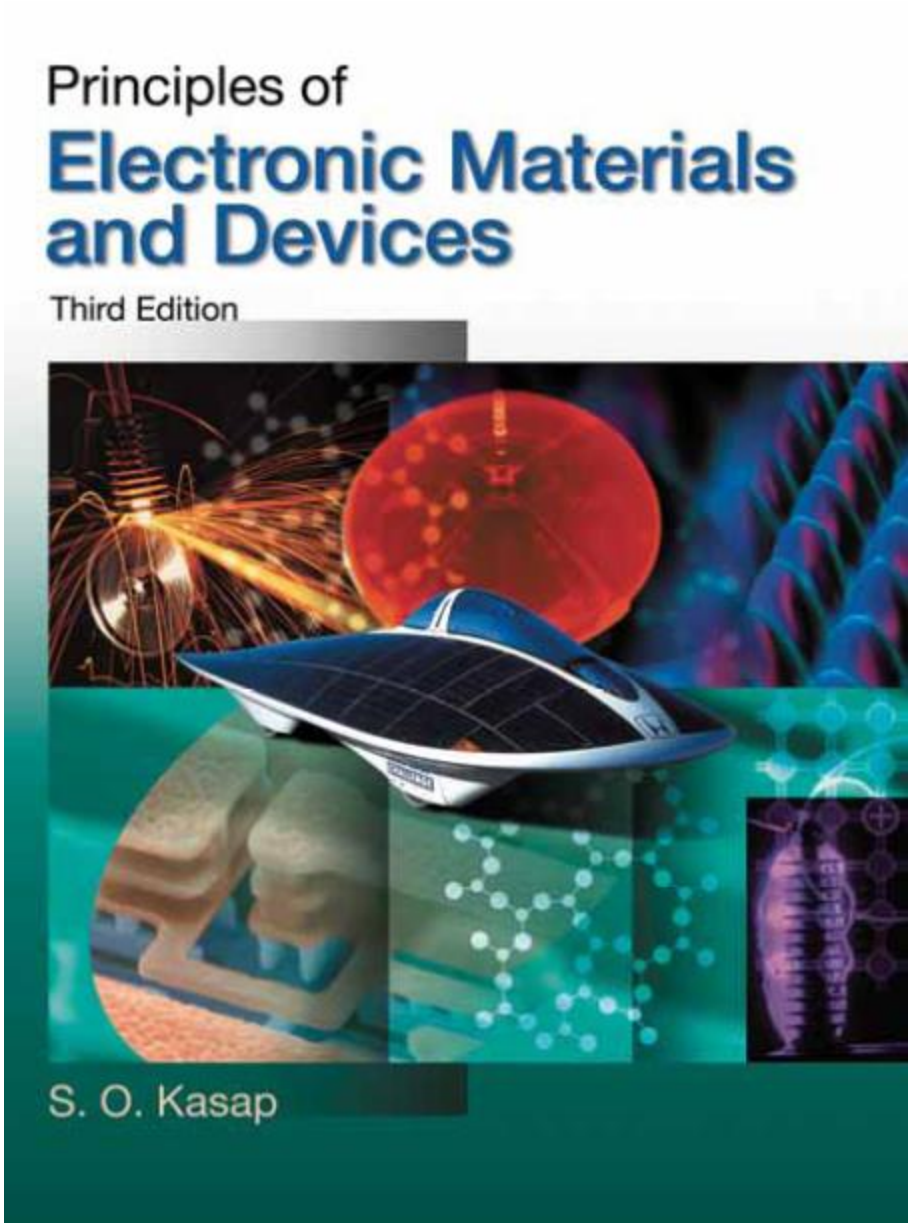
Solid State Electronics EC210
Arab Academy for Science and Technology
AAST – Cairo
Fall 2016

Lecture 8:

Semiconductors

Lecture Notes Prepared by:
Dr. Amr Bayoumi, Dr. Nadia Rafat



Lecture 8: Semicondutcors
Dr. Amr. Bayoumi

Pages

- Kasap
  - P. 373-378: Intrinsic Semiconductor
  - P.388-394: Extrinsic Semiconductor

200 mm and 300 mm Si wafers.

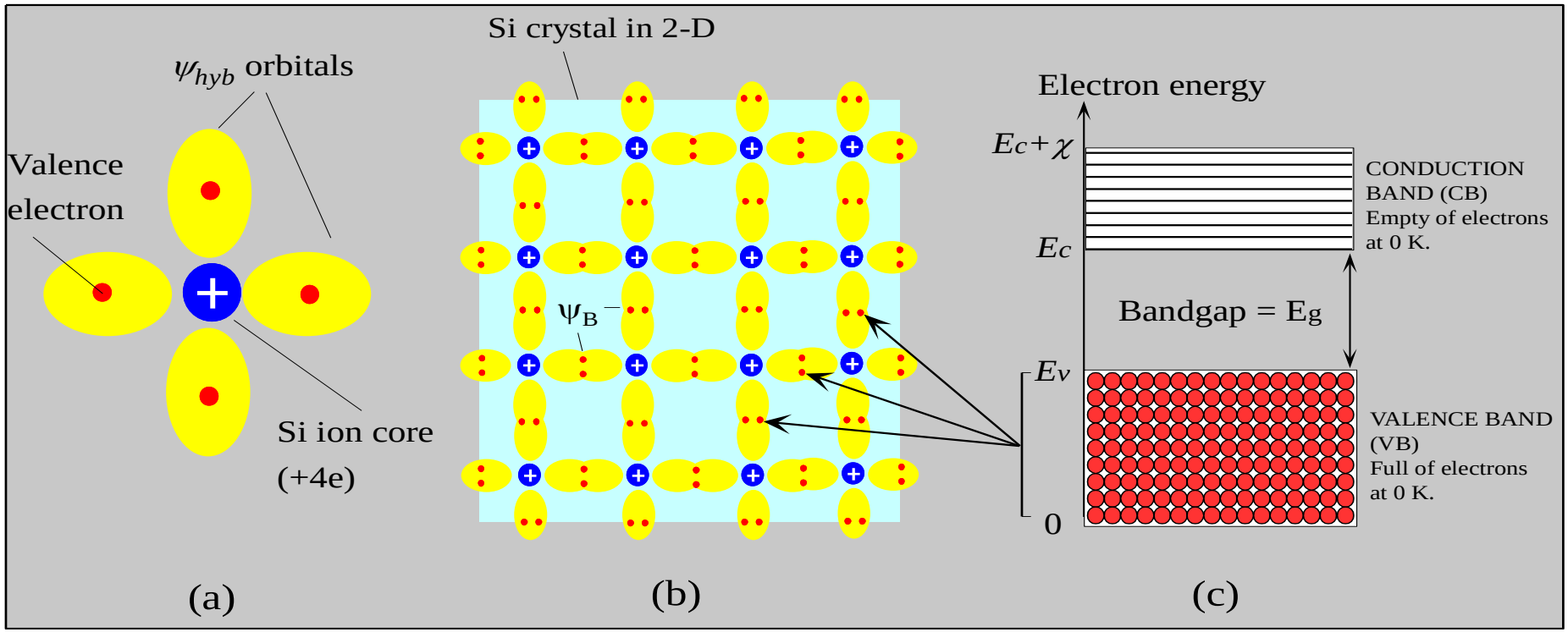
|SOURCE: Courtesy of MEMC, Electronic Materials, Inc.

GaAs ingots and wafers.

GaAs is used in high speed electronic devices, and optoelectronics.

|SOURCE: Courtesy of Sumitomo Electric Industries, Ltd.

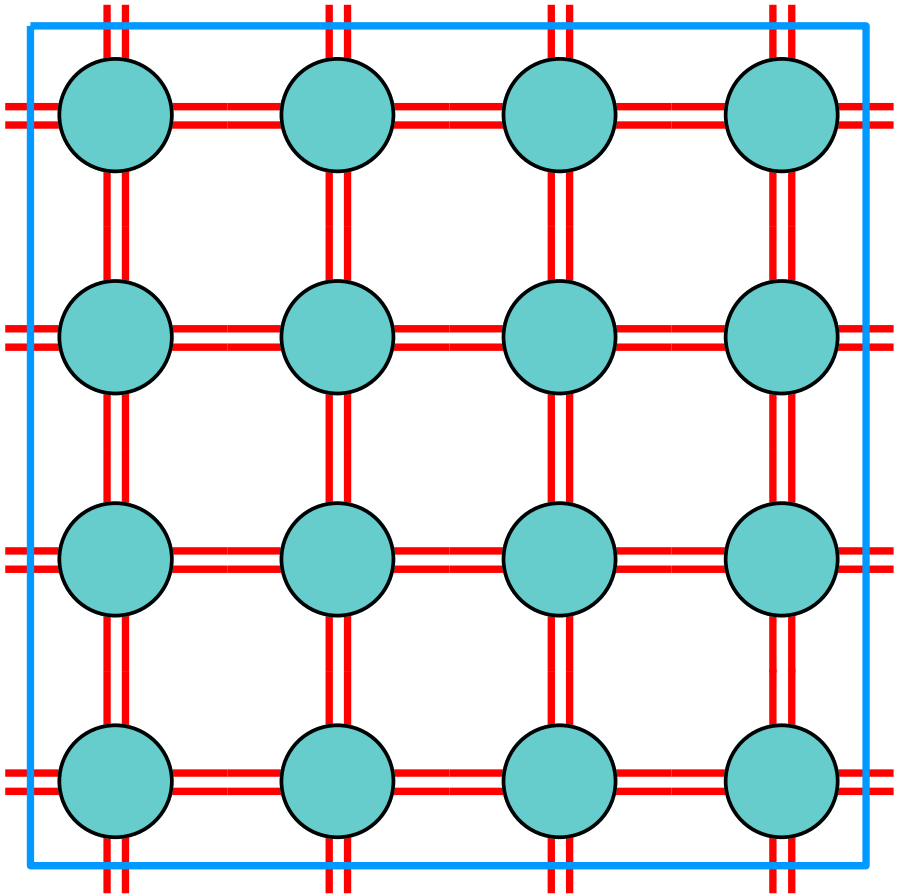
Semiconductors



(a) A simplified two dimensional illustration of a Si atom with four hybrid orbitals, ψ_{hyb}. Each orbital has one electron. (b) A simplified two dimensional view of a region of the Si crystal showing covalent bonds. (c) The energy band diagram at absolute zero of temperature.

Fig 5.1

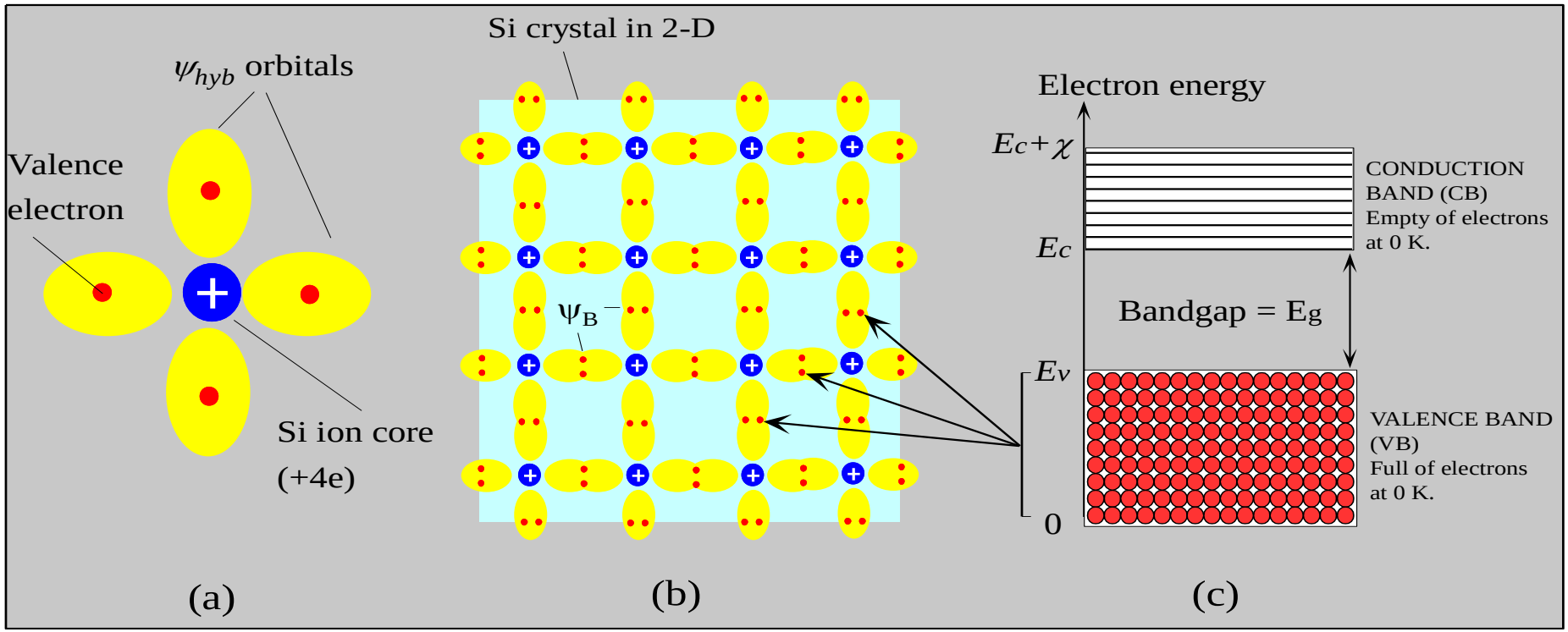
2D View of the Crystal



A two dimensional pictorial view of the Si crystal showing covalent bonds as two lines where each line is a valence electron.

Fig 5.3

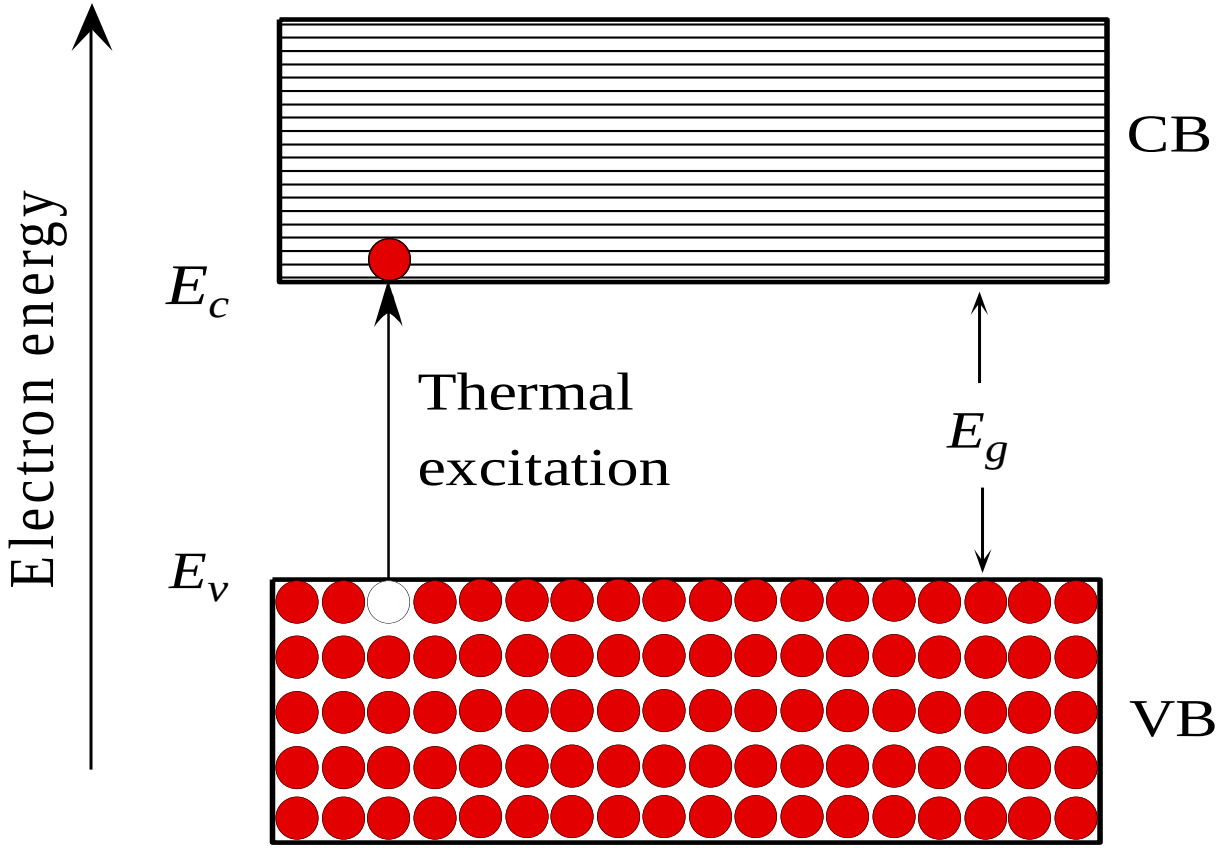
Electron Affinity



- Electron Affinity=χ=Potential Energy an electron must overcome to leave the material, starting from conduction band edge (Ec)

Fig 5.1

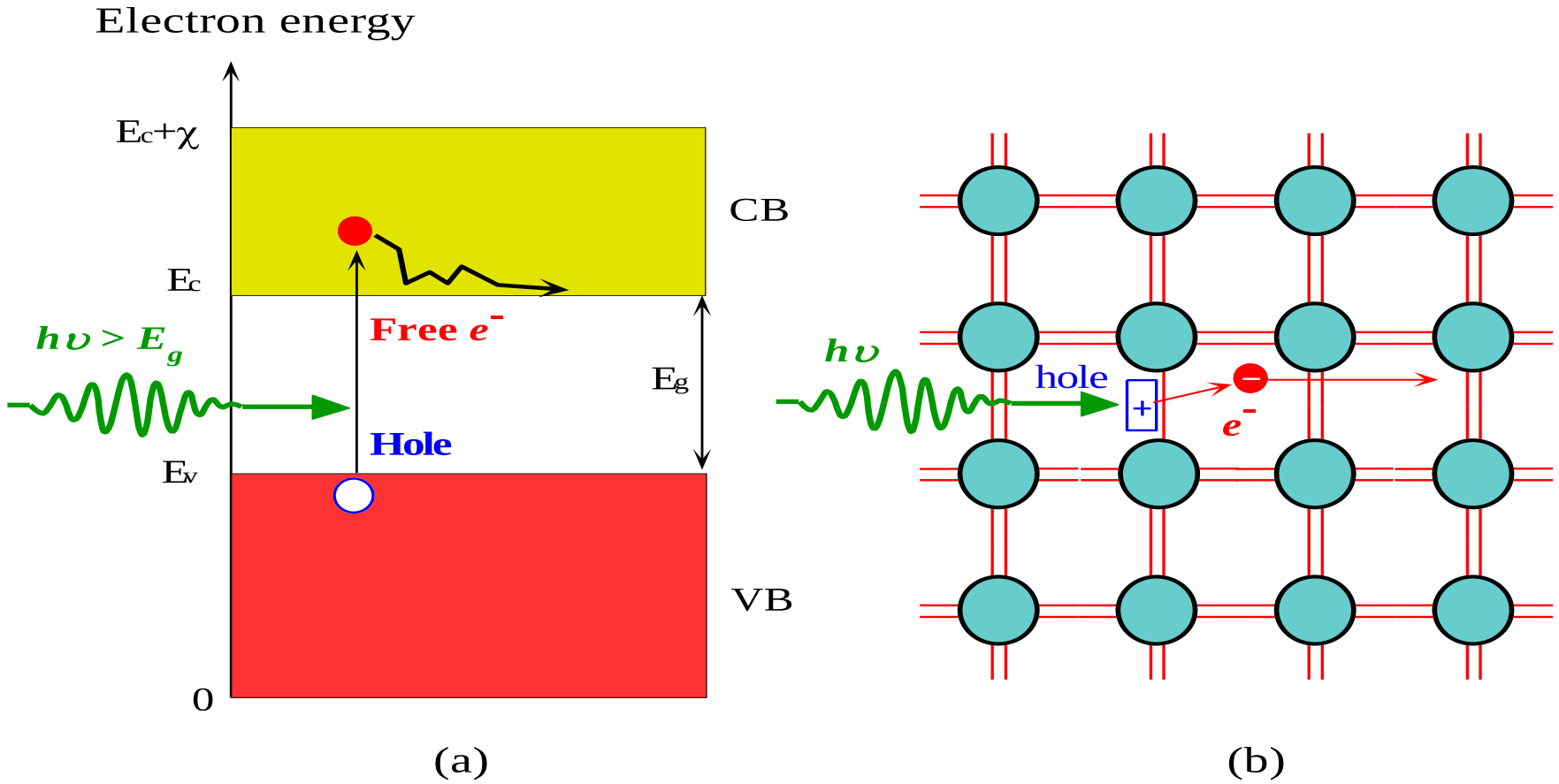
Intrinsic Semiconductors



Energy band diagram of a semiconductor. CB is the conduction band and VB is the valence band. At 0 K, the VB is full with all the valence electrons.

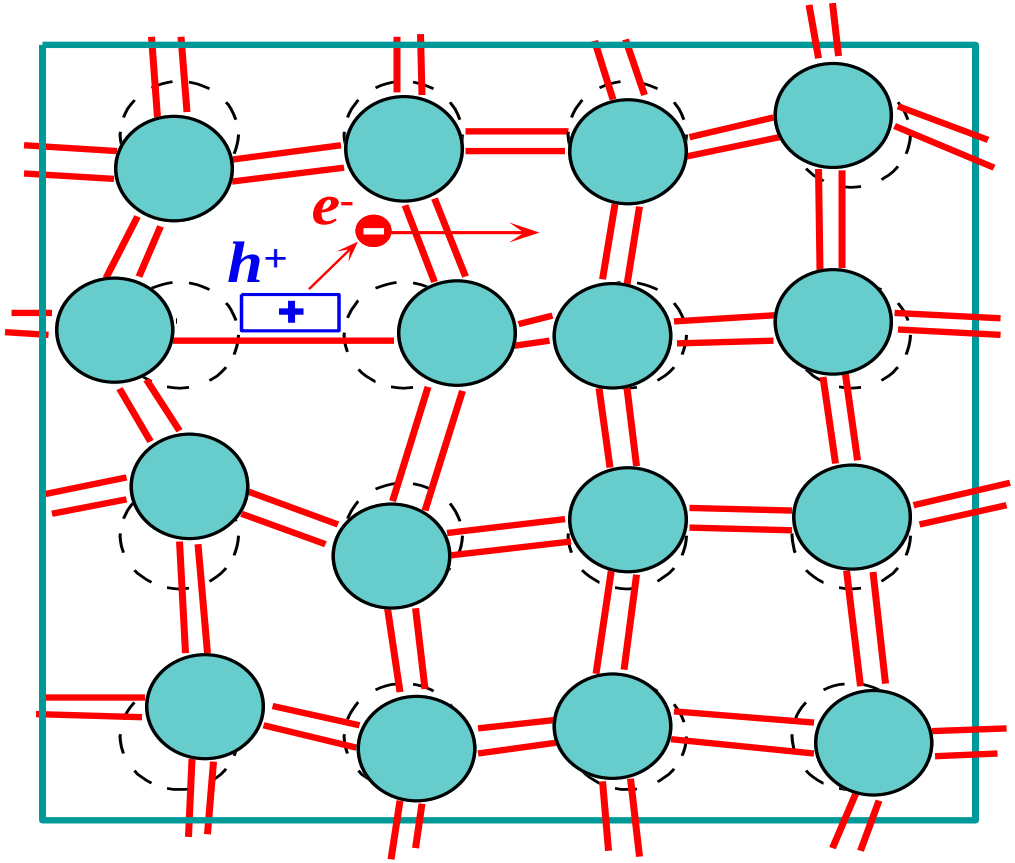
Fig 5.2

Photons Energy as a Source for Electron-Hole Pair Generation



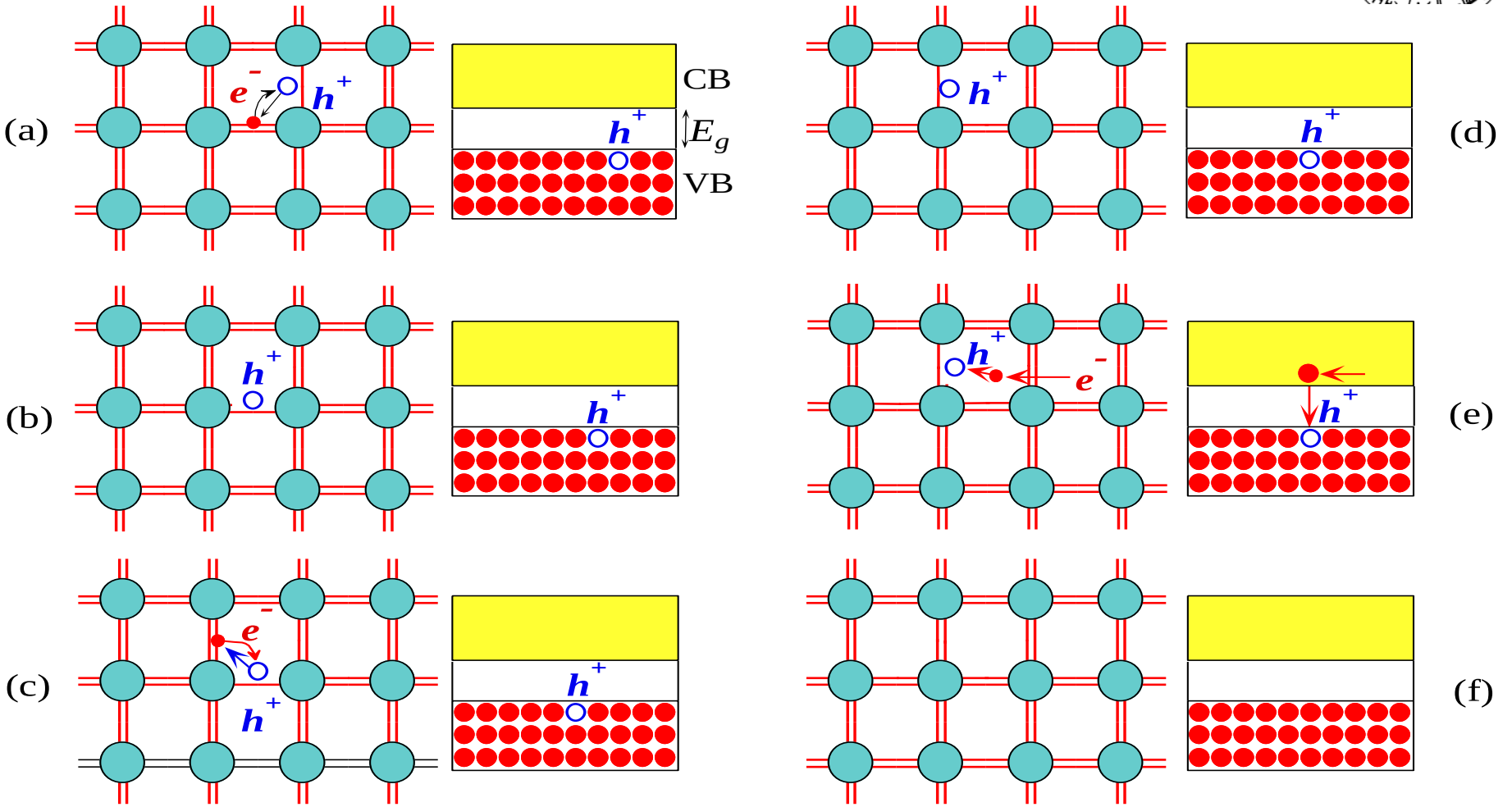
(a) A photon with an energy greater than Eg can excite an electron from the VB to the CB. (b) When a photon breaks a Si-Si bond, a free electron and a hole in the Si-Si bond are created.

Thermal Energy as a Source of Electron-Hole Pair Generations



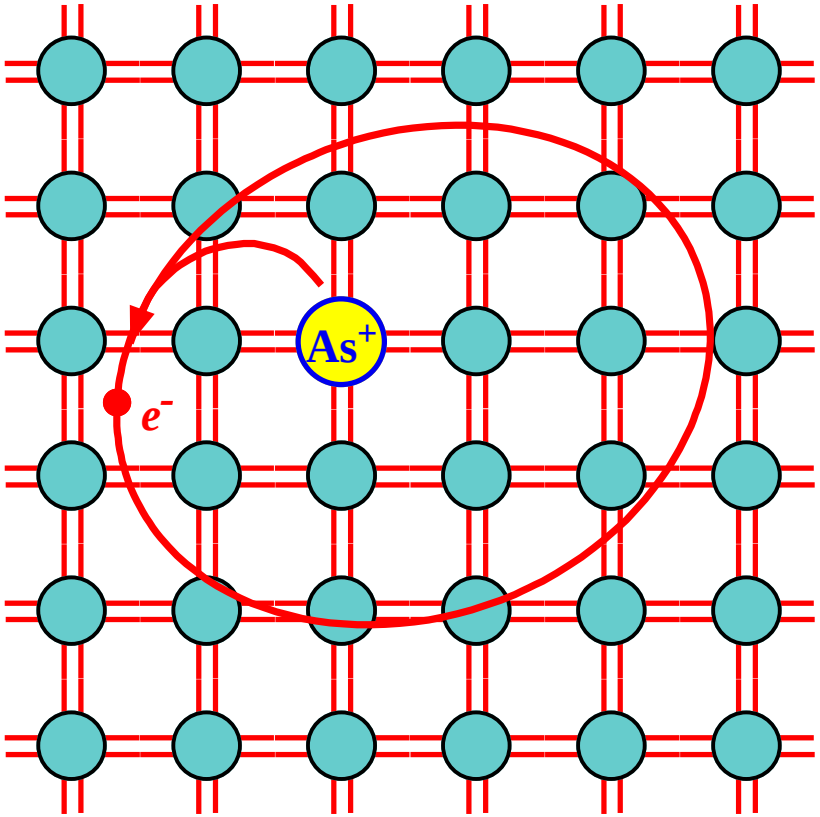
Thermal vibrations of atoms can break bonds and thereby create electron-hole pairs.

Conduction by Holes



A pictorial illustration of a hole in the valence band wandering around the crystal due to the tunneling of electrons from neighboring bonds.

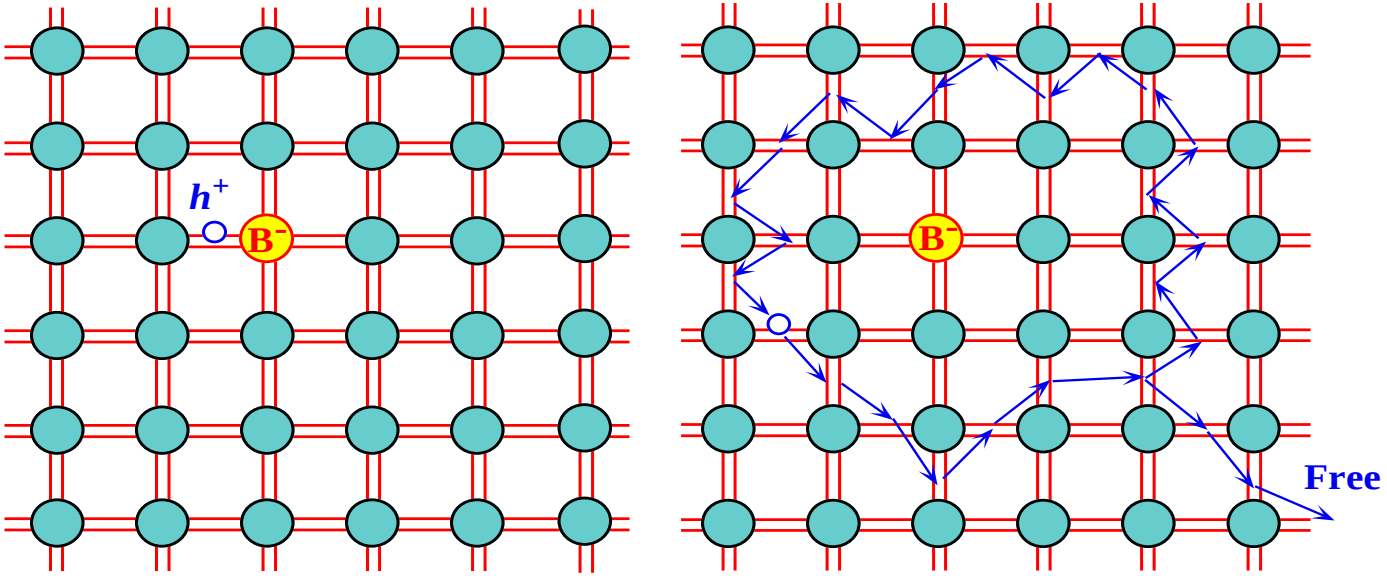
n-type Semiconductors (Extrinsic)



Arsenic doped Si crystal. The four valence electrons of As allow it to bond just like Si but the fifth electron is left orbiting the As site. The energy required to release to free fifth-electron into the CB is very small.

Fig 5.9

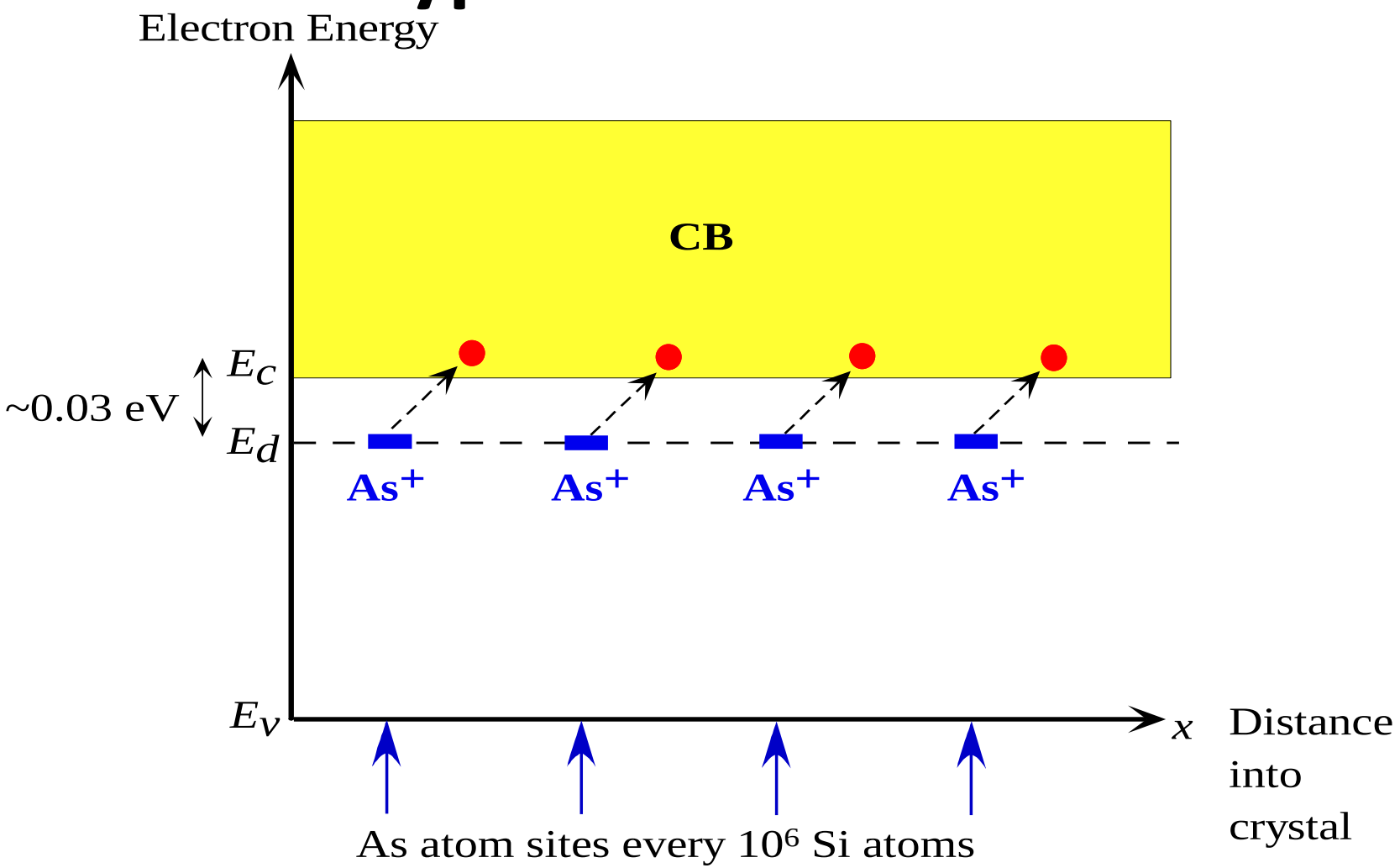
p type Semiconductors (Extrinsic)



Boron doped Si crystal. B has only three valence electrons. When it substitutes for a Si atom one of its bonds has an electron missing and therefore a hole as shown in (a). The hole orbits around the B^- site by the tunneling of electrons from neighboring bonds as shown in (b). Eventually, thermally vibrating Si atoms provides enough energy to free the hole from the B^- site into the VB as shown.

Fig 5.11

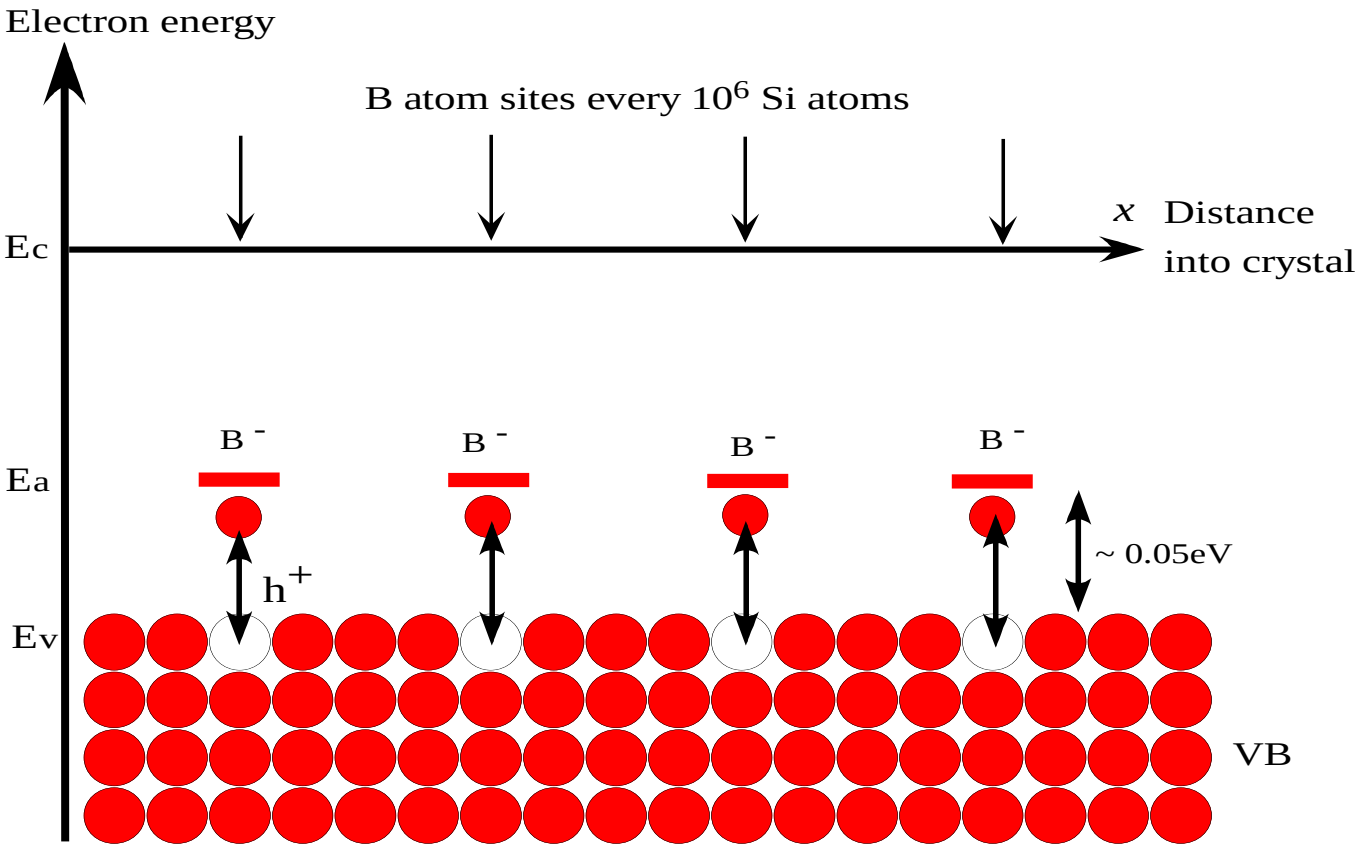
n type Semiconductors



Energy band diagram for an n-type Si doped with As. There are donor energy levels just below E_c around As^+ sites.

Fig 5.10

p type Semiconductors



Energy band diagram for a *p*-type Si doped with 1 ppm B. There are acceptor energy levels just above E_V around B^- sites. These acceptor levels accept electrons from the VB and therefore create holes in the VB.

Fig 5.12

Free Carrier Concentration (Intrinsic)

- For Intrinsic Semiconductors: i.e pure material, no external dopants:

$$n = p = n_i$$

n= number conduction electrons/unit volume

p=number of holes /unit volume

Mass Action Law:

$$np = n^2 = p^2 = {n_i}^2$$

Free Carrier Concentration (Extrinsic)

- For Extrinsic Semiconductors: i.e. with external dopants (assuming full ionization):

$$n = N_{Donor} + n_i \approx N_D. \text{ (n-type)}$$

$$p = N_{Acceptor} + n_i \approx N_A \text{ (p-type)}$$

N_{Donor}=N_D= number of donor atoms/unit volume

$N_{Acceptor}$=N_A=number of acceptor atoms /unit volume

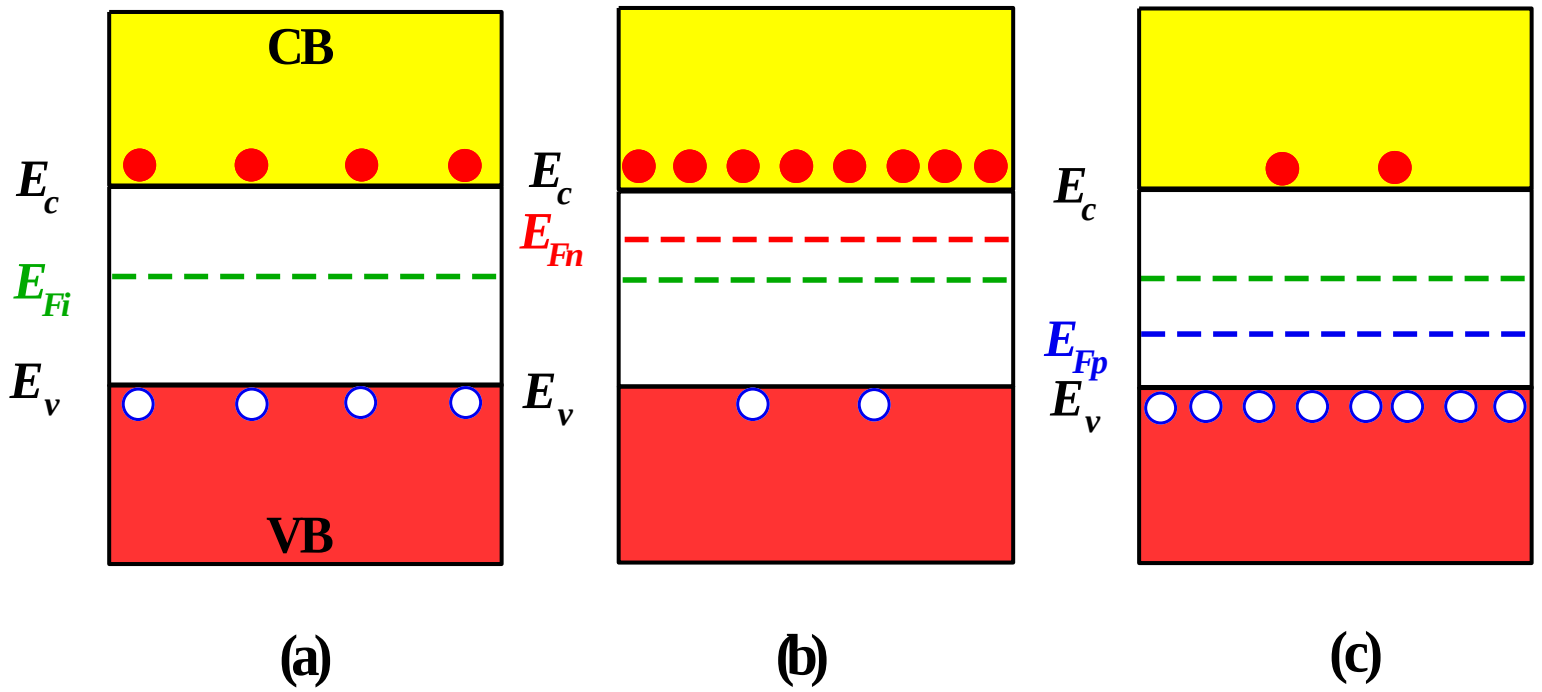
Mass Action Law also applies for extrinsic semiconductors:

$$\boldsymbol{np = n_i^2}$$

n-type: $n \approx N_D$, $p = n_i^2/n \approx n_i^2/N_D$

p-type: $p \approx N_A$, $n = n_i^2/p \approx n_i^2/N_A$

Fermi Level



Energy band diagrams for (a) intrinsic (b) *n*-type and (c) p-type semiconductors. In all cases, $np = n_i^2$

Fig 5.8

Drift Current

$$J = e\, n\, v_{de} + e\, p\, v_{dh}$$

J : current density A/m^2

n: concentration of electrons in Conduction Band cm^{-3}

p: concentration of holes in Valence Band cm^{-3}

v_{de} and v_{dh} :drift velocities "m/s"