CHAPTER 3

SEMICONDUCTOR PN JUNCTION DIODE

Objectives

After completing this course, you will be able to:

- Learn what a PN-Junction is.
- Find static and dynamic resistances in both forward and reverse biased conditions for P-N Junction diode.
- Find impurities into the other side of a single crystal of an intrinsic semiconductor to form a p-n diode with a junction called depletion region (this region is depleted off the charge carriers).

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, for example by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layer of crystal doped with another type of dopant).
- If two separate pieces of material were used, this would introduce a grain boundary between the semiconductors that would severely inhibit its utility by scattering the electrons and holes.
- p–n junctions are elementary "building blocks" 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.
- A Schottky junction is a special case of a p–n junction, where metal serves the role of the p-type semiconductor.
- The p–n junction possesses essential properties for modern electronics. A p-doped semiconductor is relatively conductive.
- The same is true of an n-doped semiconductor, but the junction between them can become depleted of charge carriers, and hence non-conductive, depending on the relative voltages of the two semiconductor regions.
- By manipulating this non-conductive layer, p–n junctions are commonly used as diodes: circuit elements that allow a flow of electricity in one direction but not in the other (opposite) direction.
- *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.
- The forward-bias and the reverse-bias properties of the p–n junction imply that it can be used as a diode.
- A p–n junction diode allows electric charges to flow in one direction, but not in the opposite direction; negative charges (electrons) can easily flow through the junction from n to p but not from p to n, and the reverse is true for holes.
- When the p–n junction is forward-biased, electric charge flows freely due to reduced resistance of the p–n junction. When the p–n junction is reverse-biased,

however, the junction barrier (and therefore resistance) becomes greater and charge flow is minimal.

Equilibrium (zero bias)

- In a p–n junction, without an external applied voltage, an equilibrium condition is reached in which a potential difference forms across the junction. This potential difference is called *built-in potential*

Electric field

- Created by the space charge region opposes the diffusion process for both electrons and holes.
- There are two concurrent phenomena: the diffusion process that tends to generate more space charge, and the electric field generated by the space charge that tends to counteract the diffusion.
- The space charge region is a zone with a net charge provided by the fixed ions (donors or acceptors) that have been left *uncovered* by majority carrier diffusion.

Forward bias

- With a battery connected this way, the holes in the p-type region and the electrons in the n-type region are pushed toward the junction and start to neutralize the depletion zone, reducing its width. 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 or switches sign. With increasing forward-bias voltage, the depletion zone eventually becomes thin enough that the zone's electric field cannot counteract charge carrier motion across the p–n junction, which as a consequence reduces electrical resistance.

Reverse bias

- Connecting the *p-type* region to the *negative* terminal of the battery 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. The connections are illustrated in the adjacent diagram.

Manufacture

- The p-n junction is created by doping, for example by ion implantation, diffusion of dopants, or by epitaxy (growing a layer of crystal doped with one type of dopant on top of a layer of crystal doped with another type of dopant).

- If two separate pieces of material were used, this would introduce a grain boundary between the semiconductors that would severely inhibit its utility by scattering the electrons and holes

Video links:

PN Junction Introduction

- ***https://www.youtube.com/watch?v=BHA4teZmwT0***

PN Junction Band Diagram

- ***https://www.youtube.com/watch?v=6VSUshhCpYg***

PN Junction Electric Field Profile

- ***https://www.youtube.com/watch?v=h5qLpyraT9M***

PN Junction Depletion Width

- ***https://www.youtube.com/watch?v=jL5BJpeWltE***

PN Junction Example: Depletion Width, E-Field

- ***https://www.youtube.com/watch?v=M3Hoa_C1Mms***

Reference:

- ***Hook, J. R.; H. E. Hall (2001). Solid State Physics. John Wiley & Sons. ISBN 978-0-471-92805-8.***
- ***Luque, Antonio; Steven Hegedus (29 March 2011). Handbook of Photovoltaic Science and Engineering. John Wiley & Sons. ISBN 978-0-470-97612-8.***
- ***Riordan, Michael; Hoddeson, Lillian (1988). Crystal fire: the invention of the transistor and the birth of the information age. USA: W. W. Norton & Company. pp. 88–97. ISBN 978-0-393-31851-7.***