NP junctions

$q(V_{bi} - V_A)$

What happens here?
To understand metal-semiconductor junctions so that we can:

1) make a diode

2) make an ohmic contact
What is the energy band diagram of a metal?
Si energy bands          metal energy bands

$E_C$  $E_F$  $E_g = 1.1\,\text{eV}$

empty states

top most band is half-filled

metals

$E_F$

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

“Schottky barrier” for holes.

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

\[ qV_{bi} = E_{FM} - E_{FS} \]
\[ qV_{bi} = (E_0 - \Phi_M) - (E_0 - \Phi_S) \]
\[ qV_{bi} = (\Phi_S - \Phi_M) \]

\[ E_0 \]
\[ \Phi_M \]
\[ E_{FM} \]
\[ \Phi_S \]
\[ E_C \]
\[ E_{FP} \]
\[ E_V \]

\[ \Phi_M \] is a known material parameter

Semiconductor workfunction

Electron affinity, \( \chi \), and bandgap are known material parameters.

\[ \Phi_S = \chi + E_G - (E_{FS} - E_V)_{\text{bulk}} \]
\[ P_0 = N_A = N_V e^{(E_V - E_{FS})/k_BT} \]
\[ (E_{FS} - E_V) = k_B T \ln \left( \frac{N_A}{N_V} \right) \]
$$qV_{bi} = (\Phi_S - \Phi_M) = \chi + E_G - (E_{FS} - E_{FV})_{bulk} - \Phi_M$$

\[ \Phi_{BP} = \chi + E_G - \Phi_M \]

a known material parameter
\[ qV_{bi} = (\Phi_S - \Phi_M) \]

\[ qV_{bi} = \Phi_{BP} \left( E_{FS} - E_V \right) \text{bulk} \]

**Vbi example**

\[ \Phi_{BP} = \Phi_S + E_G - \Phi_M \]

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

\[ V_{bi} = \frac{\Phi_{BP} \left( E_{FS} - E_V \right)_{FB}}{q} \]
$N_A = 10^{16} \text{ cm}^{-3}$

$p_0 = N_V e^{(E_F - E_S)/k_B T} \text{ cm}^{-3}$

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

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

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

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

$V_{bi} = \Phi_{BP} - (E_{FS} - E_V)_{FB} = 0.67 - 0.20 = 0.47$
1) Energy band diagrams

2) Built-in potential

Built-in potential depends on workfunction differences.

A metal – P-type semiconductor junction

\[ \Phi_M = 4.5 \]

\[ \Phi_S = 4.05 \]

\[ \Phi_{BP} \]

\[ E_0 \]

\[ E_{FM} \]

\[ E_C \]

\[ E_I \]

\[ E_{FS} \]

\[ E_V \]

\[ \Phi_M < \Phi_S \]
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.