0.06634 \text{ V}.$$

When $I = 100\ \mu\text{A} = 10^{-4}$ A, the forward-bias voltage is

$$V_a = \frac{kT}{e} \ln\left(\frac{I}{I_{sT}} + 1\right) = 0.1326 \text{ V}.$$

When $I = 1$ mA $= 10^{-3}$ A, the forward-bias voltage is

$$V_a = \frac{kT}{e} \ln\left(\frac{I}{I_{sT}} + 1\right) = 0.2017 \text{ V}.$$

3. (a) From the I-V characteristic, we have

$$I = I_{sT}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right],$$

thus, the forward-bias voltage of Schottky diode is

$$V_{a1} = \frac{kT}{e} \ln\left(\frac{I}{I_{sT1}} + 1\right).$$

Substituting 150 μA $= 1.5 \times 10^{-4}$ A for I, $AJ_{sT1} = 8 \times 10^{-4} \times 6 \times 10^{-9} = 4.8 \times 10^{-12}$ A, the forward-bias voltage of Schottky diode is

$$V_{a1} = 0.4461 \text{ V}.$$

The forward-bias voltage of pn junction diode is

$$V_{a2} = \frac{kT}{e} \ln\left(\frac{I}{I_{sT2}} + 1\right).$$

Substituting 150 μA $= 1.5 \times 10^{-4}$ A for I, $AJ_{sT1} = 8 \times 10^{-4} \times 8 \times 10^{-13} = 6.4 \times 10^{-16}$ A, the forward-bias voltage of pn junction diode is

$$V_{a2} = 0.6768 \text{ V}.$$

(b) Similar to (a), when $I = 700\ \mu\text{A} = 7 \times 10^{-4}$ A, the forward-bias voltage of Schottky diode is

$$V_{a1} = \frac{kT}{e} \ln\left(\frac{I}{I_{sT1}} + 1\right) = 0.4860 \text{ V}.$$

The forward-bias voltage of pn junction diode is

$$V_{a2} = \frac{kT}{e} \ln\left(\frac{I}{I_{sT2}} + 1\right) = 0.7166 \text{ V}.$$

(c) When $I = 1.2$ mA $= 1.2 \times 10^{-3}$ A, the forward-bias voltage of Schottky diode is

$$V_{a1} = \frac{kT}{e} \ln\left(\frac{I}{I_{sT1}} + 1\right) = 0.4999 \text{ V}.$$

The forward-bias voltage of pn junction diode is

$$V_{a2} = \frac{kT}{e} \ln\left(\frac{I}{I_{sT2}} + 1\right) = 0.7306 \text{ V}.$$

4. (a) (i) The resistance at junction is

$$R = \frac{R_c}{A} = \frac{5 \times 10^{-5}}{10^{-5}} = 5\ \Omega.$$

When the current $I = 1$ mA $= 1 \times 10^{-3}$ A, the voltage across the junction is

$$V = IR = 1 \times 10^{-3} \times 5 = 5 \times 10^{-3} \text{ V}.$$

(ii) When $I = 100\ \mu\text{A} = 1 \times 10^{-4}$ A, the voltage across the junction is

$$V = IR = 1 \times 10^{-4} \times 5 = 5 \times 10^{-4} \text{ V}.$$

(b) (i) Similar to (a), the resistance at junction is

$$R = \frac{R_c}{A} = \frac{5 \times 10^{-5}}{10^{-6}} = 50\ \Omega.$$

When the current $I = 1$ mA $= 1 \times 10^{-3}$ A, the voltage across the junction is

$$V = IR = 1 \times 10^{-3} \times 50 = 5 \times 10^{-2} \text{ V}.$$

(ii) When the current $I = 100\ \mu\text{A} = 1 \times 10^{-4}$ A, the voltage across the junction is

$$V = IR = 1 \times 10^{-4} \times 50 = 5 \times 10^{-3} \text{ V}.$$

5. (a) We have $\phi_s = \chi_s + (E_c - E_F)_{\text{FB}}$,

$$E_c - E_F = -\frac{kT}{e} \ln\left(\frac{n_0}{N_c}\right) = 0.5519 \text{ V},$$

thus $\phi_s = \chi_s + (E_c - E_F)_{\text{FB}} > 4.5518 \text{ V} > \phi_m = 4.2$ V.

The energy-band diagram for zero bias for the case when no space charge region exists at the junction is

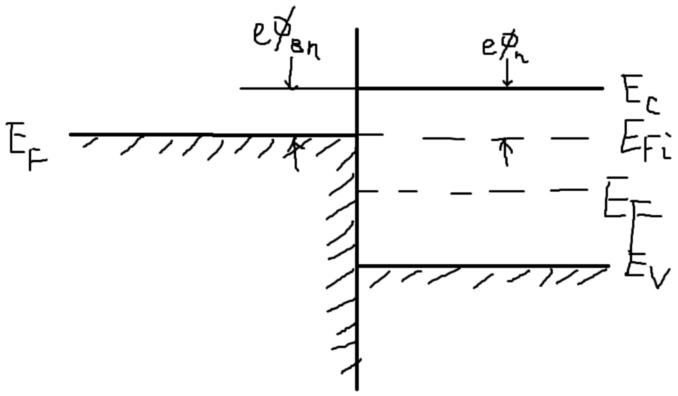

Figure 1: 5(a).

(b) The schottky barrier is

$$\phi_{Bn} = \phi_m - \chi_s = 4.2 - 4.0 = 0.2 \text{ V}.$$

$$\phi_n = \phi_{Bn} = 0.2 \text{ V}.$$

On the other hand,

$$\phi_n = \frac{kT}{e} \ln\left(\frac{N_c}{N_d}\right) = \frac{300k}{e} \ln\left(\frac{2.8 \times 10^{19}}{N_d}\right) = 0.2 \text{ V}.$$

Solving the equation,

$$N_d = 1.223 \times 10^{16} \text{ cm}^{-3}.$$

(c) From (b) we have the potential barrier height seen by electrons in the metal moving into the semiconductor is 0.2 V.

6. (a) The thermal equilibrium energy-band diagram is

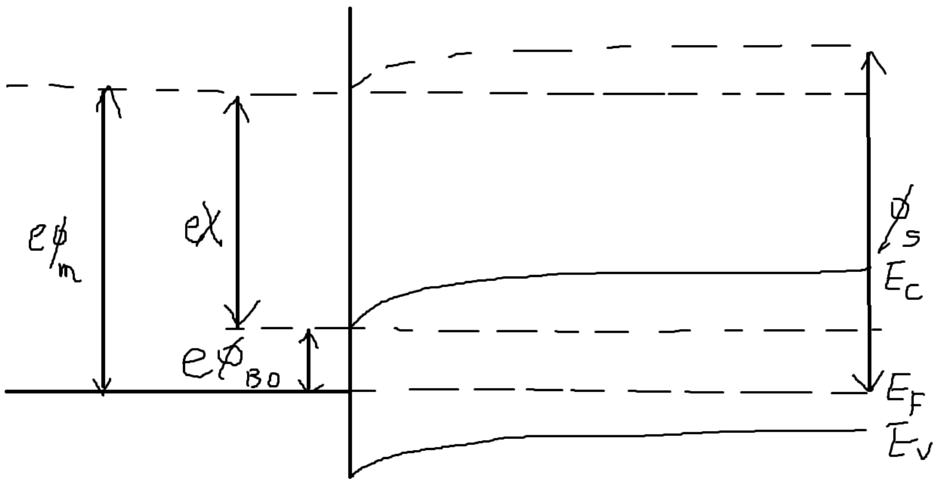

Figure 2: 6(a).

(b)

$$\phi_{B0} = \phi_m - \chi_s = 4.3 - 4.0 = 0.3 \text{ eV}.$$

(c)

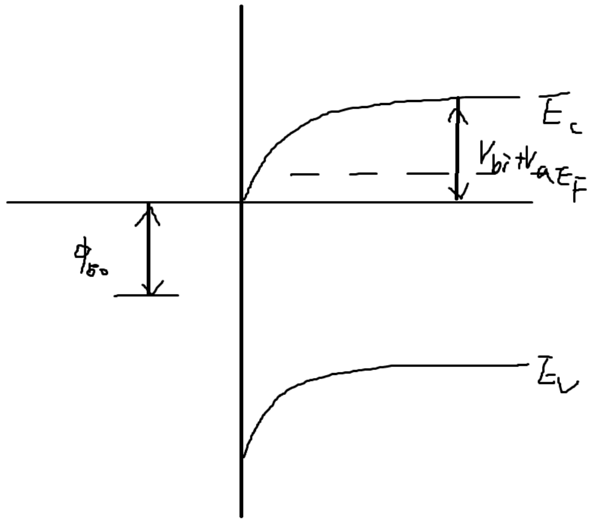

Figure 3: 6(c).

(d)

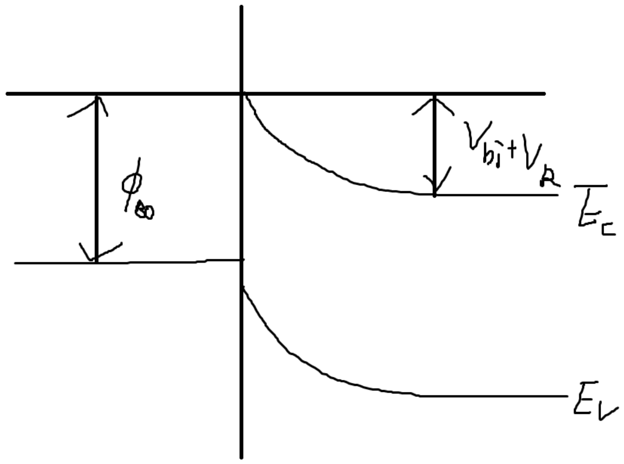

Figure 4: 6(d).