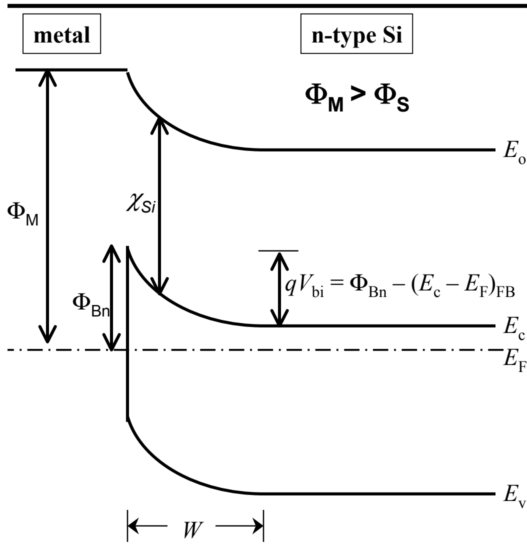
Lecture #9

<u>OUTLINE</u>

– Metal-semiconductor contacts (cont.)
  » *I-V* characteristics
  » practical ohmic contacts
  » small-signal capacitance

Reading: Finish Chapter 14

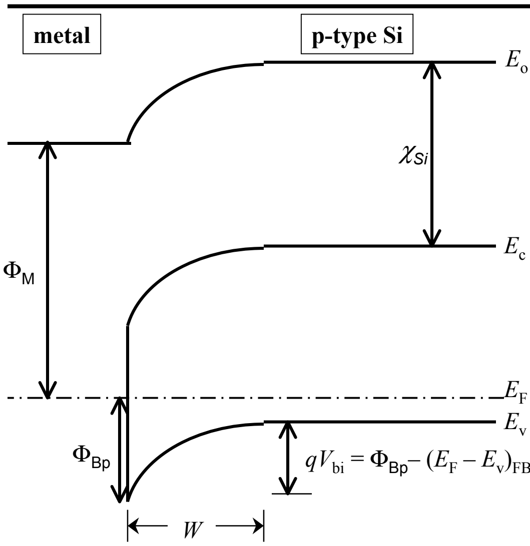
Review: Schottky Diode (n-type Si)



Equilibrium (V_A = 0) -> E_F continuous, constant

- $\Phi_{Bn} = \Phi_M - \chi$

Schottky Diode (p-type Si)



$\Phi_M < \Phi_S$

Equilibrium (V_A = 0) -> E_F continuous, constant

$$\Phi_{Bp} = \chi + E_G - \Phi_M$$

Depleted Layer Width, *W*

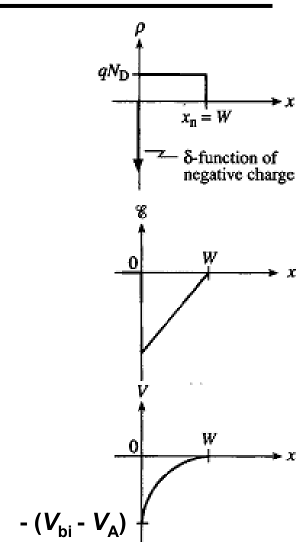
Last time, we found that

$$V(x) = \frac{-qN_D}{2K_S\varepsilon_0}(W-x)^2$$

At x = 0, V = - (V_{bi} - V_A)

$$\Rightarrow \quad W = \sqrt{\frac{2\varepsilon_s(V_{bi} - V_A)}{qN_D}}$$

- W increases with increasing $-V_A$
- W decreases with increasing N_D



W for p-type Semiconductor

$$V(x) = \frac{qN_A}{2K_S\varepsilon_0}(W - x)^2$$

At $x = 0$, $V = V_{bi} + V_A$

$$\Rightarrow \quad W = \sqrt{\frac{2\varepsilon_s (V_A + V_{bi})}{qN_A}}$$

- *W* increases with increasing V_A
- *W* decreases with increasing N_A

Current Flow in a Schottky Diode

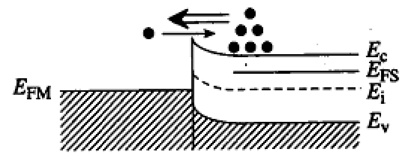
- Diode current is determined by majority-carrier flow across the MS junction
  - Under forward bias, majority-carrier diffusion from the semiconductor into the metal dominates the current
  - Under reverse bias, majority-carrier diffusion from the metal into the semiconductor dominates the current

Thermionic Emission Theory

- Electrons can cross the junction if

$$KE_x = \frac{1}{2} m v_x^{\,2} \geq q(V_{bi} - V_A)$$

$$|v_x| \geq v_{\min} \equiv \sqrt{\frac{2q}{m_n^*}(V_{bi} - V_A)}$$



- The current for electrons at a given velocity is:

$$I_{s\bullet\to M, v_x} = -qAv_x n(v_x)$$

- So, the total current over the barrier is:

$$I_{s\bullet\to M} = -qA \int_{-\infty}^{-v_{\min}} v_x n(v_x) dv_x$$

Schottky Diode *I* - *V*

- Given that

$$n(v_x) = \left[\frac{4\pi kT m_n^{*2}}{h^3}\right] e^{(E_F - E_c)/kT} e^{-(m_n^*/2kT)v_x^2}$$

- We obtain

$$I_{S\bullet\to M} = \frac{4\pi q m_n k^2}{h^3} AT^2 e^{-q\Phi_B/kT} e^{qV_A/kT}$$

$$= AT^2 J_S e^{qV_A/kT}, \text{where } J_S \approx 120 e^{-q\Phi_B/kT} \text{ A/cm}^2$$

- In the other direction, we always see the same barrier Φ_{Bn}: $I_{M\bullet\to S} = -I_{S\bullet\to M}(V_A = 0)$

- Therefore $I = I_S(e^{qV_A/kT} - 1)$ where $I_S = AT^2 J_S$

Applications of Schottky Diodes

- I_S of a Schottky diode is 10^3 to 10^8 times larger than a pn junction diode, depending on Φ_B .

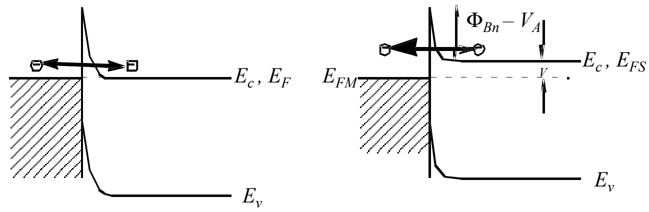
$\Rightarrow$ Schottky diodes are preferred rectifiers for low voltage, high current applications.

Practical Ohmic Contact

- In practice, most M-S contacts are rectifying

- To achieve a contact which conducts easily in both directions, we dope the semiconductor very heavily
  - → *W* is so narrow that carriers can tunnel directly through the barrier

$$W \cong \sqrt{\frac{2\varepsilon_s \Phi_{Bn}}{qN_D}}$$



tunneling probability $P = e^{-H(\Phi_{Bn}-V_A)/\sqrt{N_D}}$

$$H = 4\pi\sqrt{\varepsilon_s m_n}\,/\,h = 5.4\times10^9\sqrt{m_n / m_o}\ \text{cm}^{-3/2}\text{V}^{-1}$$

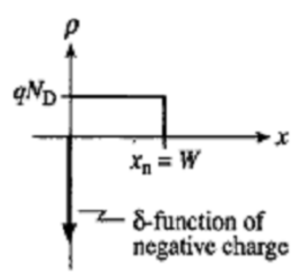
$$J_{S\to M} \approx qN_D v_{thx} P = qN_D\sqrt{kT / 2\pi m_n}\, e^{-H(\Phi_{Bn}-V_A)/\sqrt{N_D}}$$

Specific Contact Resistance

Voltage Drop across an Ohmic Contact

Review: MS-Contact Charge Distribution

- In a Schottky contact, charge is stored on either side of the MS junction
- This charge is modulated by the applied voltage



Schottky Diode: Small-Signal Capacitance

- If an A.C. voltage is applied in series with the D.C. bias V_A, the charge stored in the Schottky contact will be modulated
  $\rightarrow$ displacement current will flow

$$C = \frac{\varepsilon_s}{W} A$$

Using *C-V* Data to Determine Φ_B

$$\frac{1}{C^2} = \frac{2(V_{bi} - V_A)}{qN_D \varepsilon_s A^2}$$

Once V_{bi} is known, Φ_{Bn} can be determined:

$$qV_{bi} = q\Phi_{Bn} - (E_c - E_F)_{FB} = q\Phi_{Bn} - kT \ln \frac{N_c}{N_D}$$

Summary

Table 14.1 Electrical Nature of Ideal MS Contacts.

	n-type Semiconductor	*p-type Semiconductor*
$\Phi_M > \Phi_S$	Rectifying	Ohmic
$\Phi_M < \Phi_S$	Ohmic	Rectifying