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ECE 310 – Lecture 3

Chapter 2 of the Textbook

Basics of Semiconductor Physics

↳ Microelectronics → integrated circuits designed at μm scale

↳ Semiconductor Device Theory
" Physics "

Semiconductors

- Band diagrams
- Charge Carriers → current flow →
- Doping of semiconductor

Devices

* Diodes (pn junction)
* Transistors
  - ↳ MOSFET
  - ↳ BJT

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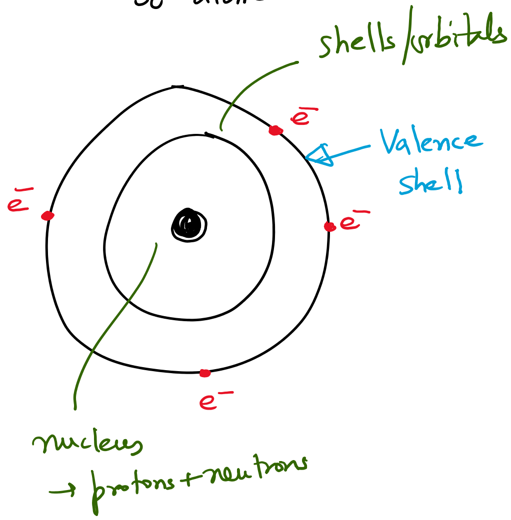
Si-atom



* Chemical activity is determined by the valence shell electrons (8 in outer shell)

Na → 1e in outer shell ← highly active donor (I)

Cl → 7e ← highly active recipient (VII)

Na^+ — Cl^- electrostatic bond

Ne → 8e ← inert inactive

3, 4, 5 — III, IV, V

4 → Si ← most popular material in microelectronics

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III	IV	V
B	C	N
Al	Si	P
Ga	Ge	As

Semiconductor → Si → IV

III – V

GaAs
GaN
InP
} compound semiconductor

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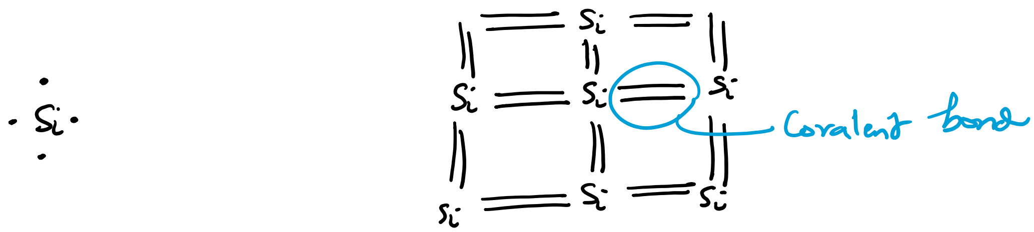
Covalent bonds

Periodic Lattice



In crystalline silicon, Si atoms form covalent bonds with their neighboring atoms.

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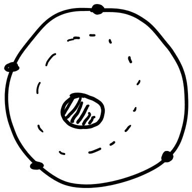
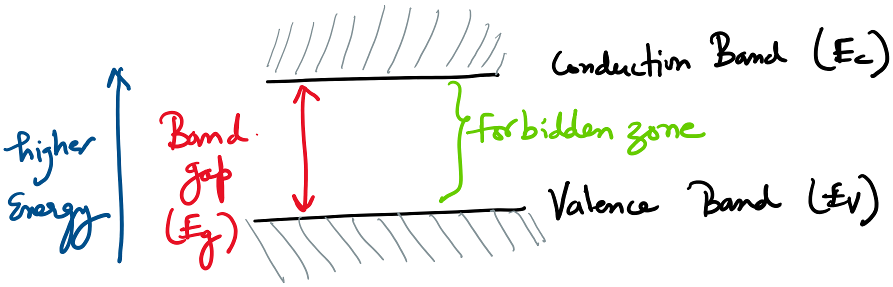
Because of periodicity in the crystal, outer shells of the atoms merge to form "Energy Bands"





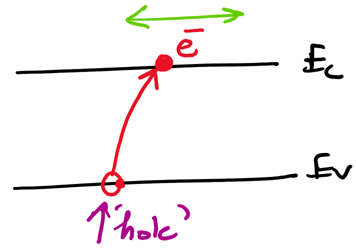
* Conduction band is responsible for electron current flow.

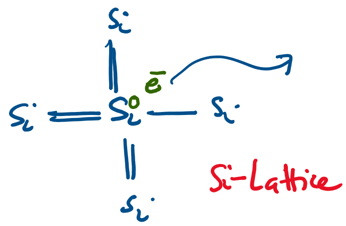
Results derived from

* Quantum physics

at $T = 0°K$

↳ valence electrons are confined to their covalent bonds





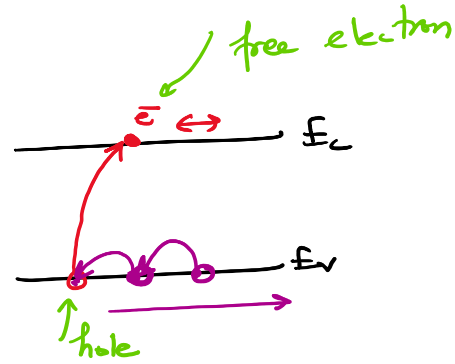
as T↑ electrons gain thermal energy and few of them break the bonds and act as charge carriers

↳ "free electrons"

Holes: the void left by the electron is called a hole

free electrons → always in the conduction band

holes → always in the valence band



→ Holes can freely move in the V.B.

↳ contributes to conduction in the semiconductor

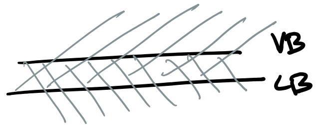
Current → (free) electrons in C.B.

Current → holes in the V.B.

* Electron-hole pair generation, recombination

Metals

Cu, Al, Au, Ag



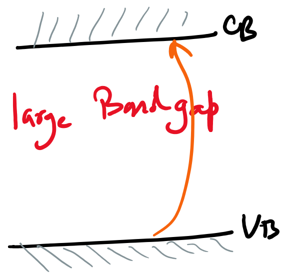
CB & VB overlap

↳ large amount of e^-s are available for conduction

↳ high conductivity (σ)

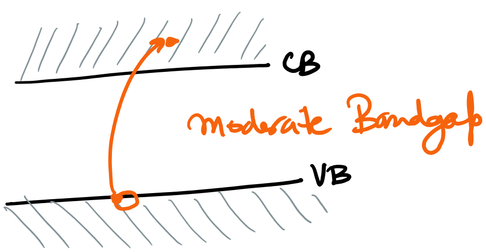
Insulators

SiO_2, plastics, wood



No conduction

Semiconductors



* easy for an electron in VB to hop to CB
* not as conductive as metals
* Can control the conductivity to create "intelligent devices"
  - ↳ logic gates
  - ↳ Amplifiers

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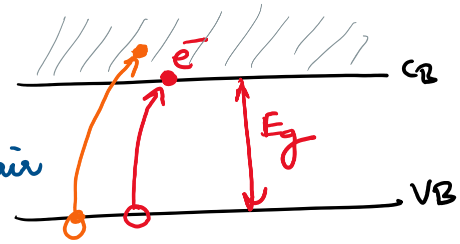
Bandgap Energy

* bandgap energy is the minimum amount of energy to create an electron-hole pair



for Si, $E_g = 1.12\ eV$ ← fundamental property of material

* How many free electrons are created at a given temperature

$$n_i = 5.2 \times 10^{15} \cdot T^{3/2} \cdot \exp\left(\frac{-E_g}{2kT}\right) \text{ electrons}/cm^3$$

↑ intrinsic carrier density

k = Boltzmann constant = 1.38×10^{-23} J/K

$E_g \downarrow \Rightarrow -E_g \uparrow \Rightarrow \exp\left(\frac{-E_g}{2kT}\right) \uparrow \Rightarrow n_i \uparrow$

$T \uparrow \Rightarrow T^{3/2} \uparrow$

$\frac{E_g}{2kT} \downarrow \Rightarrow -\frac{E_g}{2kT} \uparrow \Rightarrow \exp\left(\frac{-E_g}{2kT}\right) \uparrow$

$\Rightarrow n_i \uparrow$

Ex 2.1

$E_g = 1.12\ eV$ for Si

$T = 300K \Rightarrow 27°C$ room temperature

$n_i\big|_{T=300K} = 1.08 \times 10^{10}\ cm^{-3}$

↓ 5 orders of magnitude

$n_i\big|_{T=600K} = 1.54 \times 10^{15}\ cm^{-3}$

Silicon has 5×10^{22} atoms/cm³ $\equiv N_{Si}$

$$\frac{n_i}{N_{Si}} = \frac{10^{10}}{5 \times 10^{22}} = (5 \times 10^{12})^{-1}$$

(5×10^{12}: 5 Trillions)

⇒ only one in 5T atoms creating free electron at room temp.

$n_i \Rightarrow$ intrinsic carrier density

↳ pure crystalline Semiconductor ⇒ no impurities!

Add impurities to the semiconductor crystal (Si)

↳ Extrinsic Semiconductor.