Basics of Electronics Engineering (EC142)

Presented By:
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Semiconductor Diodes and Applications

- Introduction to Electronics
- Familiarization with basic electronic components.
- Semiconductor Theory
- Review of PN junction operation
- Plot and analyse V-I Characteristics of PN-Junction Diode
- Diode Applications – Rectifier, Clipper
- Special purpose diodes
    - Light Emitting Diode
    - Zener Diode
    - Varactor Diode
    - Photodiode

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Objective of this lecture:

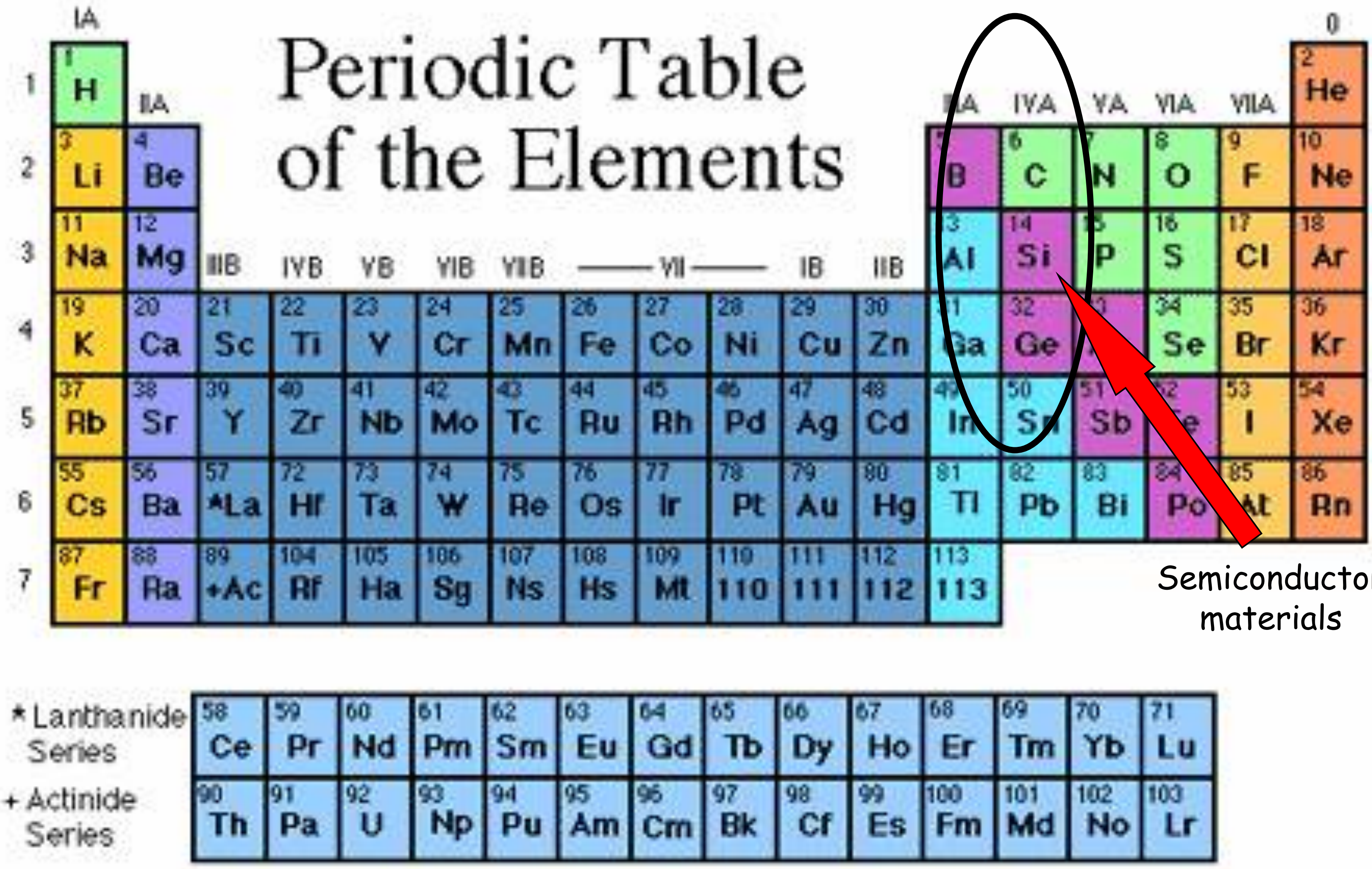
1. Define a semiconductor – no. of electrons in outer shell, location on periodic table, most commonly used ones etc.
2. Know the crystal structure of silicon, the cause and result of defects.
3. Understand intrinsic and extrinsic semiconductor behaviour, know how to affect this behaviour through doping.
4. Explain in detail what depletion regions are and how they are formed.
5. P-N junction

SEMICONDUCTORS: They are here, there, and everywhere

Possible Semiconductor Materials

Carbon	**C**	**6**	1. Very Expensive 2. Band Gap Large: 6eV 3. Difficult to produce without high contamination
Silicon	**Si**	**14**	1. Cheap 2. Ultra High Purity 3. Oxide is amazingly perfect for IC applications
Germanium	**Ge**	**32**	1. High Mobility 2. High Purity Material 3. Oxide is porous to water/hydrogen (problematic)
Tin	**Sn**	**50**	1. Only "White Tin" is semiconductor 2. Converts to metallic form under moderate heat
Lead	**Pb**	**82**	1. Only "White Lead" is semiconductor 2. Converts to metallic form under moderate heat

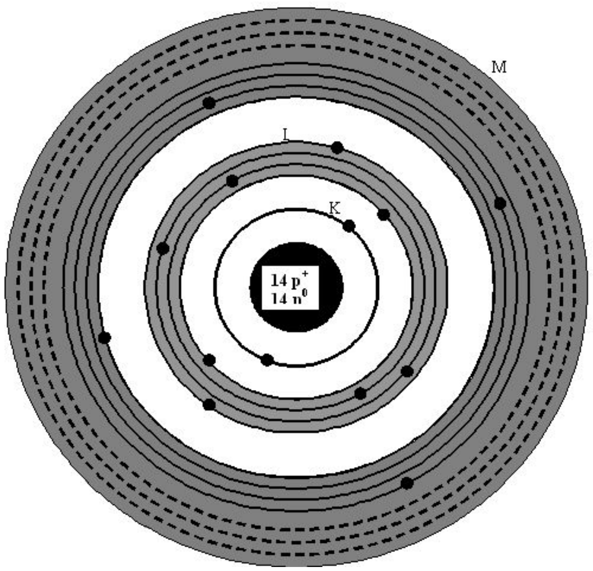
Introduction to Semiconductors

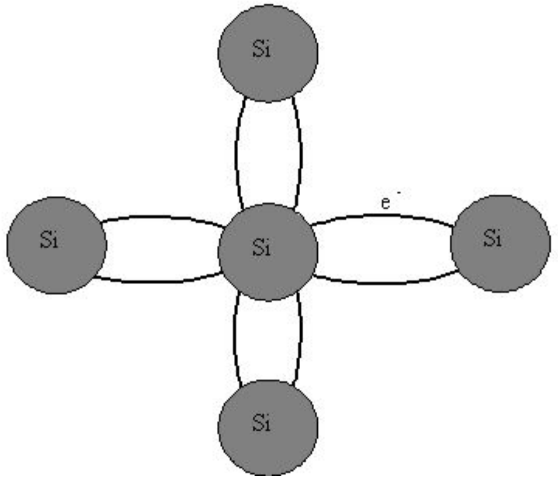


Semiconductor materials

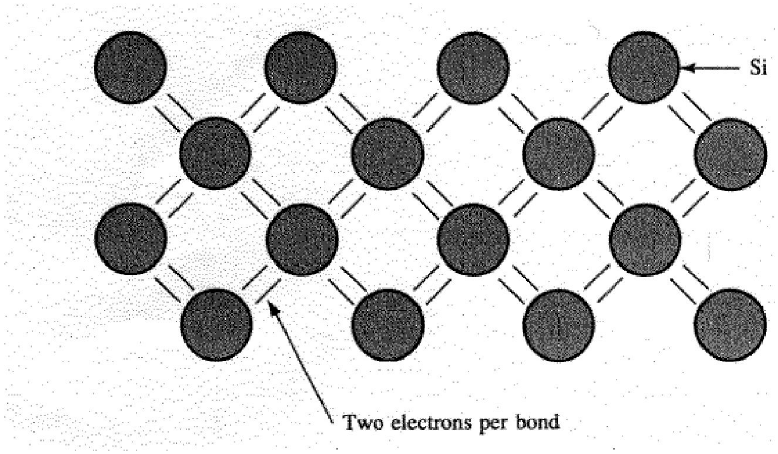
Silicon

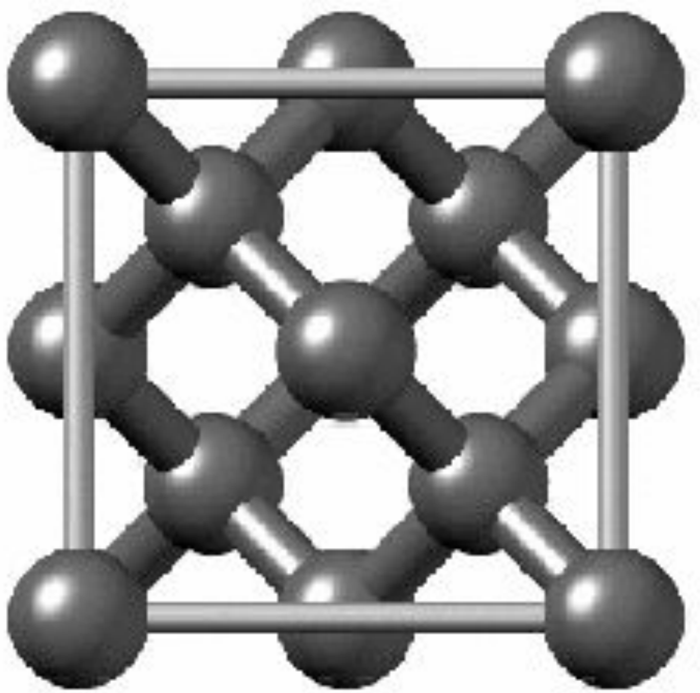
- Silicon, Si, is a group IV material having an atomic number of 14.
- It has 14 orbiting negatively charged electrons: 2 in a full K shell; 8 in a full L shell and 4 in a half-full M sub-shell.
- With a half full outer sub-shell the atom has an affinity for 4 additional electrons to try to complete the outer sub-shell.





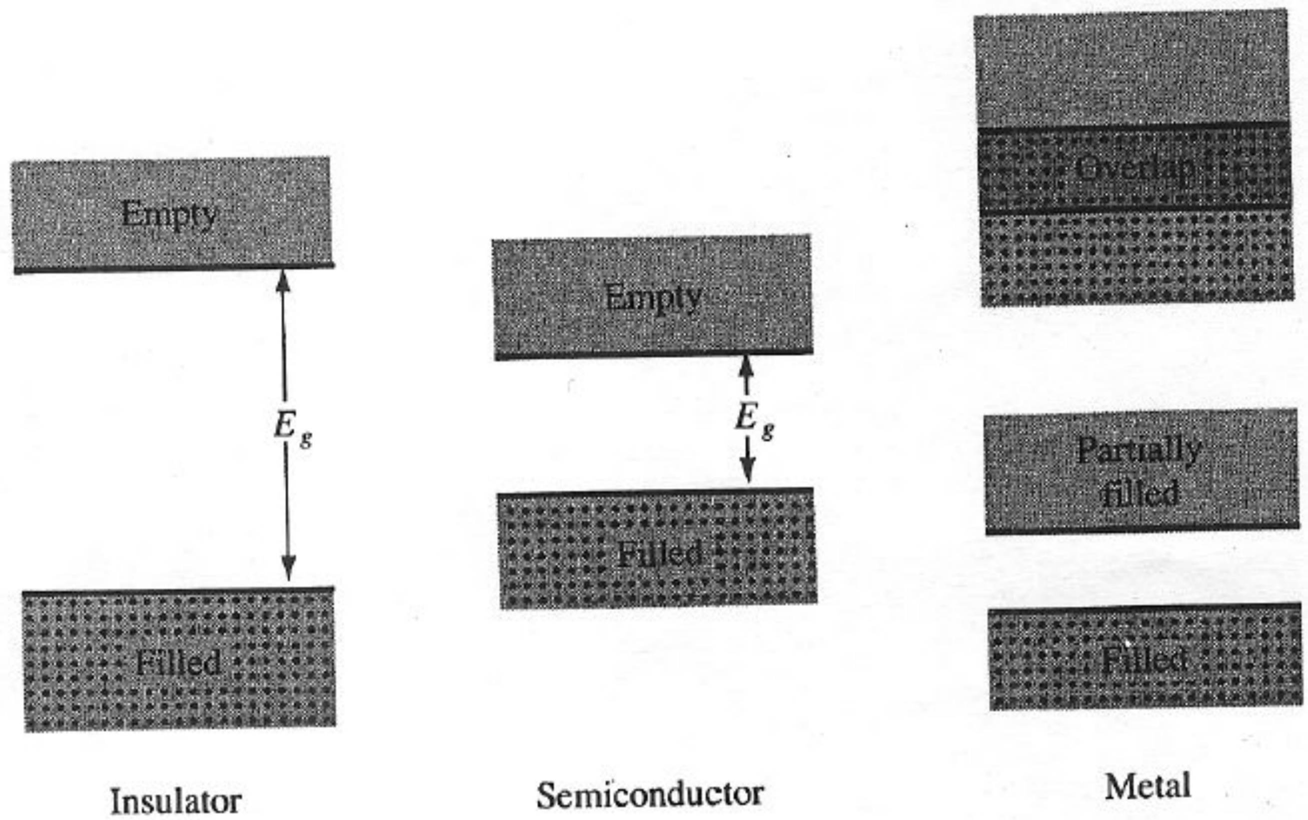
Diamond lattice structure





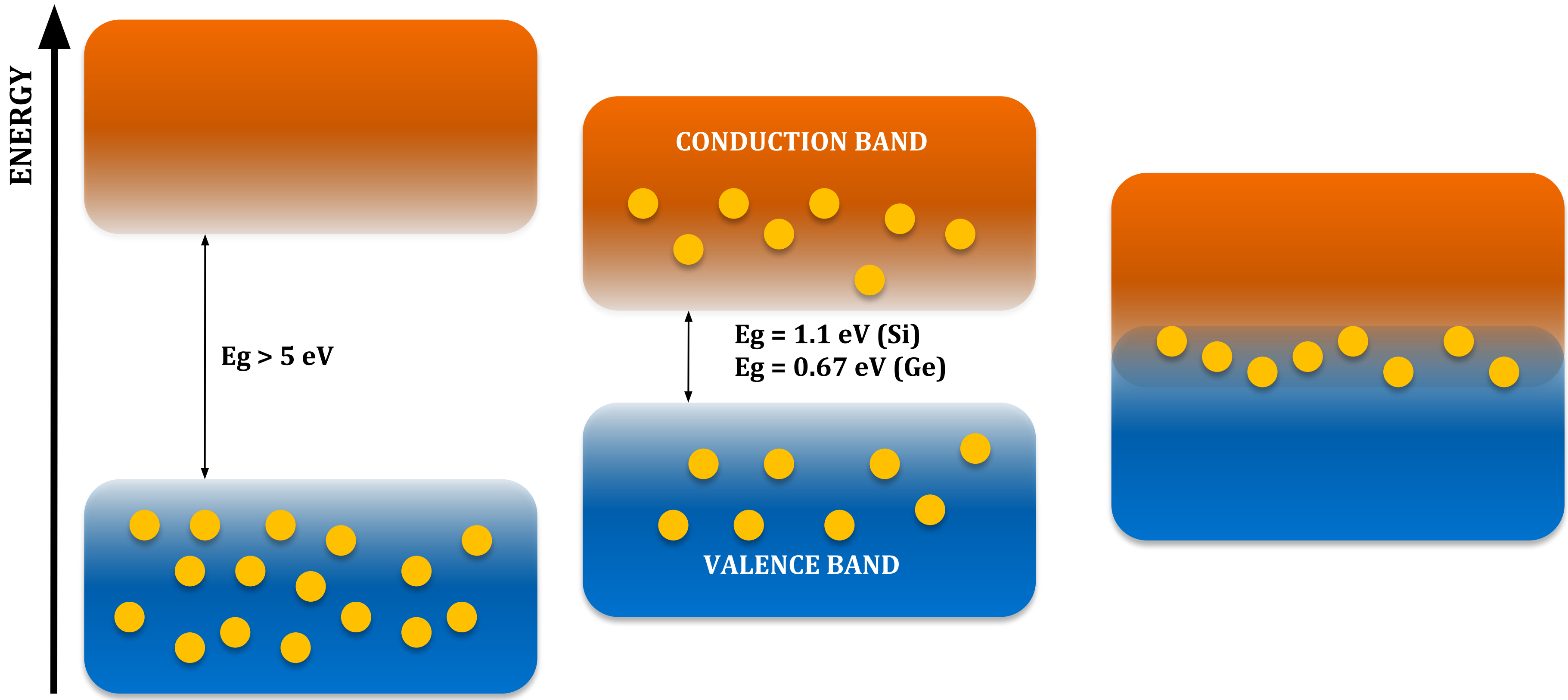
A Covalent Bond Formed by the Sharing of Electrons in an Outer Energy Level

Band Gap Energies



Typical continuous band pictures at 0 K for different solid materials.

Band Gap Energies

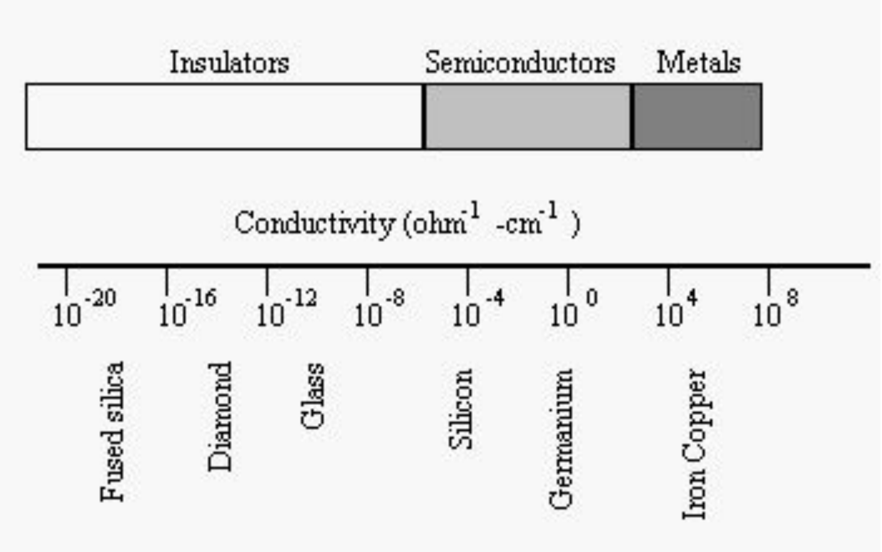


INSULATORS
$\rho = 10^{12}\ \Omega$-cm (Mica)

SEMI-CONDUCTORS
$\rho = 50\ \Omega$-cm (Germanium)
$\rho = 5 \times 10^{3}\ \Omega$-cm (Silicon)

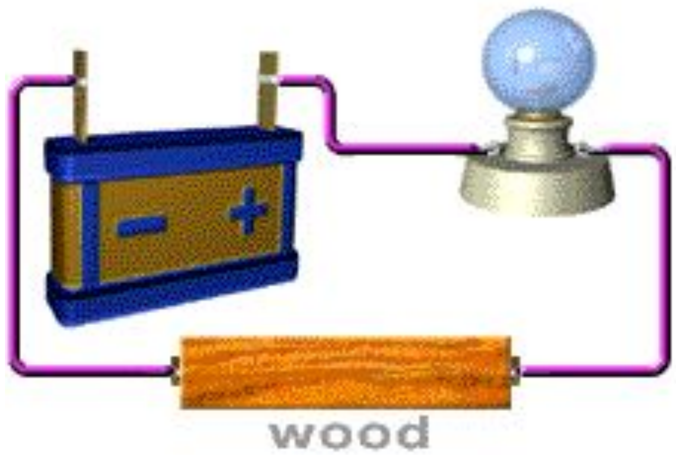
CONDUCTORS
$\rho = 10^{-6}\ \Omega$-cm (Copper)

Range of Conduciveness



The semiconductors fall somewhere midway between conductors and insulators.

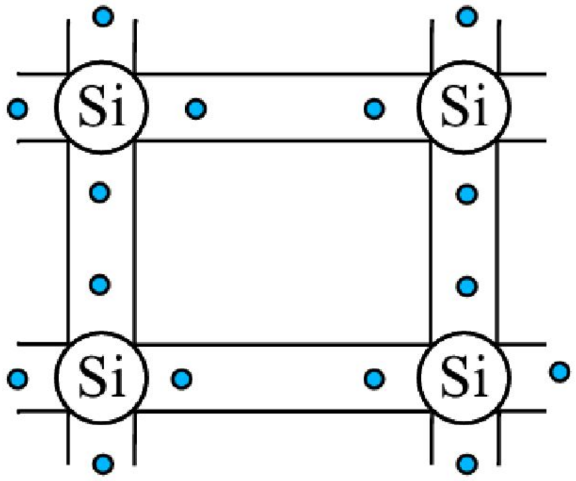
Range of Conduciveness

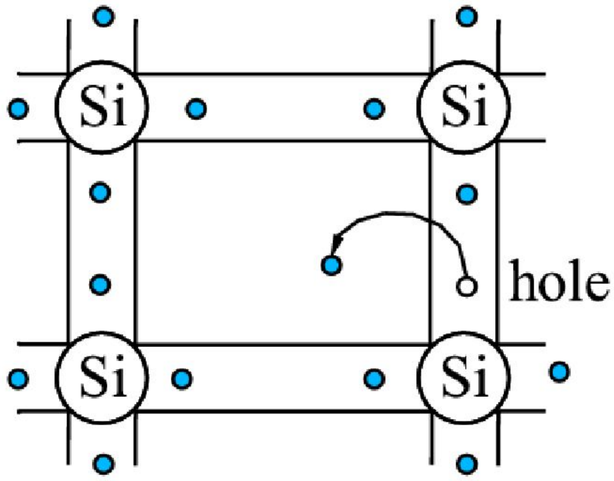


Semiconductors have special electronic properties which allow them to be insulating or conducting depending on their composition.

Electrons and Holes

Si and Ge are tetravalent elements – each atom of Si (or Ge) has 4 valence electrons in its crystal matrix





T=0 all electrons are bound in covalent bonds

no carriers available for conduction.

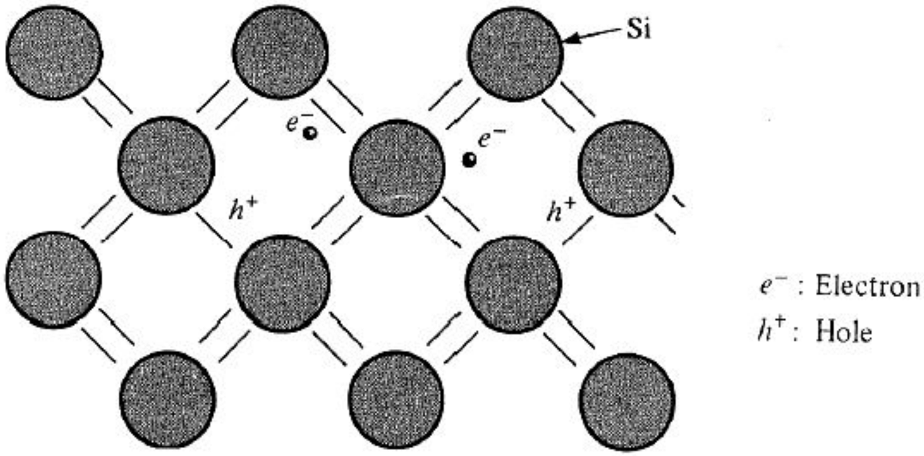
For T> 0 thermal fluctuations can break the electrons free, creating electron-hole pairs

Both can move throughout the lattice and therefore conduct current.

Intrinsic Material

A pure semiconductor crystal with no impurities or lattice defects is called an ***intrinsic*** semiconductor.

- At T=0 K, No charge carriers.
- Valence band is filled with electrons.
- Conduction band is empty.

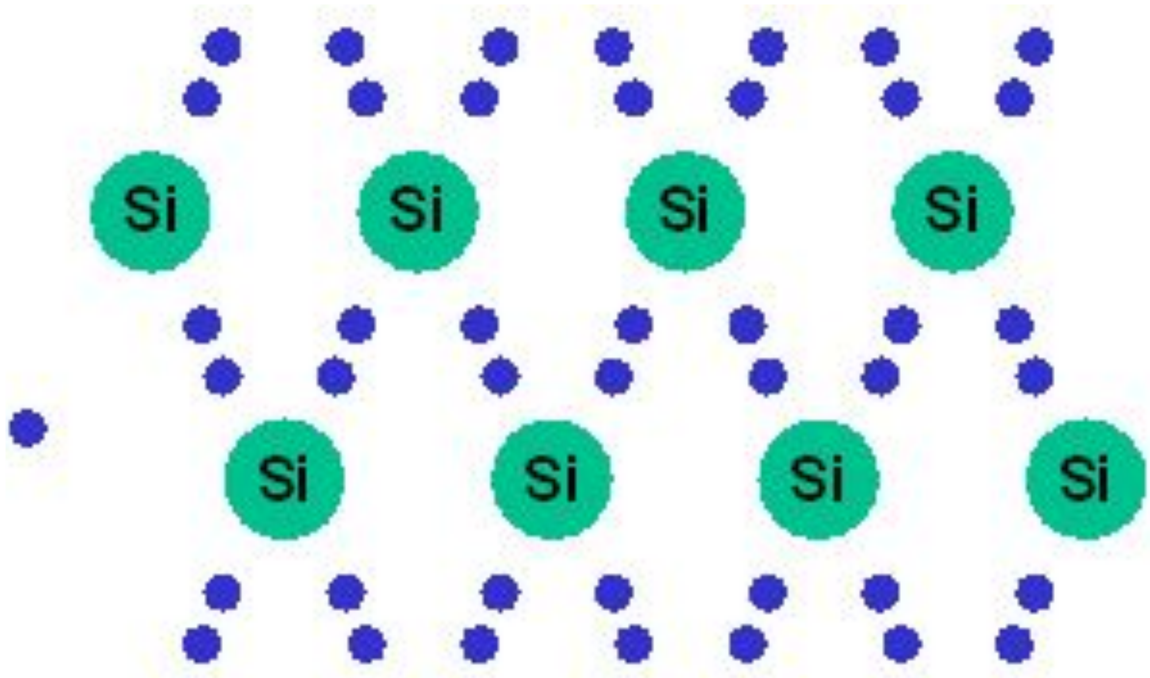


Electron-hole pairs in the covalent bonding model in the Si crystal.

- At T>0, Electron-hole pairs are generated.
- EHPs are the only charge carriers in *intrinsic material.*
- Since electron and holes are created in pairs – the electron concentration in conduction band, n (electron/cm^3) is equal to the concentration of holes in the valence band, p (holes/cm^3).
- Each of these intrinsic carrier concentrations is denoted n_i.

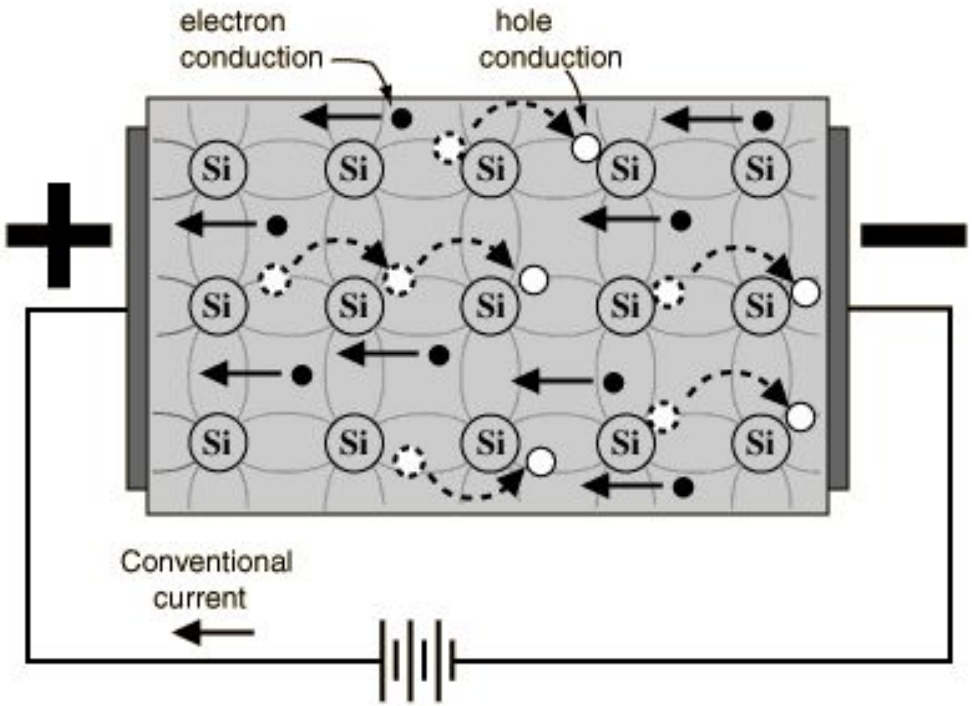
Thus for intrinsic materials $n=p=n_i$

Intrinsic Silicon



At any temperature above absolute zero temperature, there is a finite probability that an electron in the lattice will be knocked loose from its position.

Current Flow through intrinsic semiconductor

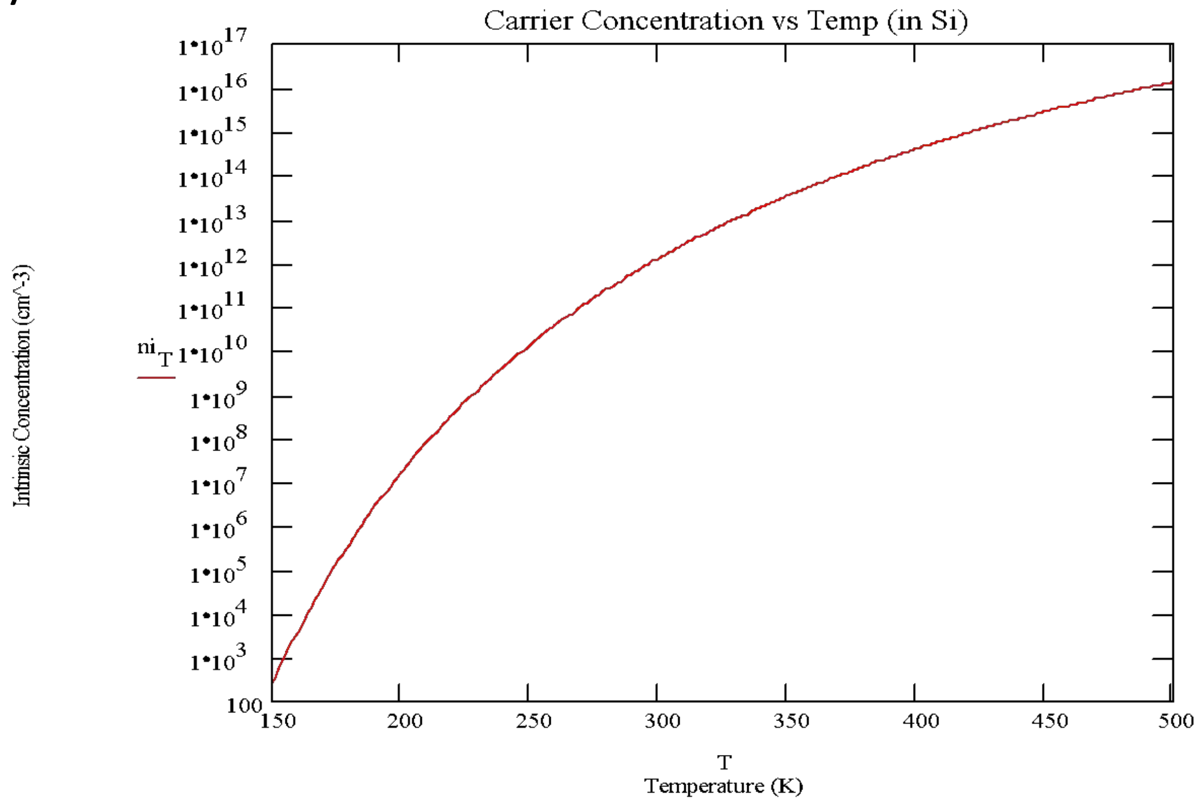


If a voltage is applied, then both the electron and the hole can contribute to a small current flow.

NOTE: When flow of carriers is due to externally applied voltage, resultant current is called **drift current**. When current flow is as a result of gradient of carrier concentration, it is called **diffusion current**.

Increasing conductivity by temperature

As temperature increases, the number of free electrons and holes created increases exponentially.



Therefore the conductivity of a semiconductor is influenced by temperature, This is because the application of heat makes it possible for some electrons in the valence band to move to the conduction band.

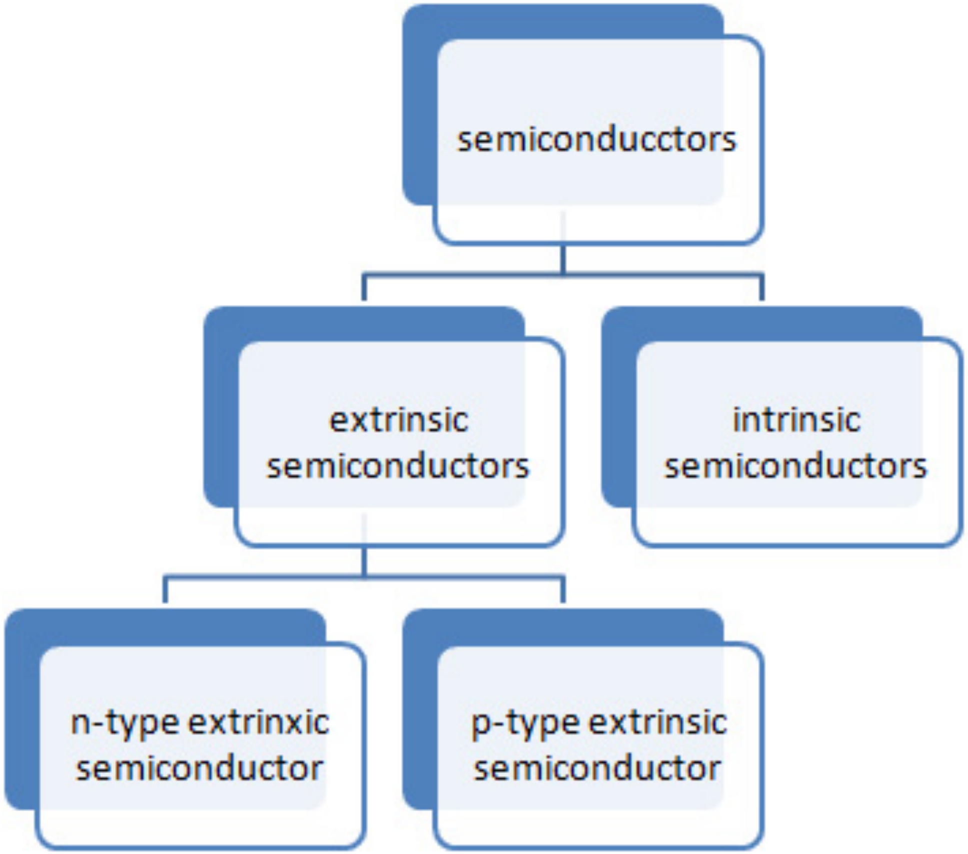
Increasing conductivity by doping

- Another way to increase the number of charge carriers is to add them in from an external source.
- **Doping** or implant is the term given to a process whereby one element is injected with atoms of another element in order to change its properties.
- Semiconductors (Si or Ge) are typically doped with elements such as Boron, Arsenic and Phosphorous to change and enhance their electrical properties.

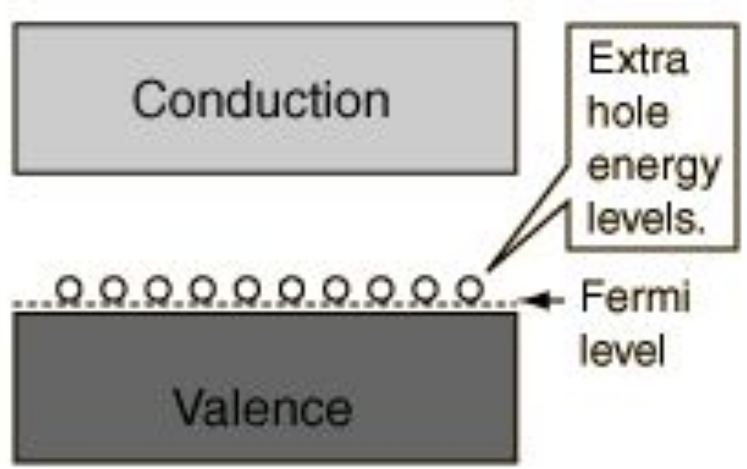
Extrinsic Semiconductors

- A semiconductor that has been subjected to "doping" is called an extrinsic material.
- There are two types of extrinsic materials – N type (formed when intrinsic semiconductor is doped with impurity atoms having 5 valence electrons e.g. antimony, arsenic, and phosphorus), and P type (formed when intrinsic semiconductor is doped with impurity atoms having 3 valence electrons e.g. boron, gallium, and indium)
- Impurity atoms for forming N-type material are called Donor type, and that for forming P-type are called Acceptor type impurity atoms.

Types of Semiconductors



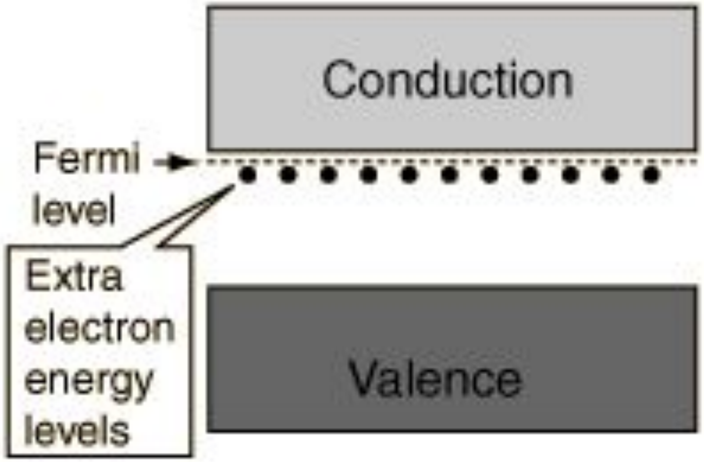
P-Type



The absence of an electron creates the effect of a positive charge, hence the name P-type.

Holes can conduct current. A hole happily accepts an electron from a neighbor, moving the hole over a space. P-type silicon is a good conductor.

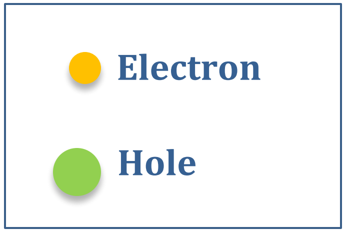
N-Type



It takes only a very small quantity of the impurity to create enough free electrons to allow an electric current to flow through the silicon. N-type silicon is a good conductor.

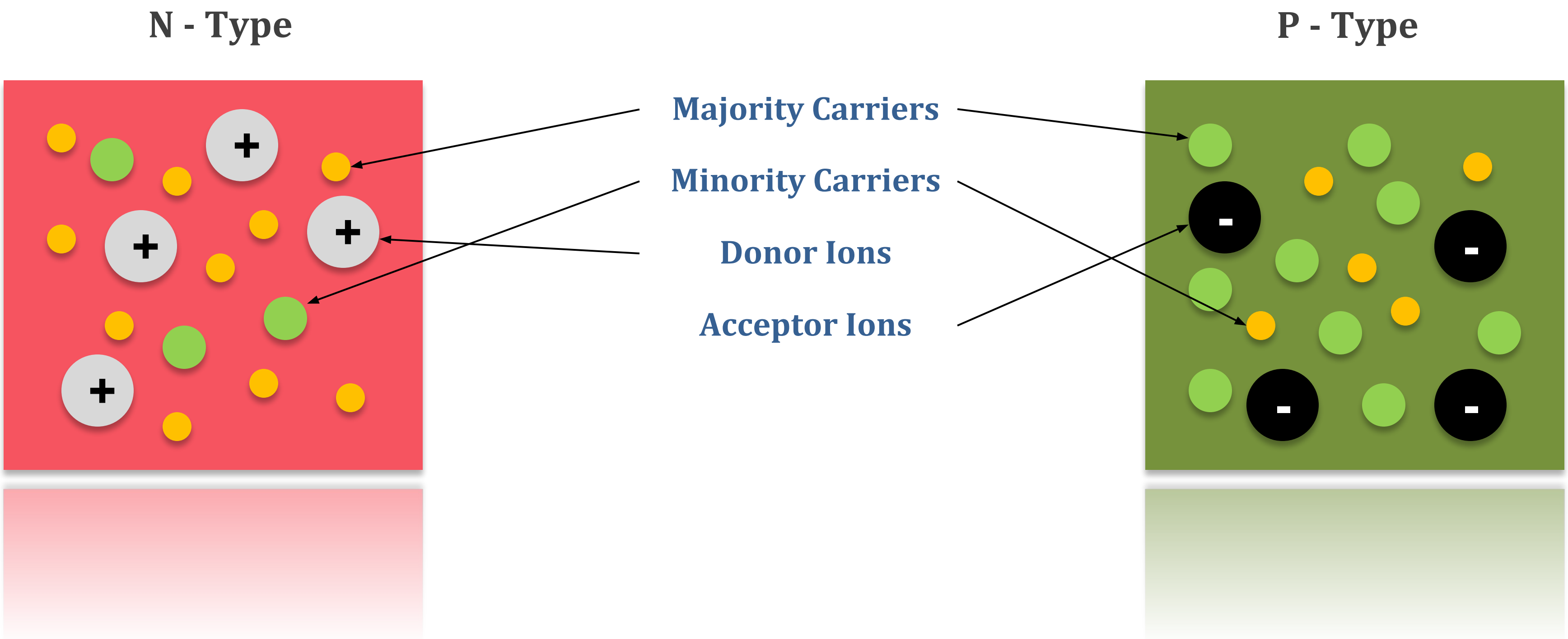
Electrons have a negative charge, hence the name N-type.

Extrinsic Semiconductors



Jargons

- Majority Carriers
- Minority Carriers
- Donor Ions
- Acceptor Ions



Modulators of conductivity

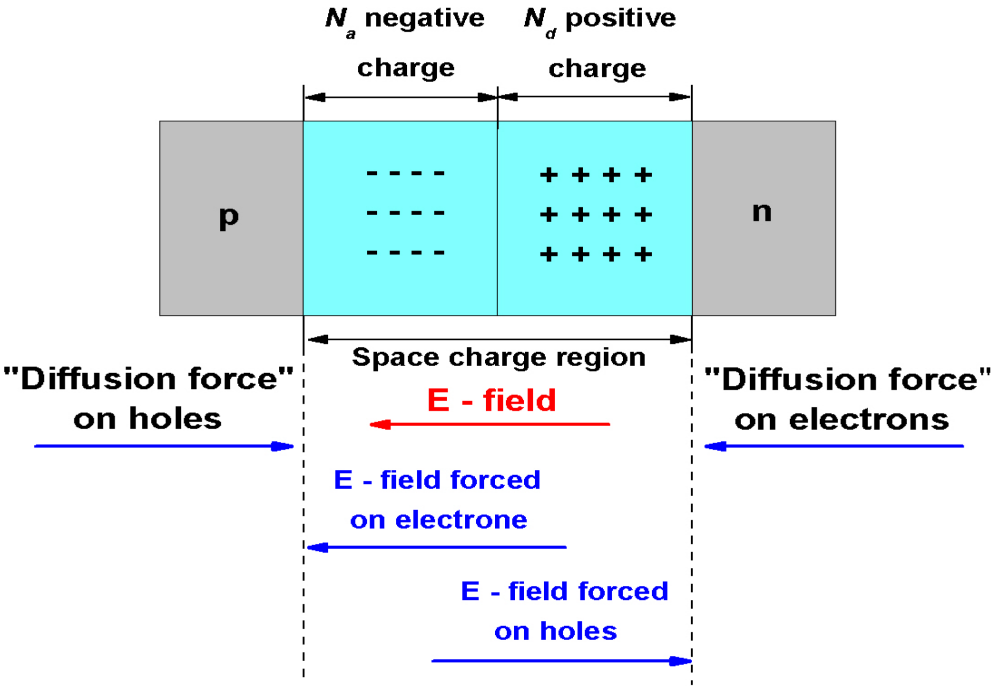
Just reviewed how conductivity of a semiconductor is affected by:

- Temperature – Increasing temperature causes conductivity to increase
- Dopants – Increasing the number of dopant atoms (implant dose) cause conductivity to increase.
- Holes are slower than electrons therefore n-type material is more conductive than p-type material.
- These parameters are in addition to those normally affecting conducting material,

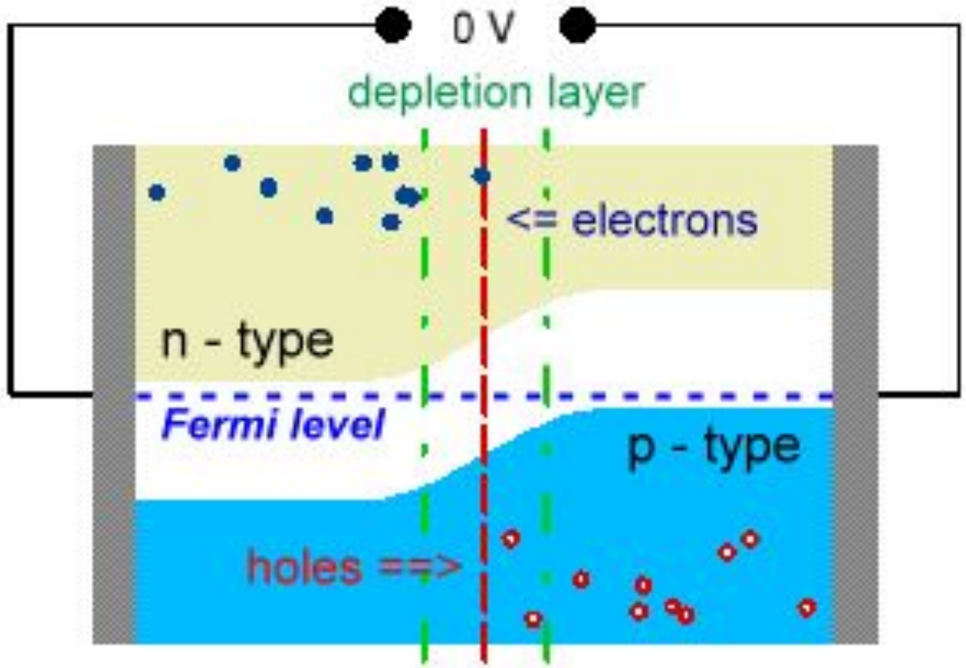
Cross sectional area	Resistance
Length	Resistance

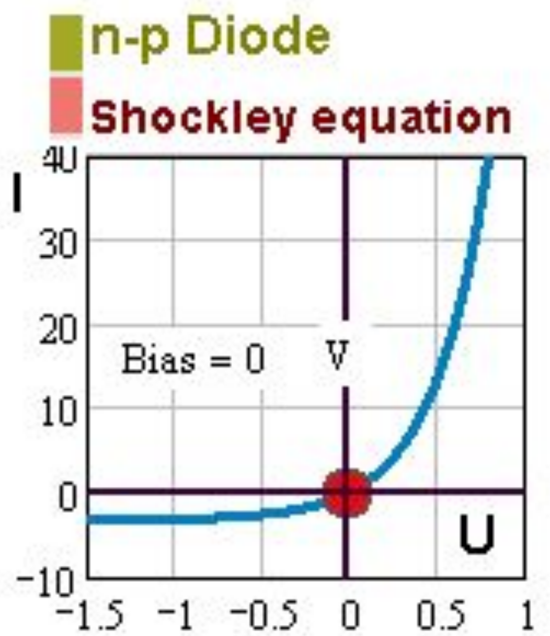
Formation of PN Junction

- If the n type and p type materials are joined together, the electrons and holes in the region of the contact (called junction) diffuse forming a depletion layer.



P-N Junction

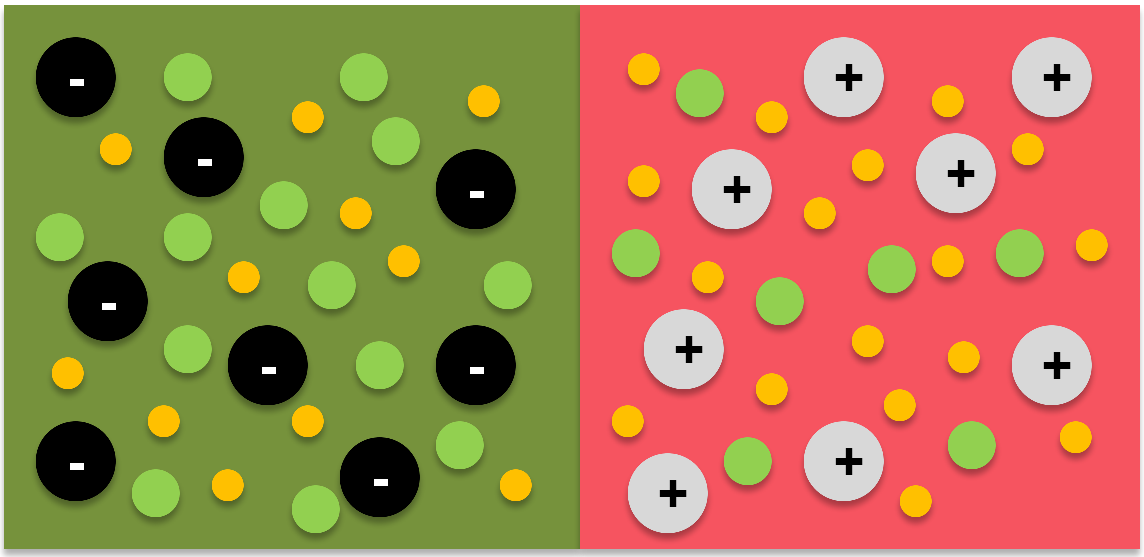




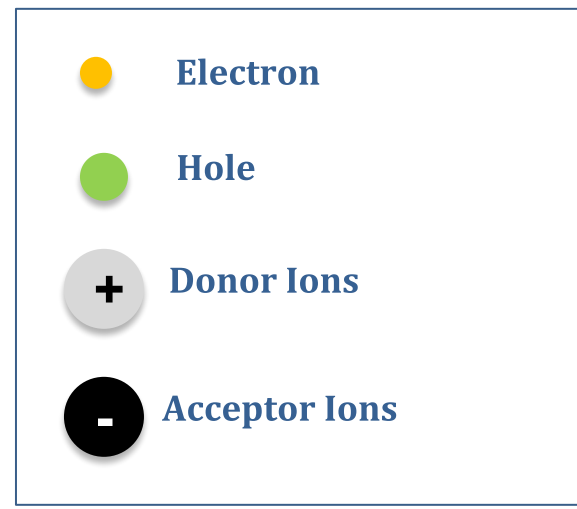
When a p-n junction is formed, some of the electrons from the n-region which have reached the conduction band are free to diffuse across the junction and combine with holes.

PN Junction

Formation of PN Junction



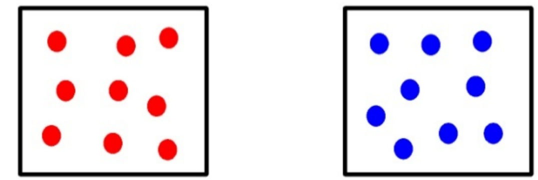
- **Formation of a PN Junction**
- **Diffusion**
- **Formation of Depletion Region**
- **Barrier Potential**



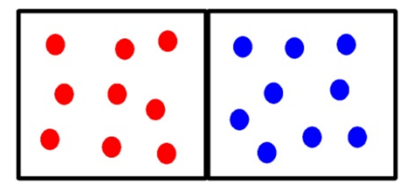
In the n-type region there are extra electrons and in the p-type region, there are holes from the acceptor impurities .

Diffusion

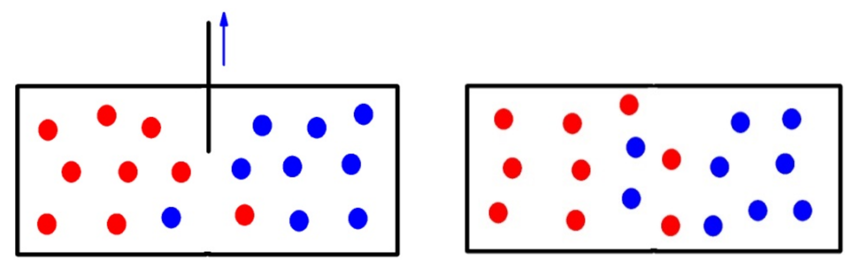
Let us assume that we have two boxes- one contains red air molecules while another one contains blue molecules. This could be due to appropriate types of pollution.



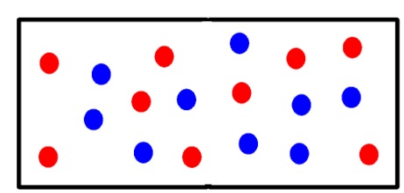
Let us join these 2 boxes together and remove the wall between them.



Each type of molecules starts to move to the region of their low concentration due to the concentration gradient in the middle.

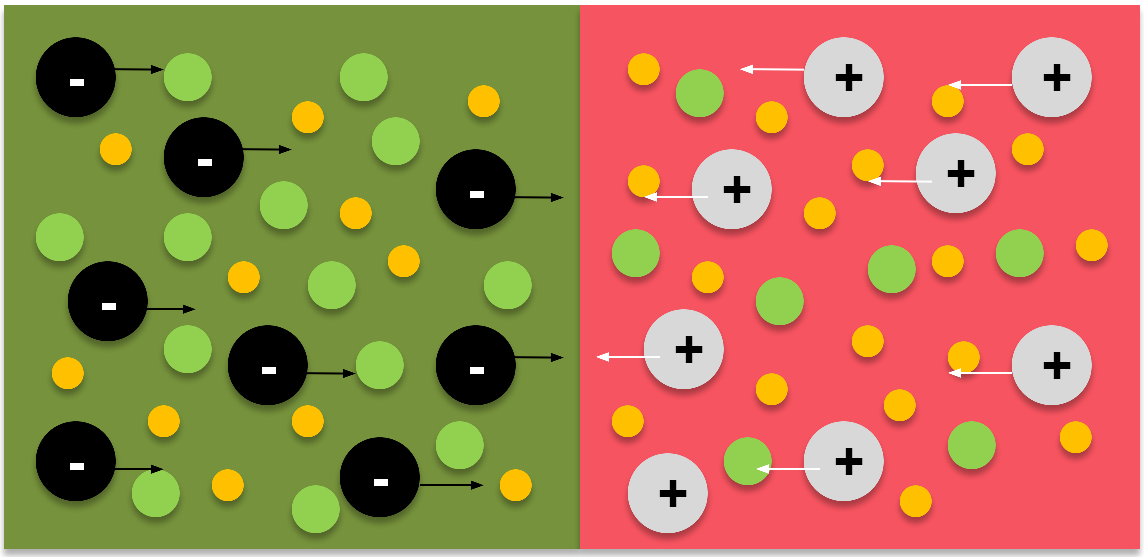


Eventually there would be a homogeneous mixture of two types of molecules.

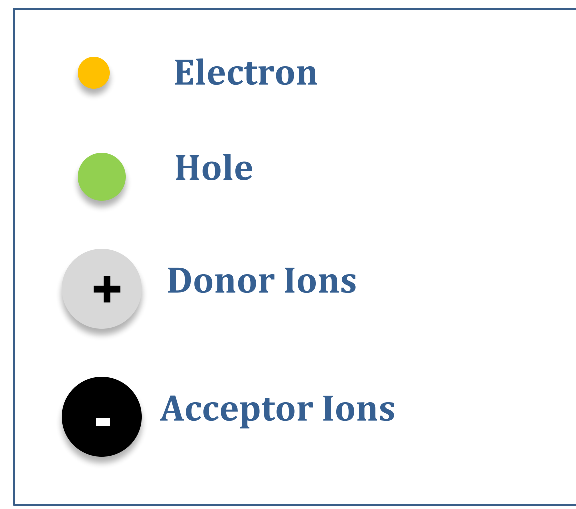


PN Junction

Diffusion



- Formation of a PN Junction
- **Diffusion**
- Formation of Depletion Region
- Barrier Potential



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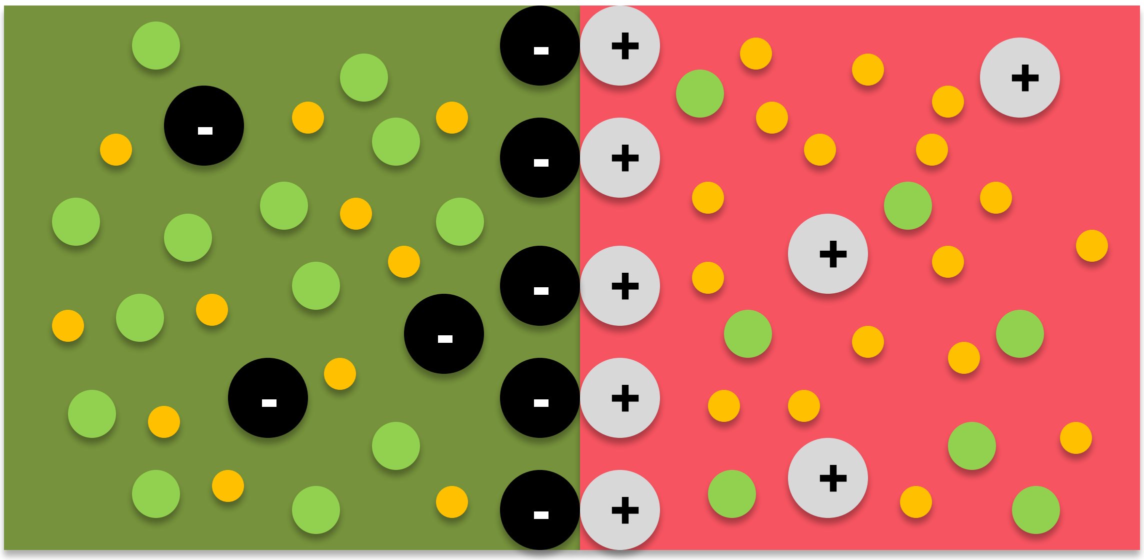
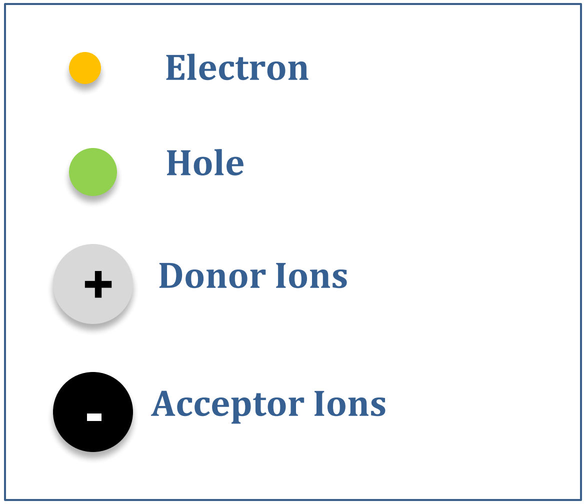
PN Junction

Formation of Depletion Region



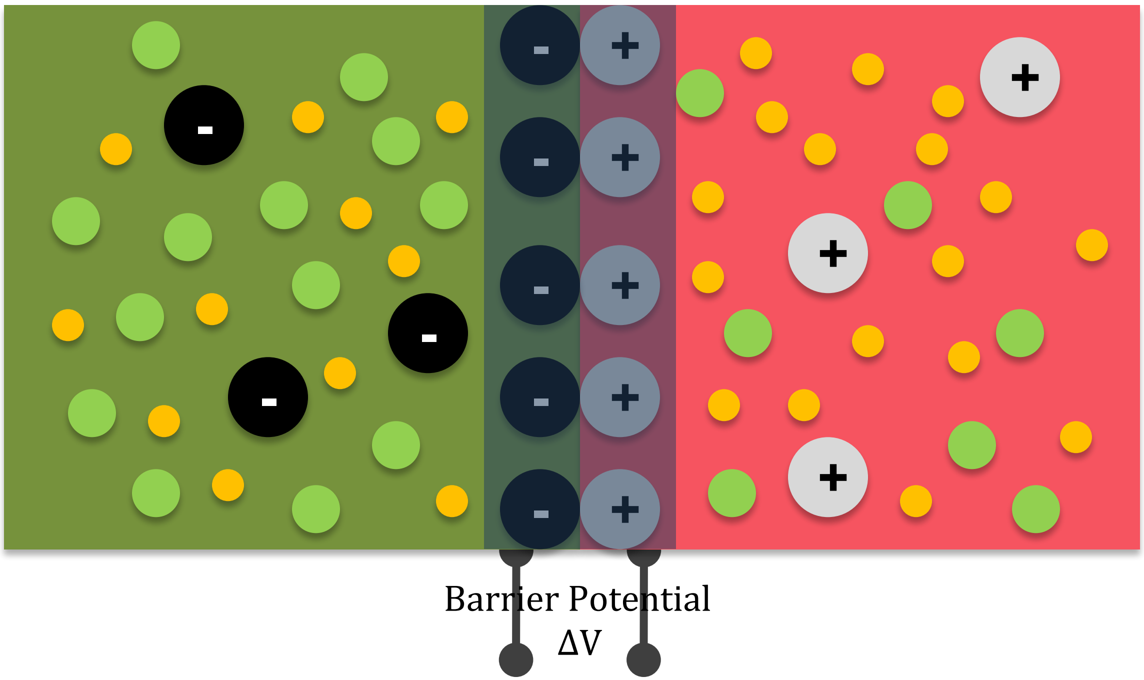
- Formation of a PN Junction
- Diffusion
- **Formation of Depletion Region**
- Barrier Potential

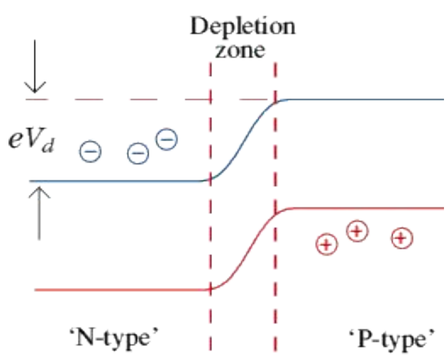
Filling a hole makes a negative ion and leaves behind a positive ion on the n-side. A space charge builds up, creating a depletion region.



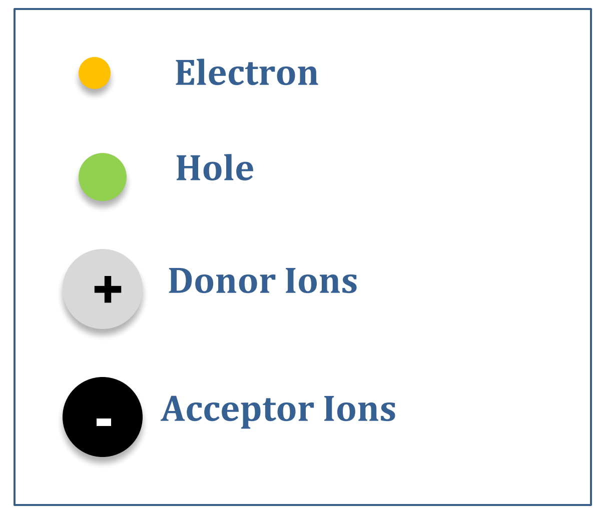
PN Junction

Barrier Potential

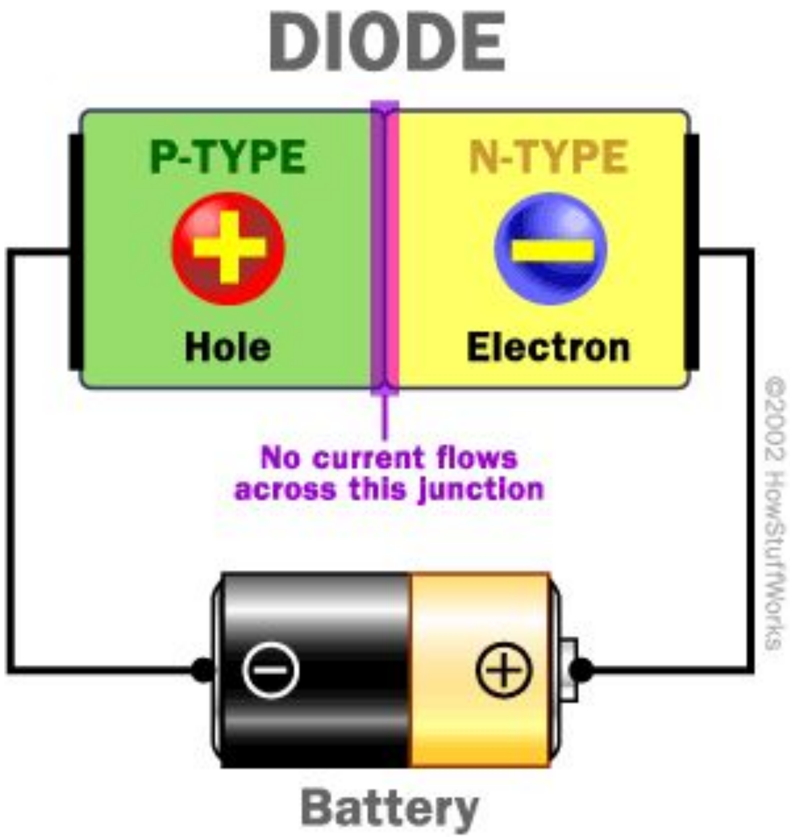




- Formation of a PN Junction
- Diffusion
- Formation of Depletion Region
- **Barrier Potential**



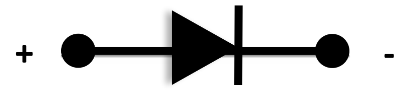
Diode

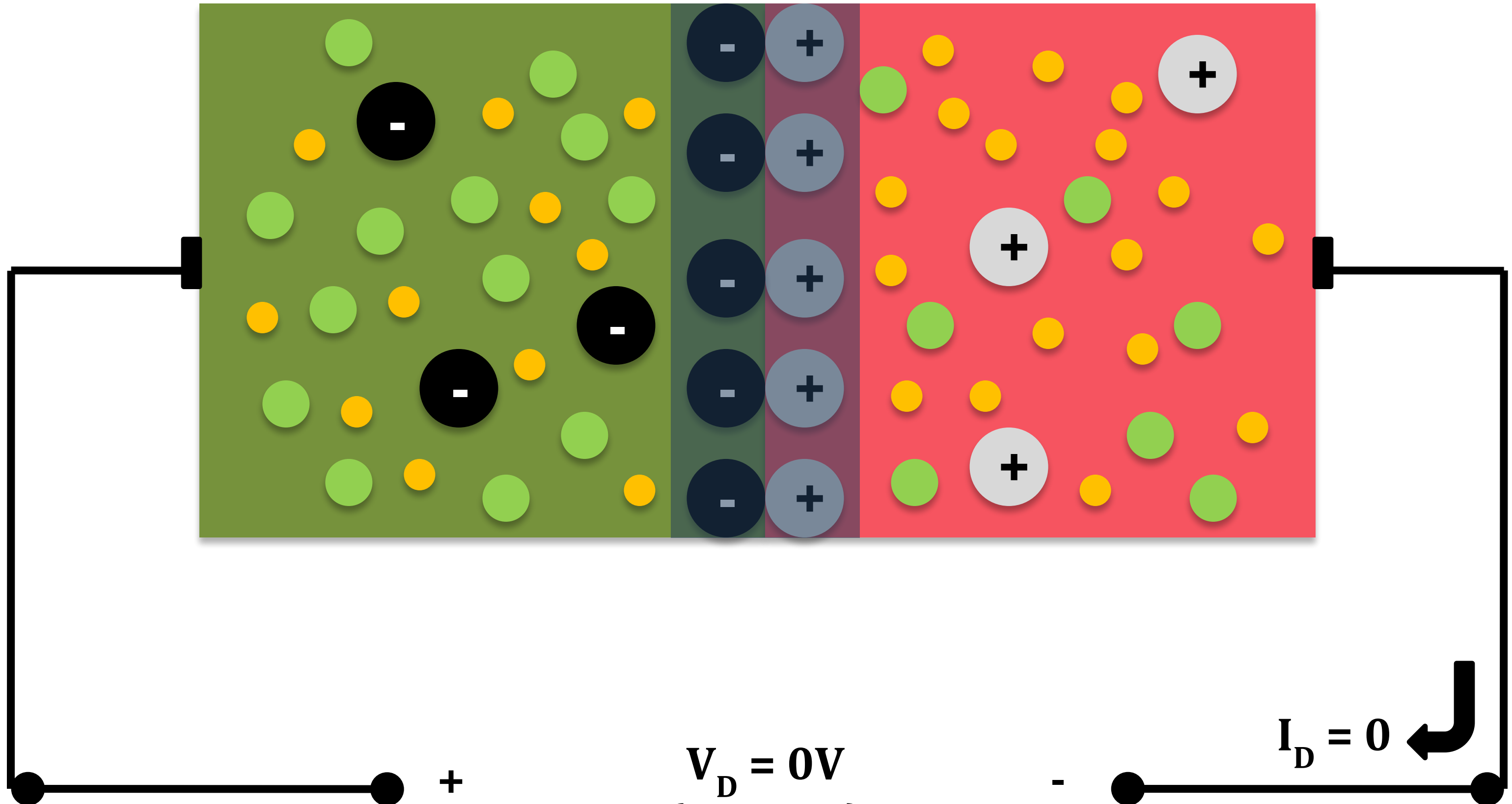


A diode is the simplest possible semiconductor device.

PN Junction Diode

1. No Bias
2. Reverse Bias
3. Forward Bias





PN Junction Diode

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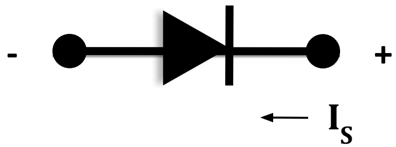
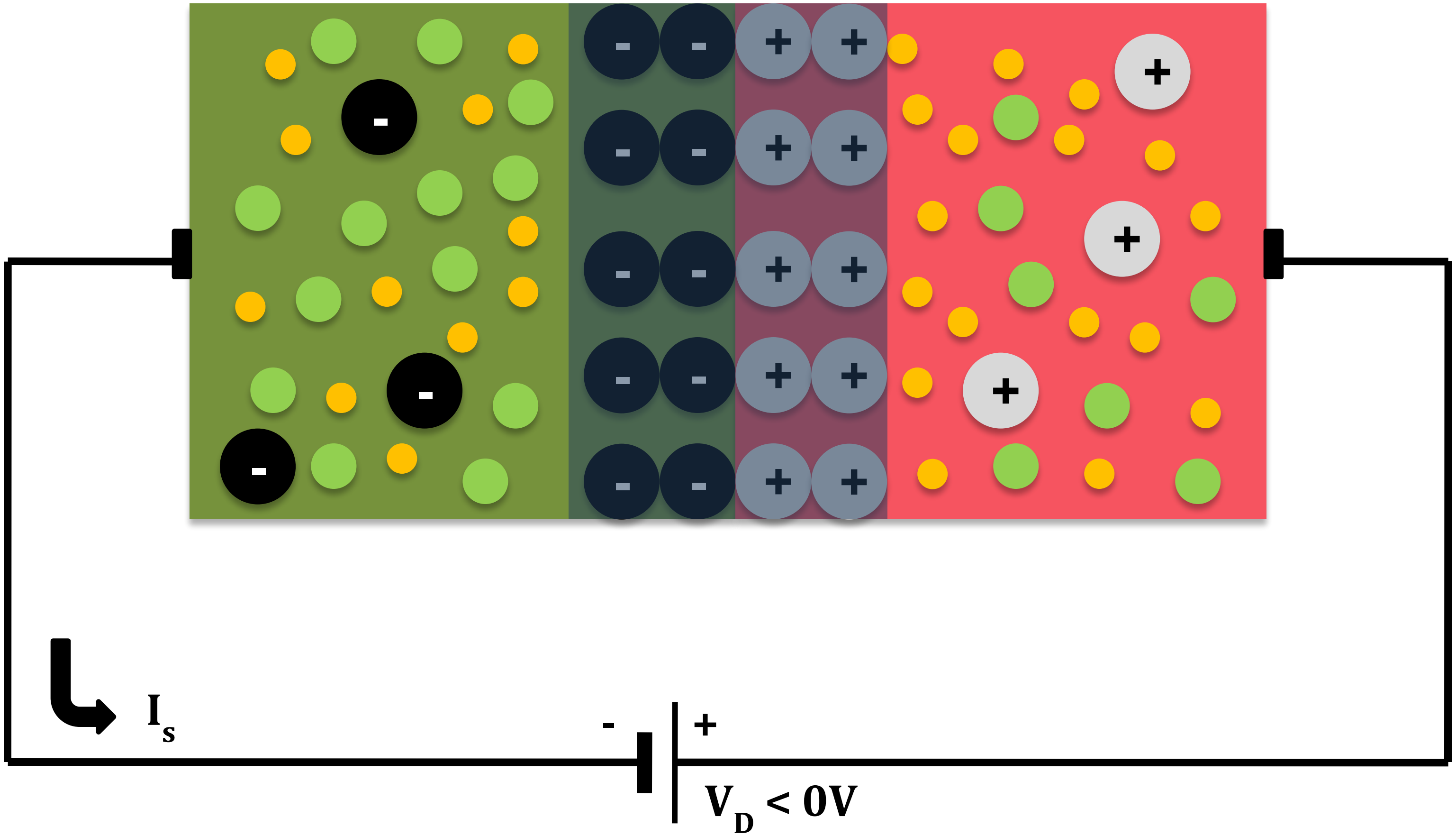
3. Forward Bias





PN Junction Diode

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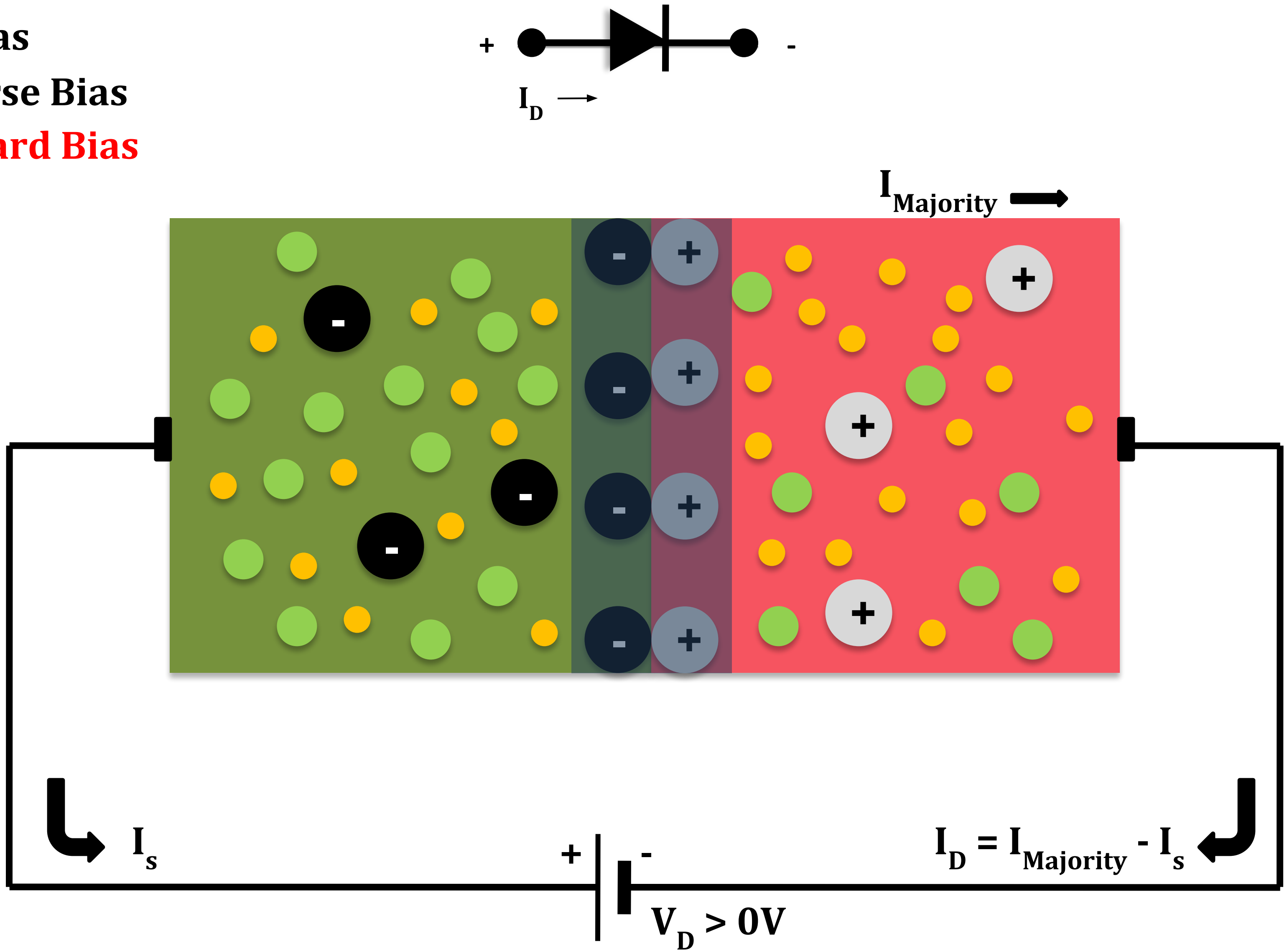

V-I Characteristics

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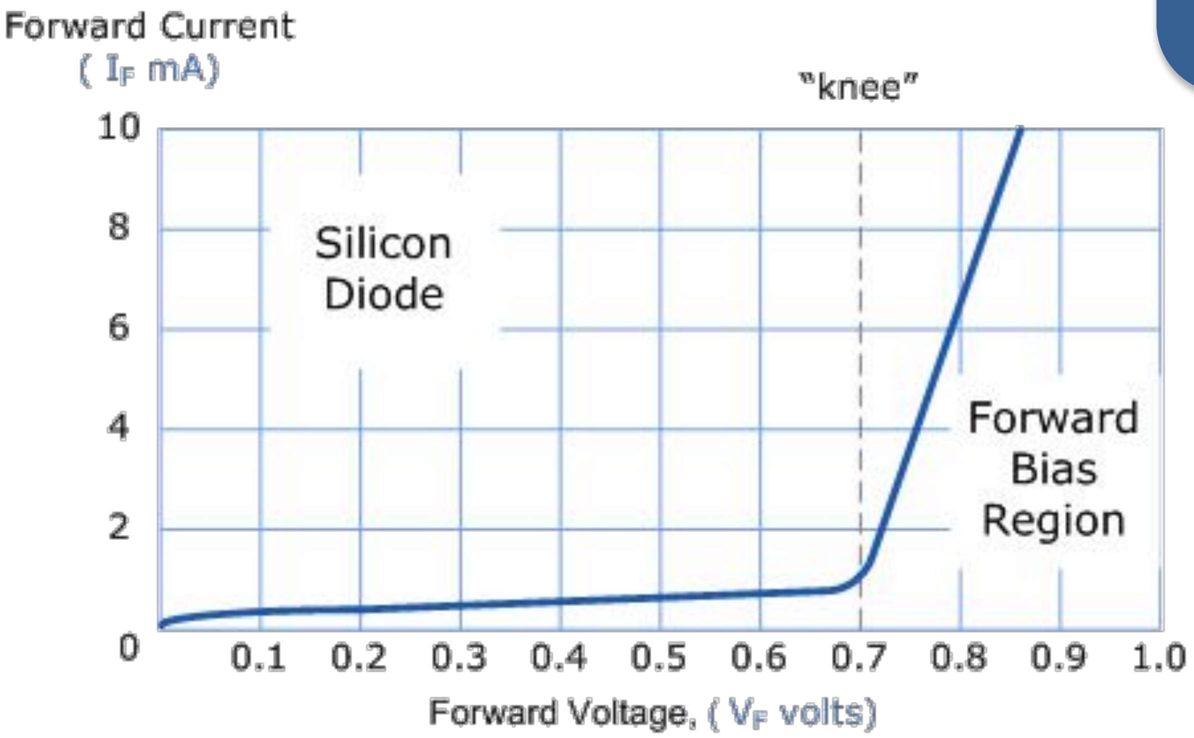
1. **Forward Bias Characteristics**
2. **Reverse Bias Characteristics**

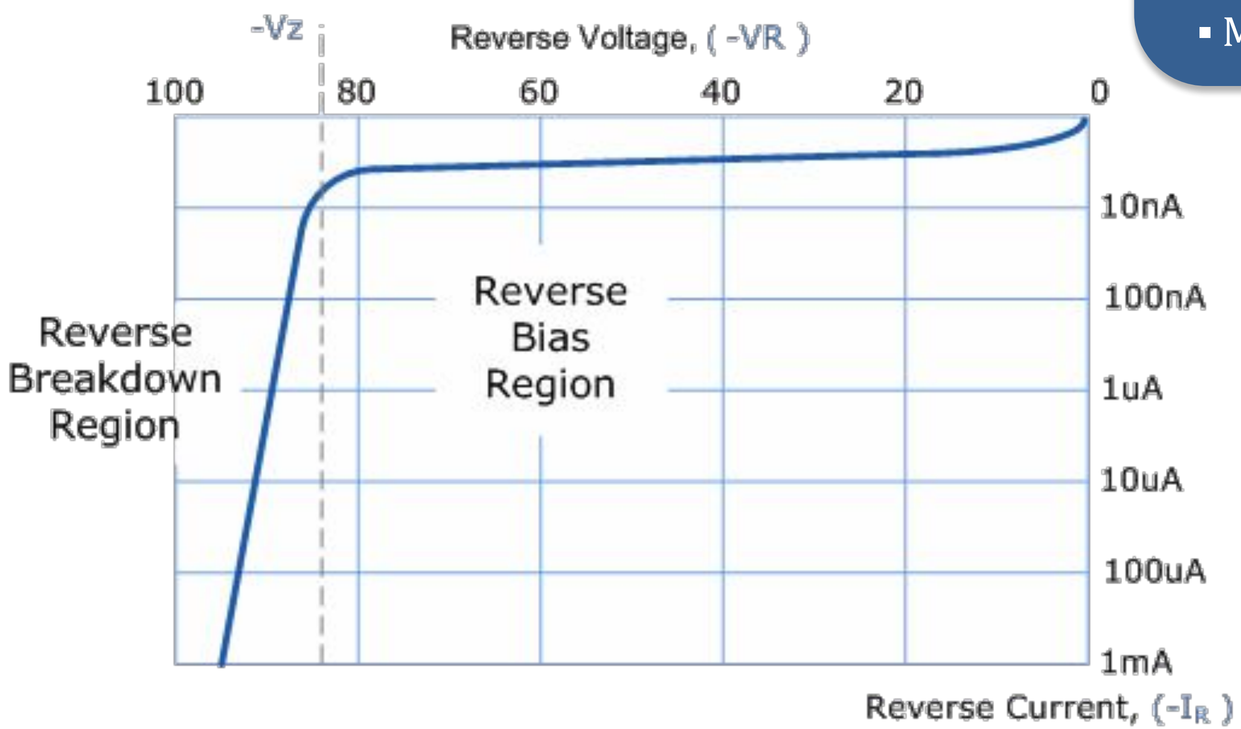
Jargons

- Knee Voltage
- Breakdown Voltage
- Maximum Forward Current
- Peak Inverse Voltage
- Maximum Power Rating



V-I Characteristics

1. **Forward Bias Characteristics**
2. **Reverse Bias Characteristics**



Jargons

- Knee Voltage
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V-I Characteristics

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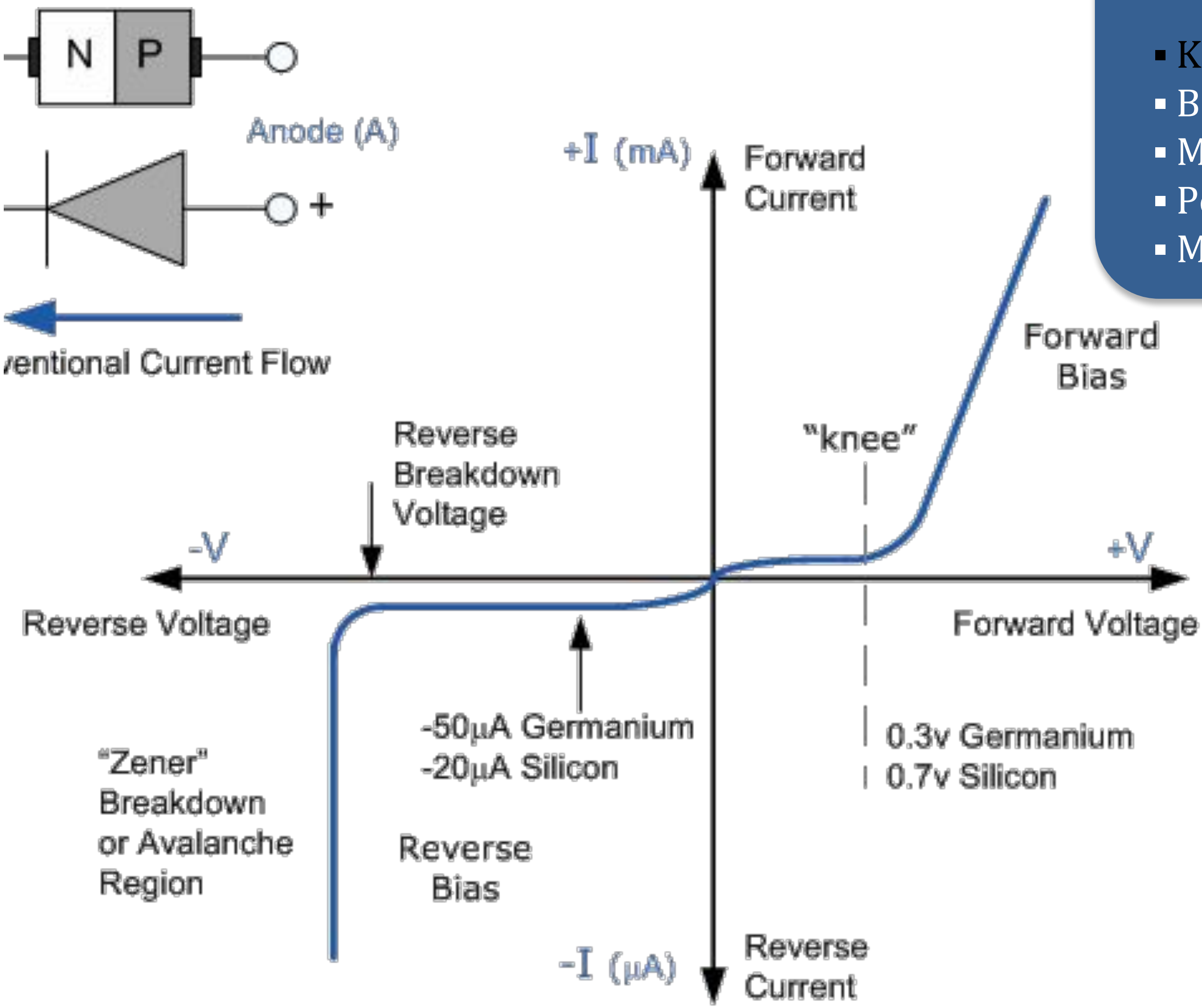
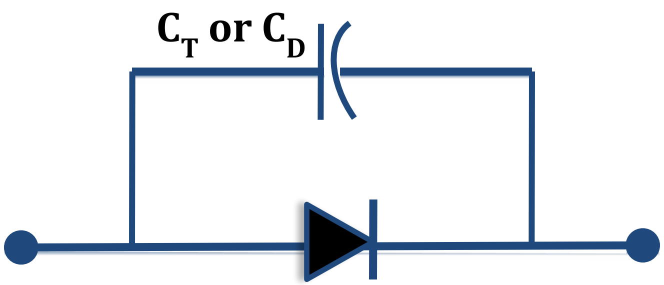


Jargons

- Knee Voltage
- Breakdown Voltage
- Maximum Forward Current
- Peak Inverse Voltage
- Maximum Power Rating

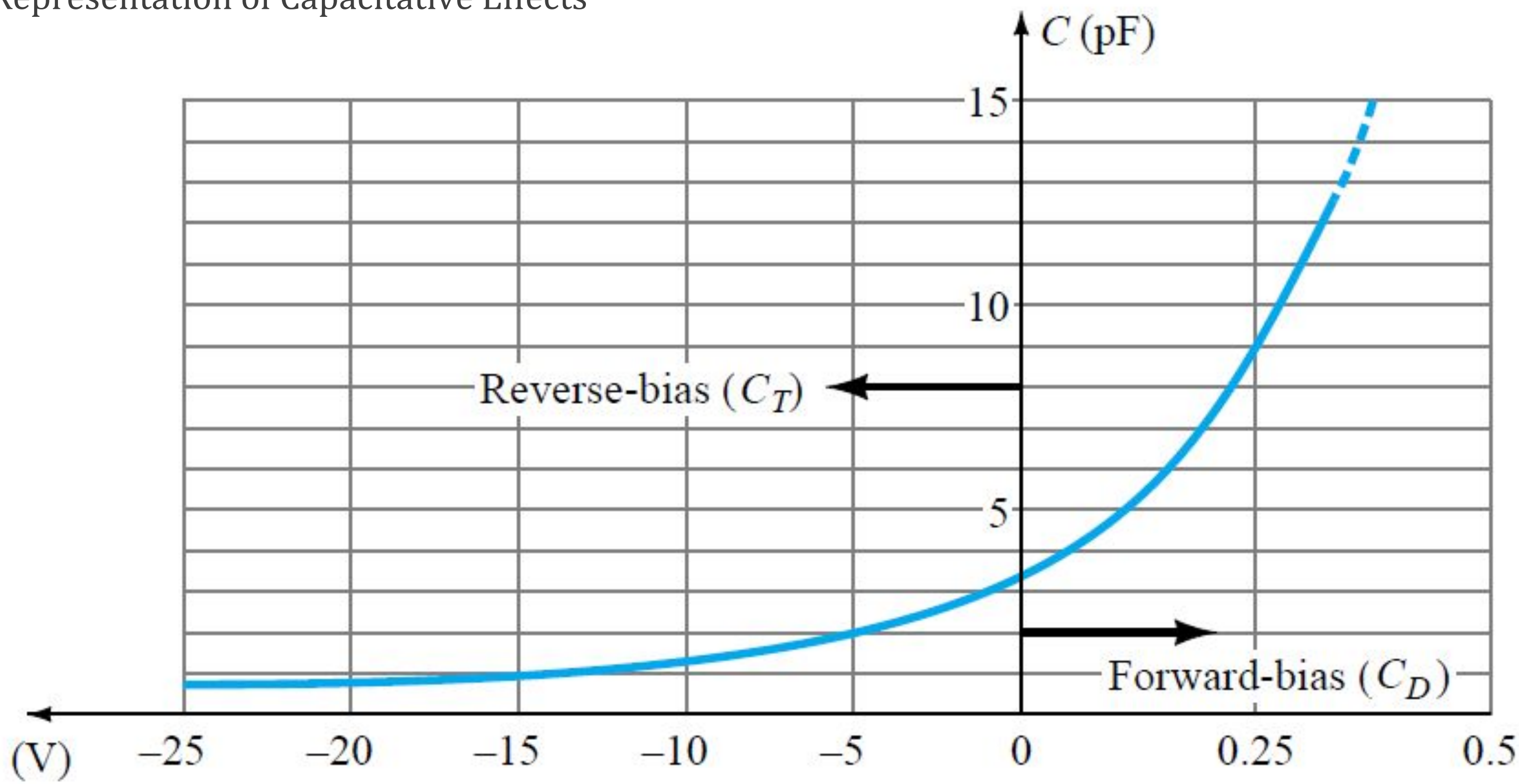
Diode Capacitances



Representation of Capacitative Effects

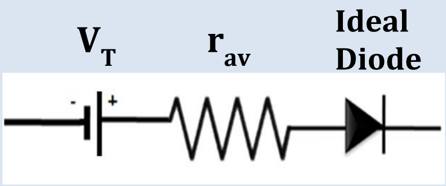
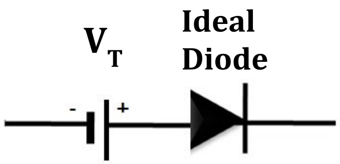
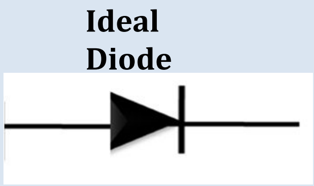
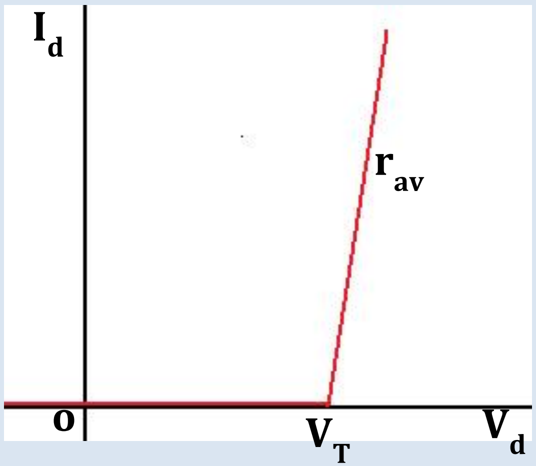
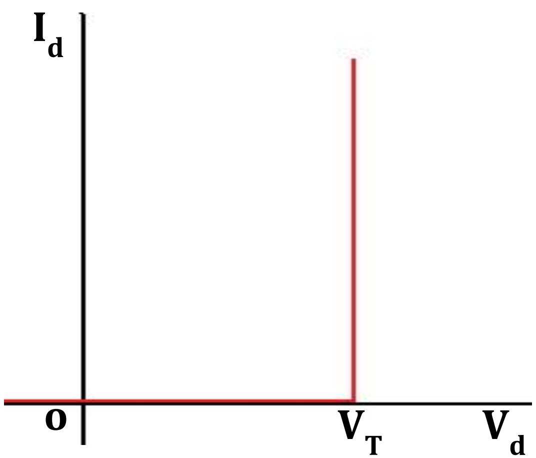
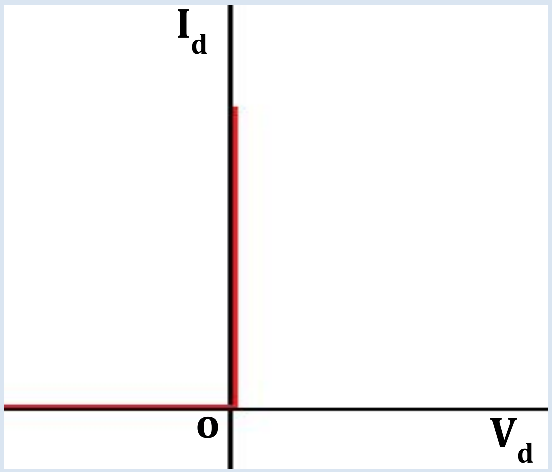
Jargons

- Transition Capacitance
- Diffusion Capacitance



Diode Capacitance versus Applied Bias

Equivalent Circuits

TYPE	**PIECEWISE-LINEAR MODEL**	**SIMPLIFIED MODEL**	**IDEAL DIODE**
CONDITION		$R_{network} \gg R_{av}$	$R_{network} \gg R_{av}$ $E_{network} \gg V_T$
MODEL			
CHARACTERISTICS			

Thank You