Ministry of Higher Education and Scientific Research

Al-Mustaqbal University College

Department of Medical Physics

Analog Electronics

Lecture 2

Intrinsic Semiconductors, Extrinsic Semiconductors, PN-Junction, and Applications

By

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Valence and conduction bands

The valence band and conduction band are the bands closest to the Fermi level, and thus determine the electrical conductivity of the solid. In non-metals, the valence band is the highest range of proton energies in which electrons are normally present at absolute zero temperature, while the conduction band is the lowest range of vacant electronic states.

The difference between the valence and conduction bands is meaningless in metals, because conduction occurs in one or more partially filled bands that take on the properties of both the valence and conduction bands.

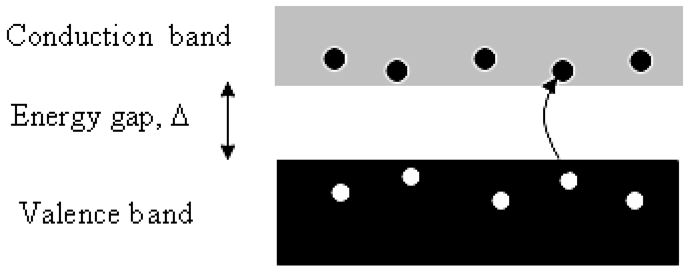

Figure (12) shows electrons and holes in

conduction band and valance band.

Intrinsic Semiconductors

An intrinsic (pure) semiconductor, also called an undoped semiconductor, is a pure semiconductor without any significant dopant species present. The number of charge carriers is therefore determined by the properties of the material itself instead of the amount of impurities. In intrinsic semiconductors the number of excited electrons and the number of holes are equal: n = p. This may be the case even after doping the semiconductor, though only if it is doped with both donors and acceptors equally. In this case, n = p still holds, and the semiconductor remains intrinsic, though doped. For example silicon and germanium.

The electrical conductivity of intrinsic semiconductors can be due to crystallographic defects or electron excitation. In an intrinsic semiconductor the number of electrons in the conduction band is equal to the number of holes in the valence band.

Electrons and holes

In an intrinsic semiconductor such as silicon at temperatures above absolute zero, there will be some electrons which are excited across the band gap into the conduction band and which can support charge flowing. When the electron in pure silicon crosses the gap, it leaves behind an electron vacancy or "hole" in the regular silicon lattice. Under the influence of an external voltage, both the electron and the hole can move across the material.

In an n-type semiconductor, the dopant contributes extra electrons, dramatically increasing the conductivity.

In a p-type semiconductor, the dopant produces extra vacancies or holes, which likewise increase the conductivity.

Intrinsic Semiconductor Current

The current which will flow in an intrinsic semiconductor consists of both electron and hole current. That is, the electrons which have been freed from their lattice positions into the conduction band can move through the material. In addition, other electrons can hop between lattice positions to fill the vacancies left by the freed electrons. This additional mechanism is called hole conduction because it is as if the holes are migrating across the material in the direction opposite to the free electron movement. The current flow in an intrinsic semiconductor is influenced by the density of energy states which in turn influences the electron density in the conduction band. This current is highly temperature dependent.

Extrinsic Semiconductors

An extrinsic semiconductor is one that has been doped; during manufacture of the semiconductor crystal a trace element or chemical called a doping agent, in order to give it different electrical properties than the pure semiconductor crystal, which is called an intrinsic semiconductor. The doping agents used are of two types, resulting in two types of extrinsic semiconductor:

- Electron donor dopant is an atom which, when incorporated in the crystal, releases a mobile conduction electron into the crystal lattice. An extrinsic semiconductor which has been doped with electron donor atoms is called an n-type semiconductor, because the majority of charge carriers in the crystal are negative electrons. For Examples: phosphorus, arsenic.

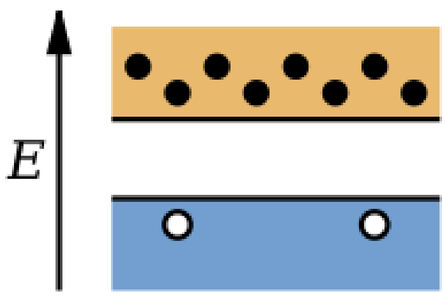

Figure (13) N-type semiconductors

- Electron acceptor dopant is an atom which accepts an electron from the lattice, creating a vacancy where an electron should be called a hole which can move through the crystal like a positively charged particle. An extrinsic semiconductor which has been doped with electron acceptor atoms is called a p-type semiconductor, because the majority of charge carriers in the crystal are positive holes. For examples: boron, aluminium, gallium.

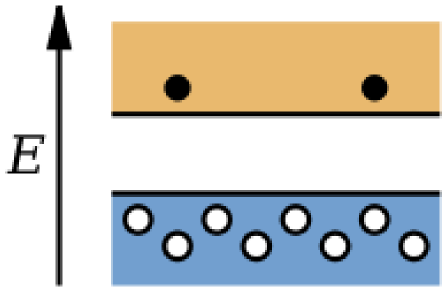

Figure (14) P-type semiconductors

Extrinsic semiconductors are used to make semiconductor electronic devices such as diodes, transistors, integrated circuits, semiconductor lasers, LEDs, and photovoltaic cells.

Semiconductor doping

Semiconductor doping is the process that changes an intrinsic semiconductor to an extrinsic semiconductor. During doping, impurity atoms are introduced to an intrinsic semiconductor. Impurity atoms are atoms of a different element than the atoms of the intrinsic semiconductor. Impurity atoms act as either donors or acceptors to the intrinsic semiconductor, changing the electron and hole concentrations of the semiconductor. Impurity atoms are classified as either donor or acceptor atoms based on the effect they have on the intrinsic semiconductor.

Donor impurity atoms have more valence electrons than the atoms they replace in the intrinsic semiconductor lattice. Donor impurities "donate" their extra valence electrons to a semiconductor's conduction band, providing excess electrons to the intrinsic semiconductor. Excess electrons increase the electron carrier concentration (n_o) of the semiconductor, making it n-type.

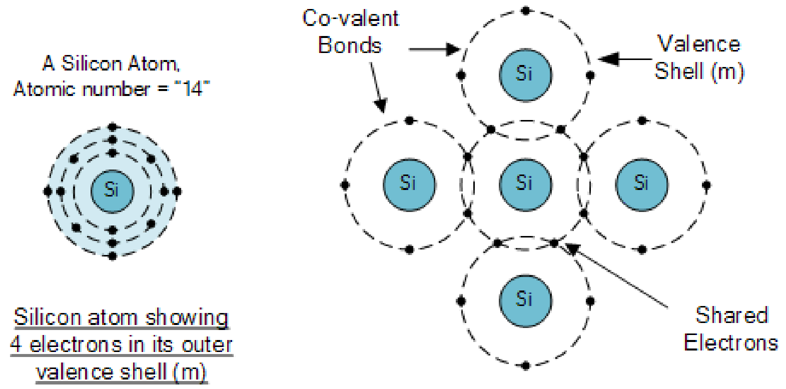

Figure (15) Pure semiconductor.

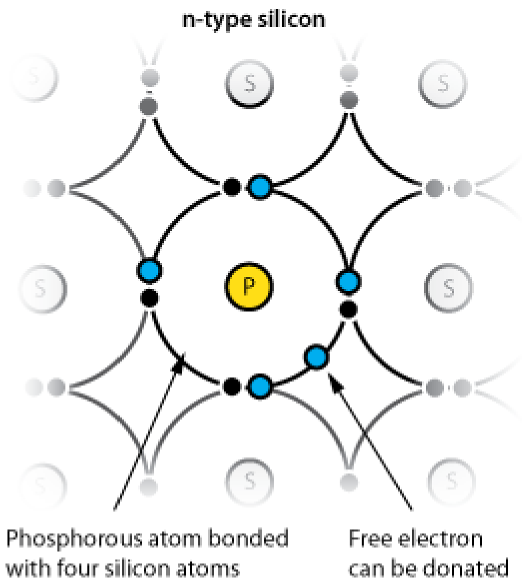

Figure (16) N-type semiconductors.

Acceptor impurity atoms have fewer valence electrons than the atoms they replace in the intrinsic semiconductor lattice. They "accept" electrons from the semiconductor's valence band. This provides excess holes to the intrinsic semiconductor. Excess holes increase the hole carrier concentration (p_o) of the semiconductor, creating a p-type semiconductor.

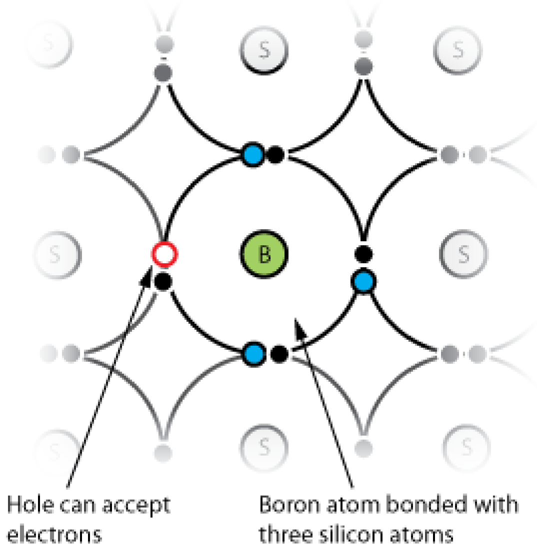

Figure (17) P-type semiconductors.

Use of extrinsic semiconductors

- A semiconductor diode (devices that allow current in only one direction) consists of p-type and n-type semiconductors placed in junction with one another. Currently, most semiconductor diodes use doped silicon or germanium.
- Transistors (devices that enable current switching) also make use of extrinsic semiconductors. Bipolar junction transistors (BJT), which amplify current, are one type of transistor. The most common BJTs are NPN and PNP type. NPN transistors have two layers of n-type

semiconductors sandwiching a p-type semiconductor. PNP transistors have two layers of p-type semiconductors sandwiching an n-type semiconductor.

- Other devices implementing the extrinsic semiconductor: Lasers, Solar cells, Photo detectors, and Light-emitting diodes.

P–N Junction

A p–n junction is a boundary or interface between two types of semiconductor materials, p-type and n-type, inside a single crystal of semiconductor. The "p" (positive) side contains an excess of holes, while the "n" (negative) side contains an excess of electrons in the outer shells of the electrically neutral atoms there. This allows electrical current to pass through the junction only in one direction. The p-n junction is created by doping.

P–N junctions are elementary of semiconductor electronic devices such as diodes, transistors, solar cells, LEDs, and integrated circuits; they are the active sites where the electronic action of the device takes place. For example, a common type of transistor, the bipolar junction transistor, consists of two p–n junctions in series, in the form n–p–n or p–n–p; while a diode can be made from a single p-n junction.

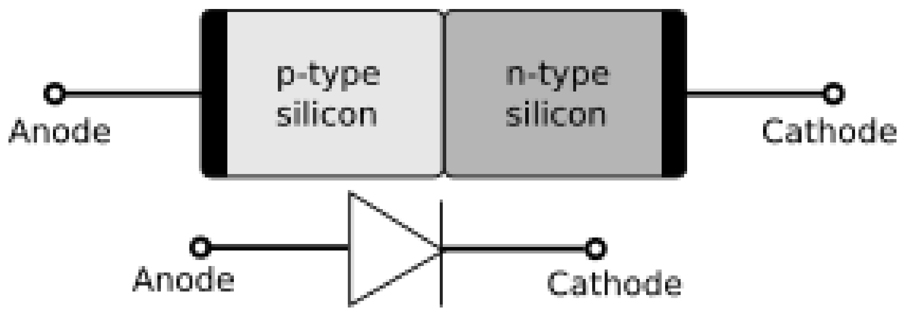

Figure (18) P-N Junction.

Properties of P-N Junction

The p–n junction has the main properties for modern electronics. Bias is the application of a voltage across a p–n junction; forward bias is in the direction of easy current flow, and reverse bias is in the direction of little or no current flow.

In forward bias, the p-type is connected with the positive terminal and the n-type is connected with the negative terminal. The positive potential applied to the p-type material repels the holes, while the negative potential applied to the n-type material repels the electrons. The change in potential between the p side and the n side decreases. With increasing forward-bias voltage, the depletion layer becomes thin enough that the electric field cannot across the p–n junction.

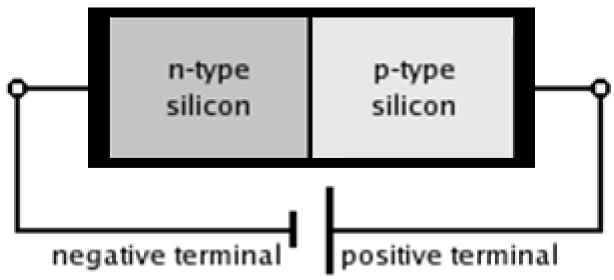

Figure (19) Forward bias in p–n junction.

In reverse bias, the p-type is connected to the negative terminal of the voltage supply and the n-type region to the positive terminal corresponds to reverse bias. If a diode is reverse-biased, the voltage at the cathode is comparatively higher than at the anode. Therefore, very little current flows until the diode breaks down.

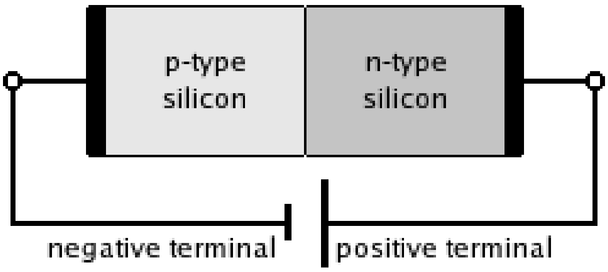

Figure (20) Reverse bias in p–n junction.

Applications of P-N Junction Diode

- P-N junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can be used in LED lighting applications.
- It is used as and as a voltage-controlled in electric circuits.