Faculty of Engineering

ECE 335: Electronic Engineering

Lecture 2: Semiconductors

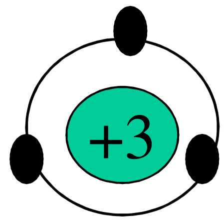
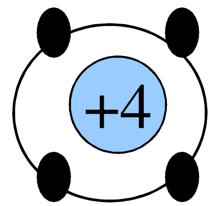
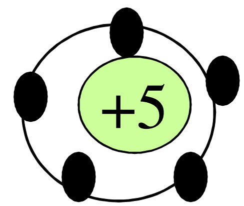
Agenda

- Intrinsic Semiconductors
- Extrinsic Semiconductors
  - N-type
  - P-type
- Carrier Transport
  - Drift
  - Diffusion

Semiconductors

- A semiconductor is a material with conducting properties between those of a good insulator (e.g. glass) and a good conductor (e.g. copper).
- The most commonly used semiconductor is silicon.

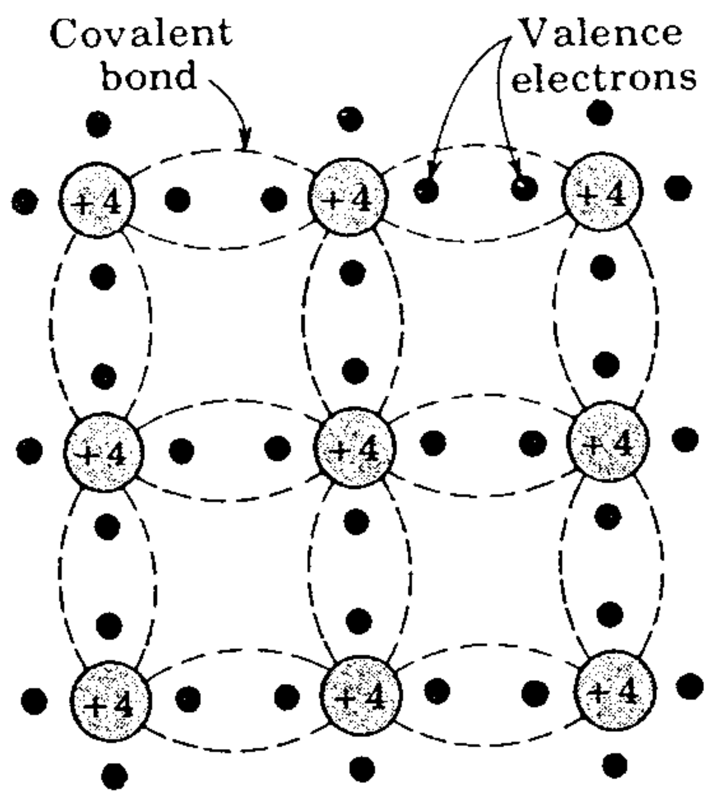
Semiconductor Elements in the Periodic Table

Group III	Group IV	Group V
		
Boron (B)	Carbon (C)	Nitrogen (N)
Aluminium (Al)	Silicon (Si)	Phosphorus (P)
Gallium (Ga)	Germanium (Ge)	Arsenic (As)
Indium (In)	Tin (Sn)	Antimony (Sb)

Semiconductors

- Each silicon atom has an outer shell with four valence electrons and four vacancies (It is a *tetravalent* element).
- In *intrinsic* (pure) silicon, atoms join together by forming *covalent bonds*. Each atom shares its valence electrons with each of four adjacent neighbours effectively filling its outer shell.

Intrinsic Semiconductors



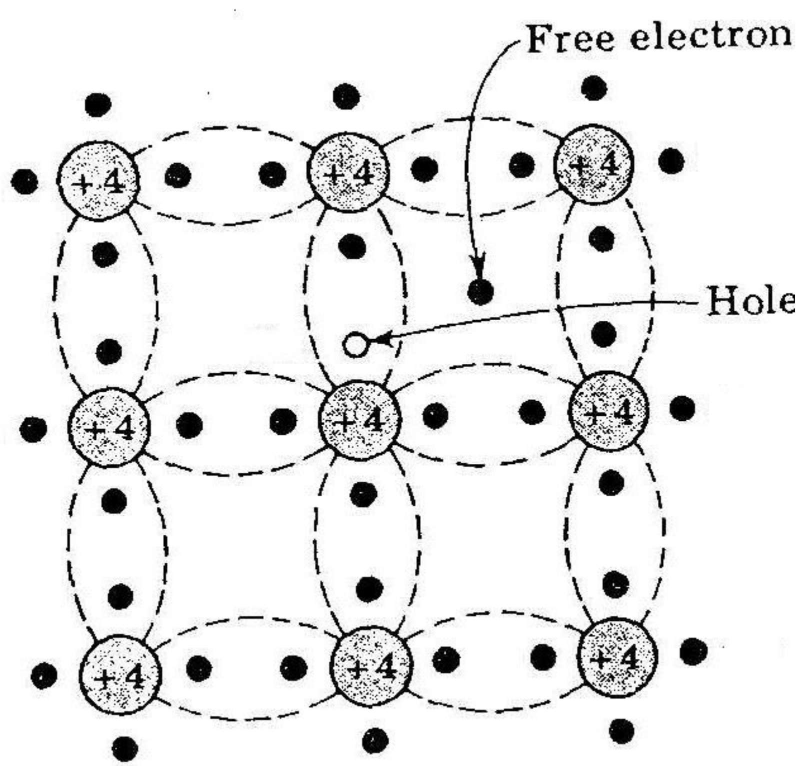
Intrinsic Semiconductors

- The structure has zero overall charge
- The complete nature of the structure means that at absolute zero temperature (0 K) none of the electrons is available for conduction…thus far the material is an insulator.

Intrinsic Semiconductors

- At room temperature some of the electrons are able to acquire sufficient thermal energy to break free from their bond.
- Whenever an electron leaves its position in the lattice it leaves a vacancy known as a *hole*.
- The process is known as *electron-hole pair generation*

Intrinsic Semiconductors



Intrinsic Semiconductors

- A freed electron can move through the body of the material until it encounters another broken bond where it is drawn in to complete the bond or *recombines*.

Intrinsic Semiconductors

- At a given temperature there is a dynamic equilibrium between thermal electron-hole *generation* and the *recombination* of electrons and holes
- As a result the concentration of electrons and holes in an intrinsic semiconductor is constant at any given temperature.
- The <u>higher</u> the temperature the <u>more</u> electron-hole pairs that are present.

Intrinsic Semiconductors

- n = conduction electron density (cm^{-3})
- p = hole density (cm^{-3})
- n_i = intrinsic carrier concentration (cm^{-3}) depends on temp and material

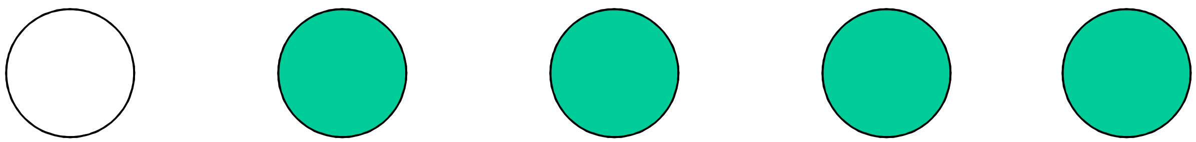
$$\mathbf{n\,p = n_i^2} \qquad , \qquad \mathbf{n = p}$$

$$\mathbf{n = p = n_i}$$

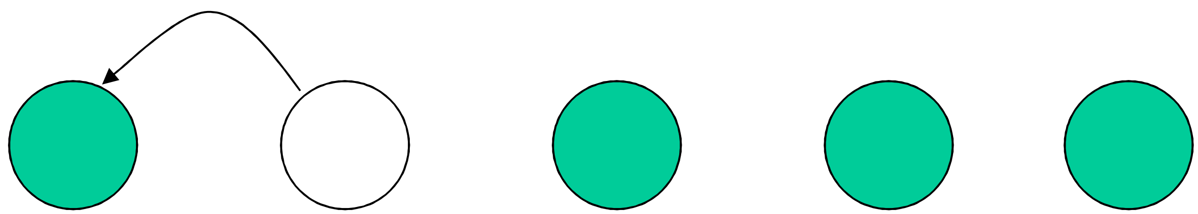
Intrinsic Semiconductors

- **Two** mechanisms for conduction become possible when a bond breaks:
- 1. Due to the movement of the freed electron.
- 2. Due to neighbouring electrons moving into the hole leaving a space behind it. (This can be most simply thought of as movement of the hole, a single moving positive charge carrier even though it is actually a series of electrons that move.

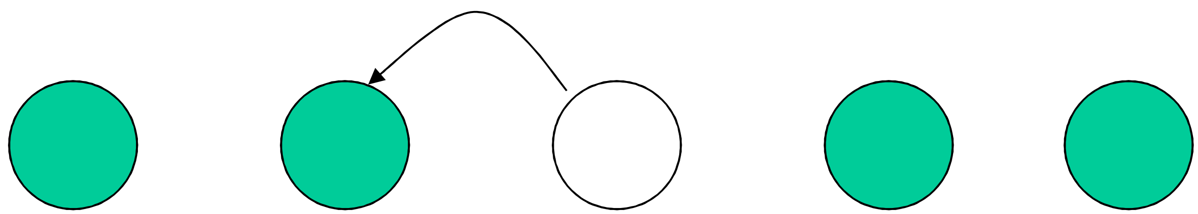
Intrinsic Semiconductors



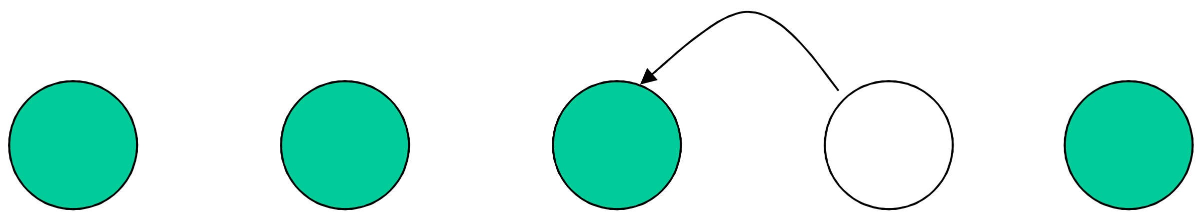
Intrinsic Semiconductors



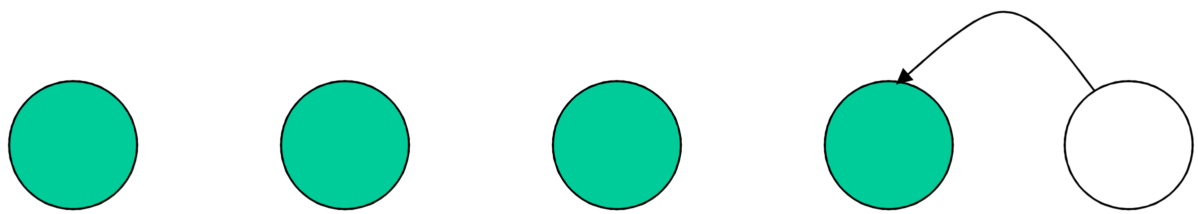
Intrinsic Semiconductors



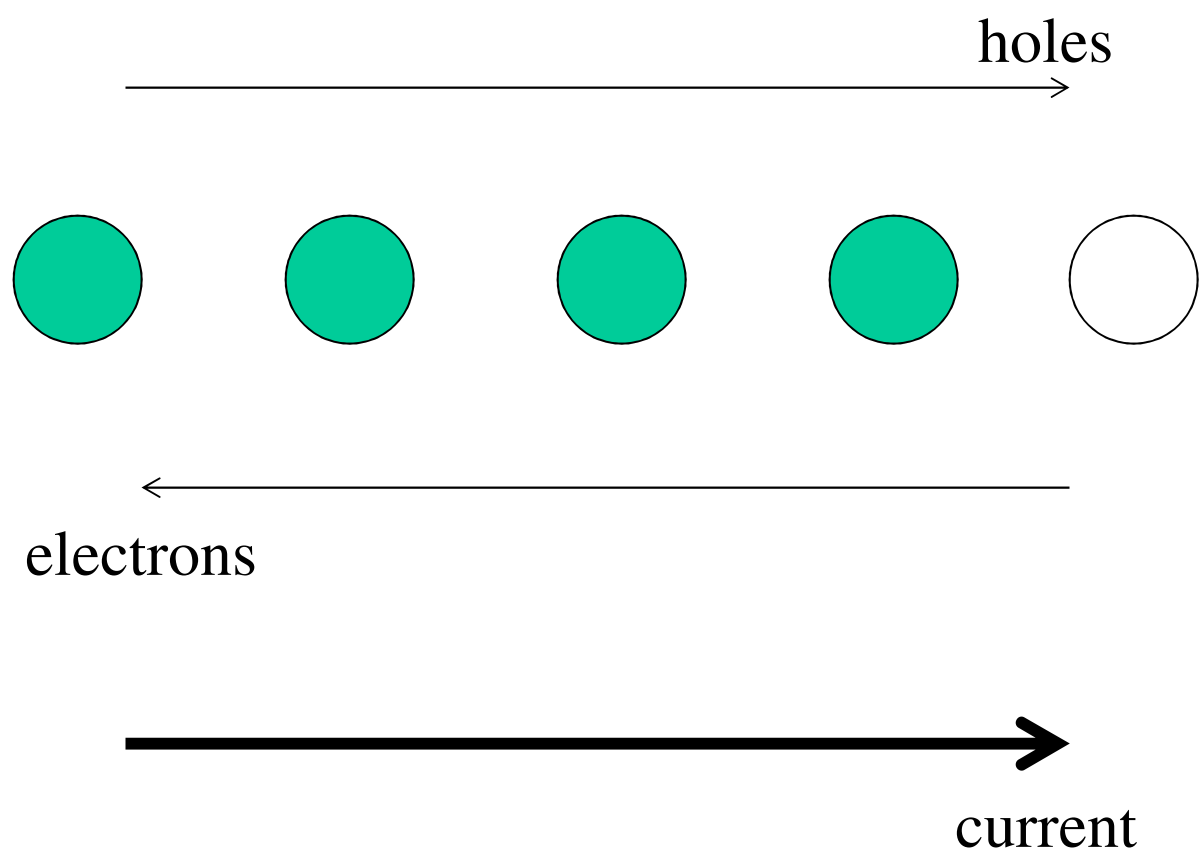
Intrinsic Semiconductors



Intrinsic Semiconductors



Intrinsic Semiconductors



Intrinsic Semiconductors

- When an electric field (voltage) is applied, the holes move in one direction and the electrons in the other.
- However both current components are in the direction of the field.
- The conduction is ohmic, i.e. current is proportional to the applied voltage (field)

Intrinsic Semiconductors

- For an intrinsic semiconductor the number of electron and hole carriers, and thus the conductivity, increases rapidly with temperature.
- This is not very useful.
- Hence we dope the material to produce an extrinsic semiconductor.

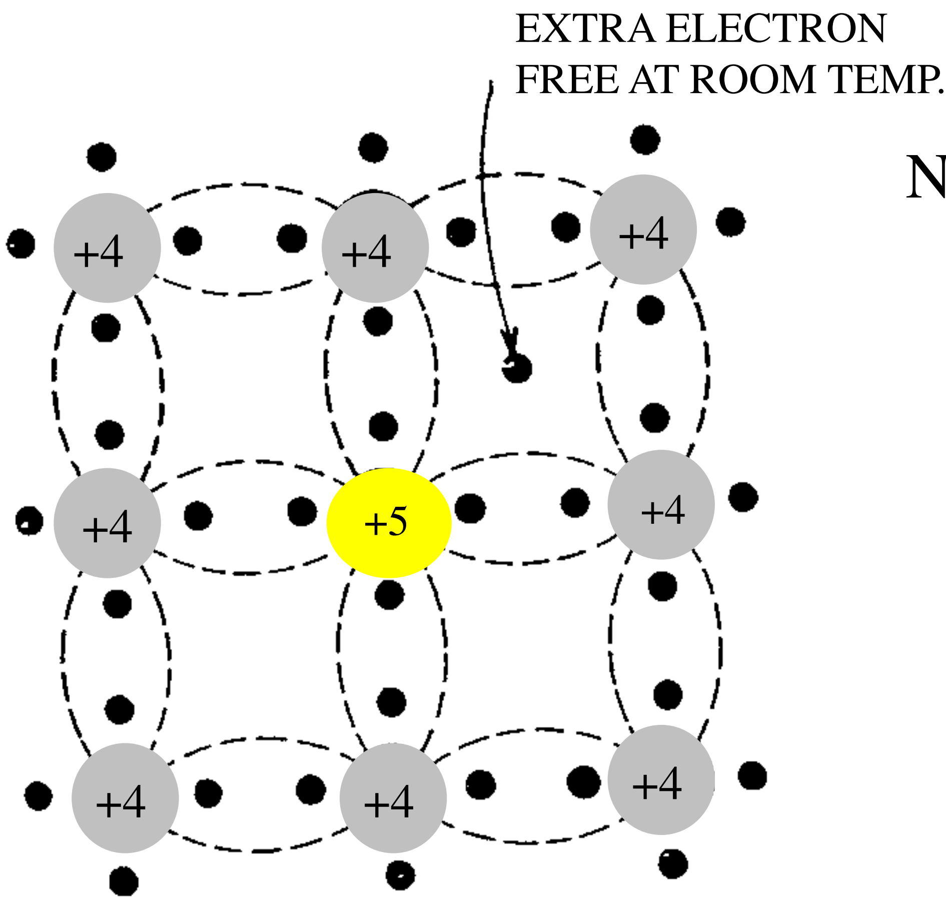
Extrinsic Semiconductors

- Instrinsic conduction is very small (see example).
- Conductivity levels can be raised and controlled by *doping* with minute levels of impurity atoms to give *extrinsic* or *doped* semiconductors.
- Extrinsic semiconductors may be further divided into either n-type or p-type

N-type Semiconductors

- An n-type impurity atom has five outer (valence) electrons, rather than the four of silicon.
- Only four of the outer electrons are required for covalent bonding. The fifth is much more easily detached from the parent atom.
- As the energy needed to free the fifth electron is smaller than the thermal energy at room temperature virtually all are freed.

N-type Semiconductors



N_D = donor implant density

$$n = p + N_D$$

$$n\,p = n_i^2$$

If $N_D >> n_i > p$

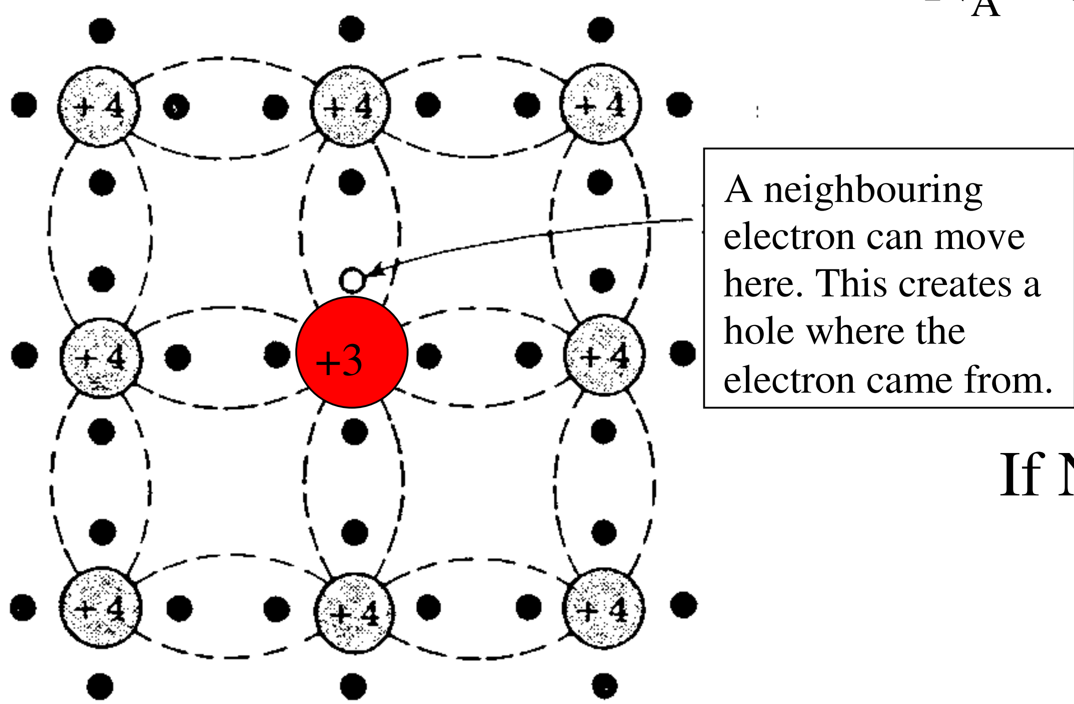
$$n \approx N_D$$

$$p \approx n_i^2 / N_D$$

P-type Semiconductors

- Here the doping atom has only three electrons in its outer shell.
- It is relatively easy for an electron from a neighbouring atom to move in, so releasing a hole at its parent atom. The freed hole is available for conduction.
- The energy needed to free the electron from its parent is usually small compared to the thermal energy so each impurity atom contributes one hole for conduction (fully ionised).

P-type Semiconductors



N_A = acceptor implant density

$$p = n + N_A$$

$$n\,p = n_i^2$$

If $N_A >> n_i > n$

$$p \approx N_A$$

$$n \approx n_i^2 / N_A$$