EN1014

Electronic Engineering

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Diodes and Diode Applications

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Main Topics

- Semiconductors for Electronic Devices
- Semiconductor Diodes
- Applications of Semiconductor Diodes

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Semiconductors for Electronic Devices

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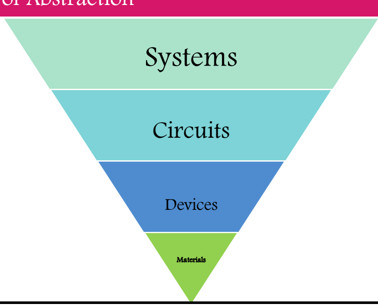
Layers of Abstraction



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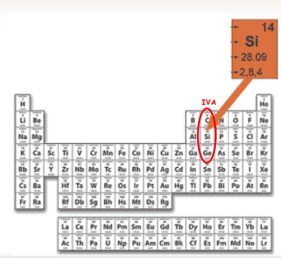
INTRINSIC SEMICONDUCTORS



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INTRINSIC SEMICONDUCTORS

- ☑ Pure Semiconductors
  - ☑ Not mixed(doped) with other materials
- ☑ Electrons and Holes are generated in pairs, due to thermal agitation even at room temperature
- ☑ Can carry a very small electric current using those free electrons and holes.

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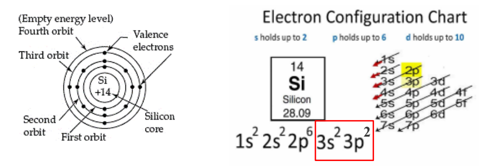
Energy Level Abstraction of Semiconductor Atoms



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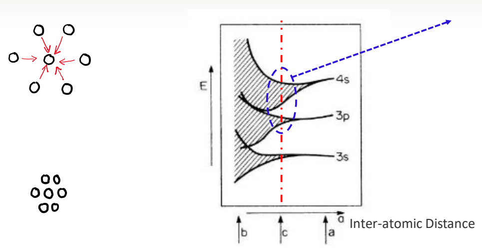
Energy Band Abstraction of Solids



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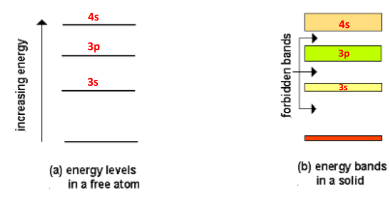
Energy Band Abstraction of Solids



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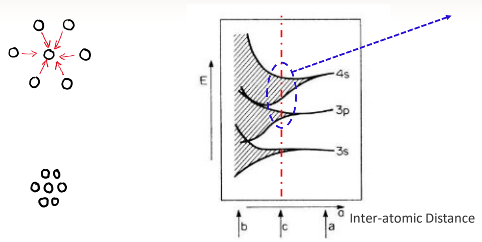
Upper Energy Bands of Silicon



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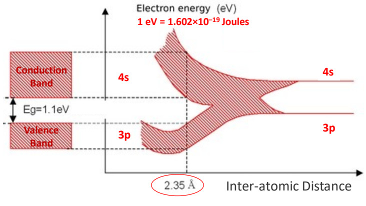
Upper Energy Bands of Silicon



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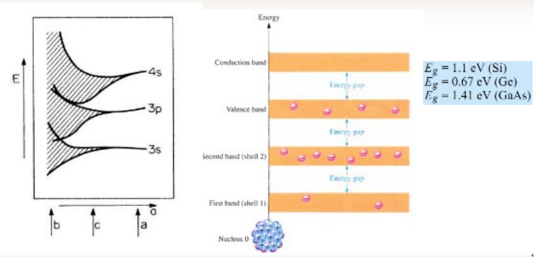
Energy Band Gaps of some semiconductors



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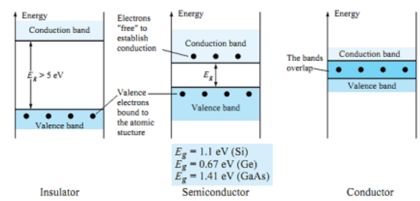
Energy Bands in Materials



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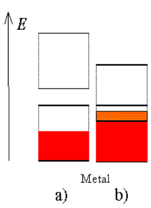
Energy Bands in Metals



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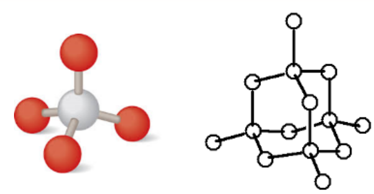
Covalent bonds in the Silicon crystal lattice structure



Tetrahedron structure

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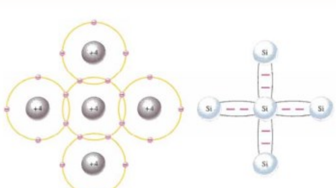
Schematic representations(Models) of covalent bonds



Four covalent bonds per atom

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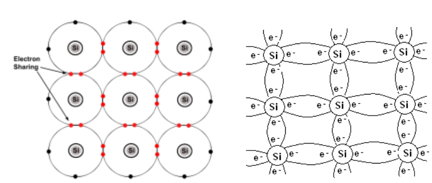
Simplified representations(Models) of lattice



Representation 1

Representation 2

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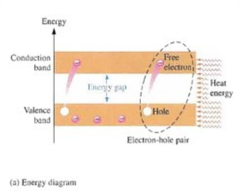
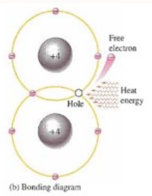
Thermal Excitation



Representation 1



Representation 2

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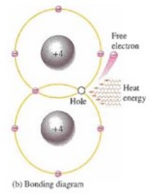
Thermal Excitation



$$\text{Covalent Bond} + \Delta E \underset{\text{Recombination process}}{\overset{\text{Generation process}}{\rightleftharpoons}} (\text{Ion})^{+} + [\text{Free e}] + \text{Hole}$$

<u>Thermal Equilibrium</u>:

Rate of generation = Rate of recombination

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Mass-action law

$$\text{Free Electrons} \times \text{Holes} = n_i^2$$

n_i is the intrinsic Carrier concentration

for intrinsic semiconductors; Holes = Free electrons = n_i

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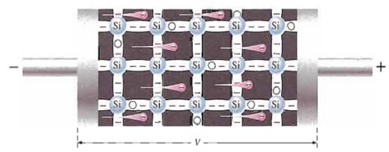
Current Flow by electrons



Current is very small at room temperature.
It is in the order of nA

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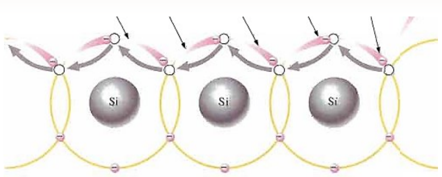
Current flow by holes



Total current = Electron current + Hole current

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SEMICONDUCTORS

- **Intrinsic Semiconductors**
  - **Pure / Not mixed /Not Doped**
- **Extrinsic Semiconductors**
  - **Doped with an impurity material**

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Making Extrinsic Semiconductors

Group III A

Group V A

Trivalent

Pentavalent

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EXTRINSIC SEMICONDUCTORS

- doped semiconductors
- p type – positive type
  majority holes
  minority electrons
- n type – negative type
  majority electrons
  minority holes

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Making Extrinsic Semiconductors

Group III A

Group V A

Trivalent

Pentavalent

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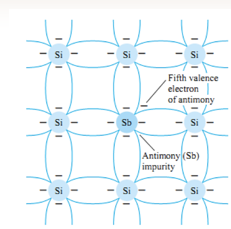
n – Type Semiconductor



https://www.youtube.com/watch?v=JBtEckh3L9Q

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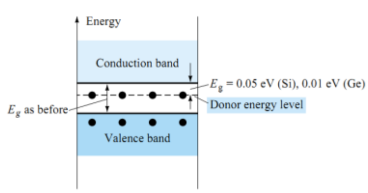
Energy Levels due to Doping



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Current carriers

Holes = All are thermally generated holes

Free electrons = Donar donated electrons + Thermally generated electrons

Covalent Bond + ΔE $\rightleftharpoons$ (Ion)$^+$ + [Free electron] + Hole

Holes decrease further in number.

At the new equilibrium state holes are minority carriers now.

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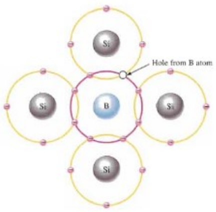
p – Type Semiconductor



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Current carriers

Free electrons = All are thermally generated holes

Holes = Acceptor associated holes + Thermally generated holes

Covalent Bond + ΔE $\rightleftharpoons$ $(\text{Ion})^{+}$ + [Free electron] + Hole

Free electrons decrease further in number.

At the new equilibrium state electrons are minority carriers now.

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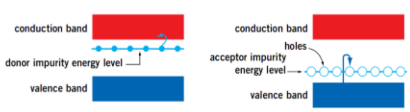
Fermi Levels



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Semiconductor Diodes

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SEMICONDUCTOR DIODES

1) p-n junction diode
2) Forward biased diode
3) Reverse biased diode
4) V/I characteristics of the diode
5) The Ideal diode

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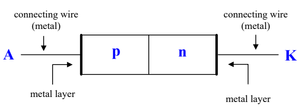
p-n JUNCTION DIODE



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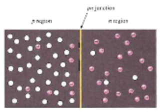
Diffusion Process

- Touching surfaces must be microscopically clean
- Electrons diffuse (spill over) from the border of the N material into the P material



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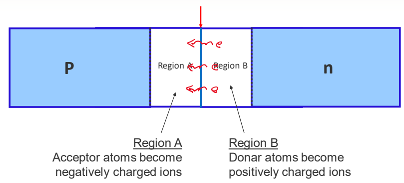

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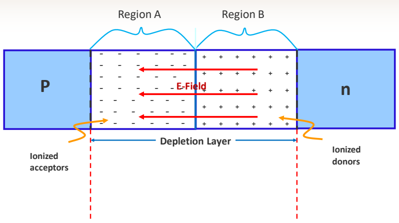

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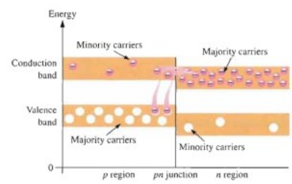
Energy Bands in p-n junction at the time of formation



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Depletion Layer

- Width of these two regions(A & B) increase until they reach an equilibrium condition
  - Now just enough e's are on the P side to repel any more e's diffusion.
- This double-layer of two opposite electric charges (+ and -) is called a *Depletion layer.*

https://youtu.be/JNi6WY7WKAI

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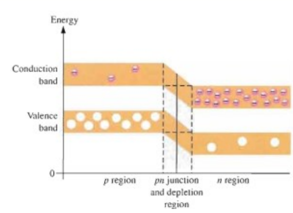
Energy Bands in p-n junction at equilibrium



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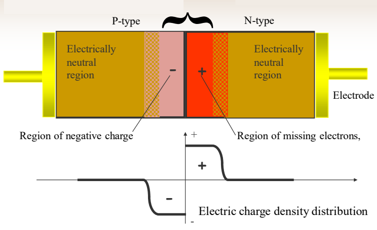

Ex. Plot E field and potential

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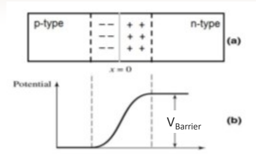
Barrier Potential



$$V_{\text{Barrier}} = \frac{kT}{q}\ln\left(\frac{N_D N_A}{n_i^2}\right)$$

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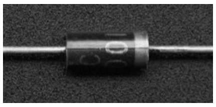
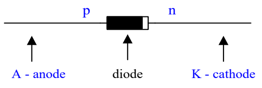
PHYSICAL APPEARANCE
Ex: 1N4000 DIODE





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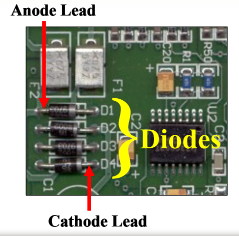
PN Junction Diodes in a circuits



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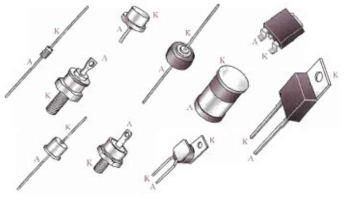
Appearance...



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Biasing

- Use of an external DC voltage to establish the correct operating conditions for an electronic device.

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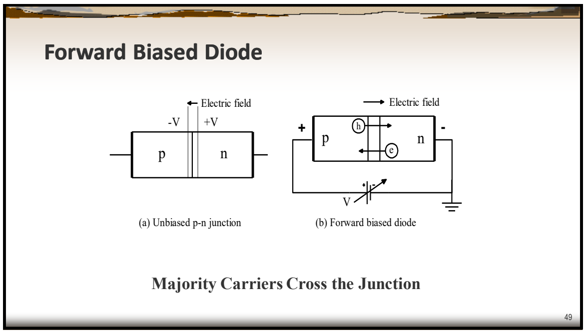

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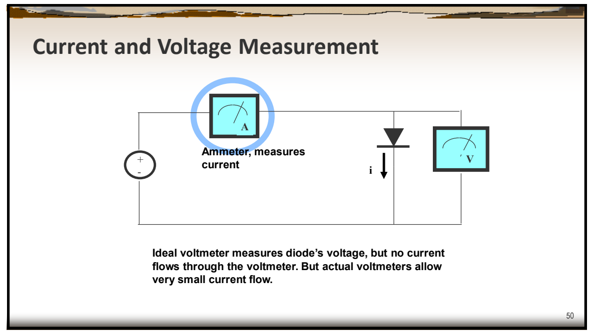

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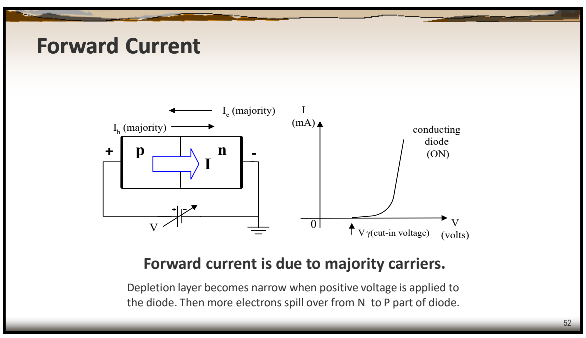

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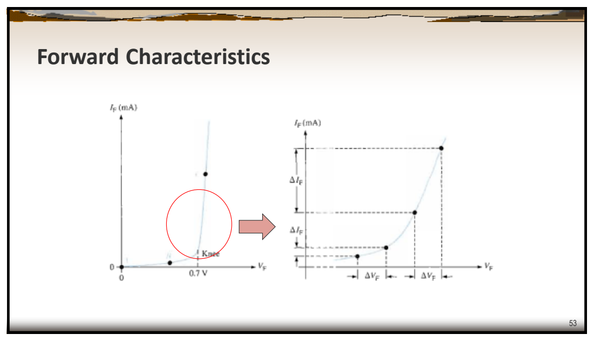

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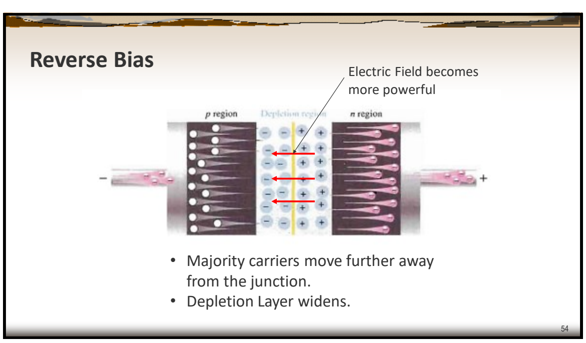

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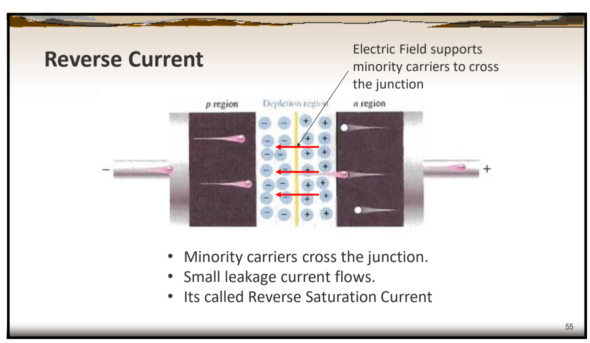

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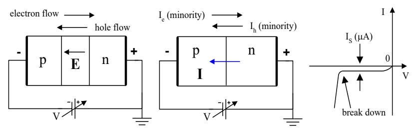
Reverse Biased Diode



(a) An electric field exists from n to p (b) A weak reverse current flows (c) V - I characteristics

Reverse current is due to minority carriers.

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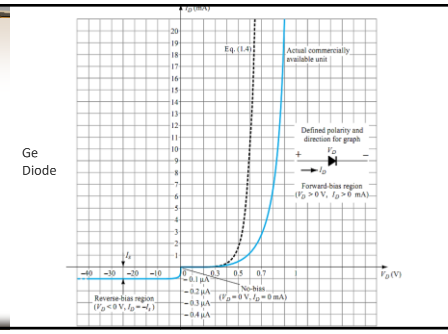
Ge Diode



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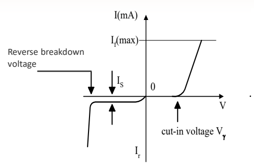
Voltage vs Current Characteristics



V - I characteristics of a diode

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