ECE-305: Spring 2018
Metal-Semiconductor Junctions

Pierret, *Semiconductor Device Fundamentals* (SDF)
Chapter 14 (pp. 477-487)

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outline

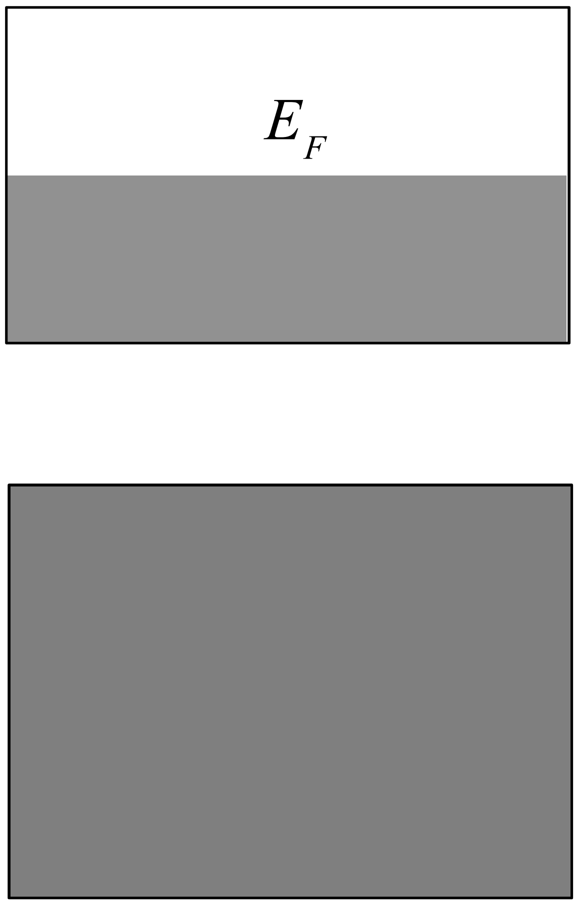
1) Equilibrium band-diagrams and Vbi
2) Band diagram under bias

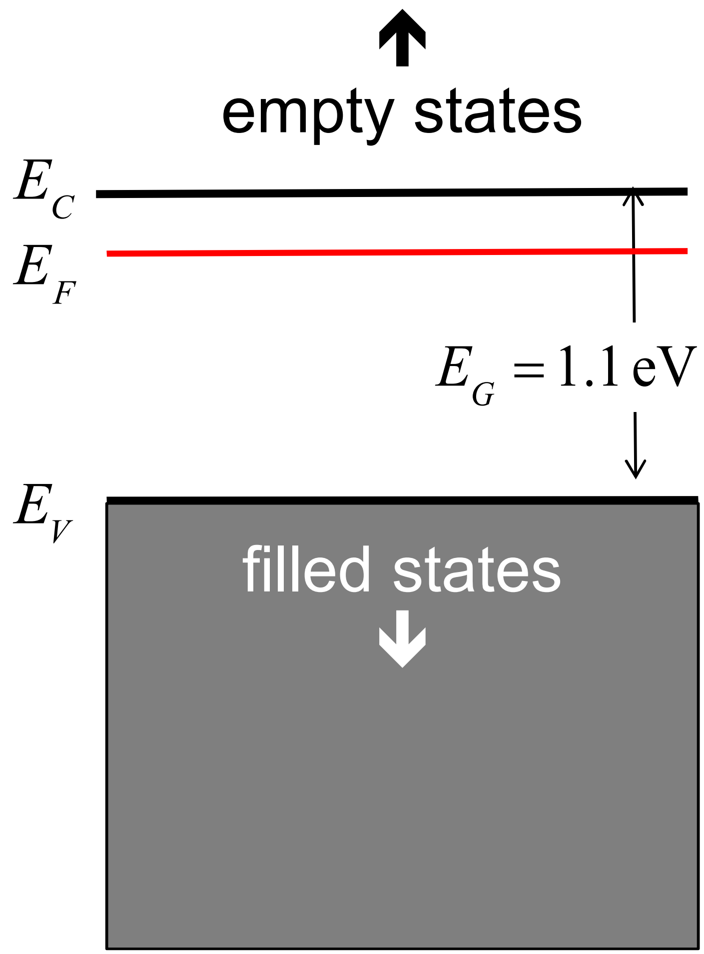
Topic Map

	Equilibrium	**DC**	Small signal	Large Signal	Circuits
Diode					
Schottky	◆				
BJT/HBT					
MOSFET					

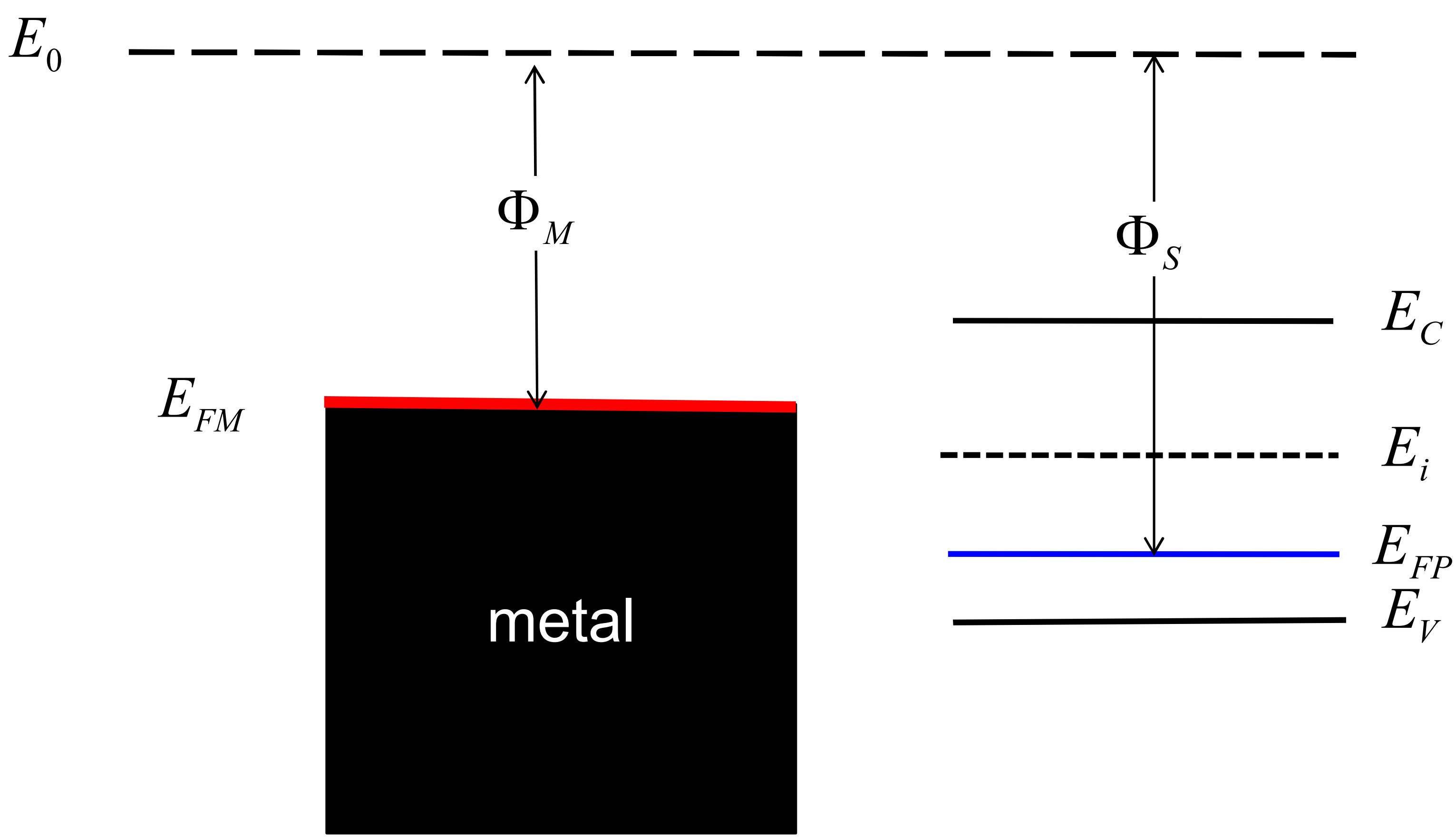
metal energy bands semiconductor energy bands

top most band is half-filled

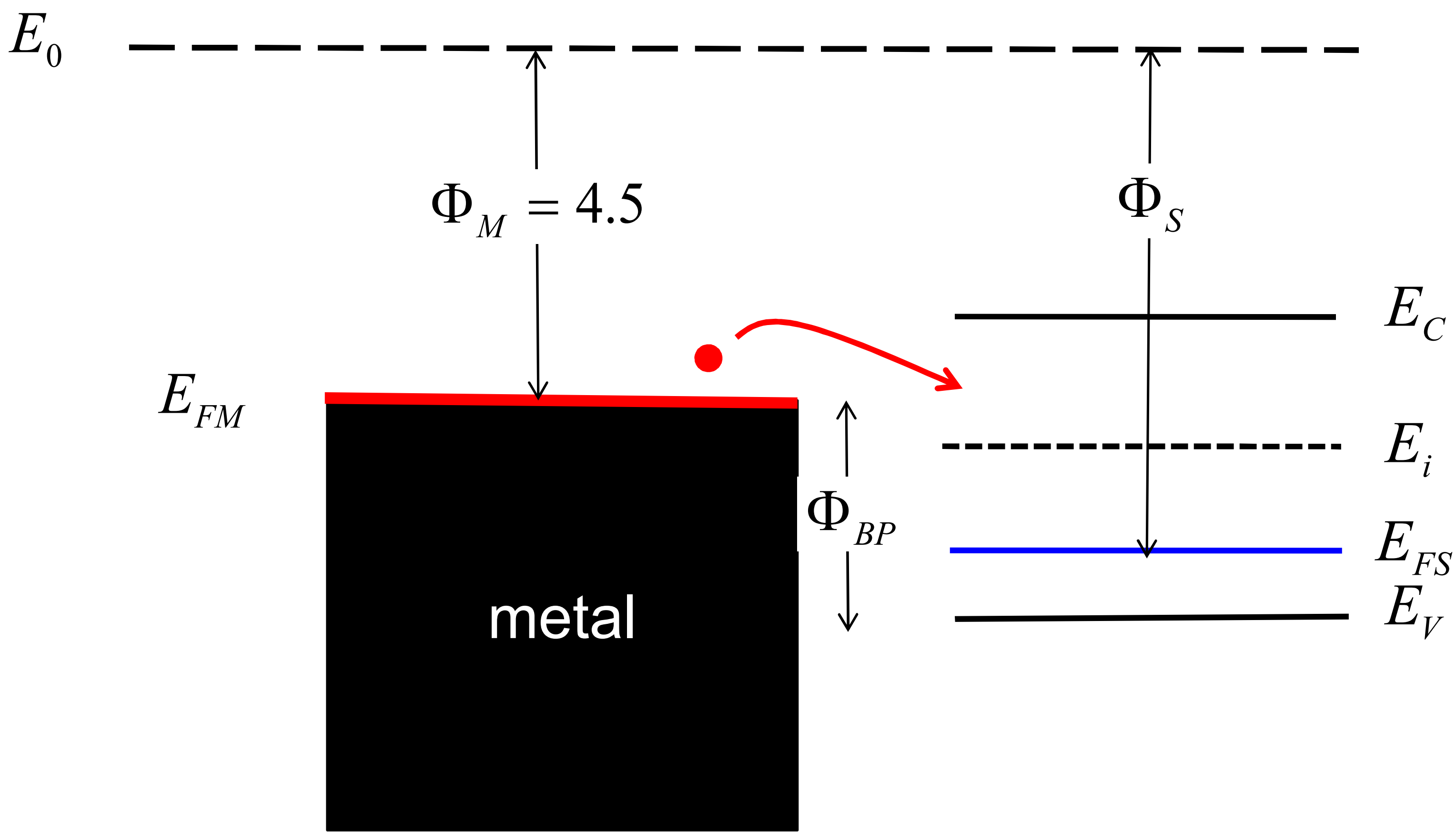




metal: p-type junction

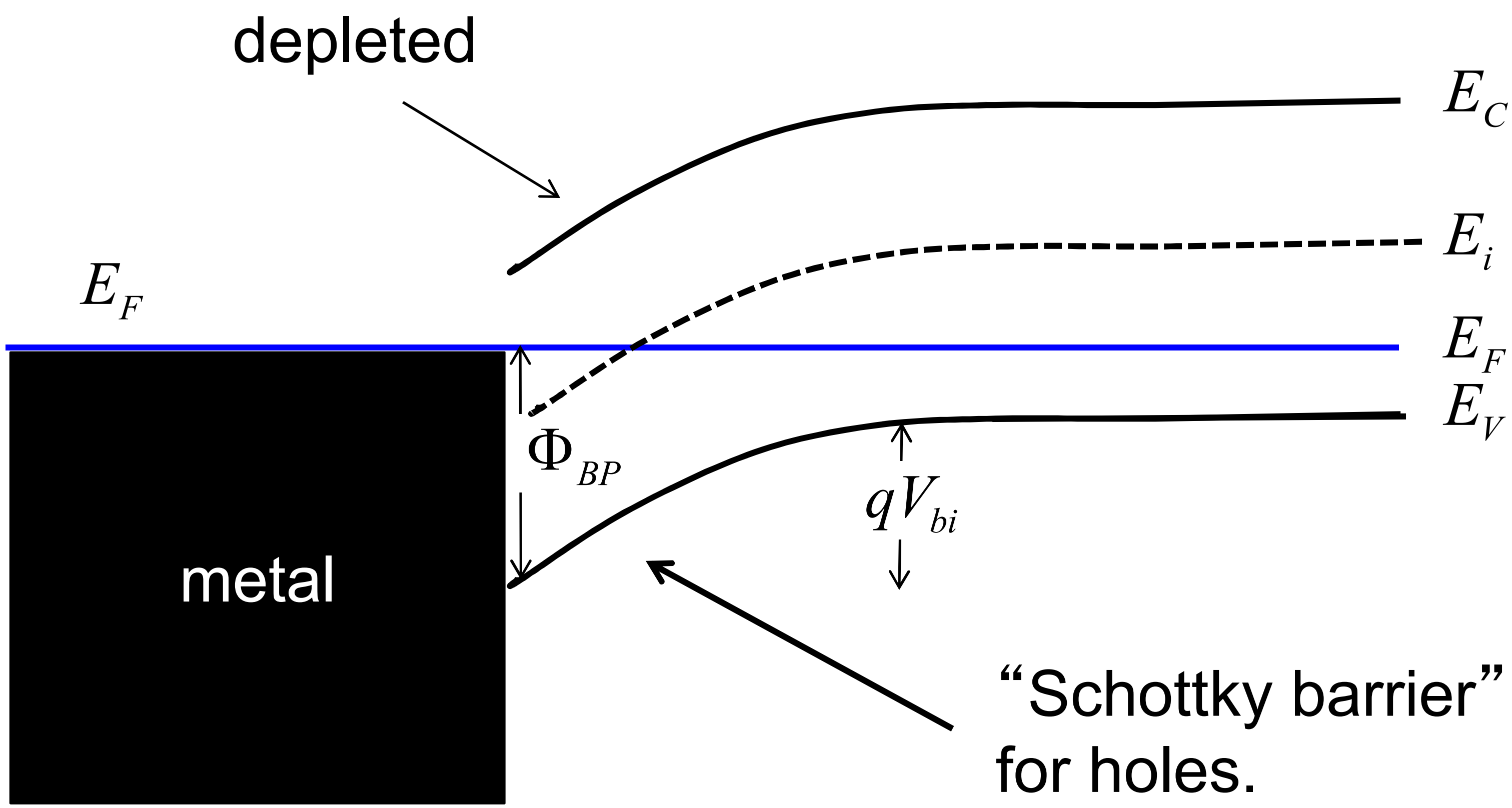


now the band diagram



band diagram

from the band diagram….potential, e-field, p(x), rho(x)



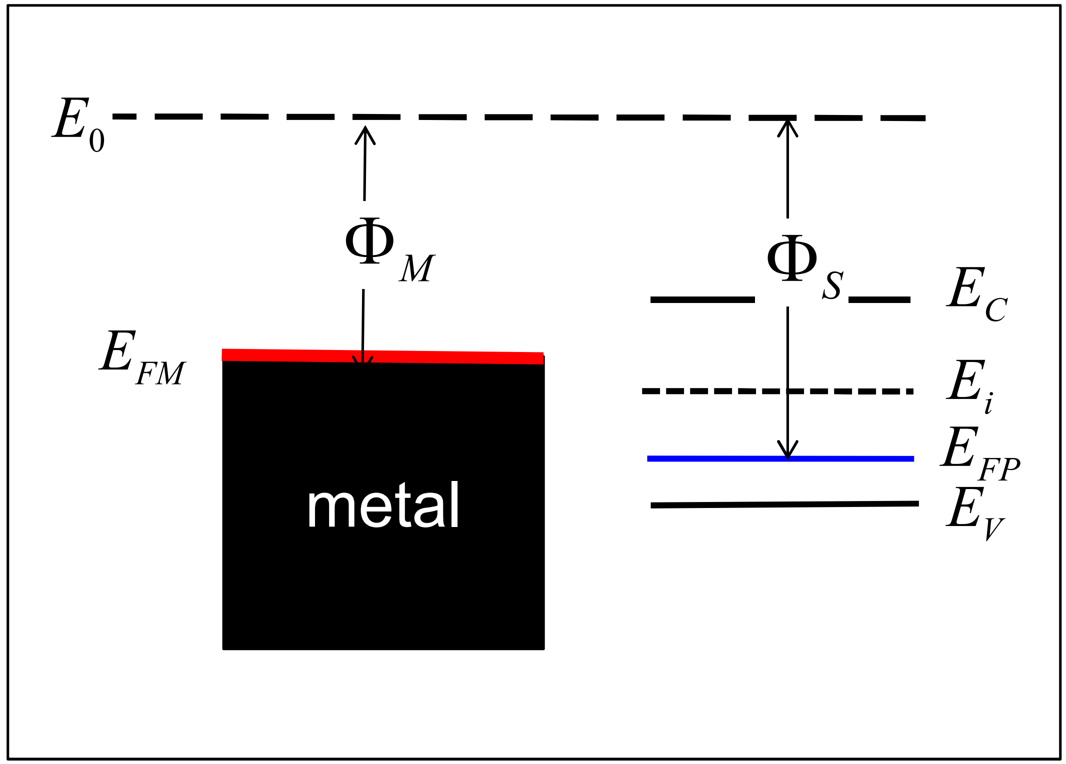
metal: p-type junction

What is the built-in voltage of a MS junction?

$$qV_{bi} = E_{FM} - E_{FS}$$

$$qV_{bi} = (E_0 - \Phi_M) - (E_0 - \Phi_S)$$

$$qV_{bi} = (\Phi_S - \Phi_M)$$



Φ_M is a known material parameter

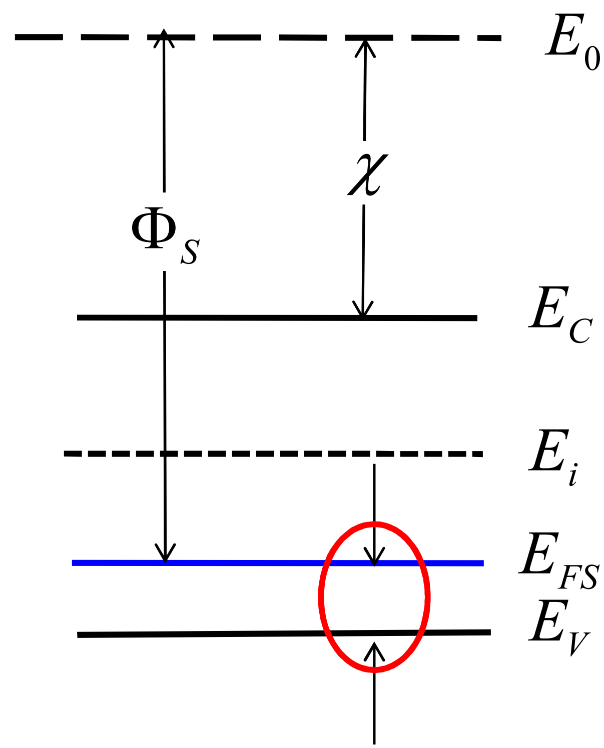
Semiconductor workfunction

Electron affinity, χ, and bandgap are known material parameters.

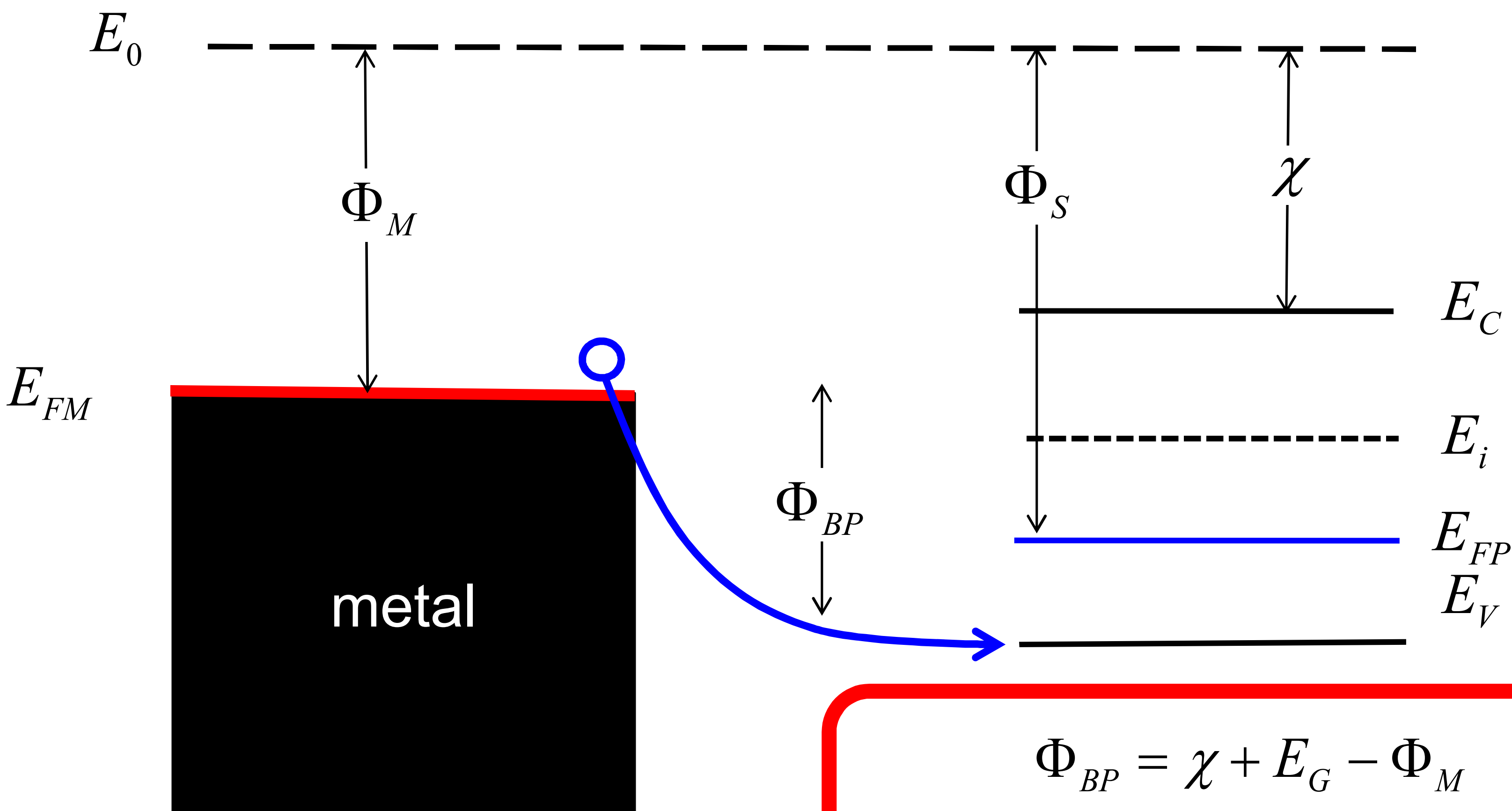
$$\Phi_S = \chi + E_G - \left(E_{FS} - E_V\right)\Big|_{bulk}$$

$$p_0 = N_A = N_V e^{(E_V - E_{FS})/k_B T}$$

$$\left(E_{FS} - E_V\right) = k_B T \ln\left(\frac{N_A}{N_V}\right)$$



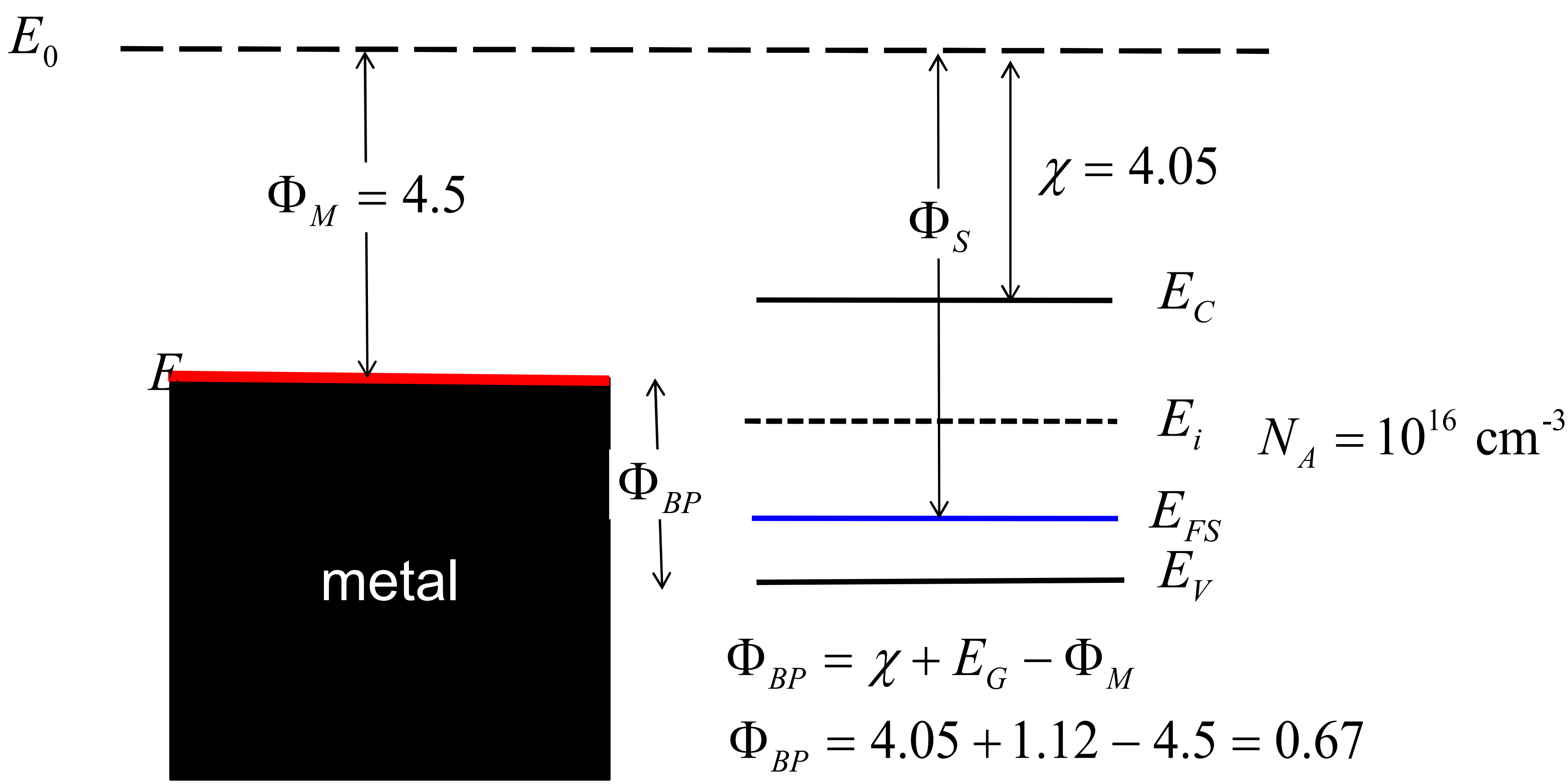
"Schottky barrier height"



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

a known material parameter

Vbi example for silicon



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

$$\Phi_{BP} = 4.05 + 1.12 - 4.5 = 0.67$$

$$V_{bi} = \frac{\Phi_{BP} - \left(E_{FS} - E_V\right)\big|_{FB}}{q}$$

Vbi example for silicon

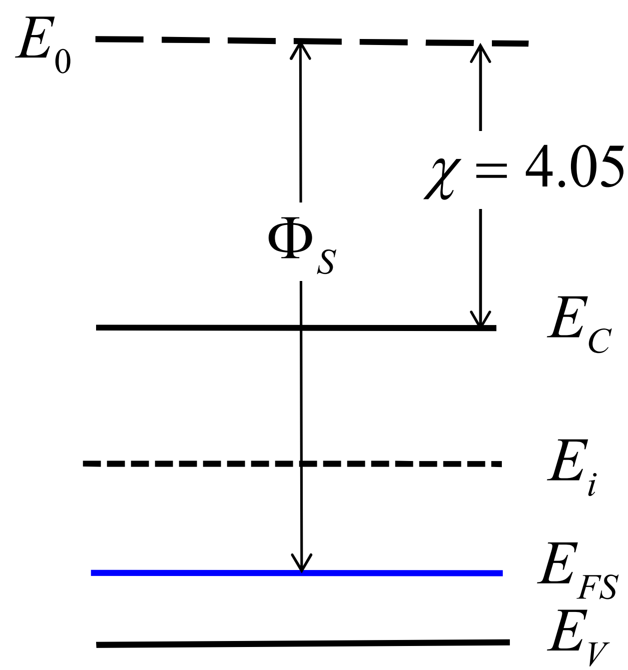
$$N_A = 10^{16} \text{ cm}^{-3}$$

$$p_0 = N_V e^{(E_V - E_{FS})/k_B T} \text{ cm}^{-3}$$

$$E_{FS} - E_V = k_B T \ln\left(\frac{N_V}{N_A}\right)$$

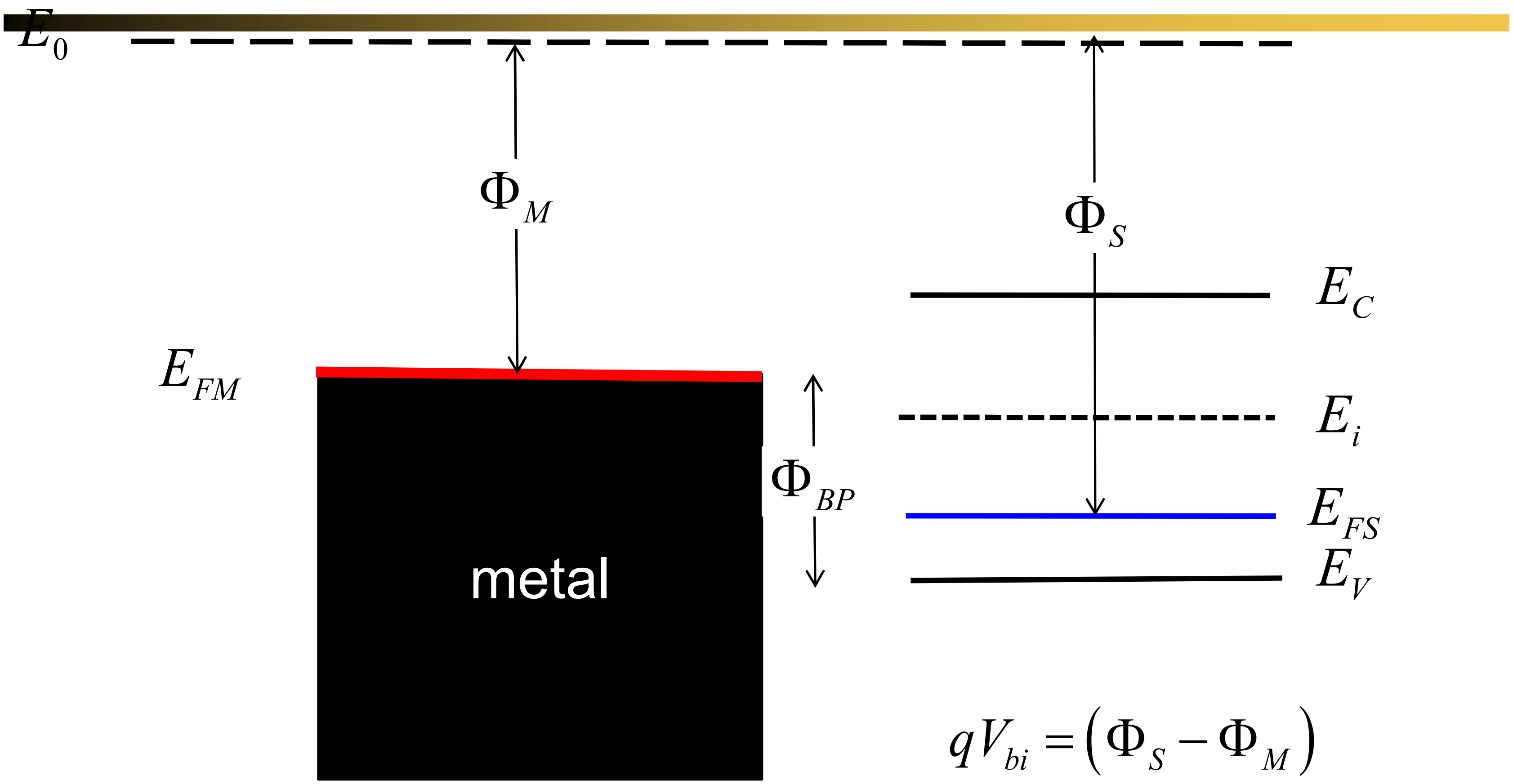
$$N_V = 2\left[\frac{\left(m_p^* k_B T\right)}{2\pi\hbar^2}\right]^{3/2}$$

$$N_V = 1.83 \times 10^{19} \text{ cm}^{-3}$$



$$\frac{E_{FS} - E_V}{q} = 0.026 \ln\left(\frac{1.83 \times 10^{19}}{10^{16}}\right) = 0.2$$

Vbi



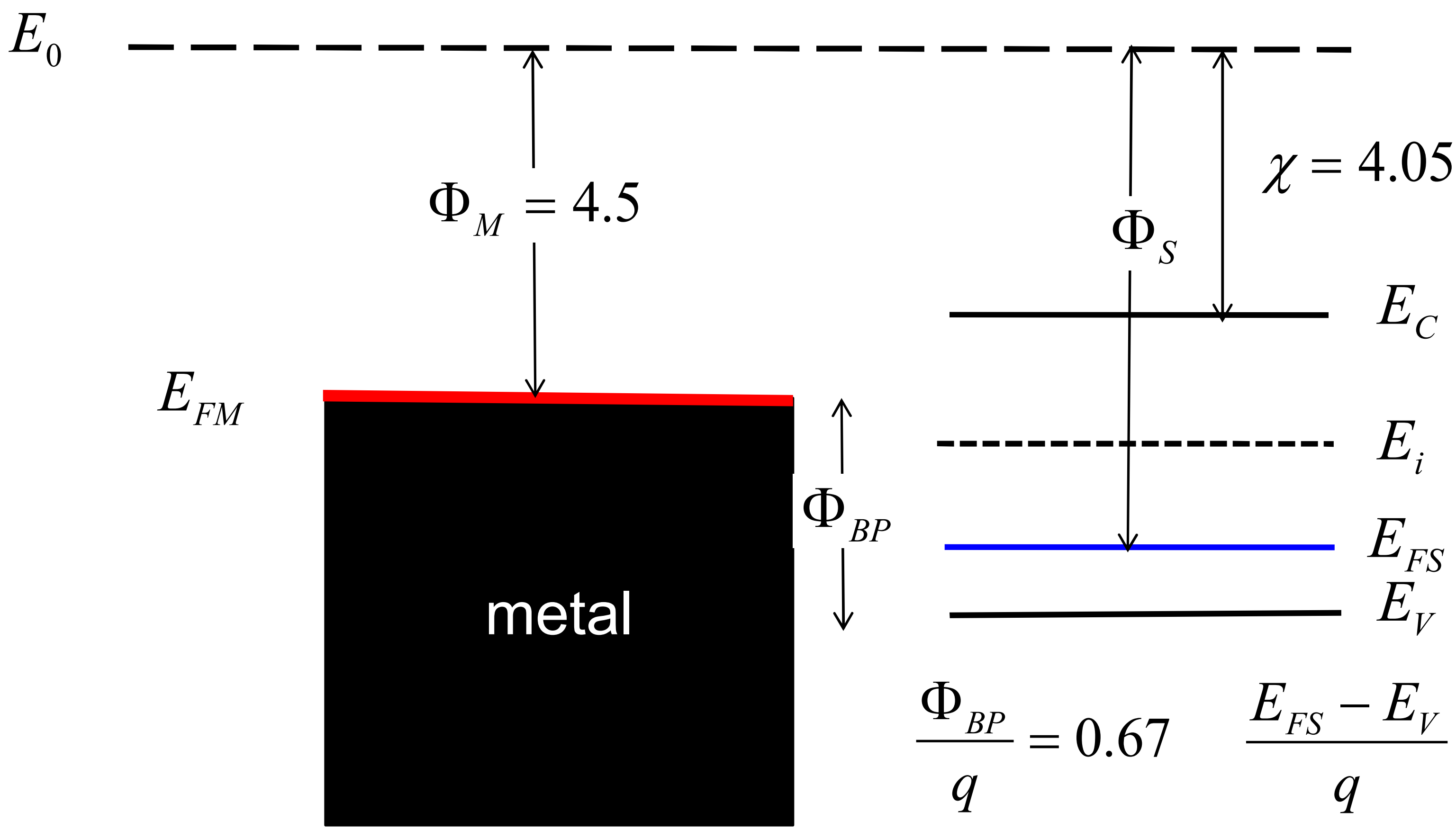
$$qV_{bi} = (\Phi_S - \Phi_M)$$

$$\Phi_S = \chi + E_G - (E_{FS} - E_V)\big|_{bulk}$$

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

$$qV_{bi} = \Phi_{BP} - (E_{FS} - E_V)\big|_{bulk}$$

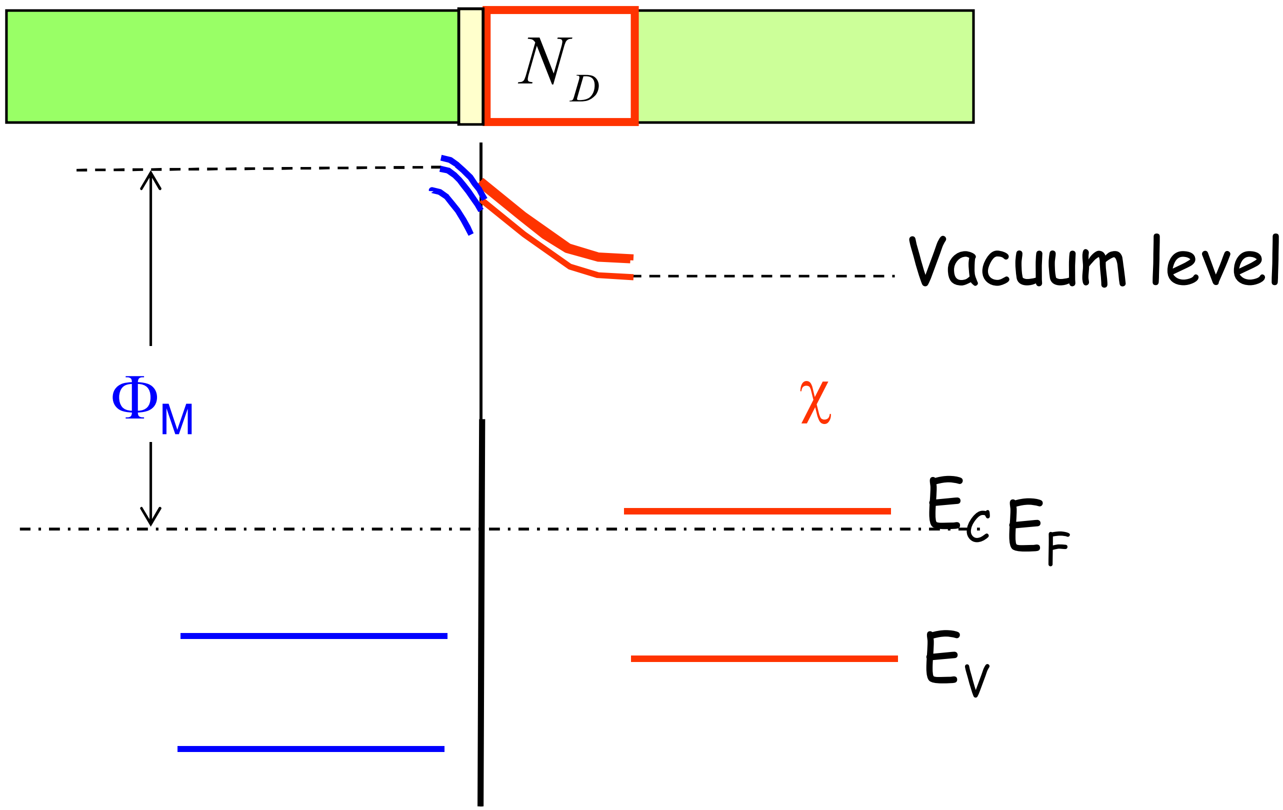
Vbi example



$$\frac{\Phi_{BP}}{q} = 0.67 \qquad \frac{E_{FS} - E_V}{q} = 0.2$$

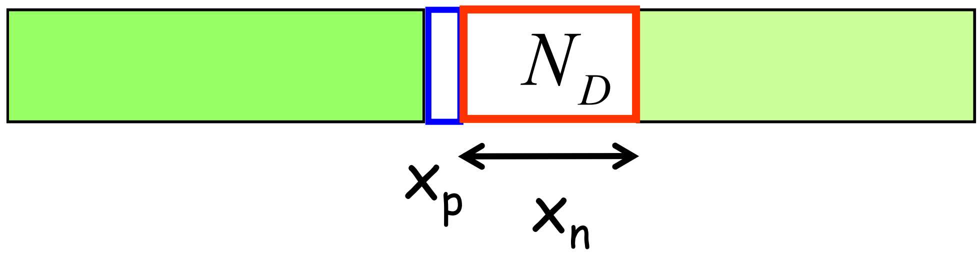
$$V_{bi} = \Phi_{BP} - \left(E_{FS} - E_V\right)\Big|_{FB} = 0.67 - 0.20 = 0.47$$

Band-diagram



Recall: $N_A x_p = N_D x_n$

Depletion Regions



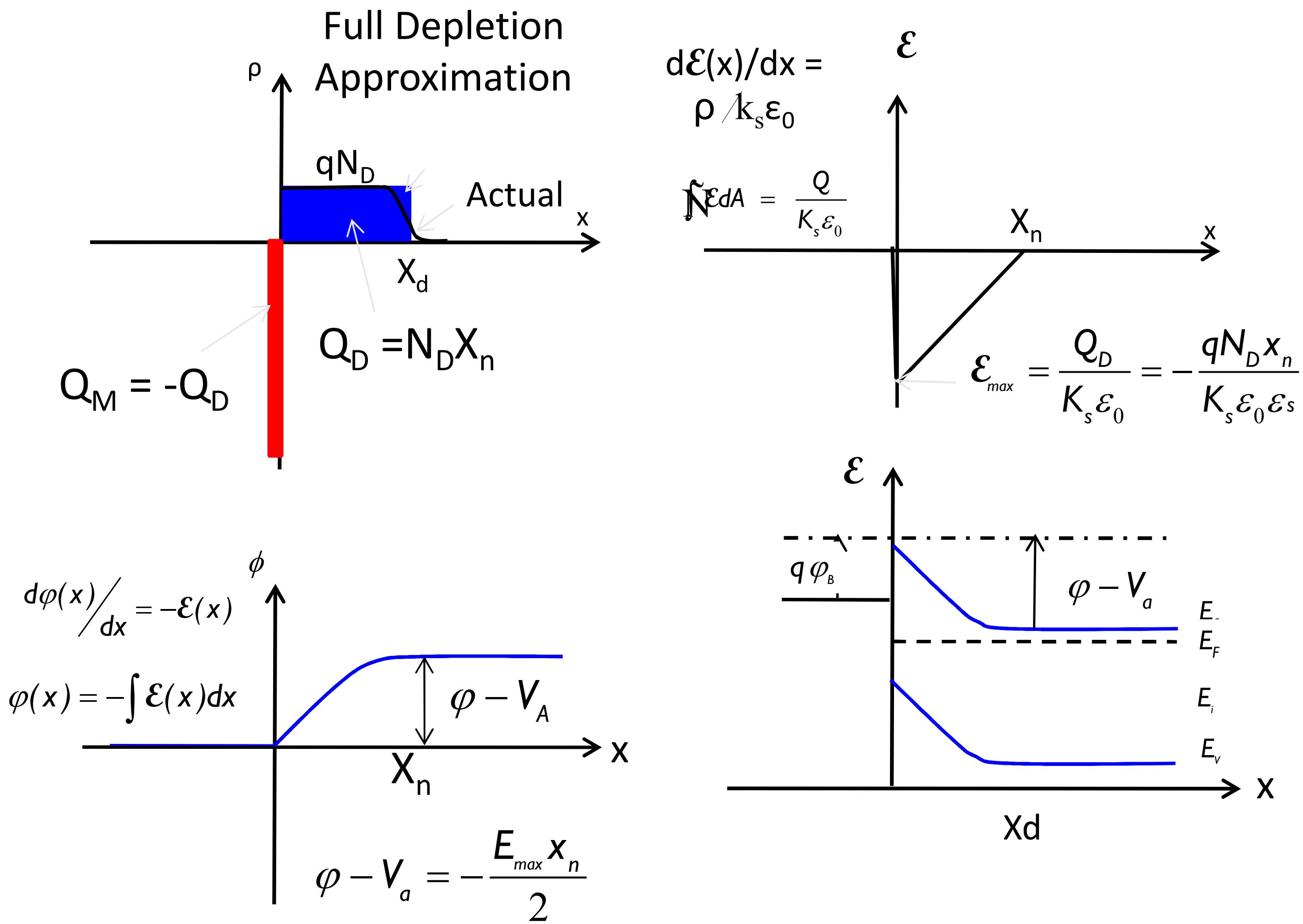
$$N_D x_n = N_M x_p$$

$$qV_{bi} = \frac{qN_D x_n^{\ 2}}{2k_s\varepsilon_0} + \frac{qN_M x_p^{\ 2}}{2k_s\varepsilon_0}$$

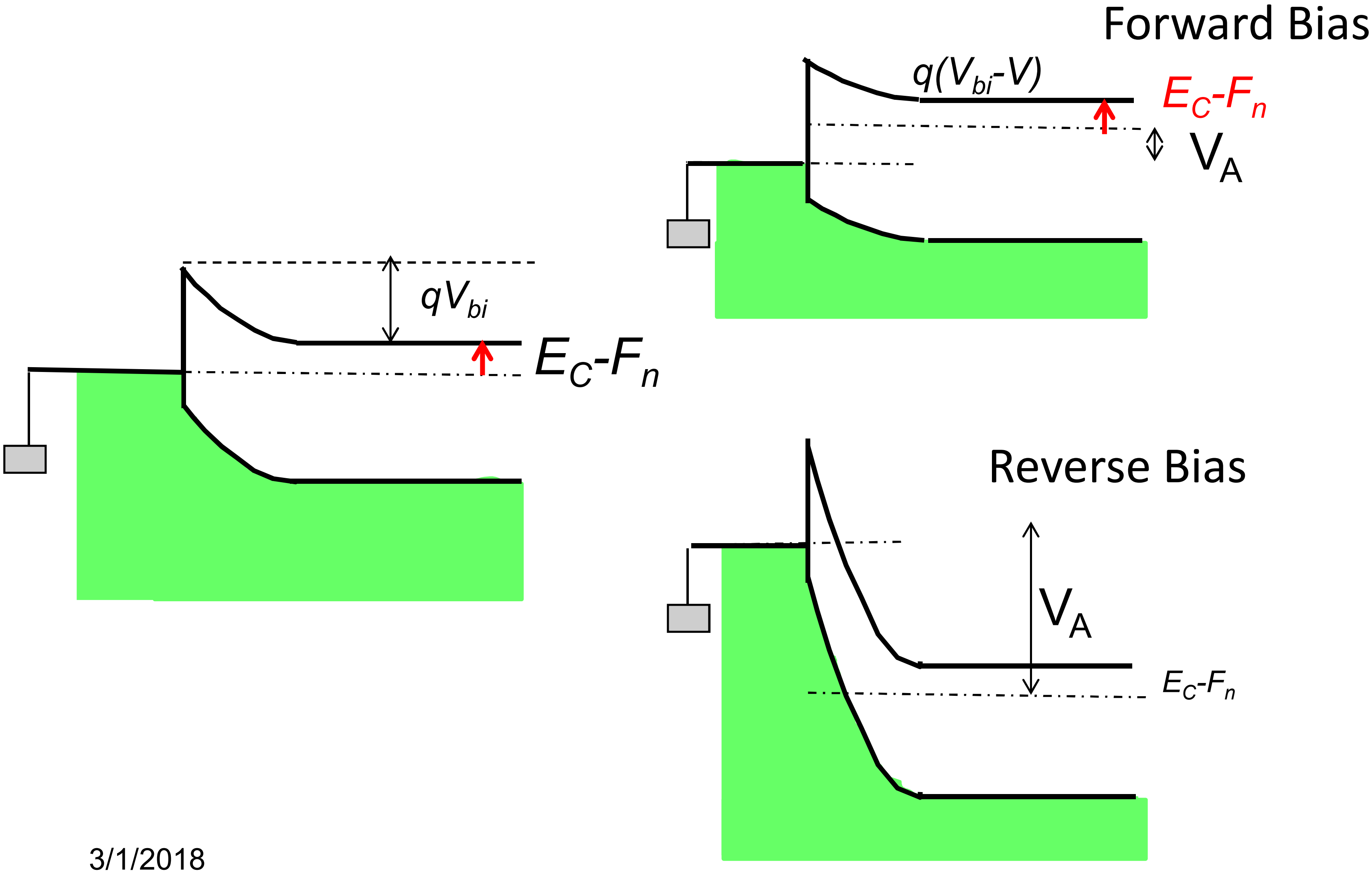
$$x_n = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_M}{N_D\left(N_M+N_D\right)}V_{bi}} \rightarrow \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{1}{N_D}V_{bi}}$$

$$x_p = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_D}{N_M\left(N_M+N_D\right)}V_{bi}} \rightarrow 0$$

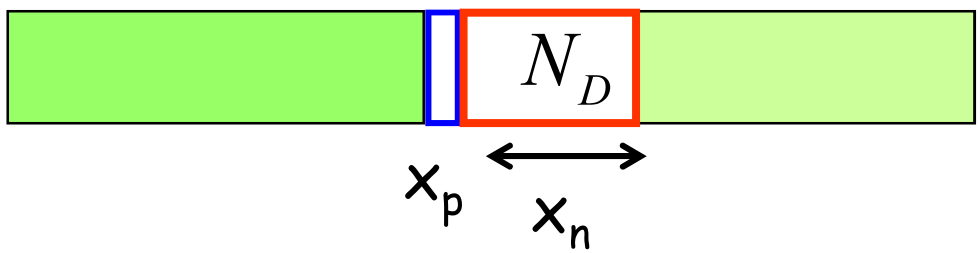
Complete Analytical Solution



Band-diagram with Bias



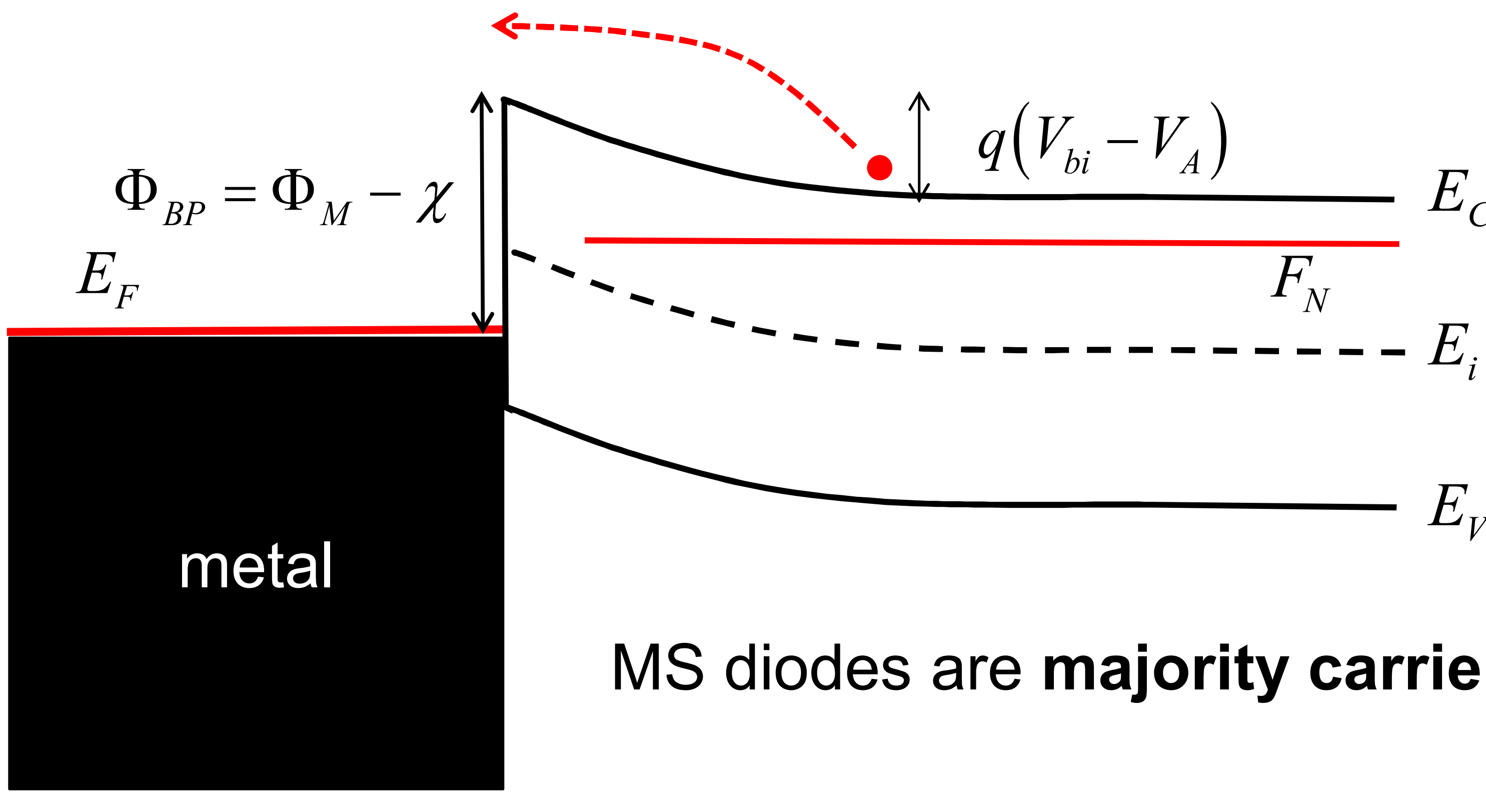
Depletion Regions with Bias



$$x_n = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_M}{N_D\left(N_M + N_D\right)}V_{bi}} \rightarrow \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{1}{N_D}\left(V_{bi} - V_A\right)}$$

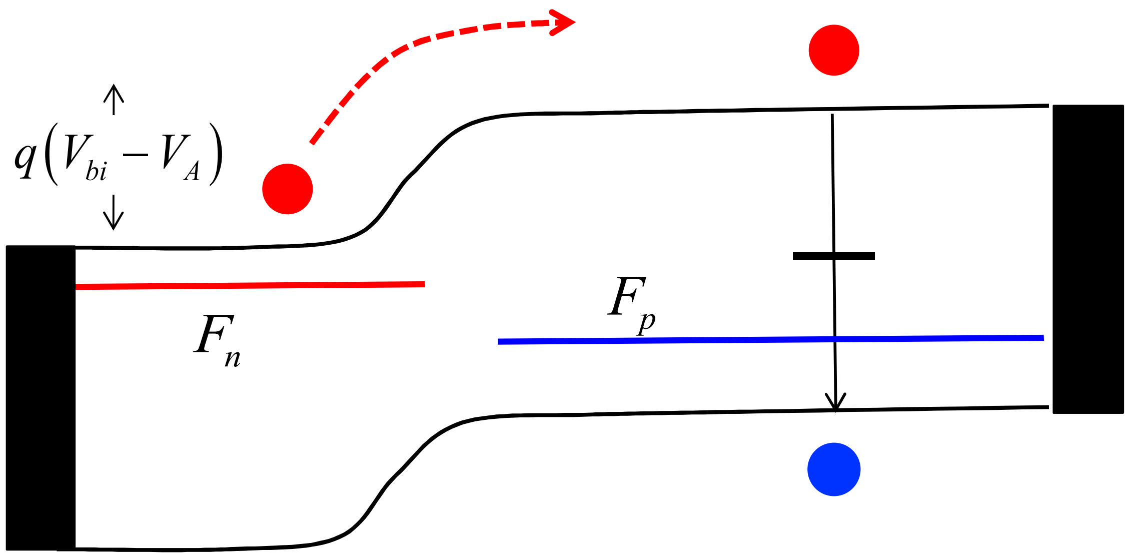
$$x_p = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_D}{N_M\left(N_M + N_D\right)}V_{bi}} \rightarrow 0$$

band diagram



MS diodes are **majority carrier** devices

MS diodes vs. PN junctions

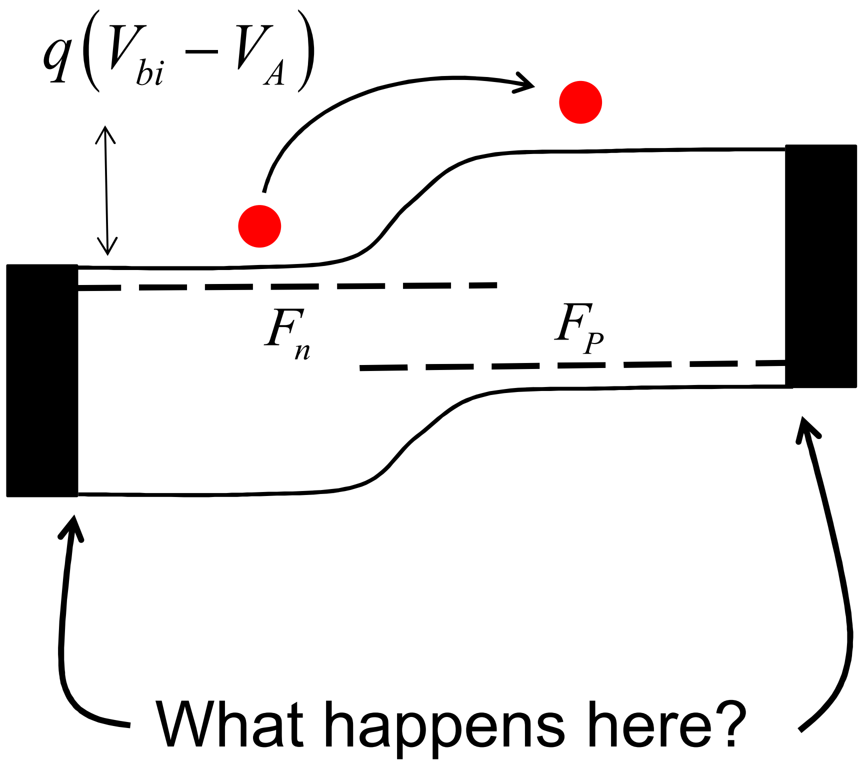


In contrast, NP junctions are **minority carrier** devices

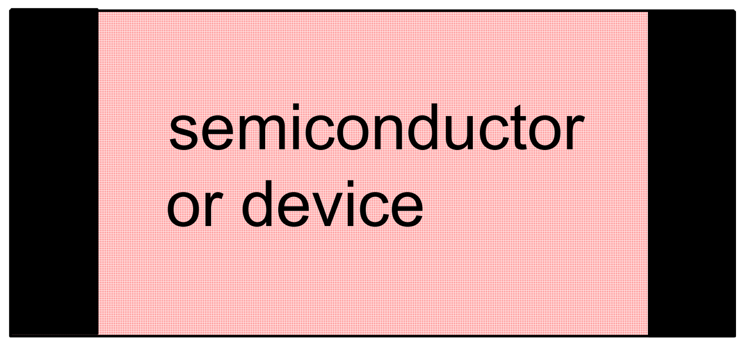
Topic Map

	Equilibrium	**DC**	Small signal	Large Signal	Circuits
Diode					
Schottky		◆			
BJT/HBT					
MOSFET					

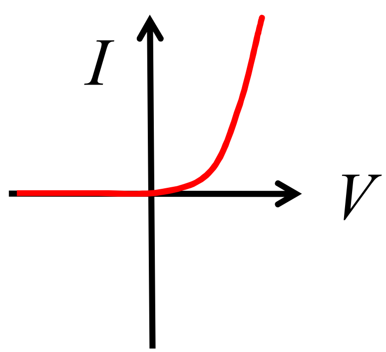
NP junctions

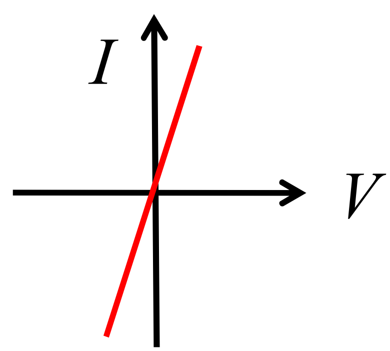


two types of MS diodes



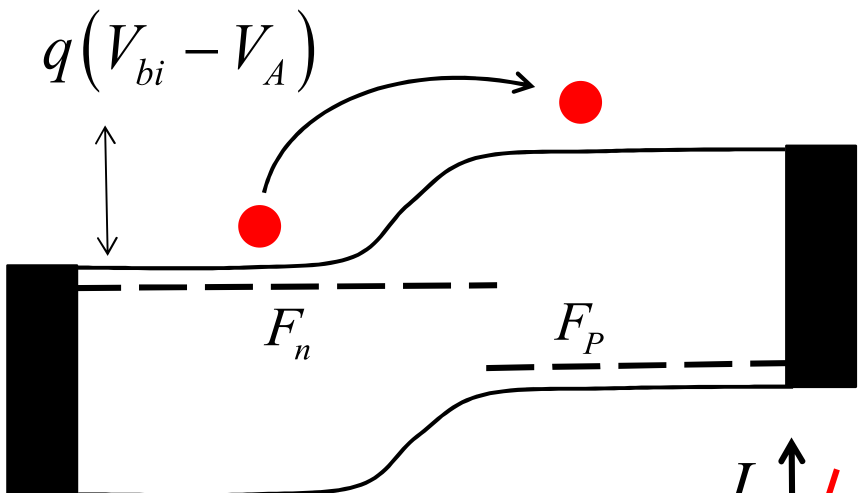
rectifying

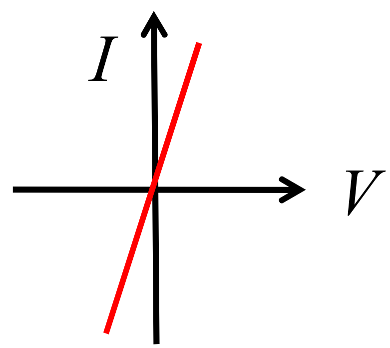




ohmic

MS ohmic contacts

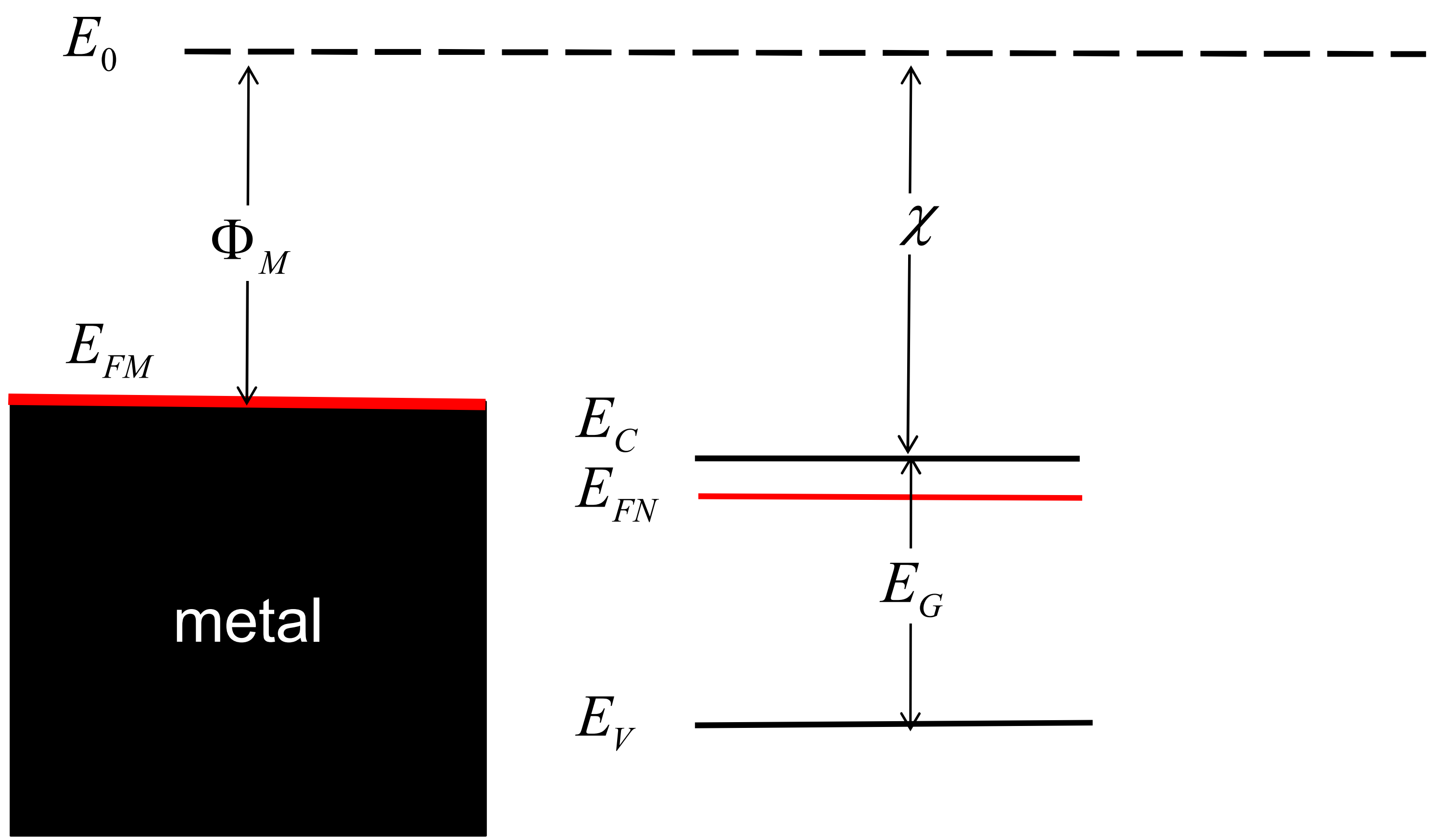




Goal: make the resistance as low as possible.

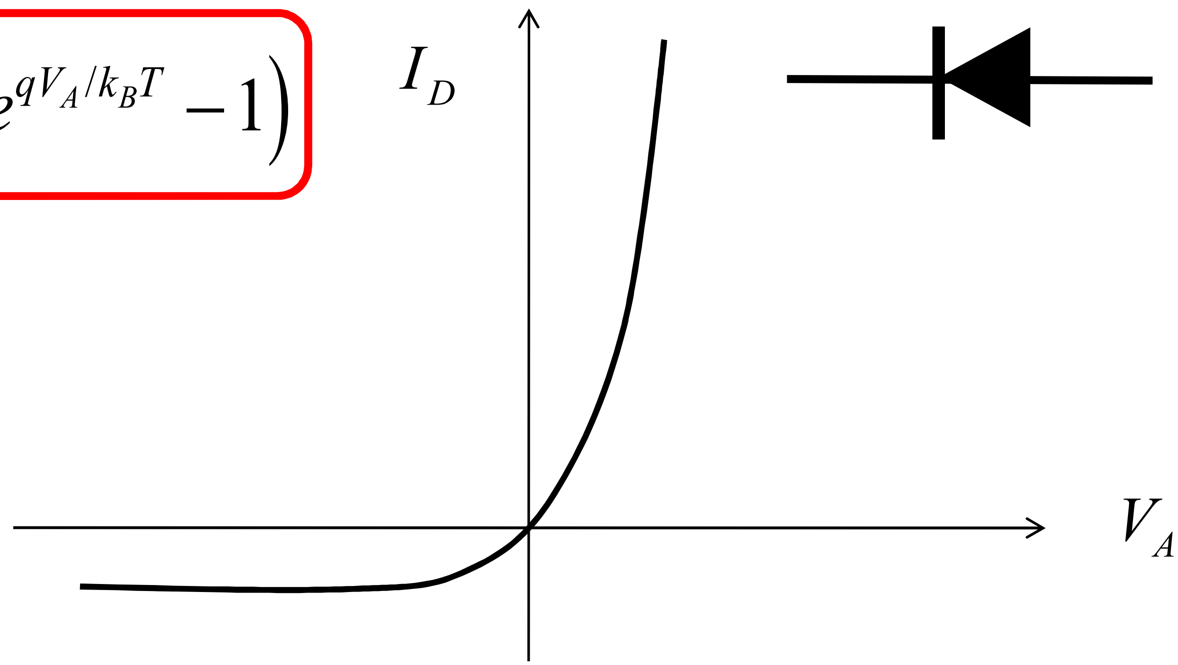
one way to make an ohmic contact

Use a low workfunction metal (for n-type semiconductors)



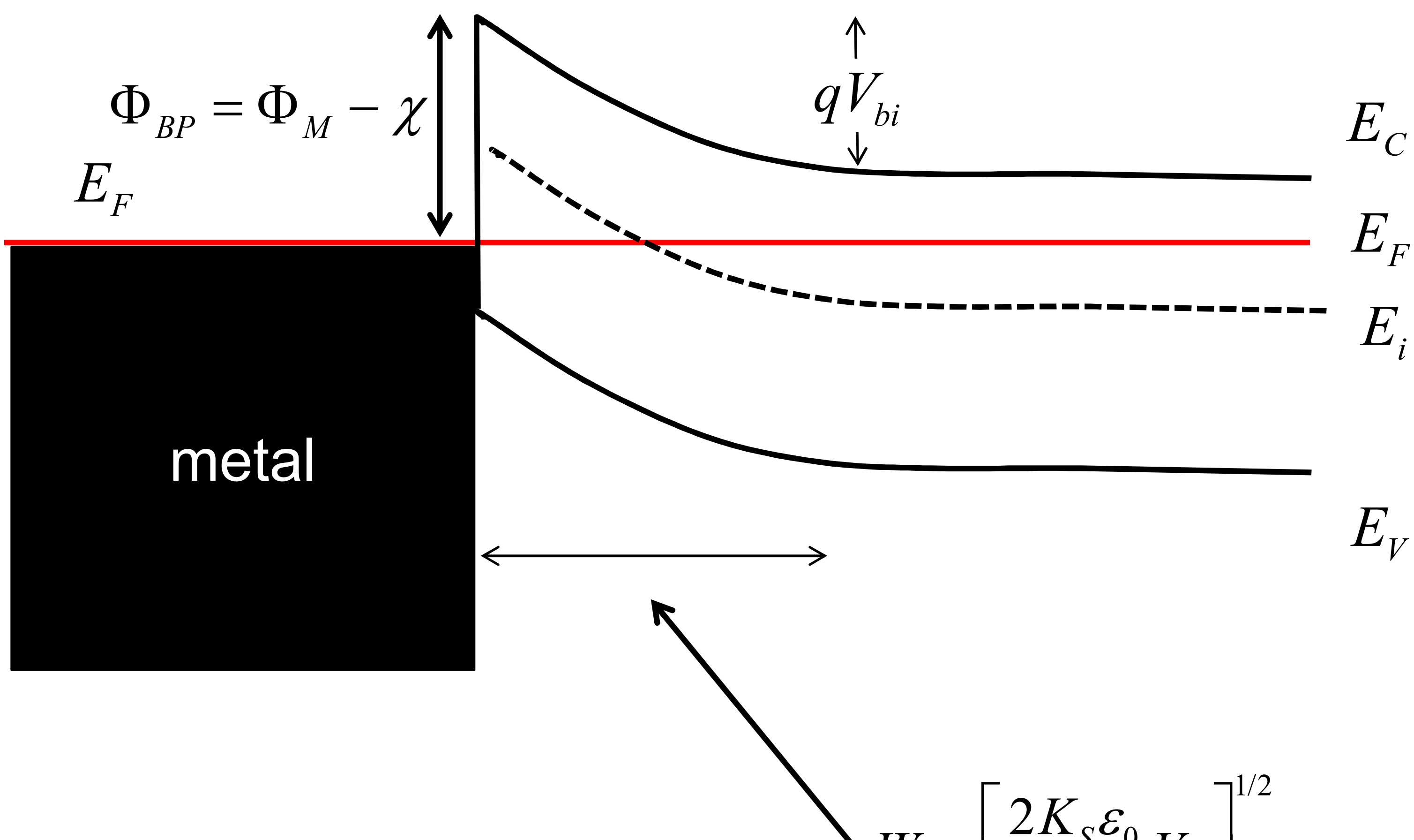
expected IV characteristics: rectifying diodes

$$I_D = I_0\left(e^{qV_A/k_BT} - 1\right)$$



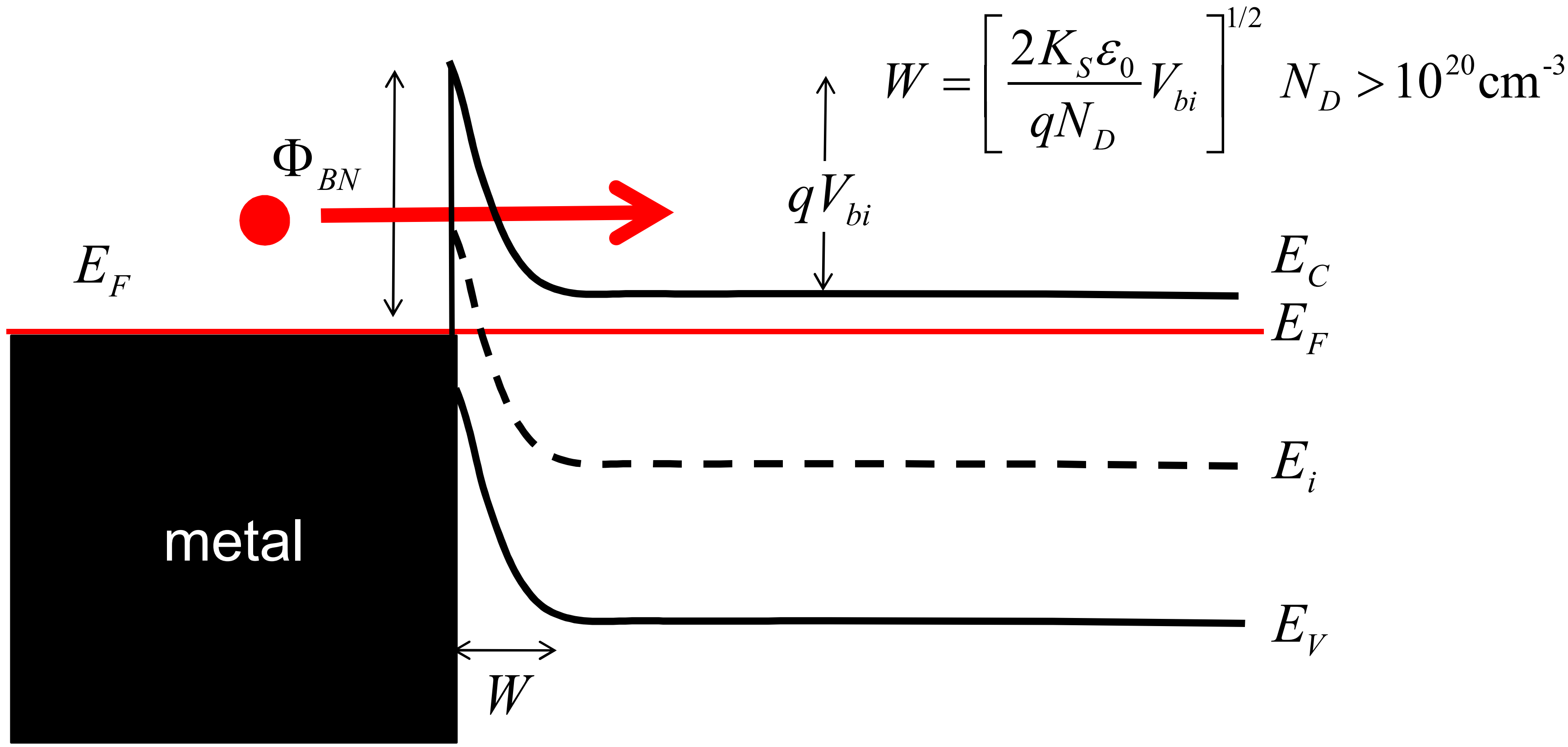
In Schottky diodes, $I_o = ?$

Another way to make an ohmic contact



$$W = \left[\frac{2K_S\varepsilon_0}{qN_D} V_{bi} \right]^{1/2}$$

alternative way to make an ohmic contact



Dope the semiconductor **very heavily** to promote quantum mechanical tunneling.

conclusions

- Studied equilibrium properties of metal-semiconductor junctions
- Bias affects semiconductor bands but leaves metal bands unchanged
- Two types of metal-semiconductor junctions: Ohmic and Schottky
- Next time, will study I-V characteristics of devices based on Schottky metal-semiconductor junctions