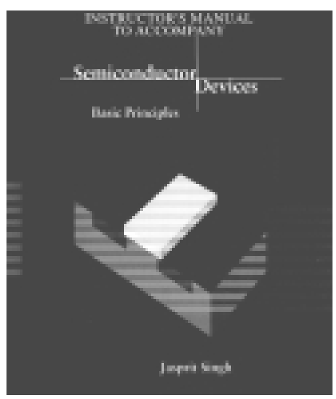
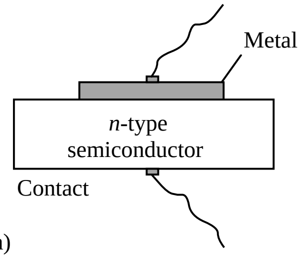
Chapter 7

METAL-SEMICONDUCTOR JUNCTIONS



Metal-semiconductor junctions are a critical component of microelectronics. The following figures provide an overview of Schottky barrier diodes, ohmic contacts, and interconnect delay issues.

BAND PROFILE OF A METAL AND SEMICONDUCTOR JUNCTION



(a)

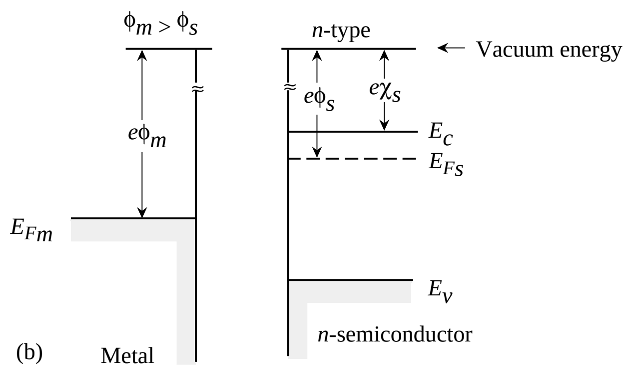
Work functions of some metals

Element	Work function, ϕ_m (volt)
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

Electron affinity of some semiconductors

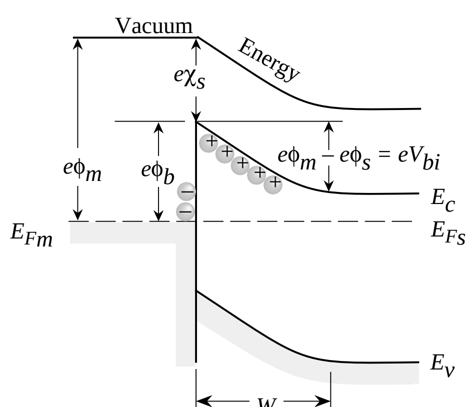
Element	Electron affinity, χ (volt)
Ge, germanium	4.13
Si, silicon	4.01
GaAs, gallium arsenide	4.07
AlAs, aluminum arsenide	3.5

Band profiles of disconnected metal and semiconductor



(b)

Formation of a Schottky junction

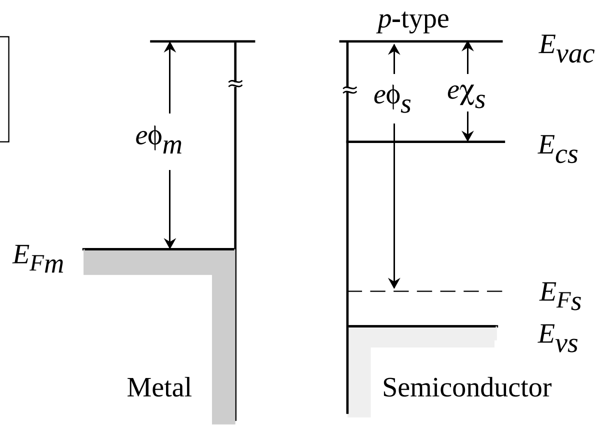


(c)

METAL-SEMICONDUCTOR JUNCTION AT EQUILIBRIUM

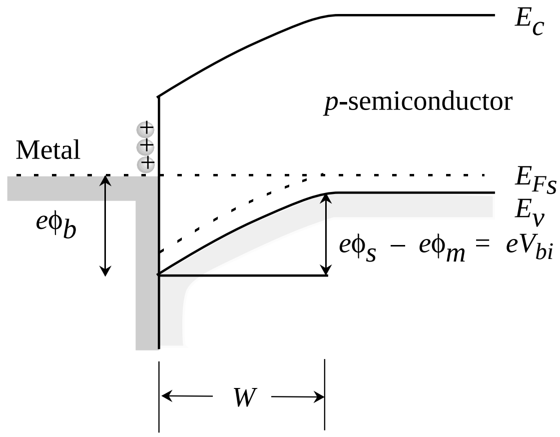
SCHOTTKY JUNCTION ON A *P*-TYPE SEMICONDUCTOR

Metal and semiconductor band profiles



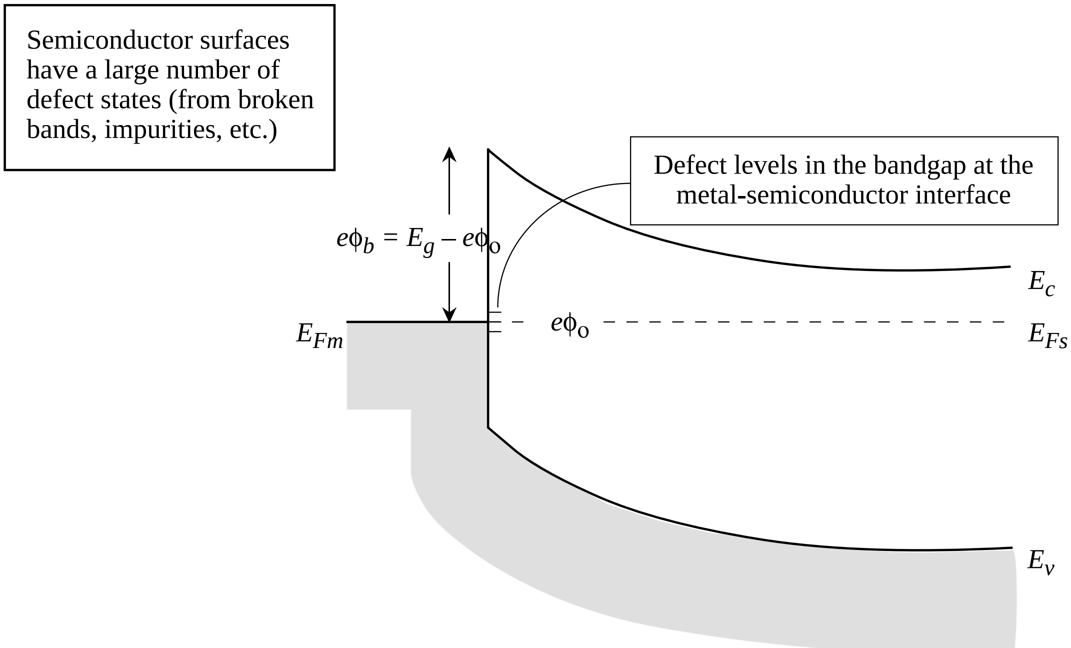
(a)

Formation of a Schottky junction for *p*-type materials



(b)

SCHOTTKY JUNCTION IN REAL SYSTEMS

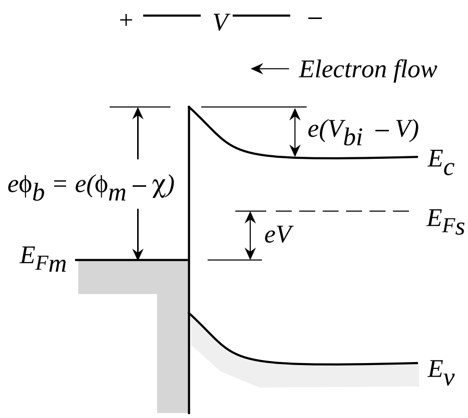


SCHOTTKY METAL	*n* Si	*p* Si	*n* GaAs
Aluminum, Al	0.7	0.8	
Titanium, Ti	0.5	0.61	
Tungsten, W	0.67		
Gold, Au	0.79	0.25	0.9
Silver, Ag			0.88
Platinum, Pt			0.86
PtSi	0.85	0.2	
$NiSi_2$	0.7	0.45	

Schottky barrier heights are determined by the semiconductor and have a rather weak dependence on the metal.

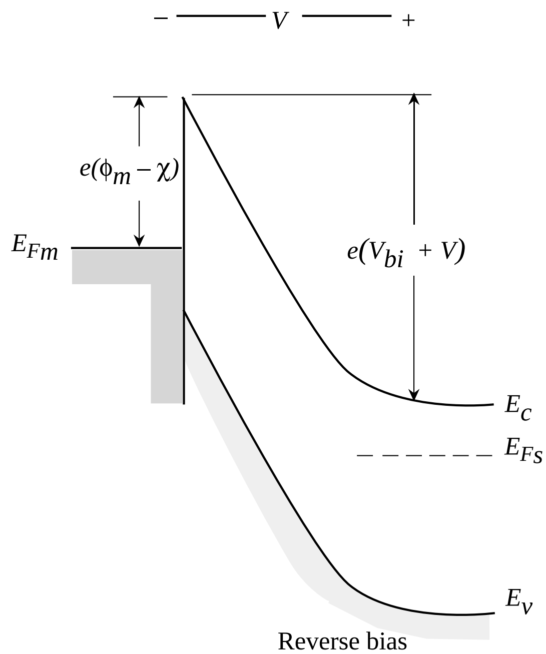
CURRENT FLOW IN A SCHOTTKY DIODE

- Metal-to-semiconductor barrier is unchanged by external bias
- Semiconductor-to-metal barrier is increased (reverse bias) or decreased (forward bias) by an external bias.



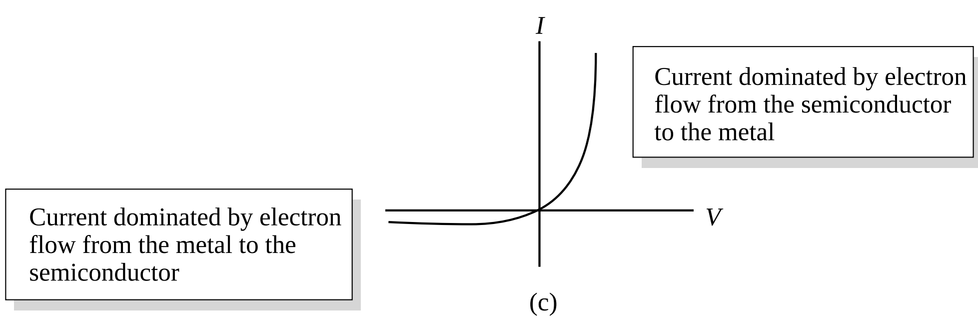
Forward bias

(a)



Reverse bias

(b)



(c)

Diode with area A:

$$I = I_s\left[\exp\left(\frac{eV}{k_BT}\right) - 1\right]$$

$$I_s = A\left(\frac{m^* e k_B^2}{2\pi^2 h^3}\right) T^2 \exp\left(\frac{-e\phi_b}{k_BT}\right)$$

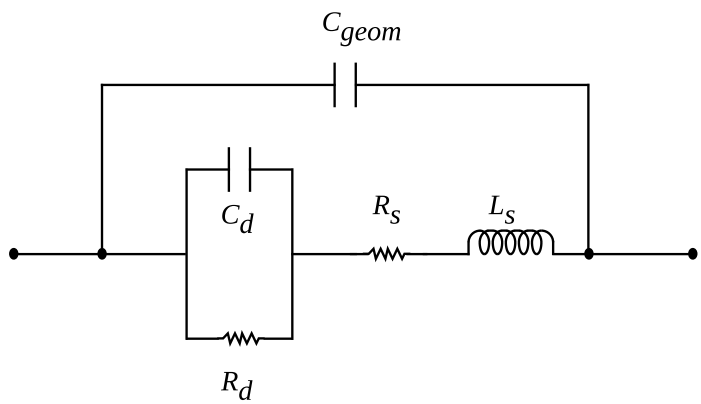
$$= A\,R^*\,T^2 \exp\left(\frac{-e\phi_b}{k_BT}\right)$$

Richardson constant: $R^* = 120\ \frac{m^*}{m_o}\ \text{Acm}^{-2}\text{K}^{-2}$

SMALL SIGNAL MODEL OF A SCHOTTKY DIODE

The Schottky diode is a majority carrier device. Unlike a *p-n* diode, in forward bias no minority carrier injection occurs. Thus there is no diffusion capacitance and the device response can be very fast.

Equivalent circuit of a diode in series with a resistor and inductor



Depletion capacitance:

$$C_d = A\left[\frac{eN_d\varepsilon}{2(V_{bi}-V)}\right]^{1/2}$$

Diode resistance:

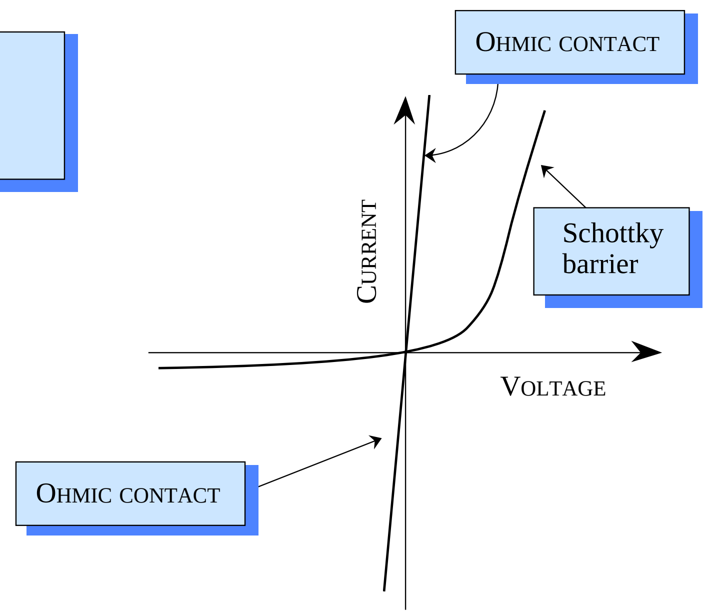
$$R_d = \frac{dV}{dI} = \frac{eI}{k_BT}$$

A comparison between the properties of a p-n and a Schottky diode

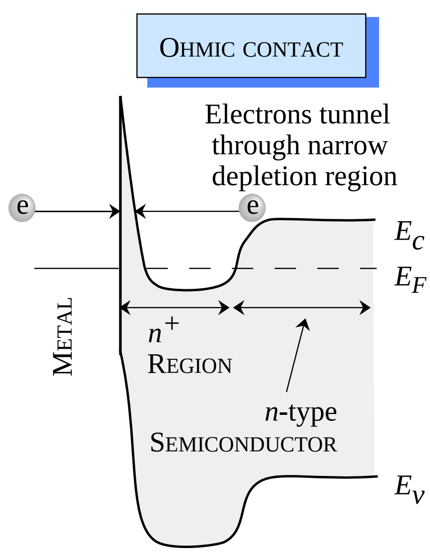
p-n diode	Schottky diode
Reverse current due to minority carriers diffusing to the depletion layer → strong temperature dependence	Reverse current due to majority carriers that overcome the barrier → less temperature dependence
Forward current due to minority carrier injection from *n*- and *p*-sides	Forward current due to majority injection from the semiconductor
Forward bias needed to make the device conducting (the cut-in voltage) is large	The cut-in voltage is quite small
Switching speed controlled by recombination (elimination) of minority injected carriers	Switching speed controlled by thermalization of "hot" injected electrons across the barrier ~ few picoseconds
Ideality factor in I-V characteristics ~ 1.2-2.0 due to recombination in depletion region	Essentially no recombination in depletion region → ideality factor ~ 1.0

METAL-SEMICONDUCTOR JUNCTIONS: OHMIC CONTACT AND SCHOTTKY JUNCTION

Current is linear in an ohmic contact ⟶ resistance is very small

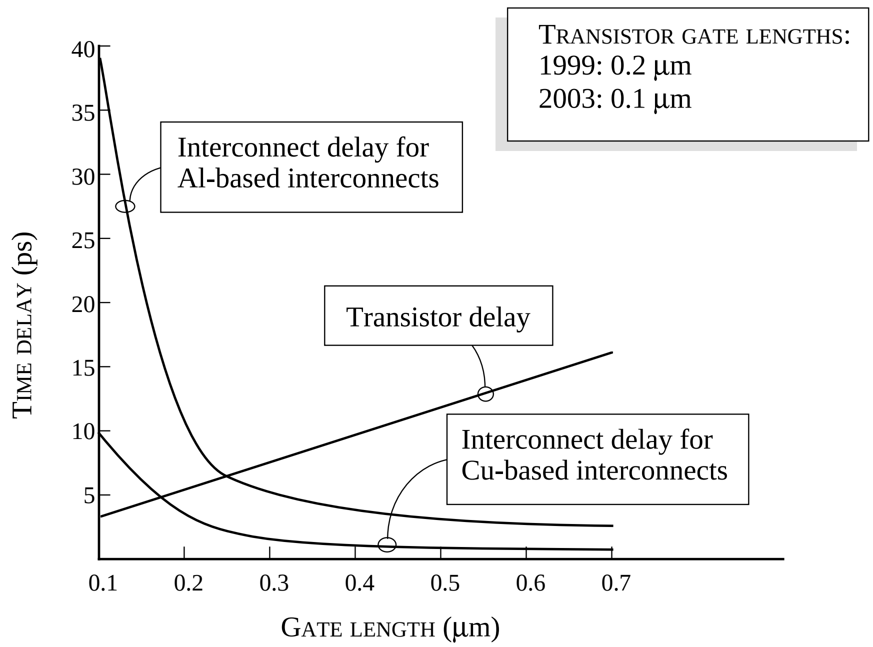


Heavy doping in the semiconductor causes a very thin depletion width and electrons can tunnel across this barrier leading to ohmic behavior



INTERCONNECT DELAY: GOING FROM AL TO CU

As device dimensions shrink interconnect cross-sections also must shrink. This increases the interconnect resistance and the associated time delay for signal propagation.



Based on Semiconductor Industry Associates Roadmap.