Basic Electronics ECE101L

Module II -Class -1

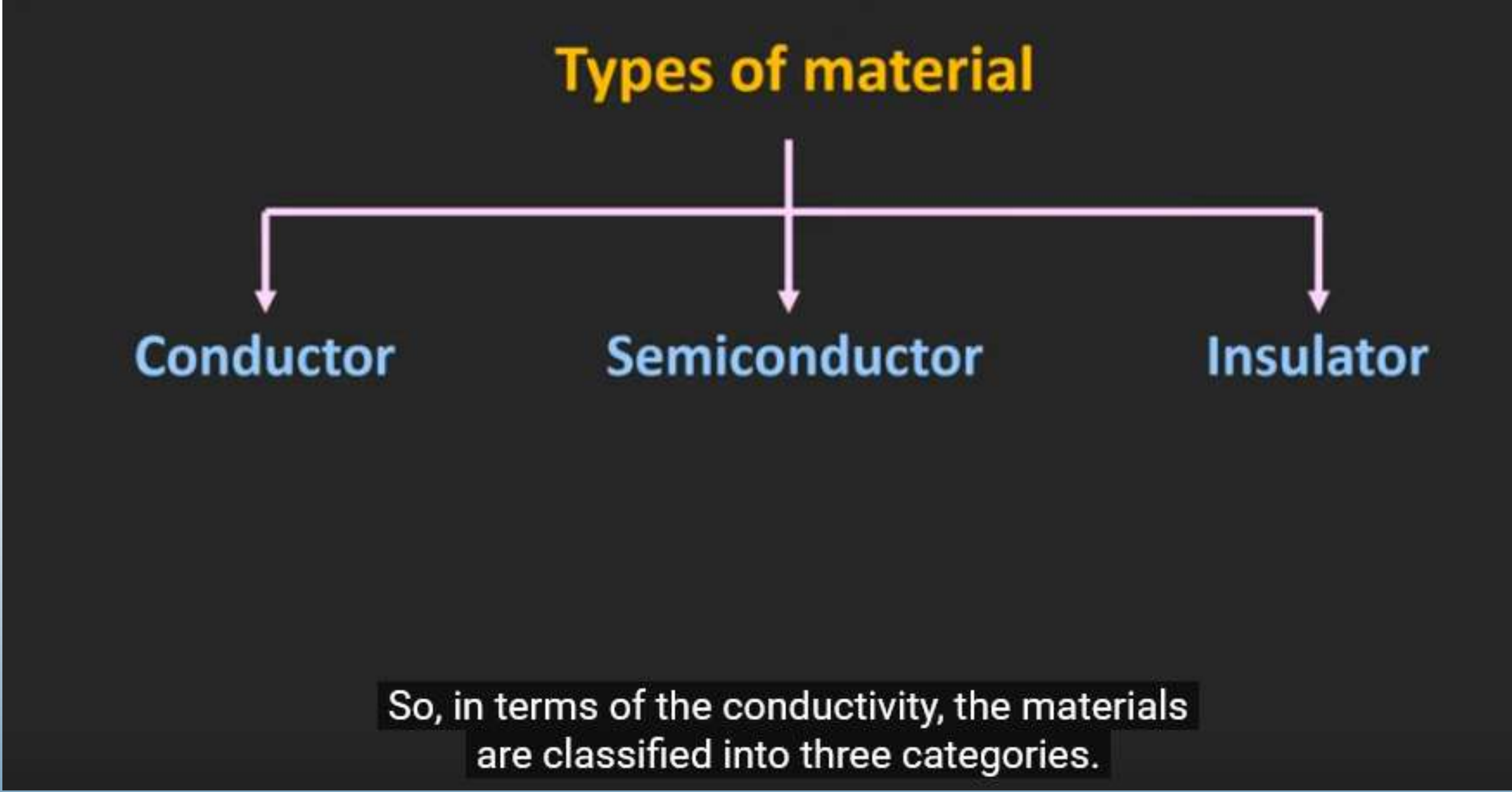
Module:2	Junction Diodes	4 hours
Intrinsic and extrinsic semiconductors – doping - PN Junctions, Formation of Junction, Physical operation of diode, Barrier Potential, I - V Characteristics, Rectifiers, Zener diode – I-V Characteristics, Zener diode as Voltage regulator.		

https://www.youtube.com/watch?v=CjAVfW_6juw

https://slideplayer.com/slide/8411906/

Semiconductor

The semiconductor materials are mainly used
for manufacturing electronic devices like



Unit of Conductivity - Siemens / meter (S/m)

Electronic Materials

- The goal of electronic materials is to generate and control the flow of an electrical current.

- Electronic materials include:

1. <u>Conductors</u>: have low resistance which allows electrical current flow
2. <u>Insulators</u>: have high resistance which suppresses electrical current flow
3. <u>Semiconductors</u>: can allow or suppress electrical current flow

Conductors

- Good conductors have low resistance so electrons flow through them with ease.
- **Best** element conductors include:
  – Copper, silver, gold, aluminum, & nickel
- Alloys are also good conductors:
  – Brass & steel
- Good conductors can also be liquid:
  – Salt water

Conductor

Silver

Copper

Gold

Aluminium

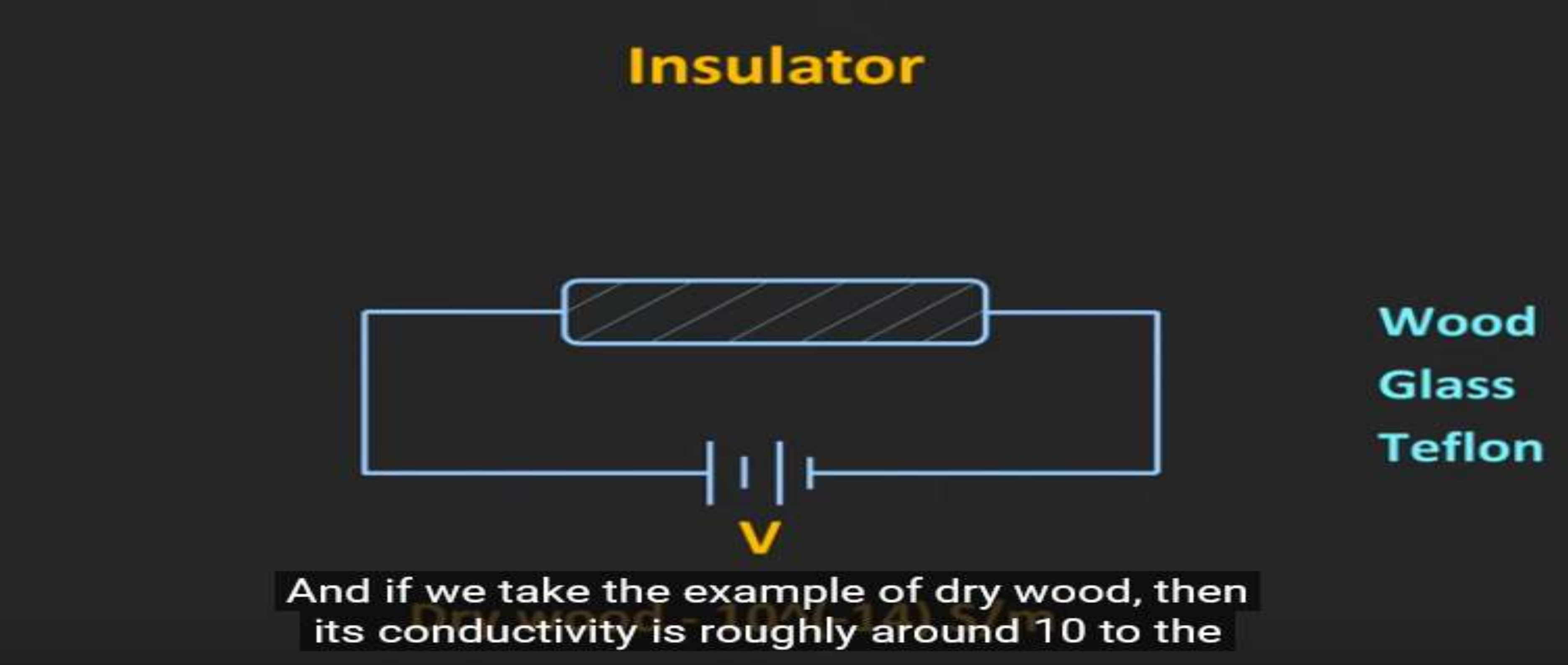
Copper - 10^7 S/m

So, the conductor has very good conductivity or we can say that whenever the voltage is

applied to this conductor then it allows the generous flow of charge.

Insulators

- Insulators have a high resistance so current does not flow in them.
- Good insulators include:
  - Glass, ceramic, plastics, & wood
- Most insulators are compounds of several elements.
- The atoms are tightly bound to one another so electrons are difficult to strip away for current flow.



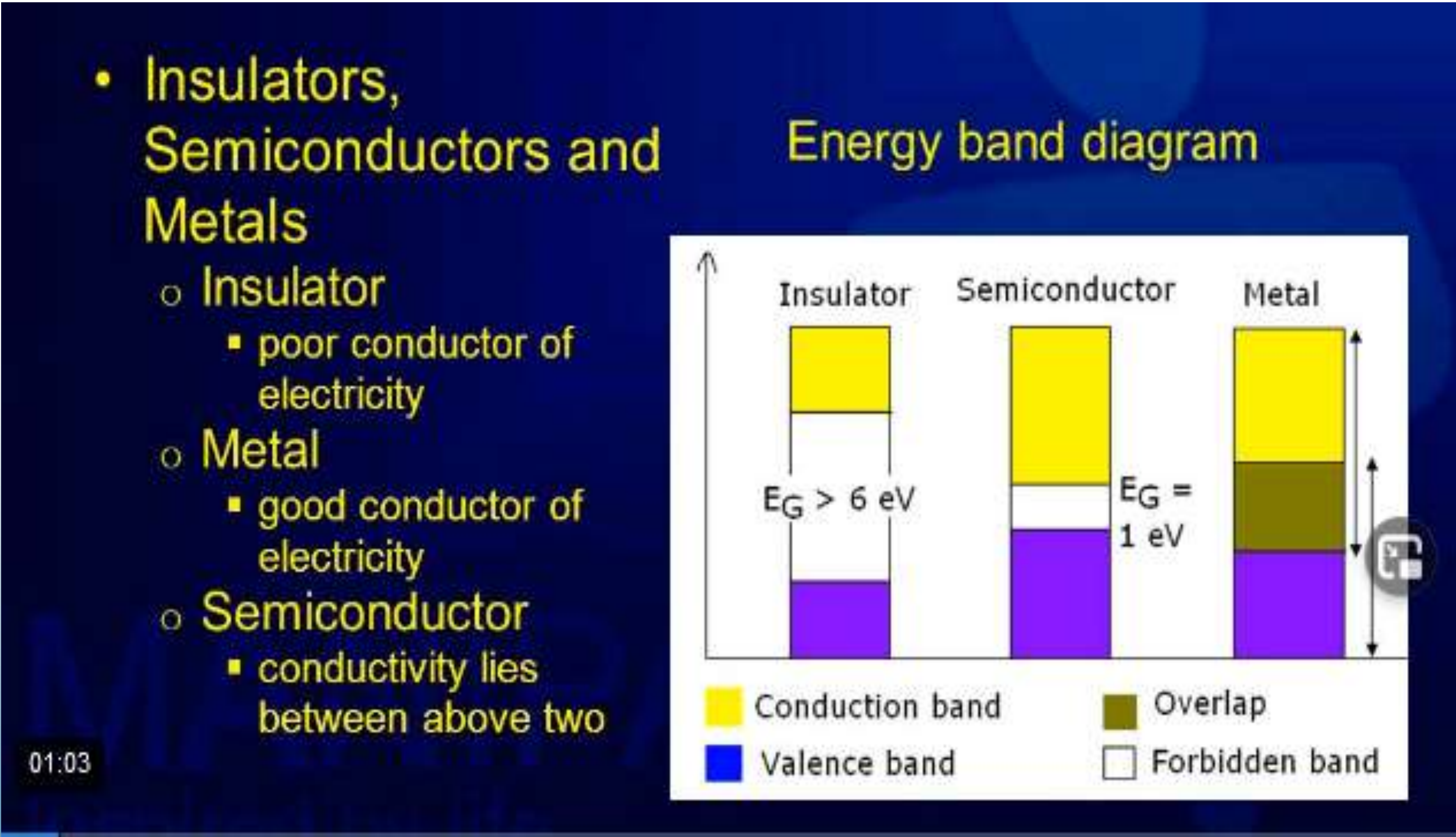
Dry wood - 10^(-14) S/m

power minus 14 Siemens per meter.

insulator has very poor conductivity.

Semiconductors

- Semiconductors are materials that essentially can be conditioned to act as good conductors, or good insulators, or any thing in between.
- Common elements such as **carbon, silicon**, and **germanium** are semiconductors.
- Silicon is the best and most widely used semiconductor.



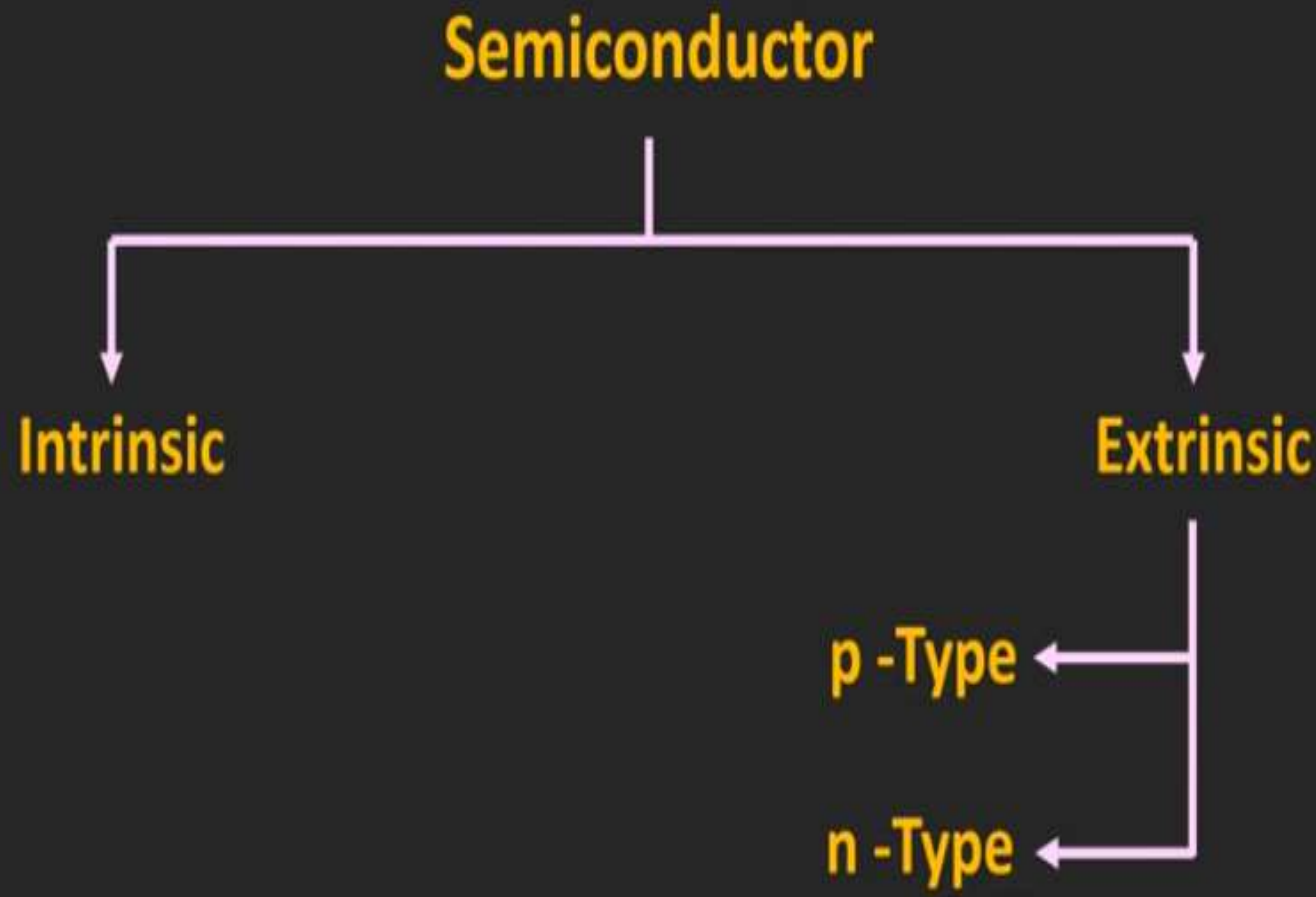
In solid-state physics, the energy gap or the band gap is an energy range between valence band and conduction band where electron states are forbidden.

Classification of materials

Semiconductor

- Silicon : $E_G \approx 1.21$ eV at 0 K (1.1 eV at 300 K)
- Germanium : $E_G \approx 0.79$ eV at 0 K (0.67 eV at 300 K)
- At 0 K, valence band is full, conduction band is empty
- Si and Ge are insulators at 0 K
- Conductivity increases (or resistivity decreases) with increase in temperature
- Semiconductors possess negative temp coeff of resistance
- At room temp and above, Si and Ge are semiconductors i.e., some electrons are present in conduction band

- Metal
  - The valence band and conduction band overlap
  - Even at 0 K, conduction band has electrons
  - So metals are good conductors of electricity

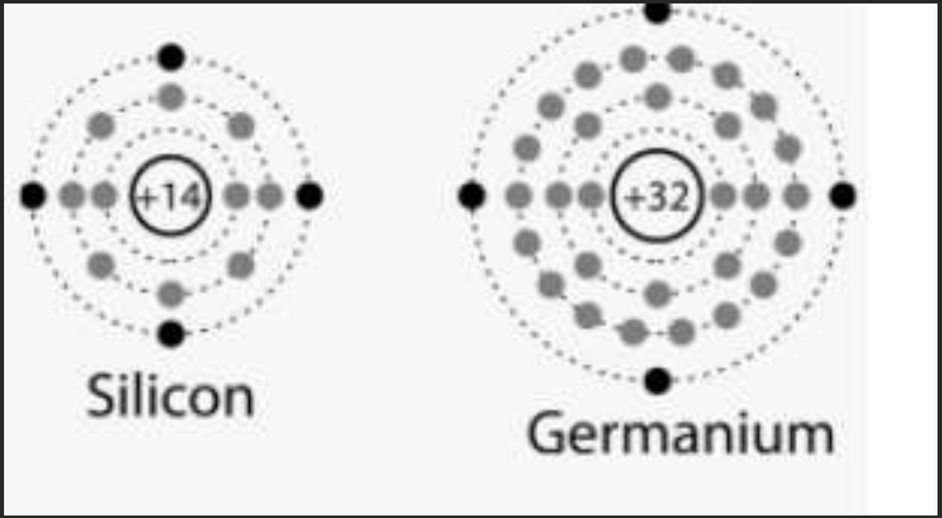

Semiconductor
Intrinsic
Extrinsic
p -Type
n -Type

Semiconductor

Silicon (Si)

Germanium (Ge)

Gallium Arsenide (GaAs)

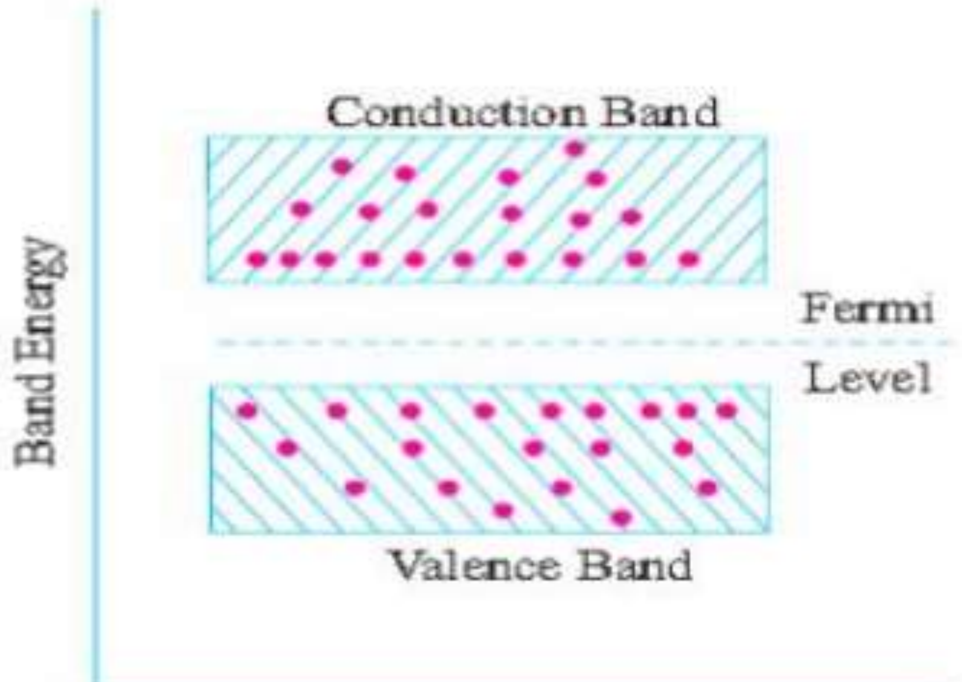


Intrinsic semiconductors

- An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.
- Examples : Si, Ge
- The energy gap is so small that even at ordinary room temperature; there are many electrons which possess sufficient energy to jump across the small energy gap between the valence and the conduction bands.
- Alternatively, an intrinsic semiconductor may be defined as one in which the number of conduction electrons is equal to the number of holes.

- Fermi Level: Fermi level is the term used to describe the top of the collection of electron energy levels at absolute zero temperature. the highest energy **level** which an electron can occupy the valance band at 0k is called **Fermi** energy (E_f).
- Fermi level lies in the mid of forbidden gap in intrinsic semiconductor.

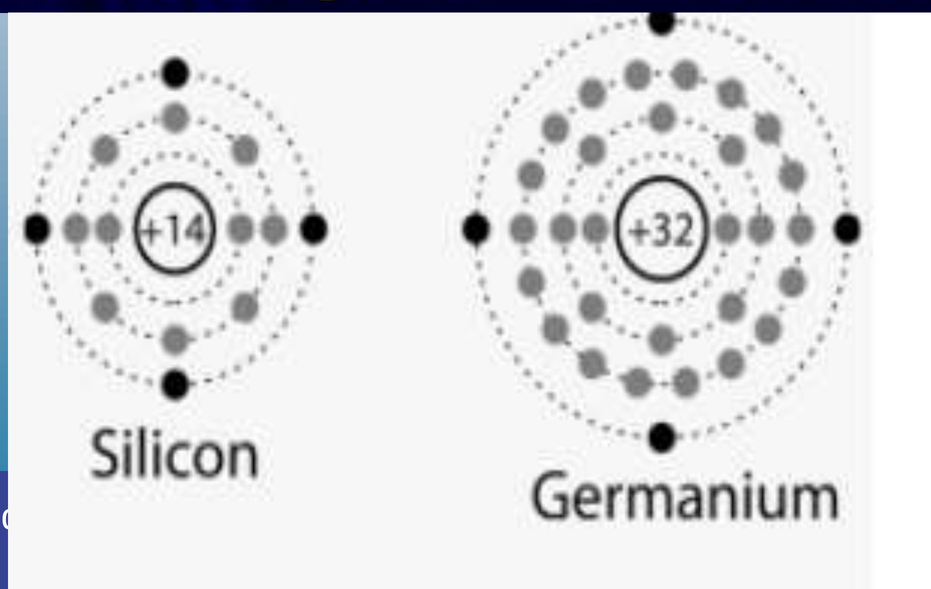
The probability of occupation of energy levels in valence band and conduction band is called *Fermi level*.



In intrinsic semiconductor, the number of holes in valence band is equal to the number of electrons in the conduction band. Hence, the probability of occupation of energy levels in conduction band and valence band are equal. Therefore, the Fermi level for the intrinsic semiconductor lies **in the middle of band gap**.

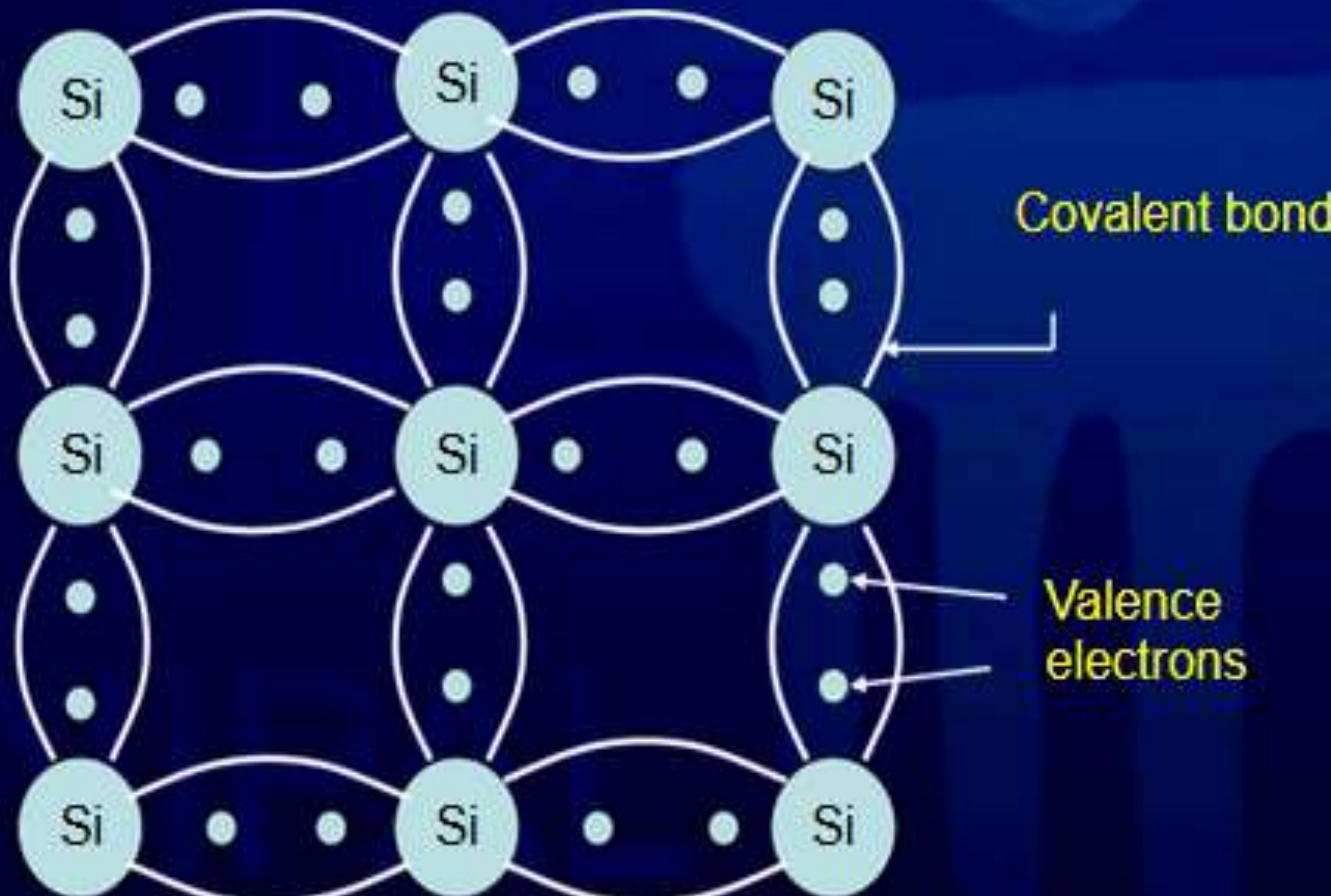
Intrinsic Semiconductors

- Semiconductors such as Si and Ge have 4 electrons (tetravalent) in the outermost shell
- In crystal structure of these materials, atoms are arranged in tetrahedron structure with one atom at each vertex
- Each atom contributes 4 valence electrons to the crystal; Each atom shares one electron each from its 4 neighbours, thus forming covalent bond
- Because of covalent bonding, electrons are tightly bound to crystal – not available for



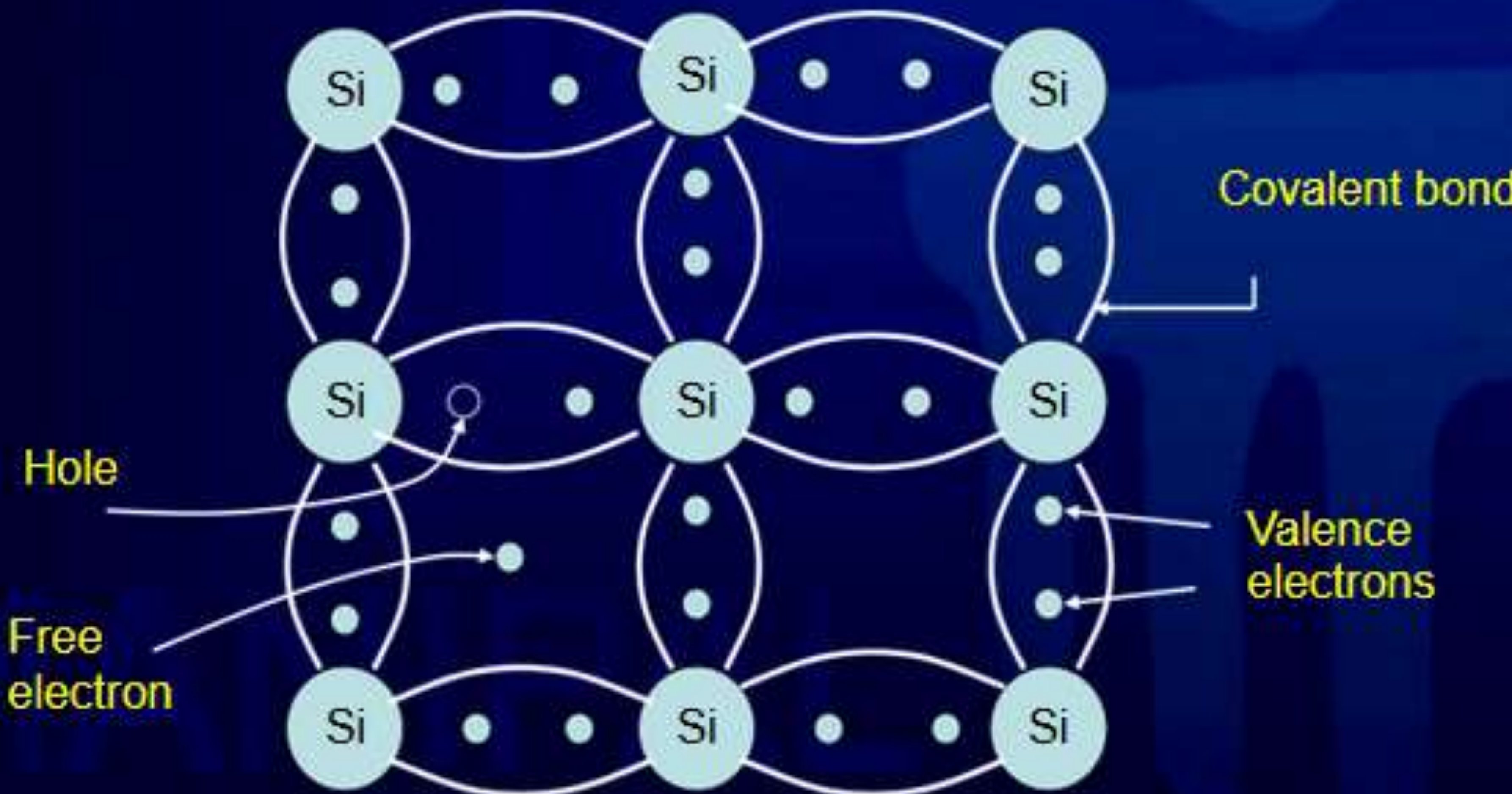
Intrinsic Semiconductors

- Bond structure of Si and Ge at 0 K

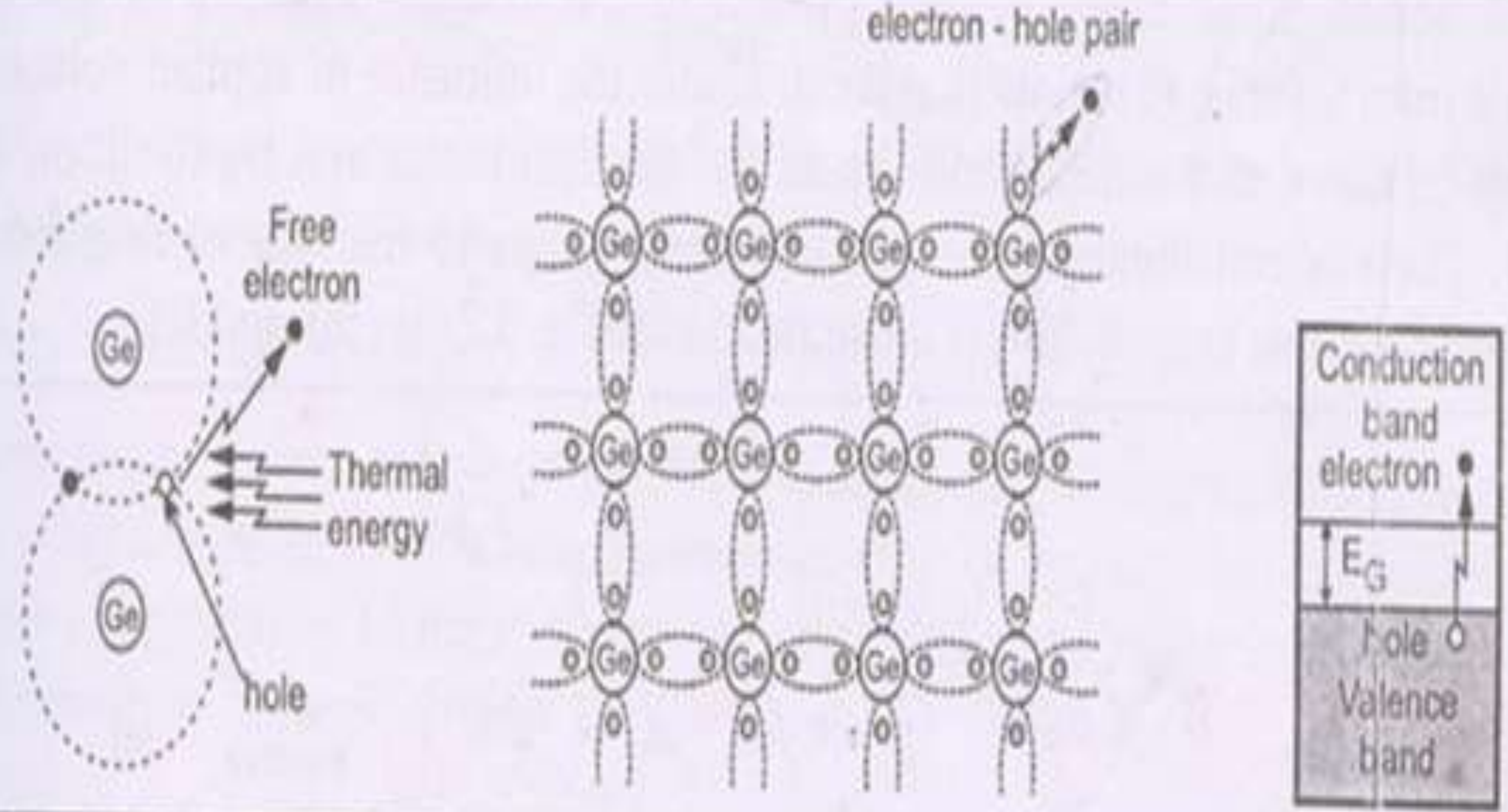


Intrinsic Semiconductors

- Bond structure of Si and Ge at 300 K



Intrinsic Semiconductors



(a) Breaking of covalent bond

(b) Electron-hole pair in a germanium crystal

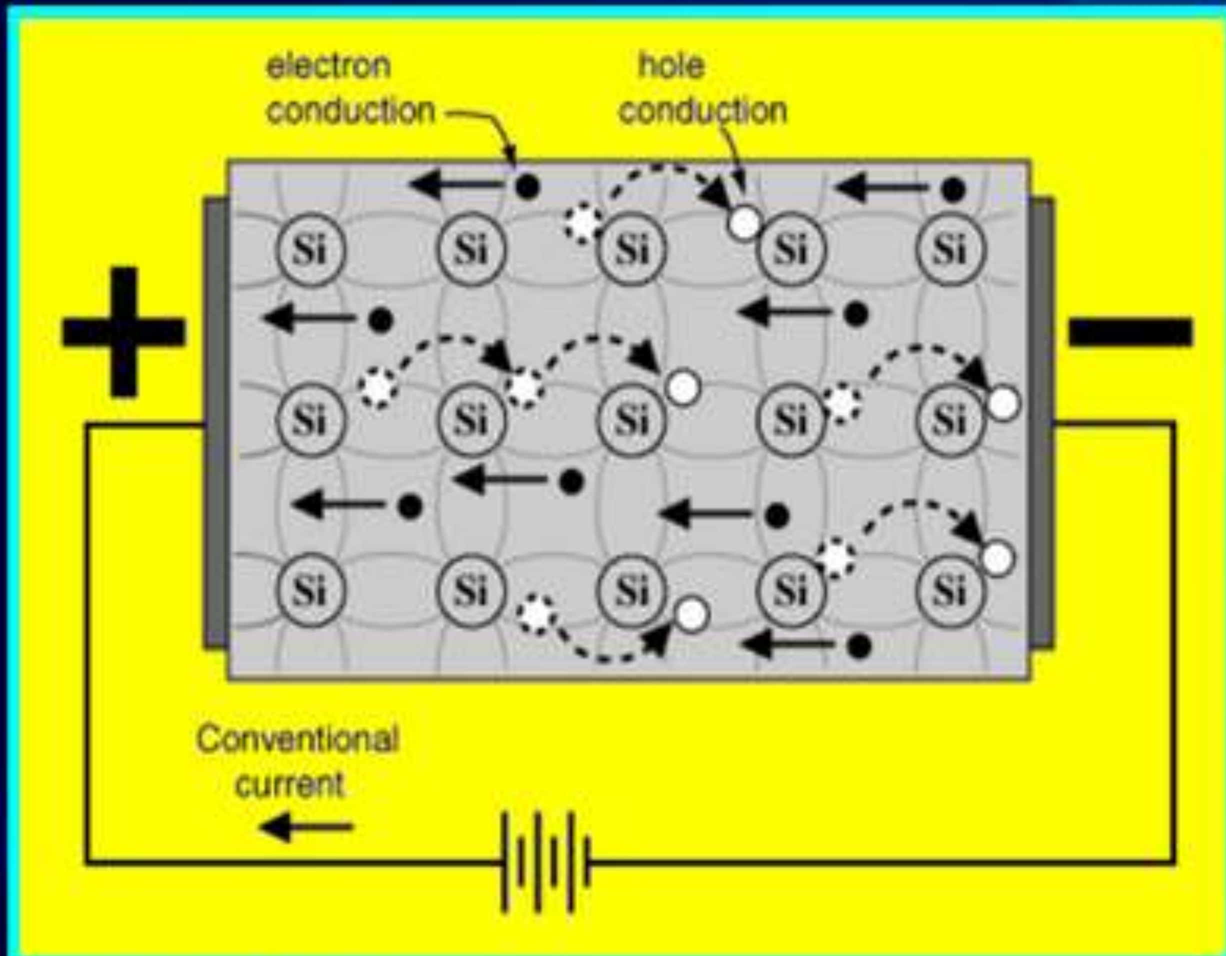
(c) Energy band cliagram

Intrinsic Semiconductors

- Free electrons are "free" to wander throughout the crystal
- Hole is the absence of an electron in the covalent bond
- In intrinsic semiconductor, each free electron gives rise to one hole.
- Concentration of holes and free electrons are same. Denoted as n_i (called intrinsic charge concentration)
- Free electrons and holes are now available for conduction
- A hole may get filled up by another electron liberated from another covalent bond – effective movement of hole

Conduction in semiconductors

Both free electrons and holes contribute to current flow



Conduction in semiconductors

- Let concentration of free electrons = n
- Let concentration of holes = p
- In intrinsic semiconductor, $n = p = n_i$
- Current density = conductivity × electric field intensity

$J = \sigma E$ (Ohm's law)

- Conductivity is given by: $\sigma = n\, q\, \mu_n + p\, q\, \mu_p$

$= n_i\, q\, (\mu_n + \mu_p)$

μ_n is mobility of free electrons

μ_p is mobility of holes ($\mu_n > \mu_p$)

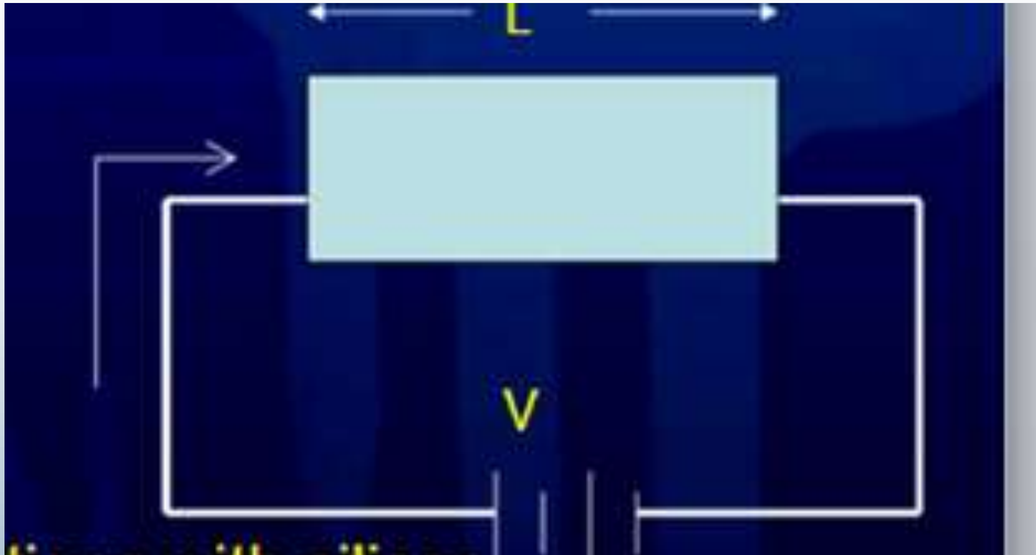
q is electronic charge = 1.6×10^{-19} C

In solid-state physics, the electron mobility **characterises how quickly an electron can move through a metal or semiconductor when pulled by an electric field**.

Conduction in semiconductors

Some properties at 300 K	Ge	Si
Electron mobility μ_n ($m^2/V\text{-}s$)	0.38	0.13
Hole mobility μ_p ($m^2/V\text{-}s$)	0.18	0.05
Intrinsic Concentration n_i (m^{-3})	2.5×10^{19}	1.5×10^{16}
Intrinsic resistivity (Ω-m)	0.45	2300
Concentration of atoms in crystal (cm^{-3})	4.4×10^{22}	5.0×10^{22}

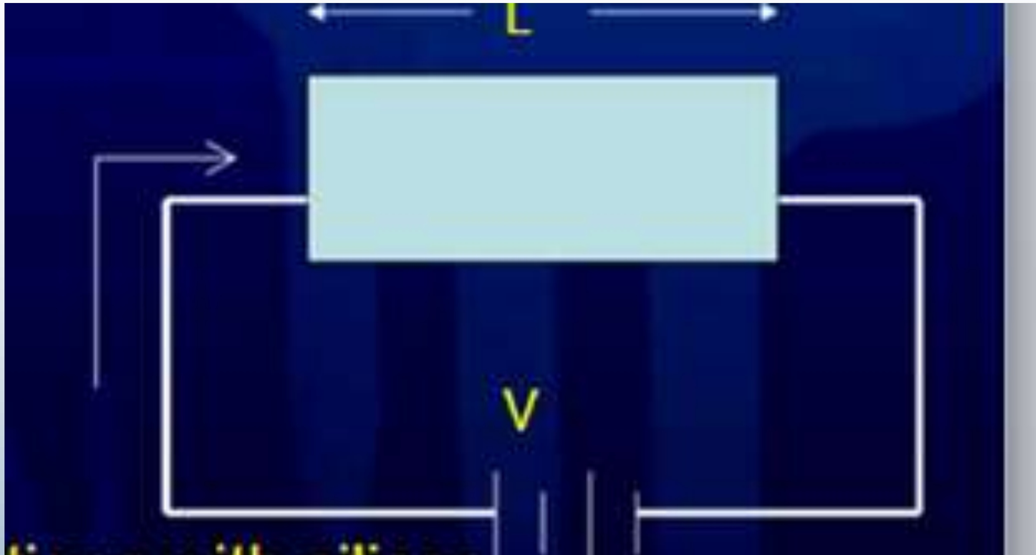
conductivity and resistivity



Resistivity $\rho = 1/\sigma$

Resistance $R = \rho L / A$

conductivity and resistivity



Resistivity $\rho = 1/\sigma$

Resistance $R = \rho L / A$

- Determine the conductivity and resistivity of pure germanium at 300 K. If the length of the Ge is 4 cm and cross section area is 1 cm^2, then what is its resistance? If a potential difference of 5 V is applied between the two ends of semiconductor, what is the amount of current that flows?

Velocity of charge particle

- Velocity of charge particle = mobility × electric field

$v = \mu E$

- Free electron velocity is $v_n = \mu_n E$
- Hole velocity is $v_p = \mu_p E$

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- What is the electron velocity and hole velocity in a bar of silicon at room temperature (300 K), when an electric field of 1800 V/m is applied across it? (Ans: 234, 90 m/s)
- A bar of intrinsic Ge, 6 cm long, has a potential difference of 12 V applied across its ends. If the electron velocity in the bar is 76 m/s, what is the electron mobility?

In an intrinsic semiconductor, the intrinsic carrier density is:

Concept:

The intrinsic carrier concentration is given by:

$$n_i^2 = n_0 p_o \quad \text{--- (1)}$$

n_0 = Electron concentration, given by:

$$n_0 = N_C e^{-\frac{(E_C - E_F)}{kT}}$$

p_0 = Hole concentration, given by:

$$p_0 = N_V e^{-\frac{(E_F - E_V)}{kT}}$$

N_C = Effective density of levels in the conduction band

N_V = Effective density of levels in the valence band

E_C = Conduction band level

E_V = Valence band level

E_F = Fermi Level

Application:

Substituting the values of n_0 and p_0 in equation-(1), we get:

$$n_i = \sqrt{N_C}\sqrt{N_V}.e^{-\frac{E_C - E_V}{2kT}}$$

Since $E_C - E_V = E_g$

$$n_i = \sqrt{N_C}\sqrt{N_V}.e^{-\frac{E_g}{2kT}}$$

Two initially identical samples A & B of pure germanium are doped with donors to concentrations of 1×10^{20} and 3×10^{20} respectively. If the hole concentration in A is 9×10^{12} then the hole concentration in B at the same temperature will be

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According to Mass Action law

$$np = n_i^2$$

Where,

n = electron concentration

p = hole concentration

n_i = intrinsic concentration

Calculation:

For sample A:

$n = 1 \times 10^{20}\ m^{-3}$

$p = 9 \times 10^{12}\ m^{-3}$

By mass Action law

$$np = n_i^2$$

$$n_i^2 = 9 \times 10^{32} \qquad \text{---(1)}$$

For sample B:

$n = 3 \times 10^{20}\ m^{-3}$

Since samples A and B are identical so intrinsic concentration (n_i) will be the same for both.

$$n_i^2 = 9 \times 10^{32} = np$$

$$p = \frac{9 \times 10^{32}}{3 \times 10^{20}} = 3 \times 10^{12}\ m^{-3}$$

The Intrinsic carrier density at room temperature in Ge is 2.37×10^{19} m^{3} if the electron and hole mobilities are 0.38 and 0.18 $m^{2}\,V^{-1}\,s^{-1}$ respectively, calculate the resistivity.

The Intrinsic carrier density at room temperature in Ge is $2.37 \times 10^{19}\ m^3$ if the electron and hole mobilities are 0.38 and $0.18\ m^2\ V^{-1}\ s^{-1}$ respectively, calculate the resistivity.

Given:

$$n_i = 2.37 \times 10^{19}\ m^3$$

$$\mu_e = 0.38\ m^2\ V^{-1}\ s^{-1}$$

$$\mu_h = 0.18\ m^2\ V^{-1}\ s^{-1}$$

Conductivity $\sigma = n_i\, e\, (\mu_e + \mu_h)$

$$= 2.37 \times 10^{19} \times 1.6 \times 10^{-19}\ (0.38 + 0.18)$$

$$= 2.1235\ \Omega^{-1}\ m^{-1}$$

Resistivity $\rho = \dfrac{1}{\sigma}$

$$\rho = \frac{1}{2.1235}$$

Resistivity $\rho = 0.4709\ \Omega\ m$

The intrinsic carrier density of a semiconductor is $2.1 \times 10^{19}\ m^{-3}$. The electron and hole mobilities are 0.4 and $0.2\ m^2\ V^{-1}\ s^{-1}$ respectively. Calculate the conductivity.

Solution:

Given data:

Intrinsic carrier concentration $n_i = 2.1 \times 10^{19}\ m^{-3}$

Mobility of electron $\mu_e = 0.4\ m^2\ V^{-1}\ s^{-1}$

Mobility of hole $\mu_h = 0.2\ m^2\ V^{-1}\ s^{-1}$

Conductivity $\sigma = n_i e (\mu_e + \mu_h)$

$$= 2.1 \times 10^{19} \times 1.6 \times 10^{-19} \times (0.4 + 0.2)$$

Conductivity $\sigma = 2.016\ \Omega^{-1}\ m^{-1}$

The electron mobility and hole mobility in Si are 0.135 $m^2 V^{-1} s^{-1}$ and 0.048 $m^2 V^{-1} s^{-1}$ respectively at room temperature. If the carrier concentration is 1.5×10^{16} m^{-3}. Calculate the resistivity of Si at room temperature.

Solution:

Given data:

Carrier concentration	$n_i = 1.5 \times 10^{16}\ m^{-3}$
Mobility of electron	$\mu_e = 0.135\ m^2 V^{-1} s^{-1}$
Mobility of hole	$\mu_h = 0.048\ m^2 V^{-1} s^{-1}$

i) Electrical Conductivity σ

$$\sigma = n_i e (\mu_e + \mu_h)$$

$$= 1.5 \times 10^{16} \times 1.6 \times 10^{-19} \times (0.135 + 0.048)$$

$$\sigma = 0.4392 \times 10^{-3}\ \Omega^{-1} m^{-1}$$

ii) Resistivity pf silicon

$$\rho = \frac{1}{\sigma}$$

$$= \frac{1}{0.4392 \times 10^{-3}}$$

$$\rho = 2.2768\ \Omega\ m$$