Semiconductors

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Materials Based on electrical resistivity

Resistivity range in Ohm m ⇨ *25 orders of magnitude*

⟵ Metallic materials ⟶ ⟵ Semi-conductors ⟶

10^{-9}	10^{-7}	10^{-5}	10^{-3}	10^{-1}	10^{-1}	10^{3}
Ag Cu Al Au	Ni Pb	Sb Bi Graphite	Ge (doped)	Ge		Si

⟵ Insulators ⟶

10^{5}	10^{7}	10^{9}	10^{11}	10^{13}	10^{15}	10^{17}
Window glass *Ionic conductivity*		Bakelite	Porcelain Diamond Rubber Polyethylene	Lucite Mica	PVC	SiO_2 (pure)

Intrinsic semiconductors

Pure material semiconductors

- Group IVA materials

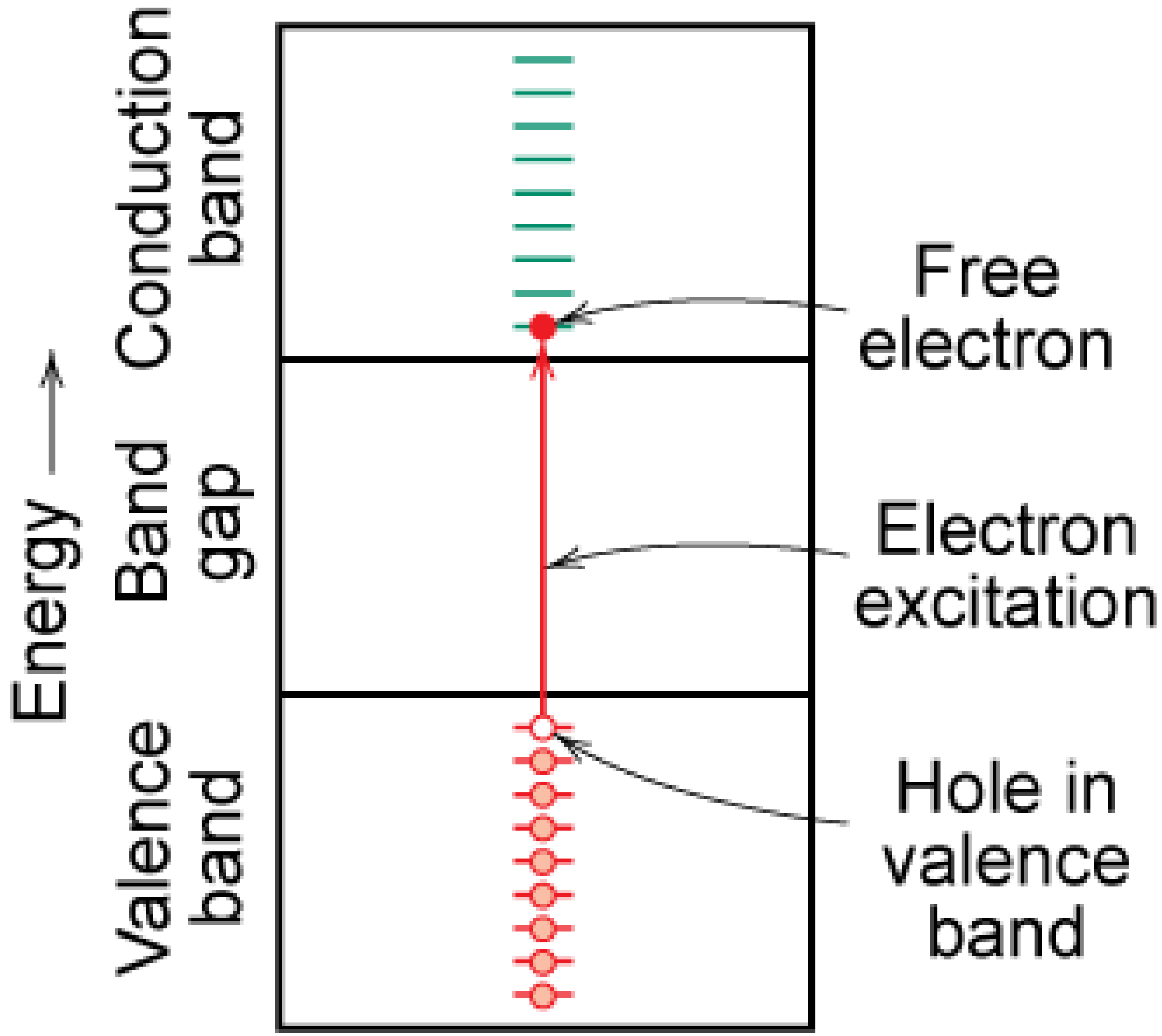
  e.g., Silicon & Germanium

- Compound semiconductors
  - III-V compounds

    e.g., GaAs & InSb
  - II-VI compounds

    e.g., CdS & ZnTe
  - The wider the electronegativity difference between the elements the wider the energy gap.

Charge carriers in semiconductors



Two types of electronic charge carriers:

Free Electron

– negative charge

– in conduction band

Hole

– positive charge

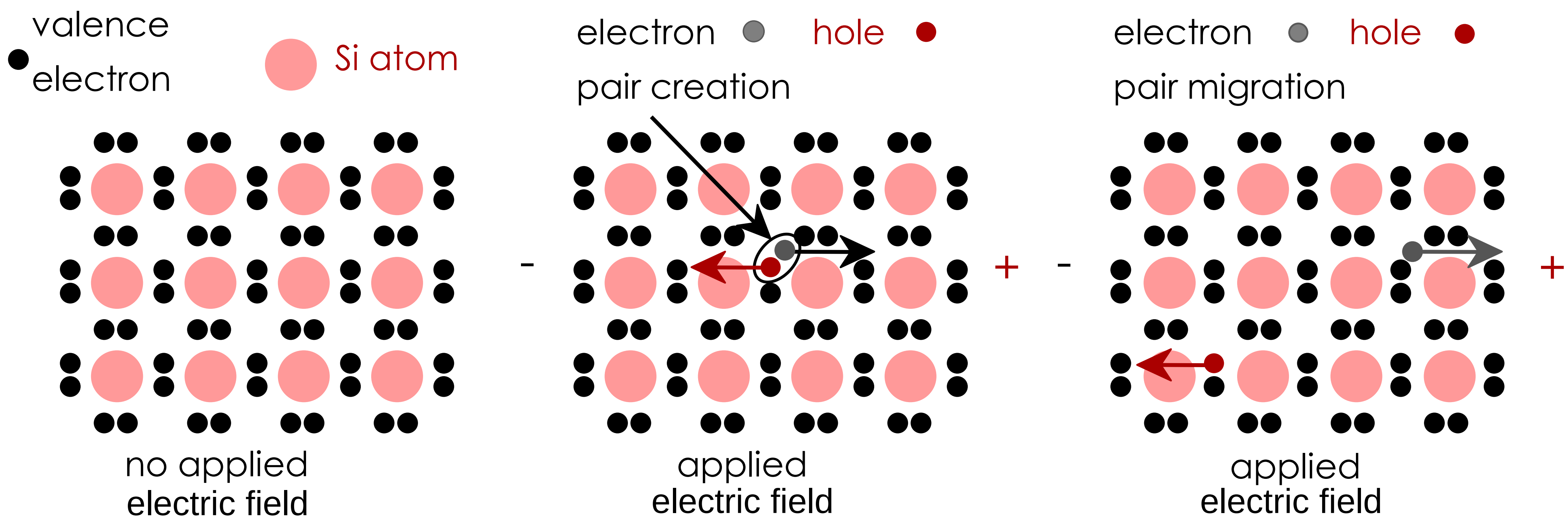
– vacant electron state in the valence band

Move at different speeds - drift velocities

Intrinsic Semiconductors

Conduction in terms of electron and hole migration

Concept of electrons and holes:



Electrical Conductivity given by:

holes/m^3

$$\sigma = n|e|\mu_e + p|e|\mu_h$$

hole mobility

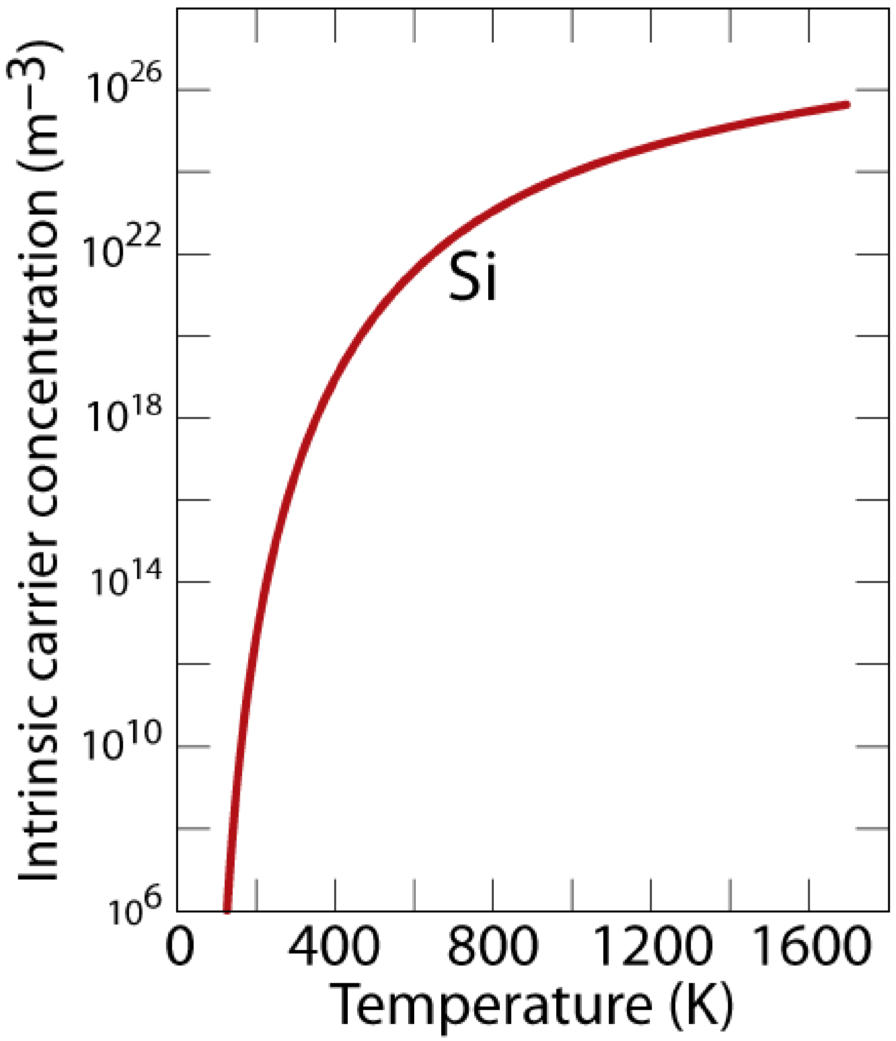
electrons/m^3

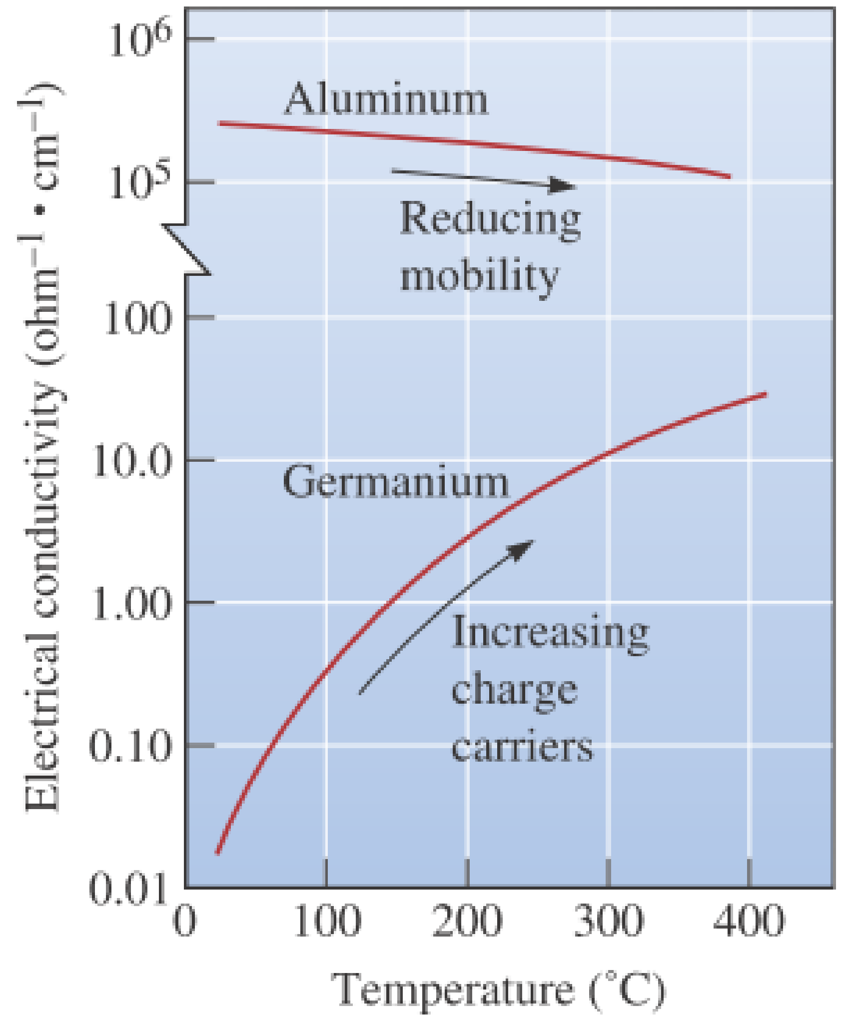
electron mobility

- for intrinsic semiconductors ***n* = *p* = *n*$_i$**
- $\sigma = n_i|e|(\mu_e + \mu_h)$

Intrinsic Semiconductors: Conductivity vs *T*

- Data for Pure Silicon:
  - -- σ increases with *T*
  - -- opposite to metals





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

$$n_i \propto e^{-E_{gap}/kT}$$

material	band gap (eV)
Si	1.11
Ge	0.67
GaP	2.25
CdS	2.40

No. of electron = No. of holes in intrinsic semiconductors at any given temperature

Extrinsic semiconductors

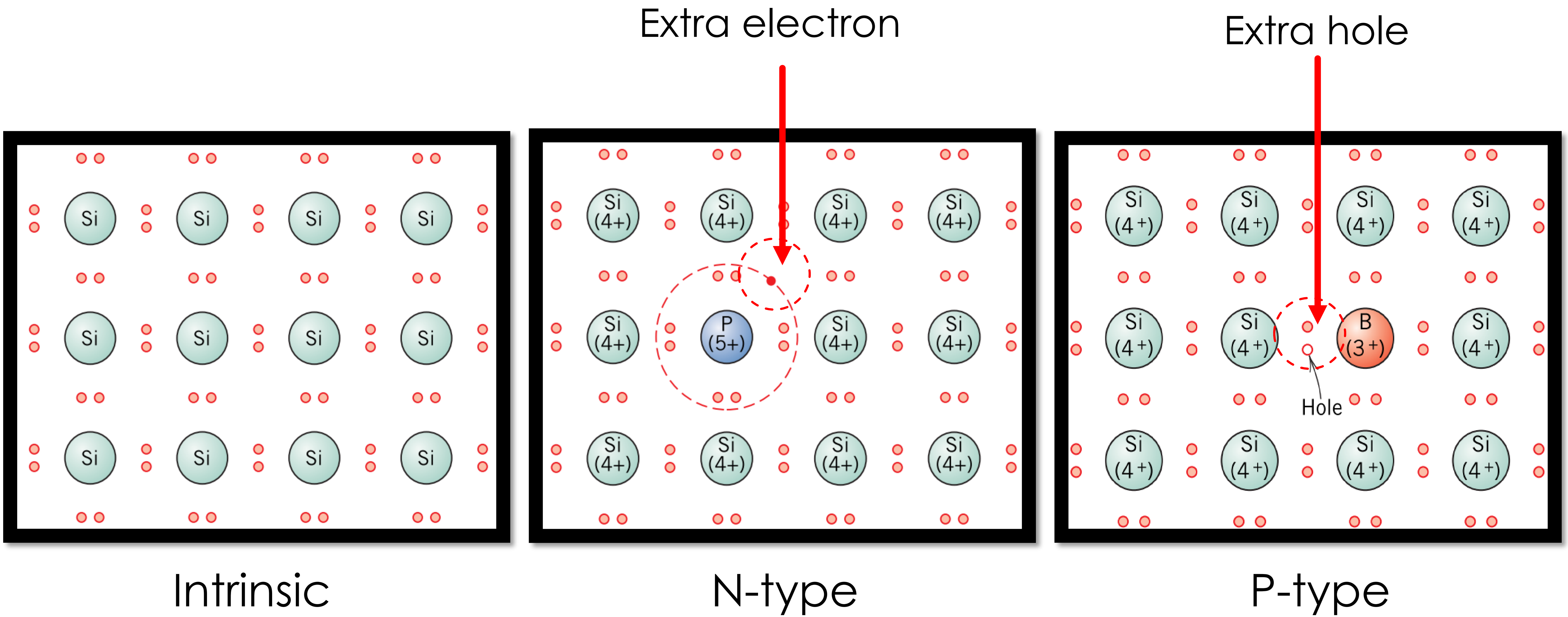
The addition of doping elements significantly increases the conductivity of a semiconductor. In fact impurity is accidentally present in semiconductors (even in low concentrations like 1 atom in 10^{12} atoms), which make it extrinsic.

- Doping of Si

- V column element *(P, As, Sb)* → the extra unbonded electron is practically free
  - ⇨ Energy level near the conduction band
  - ⇨ n- type semiconductor

- III column element *(Al, Ga, In)* → the extra electron for bonding supplied by a neighbouring Si atom → leaves a hole in Si.
  - ⇨ Energy level near the valence band
  - ⇨ p- type semiconductor

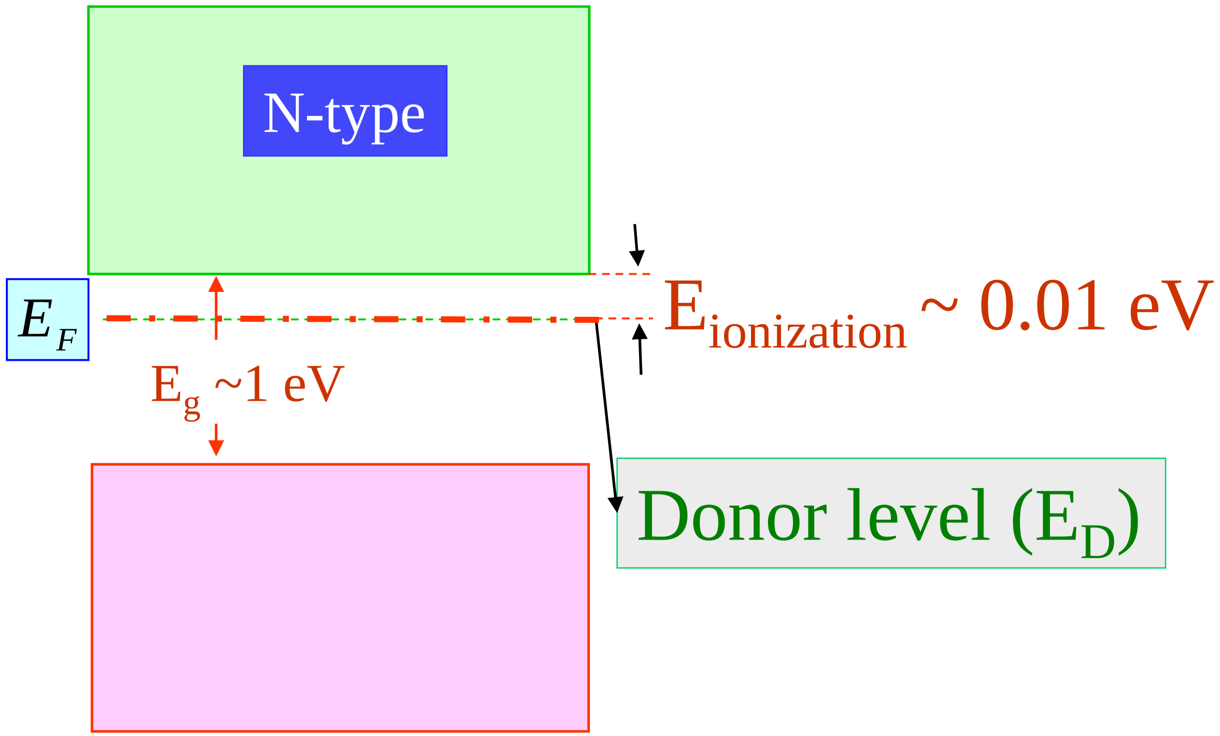
Extrinsic semiconductors



Ionization energies for dopants in Si & Ge (in eV)

Type	Element	In Si	In Ge
n-type	P	0.044	0.012
	As	0.049	0.013
	Sb	0.039	0.010
p-type	B	0.045	0.010
	Al	0.057	0.010
	Ga	0.065	0.011
	In	0.16	0.011

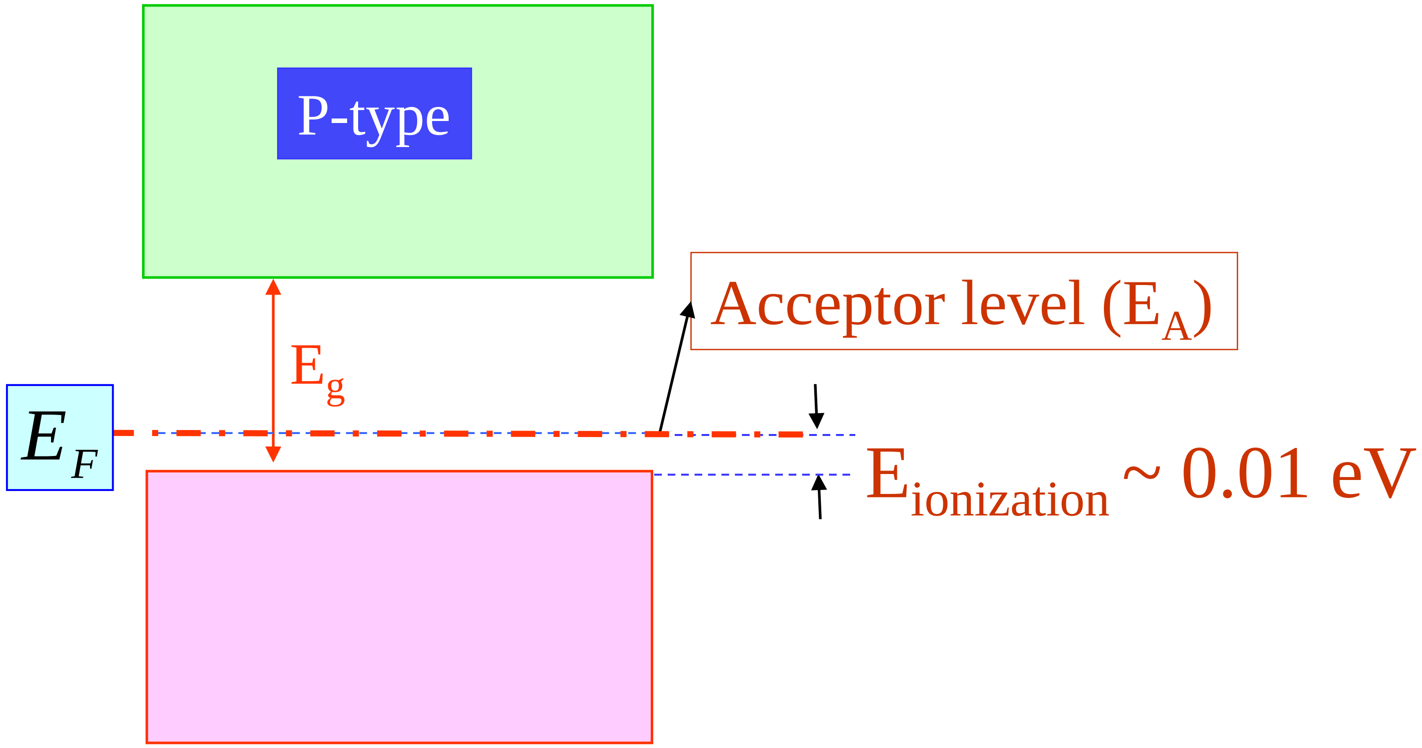
N – type semiconductors



- Ionization Energy→
  Energy required to promote an electron from the Donor level to conduction band.
- $E_{Ionization} < E_g$
  ⇒ even at RT large fraction of the donor electrons are exited into the conduction band.

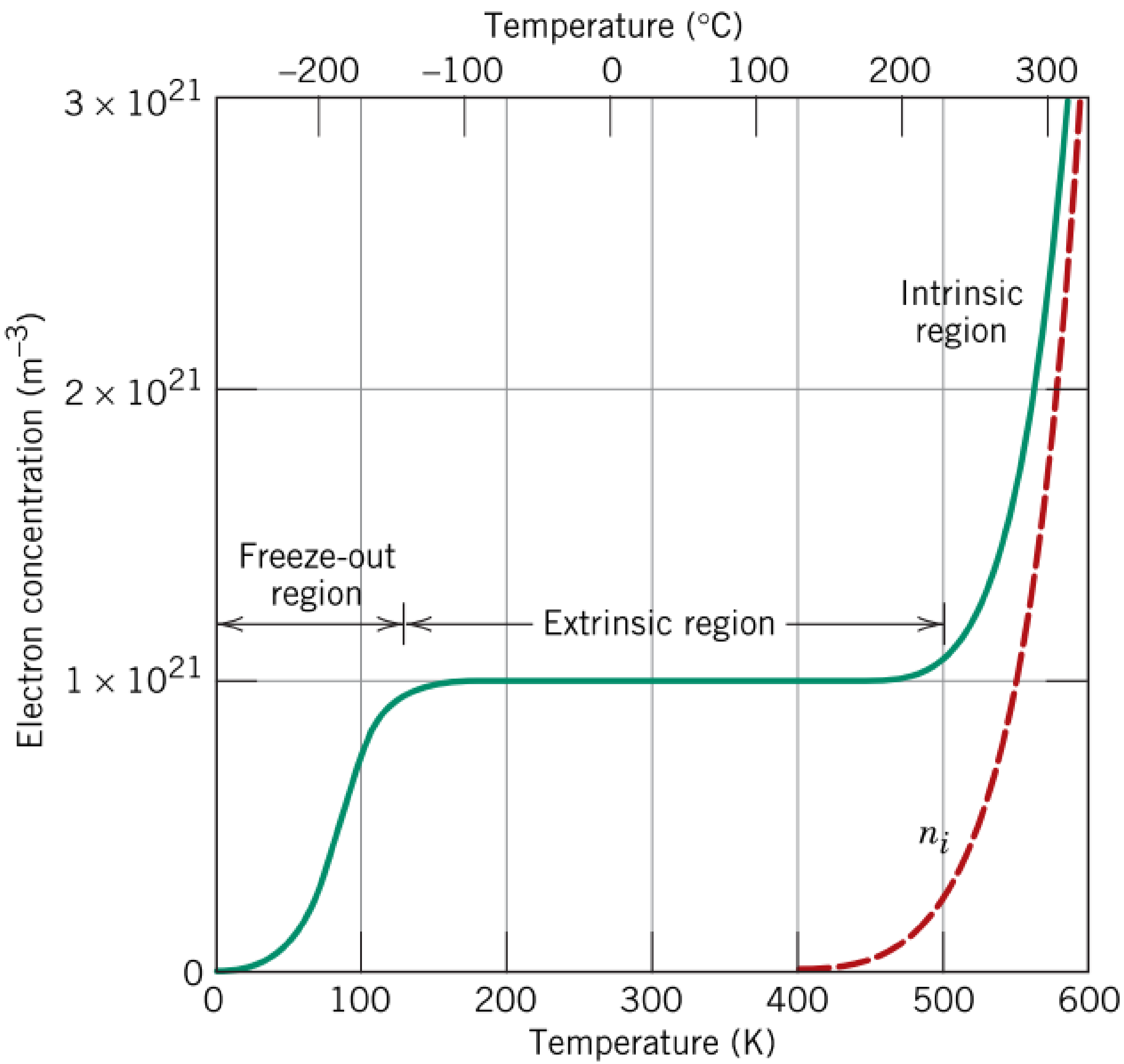
- Electrons in the conduction band are the majority charge carriers
- The fraction of the donor level electrons excited into the conduction band is much larger than the number of electrons excited from the valence band
- The number of holes is very small in an n-type semiconductor
- ⇒ Number of electrons ≠ Number of holes

P – type semiconductors



- At zero K the holes are bound to the dopant atom
- As T↑ the holes gain thermal energy and break away from the dopant atom $\Rightarrow$ available for conduction
- The level of the bound holes are called the acceptor level (which can accept and electron) and acceptor level is close to the valance band
- Holes are the majority charge carriers
- Intrinsically excited electrons are small in number
- $\Rightarrow$ Number of electrons $\neq$ Number of holes

Extrinsic Semiconductors: Conductivity vs T



1. Freeze out region – Insufficient energy for excitation
2. Exhaustive region – Electrons from the impurity doping
3. Intrinsic region – Electrons from the host semiconductor

Summary

1. Electrons and holes are the two charge carriers in the semiconductors.
2. The numbers of electrons and holes are always constant in intrinsic semiconductors.
3. Donor and acceptor impurities have less ionization energy as compared to the band gap.
4. Number of electrons and holes in extrinsic semiconductors are different.