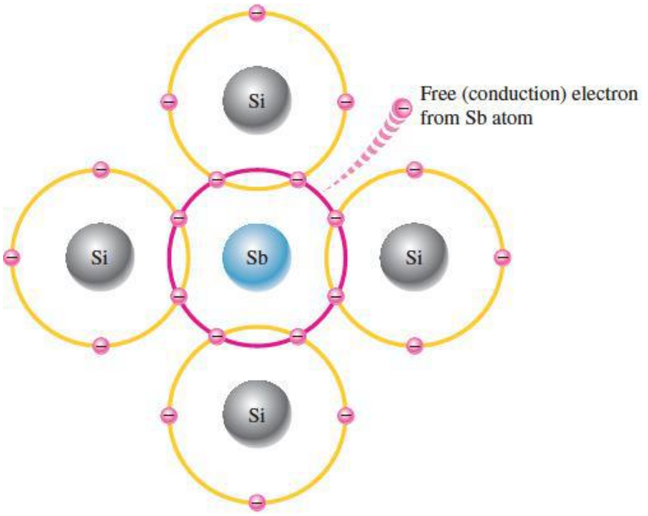
الكلية	**كلية الهندسة**
القسم	**قسم الهندسة الكهربائية**
المادة باللغة الانجليزية	Fundamentals of Electronics I
المادة باللغة العربية	**أسس الإلكترونيك ١**
المرحلة الدراسية	**الثانية**
اسم التدريسي	**حامد ردام حسين**
عنوان المحاضرة باللغة الانجليزية	SEMICONDUCTOR DIODES
عنوان المحاضرة باللغة العربية	**ثنائيات أشباه الموصلات**
رقم المحاضرة	3
المصادر والمراجع	Electronic Devices and Circuit Theory 11thEdition by Robert L. Boylestad, Louis Nashelsky
	Electronic Devices 9th Edition by Thomas L. Floyd

Lecture 2: N-type & P-type materials

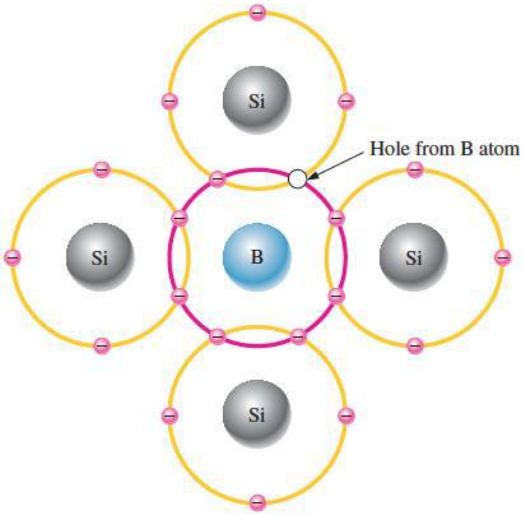
1. Doping (Adding Impurities)

- Semiconductive materials do not conduct current well and are of limited value in their intrinsic state.
- Intrinsic silicon (or germanium) must be modified by increasing the number of free electrons or holes to increase its conductivity and make it useful in electronic devices.
- This is done by adding impurities to the intrinsic material.
- This process, called **doping**, increases the number of current carriers (electrons or holes).
- By adding certain impurities to pure (intrinsic) silicon, more holes or more electrons can be produced within the crystal.
- To increase the number of conduction band electrons, **pentavalent impurities** are added, forming an **n-type semiconductor**. These are elements to the right of Si on the Periodic Table.
- To increase the number of holes, **trivalent impurities** are added, **forming a p-type semiconductor.** These are elements to the left of Si on the Periodic Table.

III	IV	V
B	C	N
Al	Si	P
Ga	Ge	As
In	Sn	Sb



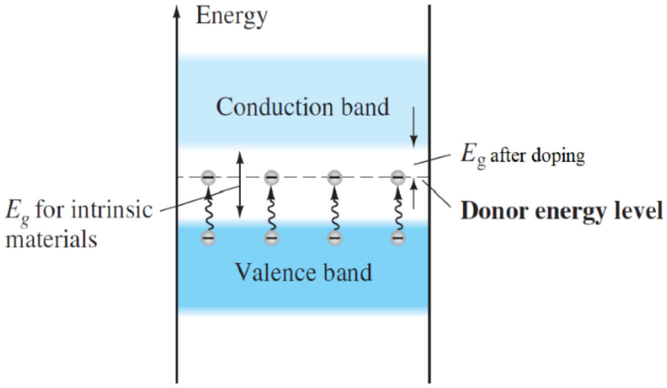
Pentavalent impurity atom in a silicon crystal structure. The extra electron from the antimony (Sb) atom becomes a free electron.



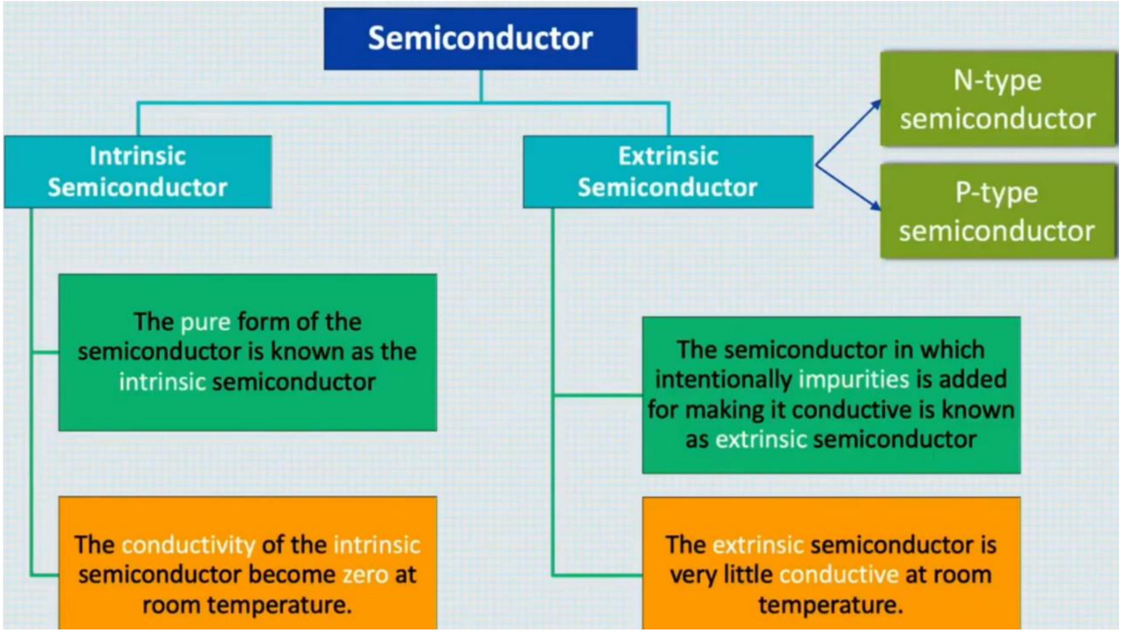
Trivalent impurity atom in a silicon crystal structure. A boron (B) impurity atom is shown in the center.

2. N-Type and P-Type materials

- Semiconductive materials do not conduct current well in their intrinsic state.
- The characteristics of semiconductor material can be altered significantly by the addition of specific impurity atoms to the relatively pure semiconductor material.
- These impurities, although only added at 1 part in 10 million, can alter the band structure sufficiently to totally change the electrical properties of the material.



- Semiconductor material that has been subjected to the doping process is called an **extrinsic material**.



The pure form of the semiconductor is known as the intrinsic semiconductor

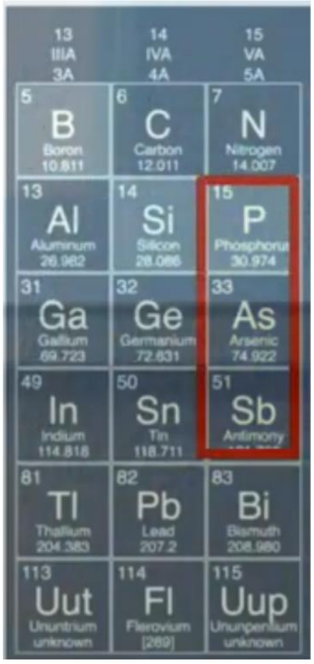
The conductivity of the intrinsic semiconductor become zero at room temperature.

The semiconductor in which intentionally impurities is added for making it conductive is known as extrinsic semiconductor

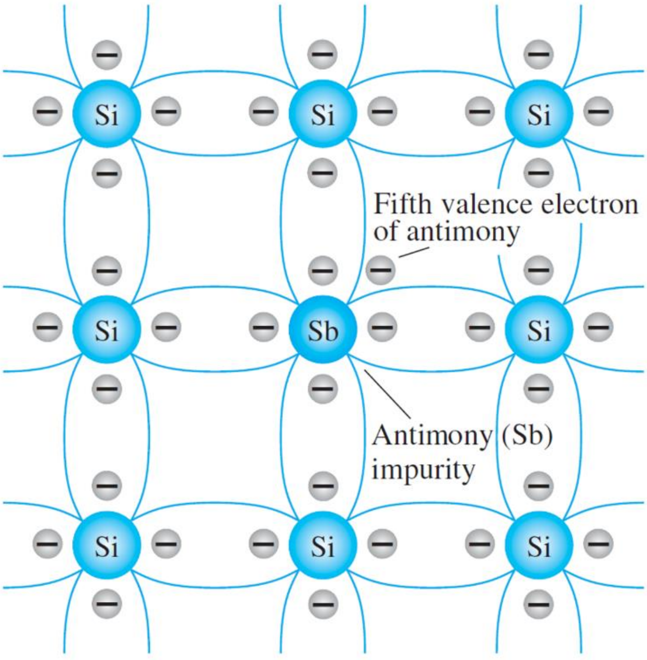
The extrinsic semiconductor is very little conductive at room temperature.

3. N-Type Semiconductor

- An N-type material is created by introducing impurity elements that have five valence electrons (pentavalent), Such as antimony, arsenic and phosphorus.
- This remaining electron, loosely bound to its parent (antimony) atom, is relatively free to move.
- The **electrons** are called the **majority carriers** in *n*-type material.
- There are also a few holes that are created when electron-hole pairs are thermally generated.
- Holes in an n-type material are called **minority carriers**.
- Diffused impurities with five valence electrons are **called donor atoms**.



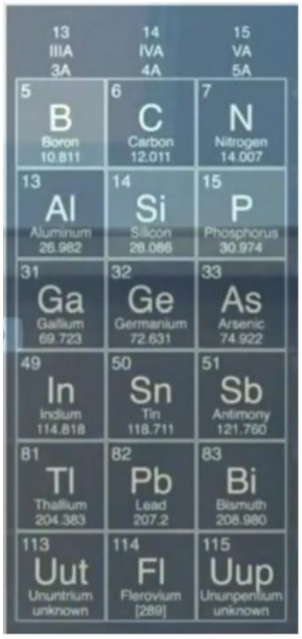
13 IIIA 3A	14 IVA 4A	15 VA 5A
5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007
13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974
31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922
49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony
81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980
113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown



Antimony impurity in n-type material.

4. P-Type Semiconductor

- The P-type material is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons (trivalent), such as boron, gallium, and indium.
- The resulting vacancy is called a hole, indicating the absence of a negative charge.
- The holes are the majority carriers in p-type material.
- There are also a few conduction-band electrons that are created when electron-hole pairs are thermally generated.
- Conduction-band **electrons** in p-type material are the **minority carriers**
- The diffused impurities with three valence electrons are **called acceptor atoms**.



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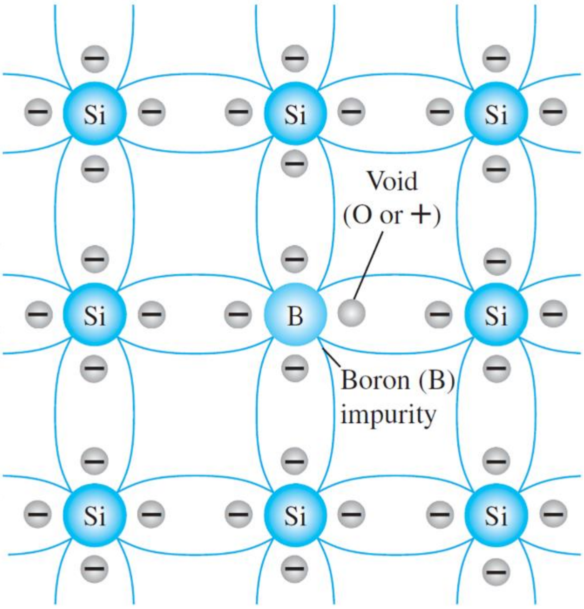
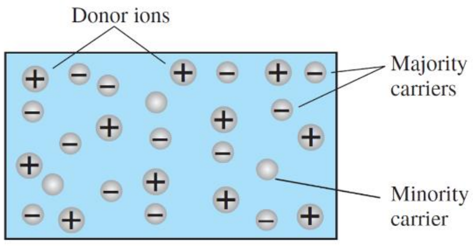


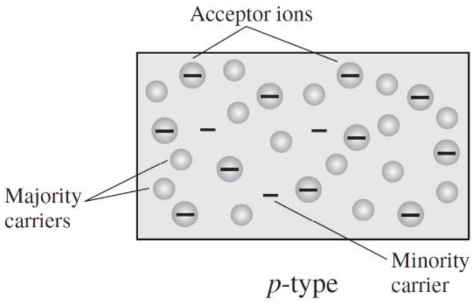
Boron impurity in p-type material.

5. Majority and minority carriers



n-type

In an n-type material the **electron** is called the majority carrier and the **hole** the majority the minority carrier.

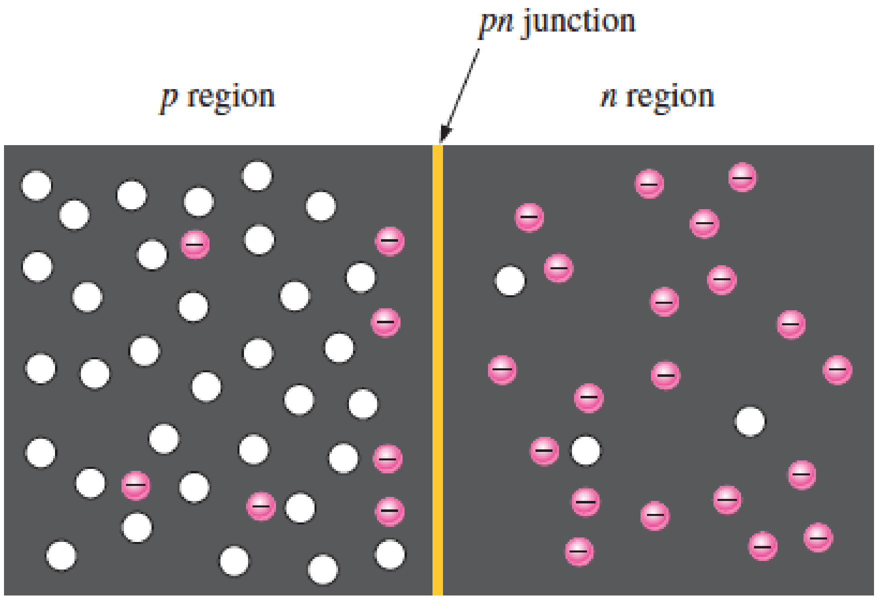


p-type

In a p-type material the **hole** is the majority carrier and the **electron** the majority the minority carrier.

6. The PN Junction

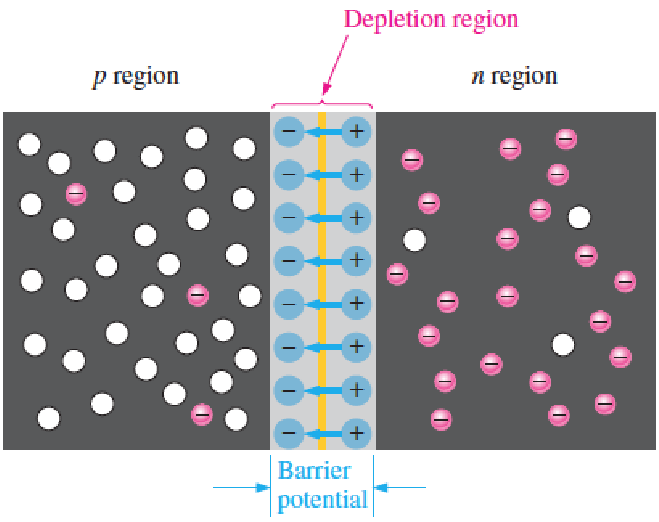
- When you take a block of silicon and dope part of it with a trivalent impurity and the other part with a pentavalent impurity, a boundary called the ***pn* junction** is formed between the resulting *p*-type and *n*-type portions.
- **The *PN* junction is the basis for diodes, transistors, solar cells, and other devices.**



The basic silicon structure at the **instant** of junction formation showing only the majority and minority carriers.

7. Formation of the Depletion Region

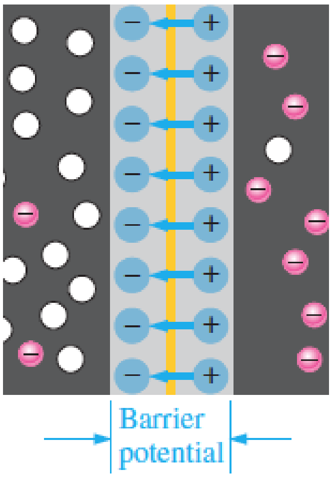
- At the **instant** of the *pn* junction formation, the free electrons near the junction in the *n* region begin to **diffuse** across the junction into the *p* region where they **combine** with holes near the junction.



- **Before** the *pn* junction is formed, there are as many electrons as protons in the *n*-type material, making the **material neutral** in terms of net charge. The same is true for the *p*-type material.
- **After** the *pn* junction is formed, the ***n* region loses free electrons** as they diffuse across the junction.
- This creates a layer of **positive charges** (pentavalent ions) near the junction.
- As the electrons move across the junction, the *p* region loses holes as the electrons and holes combine.
- This creates a layer of **negative charges** (trivalent ions) near the junction.
- These two layers of positive and negative charges form the **depletion region.**
- **In the end, equilibrium is established, and there is no further diffusion of electrons across the junction.**

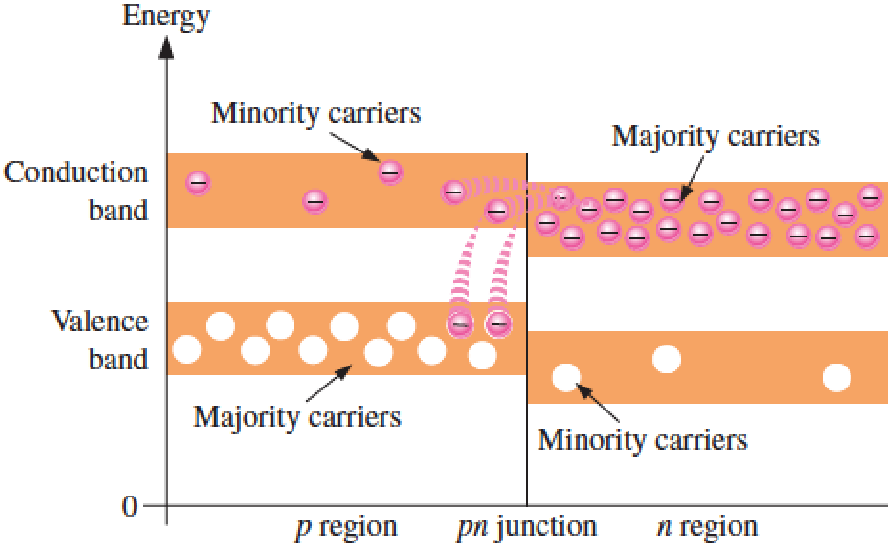
8. Barrier Potential

- An ***electric field*** *is established in* the depletion region.
- This electric field is a barrier to the free electrons in the *n* region, and energy must be expended to move an electron through the electric field.
- This potential difference is called the **barrier potential** and is expressed in volts. (0.7 V for silicon and 0.3 V for germanium at 25°C).

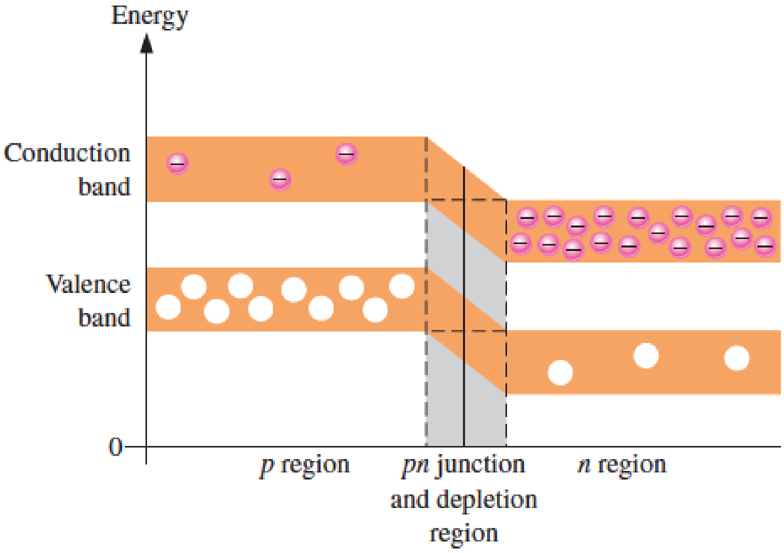


9. Energy Diagrams

- The valence and conduction bands in the *n* region are at lower energy levels than those in the *p* region, but there is a significant amount of overlapping.
- The free **electrons** in the *n* region that occupy the **upper part** of the conduction band in terms of their energy can easily **diffuse** across the junction and temporarily become free electrons in the **lower part** of the *p*-region conduction band. After crossing the junction, the electrons quickly lose energy and **fall into** the holes in the *p*-region valence band.



- As the diffusion continues, the depletion region begins to form and the energy level of the *n*-region conduction band decreases.
- The decrease in the energy level of the conduction band in the *n* region is due to the **loss of the higher-energy electrons** that have diffused across the junction to the *p* region.
- After the depletion region is formed, there are no electrons left in the *n*-region conduction band with enough energy to get across the junction to the *p*-region conduction band, as indicated by the alignment of the top of the *n*-region conduction band and the bottom of the *p*-region conduction band.



10. Summary

- An *n*-type semiconductive material is created by adding impurity atoms that have five valence electrons. A *p*-type semiconductor is created by adding impurity atoms with only three valence electrons.
- The process of adding pentavalent or trivalent impurities to a semiconductor is called ***doping***.
- A *pn* junction is formed when part of a material is doped *n*-type and part of it is doped *p*-type. A depletion region forms starting at the junction that is devoid of any majority carriers. The depletion region is formed by ionization.
- The barrier potential is typically 0.7 V for a silicon diode and 0.3 V for germanium.

11. Review Questions

1. Define doping.
2. How is an n -type semiconductor formed?
3. By what process are the majority carriers produced?
4. By what process are the minority carriers produced?
5. What is the difference between intrinsic and extrinsic semiconductors?
6. What is a pn junction?
7. Explain diffusion.
8. Describe the depletion region.
9. Explain what the barrier potential is and how it is created.