
VE320 – Summer 2024

Introduction to Semiconductor Devices

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Chapter 9 Metal-Semiconductor Schottky Junction

Outline

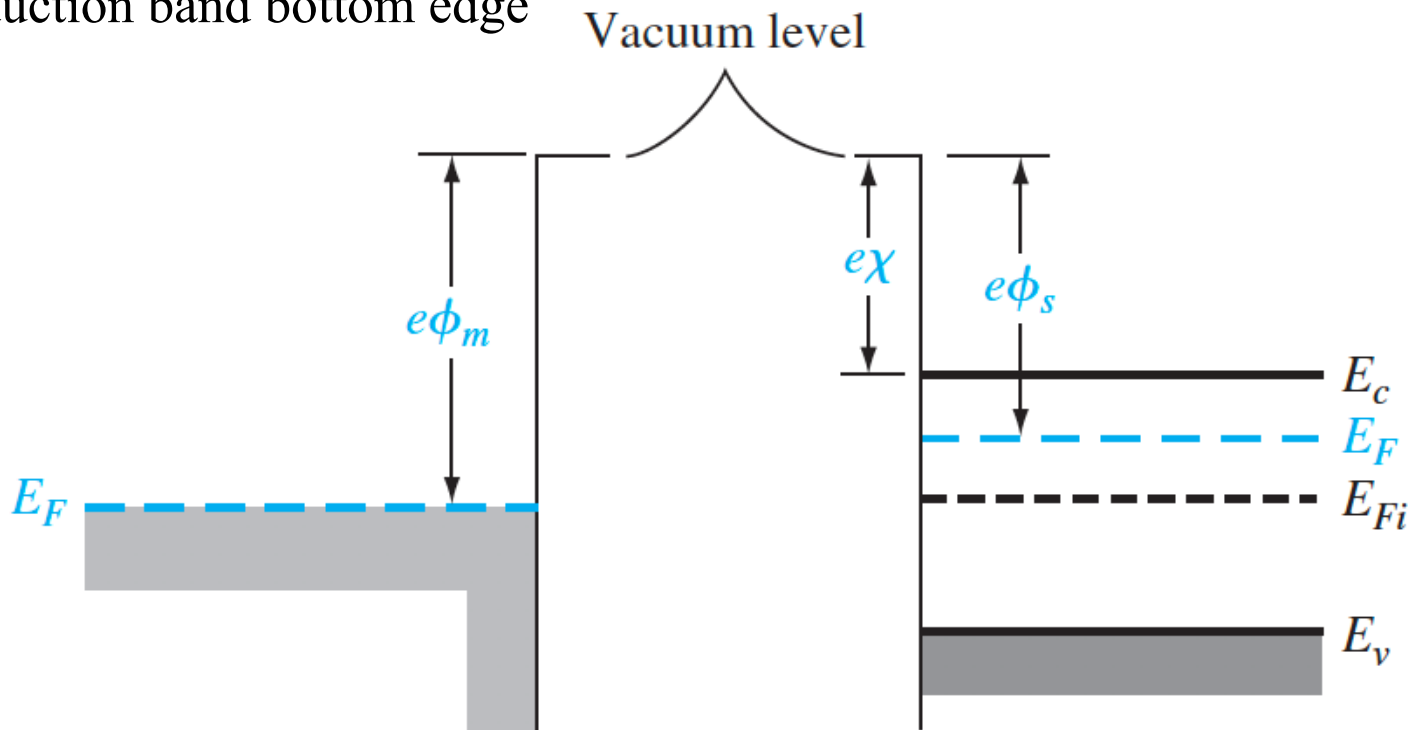
9.1 The Schottky barrier diode

9.2 Metal-semiconductor Ohmic contacts

9.1 The Schottky barrier diode

Qualitative characteristics

- Work function: energy difference between the vacuum energy level and the Fermi level
- Electron affinity: energy difference between the vacuum energy level and conduction band bottom edge



9.1 The Schottky barrier diode

Qualitative characteristics

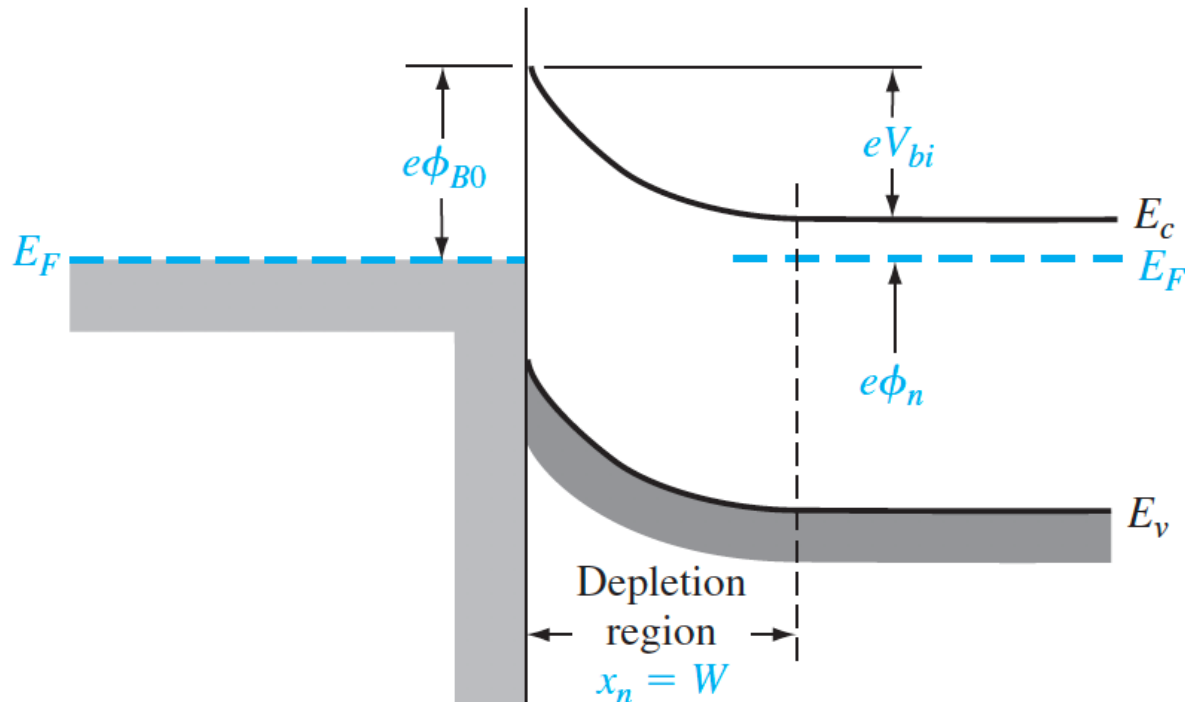
Element	Work function, ϕ_m
Ag, silver	4.26
Al, aluminum	4.28
Au, gold	5.1
Cr, chromium	4.5
Mo, molybdenum	4.6
Ni, nickel	5.15
Pd, palladium	5.12
Pt, platinum	5.65
Ti, titanium	4.33
W, tungsten	4.55

Element	Electron affinity, χ
Ge, germanium	4.13
Si, silicon	4.01
GaAs, gallium arsenide	4.07
AlAs, aluminum arsenide	3.5

9.1 The Schottky barrier diode

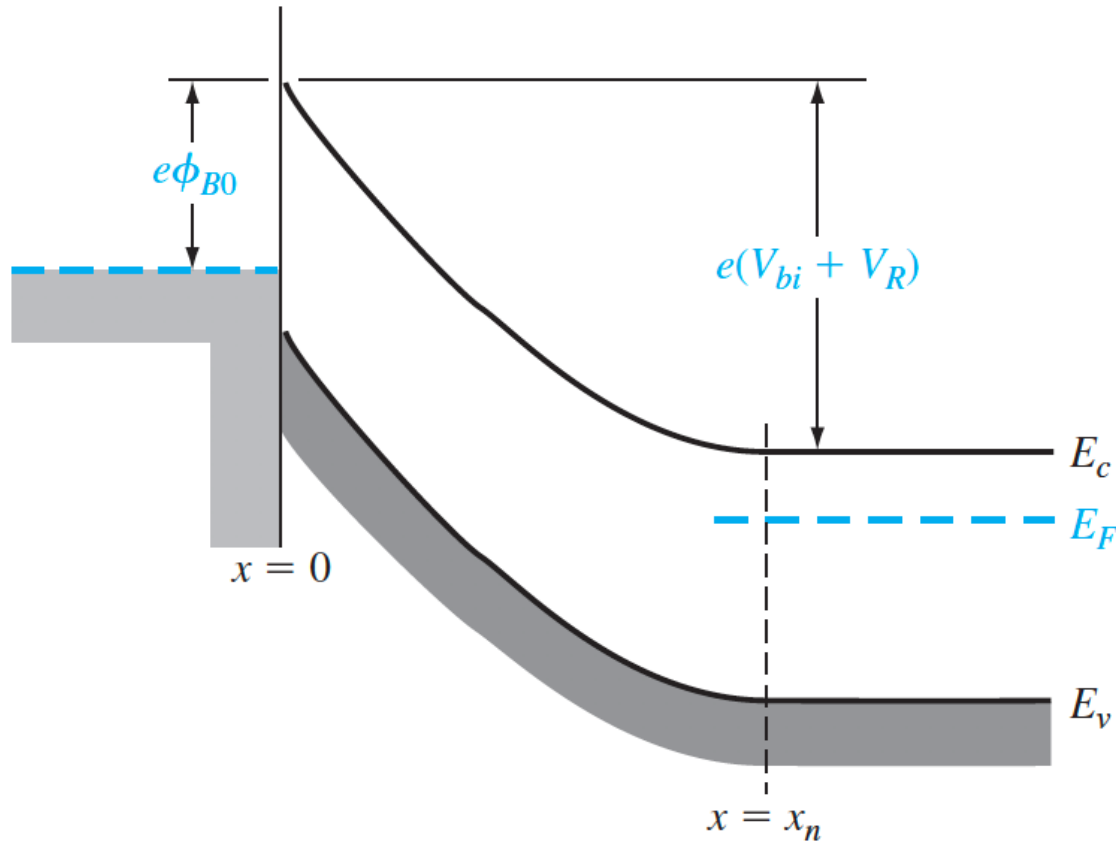
Qualitative characteristics

- Schottky barrier: $\phi_{B0} = (\phi_m - \chi)$
- Built-in potential barrier: $V_{bi} = \phi_{B0} - \phi_n$



9.1 The Schottky barrier diode

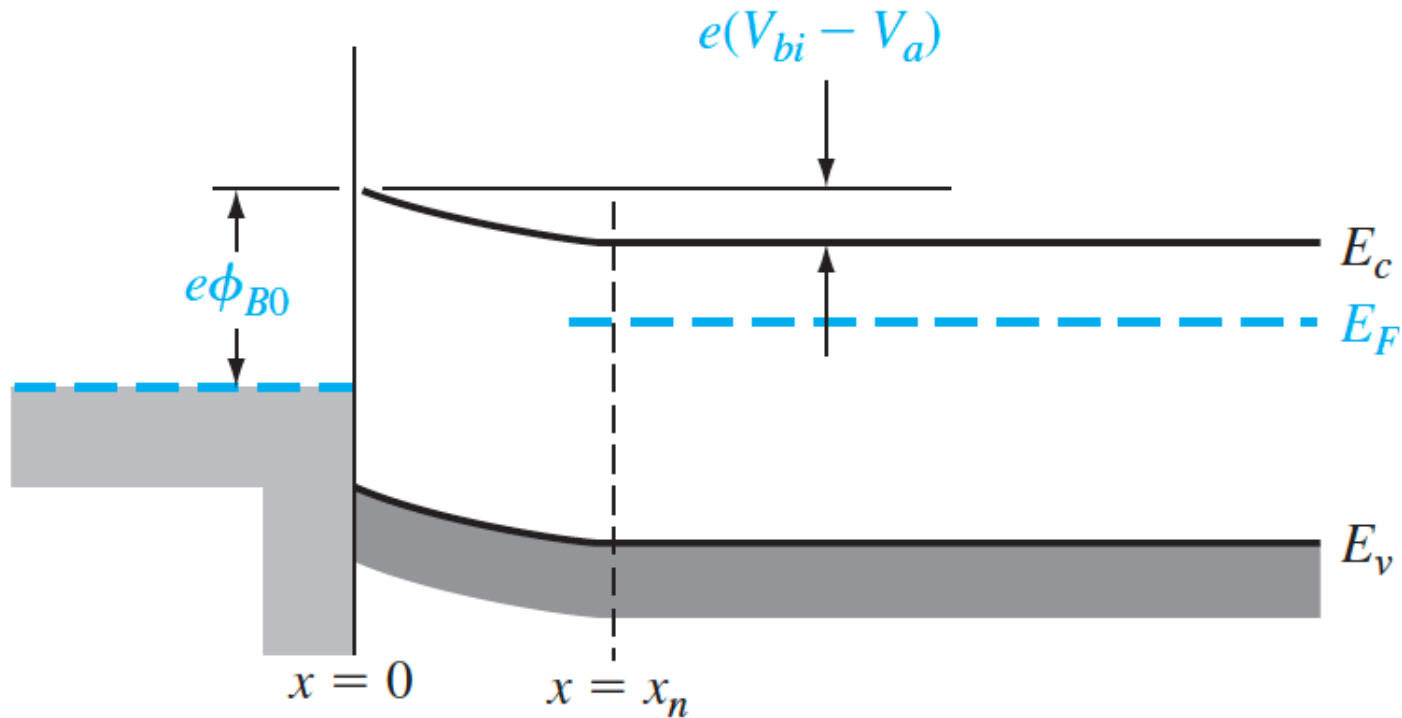
Qualitative characteristics



Reverse bias

9.1 The Schottky barrier diode

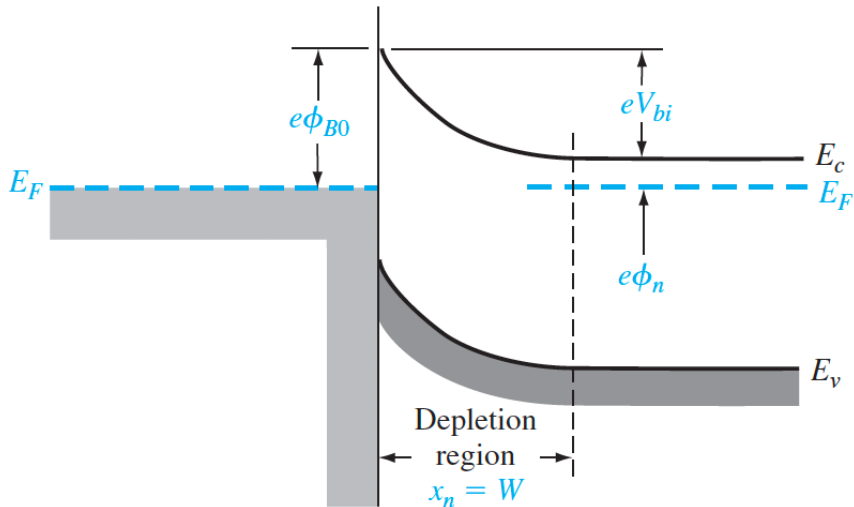
Qualitative characteristics



Forward bias

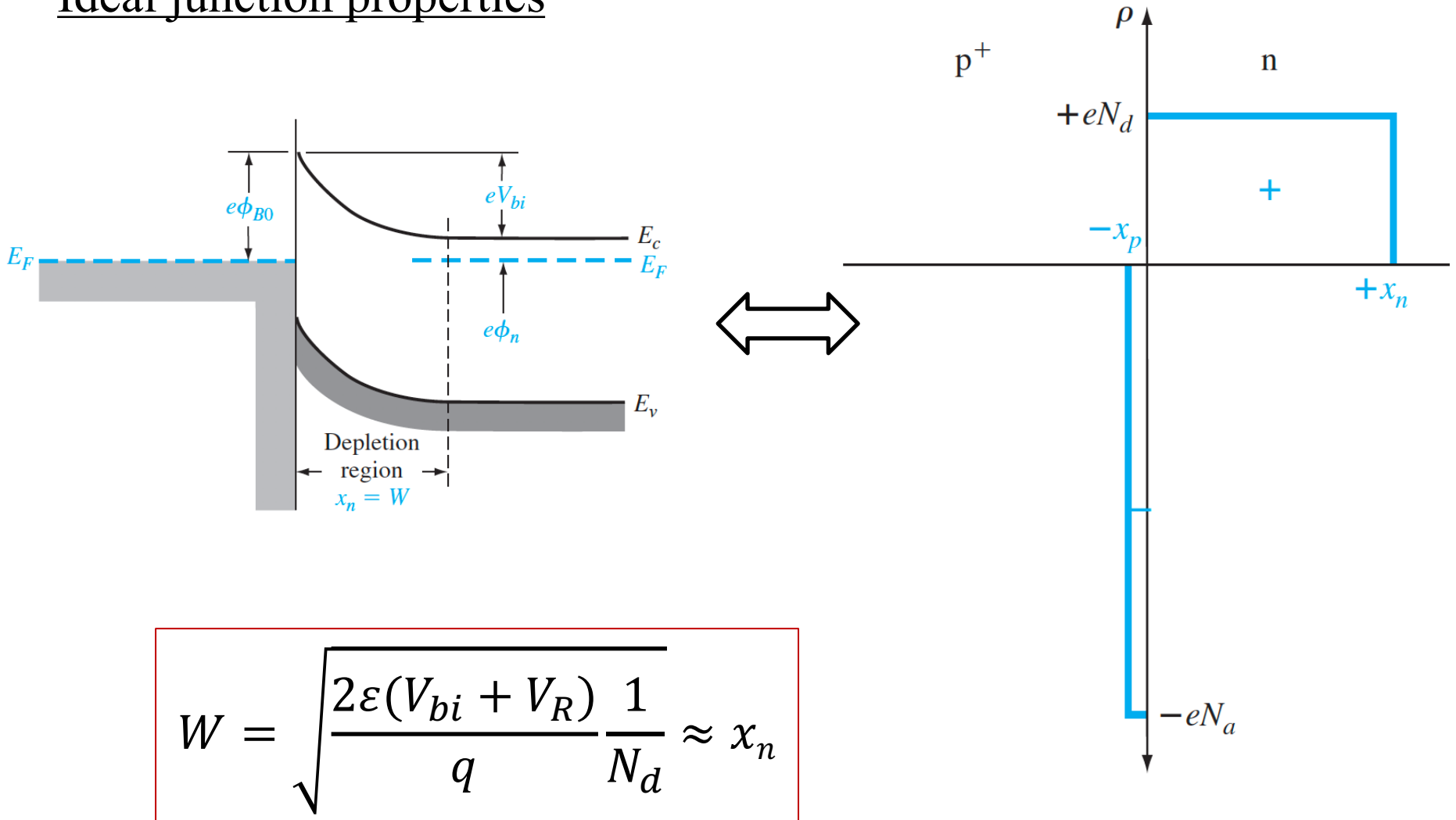
9.1 The Schottky barrier diode

Ideal junction properties (electric field)



9.1 The Schottky barrier diode

Ideal junction properties



Check your understanding

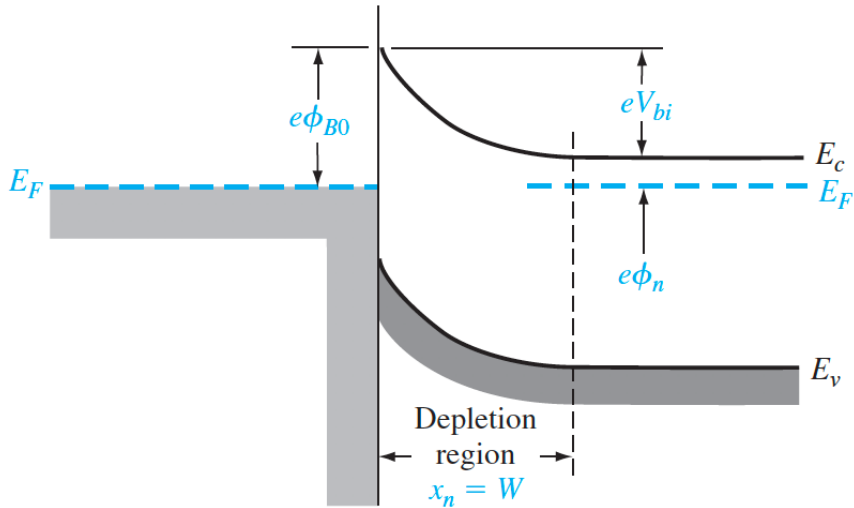
Problem example #1

A metal-semiconductor junction is formed between a metal with a work function of 4.3 eV and p-type silicon with an electron affinity of 4.0 eV. The acceptor doping concentration in the silicon is $N_a = 5 \times 10^{16} \text{ cm}^{-3}$. Assume $T = 300\text{K}$. (a) Sketch the energy-band diagram. (b) Determine the height of the Schottky barrier. (c) Sketch the energy-band diagram with an applied reverse-biased voltage of $V_R = 3\text{V}$. (d) Sketch the energy-band diagram with applied forward-bias voltage of $V_a = 0.25\text{V}$.

9.1 The Schottky barrier diode

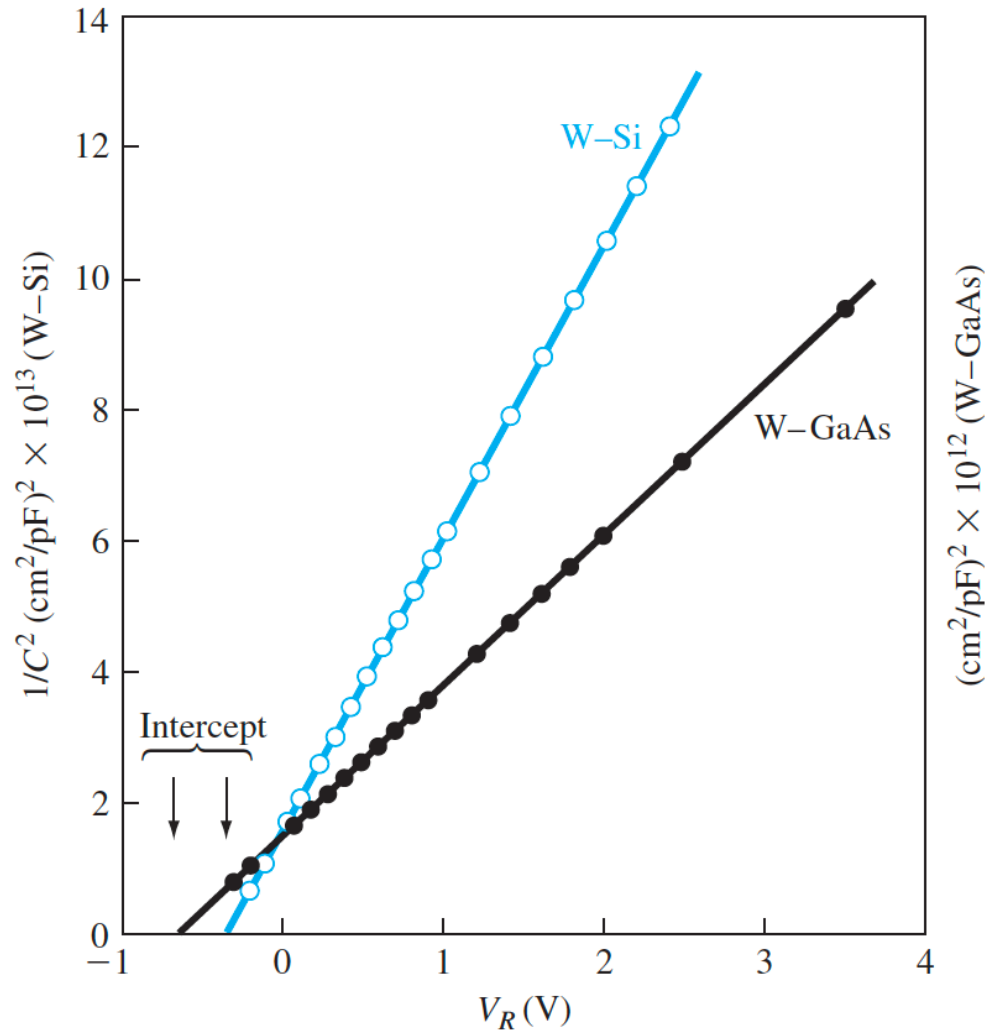
9.1 The Schottky barrier diode

Ideal junction properties (capacitance)



9.1 The Schottky barrier diode

Ideal junction properties



9.1 The Schottky barrier diode

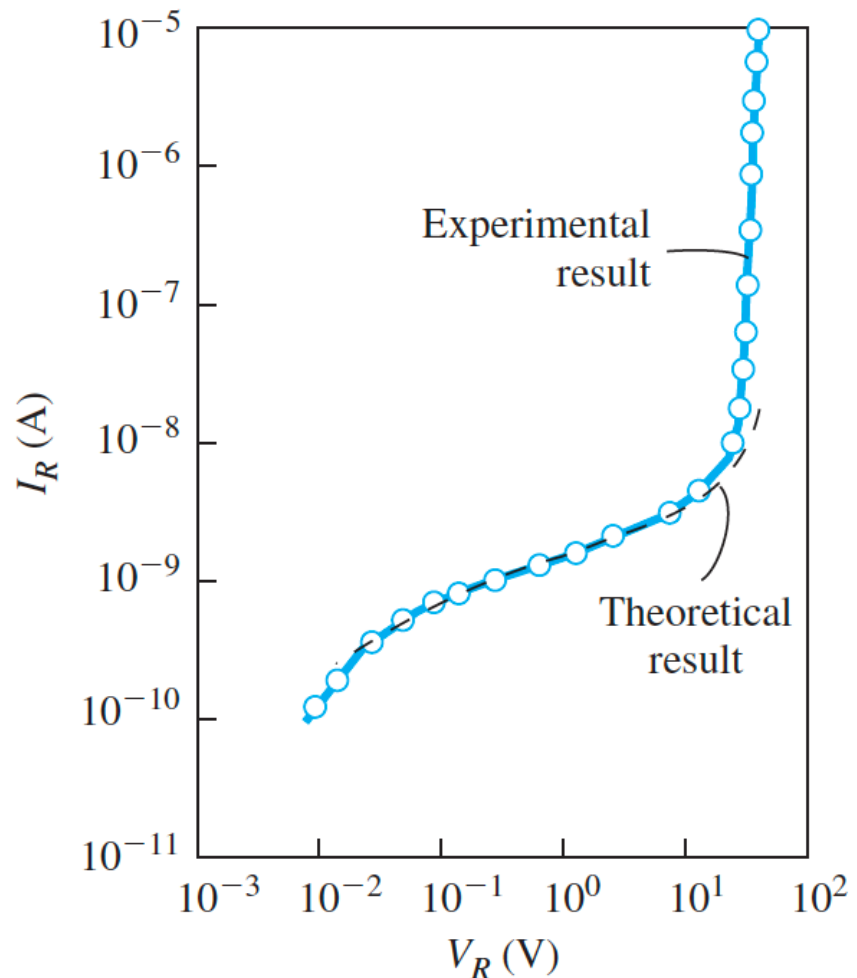
Current-voltage relationship

$$J = J_{sT} \left[\exp \left(\frac{eV_a}{kT} \right) - 1 \right]$$

$$J_{sT} = A^* T^2 \exp \left(\frac{-e\phi_{Bn}}{kT} \right)$$

$$A^* \equiv \frac{4\pi e m_n^* k^2}{h^3}$$

Richardson constant



$$J_{sT} = A^* T^2 \exp \left(\frac{-e\phi_{B0}}{kT} \right) \exp \left(\frac{e\Delta\phi}{kT} \right)$$

9.1 The Schottky barrier diode

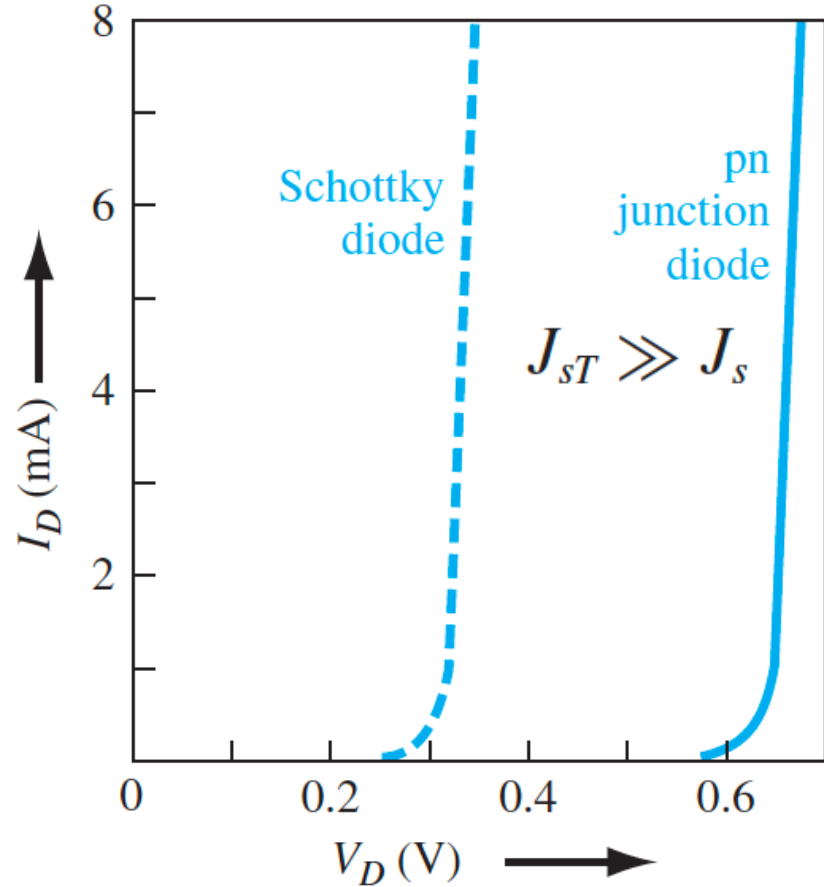
Compare Schottky diode and PN junction

$$J = J_{sT} \left[\exp \left(\frac{eV_a}{kT} \right) - 1 \right]$$

$$J_{sT} = A^* T^2 \exp \left(\frac{-e\phi_{Bn}}{kT} \right)$$

$$A^* \equiv \frac{4\pi e m_n^* k^2}{h^3}$$

Richardson constant



$$J_s = \frac{eD_n n_{po}}{L_n} + \frac{eD_p p_{no}}{L_p}$$

Check your understanding

Problem example #2

Consider a tungsten barrier on silicon with a measured barrier height of $\phi_{Bn} = 0.67\text{eV}$. The effective Richardson constant is $A^* = 114 \text{ A/K}^2\text{cm}^2$. $T = 300\text{K}$.

Check your understanding

Check your understanding

Problem example #3

Control of the Schottky Barrier Height in Monolayer WS₂ FETs using Molecular Doping

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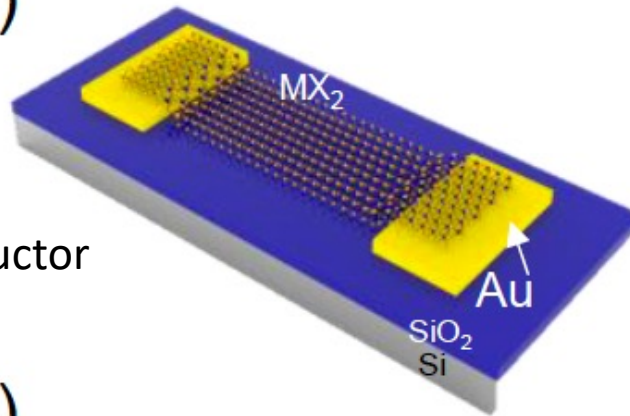
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Check your understanding

Problem example #3

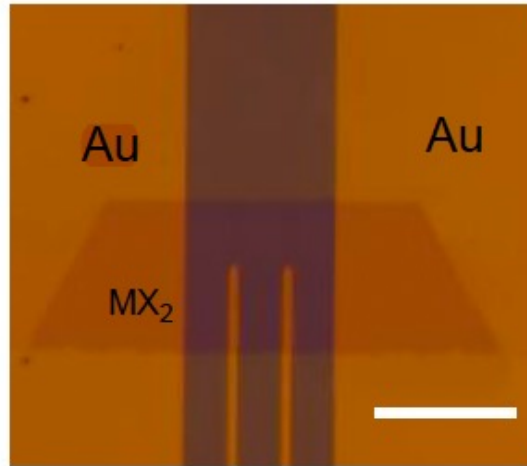
$$I_{sd} = AA_{2D}^* T^{3/2} \exp \left[-\frac{q}{k_B T} \left(\Phi_B - \frac{V_{ds}}{n} \right) \right]$$

(a)



WS₂ atomically thin
monolayer semiconductor

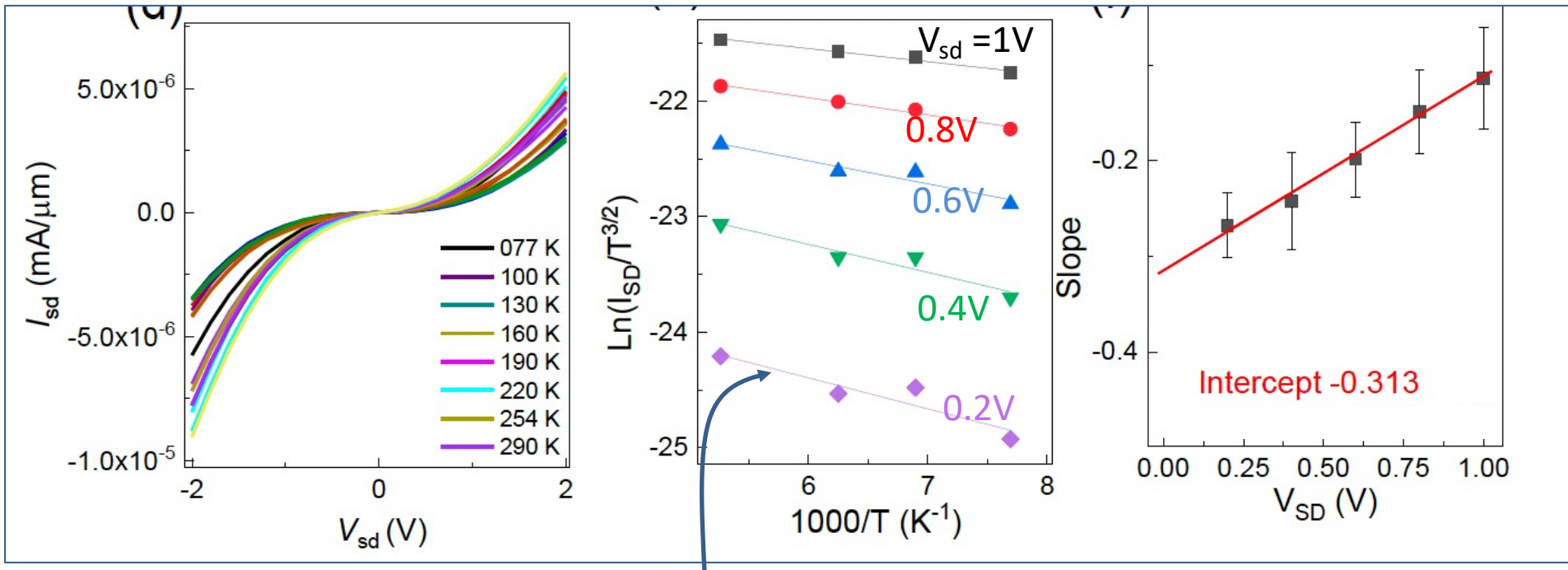
(b)



Check your understanding

Problem example #3

$$I_{sd} = AA_{2D}^* T^{3/2} \exp \left[-\frac{q}{k_B T} \left(\Phi_B - \frac{V_{ds}}{n} \right) \right]$$



Line 1

- 1) Write the analytical expression of Line 1 if we take $1000/T$ as x and $\ln(I_{SD}/T^{3/2})$ as y ?
- 2) Write the expression of Slope in the right figure.
- 3) Find Schottky barrier height Φ_B

Check your understanding

Problem example #3

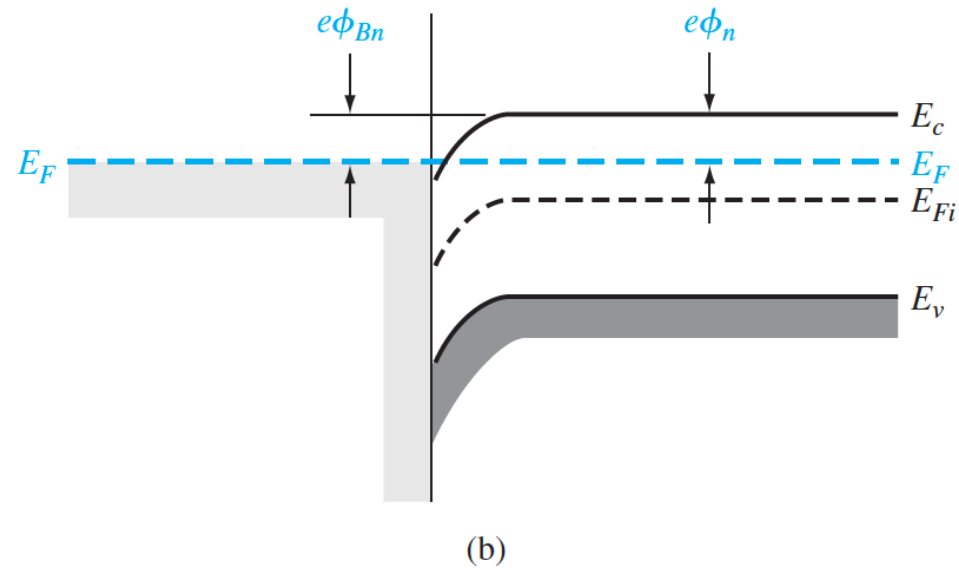
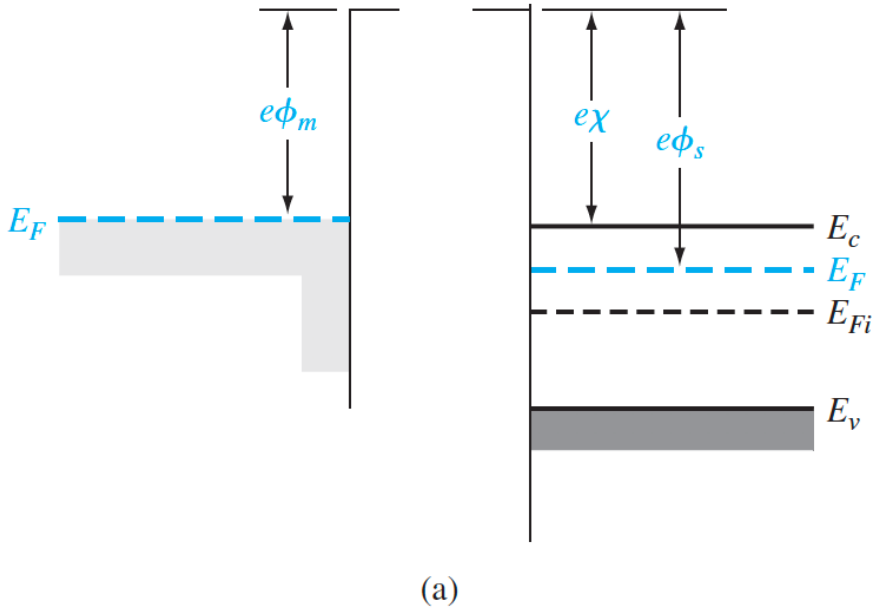
Outline

9.1 The Schottky barrier diode

9.2 Metal-semiconductor Ohmic contacts

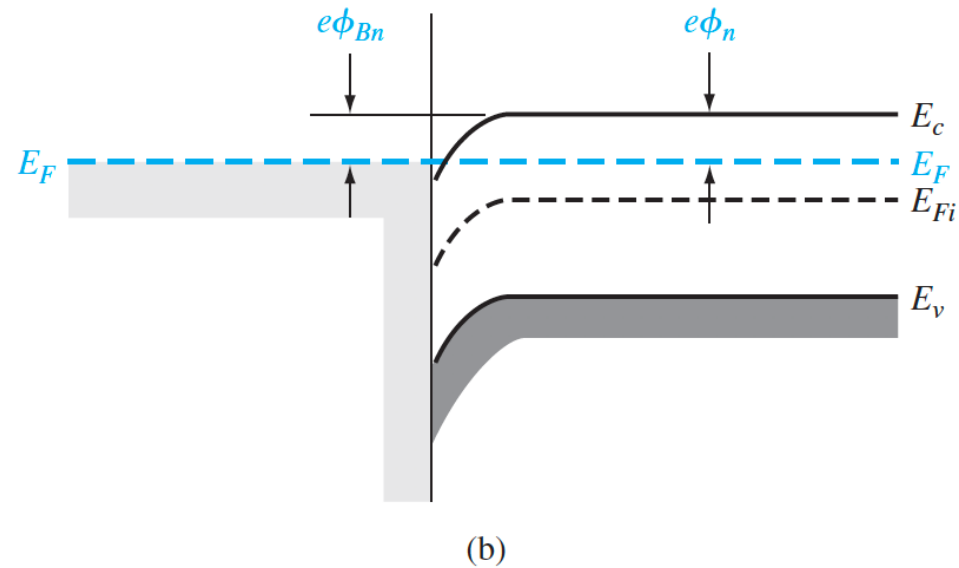
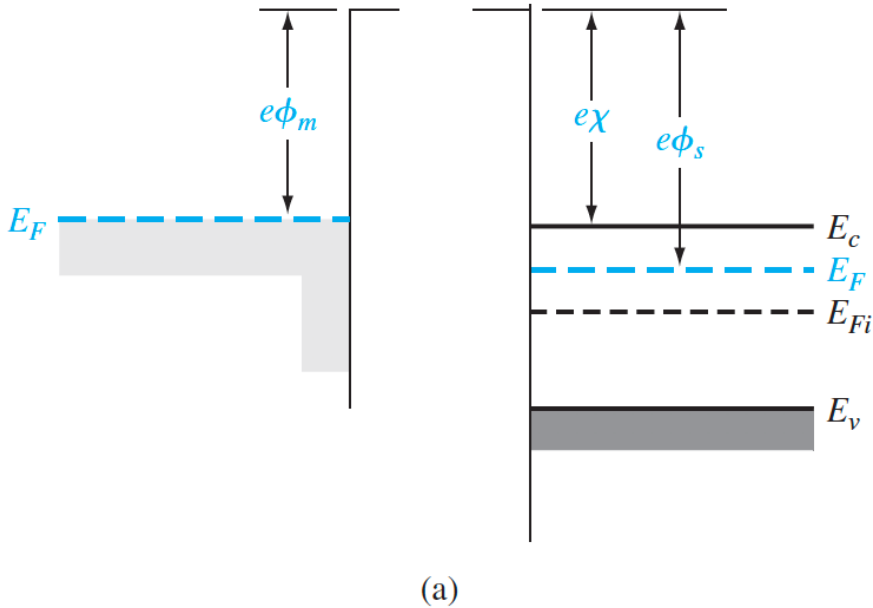
9.2 Metal-semiconductor Ohmic contacts

Ideal Nonrectifying Barrier



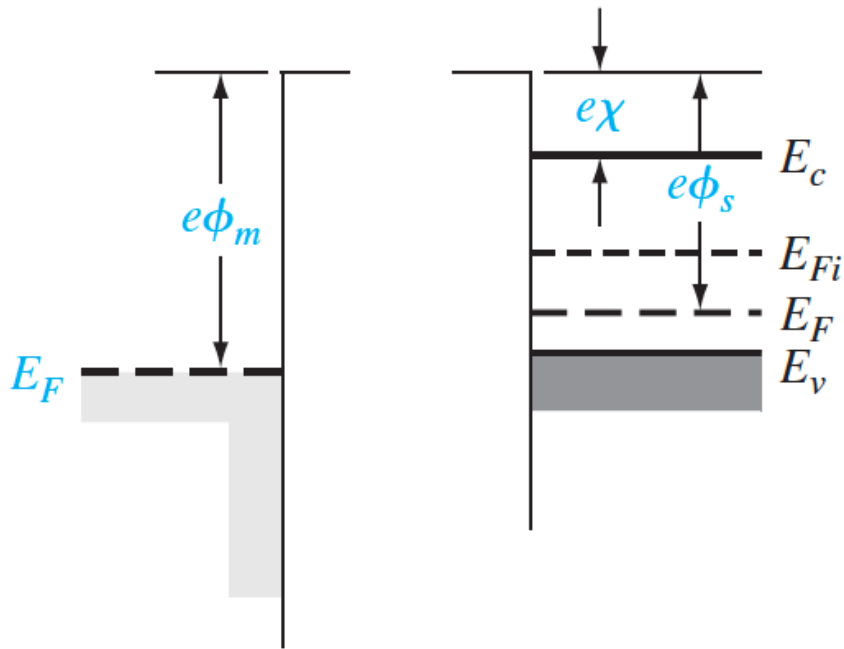
9.2 Metal-semiconductor Ohmic contacts

Ideal Nonrectifying Barrier

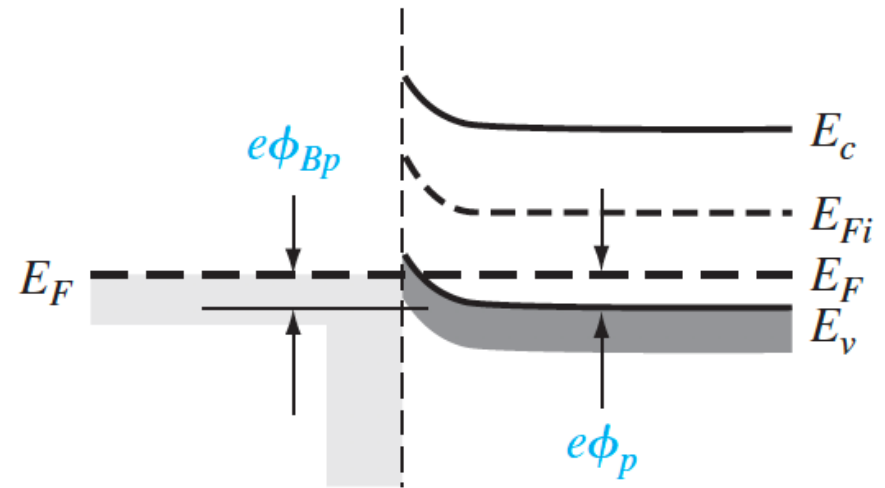


9.2 Metal-semiconductor Ohmic contacts

Ideal Nonrectifying Barrier

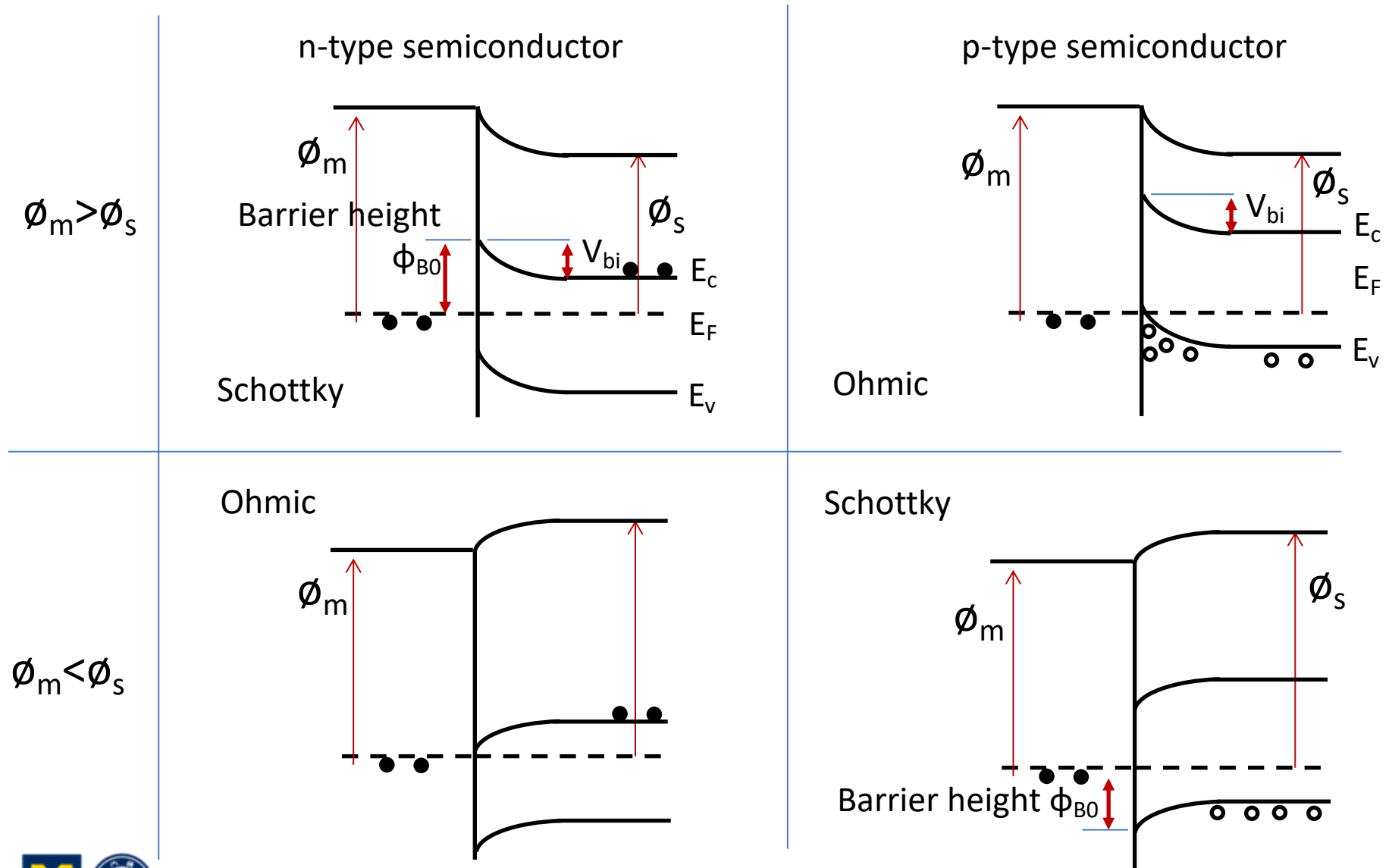


(a)



(b)

9.2 Metal-semiconductor Ohmic contacts



Check your understanding

Problem example #4

For Si, if it is doped with phosphorus at a concentration of 10^{15} cm^{-3} , what metal you can choose from the list for Ohmic contact.

Repeat the question above for p-type Si doping at the concentration of 10^{17} cm^{-3} . Si has an electron affinity of 4.01 eV and a bandgap of 1.12 eV.

Table 9.1 | Work functions of some elements

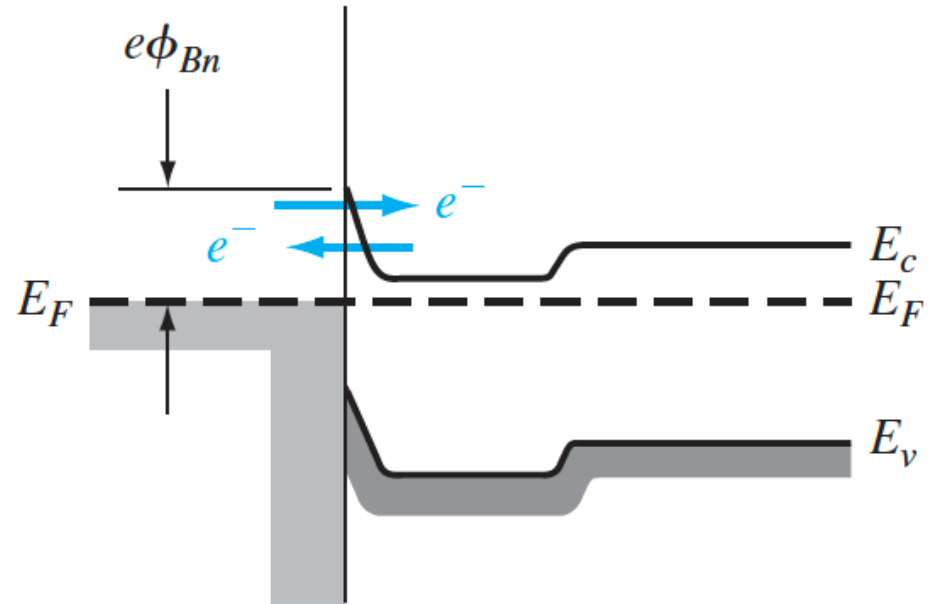
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Check your understanding

Problem example #4

9.2 Metal-semiconductor Ohmic contacts

1. Tunneling Barrier



The tunneling current has the form

$$J_t \propto \exp\left(\frac{-e\phi_{Bn}}{E_{oo}}\right)$$

where

$$E_{oo} = \frac{e\hbar}{2} \sqrt{\frac{N_d}{\epsilon_s m_n^*}}$$

The tunneling current increases exponentially with doping concentration.

9.2 Metal-semiconductor Ohmic contacts

2.Silicide alloy

Nickel silicide, NiSi

Titanium silicide, TiSi₂

