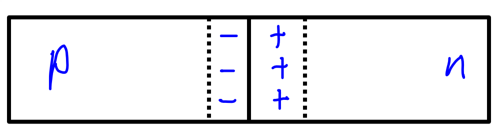
Schottky Diode and MOSFET

Chapters 14 and 17 of textbook

pn Junction Summary

No bias



p (net) diffusion →

p (net) drift ←

n (net) diffusion ←

n (net) drift →

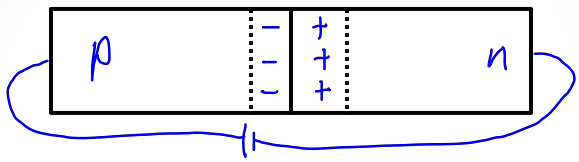
Each net diffusion or net drift is the result of combined drift and diffusion (as carriers experience both at all times).

Here, "drift" and "diffusion" refer to what goes on through the depletion region.

The net drift requires the diffusion of minority carriers within the quasi-neutral region into the depletion region.

pn Junction Summary

Forward bias

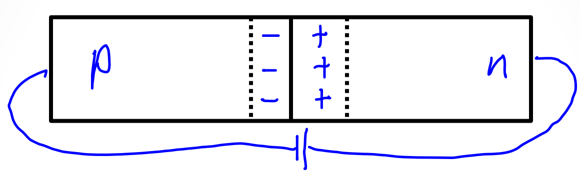


- p (net) diffusion
- p (net) drift
- n (net) diffusion
- n (net) drift

Diffusion process gets amplified exponentially (this figure does not do justice; arrows must be much longer).

pn Junction Summary

Reverse bias



- p (net) diffusion
- p (net) drift
- n (net) diffusion
- n (net) drift

Diffusion process gets reduced exponentially (this figure does not do justice; arrows must be invisibly small).

Work function, Electron Affinity, … Intrinsic Surface Property

- Work function:

$$\Phi \equiv E_0 - E_F$$

E_0 is the "vacuum level" – the zero electron energy just outside the specimen.

- Electron affinity energy:

The minimum energy released when an electron is added to the specimen. For an intrinsic s.c. at T=0, it is

$$\chi = E_0 - E_c$$

- Electron ionization energy:

The minimum energy required to removed an electron from the specimen. For an intrinsic s.c. at T=0,

$$E_i = E_0 - E_v$$

Ideal MS Junction

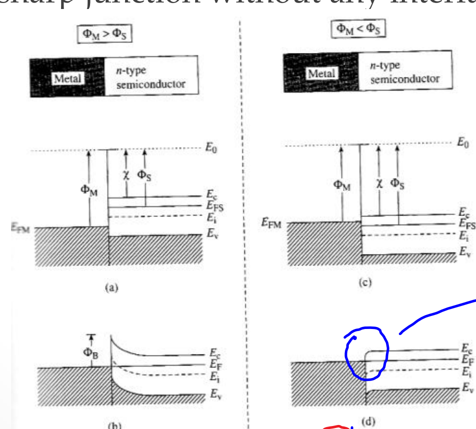
- Let us assume an ideal metal to semiconductor junction: atomically sharp junction without any interface effect.

Energy Barrier

$\Phi_B = \Phi_M - \chi$

like pn junction

not like pn junction

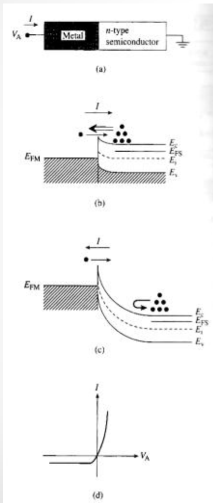


little barrier

net charge

very thin

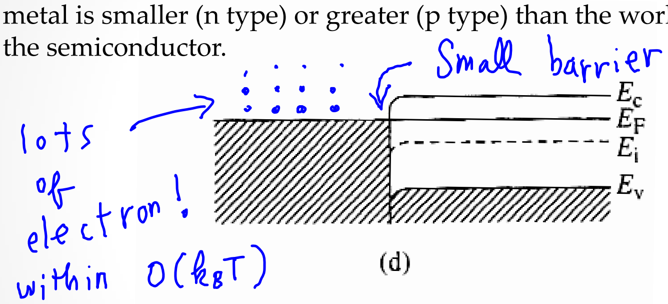
Schottky Diode



- Diode action when the work function of metal is greater (n type) or smaller (p type) than that of the semiconductor.
- The action is due to majority carriers only (electrons for n type or holes for p type)
- The action on minority carriers is really minor.

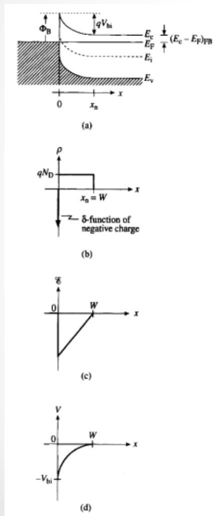
Ohmic Contact

Ohmic contact for an ideal MS junction if the work function of the metal is smaller (n type) or greater (p type) than the work function of the semiconductor.



In real MS junctions, $\Phi_B \neq \Phi_M - \chi$, due to interface charges ("surface states"). E_F gets pinned already by the in-gap states (read LN 12.5). Φ_B is always large! Then, the Ohmic contact is made by reducing W, with the use of highly doped semiconductor and annealing. Metal = Al, $TiSi_2$.

Schottky Diode



- The saturation current is $V_{bi} = \frac{\Phi_B - (E_c - E_F)_{FB}}{e}$
- FB = flat band (bulk not interface).
- Depletion approximation
- Note that the E field is discontinuous at $x = 0$.
- $W = \sqrt{\frac{2K_s\epsilon_0}{eN_D}(V_{bi} - V_A)}$

Schottky Diode

- "Net drift" in this case is the thermionic emission current.

$$I_s = A\mathcal{A}^*T^2 \exp(-\beta\Phi_B)$$

$$\mathcal{A}^* = \mathcal{A}m^*/m_e, \quad \mathcal{A} = 120\ \mathrm{A/(cm^2K^2)}$$ Richardson's constant

$$I = I_s(\exp(\beta V_A) - 1)$$

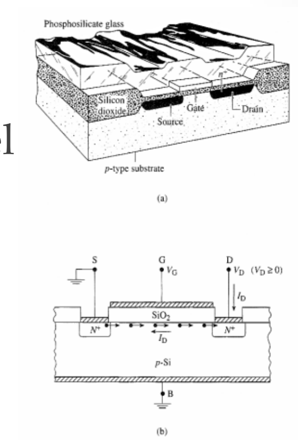
- I never saturates on reverse bias due to the V_A dependence of Φ_B (image charge potential of a charge leaving a metal; Eq. T14.26,27).
- Schottky Diodes are used when the speed matters (no minority carriers involved).

MOSFET

- Metal oxide semiconductor field effect transistor
- Work horse for modern devices (Intel processors)
- Insulator Important!

  SiO_2, $K_s = 3.9$

  HfO_2, $K_s = 25$



MOSFET

- Inversion Layer by Gate Voltage

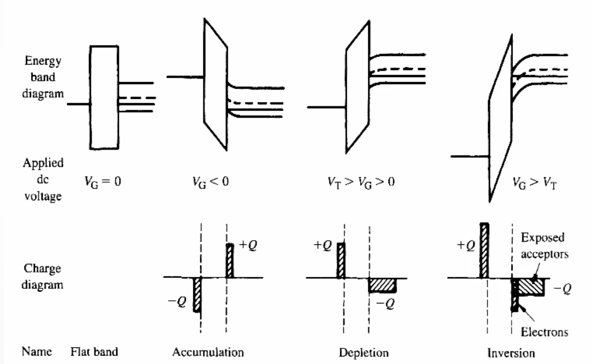


Figure 16.6 Energy band and block charge diagrams for a *p*-type device under flat band, accumulation, depletion, and inversion conditions.

MOSFET

- Source Drain Current

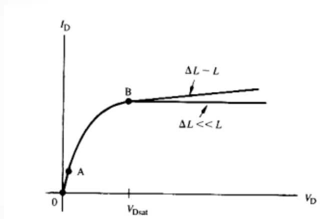


Figure 17.3 General variation of I_D with V_D for a given $V_G > V_T$.