Chapter 16

Diodes and Applications

Objectives

- Understand the basic structure of semiconductors and how they conduct current
- Describe the characteristics and biasing of a *pn* junction diode
- Describe the basic diode characteristics
- Analyze the operation of a half-wave rectifier and a full-wave rectifier

Objectives

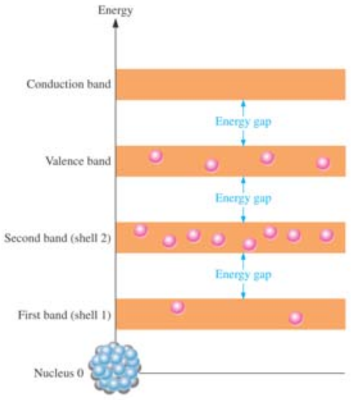
- Describe the operation of power supplies
- Understand the basic operation and describe some applications of four special-purpose diodes

Introduction to Semiconductors

- Two types of semiconductive materials are silicon and germainium
  - both have four valance electrons
- When silicon and germanium atoms combine into molecules to form a solid material, they arrange themselves in a fixed pattern called a crystal
  - atoms within the crystal structure are held together by covalent bonds (atoms share valence electrons)
- An intrinsic crystal is one that has no impurities

Introduction to Semiconductors

- When an electron jumps to the conduction band, a vacancy is left in the valence band within the crystal (called a **hole**)
  - called an electron-hole pair
- Recombination occurs when a conduction-band electron loses energy and falls back into a hole in the valence band



Introduction to Semiconductors

- In an intrinsic semiconductor, there are relatively few free electrons
  - pure semiconductive materials are neither good conductors nor good insulators
- Intrinsic semiconductive materials must be modified by increasing the free electrons and holes to increase its conductivity and make it useful for electronic devices
  - by adding impurities, *n*-type and *p*-type extrinsic semiconductive material can be produced

Introduction to Semiconductors

- Doping is the process of adding impurities to intrinsic semiconductive materials to increase and control conductivity within the material
  - *n*-type material is formed by adding **pentavalent** (5 valence electrons) impurity atoms
    - electrons are called **majority carriers** in *n*-type material
    - holes are called **minority carriers** in *n*-type material
  - *p*-type material is formed by adding **trivalent** (3 valence electrons) impurity atoms
    - holes are called **majority carriers** in *p*-type material
    - electrons are called **minority carriers** in *p*-type material

The PN Junction Diode

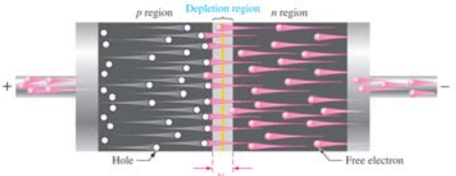
- A diode consists of an *n* region and a *p* region separated by a *pn* junction
  - the *n* region has many conduction electrons
  - the *p* region has many holes
- As a result of recombination, a large number of positive (in the *n* region) and negative (in the *p* region) ions builds up near the *pn* junction, essentially depleting the region of any conduction electrons or holes - termed the *depletion region*

The PN Junction Diode

- The **barrier potential**, V_B, is the amount of voltage required to move electrons through the electric field
  - At 25°C, it is approximately 0.7 V for silicon and 0.3 V for germanium
  - As the junction temperature increases, the barrier potential decreases, and vice versa

The PN Junction Diode

- Forward bias is the condition that permits current through a diode
  - the negative terminal of the V_{BIAS} source is connected to the *n* region, and the positive terminal is connected to the *p* region



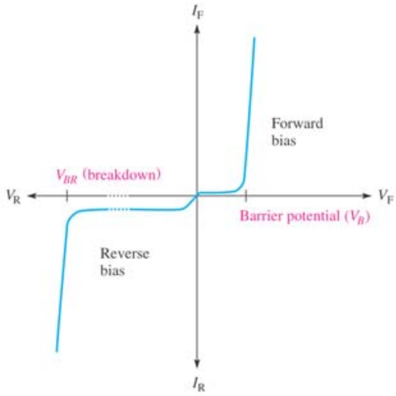
The PN Junction Diode

- The negative terminal of the bias-voltage source pushes the conduction-band electrons in the *n* region toward the *pn* junction, while the positive terminal pushes the holes in the *p* region toward the *pn* junction
- When it overcomes the barrier potential (V_B), the external voltage source provides the *n* region electrons with enough energy to penetrate the depletion region and move through the junction

The PN Junction Diode

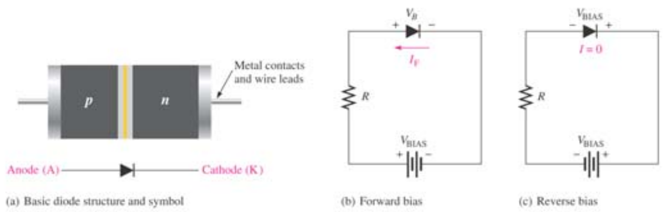
- Reverse bias is the condition that prevent current through the diode
  - the negative terminal of the V_{BIAS} source is connected to the *p* region, and the positive terminal is connected to the *n* region
- If the external reverse-bias voltage is increased to a large enough value, **reverse breakdown** occurs
  - minority conduction-band electrons acquire enough energy from the external source to accelerate toward the positive end of the diode, colliding with atoms and knocking valence electrons into the conduction band

Diode Characteristics



Diode Characteristics

- The “arrowhead” in the diode symbol points in the direction opposite the electron flow
  - The **anode** (A) is the *p* region
  - The **cathode** (K) is the *n* region

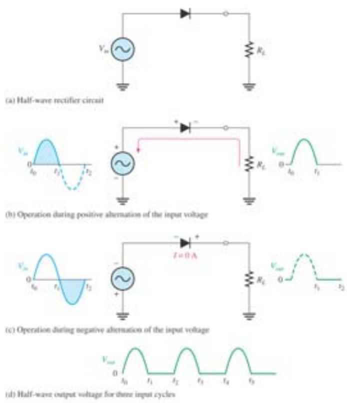


Diode Characteristics

- The simplest way to visualize diode operation is to think of it as a switch
  - When forward-biased, the diode ideally acts as a closed (on) switch
  - When reverse-biased, it acts as an open (off) switch

Diode Rectifiers

- A diode is connected to an ac source that provides the input voltage, V_{in}, and to a load resistor, R_L, forming a **half-wave rectifier**
  - **on the positive half-cycle, the diode is forward biased**



Diode Rectifiers

- When the diode barrier potential is taken into account, as in the practical model, the input voltage must overcome the barrier potential before the diode becomes forward-biased
  - This results in a half-wave output voltage with a peak value that is 0.7 V less than the peak value of the input voltage
  - It is often practical to neglect the effect of barrier potential when the peak value of the applied voltage is much greater than the barrier potential

Diode Rectifiers

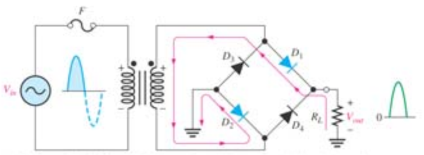
- *Peak Inverse Voltage* (PIV) is the maximum value of reverse voltage that a diode can withstand
- A full-wave rectifier allows unidirectional current to the load during the entire input cycle
  - whereas the half-wave rectifier allows this only during one-half of the cycle
- The average value for a full-wave rectifier output voltage is twice that of the half-wave rectifier

$$\mathbf{V_{AVG} = 2V_{P(out)} / \pi}$$

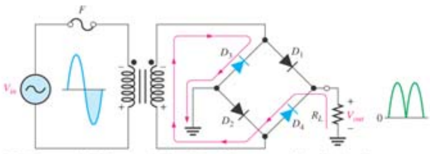
Diode Rectifiers

- The full-wave bridge rectifier uses four diodes, as shown on the next slide
  - When the input cycle is positive as in part (a), diodes D_1 and D_2 are forward-biased and conduct current, while diodes D_3 and D_4 are reverse-biased
  - When the input cycle is negative as in part (b), diodes D_3 and D_4 are forward-biased and conduct current, while diodes D_1 and D_2 are reverse-biased

Diode Rectifiers



(a) During positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.



(b) During negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

Diode Rectifiers

- Two diodes are always in series with the load during both the positive and negative half-cycles
- Neglecting the barrier potentials of the the two diodes, the output voltage is a full-wave rectified voltage with a peak value equal to the peak secondary voltage
- The PIV of the diodes must equal the peak secondary voltage:

$$\mathbf{PIV = V_{P(out)}}$$

Power Supplies

- The dc power supply converts the standard 110 V, 60 Hz ac available at the wall outlets into a constant dc voltage
  - dc voltage is used in most electronic circuits
- A capacitor is used to filter the output of the rectifier, charging during each quarter-cycle that the input voltage exceeds the capacitor voltage, and discharging through the load when the input voltage decreases below the capacitor voltage, at which point the diodes become reverse biased

Power Supplies

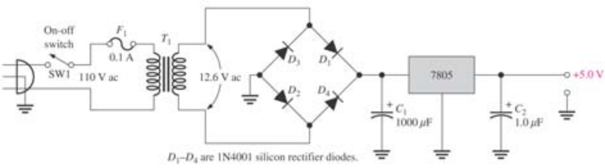
- Since the capacitor charges to a peak value equal to $V_{P(in)}$, the peak inverse voltage of the diode in this application must be:

$$\mathbf{PIV = 2\ V_{P(in)}}$$

- Ripple voltage is the variation in output voltage due to charging and discharging of the capacitor
  - For a given input frequency, ripple voltage for a full-wave rectifier will be less than that for a half-wave rectifier

Power Supplies

- An integrated circuit regulator (three-terminal regulator) is a device that is connected to the output of a filtered rectifier and maintains a constant output voltage despite changes in the input voltage or the load current



Special Purpose Diodes

- The zener diode is used to provide an output reference voltage that is stable despite changes in input voltage
  - Used as a reference in regulated power supplies
  - The zener diode is designed for operation in the reverse breakdown region, where the voltage remains almost constant over a wide range of reverse current values

Special Purpose Diodes

- A varactor diode utilize the inherent capacitance of the depletion region of a reverse-biased *pn* junction to vary capacitance by changing the reverse voltage
  - The *p* and *n* regions are conductive, and act as the capacitor plates
  - The depletion layer created by the reverse bias acts as a capacitor dielectric because it is nonconductive
    - as the reverse bias increases, the depletion region widens, and the capacitance across the diode decreases
    - as the reverse bias decreases, the depletion region narrows, and the capacitance across the diode increases

Special Purpose Diodes

- The light-emitting diode (LED)
  - when the device is forward-biased, electrons cross the *pn* junction from the *n*-type material and recombine with holes in the *p*-type material
  - Since the electrons in the conduction band are at a higher energy level than the holes in the valence band, when recombination takes place, energy is released in the form of heat and light
  - A large exposed surface on one layer of the LED permits the photons to be emitted as light, termed *electroluminescence*

Summary

- The process of adding impurities to an intrinsic (pure) semiconductor to increase and control conductivity is called *doping*
- A *p*-type semiconductor is doped with trivalent impurity atoms
- a *n*-type semiconductor is doped with pentavalent impurity atoms
- The depletion region is a region adjacent to the *pn* junction containing no majority carriers

Summary

- Forward bias permits majority carrier current through the diode
- Reverse bias prevents majority carrier current
- The single diode in a half-wave rectifier conducts for half of the input cycle
- The PIV is the maximum voltage appearing across the diode in reverse bias
- The output frequency of a full-wave rectifier is twice the input frequency

Summary

- A capacitor-input filter provides a dc output approximately equal to the peak of the input
- Ripple voltage is caused by the charging and discharging of the filter capacitor
- Regulation of output voltage over a range of input voltages is called input or *line regulation*
- The zener diode operates in reverse breakdown
- A zener diode maintains an essentially constant voltage across its terminals over a specified range of zener currents

Summary

- Zener diodes can be used as voltage references in a variety of applications
- A varactor diode acts as a variable capacitor under reverse-biased conditions
- The capacitance of a varactor diode varies inversely with reverse-biased voltage