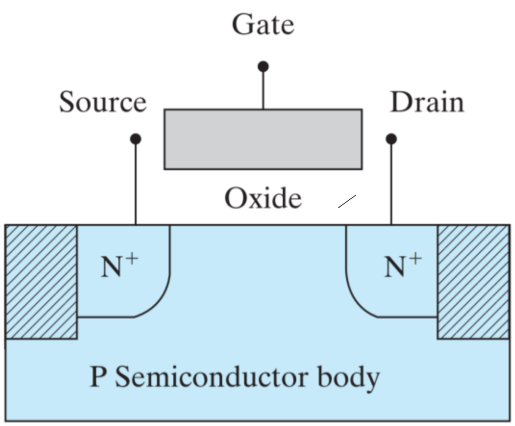
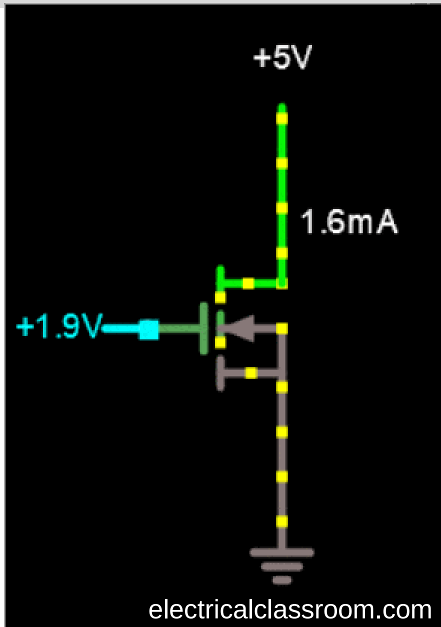
MS Contacts and Schottky diodes



EE302

Prof. Sangyoon Han

Fall 2023

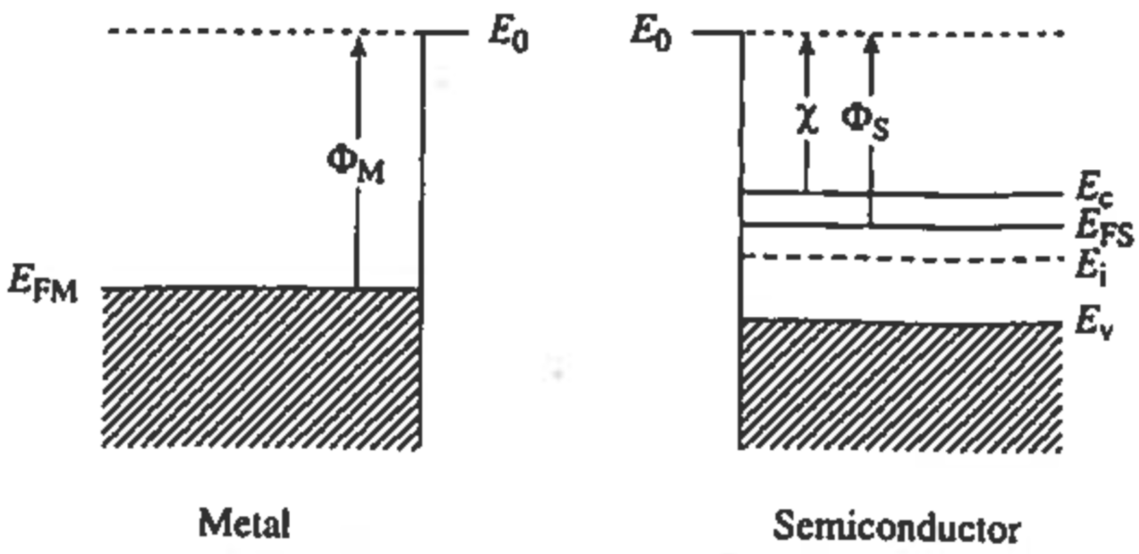


References:
- (R. Pierret) Chapter 14
- (C. Hu) Chapter 4
- Materials from SE393 (Prof. Hongki Kang)

Overview

- **Metal–Semiconductor contacts**
  - **What would happen if metal meets semiconductor?**

- **Schottky Diodes**
  - **Similar to PN diode**
  - **Metal / Semiconductor**

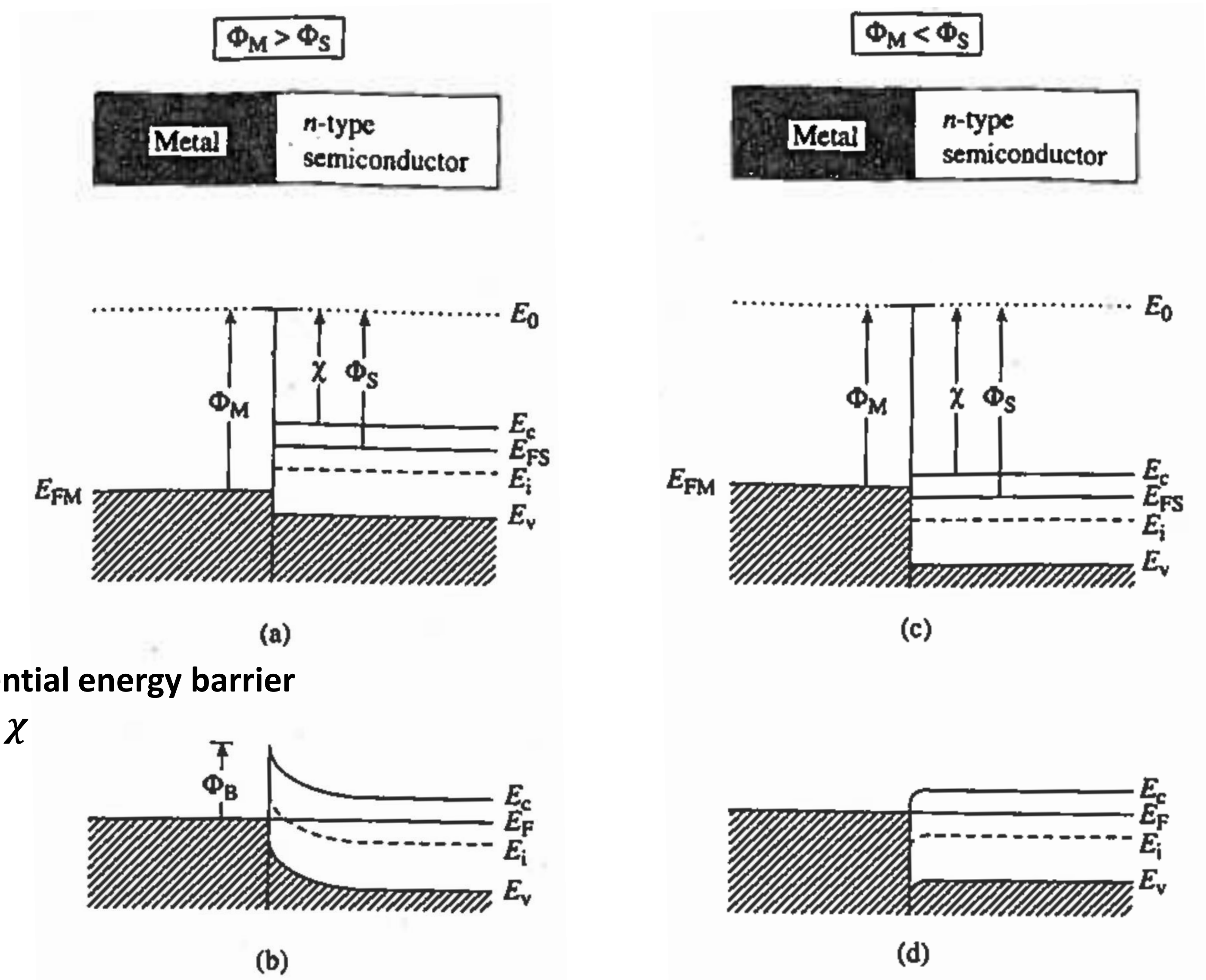


- ***E$_0$***: Vaccum level
- ***E$_{F(M,S)}$***: Fermi level
- χ: Electron affinity
  - $\chi = E_0 - E_c$
- ***ϕ$_{(M,S)}$***: Workfunction
  - $\phi_M = E_0 - E_{FM}$, $\phi_S = E_0 - E_{FS}$

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

Metal / *n*-type Semiconductor

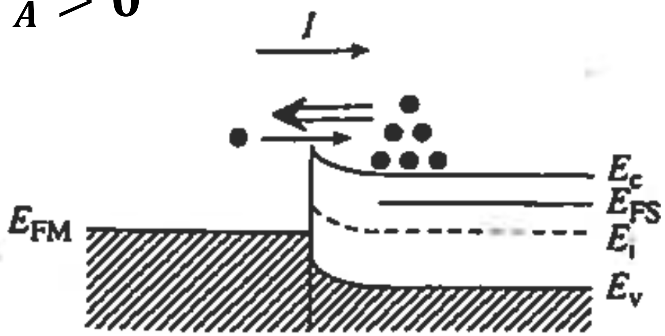


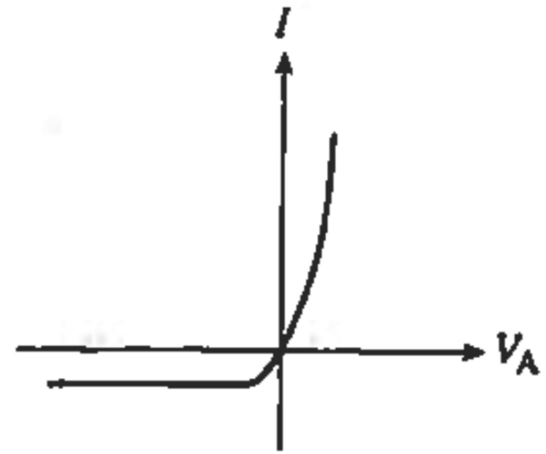
Surface potential energy barrier

$$\phi_B = \phi_M - \chi$$

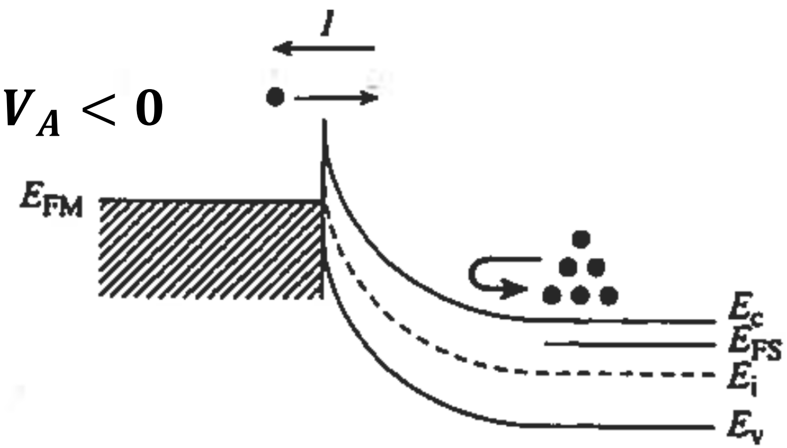
Metal / *n*-type Semiconductor ($\phi_M > \phi_S$, *rectifying* contact)

- $V_A > 0$



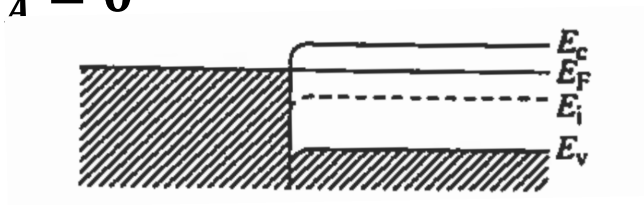


- $V_A < 0$

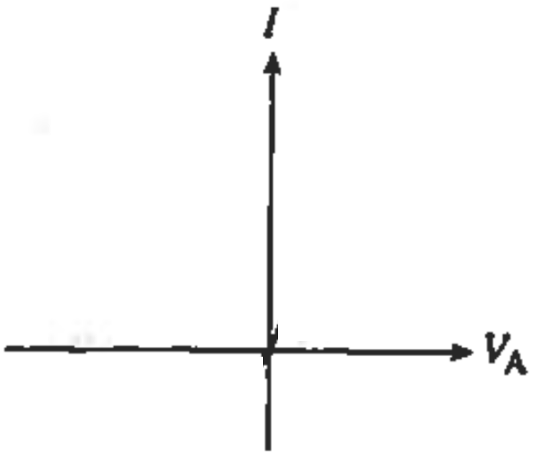


Metal / *n*-type Semiconductor ($\phi_M < \phi_S$, *ohmic* contact)

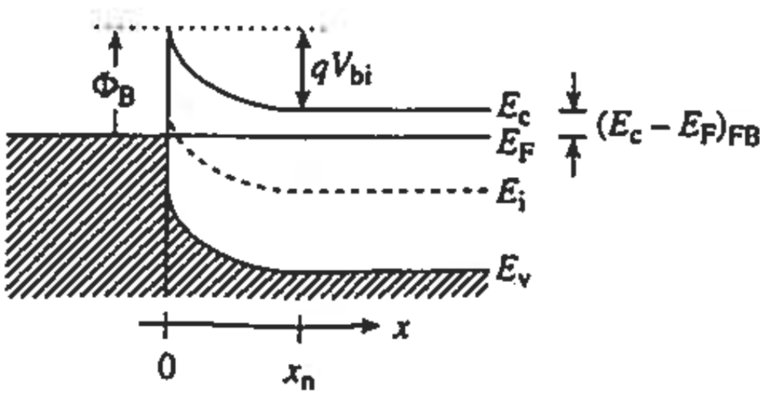
- $V_A = 0$



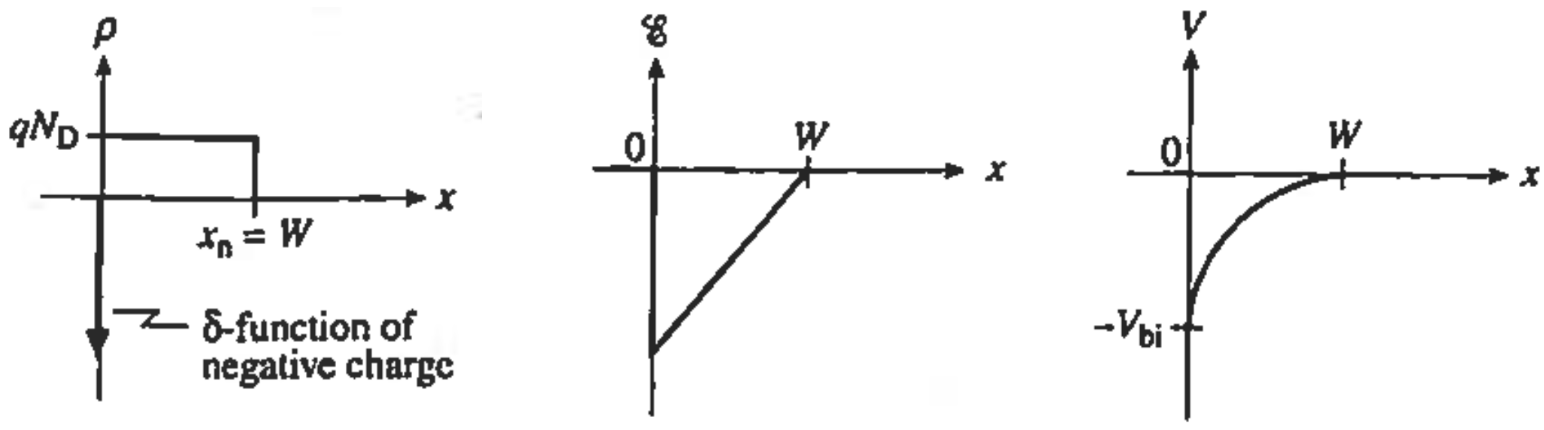
- $V_A > 0$



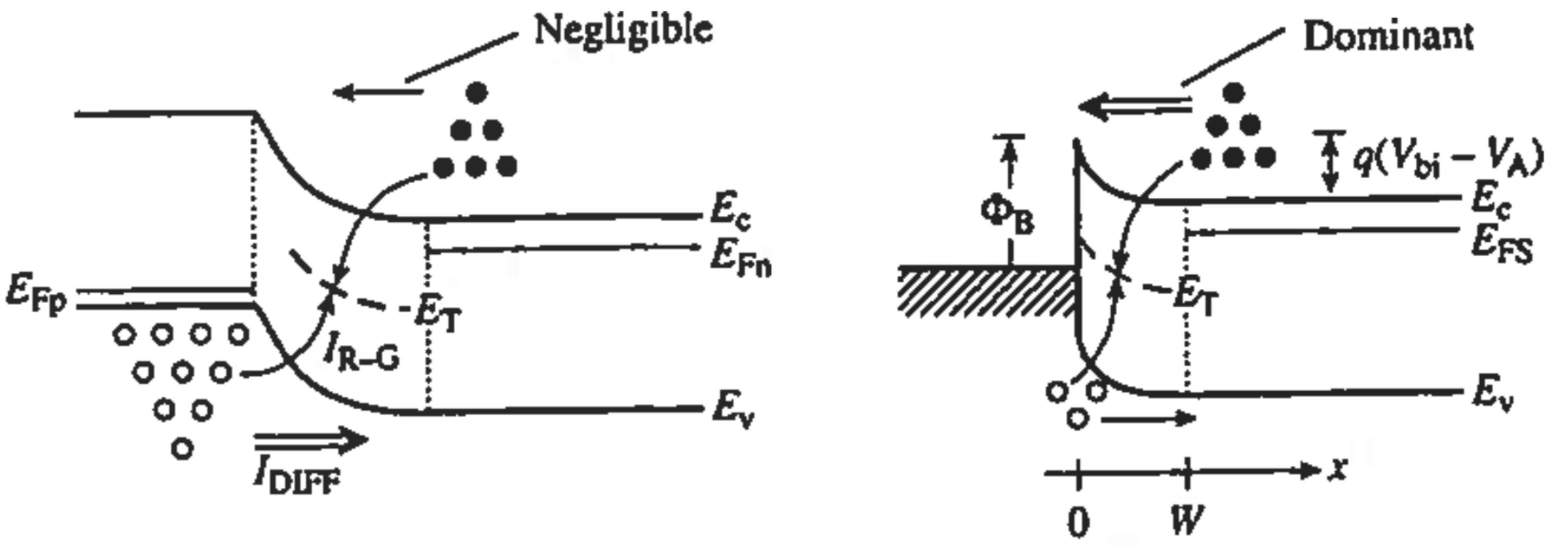
- $V_A < 0$



- **Built-in voltage (*V_{bi}*)**



Thermionic emission current

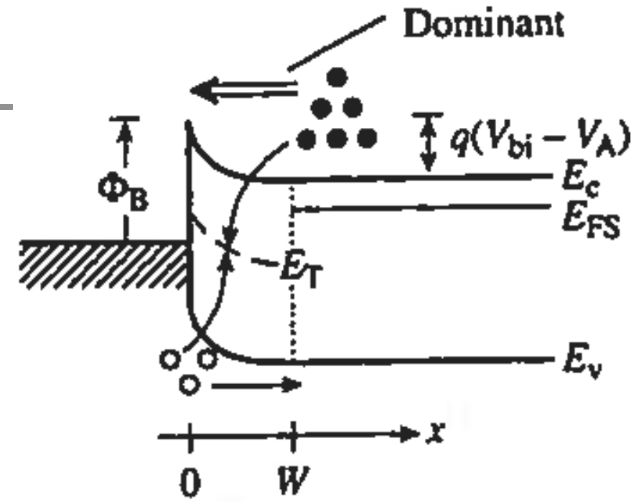


(a) p^+–n junction diode

(b) MS diode

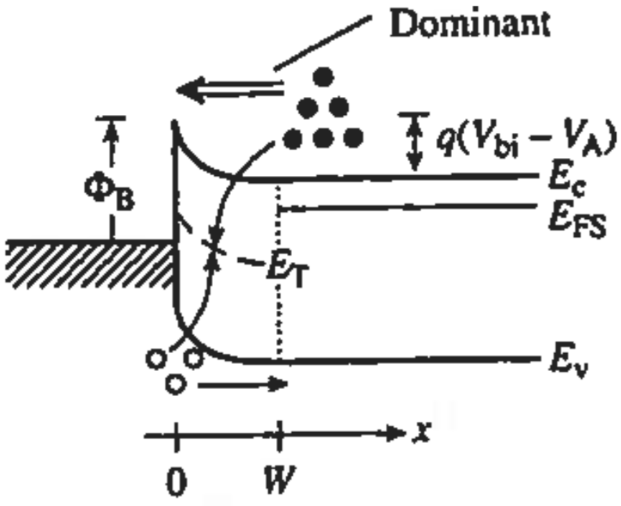
- **The electrostatics of the MS diode (Schottky diod) is similar to P^+N junction diode.**
- **However, mechanism of d.c. current flow (I–V) is different.**
- **Electron injection from the semiconductor to metal dominates in MS diode**

I –V Characteristics



- **Thermionic emission current**
  - **If K.E. > potential barrier**
  - **Surmount the barrier to cross into the metal**
  - K.E.= $\frac{1}{2}m_n^* v_x^2 \geq q(V_{bi} - V_A)$
  - $v_x \geq \sqrt{2q(V_{bi} - V_A)/m_n^*}$
  - $n(v_x)$: **# of electrons having velocity of** v_x
  - **Drift current for the electrons having velocity of** v_x
    - $I_{S\to M} = -qAv_x n(v_x)$
  - **Total drift current for all the electrons having velocity** $\geq v_x$
    - $I_{S\to M} = -qA\int_{-\infty}^{-v_x} v_x n(v_x) dv_x$
    - $I_{S\to M} = A\left(\frac{4\pi q m_n^* k^2}{h^3}\right)T^2 e^{-\frac{\phi_B}{kT}} e^{\frac{qV_A}{kT}} = I_S e^{\frac{qV_A}{kT}}$

$n(v_x)$ **~ exponential**

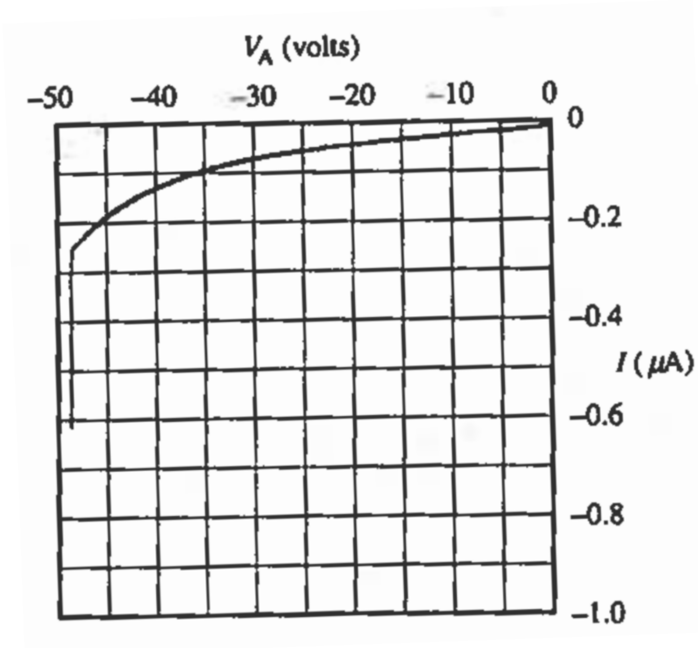


- **Metal to semiconductor**
  - **Always see the same barrier (ϕ_B)**
  - $I_{M\to S}(V_A) = I_{M\to S}(V_A = 0)$
  - **Under equilibrium, no net current**
  - $I_{M\to S}(V_A = 0) = -I_{S\to M}(V_A = 0) = -A\left(\frac{4\pi q m_n^* k^2}{h^3}\right)T^2 e^{-\frac{\phi_B}{kT}} = -I_S$

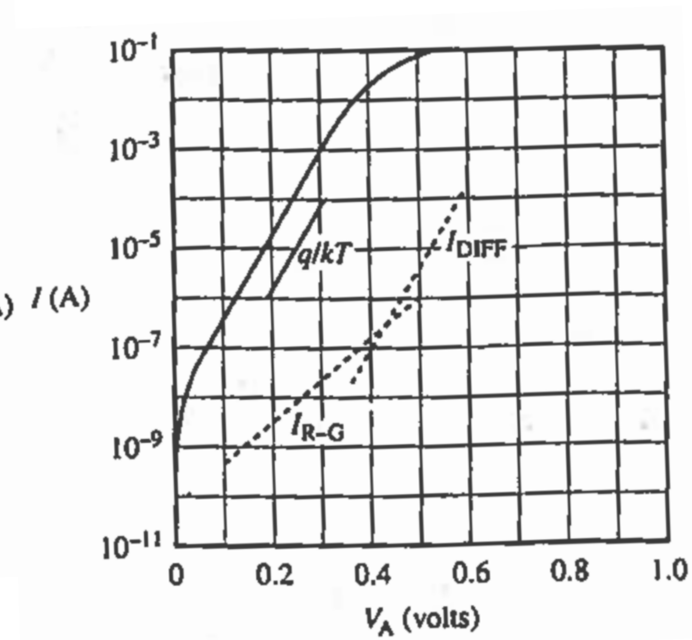
- **Total current**
  - $I_{M\to S}(V_A) + I_{S\to M}(V_A)$
  - $I_S(e^{\frac{qV_A}{kT}} - 1)$

Ideal MS diode equation…

I –V Characteristics



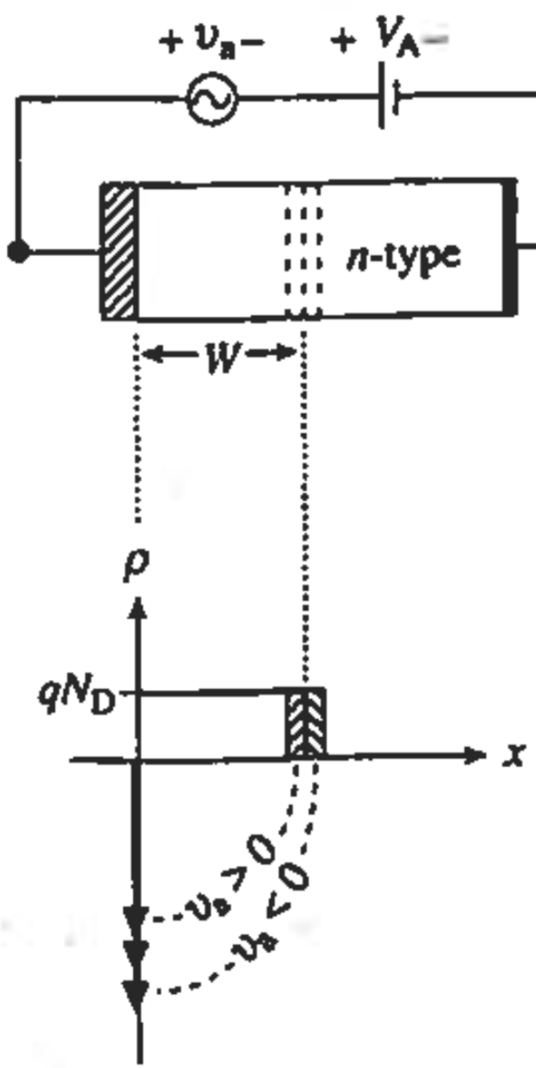
Reverse **bias**

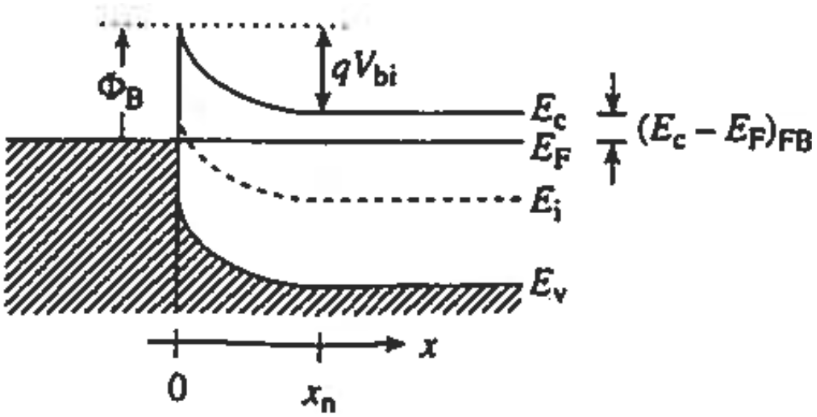


Forward **bias**

- **Non-ideal behaviors**
  - **Avalanching breakdown**
  - **Series resistance**
  - **No high level injection**
  - **Schottky barrier lowering** $(\Delta\phi_B)$

a.c. Response





- **Parallel plate capacitor-like junction capacitor**
  - **Different responding charges in metal**
  - **PN diode:**
  - **MS diode:**
  - **Majority carriers → quick response**
- **Forward bias diffusion capacitance?**
  - **Diffused minority carriers are ignorable in MS diode**

Applications

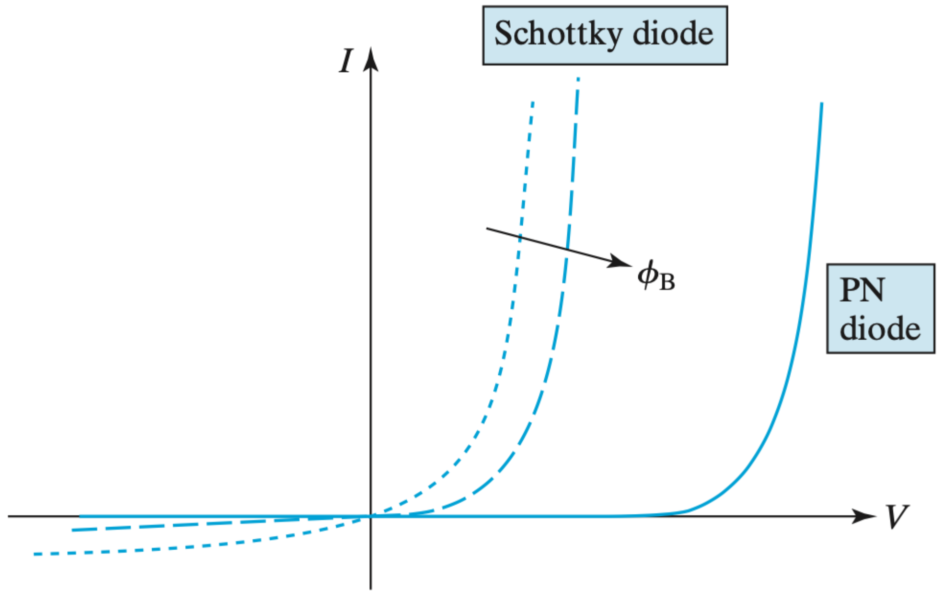
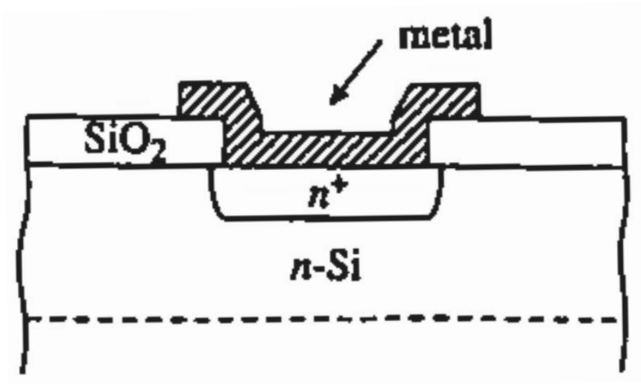


FIGURE 4–40 Schematic *IV* characteristics of PN and Schottky diodes having the same area.

- **Low-voltage and high-current rectifier applications**
  - **Smaller power loss**
- **Higher speed switching applications**
  - **Majority carrier driven**

Ohmic Contacts



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- **In practice, it is difficult to tune the barrier height (ϕ_B).**
- **High doping in the semi can lead to ohmic contact regardless of ϕ_B.**

Summary

- **Metal–Semiconductor contacts**
  - **Mostly depends on material characteristics**
  - **Could be rectifying (diode-like behavior) or ohmic (low-resistance)**

- **Schottky Diodes (MS diode)**
  - **Similar to PN diode in *I–V* characteristics**
  - **Different mechanism, though.**
  - **Entirely majority carrier driven**
    - **Faster switching**