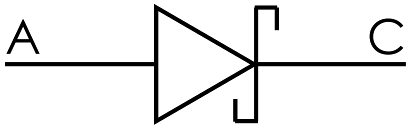
METAL-SEMICONDUCTOR CONTACTS IN A NUTSHELL

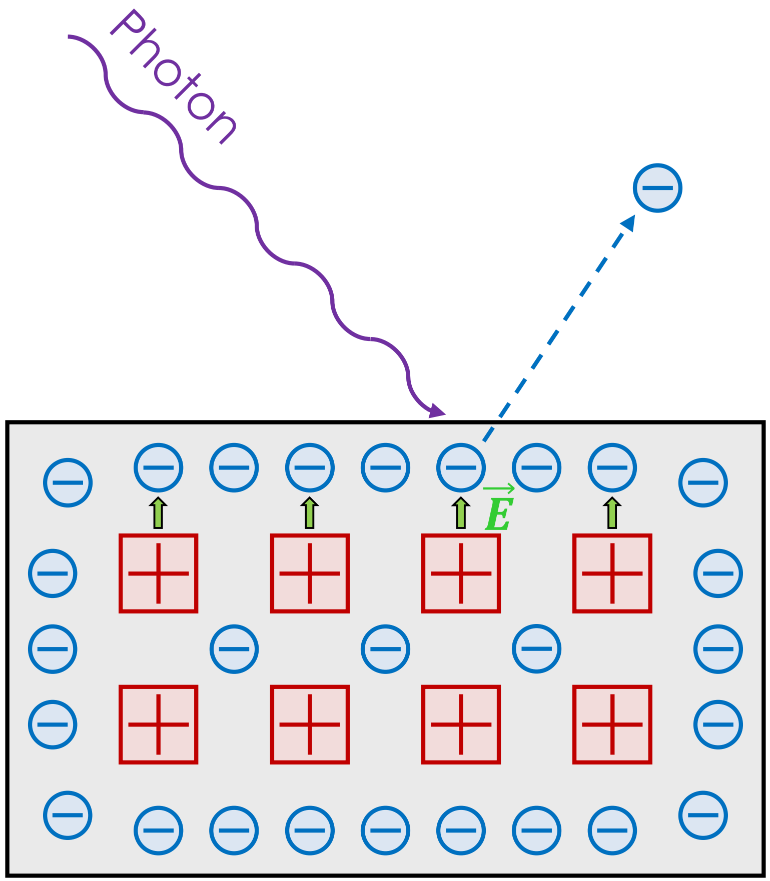
[PHT.301UF] Physics of Semiconductor Devices (17W)

Student presentation by
Ko Odreitz

Supervisor: *Peter Hadley*
http://www.if.tugraz.at/web.php?1



Basics: Work Function of a Metal



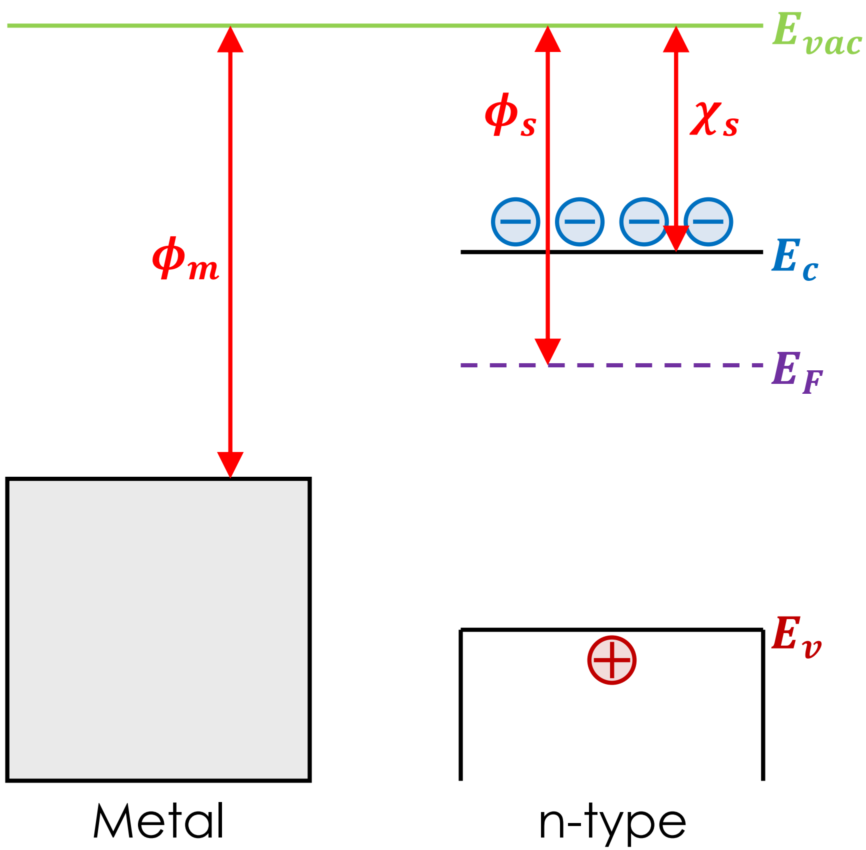
Metal: free electrons among
a lattice of positively charged ions

Work Function ϕ_m [V]
Minimum energy to remove an electron from the solid surface.

Element		$e\phi_m$ [1]
Al	aluminum	4.06 – 4.26
Ag	silver	4.26 – 4.74
W	tungsten	4.32 – 5.22
Cu	copper	4.53 – 5.10
Au	gold	5.10 – 5.47
Pt	platinum	5.12 – 5.93

[1] Editor-in-Chief John R. Rumble. *CRC Handbook of Chemistry and Physics.*

Basics: Work Function vs Electron Affinity



Electron Affinity χ_s [V]

$\chi_s = E_{vac} - E_c$

Vacuum Level E_{vac} [V]

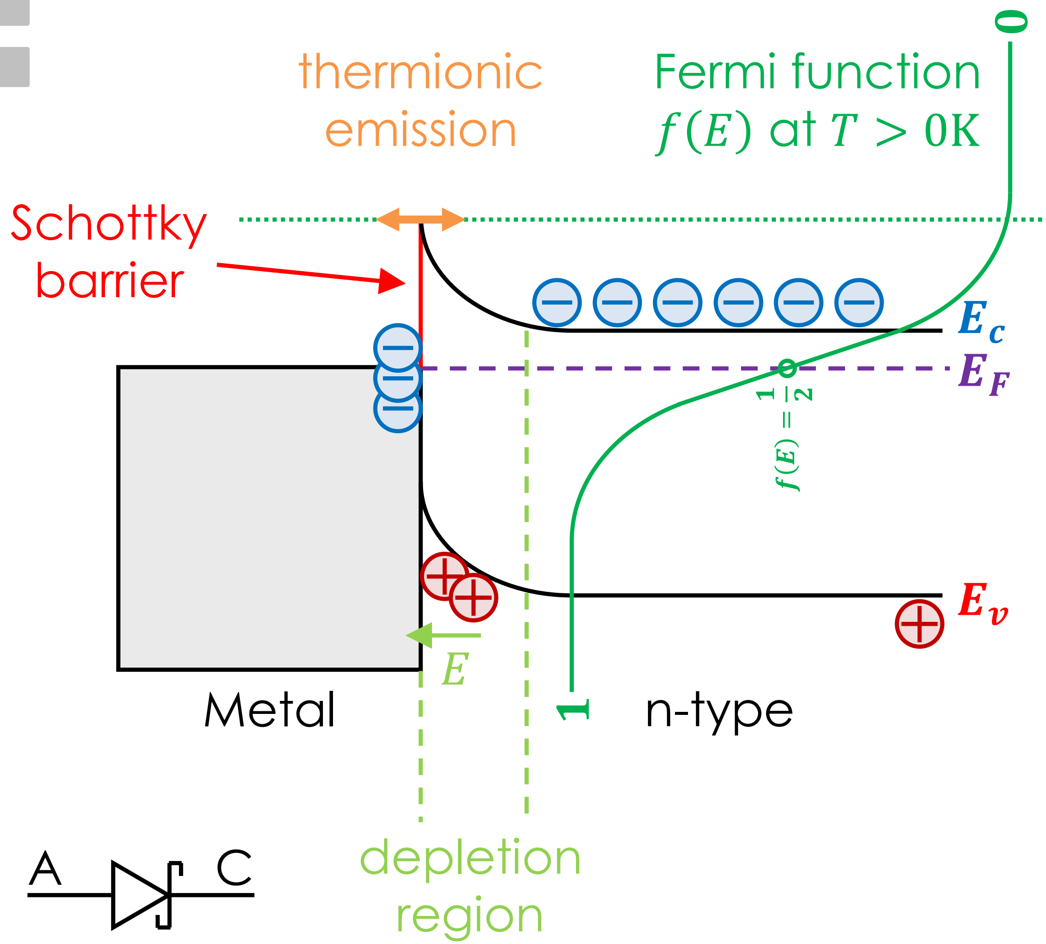
Energy level where the electrons are freed from the surfaces' forces.

Element		$e\chi_s$ [2]
AlAs	aluminum arsenide	3.5
GaAs	gallium arsenide	4.07
Si	silicon	4.01
Ge	germanium	4.13

[2] Jasprit Singh. *Semiconductor Devices. Basic Principles.*

N-TYPE SCHOTTKY CONTACT

$\phi_s < \phi_m$: E_c and E_v bend down



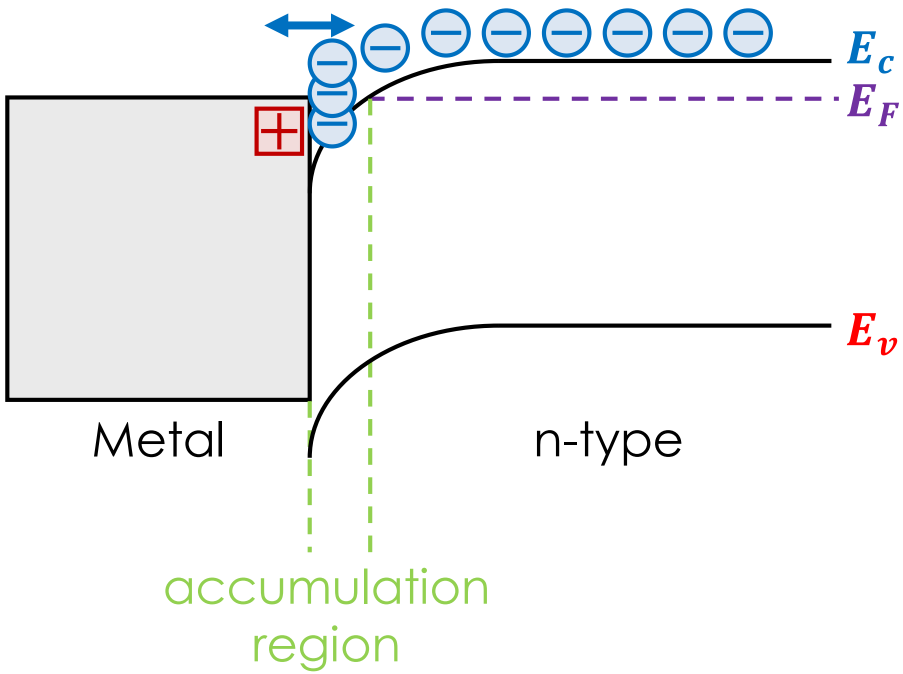
Electrons from the semiconductor see a barrier. Its' height depends on the applied voltage.

Some electrons already have enough energy to go over the barrier.

Electrons from the metal always see the same Schottky barrier height.

N-TYPE OHMIC CONTACT

$\phi_s > \phi_m : E_c$ and E_v bend up

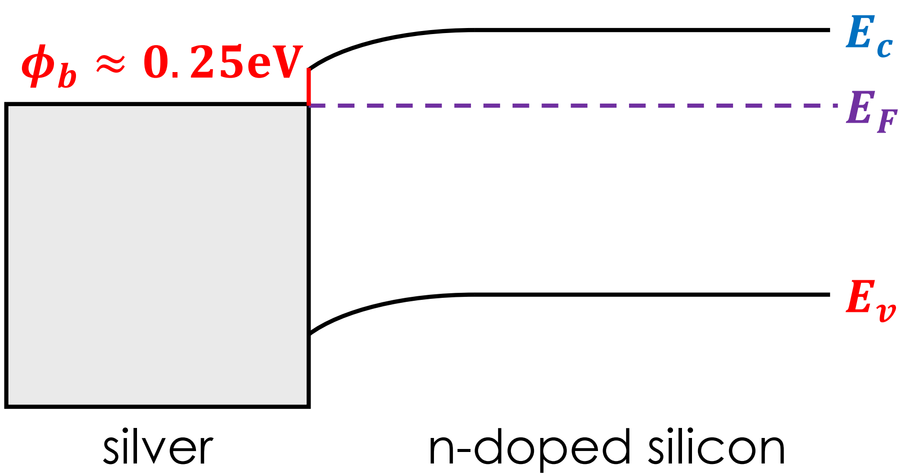


With a correct combination of materials we could obtain a near-ohmic behavior.

E.g.:
n-type + ***Ca*** or ***Ba*** *(low ϕ_m)*
p-type + ***Pt*** or ***Au*** *(high ϕ_m)*

Low resistance contacts are difficult to form in ***Si***, ***Ge***, ***GaAs*** due to interface states (Fermi level pinning).

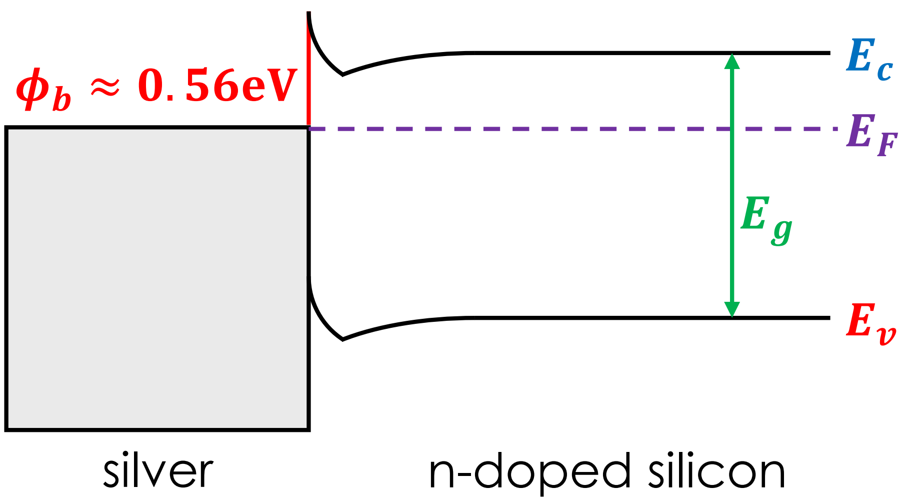
Interface States



According to the *Schottky-Mott* rule, we expect to obtain a barrier height about $\phi_b \approx \phi_m - \chi_s$

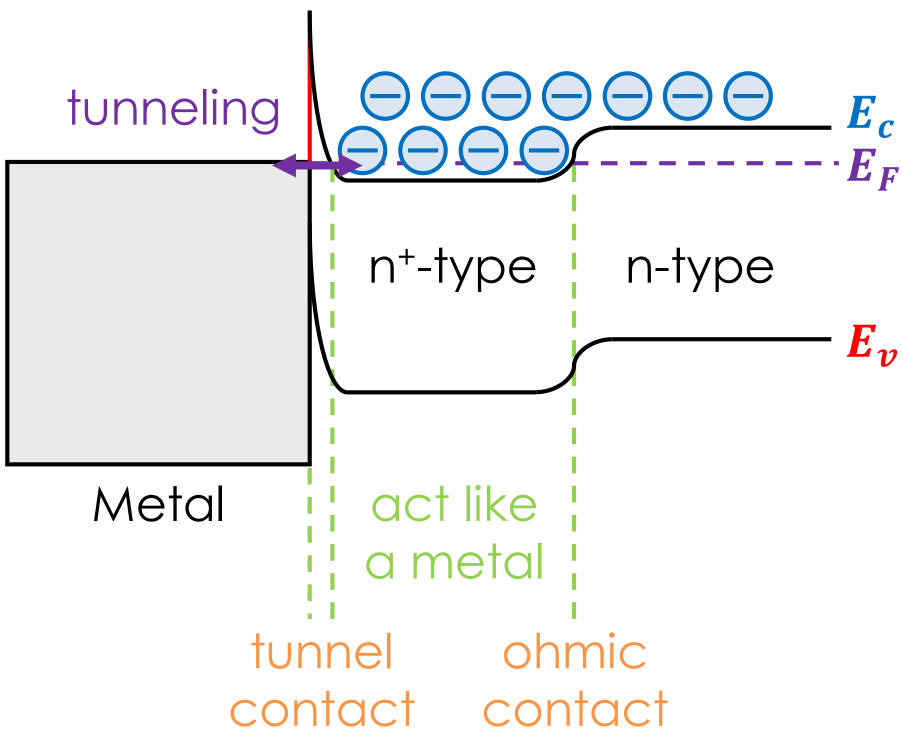
work function theory

Fermi level pinning



In reality, interface states are pinning the Fermi level close to the middle of the band gap: $\phi_b \approx E_g/2$

N-type Tunnel Contact



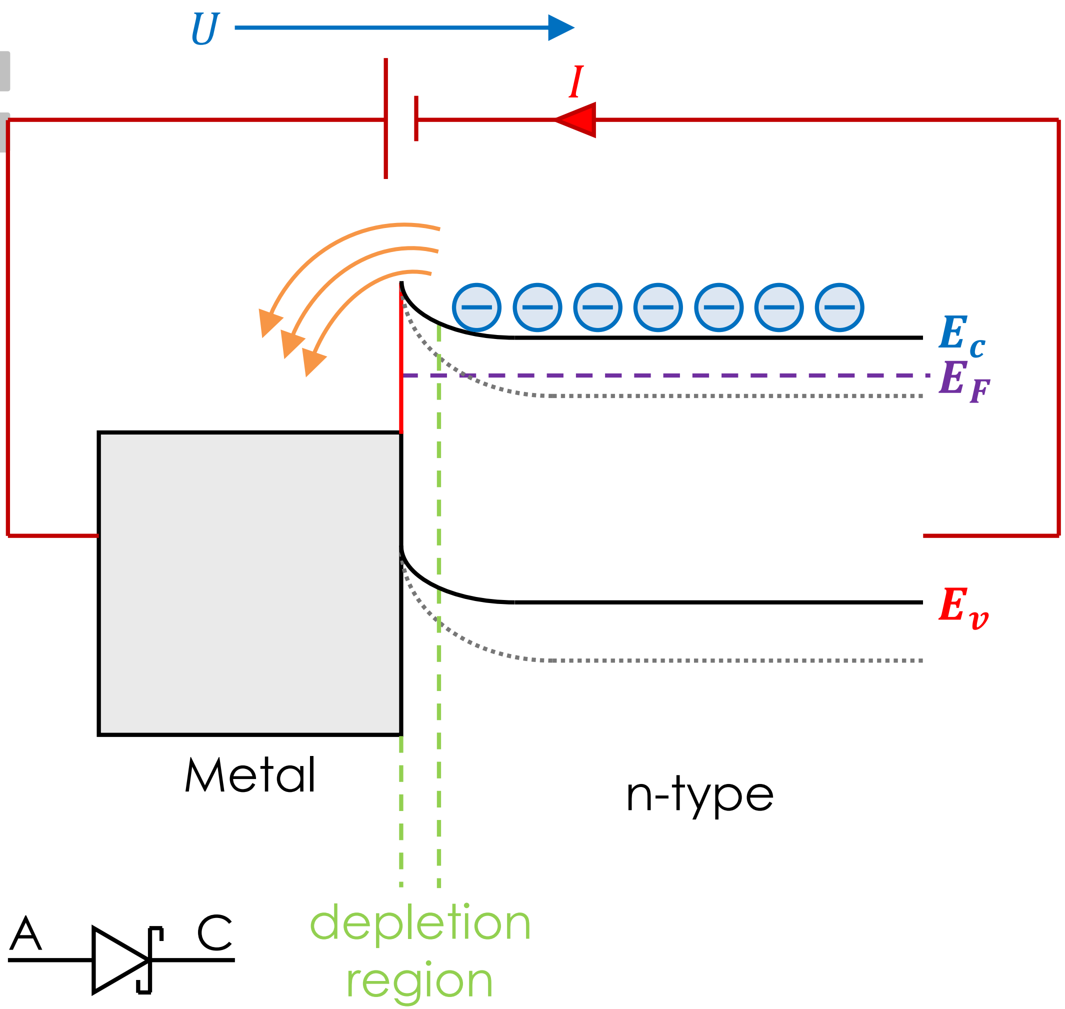
Ohmic contacts form more easily when the semiconductor is highly doped nearby the junction.

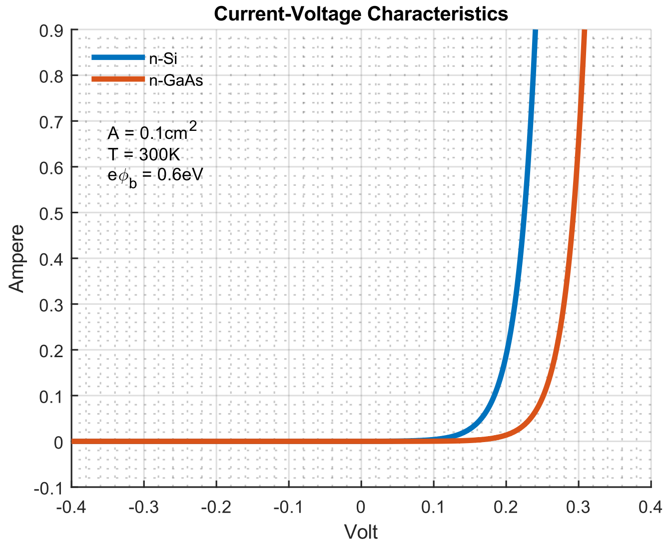
A high doping narrows the depletion region and increases the probability for tunneling significantly.

This behavior is commonly used for creating metal contacts to the outside.

N-type Schottky Forward Biased

$$I = I_s \cdot \left[e^{\frac{eU}{k_B \cdot T}} - 1 \right]$$





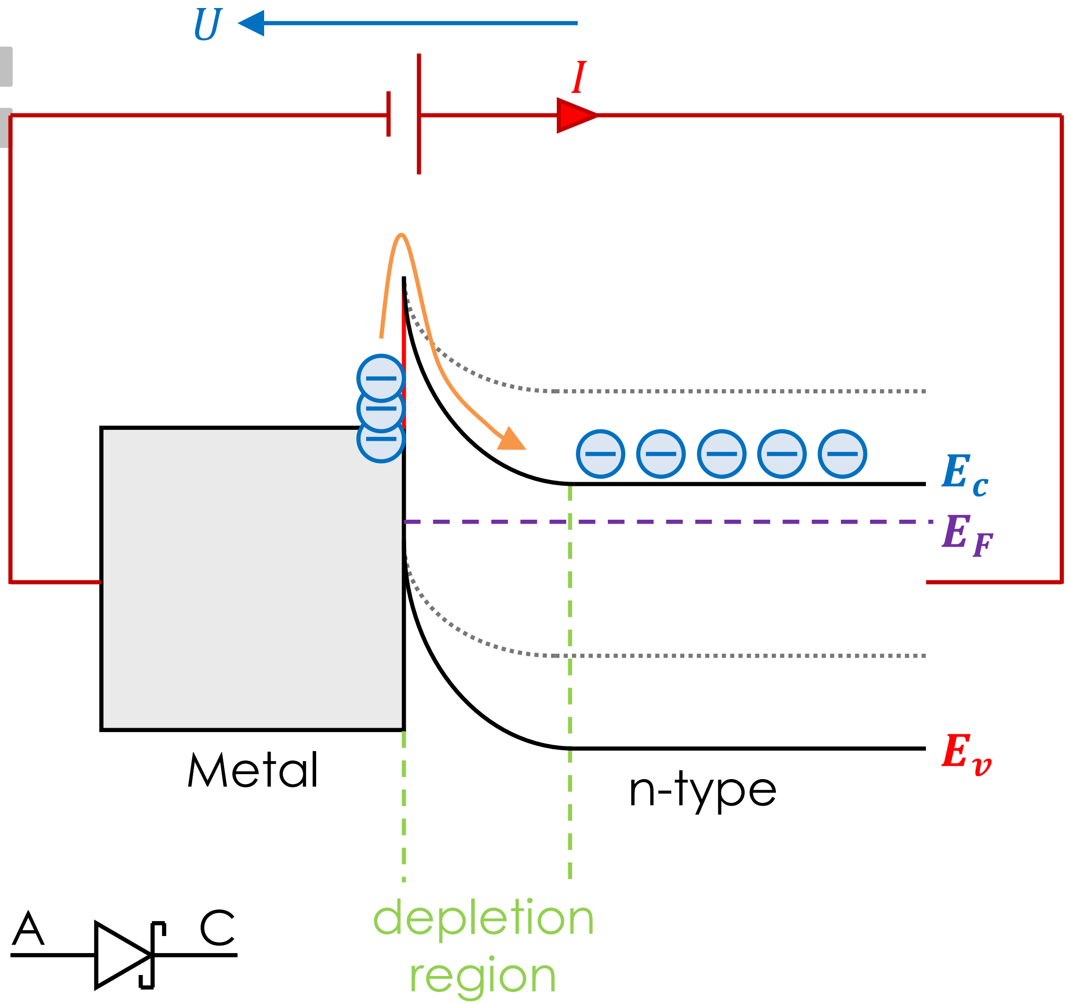
$$I_s = A_R \cdot A \cdot T^2 \cdot e^{\frac{-e\phi_b}{k_B \cdot T}}$$

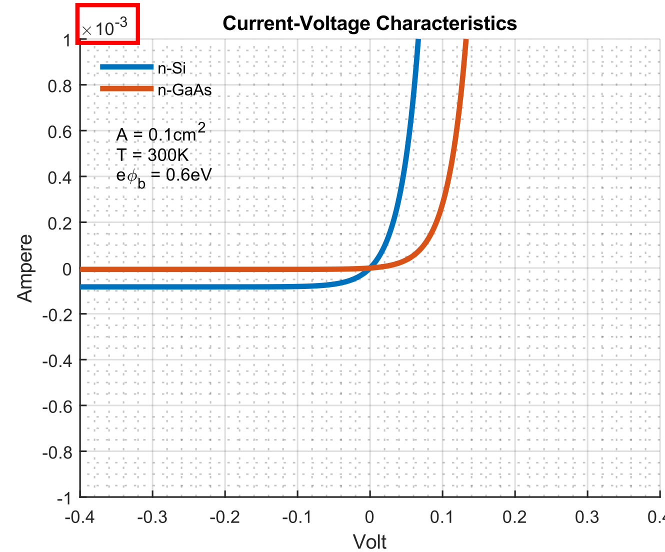
Material	Richardson constant [2]
n - GaAs	$8 \cdot \mathrm{A} \cdot \mathrm{K}^{-2} \cdot \mathrm{cm}^{-2}$
p - Si	$32 \cdot \mathrm{A} \cdot \mathrm{K}^{-2} \cdot \mathrm{cm}^{-2}$
p - GaAs	$74 \cdot \mathrm{A} \cdot \mathrm{K}^{-2} \cdot \mathrm{cm}^{-2}$
n - Si	$110 \cdot \mathrm{A} \cdot \mathrm{K}^{-2} \cdot \mathrm{cm}^{-2}$

[2] Jasprit Singh. *Semiconductor Devices. Basic Principles.*

N-TYPE SCHOTTKY REVERSE BIASED

$$I = I_s \cdot \left[e^{\frac{eU}{k_B \cdot T}} - 1\right]$$



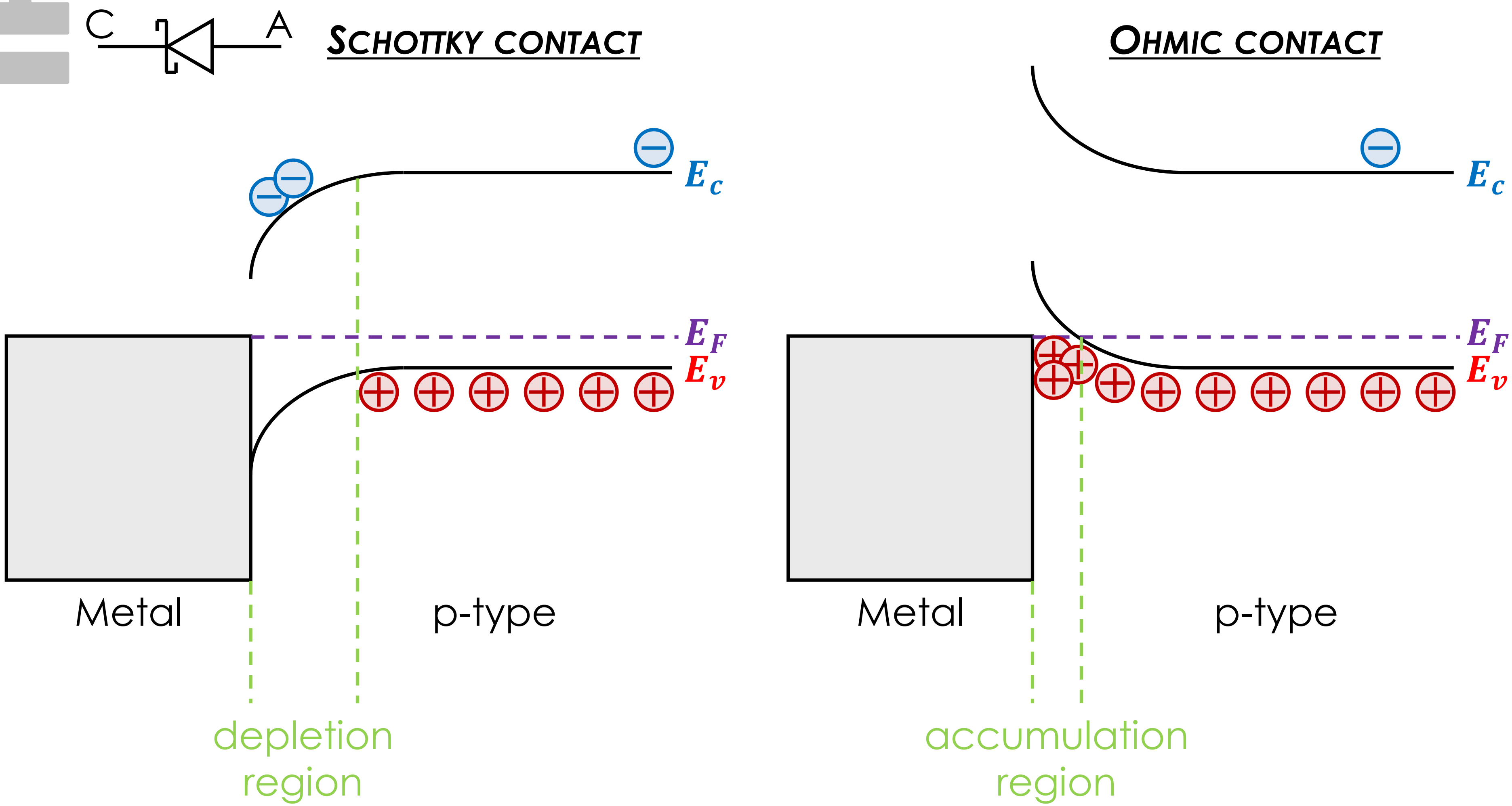


$$I_s = A_R \cdot A \cdot T^2 \cdot e^{\frac{-e\phi_b}{k_B \cdot T}}$$

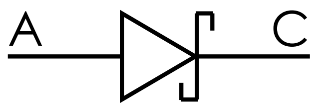
Material	Richardson constant [2]
n - GaAs	$8 \cdot A \cdot K^{-2} \cdot cm^{-2}$
p - Si	$32 \cdot A \cdot K^{-2} \cdot cm^{-2}$
p - GaAs	$74 \cdot A \cdot K^{-2} \cdot cm^{-2}$
n - Si	$110 \cdot A \cdot K^{-2} \cdot cm^{-2}$

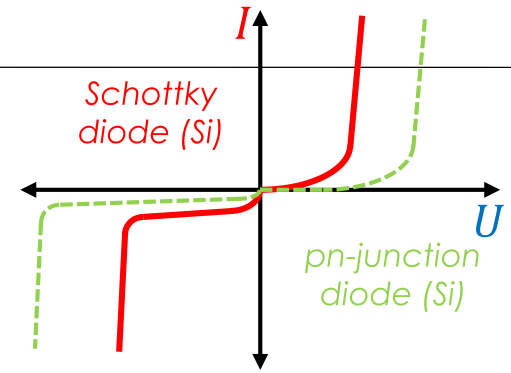
[2] Jasprit Singh. *Semiconductor Devices. Basic Principles.*

P-type in a Nutshell



Schottky Diode Facts





Qualitative graph

Interface States

Usually, metal and semiconductor consist out of different crystal structures. Therefore, there are many broken bonds at the interface. Those act like dopants and cause a Fermi level pinning phenomenon.

Switching Speed

Schottky diodes are majority carrier devices and are faster than pn-junction diodes because no slow random recombination takes place.

Volt-Ampere Characteristics

The value of the forward voltage is minimal in Schottky diodes. However, it possesses a higher leakage current. In addition, the reverse breakdown voltage is also small.

Capacitance-Volt Measurements [3]

Due to the abrupt junction, the depletion width only increases in the semiconductor. Therefore, the doping concentration can be calculated easily: *($N_x = N_A$ if p-type; $N_x = N_D$ if n-type)*

$$W = \frac{\varepsilon}{C_j} = \sqrt{\frac{2 \cdot \varepsilon \cdot (U_{bi} - U)}{e \cdot N_x}}$$

[3] Peter Hadley. *Lecture Slides.*