ECE-305: Spring 2015

Metal-Semiconductor Junctions

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

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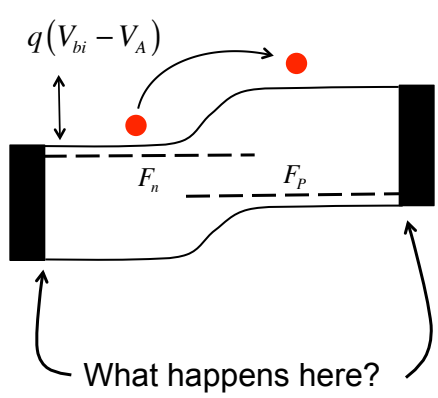
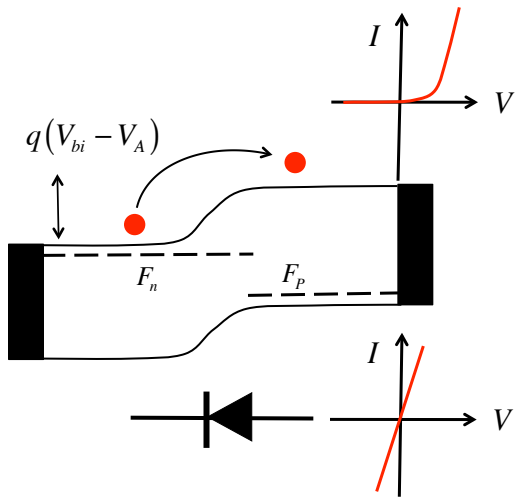
NP junctions



ohmic contacts



goals

To understand metal-semiconductor junctions so that we can:

1) make a diode

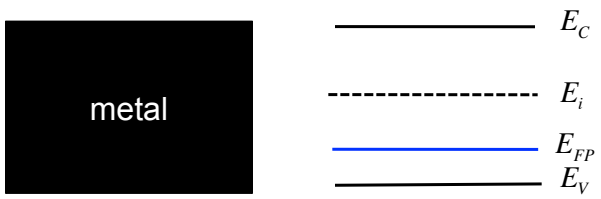
2) make an ohmic contact

outline

1) **Energy band diagrams**

2) Built-in potential

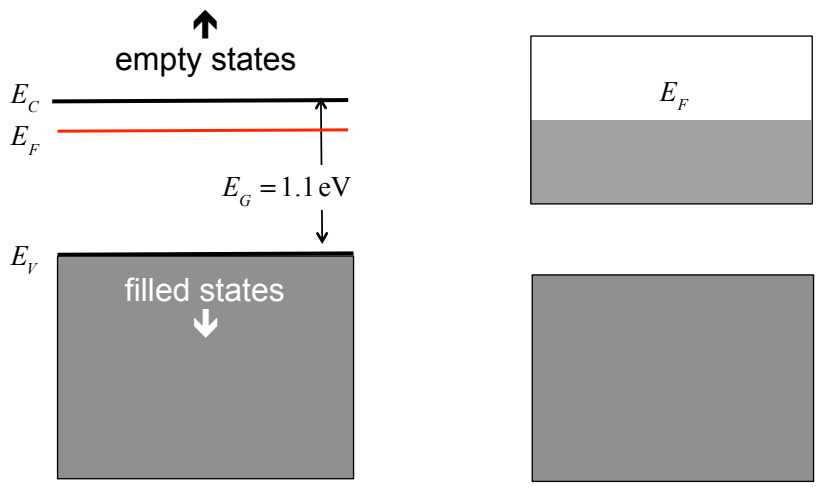
metal to p-type junction



What is the energy band diagram of a metal?

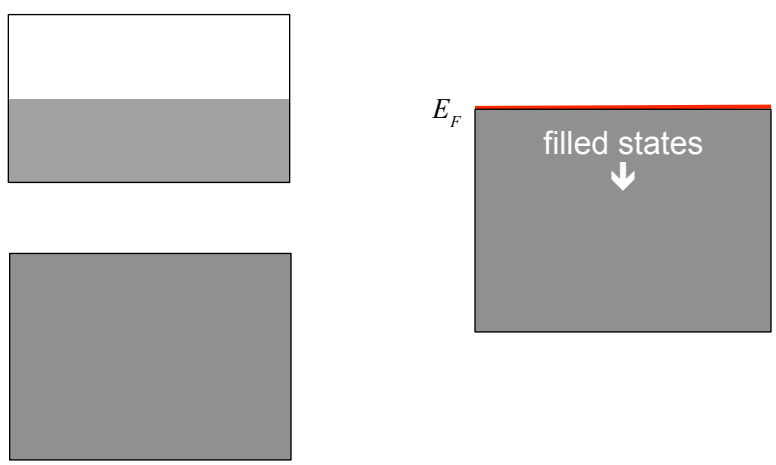
Si energy bands

metal energy bands

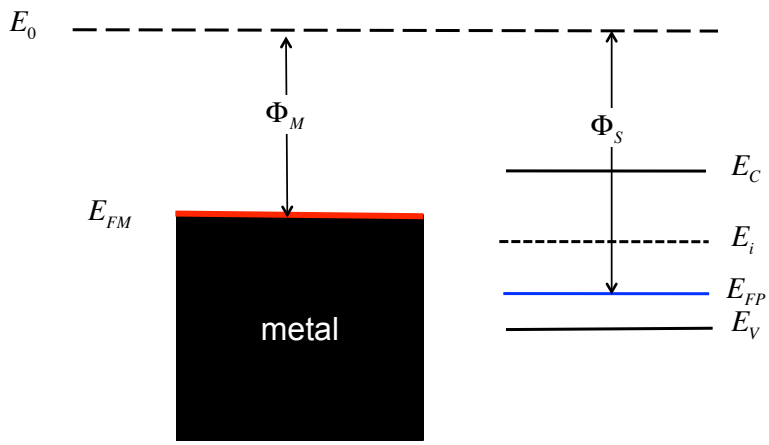


metals

top most band is half-filled

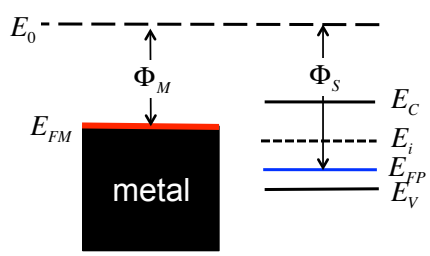


metal: p-type junction



Question 1)

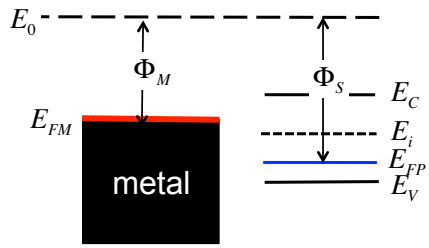
When the metal and semiconductor are brought together, which of the following is true?



a) Electrons will transfer from the semiconductor to the metal.
b) Electrons will transfer from the metal to the semiconductor..
c) There will be no transfer of electrons.
d) Dopants will transfer from the semiconductor to the metal.
e) Dopants will transfer from the metal to the semiconductor.

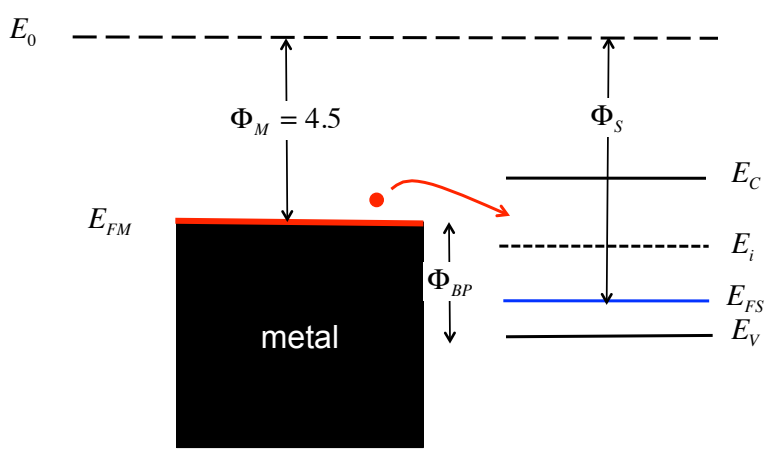
Question 2)

When the metal and semiconductor are brought together, which of the following is true?



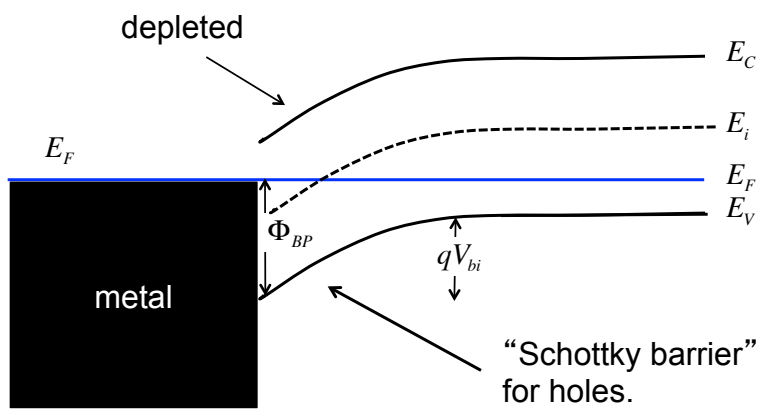
a) The semiconductor will acquire a potential that is > the metal.
b) The semiconductor will acquire a potential that is = the metal.
c) The semiconductor will acquire a potential that is < the metal.
d) The semiconductor will acquire a potential of $+\Phi_S/q$
e) The semiconductor will acquire a potential of $-\Phi_S/q$

now the band diagram



band diagram

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

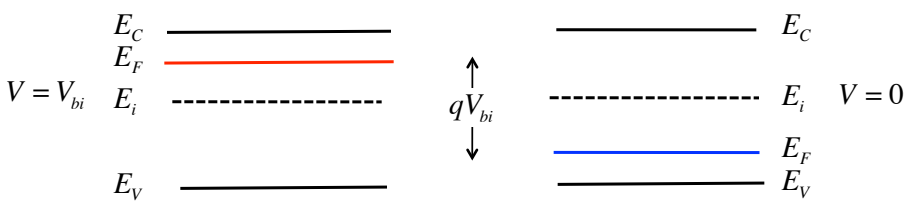


outline

1) Energy band diagrams

2) Built-in potential

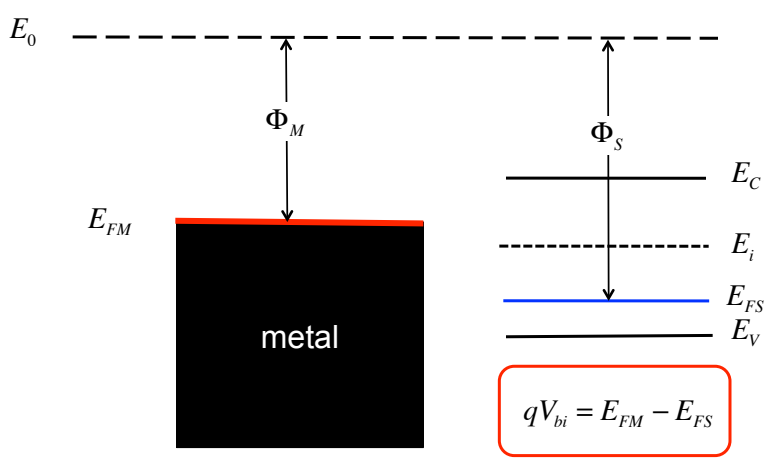
recall: the built in potential



Potential on the left must be larger than the potential on the right.

How much larger? $qV_{bi} = E_{FN} - E_{FP} = k_B T \ln\left(\frac{N_A N_D}{n_i^2}\right)$

metal: p-type junction



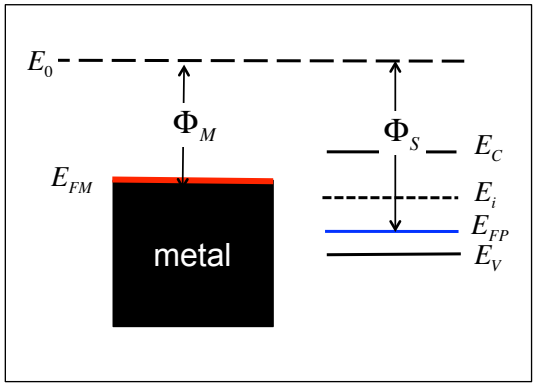
What is the built-in voltage of a MS junction?

metal: p-type 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

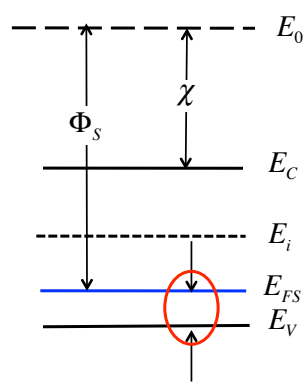
Semiconductor workfunction

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

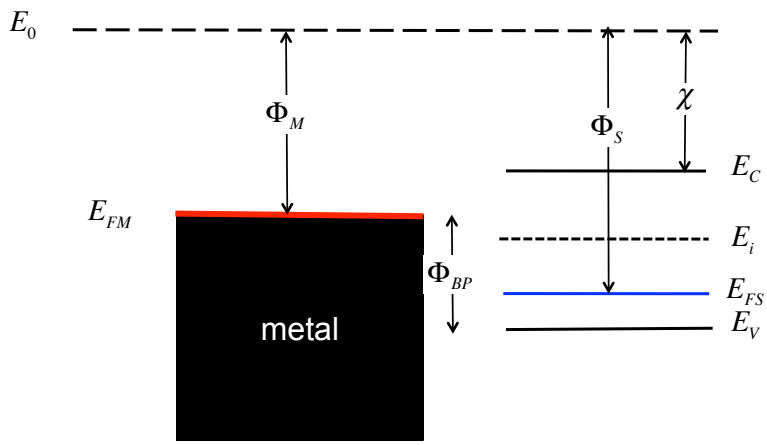
$$\Phi_S = \chi + E_G - (E_{FS} - E_V)\big|_{bulk}$$

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

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

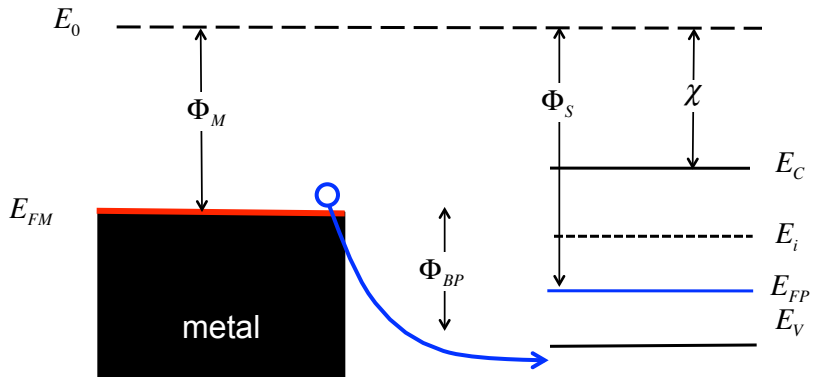


Vbi



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

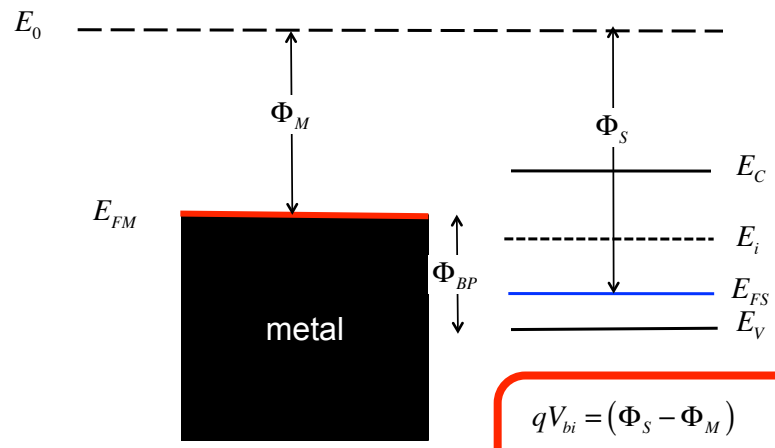
"Schottky barrier height"



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

a known material parameter

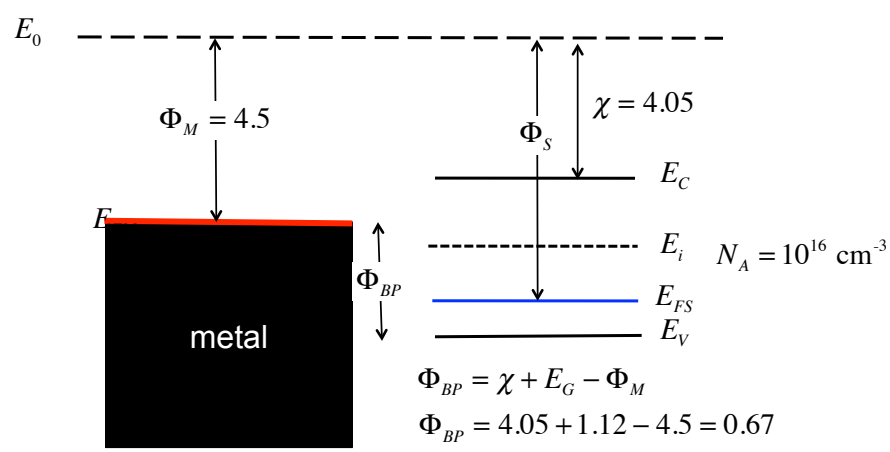
Vbi



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

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

Vbi example



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

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

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

Vbi example

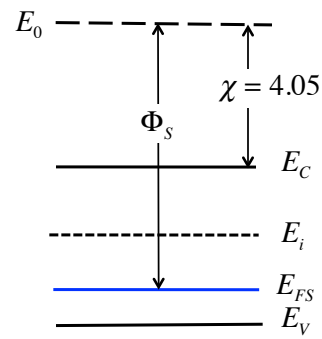
$$N_A = 10^{16}\ \text{cm}^{-3}$$

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

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

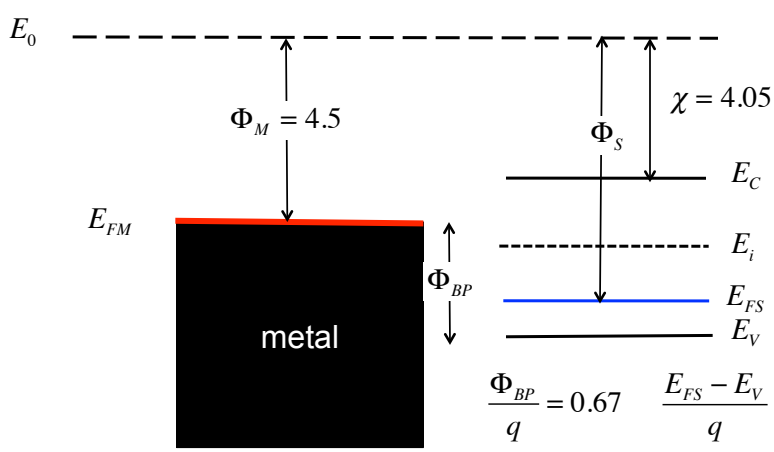
$$N_V = 2\left[\frac{\left(m_p^* k_B T\right)}{2\pi\hbar^2}\right]^{3/2}$$

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



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

Vbi example



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

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

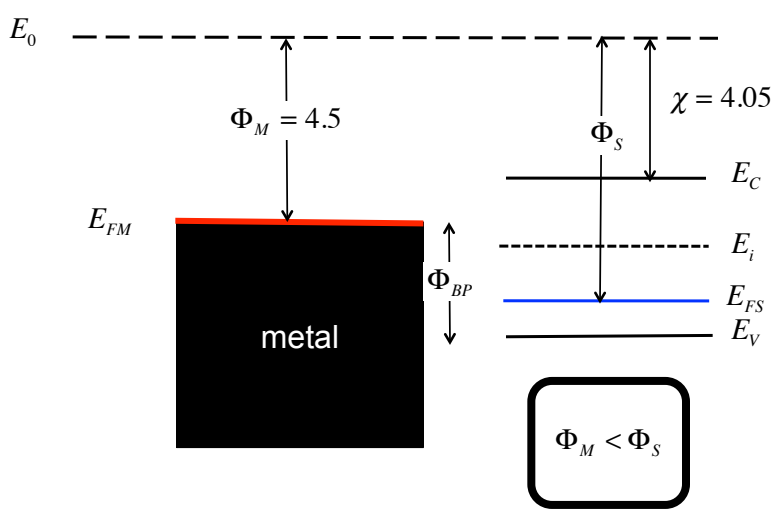
summary

1) Energy band diagrams

2) Built-in potential

Built-in potential depends on workfunction differences.

A metal – P-type semiconductor junction



summary

1) Built-in potential depends on workfunction differences.

2) Electrostatics is just like a one-sided NP junction.

3) Only majority carriers are involved.

4) Energy barrier in the e-band diagram we have considered implies a rectifying characteristic.