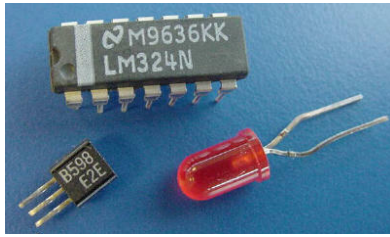


## Semi conductors



Semiconductors have had a monumental impact on our society. You find semiconductors at the heart of microprocessor chips as well as transistors. Anything that's computerized or uses radio waves depends on semiconductors.

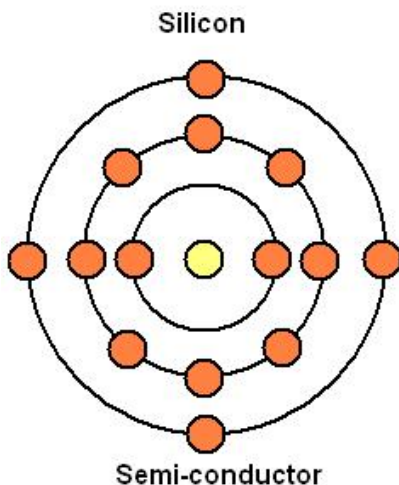
Today, most semiconductor chips and transistors are created with **silicon**. You may have heard expressions like "Silicon Valley" and the "silicon economy," and that's why -- silicon is the heart of any electronic device. Below shows the a snippet of the periodic table, the materials we refer to semiconductors are some of the group four elements.

5 <b>B</b> Boron 2.34	6 <b>C</b> Carbon 2.62	7 <b>N</b> Nitrogen 1.251
13 <b>Al</b> Aluminum 2.70	14 <b>Si</b> Silicon 2.33	15 <b>P</b> Phosphorus 1.82
31 <b>Ga</b> Gallium 5.91	32 <b>Ge</b> Germanium 5.32	33 <b>As</b> Arsenic 5.72

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**Definition:** Semi conductors can be defined as a material which lies between that of a good conductor and an insulator.

Carbon, **silicon** and **germanium** (germanium, like silicon, is also a semiconductor) have a unique property in their electron structure -- each has **four electrons in its outer orbital**. This allows them to form nice crystals. The four electrons form perfect covalent bonds with four neighboring atoms, creating a **lattice**. In carbon, we know the crystalline form as diamond. In silicon, the crystalline form is a silvery, metallic-looking substance. Other semiconductor materials are cadmium sulphide, lead sulphide and gallium arsenide.



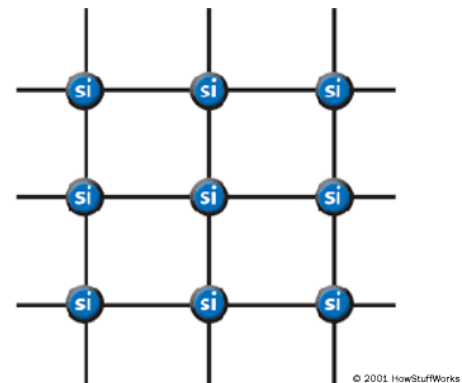
### Intrinsic Semiconductors

These conductors are made of pure silicon or germanium. Combination intrinsic semiconductors exist as well. Materials such as cadmium sulphide or lead sulphide combine to give these types of semiconductors their electrical property (decrease in resistance as the temperature increases).

At absolute zero, the electrons in these materials form perfect covalent bonds and thus will not allow the passage of electrons. Thus it behaves as an insulator at absolute zero.

When heated however,

some of the electrons gain enough energy to break free of these covalent bonds. These electrons can a charge across the material when a voltage or potential difference is applied across the material. The higher the temperature, then the greater the number of electrons that becomes free.



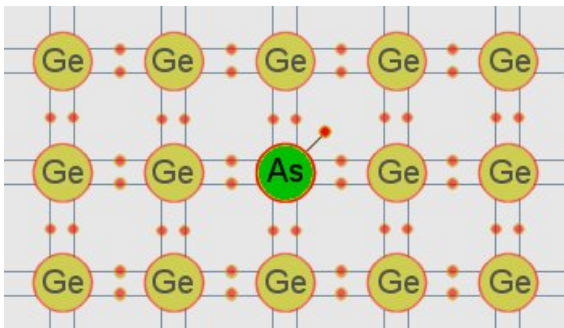
## Doping – Extrinsic Semiconductors

Metals tend to be good conductors of electricity because they usually have "free electrons" that can move easily between atoms, and electricity involves the flow of electrons. While silicon crystals look metallic, they are not, in fact, metals. All of the outer electrons in a silicon crystal are involved in **perfect covalent bonds**, so they can't move around. A pure silicon crystal is nearly an **insulator** -- very little electricity will flow through it.

But you can change all this through a process called doping.

Extrinsic semiconductors have added to them carefully controlled amounts of impurities (atoms/molecules). The impurities are added in parts per million so that they do not disturb the natural lattice of the host material. This alteration causes a drastic change in the electrical properties of the semi conductor. They are two types of semi conductors: **n-type** and **p- type**.

### N-type

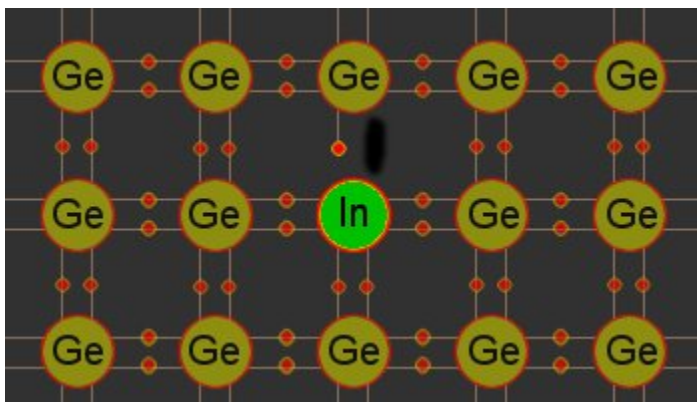


These semiconductors have an impurity added to them which has five electrons in its outer shell. Phosphorous, Arsenic and Antimony atoms can be used. These atoms will replace the silicon atom and four of its electrons will form covalent bonds with neighboring silicon atoms. The final electron (fifth) is not used and is therefore free. This material thus has a surplus of free electrons which can be used to conduct an electrical current. The added atoms are

referred to as **donor atoms** since they donate free electrons.

### P - type

The second type of impurity, when added to a semiconductor material, tends to compensate for its deficiency of 1 valence electron by acquiring an electron from its neighbor. Impurities of this type have only 3 valence electrons and are called **trivalent** impurities. Aluminum, indium, gallium, and boron are trivalent impurities. Because these materials accept 1 electron from the doped material, they are also called **acceptor** impurities.



A trivalent (acceptor) impurity element can also be used to dope germanium. In this case, the impurity is 1 electron short of the required amount of electrons needed to establish covalent bonds with 4 neighboring atoms. Thus, in a single covalent bond, there will be only 1 electron instead of 2. This arrangement leaves a hole in that covalent bond. Figure 2 illustrates this theory by showing what happens when germanium is doped

with an indium (In) atom. Notice, the indium atom in the figure is 1 electron short of the required amount of electrons needed to form covalent bonds with 4 neighboring atoms and, therefore, creates a hole in the structure. (*Gallium and boron, which are also trivalent impurities, exhibit these same characteristics when added to germanium*). The holes can only be present in this type semiconductor when a trivalent impurity is used. Note that a hole carrier is **not** created by the removal of an electron from a neutral atom, but is created when a trivalent impurity enters into covalent bonds with a tetravalent (4 valence electrons) crystal structure. The holes in this type of semiconductor (*p*-type) are considered the **majority** carriers since they are present in the material in the greatest quantity. The electrons, on the other hand, are the **minority** carriers.

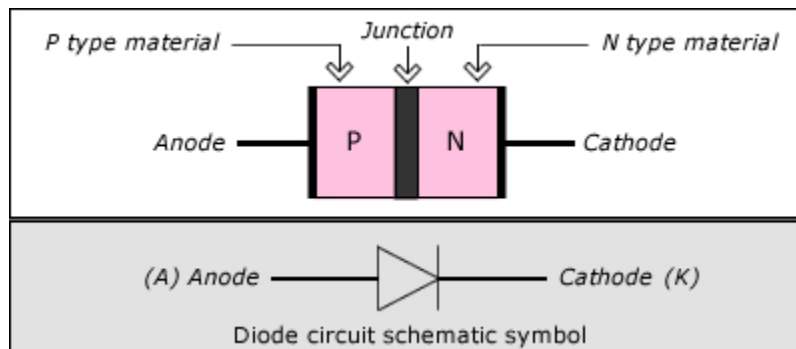
Current Flow in the *p*-type Material is by positive holes, instead of negative electrons. A hole moves from the positive terminal of the *p*-material to the negative terminal. Electrons from the external circuit enter the negative terminal of the material and fill holes in the vicinity of this terminal. At the positive terminal, electrons are removed from the covalent bonds, thus creating new holes. This process continues as the steady stream of holes (hole current) moves toward the negative terminal.

Notice in both *n*-type and *p*-type materials, current flow in the external circuit consists of electrons moving out of the negative terminal of the battery and into the positive terminal of the battery. Hole flow, on the other hand, only exists within the material itself.

## Junction Diode

Junction Diodes are two terminal semiconductor devices that are made out of P type and N type (doped) material. One terminal is connected to P material and the other one is connected to N material. The common connecting points where these materials are joined is called the **junction**.

Diodes permit the current to flow in one direction and block the flow of current in the opposite direction.



There are two operating regions and two possible "biasing" conditions for the standard **Junction Diode** and these are:

1. **Reverse Bias** - The voltage potential is connected negative, (-ve) to the P-type material and positive, (+ve) to the N-type material across the diode which has the effect of *Increasing* the PN-junction width.
2. **Forward Bias** - The voltage potential is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has the effect of *Decreasing* the PN-junction width.

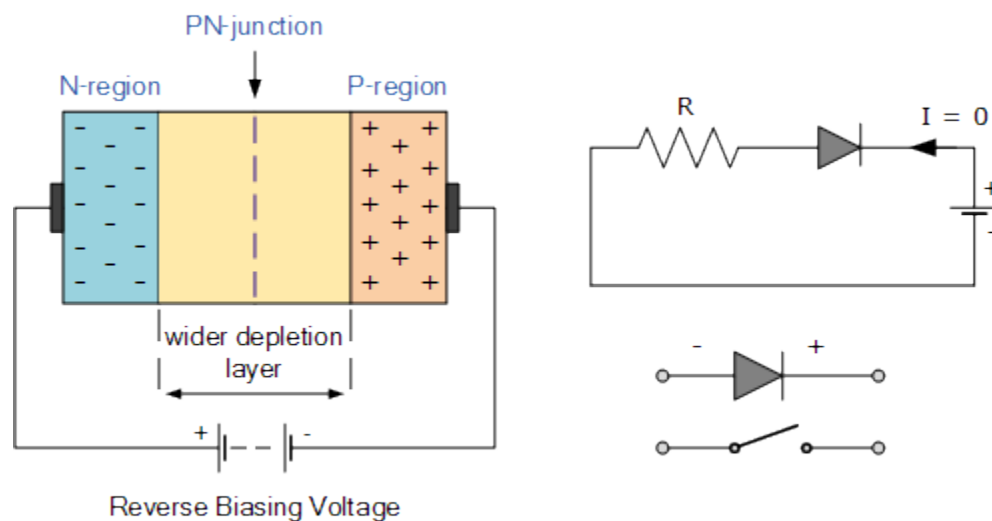
## Reverse Biased Junction Diode

(Assume conventional current flow for the following diagrams)

When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material. The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material.

### Reverse Biased Junction Diode showing an Increase in the Depletion Layer



This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small **leakage current** does flow through the junction which can be measured in microamperes, ( $\mu\text{A}$ ). One final point, if the reverse bias voltage  $V_r$  applied to the diode is increased to a sufficiently high enough value, it will cause the PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current.

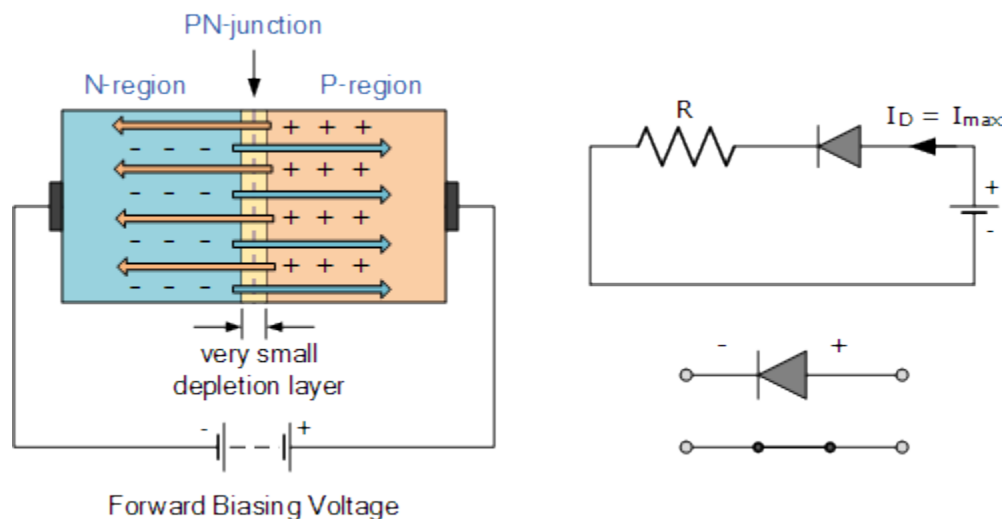
## Forward Biased Junction Diode

When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the "knee" on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.

The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the "knee" point.

### Forward Biased Junction Diode showing a Reduction in the Depletion Layer

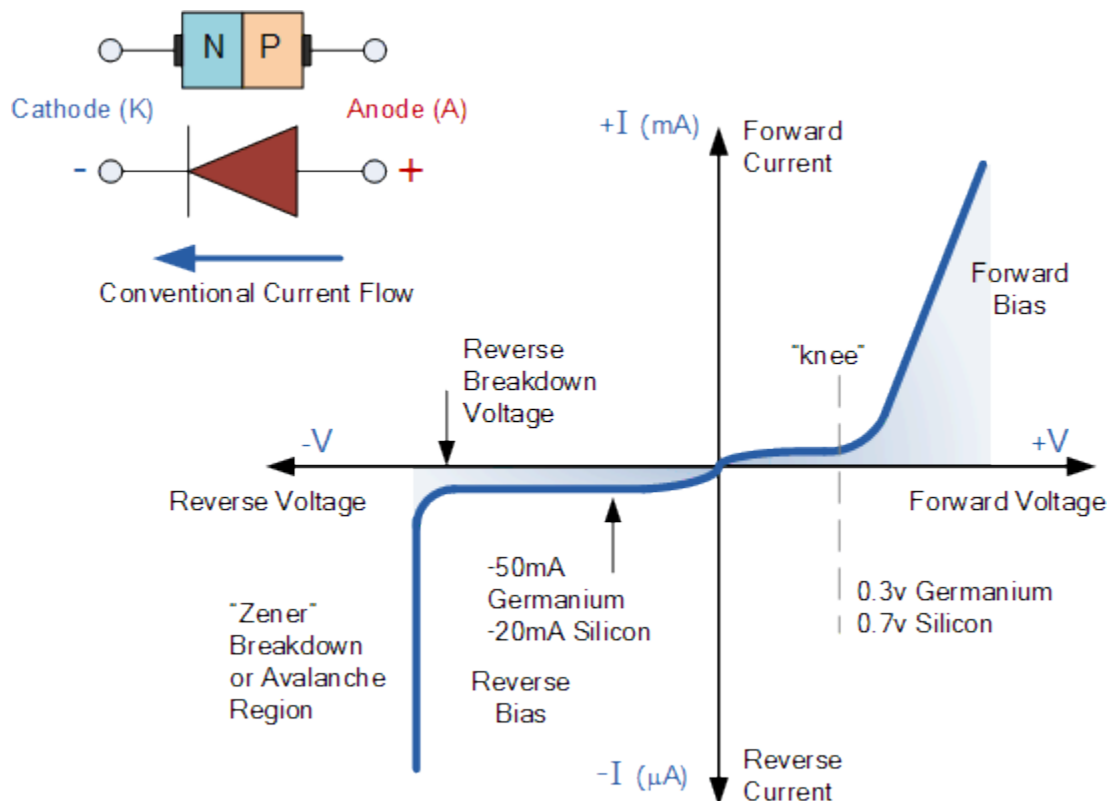


This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes.

Since the diode can conduct "infinite" current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

## Current – Voltage characteristics of a Diode

A diode is a nonlinear device. This is demonstrated in the following graph, and the fact that it's current versus voltage is not a straight line.



In the forward region of the graph, the voltage at which the current starts to increase quickly is called the knee voltage of the diode.

Study of a diode circuit usually comes down to determining if the diode voltage is higher or lower than the knee voltage.

- If the knee voltage is higher, the diode conducts easily
- If the knee voltage is lower, the diode conducts poorly

(The knee voltage for a silicon diode is approximately 0.7 volt and for a germanium diode 0.3 volt)

### Breakdown voltage:

Diodes have a maximum voltage rating, and also there is a limit to how much reverse voltage a diode could withstand before it is damaged. If you continue to increase the reverse voltage, you will ultimately reach the breakdown voltage of the diode, at which the component will lose its characteristics and will allow the current to flow in either directions.

**Maximum DC forward current:**

If the current in a diode is too large, the excessive heat can destroy the component. For this reason the manufacturer's data sheet indicates the maximum current a diode can safely handle without shortening its life or affecting its characteristics.

END PN JUNCTION DIODES