Semiconductors

EDUCATION PHYSICS

OUTLINES

Chapter 1: * Introduction to semiconductors

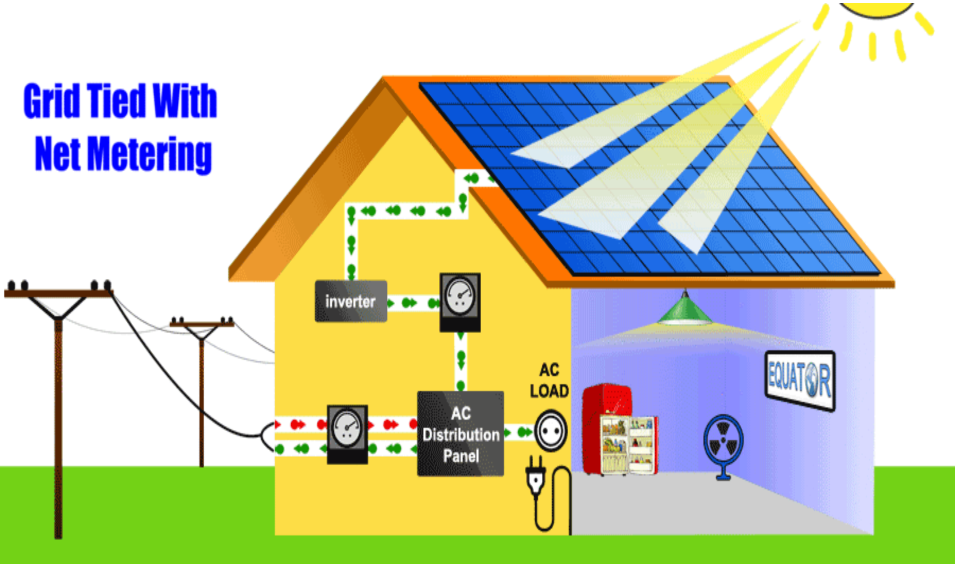
* Elements and atomic structure
* Energy band diagram
* Silicon (Si) crystalline structure
* Intrinsic and extrinsic semiconductors

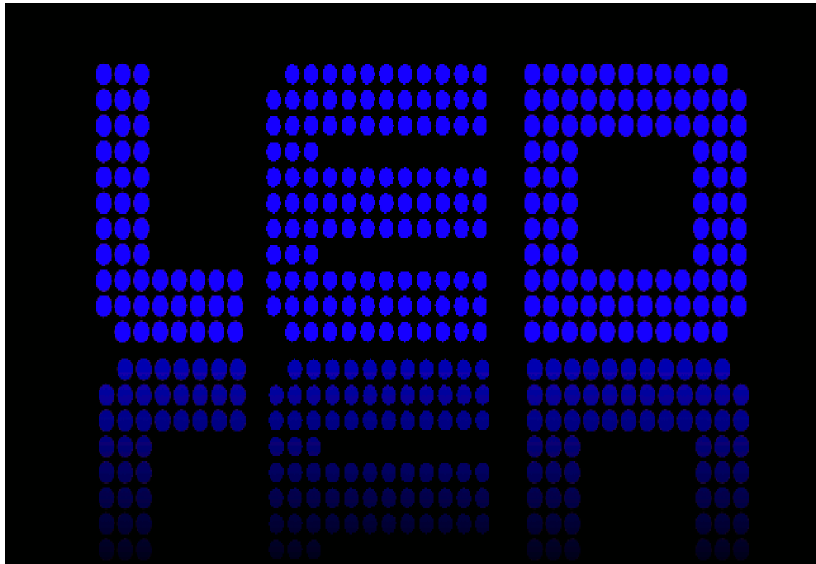
Chapter 2: Optical and Electrical properties of semiconductors

Chapter 3: Junctions and device fabrication

Chapter 4: Applications of semiconductors

- A ***semiconductor*** material has an electrical conductivity value falling between that of a conductor, such as metallic copper, and an insulator, such as glass. Semiconductors conducting properties may be altered in useful applications such as laser, solar cells, light panels and LEDs.
- A ***semiconductor*** resistance ***decreases*** as its temperature ***increases***, which is the behavior opposite to that of a metal.



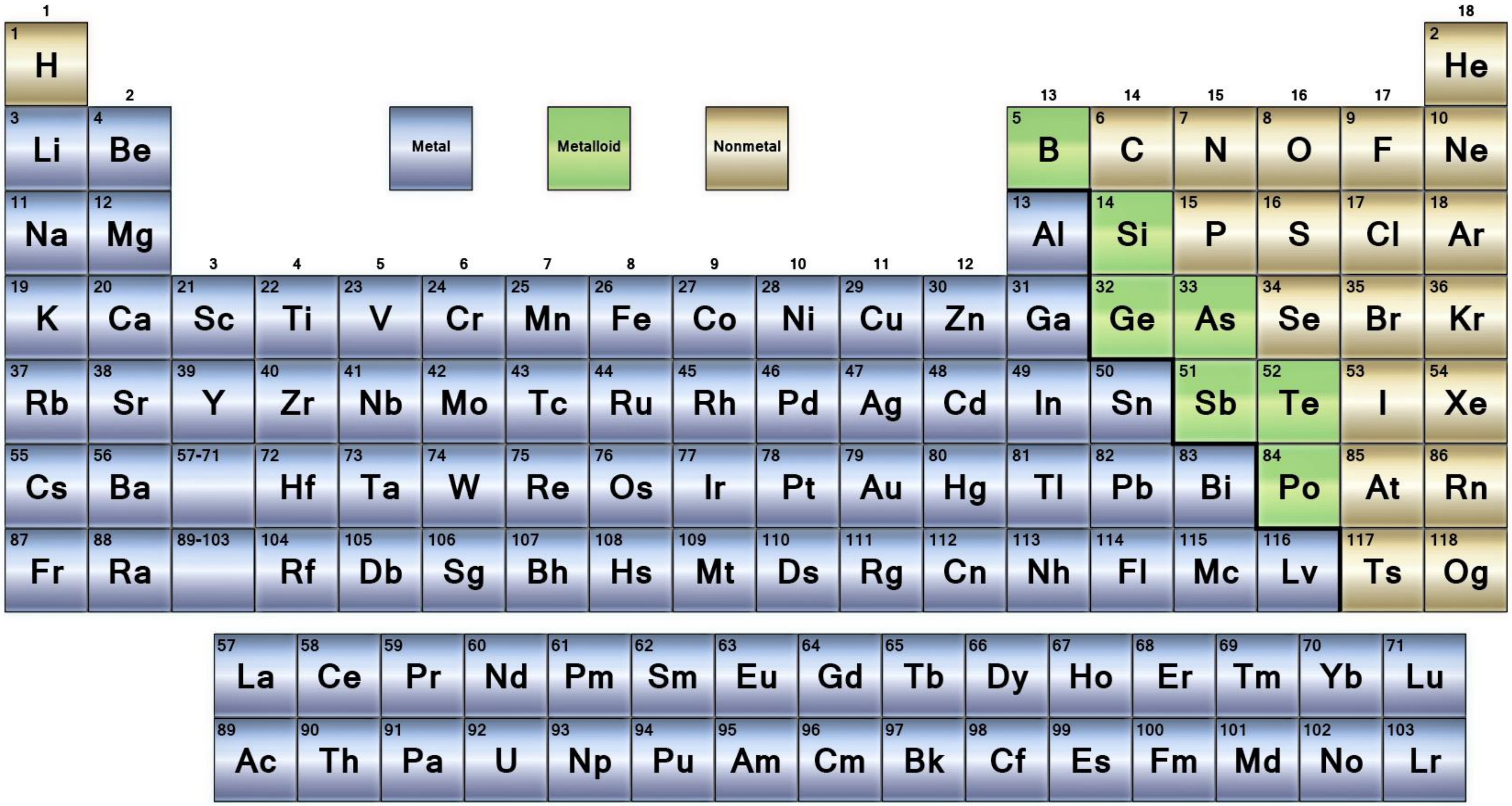


- Silicon is a critical element for fabricating most electronic circuits.

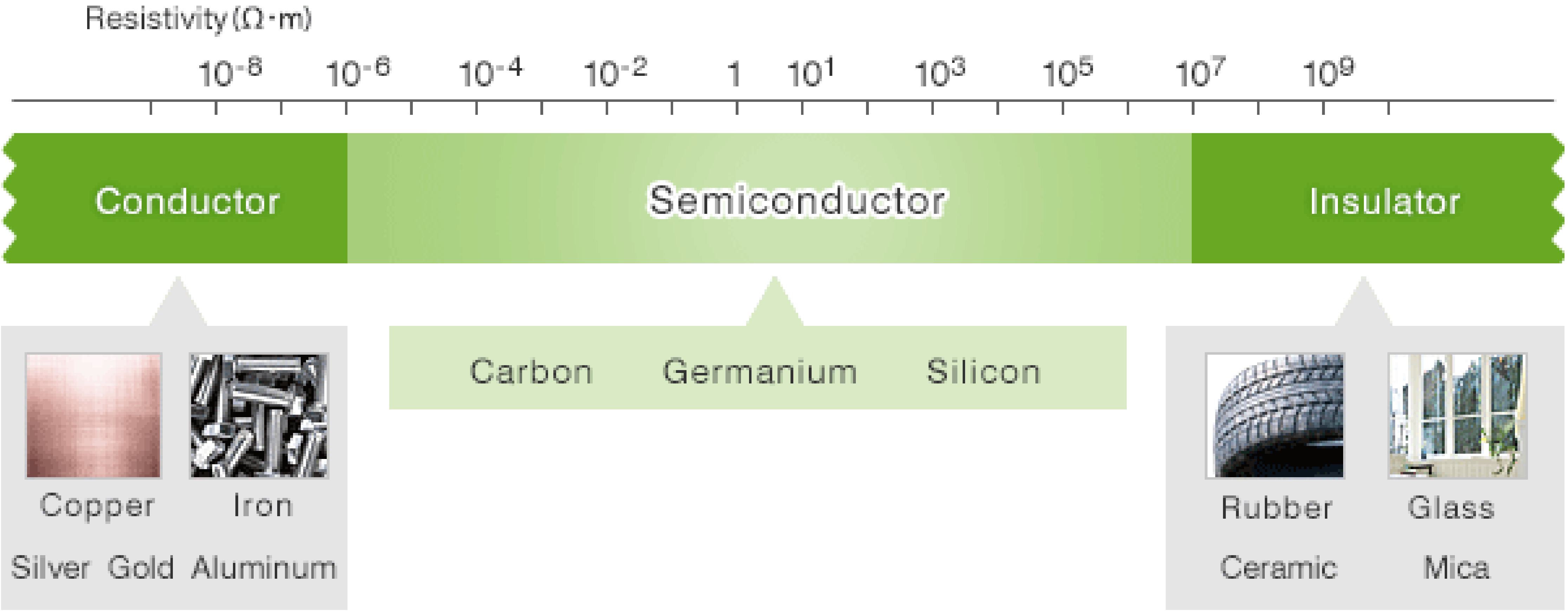
- **The most outstanding feature of semiconductors is that** ***the electrical properties of a semiconductor material can be modified.***


Fire Smoke Detector Alarm

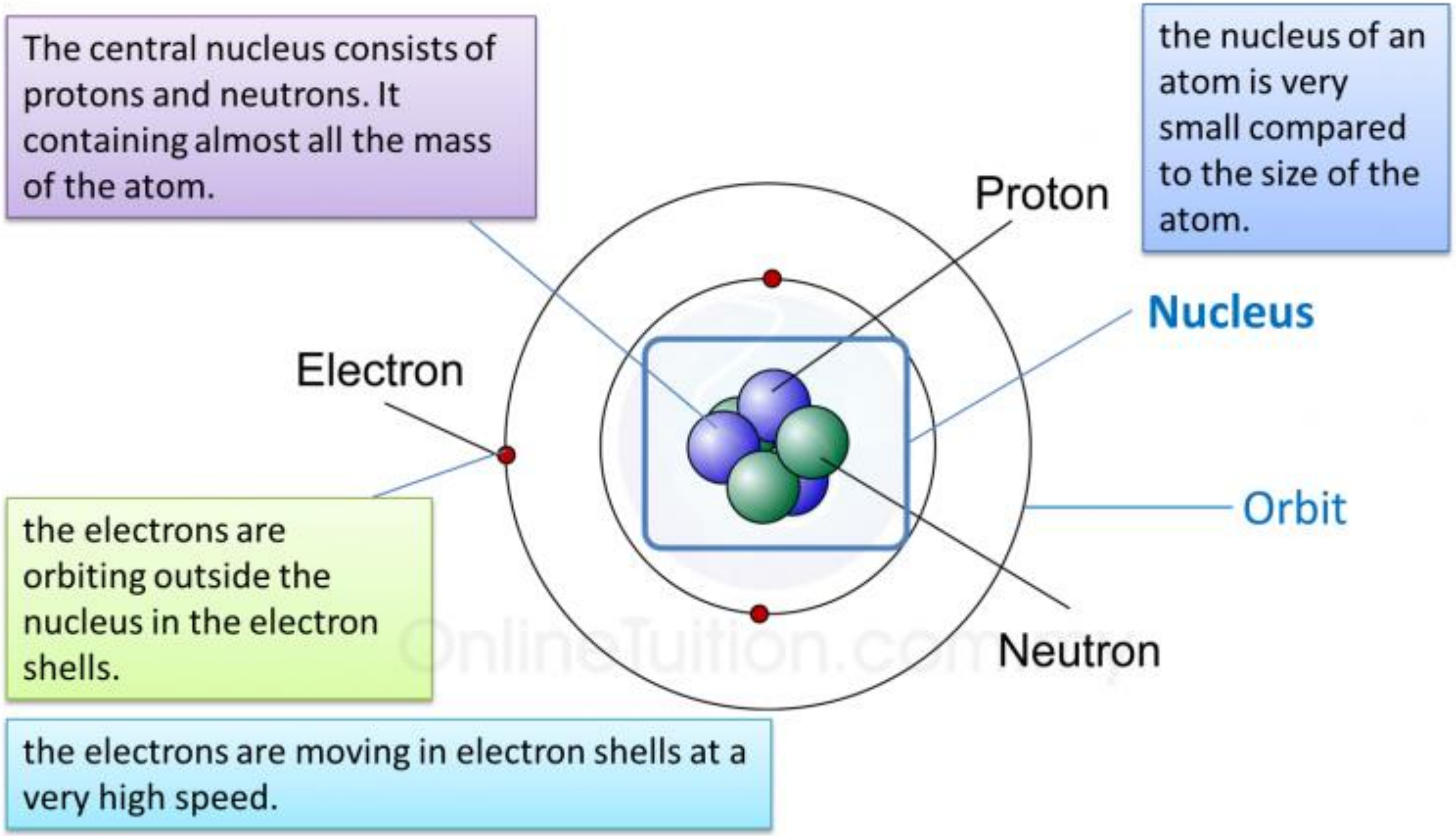
Semiconductors are especially important as varying conditions like temperature, pressure, … darkness can easily change their conductivity. The combination of various semiconductor types together generates devices with special electrical properties, which allow control of electrical signals



Semiconductor's conductivity



The structure of Atoms



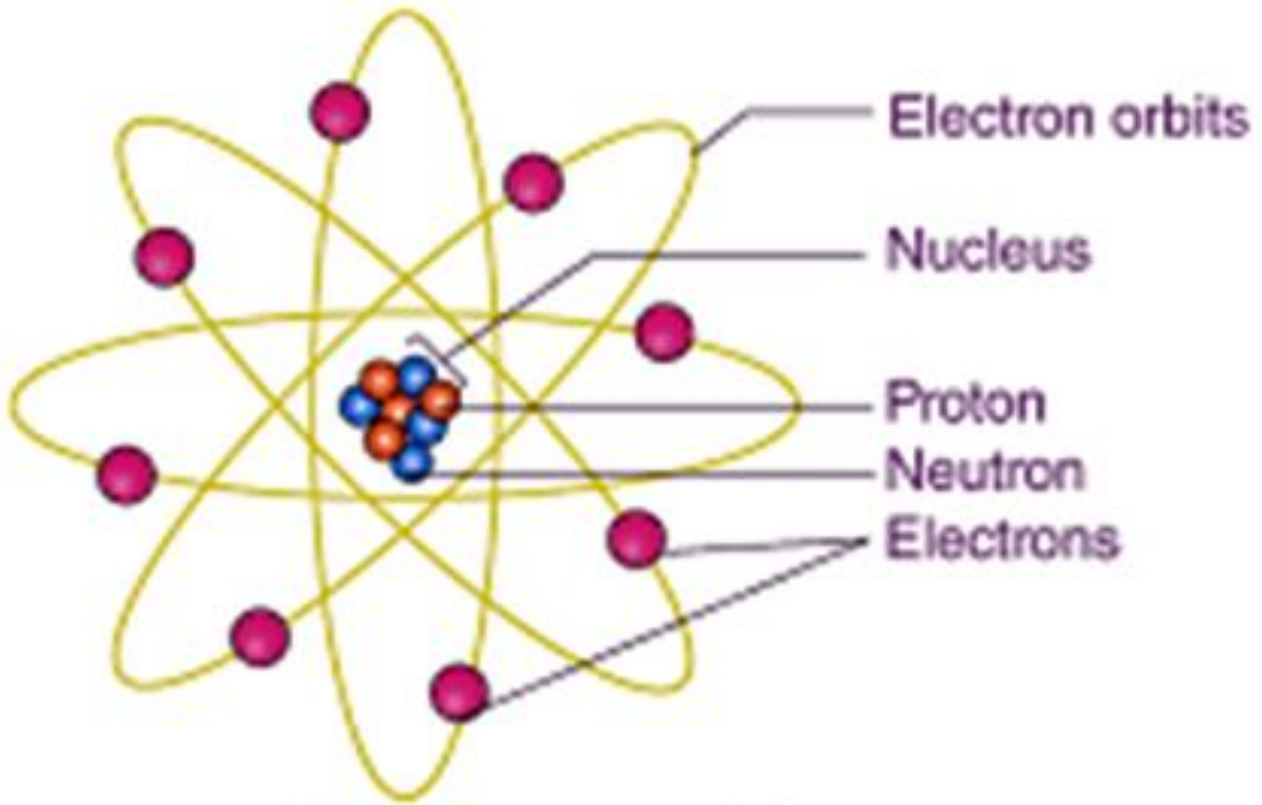
Structure of matter

* Atoms are made of electrons, protons and neutrons.

* Solid materials are classed, from the standpoint of electrical conductivity, as conductors, semiconductors or insulators.

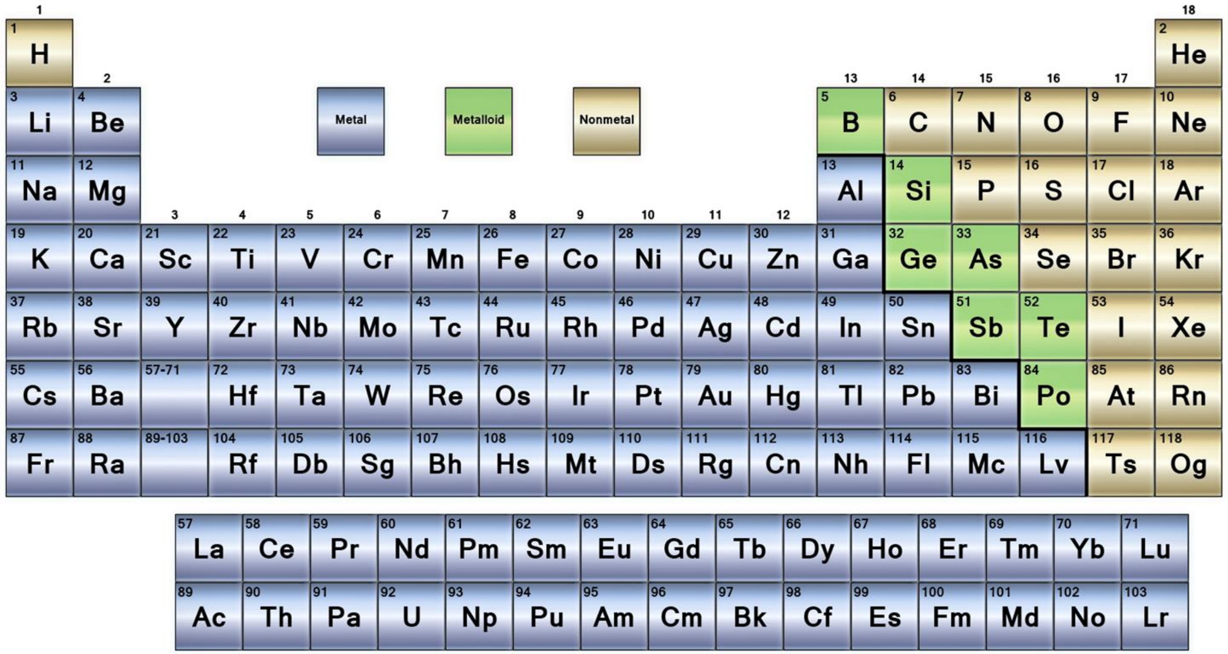
* Conductivity depends on the number of electrons in the valence orbit.

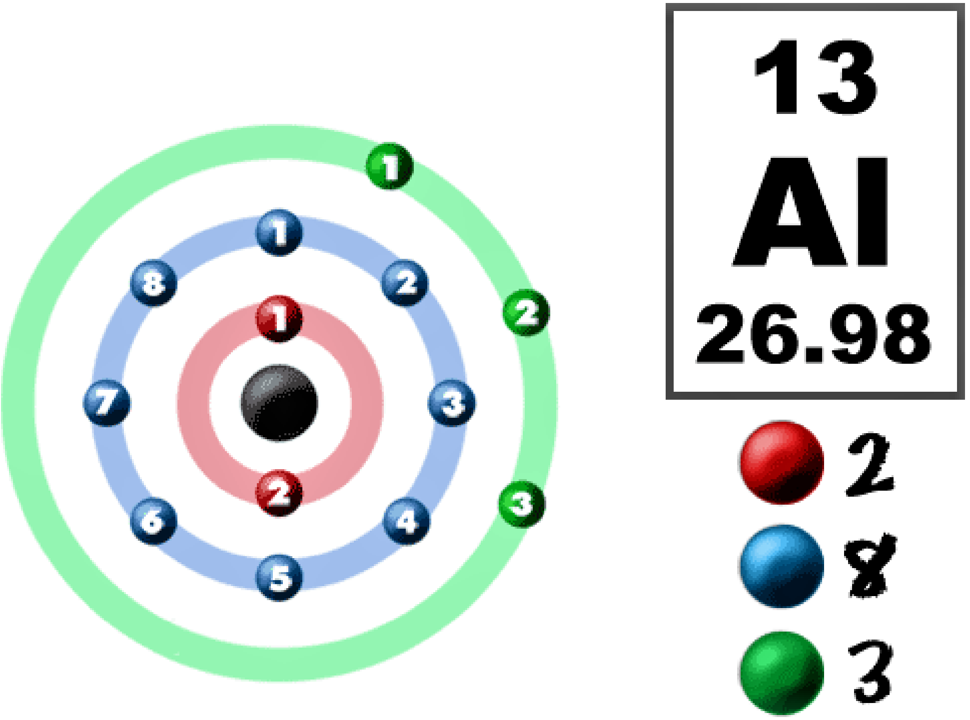
* To be conductor, the substance must contain mobile electrons that can move freely between the atoms.



The Structure of Atom

Structure of matter

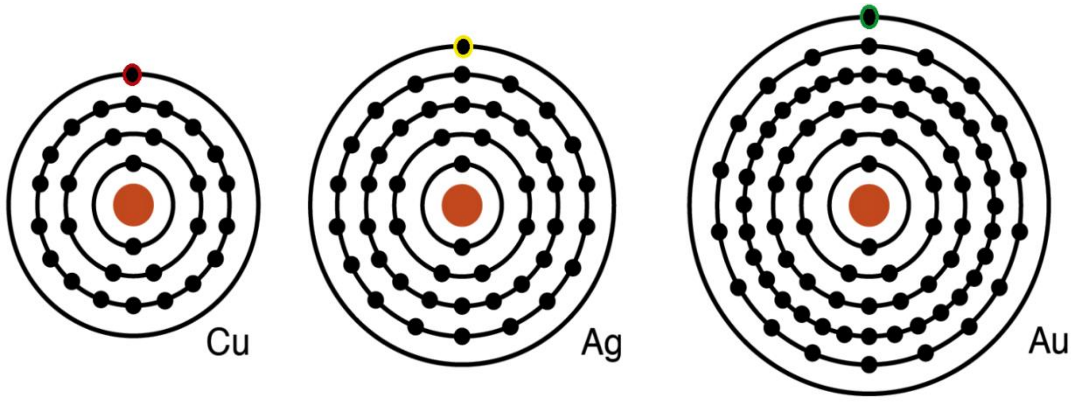




Structure of matter

Conductive Order of Metals

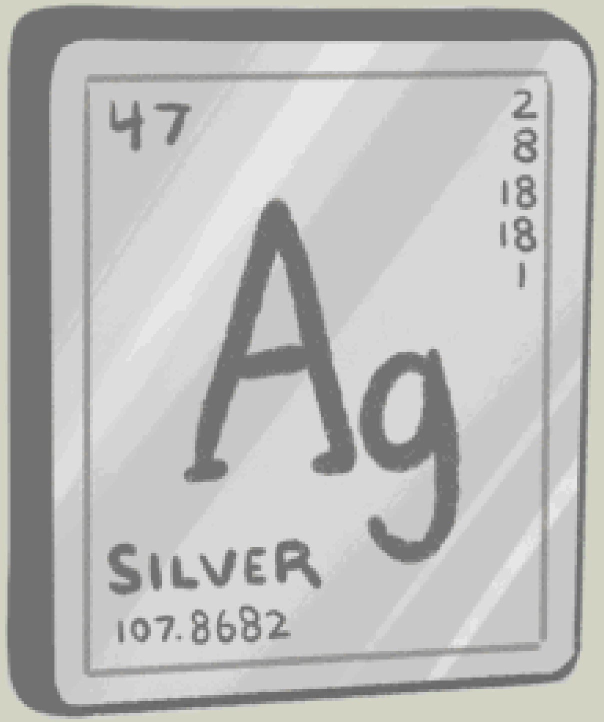
1	SILVER (PURE)
2	COPPER (PURE)
3	GOLD (PURE)
4	ALUMINUM
5	ZINC
6	NICKEL
7	BRASS
8	BRONZE
9	IRON (PURE)
10	PLATINUM
11	STEEL (CARBONIZED)
12	LEAD (PURE)
13	STAINLESS STEEL



copper Silver Gold

THE MOST CONDUCTIVE ELEMENTS

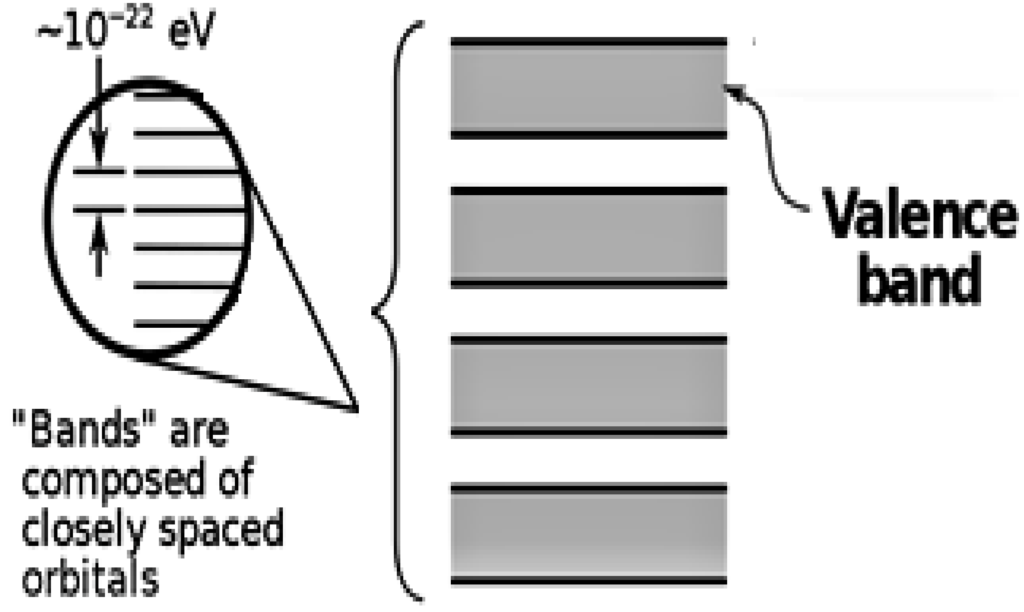
The most conductive elements of the periodic table are metals. Silver has the highest electrical conductivity.



1. Silver
2. Copper
3. Gold
4. Aluminum
5. Beryllium
6. Calcium
7. Magnesium
8. Rhodium
9. Sodium
10. Iridium

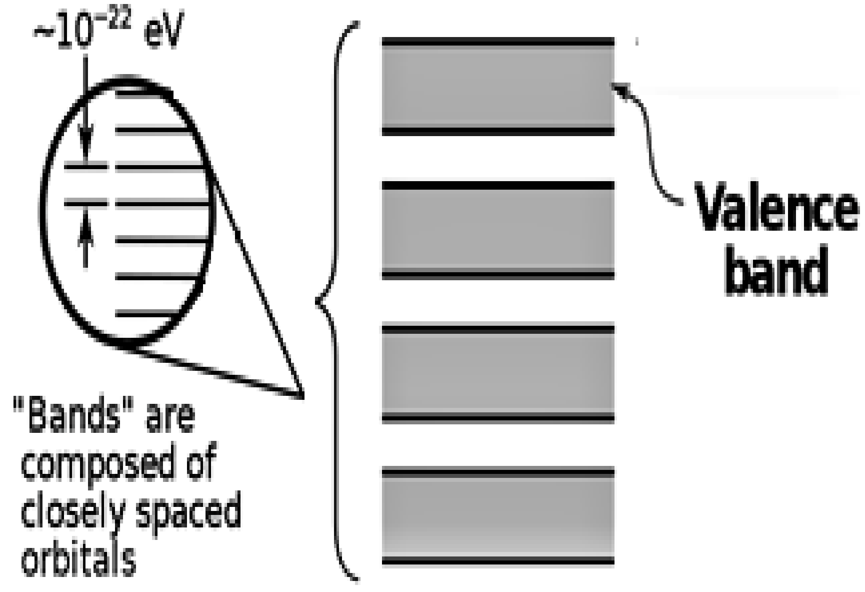
Electronic band structure

- As it was explained (agreed) electrons are responsible to determine material electrical conductivity. Therefore, at this point, it is very important to understand the term band in order to understand the concept of band structure.
- Basically, **band** can be understood as a region that contains a group of **levels!** As we are studying material conductivity thus, **levels** refers to **energy levels of electrons**.
- Now, it becomes clear to proceed with the concept "electronic band structure"



Band structure (Electronic band structure)

❖ The **electronic band structure** (or simply **band structure**) of a solid describes range of energy levels that electrons may have within it, as well as the ranges of energy that they may not have (called; ***band gaps* or *forbidden bands*).**



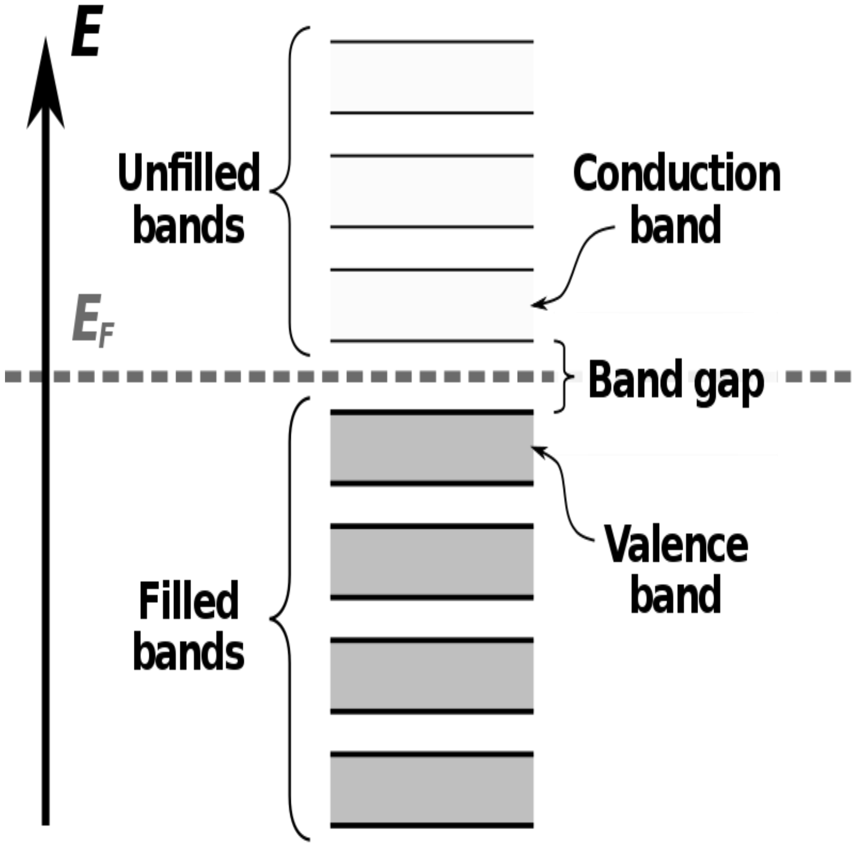
- **Energy band** is a range (levels) of energies associated with the states (Density of states) of electrons of the atoms in a solid.

- According to Pauli exclusion principle; each atomic orbital split into *N* discrete orbitals, each with a different energy.

- Since the number of atoms in a macroscopic piece of solid is a very large number (N~10^{22}), the number of orbitals is very large and thus they are very closely spaced in energy (of the order of 10^{-22} eV).

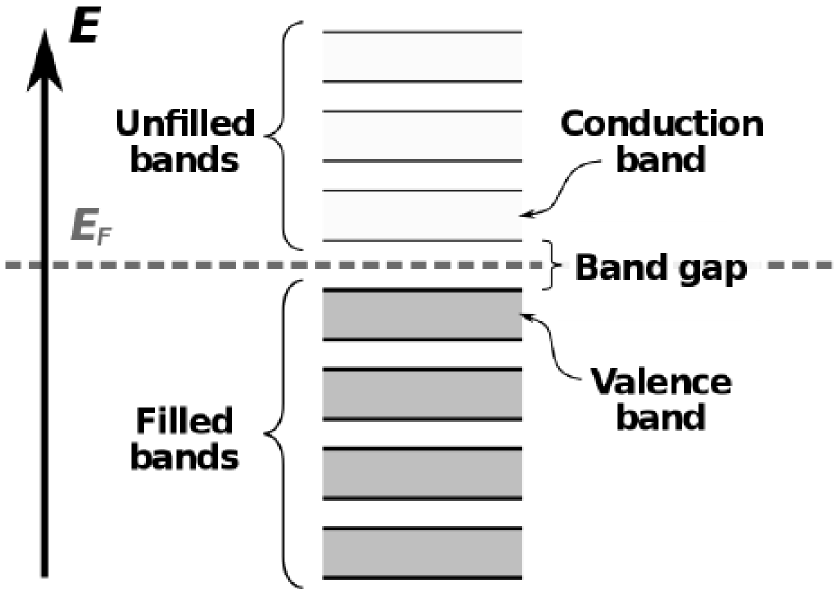
- The energy of adjacent levels is so close together that they can be considered as a continuum, known as an energy **band**.

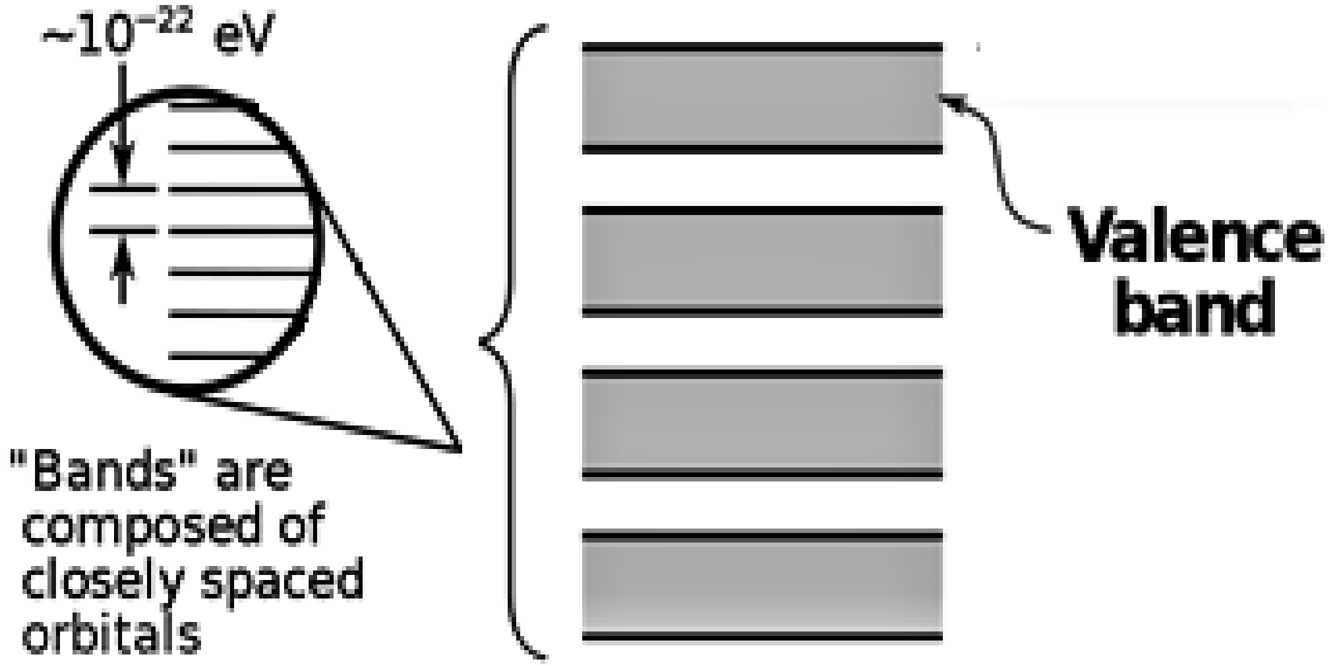
- This formation of bands is mostly a feature of the outermost electrons (**valence electrons**) in the atom, which are the ones involved in chemical bonding and **electrical conductivity.**



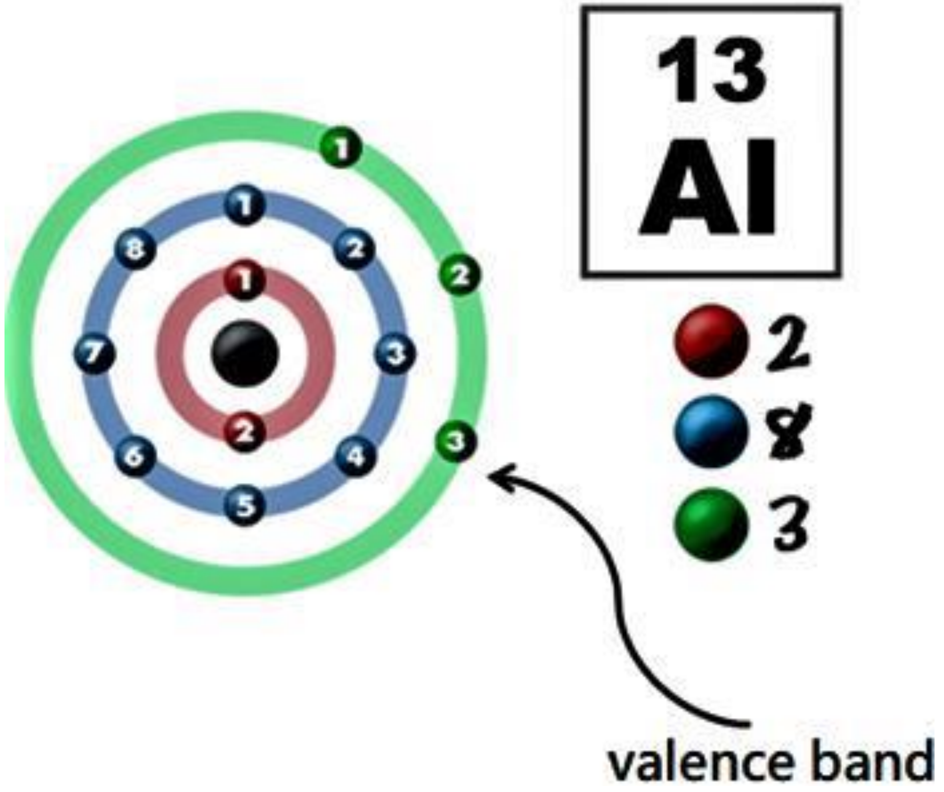
A schematic diagram shows the electronic band structure for a semiconductor

Band structure

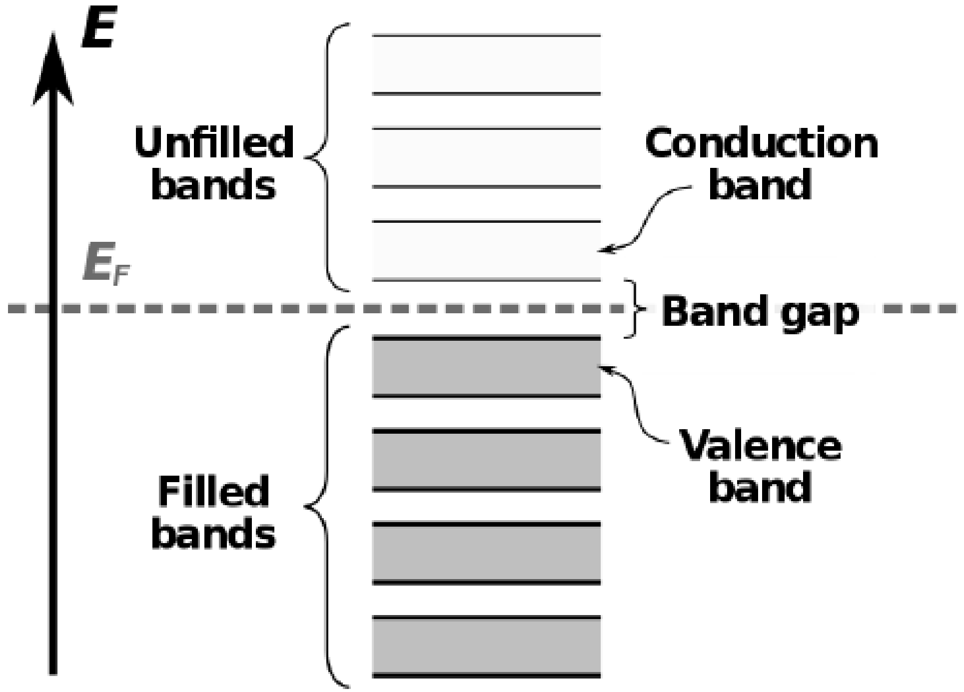




Atomic structure *Vs* Band structure



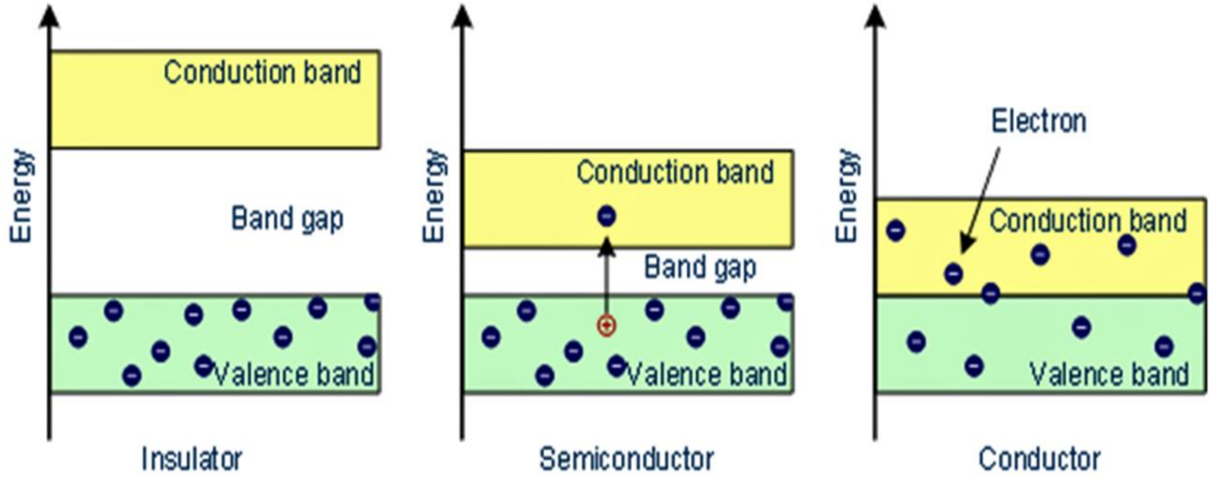
❖ It is important because it helps us to understand why materials have different properties and how are they bonding (defining the structure).
❖ It shows the arrangement (distribution) of the electrons



- Describes the range of energy levels that electrons may have within it, as well as the ranges of energy that they may not have (called ***band gaps* or *forbidden bands***).
- According to that, **energy band** is a range (levels) of energies associated with the states (Density of states) of electrons of the atoms in a crystal (solid).

Valence band and conduction band

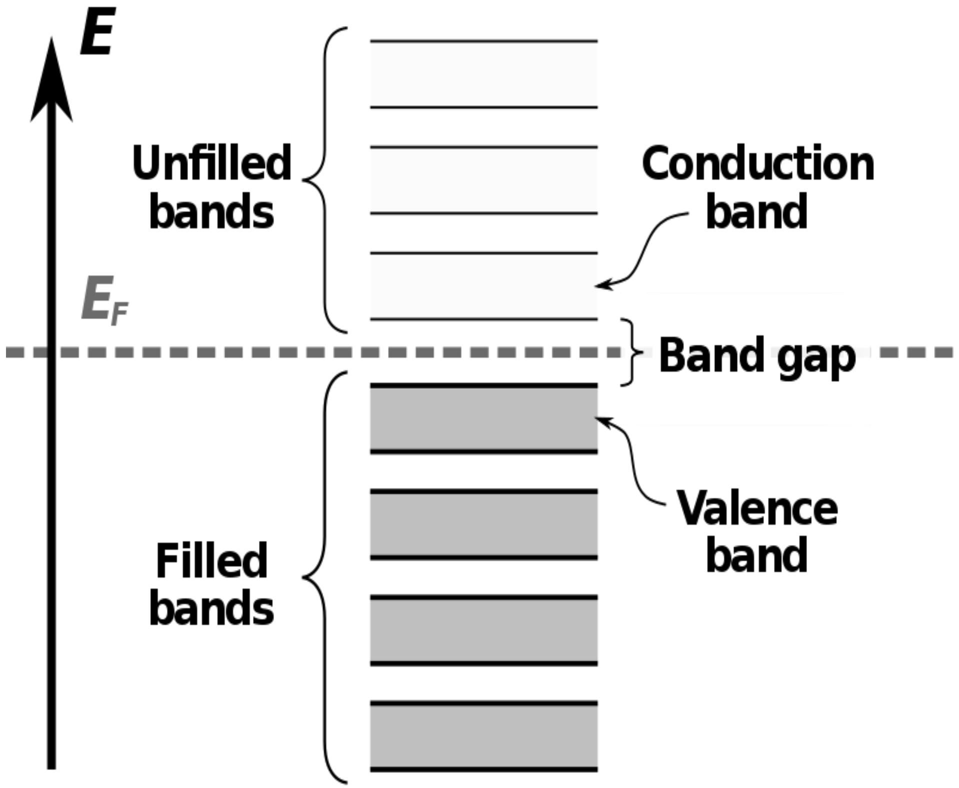
- Solids are consisted of huge tiny particles known as atoms that are surrounded by electrons.
- Electrons at the outermost orbital (shell) of atoms determine solids conductivity, known as ***valance*** electrons.
- Based on that, two bands can be defined that are describing material band structure.



Valence band, band gap and conduction band for semiconductors

- **Energy band** is a range (levels) of energies associated with the states (Density of states) of electrons of the atoms in a solid.
- In a semiconductor, there is a valence band containing many states that electrons occupy.
- Unlike conductors, semiconductors have a defined (about an order electron.Volts *eV*) gap known as energy gap (E_g) which separates the valance band and the conduction band.
- Electrons require **an amount of energy** to be excited from the valance band and overcome the energy gap to promote conductivity.

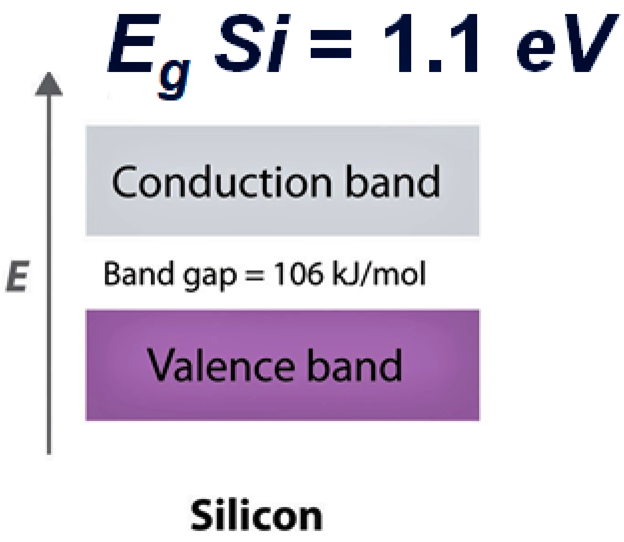
- The amount of energy need to conduct energy is **higher than or equal** to the energy of the gap.

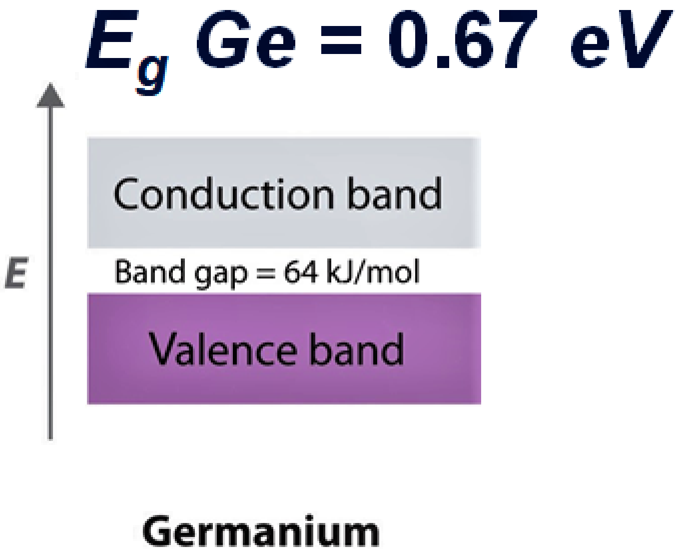


- The term "**band gap**" refers to the energy difference (in electron volts ***eV***) between the highest occupied energy state of the valence band and the lowest unoccupied state of the conduction band.

Band gap indicative of the electrical conductivity of a material.

- The required energy differs with different materials (Different applications). Electrons can gain enough energy to jump to the conduction band by absorbing either a phonon (heat) or a photon (light).





The difference between E_c and E_v is the bandgap energy or energy gap, E_g.

For silicon, the energy gap is about 1.1 eV.

The band-gap energy can be determined by measuring the absorption of light by the semiconductor as a function of the photon energy, *hν*. The light is strongly absorbed only when *hν* is larger than E_g

USEFUL RELATIONSHIP:

$$E_g = \frac{1240\ \text{eV}.nm}{\lambda\ (nm)}$$

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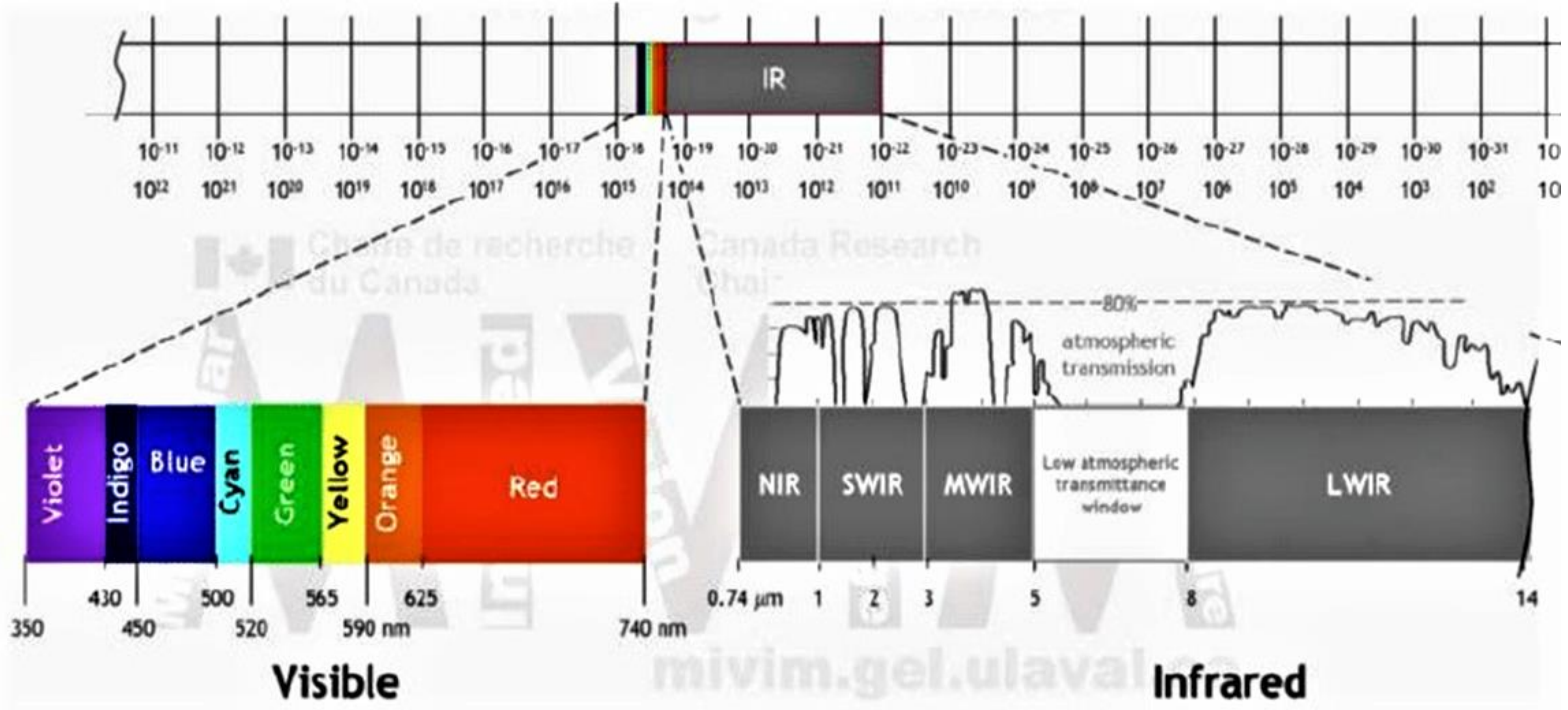
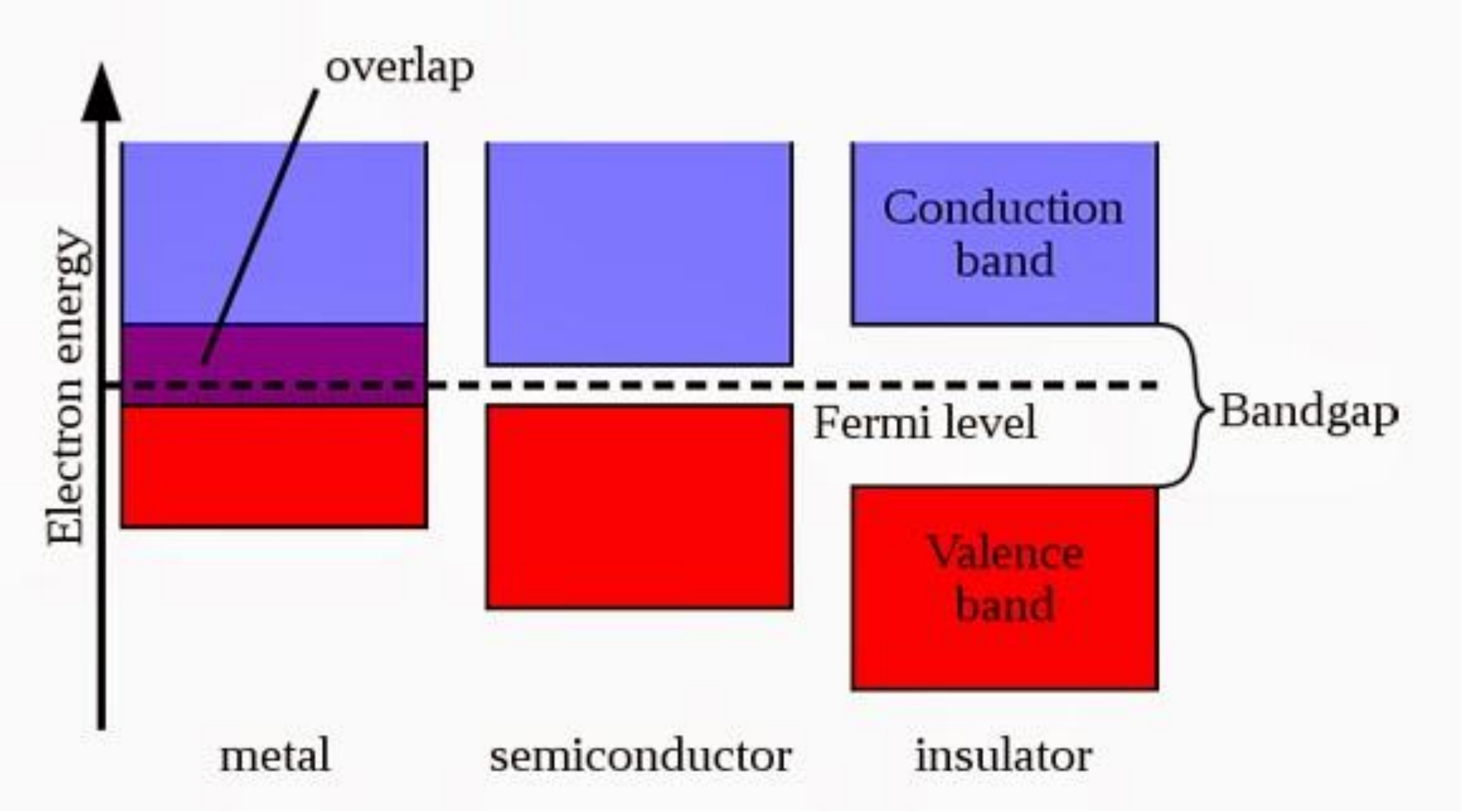


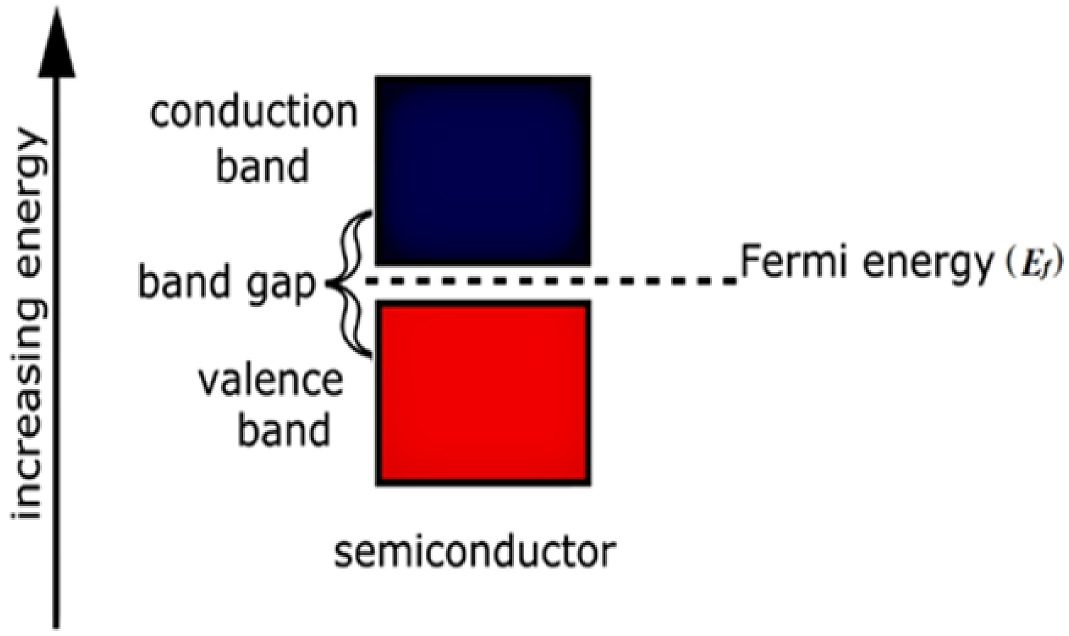
Light colors Vs wavelengths

Type	Name	Wavelength
Ultraviolet	UV-C	100nm-280nm
	UV-B	280nm-315nm
	UV-A	315nm-400nm
Visible light	Purple	400nm-435nm
	Blue	435nm-480nm
	Patina	480nm-490nm
	Blue green	490nm-500nm
	Green	500nm-560nm
	Yellow green	560nm-580nm
	Yellow	580nm-595nm
	Orange	595nm-610nm
	Red	610nm-750nm
	Red purple	750nm-800nm
Infrared	IR-A	800nm-1400nm
	IR-B	1400nm-3000nm
	IR-C	3000nm-100万nm

band theory.mp4


overlap
Electron energy
Conduction band
Fermi level
Bandgap
Valence band
metal
semiconductor
insulator

- Fermi level represents electrons (charged particles) population with energy level at which no electrons (charged particles) will have enough energy to rise above at absolute zero.
- Fermi level follows charge carriers at highest level of energy
- Fermi level is important to be known to estimate materials conductivity.
- In semiconductors, the position of the Fermi level is within the band gap. For pure semiconductor it is approximately in the middle of the band gap.

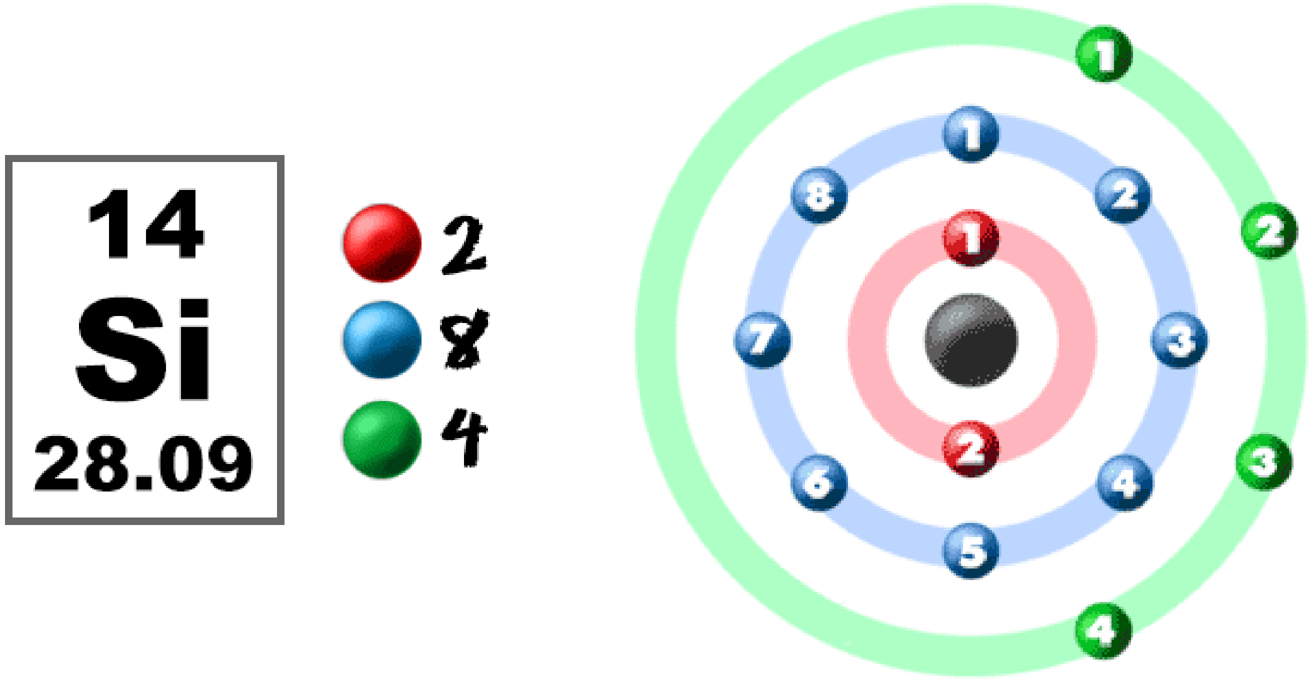


$$f(E) = \frac{1}{1 + e^{(E - E_f)/k_B T}}$$

Silicon (Si) crystal structure

- The atomic structure of a semiconductor determines its conductivity due to electrons transitions within the crystal

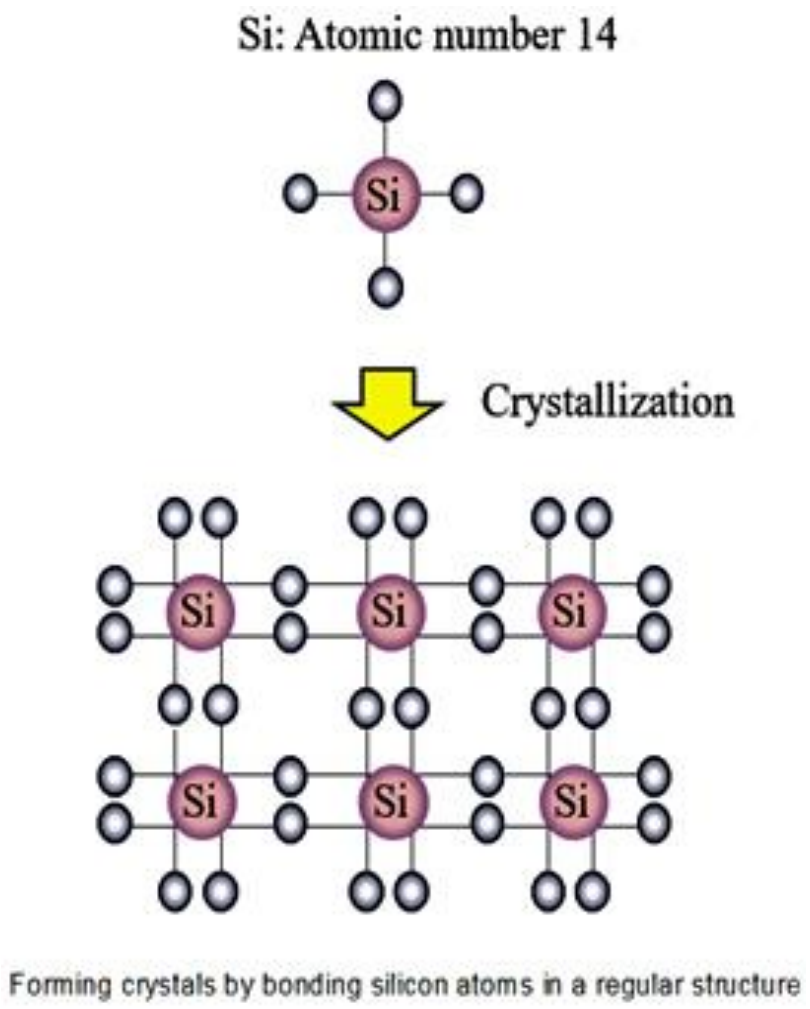
- Silicon is a chemical element with the symbol Si and atomic number 14. A silicon atom has 14 electrons around the nucleus, and of these, there are 4 valence electrons on the outermost orbital



Silicon (Si) crystal structure

- When silicon atoms come close to each other, each valence electron of atom is shared with the neighboring atom and each valence electron of neighboring atom is shared with this atom.

- Likewise, each atom will share four valence electrons with the four neighboring atoms and four neighboring atoms will share each valence electron with this atom. Therefore, total eight electrons are shared. Silicon atom forms four covalent bonds with the four neighboring atoms.



The figure shows howe silicon atoms are bonding to form a silicon crystal)

Electrical conduction in semiconductors

- There are two general categories of semiconductors:

Intrinsic (pure) semiconductors, which are composed of only one material, and

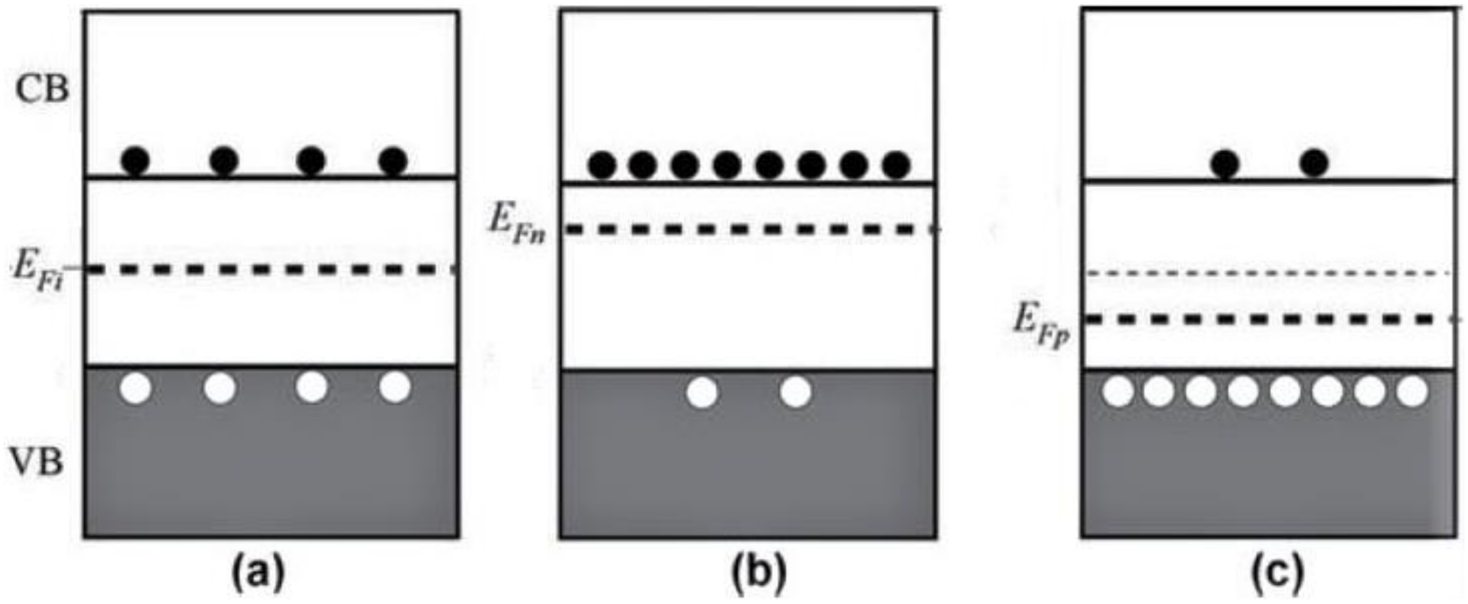
Extrinsic (impure) semiconductors, which have had other substances added to them to alter their properties

In semiconductor production, the process of creating extrinsic semiconductors by adding substances to a pure semiconductor for the purposes of modulating its properties is known as doping. In an intrinsic semiconductor under thermal equilibrium, the concentrations of electrons and holes are equivalent.

Electrical Conduction in Semiconductors

- There are two general categories of semiconductors: **intrinsic** (pure) semiconductors, and **extrinsic** (impure) semiconductors

- The process of creating extrinsic semiconductors by adding substances to a pure semiconductor is known as ***doping***



intrinsic (pure)

extrinsic (doped)

(b): **n-type**, (c): **p-type**