Analog electronics

First lecture

Introduction, materials types, semiconductors types

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Outline

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1.1 Introduction

The world of electronics is all about electrical circuits, electronic components, and interconnected technologies. All these elements can be primarily categorized as **digital, analog, or a combination of both**. However, here we will be focusing on the basics of the analog category in detail.

Analog electronics is a branch of electronics that deals with a continuously variable signal. It's widely used in radio and audio equipment along with other applications where signals are derived from analog sensors before being converted into digital signals for subsequent storage and processing. Although digital circuits are considered as a dominant part of today's technological world, some of the most fundamental components in a digital system are actually analog in nature.

Analog means continuous and real. The world we live in is analog in nature, implying that it's full of infinite possibilities. The number of smells we can sense, the number of tones we can hear, or the number of colors we can paint with; everything is infinite. The people working in the field of analog electronics are basically dealing with analog devices and circuits.

Analog Signals

In electrical engineering, signals are basically time-varying quantities (usually voltage or current). So when we talk about the signal it means we are talking about a voltage that's changing over time.

An **analog signal** is continuous in both time and amplitude. Analog signal is a form of electrical energy (voltage, current or electromagnetic power) for which there is a linear relationship between electrical quantity and the value that the signal represents.

Digital Signals are the signal, whose amplitude takes only limited values (discrete values) is called Digital signal.

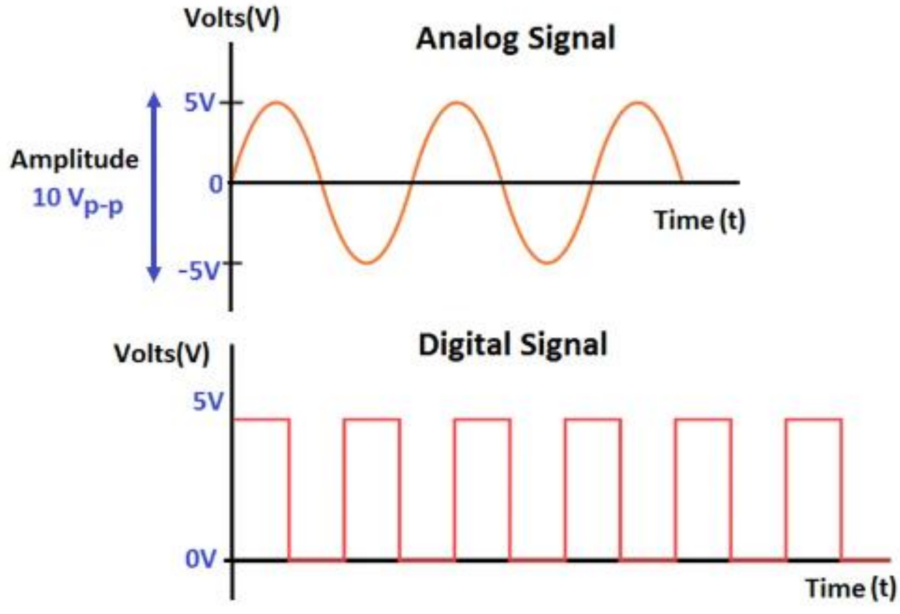


Figure 1: show analog and digital signals.

1.2 Materials types

We can classify materials generally according to the ability of charge to move through them

1.2.1 ***Conductors:*** are materials through which charge can move rather freely without resistance, capable of passing an electric current and are also good conductors of heat, examples include metals (such as copper in common lamp wire), the human body, and tap water.

1.2.2 ***Insulators***: Electrical insulators are materials in which all of the electrons are bound to atoms. and they have a high resistance to the passage of any current through them, and one of the most important uses of electrical insulators is to cover conductors is critical to safety. Examples of good insulators include glass, rubber and wood.

1.2.3 Semiconductor materials can be defined that they are materials whose electrical conductivity is medium, they are neither conductors nor insulators ,as they are located in the region between insulating materials and conductive materials. Semiconductors constitute the future of modern electronic systems, and examples of which are silicon (Si) and germanium (Ge).

Devices and equipment that manufacture semiconductor materials are the basis of modern electronics, which include radio, computer, telephone, television and many other devices. Semiconductor electronic parts include transistors, solar cells, diodes, LEDs, and analog and digital integrated circuits.

1.3 Intrinsic semiconductors

An intrinsic semiconductor is a pure semiconductor likes silicon and germanium. A silicon crystal is an intrinsic semiconductor if every atom in the crystal is a silicon atom. At room temperature, a silicon crystal acts like an insulator because it has only a few free electrons and holes produced by thermal energy. In intrinsic semiconductors, the number of excited electrons (n) is equal to the number of holes (p); $n = p$.

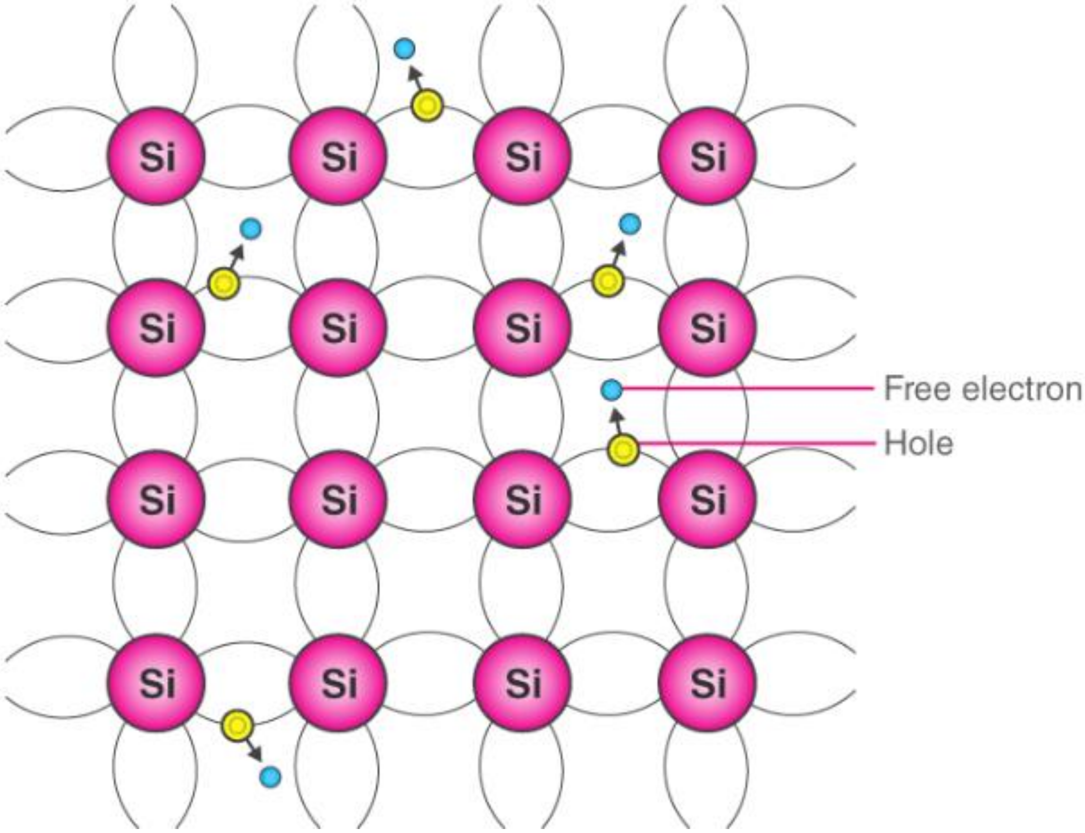


Figure 2: Electrons and Holes configuration in a Silicon atom.

1.4 Extrinsic semiconductors

Extrinsic semiconductors are semiconductors that are doped with specific impurities. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors.

While adding impurities, a small amount of suitable impurity is added to pure material, increasing its conductivity by many times. Extrinsic semiconductors are also called impurity semiconductors or doped semiconductors. The process of adding impurities deliberately is termed as doping and the atoms that are used as an impurity are termed as dopants. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes and transistors.

These dopants give rise to two types of semiconductors as follows:

1- n-type semiconductors
2- p-type semiconductors

n-type semiconductors

When a tetravalent atom such as Si or Ge is doped with a pentavalent atom such as phosphorus (P), arsenic (As), or antimony (Sb) , it occupies the position of an atom in the crystal lattice of the Si atom. The four of the electrons of the pentavalent atom bond with the four neighbouring silicon atoms, and the fifth one remains weakly bound to the parent atom. As a result, the ionization energy required to set the fifth electron free is very low, and the electrons become free to move in the lattice of the semiconductor.

p-type semiconductors

When a tetravalent atom such as Si or Ge is doped with a trivalent impurity such as Aluminum (Al) boron (B) or indium (In), etc., the dopant atom has one less electron than the surrounding atoms of Si or Ge. Thus, the fourth atom of the tetravalent atom is free, and a hole or vacancy is generated in the trivalent atom. In such materials, the holes are the charge carriers.

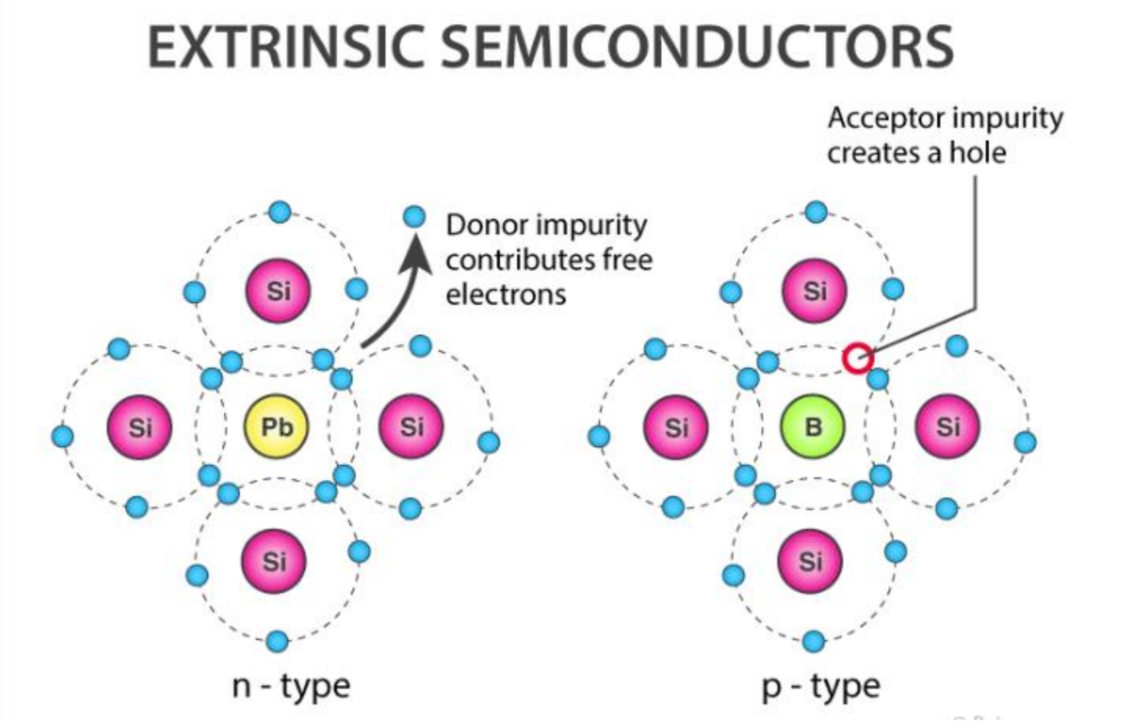


Figure 3: Extrinsic semiconductors: n-type semiconductors, p-type semiconductors

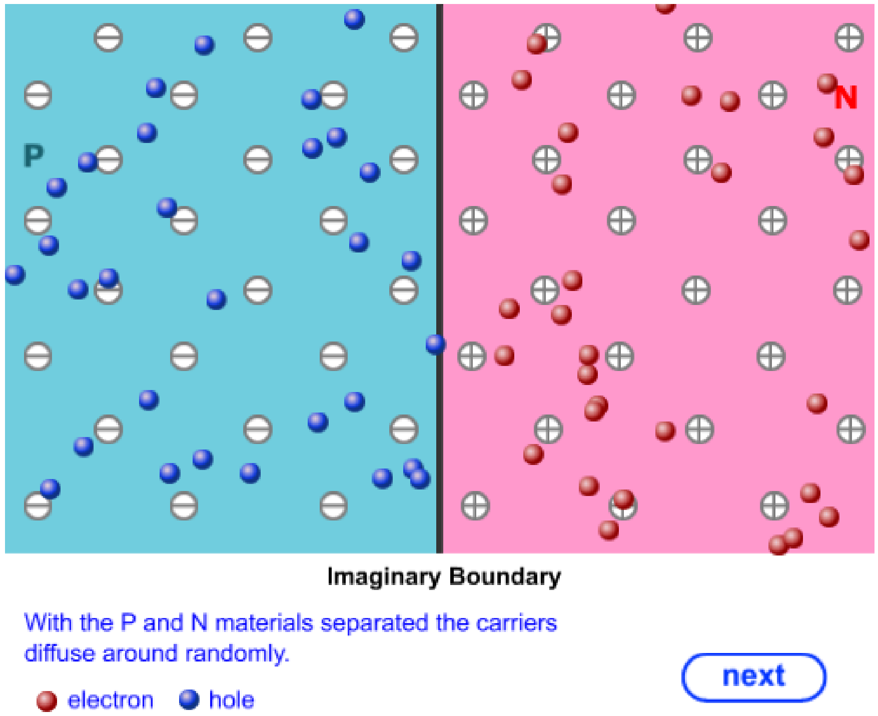
1.5 PN-junction and applications

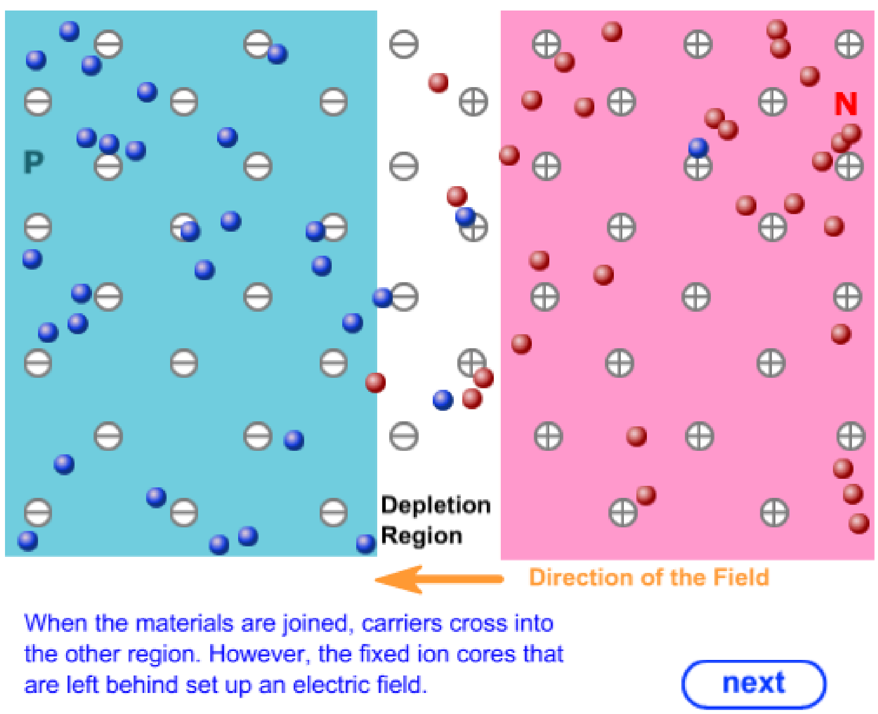
A P-N junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.

In a semiconductor, the P-N junction is created by the method of doping. The p-side or the positive side of the semiconductor has an excess of holes, and the n-side or the negative side has an excess of electrons.

Formation of a PN-Junction

P-n junctions are formed by joining n-type and p-type semiconductor materials, as shown below. Since the n-type region has a high electron concentration and the p-type a high hole concentration, electrons diffuse from the n-type side to the p-type side. Similarly, holes flow by diffusion from the p-type side to the n-type side. If the electrons and holes were not charged, this diffusion process would continue until the concentration of electrons and holes on the two sides were the same. However, in a p-n junction, when the electrons and holes move to the other side of the junction, they leave behind exposed charges on dopant atom sites, which are fixed in the crystal lattice and are unable to move. On the n-type side, positive ion cores are exposed. On the p-type side, negative ion cores are exposed. An electric field E forms between the positive ion cores in the n-type material and negative ion cores in the p-type material. This region is called the "depletion region" since the electric field quickly sweeps free carriers out, hence the region is depleted of free carriers. A "built-in" potential is formed at the junction due to E. The animation below shows the formation of the E at the junction between n and p-type material. Can use p-n junction as photodiode, solar cell, LED lighting applications and voltage-controlled oscillator.





1.6 References

Electronics principles (fourth edition) by Malvino.