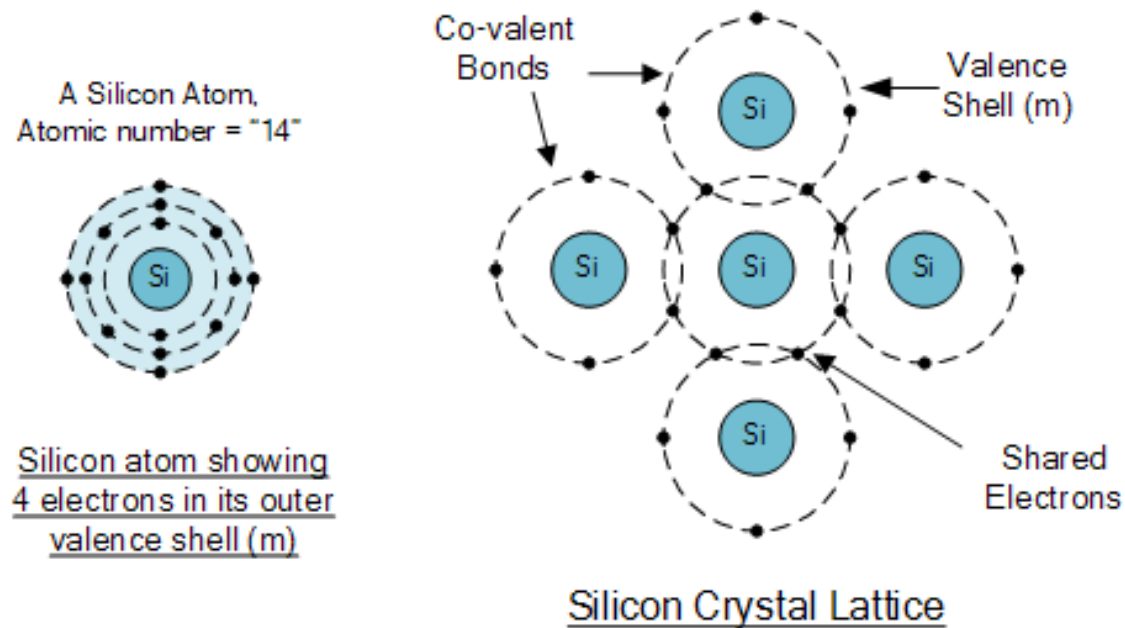


Junction Diode and Its Applications

Introduction:

What is semiconductor:

Semiconductors materials such as silicon (Si), germanium (Ge) and gallium arsenide (GaAs), have electrical properties somewhere in the middle, between those of a “conductor” and an “insulator”. They are not good conductors nor good insulators (hence their name “semi”-conductors).



Intrinsic Semiconductor (Si , Ge)

Extrinsic Semiconductor

- N type**
- P type**

N-type Semiconductor Basics

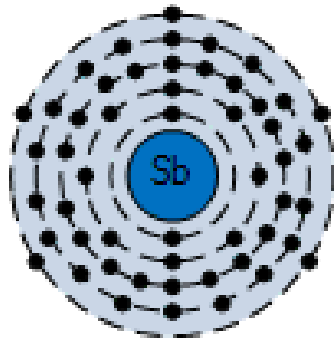
- In order for our silicon crystal to conduct electricity, we need to introduce an impurity atom such as Arsenic, Antimony or Phosphorus into the crystalline structure making it extrinsic (impurities are added). These atoms have five outer electrons in their outermost orbital to share with neighbouring atoms and are commonly called “Pentavalent” impurities.
- This allows four out of the five orbital electrons to bond with its neighbouring silicon atoms leaving one “free electron” to become mobile when an electrical voltage is applied (electron flow). As each impurity atom “donates” one electron, pentavalent atoms are generally known as “donors”.
- **Antimony** (symbol Sb) as well as **Phosphorus** (symbol P), are frequently used as a pentavalent additive to silicon. Antimony has 51 electrons arranged in five shells around its nucleus with the outermost orbital having five electrons.

N-type Semiconductor Basics

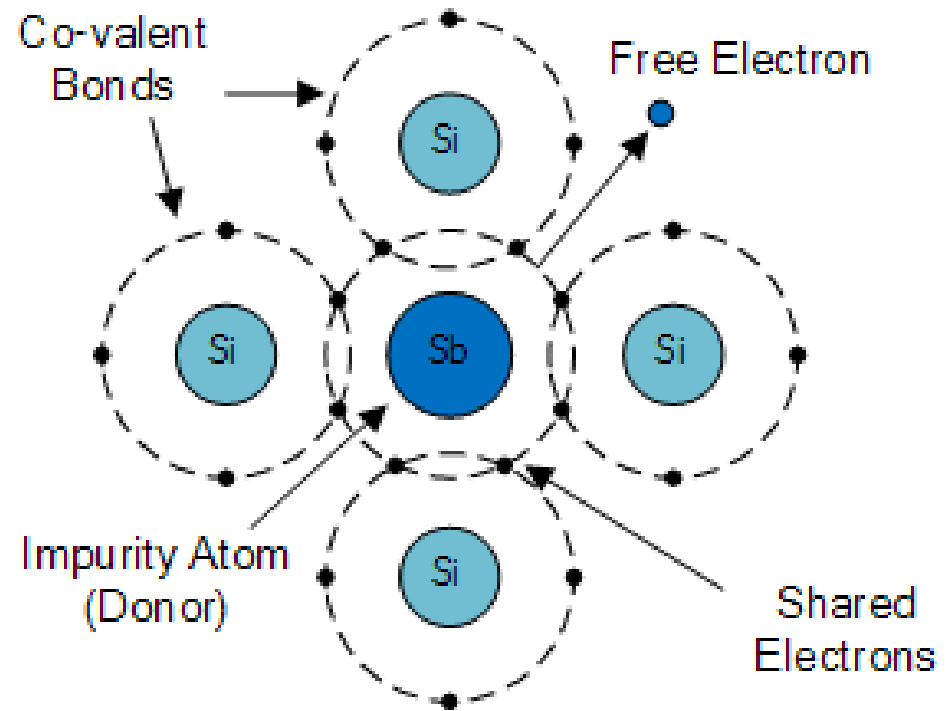
- The resulting semiconductor material has an excess of current-carrying electrons, each with a negative charge, and is therefore referred to as an **N-type** material with the electrons called “Majority Carriers” while the resulting holes are called “Minority Carriers”.
- When stimulated by an external power source, the electrons freed from the silicon atoms by this stimulation are quickly replaced by the free electrons available from the doped Antimony atoms. But this action still leaves an extra electron (the freed electron) floating around the doped crystal making it negatively charged.
- Then a semiconductor material is classed as N-type when its donor density is greater than its acceptor density, in other words, it has more electrons than holes thereby creating a negative pole as shown

N-type Semiconductor Basics

An Antimony Atom,
Atomic number = "51"



Antimony atom showing
5 electrons in its outer
valence shell (o)



N-Type
Semiconductor

P-Type Semiconductor Basics

- If we go the other way, and introduce a “Trivalent” (3-electron) impurity into the crystalline structure, such as Aluminium, Boron or Indium, which have only three valence electrons available in their outermost orbital, the fourth closed bond cannot be formed. Therefore, a complete connection is not possible, giving the semiconductor material an abundance of positively charged carriers known as holes in the structure of the crystal where electrons are effectively missing.

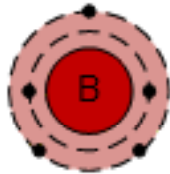
- As there is now a hole in the silicon crystal, a neighbouring electron is attracted to it and will try to move into the hole to fill it. However, the electron filling the hole leaves another hole behind it as it moves. This in turn attracts another electron which in turn creates another hole behind it, and so forth giving the appearance that the holes are moving as a positive charge through the crystal structure (conventional current flow).

P-Type Semiconductor Basics

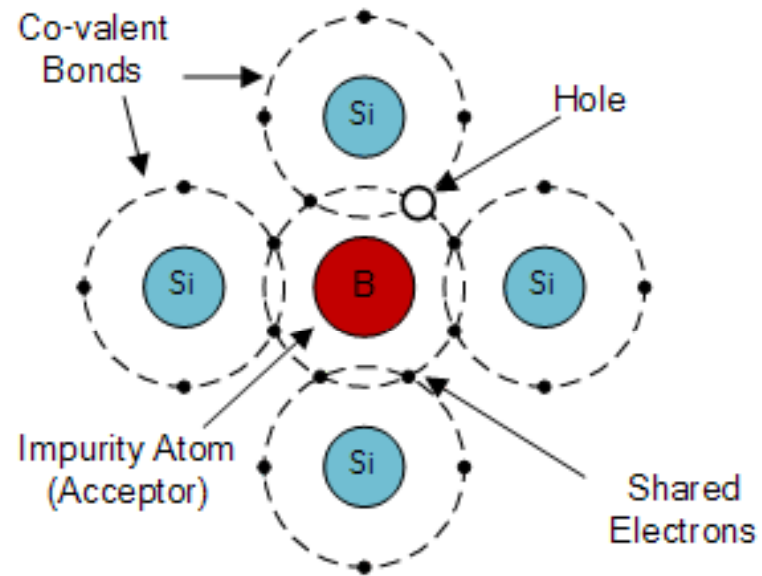
- This movement of holes results in a shortage of electrons in the silicon turning the entire doped crystal into a positive pole. As each impurity atom generates a hole, trivalent impurities are generally known as “**Acceptors**” as they are continually “accepting” extra or free electrons.
 - **Boron** (symbol B) is commonly used as a trivalent additive as it has only five electrons arranged in three shells around its nucleus with the outermost orbital having only three electrons. The doping of Boron atoms causes conduction to consist mainly of positive charge carriers resulting in a **P-type** material with the positive holes being called “Majority Carriers” while the free electrons are called “Minority Carriers”.
- Then a semiconductor basics material is classed as P-type when its acceptor density is greater than its donor density. Therefore, a P-type semiconductor has more holes than electrons.

P-Type Semiconductor Basics

A Boron Atom,
Atomic number = "5"



Boron atom showing
3 electrons in its outer
valence shell (L)



P-Type
Semiconductor

Semiconductor Basics Summary

N-type (e.g. doped with Antimony)

These are materials which have **Pentavalent** impurity atoms (Donors) added and conduct by “electron” movement and are therefore called, **N-type Semiconductors**.

In N-type semiconductors there are:

1. The Donors are positively charged.
2. There are a large number of free electrons.
3. A small number of holes in relation to the number of free electrons.
4. Doping gives:
 - positively charged donors.
 - negatively charged free electrons.
5. Supply of energy gives:
 - negatively charged free electrons.
 - positively charged holes.

Semiconductor Basics Summary

P-type (e.g. doped with Boron)

These are materials which have **Trivalent** impurity atoms (Acceptors) added and conduct by “hole” movement and are therefore called, **P-type Semiconductors**.

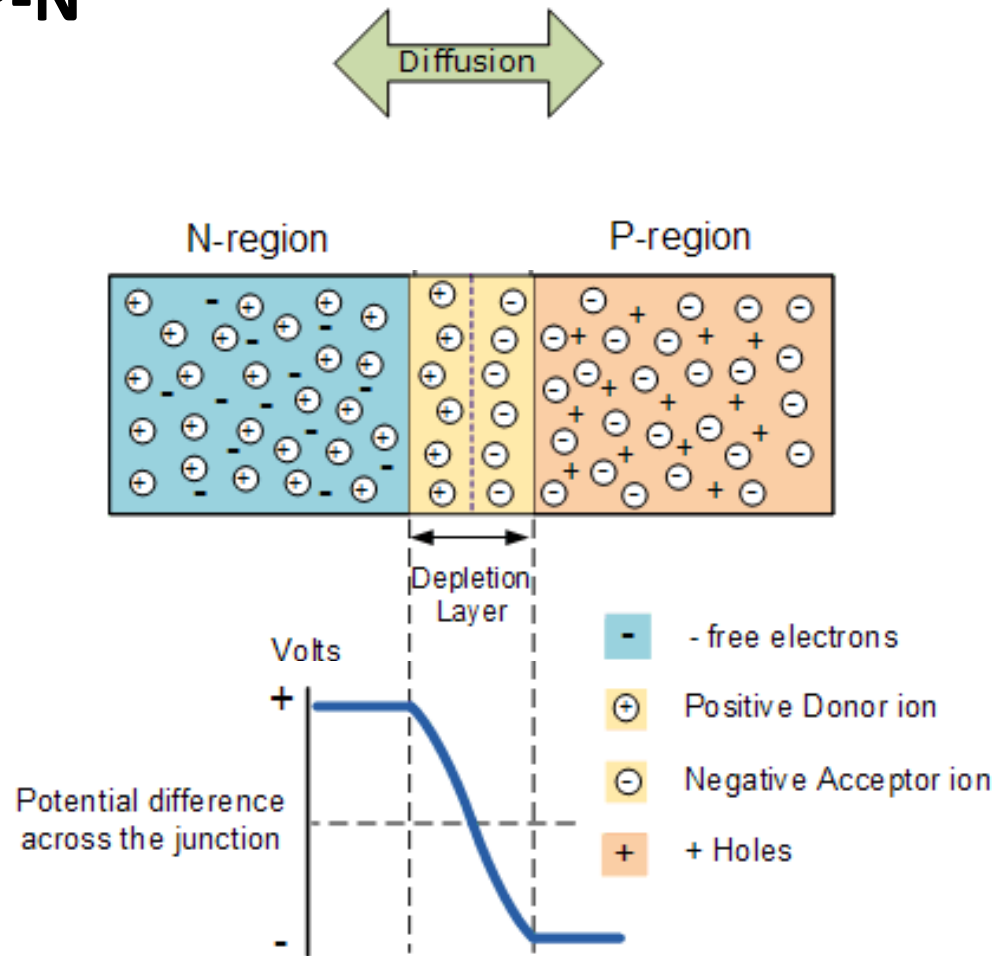
In these types of materials are:

1. The Acceptors are negatively charged.
2. There are a large number of holes.
3. A small number of free electrons in relation to the number of holes.
4. Doping gives:
 - negatively charged acceptors.
 - positively charged holes.
5. Supply of energy gives:
 - positively charged holes.
 - negatively charged free electrons.

Both P and N-types as a whole, are electrically neutral on their own

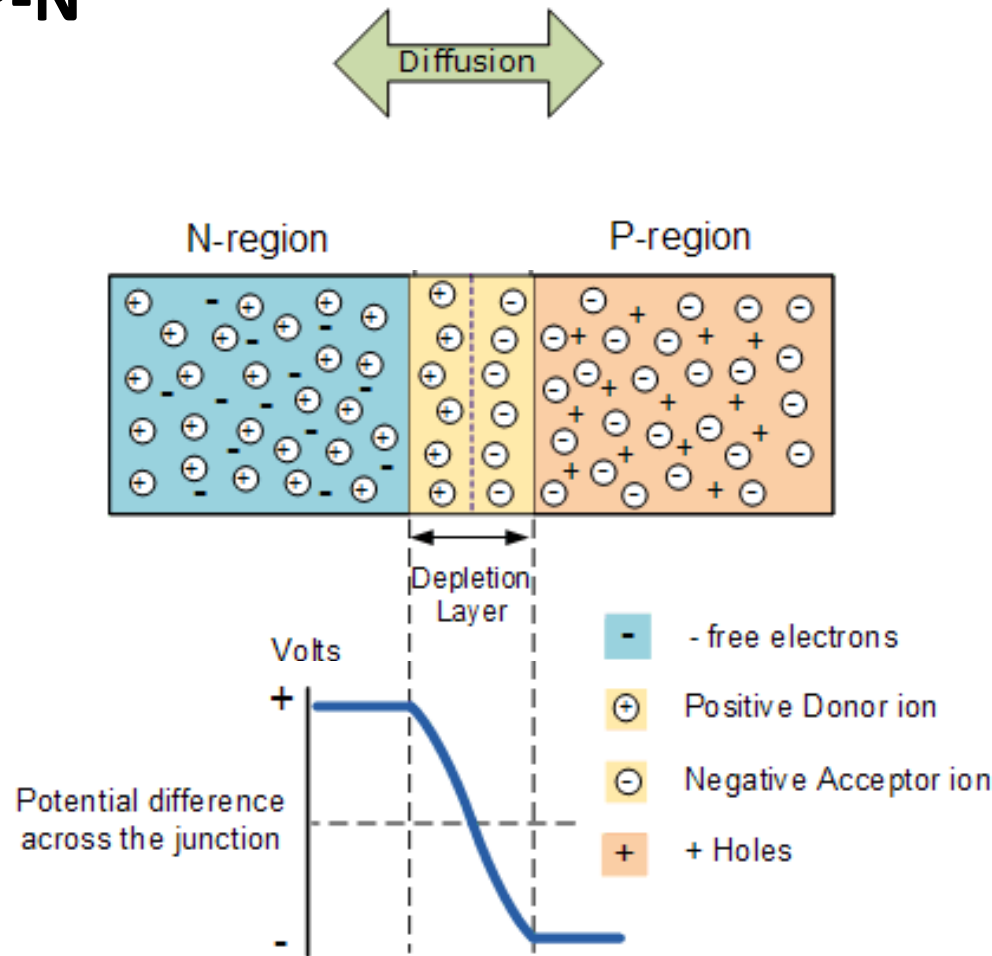
PN Junction

Unbiased P-N Junction



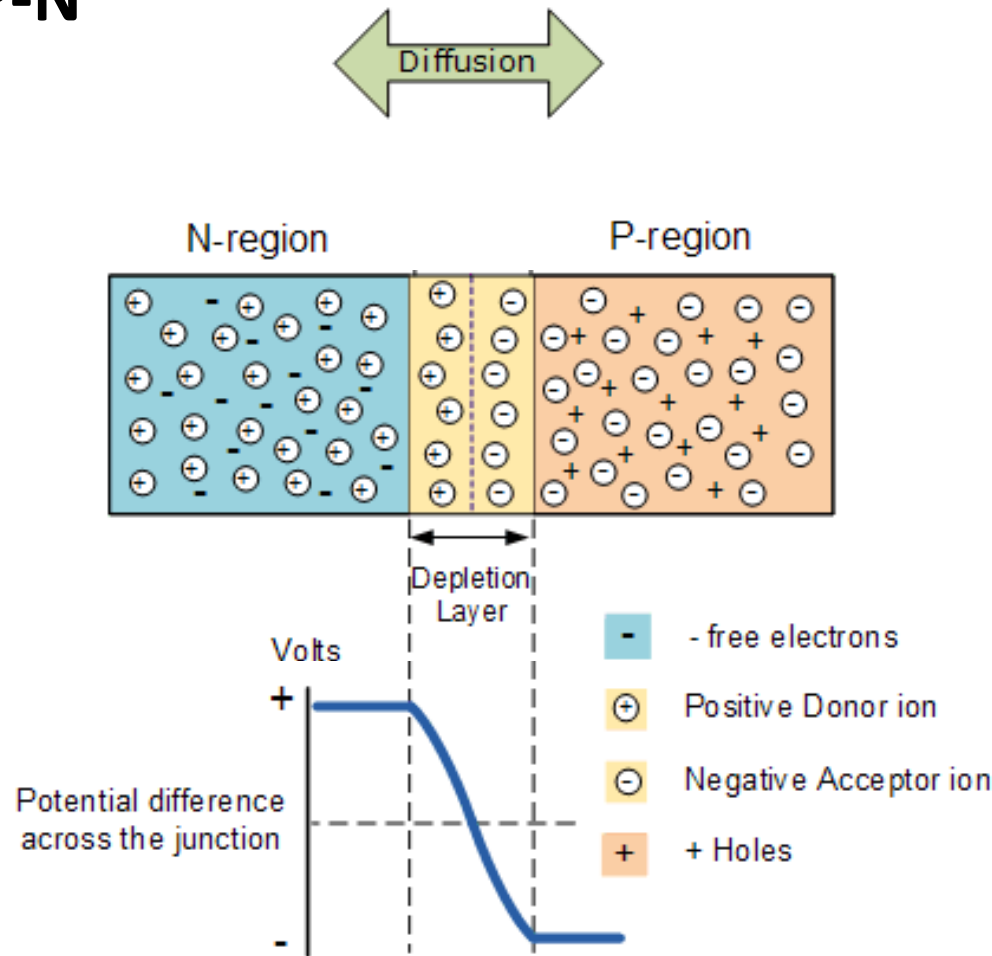
When the N-type semiconductor and P-type semiconductor materials are first joined together a very large density gradient exists between both sides of the PN junction. The result is that some of the free electrons from the donor impurity atoms begin to migrate across this newly formed junction to fill up the holes in the P-type material producing negative ions.

Unbiased P-N Junction



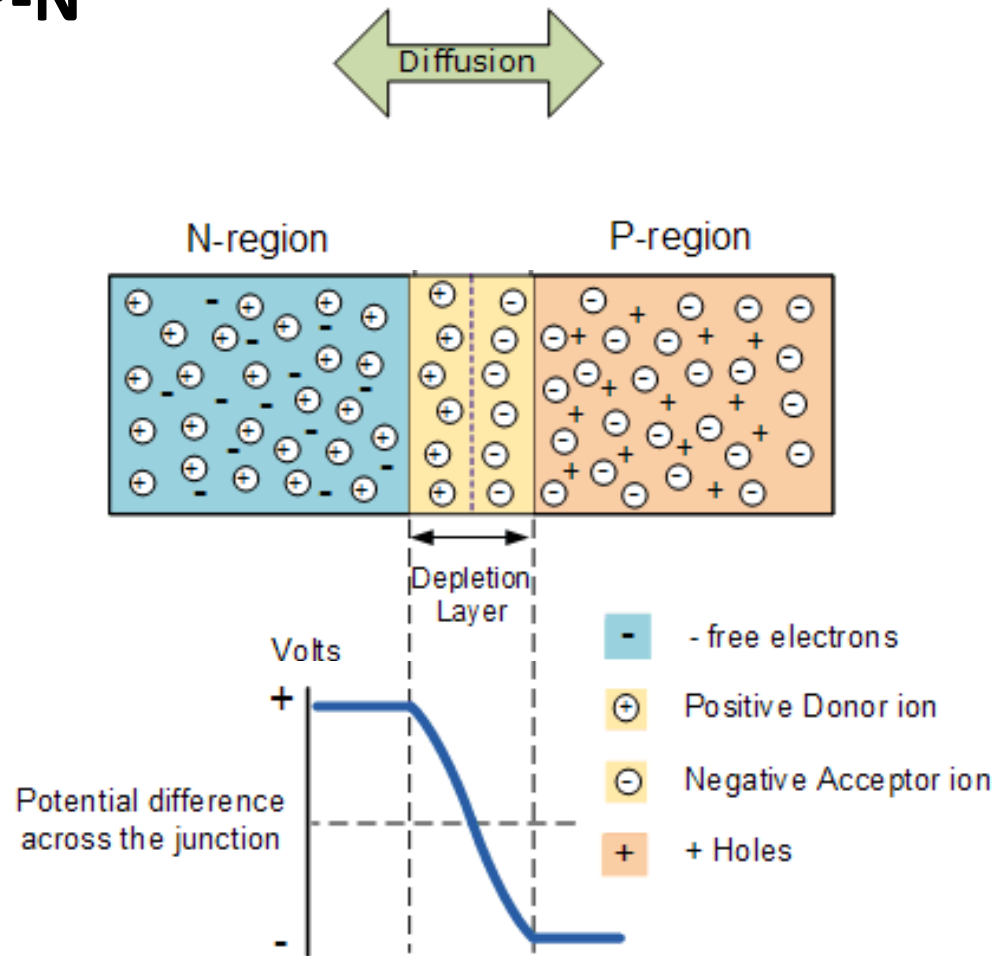
However, because the electrons have moved across the PN junction from the N-type silicon to the P-type silicon, they leave behind positively charged donor ions (N_D) on the negative side and now the holes from the acceptor impurity migrate across the junction in the opposite direction into the region where there are large numbers of free electrons.

Unbiased P-N Junction



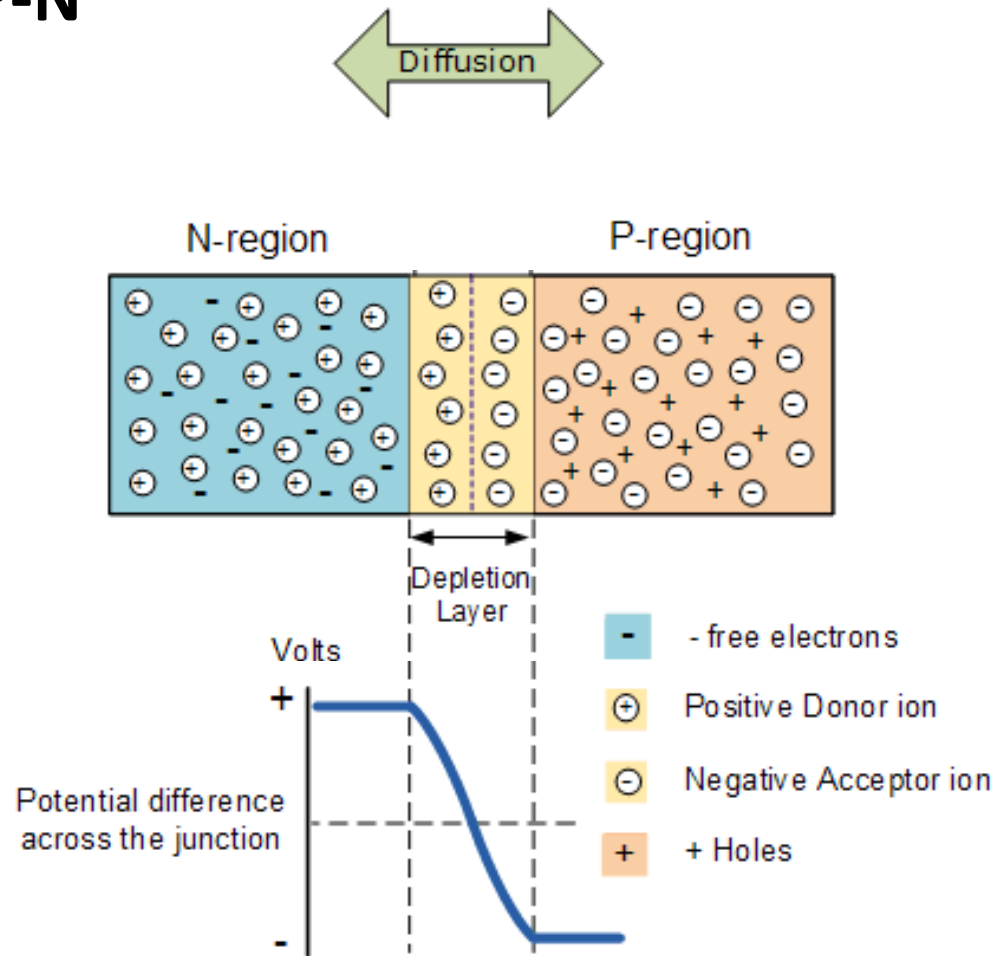
As a result, the charge density of the P-type along the junction is filled with negatively charged acceptor ions (N_A), and the charge density of the N-type along the junction becomes positive. This charge transfer of electrons and holes across the PN junction is known as **diffusion**. The width of these P and N layers depends on how heavily each side is doped with acceptor density N_A , and donor density N_D , respectively.

Unbiased P-N Junction



This process continues back and forth until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more charge carriers from crossing over the junction. Eventually a state of equilibrium (electrically neutral situation) will occur producing a “potential barrier” zone around the area of the junction as the donor atoms repel the holes and the acceptor atoms repel the electrons.

Unbiased P-N Junction

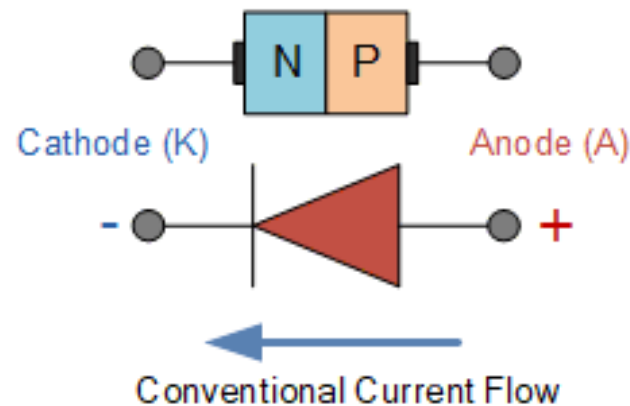


Since no free charge carriers can rest in a position where there is a potential barrier, the regions on either sides of the junction now become completely depleted of any more free carriers in comparison to the N and P type materials further away from the junction. This area around the **PN Junction** is now called the **Depletion Layer**.

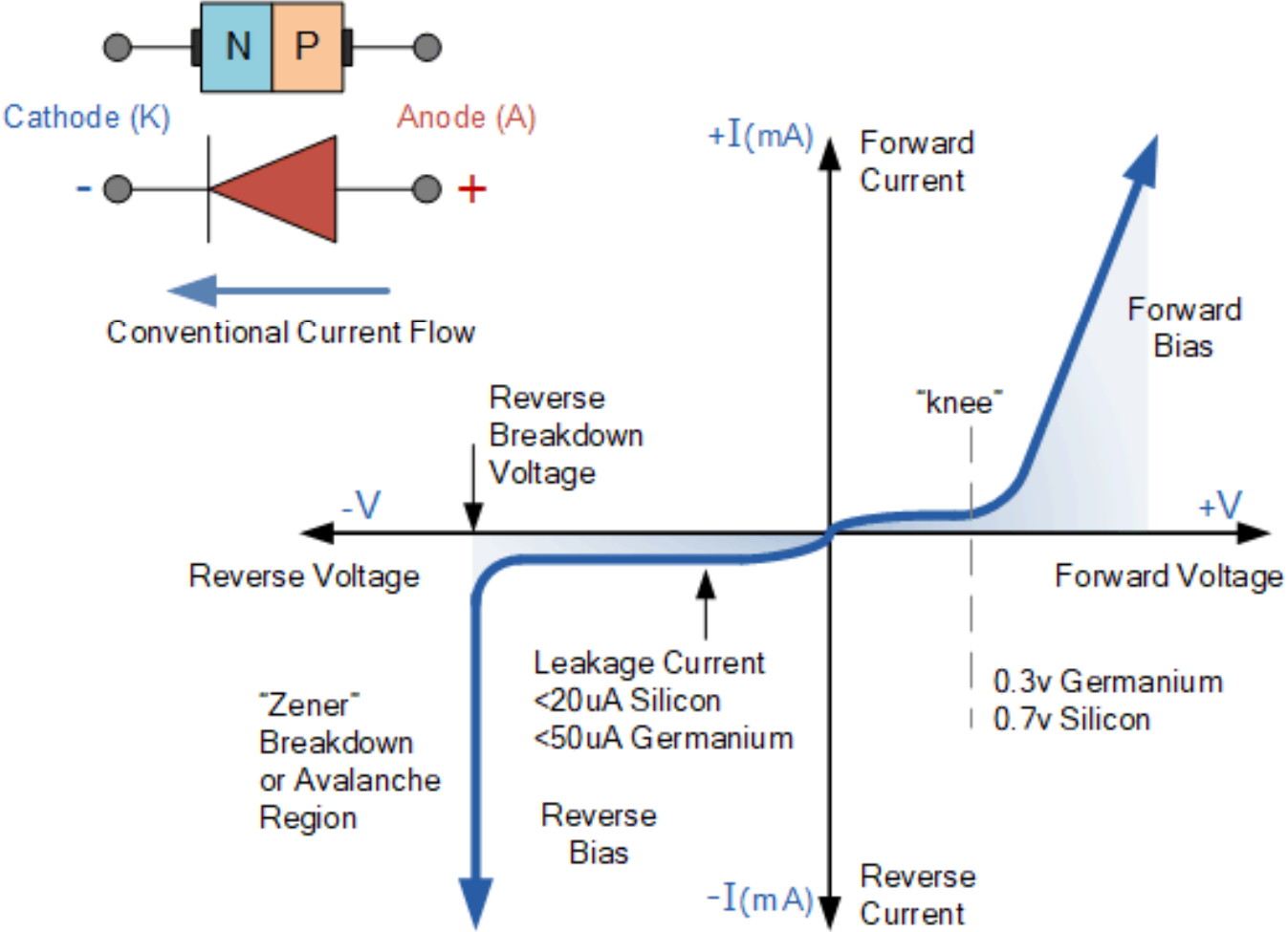
Biased P-N Junction

- The effect of adding this additional energy source results in the free electrons being able to cross the depletion region from one side to the other. The behaviour of the PN junction with regards to the potential barrier's width produces an asymmetrical conducting two terminal device, better known as the **PN Junction Diode**.

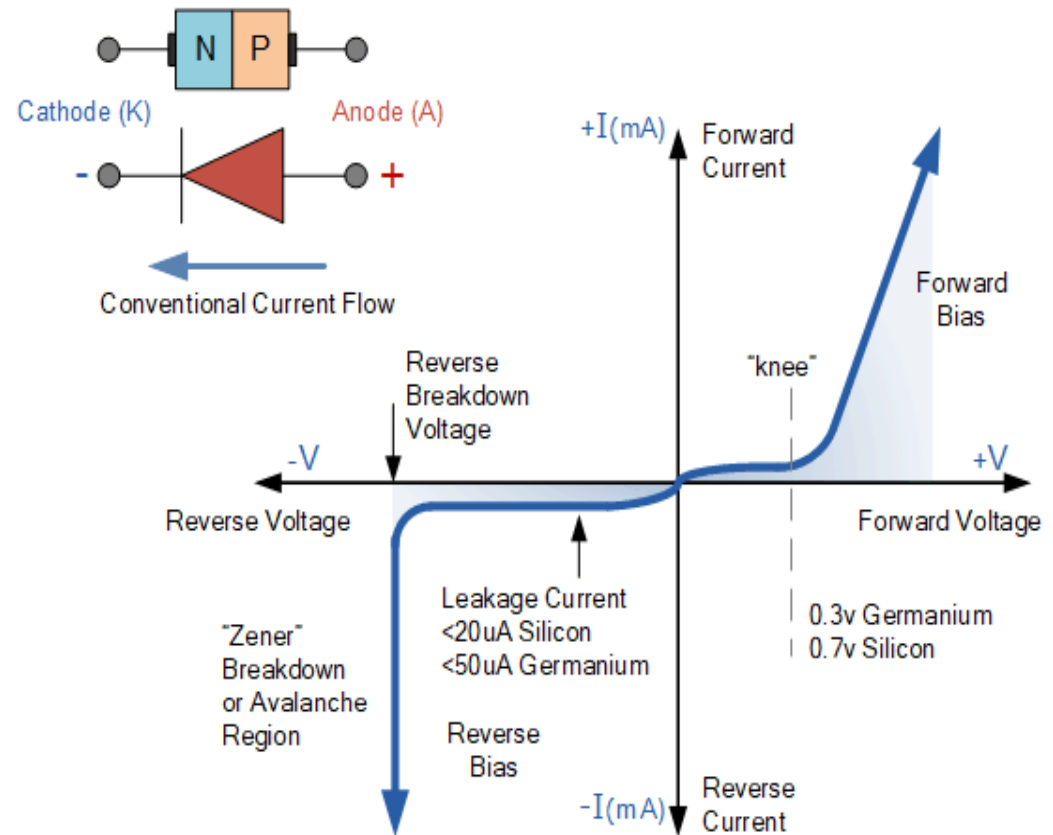
- A *PN Junction Diode* is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I-V) relationship and therefore we can not described its operation by simply using an equation such as Ohm's law.



Biased (Forward bias and Reverse bias) P-N Junction

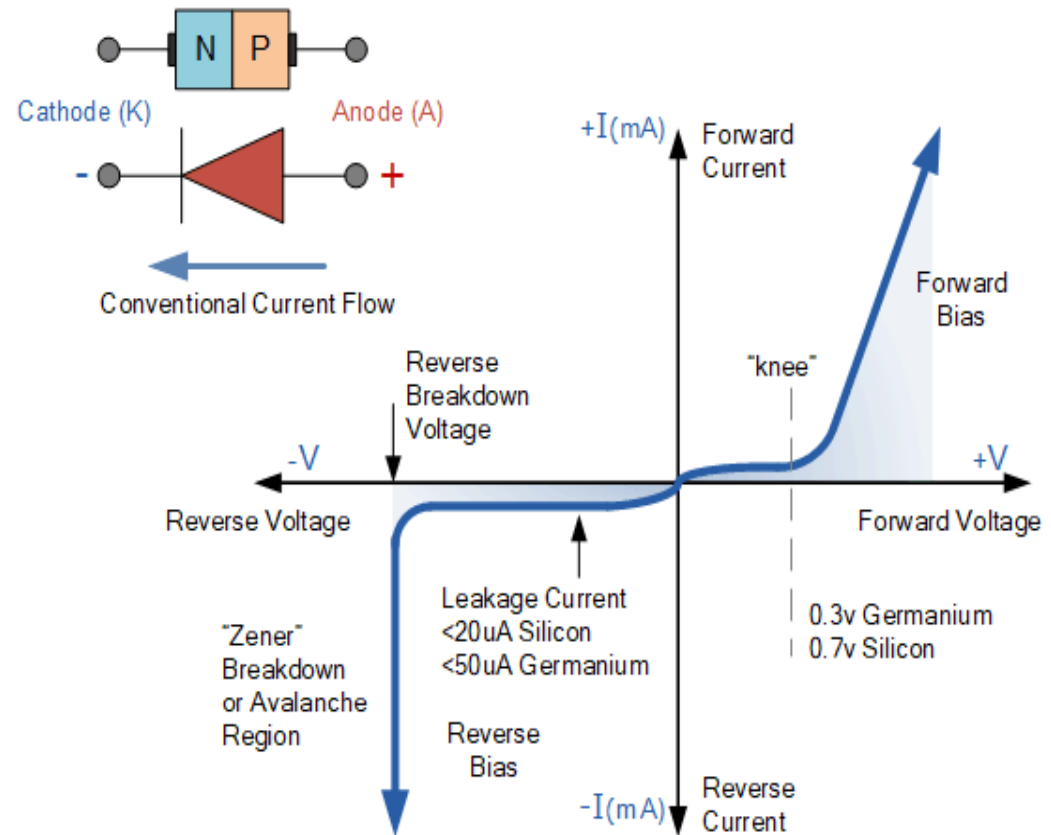


Biased (Forward bias and Reverse bias) P-N Junction



If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

Biased (Forward bias and Reverse bias) P-N Junction



By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking the flow of current through the diodes pn-junction.

Cut in voltage (Knee voltage):

- The voltage at which the forward diode current starts increasing rapidly is known as the cut in voltage of a diode. The cut in voltage is very close to the barrier potential. Cut in voltage is also called as knee voltage.
- Generally a diode is forward biased above the cut in voltage. The cut in voltage for a silicon diode is 0.6 V and that for a germanium diode is 0.2V.

- ▶ **The current in a p-n Junction diode is given by**

Shockley Equation $I = I_0(\exp^{qV/nkT} - 1)$