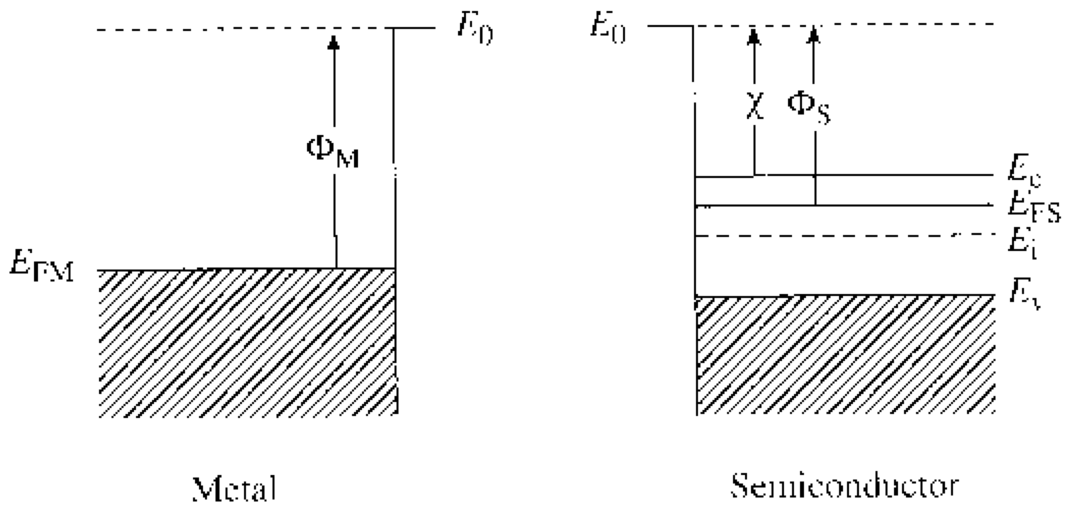
Chapter 14-1. Metal-semiconductor (MS) junctions

Many of the properties of pn junctions can be realized by forming an appropriate metal-semiconductor rectifying contact (Schottky contact)

- Simple to fabricate
- Switching speed is much higher than that of p-n junction diodes

Metal-Semiconductor junctions are also used as ohmic-contact to carry current into and out of the semiconductor device

Ideal MS contacts



Assumptions - Ideal MS contacts

- M and S are in intimate contact, on atomic scale
- No oxides or charges at the interface
- No intermixing at the interface

MS contacts

Vacuum level, E_0 - corresponds to energy of free electrons.

The difference between vacuum level and Fermi-level is called workfunction, Φ of materials.

- **Workfunction, Φ_M** is an invariant property of metal. It is the minimum energy required to free up electrons from metal. (3.66 eV for Mg, 5.15eV for Ni etc.)

The semiconductor **workfunction, Φ_s,** depends on the doping.

$$\Phi_S = \chi + (E_C - E_F)_{FB}$$

where $\chi = (E_0 - E_C)|_{SURFACE}$ is a a fundamental property of the semiconductor. (Example: χ = 4.0 eV, 4.03 eV and 4.07 eV for Ge, Si and GaAs respectively)

Energy band diagrams for ideal MS contacts

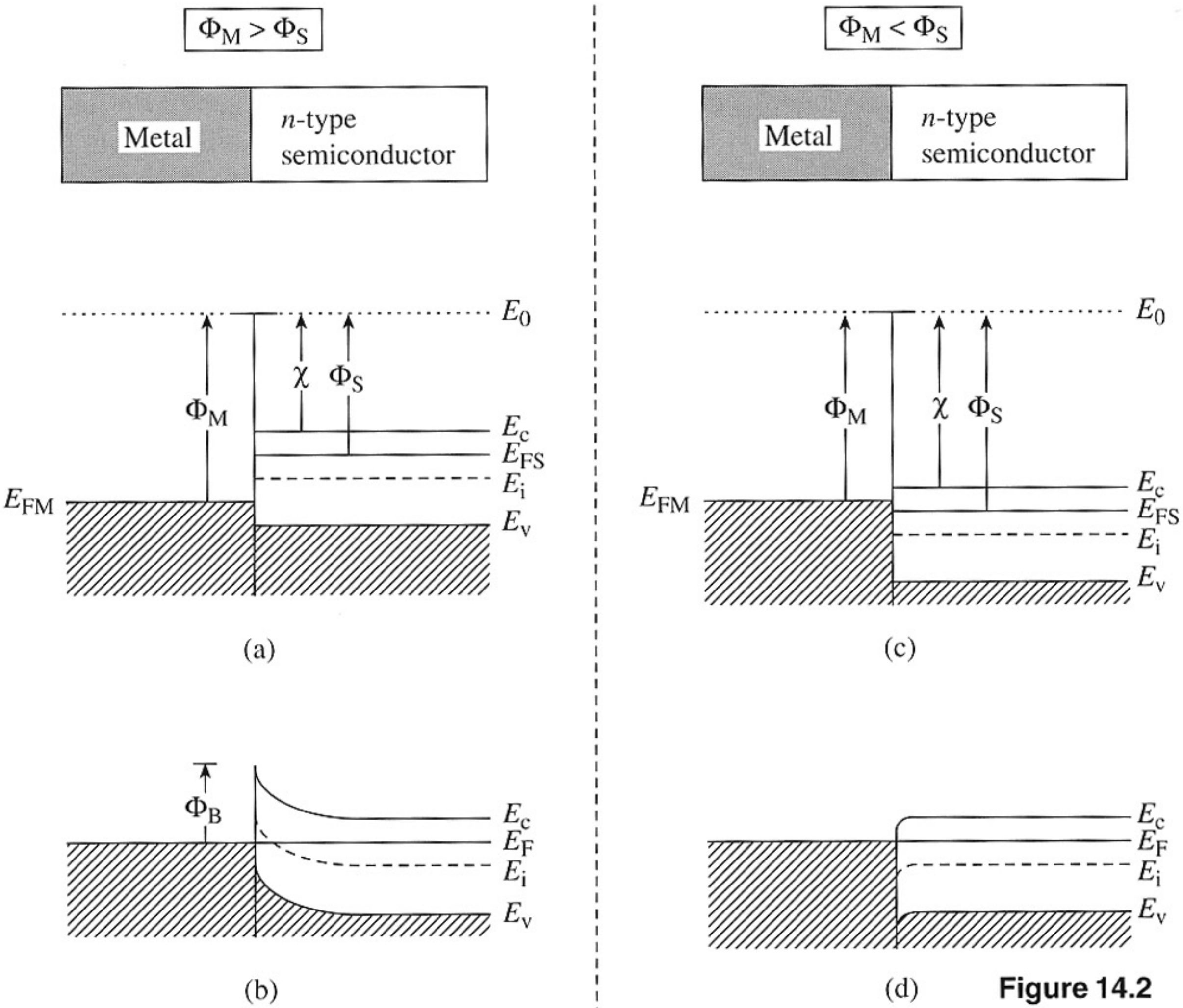


Figure 14.2

(a) and (c) An instant after contact formation

(b) and (d) under equilibrium conditions

$\Phi_M > \Phi_S$ $\qquad$ $\Phi_M < \Phi_S$

MS (n-type) contact with $\Phi_M > \Phi_S$

Soon after the contact formation, electrons will begin to flow from S to M near junction.

Creates surface depletion layer, and hence a built-in electric field (similar to p^+-n junction).

Under equilibrium, net flow of carriers will be zero, and Fermi-level will be constant.

A barrier Φ_B forms for electron flow from M to S.

$\Phi_B = \Phi_M - \chi$ ... ideal MS (n-type) contact. Φ_B is called "barrier height".

Electrons in semiconductor will encounter an energy barrier equal to $\Phi_M - \Phi_S$ while flowing from S to M.

MS (n-type) contact with $\Phi_M > \Phi_S$

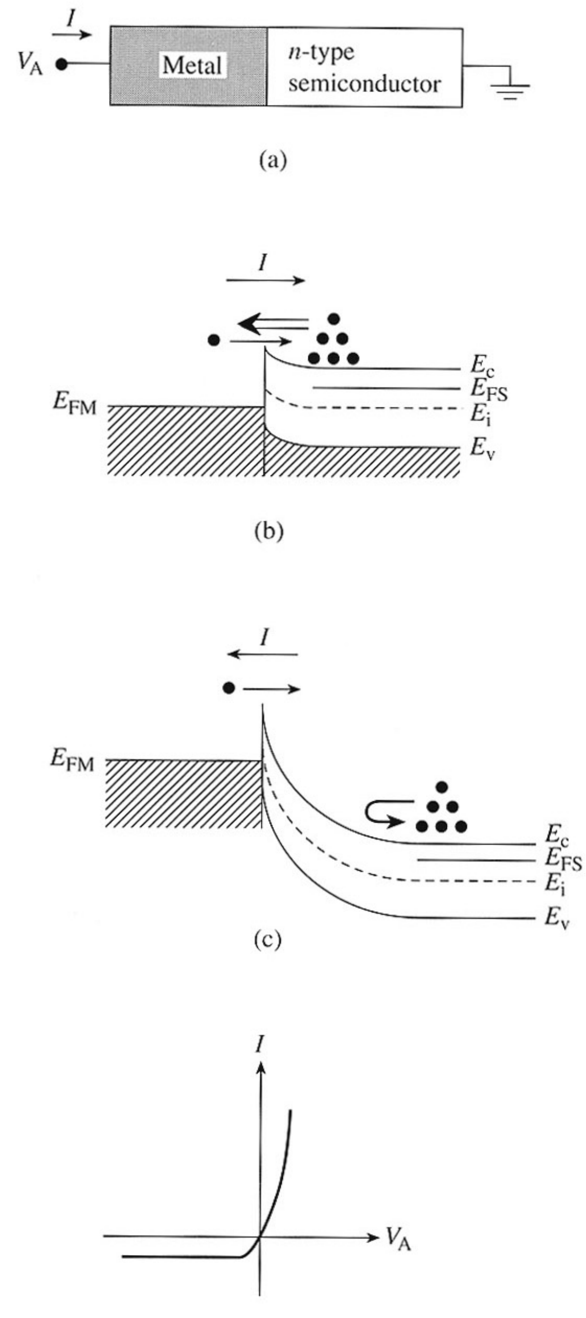


Figure 14.3

Response to applied bias for n-type semiconductor

Note: An applied positive voltage lowers the band since energy bands are drawn with respect to electron energy.

MS (n-type) contact with $\Phi_M < \Phi_S$

No barrier for electron flow from S to M. So, even a small $V_A > 0$ results in large current.

As drawn, small barrier exists for electron flow from M to S, but vanishes when $V_A < 0$ is applied to the metal. Large current flows when $V_A < 0$.

The MS(n-type) contact when $\Phi_M < \Phi_S$ behaves like an ohmic contact.

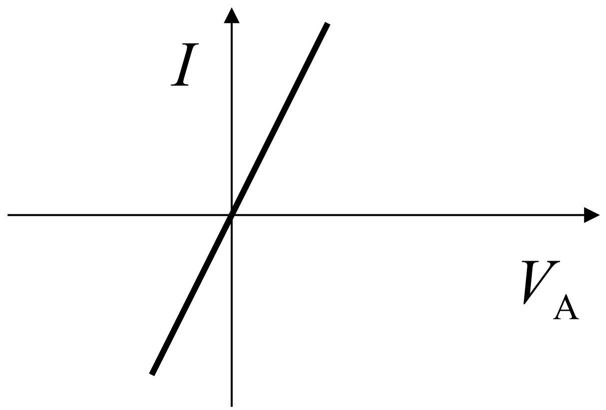


Table 14.1 Electrical nature of ideal MS contacts

	n-type	**p-type**
$\Phi_M > \Phi_S$	rectifying	ohmic
$\Phi_M < \Phi_S$	ohmic	rectifying

Schottky diode

$$V_{\mathrm{bi}} = \frac{1}{q}\left[\Phi_{\mathrm{B}} - (E_{\mathrm{C}} - E_{\mathrm{F}})_{\mathrm{FB}}\right]$$

$$\begin{aligned} \rho &\approx qN_{\mathrm{D}} \quad \text{for } \ 0 \le x \le W \\ &\approx 0 \qquad\ \ \text{for } \ x > W \end{aligned}$$

$$\frac{\mathrm{d}\mathcal{E}}{\mathrm{d}x} = \frac{\rho}{\varepsilon_{\mathrm{Si}}} = \frac{qN_{\mathrm{D}}}{\varepsilon_{\mathrm{Si}}} \quad \text{for} \quad 0 \le x \le W$$

$$\mathcal{E}(x=0) = \frac{q\,N_{\mathrm{D}}\,W}{\varepsilon_{\mathrm{Si}}}$$

$$W = \left[\frac{2\,\varepsilon_{\mathrm{Si}}}{q\,N_{\mathrm{D}}}(V_{\mathrm{bi}} - V_{\mathrm{A}})\right]^{1/2}$$

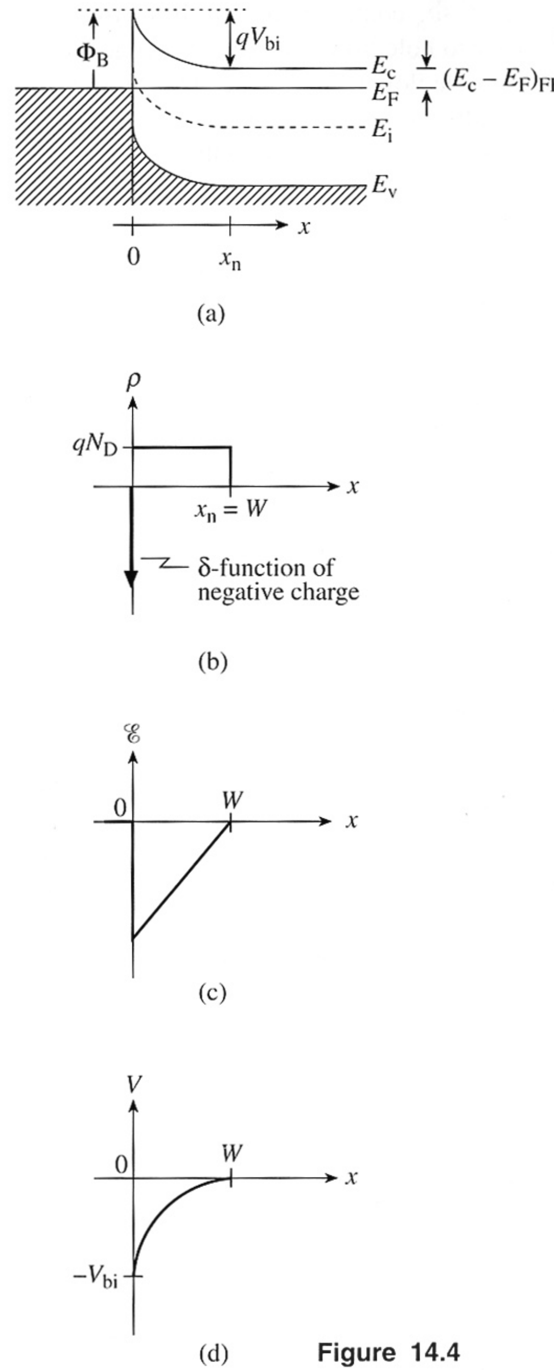


Figure 14.4

Example

Find barrier height, built-in voltage, maximum E-field, and the depletion layer width at equilibrium for W-Si (n-type) contact.

Given: $\Phi_M = 4.55\text{eV}$ for W; $\chi(\text{Si}) = 4.01\text{eV}$; Si doping $= 10^{16}\,\text{cm}^{-3}$

Draw the band diagram at equilibrium.

Solution:

Find $E_F - E_i$ $\quad$ $E_F - E_i = 0.357\text{eV}$

Find $E_C - E_F$ $\quad$ $E_C - E_F = 0.193\text{eV}$

$$\Phi_B = \Phi_M - \chi = 0.54\text{eV}$$

$$\Phi_S = \chi + (E_C - E_F)_{FB} = 4.203\text{ eV}$$

$V_{bi} = 0.347\text{ V}$

$W = 0.21\ \mu\text{m}$

$\mathcal{E}(x = 0) = \mathcal{E}_{max} = 3.4 \times 10^4\,\text{V/cm}$

Chapter 14-2. Schottky diode I-V characteristics

Schottky diode is a metal-semiconductor (MS) diode

Historically, Schottky diodes are the oldest diodes

MS diode electrostatics and the general shape of the MS diode I-V characteristics are similar to p^+n diodes, but the details of current flow are different.

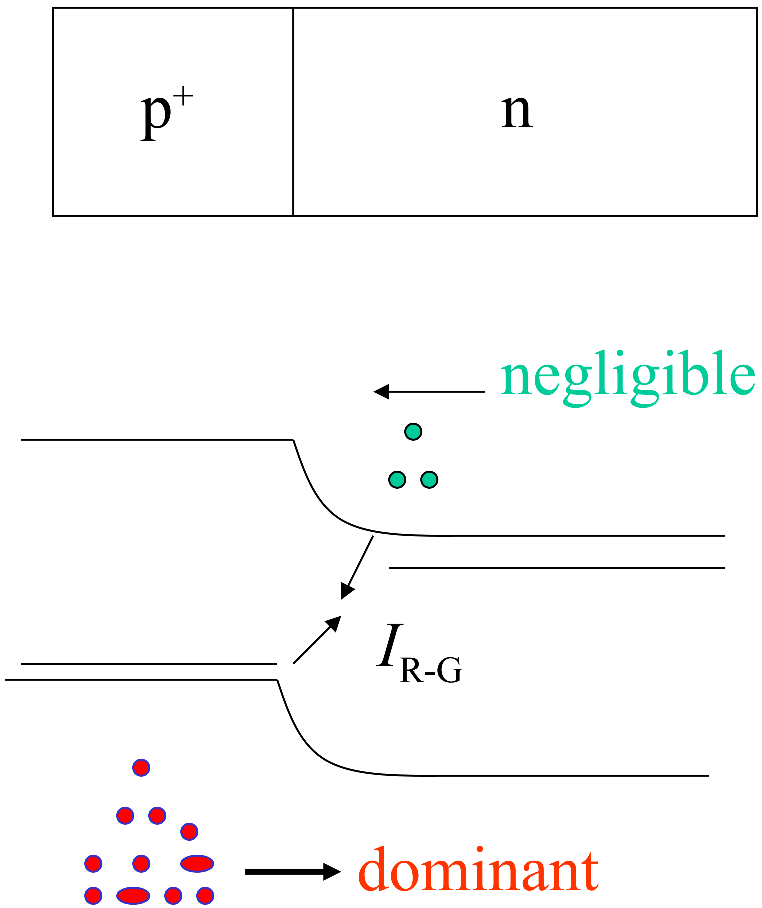
Dominant currents in a p^+n diode

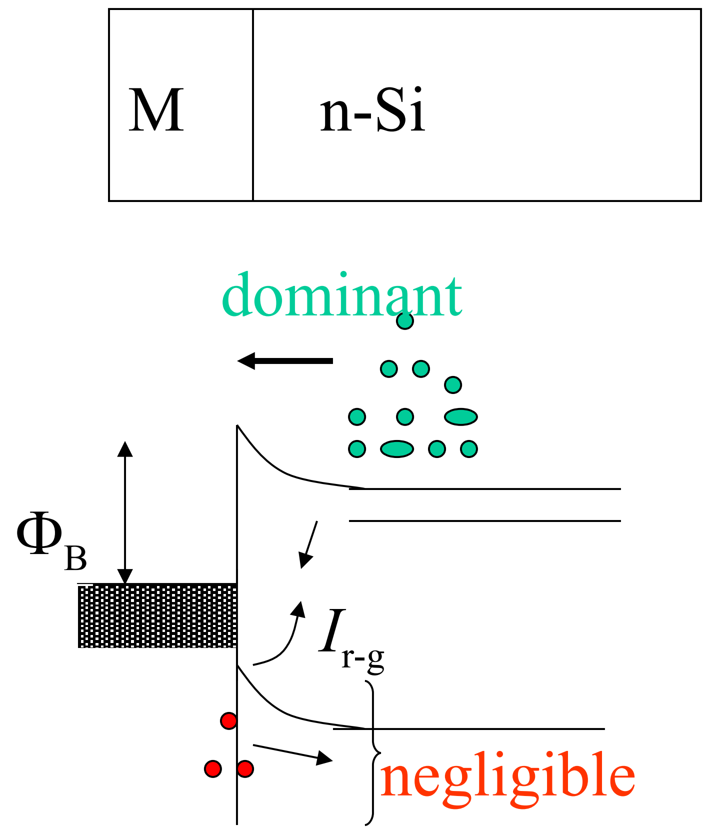
- arise from recombination in the depletion layer under small forward bias.
- arise from hole injection from p^+ side under larger forward bias.

Dominant currents in a MS Schottky diodes

- Electron injection from the semiconductor to the metal.

Current components in a p$^+$n and MS Schottky diodes





I-V characteristics

$$I = I_s \left(e^{\frac{qV_A}{kT}} - 1 \right) \quad \text{where} \quad I_s = A\mathcal{A}^* T^2 e^{-\frac{\Phi_B}{kT}}$$

where Φ_B is Schottky barrier height, V_A is applied voltage, A is area, and $\mathcal{A}^*$ is Richardson's constant.

The reverse leakage current for a Schottky diode is generally much larger than that for a p^+n diode.

Since MS Schottky diode is a majority carrier devices, the frequency response of the device is much higher than that of equivalent p^+ n diode.