Electrical Circuits for Engineers (EC1000)

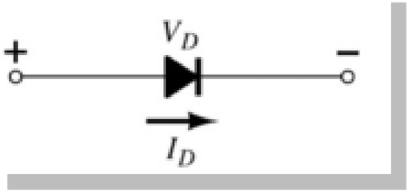
Lecture-13
Semiconductor Diodes

Semiconductor Diodes

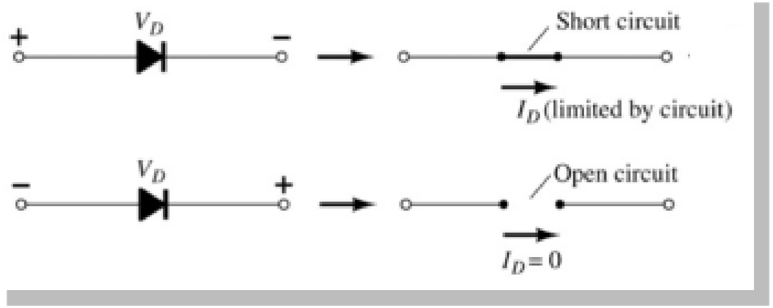
- Introduction
- Diodes
- Semiconductors
- *pn* Junctions
- Semiconductor Diodes
- Special-Purpose Diodes
- Diode Circuits

Diodes

The diode is a 2-terminal device.

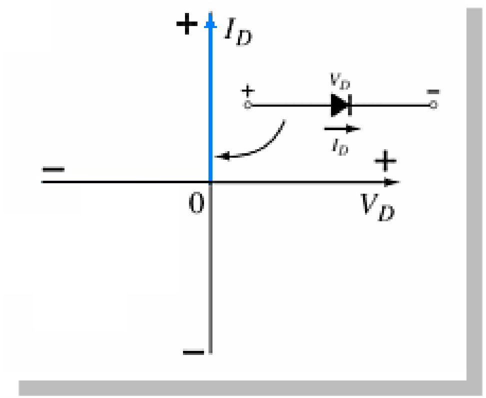


A diode ideally conducts in only one direction.



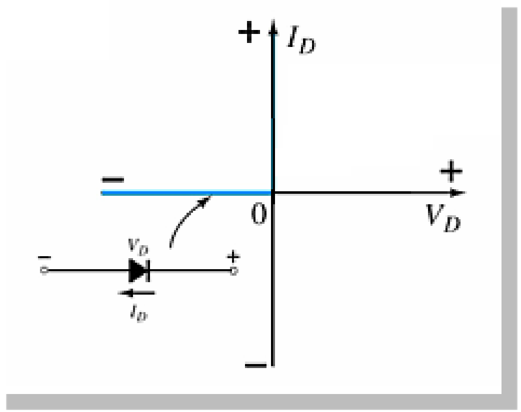
Conduction Region

- **The voltage across the diode is 0 V**
- **The current is infinite**
- **The forward resistance is defined as $R_F = V_F / I_F$**
- **The diode acts like a short**



Non-Conduction Region

- **All of the voltage is across the diode**
- **The current is 0 A**
- **The reverse resistance is defined as $R_R = V_R / I_R$**
- **The diode acts like open**



Electrical Properties of Solids

Conductors

e.g. copper or aluminium

have a cloud of free electrons (at all temperatures above absolute zero). If an electric field is applied electrons will flow causing an electric current

Insulators

e.g. polythene

electrons are tightly bound to atoms so few can break free to conduct electricity

- **Semiconductors**
  - e.g. silicon or germanium
  - at very low temperatures these have the properties of insulators
  - as the material warms up some electrons break free and can move about, and it takes on the properties of a conductor.
  - however, semiconductors have several properties that make them distinct from conductors and insulators.

Semiconductors

- **Pure semiconductors**
  - thermal vibration results in some bonds being broken generating **free electrons** which move about these leave behind **holes** which accept electrons from adjacent atoms and therefore also move about
  - electrons are **negative charge carriers**
  - holes are **positive charge carriers**
- At room temperatures there are few charge carriers
  - *pure* semiconductors are poor conductors
  - this is **intrinsic conduction**

Doping

The electrical characteristics of silicon and germanium are improved by adding materials in a process called doping.

There are just two types of doped semiconductor materials:

***n*-type**
***p*-type**

- ***n*-type materials contain an excess of conduction band electrons.**
- ***p*-type materials contain an excess of valence band holes.**

  - both *n*-type and *p*-type materials have much greater conductivity than pure semiconductors
  - this is **extrinsic conduction**

Semiconductor Materials

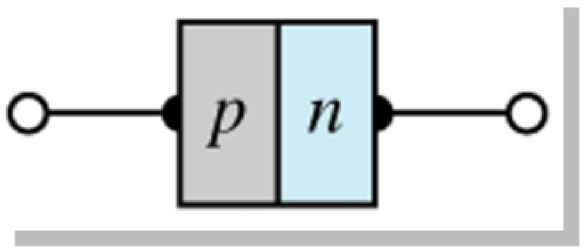
Materials commonly used in the development of semiconductor devices:

- **Silicon (Si)**
- **Germanium (Ge)**
- **Gallium Arsenide (GaAs)**

p-n Junctions

One end of a silicon or germanium crystal can be doped as a *p*-type material and the other end as an *n*-type material.

The result is a *p-n* junction.

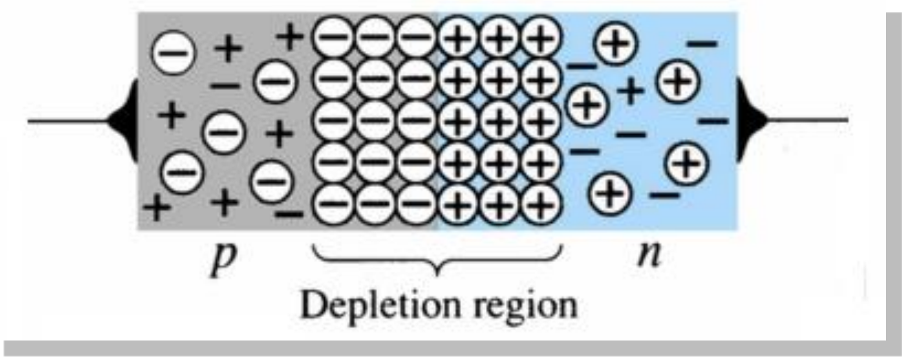


p-n Junctions

At the *p-n* junction, the excess conduction-band electrons on the *n*-type side are attracted to the valence-band holes on the *p*-type side.

The electrons in the *n*-type material migrate across the junction to the *p*-type material (electron flow).

The electron migration results in a **negative** charge on the p-type side of the junction and a **positive** charge on the n-type side of the junction.



The result is the formation of a **depletion region** around the junction.

Diode Operating Conditions

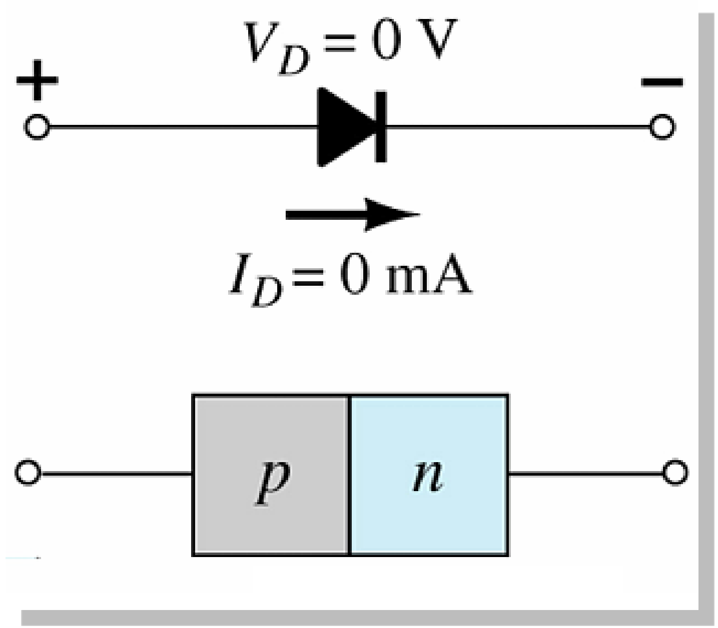
A diode has three operating conditions:

- **No bias**
- **Forward bias**
- **Reverse bias**

Diode Operating Conditions

No Bias

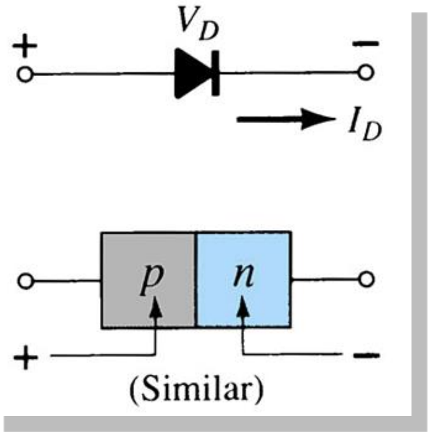
- **No external voltage is applied: $V_D = 0$ V**
- **No current is flowing: $I_D = 0$ A**
- **Only a modest depletion region exists**

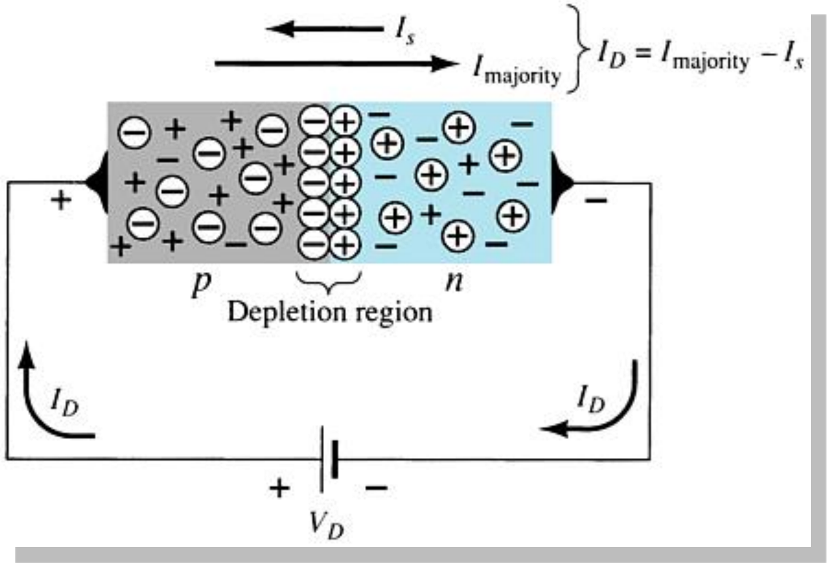


Diode Operating Conditions

Forward Bias

External voltage is applied across the *p-n* junction in the same polarity as the *p-* and *n-*type materials.



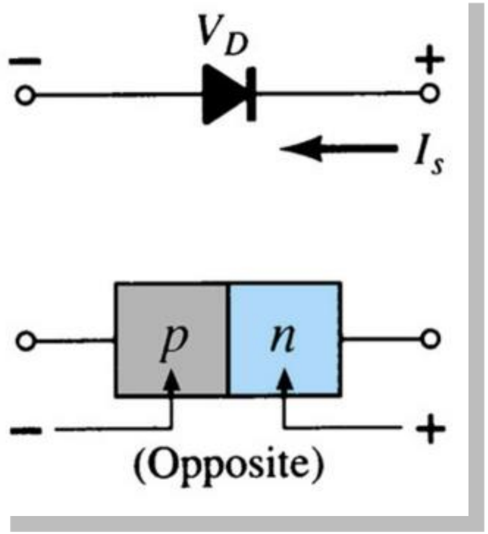


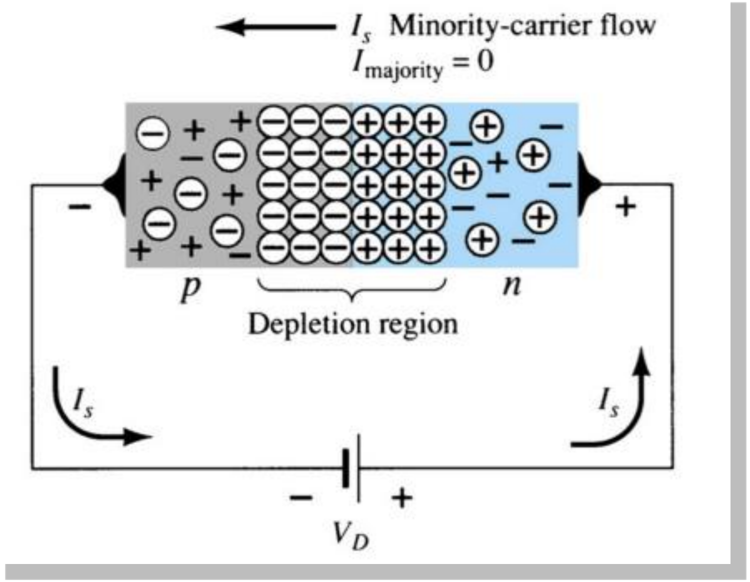
- **The forward voltage causes the depletion region to narrow.**
- **The electrons and holes are pushed toward the *p-n* junction.**
- **The electrons and holes have sufficient energy to cross the *p-n* junction.**

Diode Operating Conditions

Reverse Bias

External voltage is applied across the *p*-*n* junction in the opposite polarity of the *p*- and *n*-type materials.



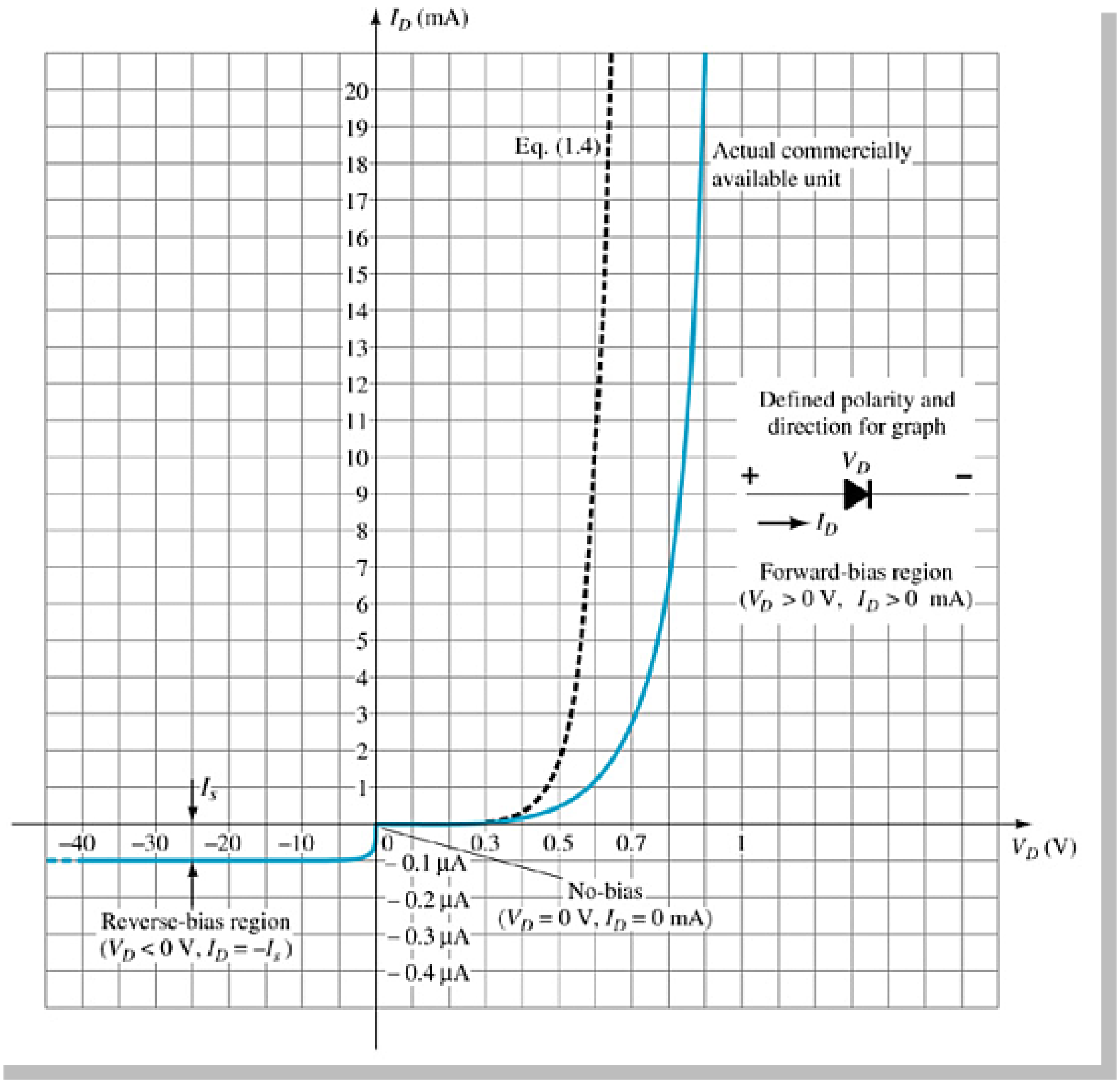


The reverse voltage causes the depletion region to widen.
The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.
The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.

Actual Diode Characteristics

- **Note the regions for no bias, reverse bias, and forward bias conditions.**

- **Carefully note the scale for each of these conditions.**



Majority and Minority Carriers

Two currents through a diode:

Majority Carriers

- **The majority carriers in *n*-type materials are electrons.**
- **The majority carriers in *p*-type materials are holes.**

Minority Carriers

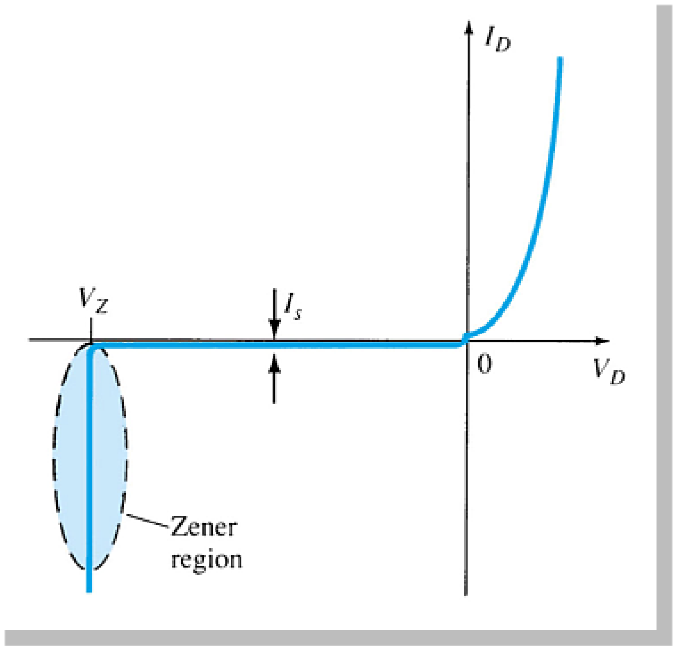
- **The minority carriers in *n*-type materials are holes.**
- **The minority carriers in *p*-type materials are electrons.**

Zener Region

The Zener region is in the diode's reverse-bias region.

At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.

- The maximum reverse voltage that won't take a diode into the zener region is called the **peak inverse voltage** or **peak reverse voltage**.
- The voltage that causes a diode to enter the zener region of operation is called the **zener voltage (V_Z)**.



Forward Bias Voltage

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the *p-n* junction. This energy comes from the external voltage applied across the diode.

The forward bias voltage required for a:

- **gallium arsenide diode ≅ 1.2 V**
- **silicon diode ≅ 0.7 V**
- **germanium diode ≅ 0.3 V**

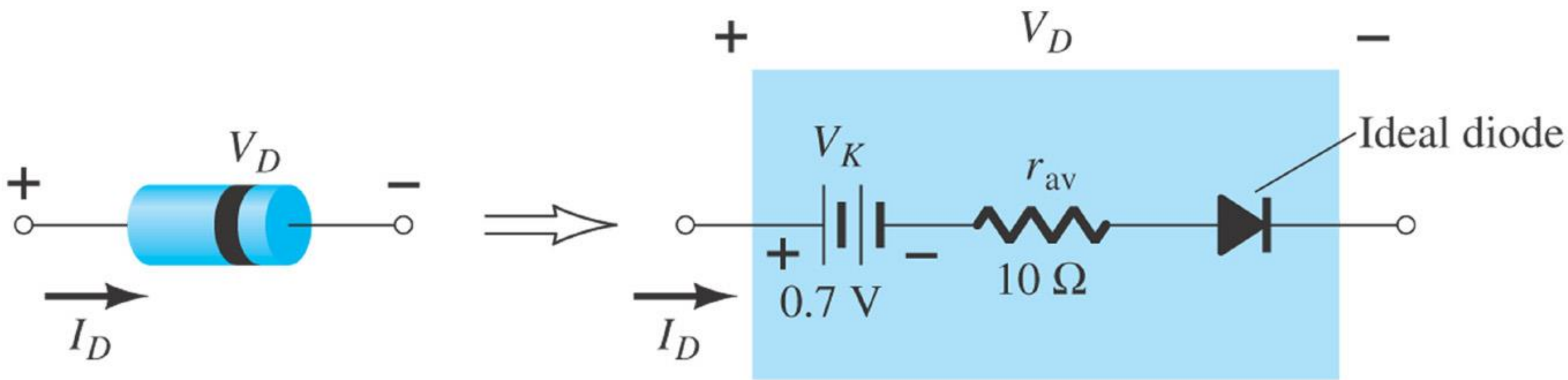
Temperature Effects

As temperature increases it adds energy to the diode.

- It reduces the required forward bias voltage for forward-bias conduction.
- It increases the amount of reverse current in the reverse-bias condition.
- It increases maximum reverse bias avalanche voltage.

Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.

Diode Equivalent Circuit

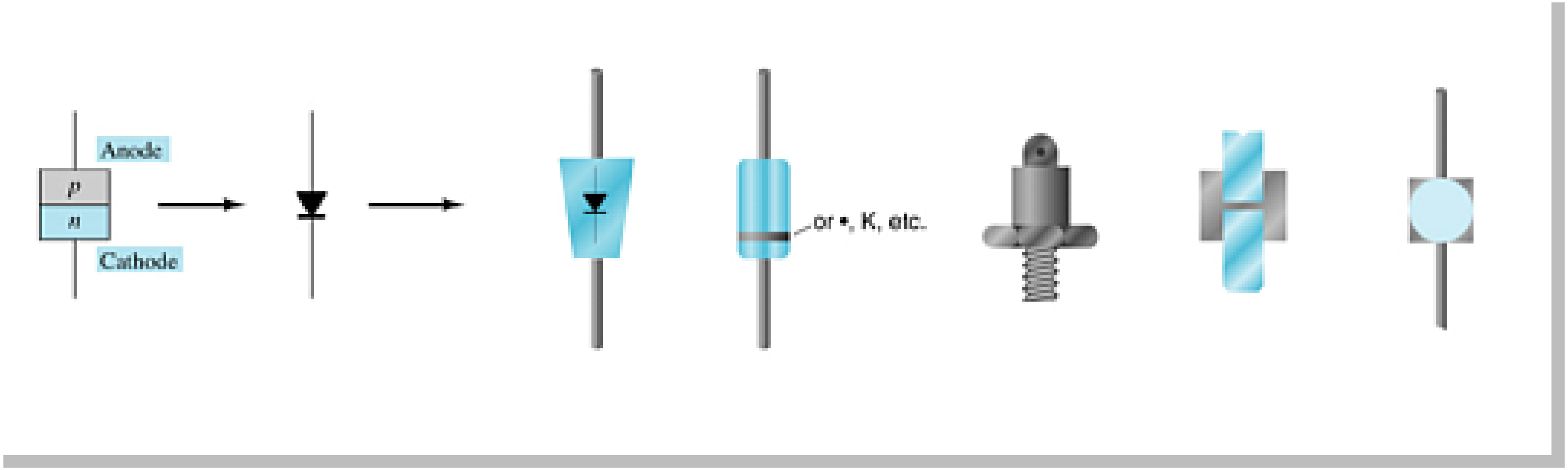


Diode Specification Sheets

Data about a diode is presented uniformly for many different diodes. This makes cross-matching of diodes for replacement or design easier.

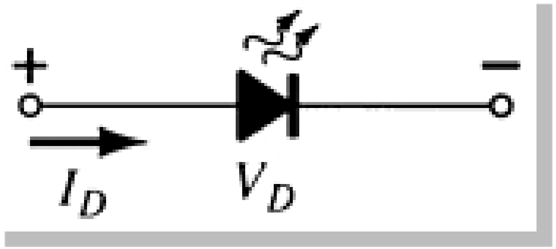
1. Forward Voltage (V_F) at a specified current and temperature
2. Maximum forward current (I_F) at a specified temperature
3. Reverse saturation current (I_R) at a specified voltage and temperature
4. Reverse voltage rating, PIV or PRV or V(BR), at a specified temperature
5. Maximum power dissipation at a specified temperature
6. Capacitance levels
7. Reverse recovery time, t_{rr}
8. Operating temperature range

Diode Symbol and Packaging

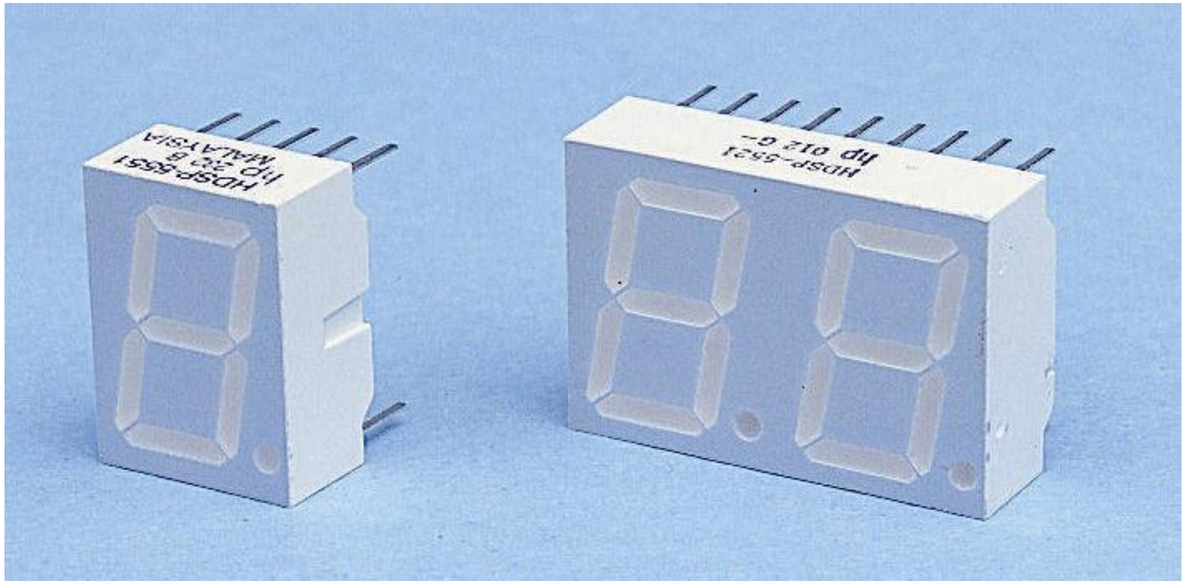


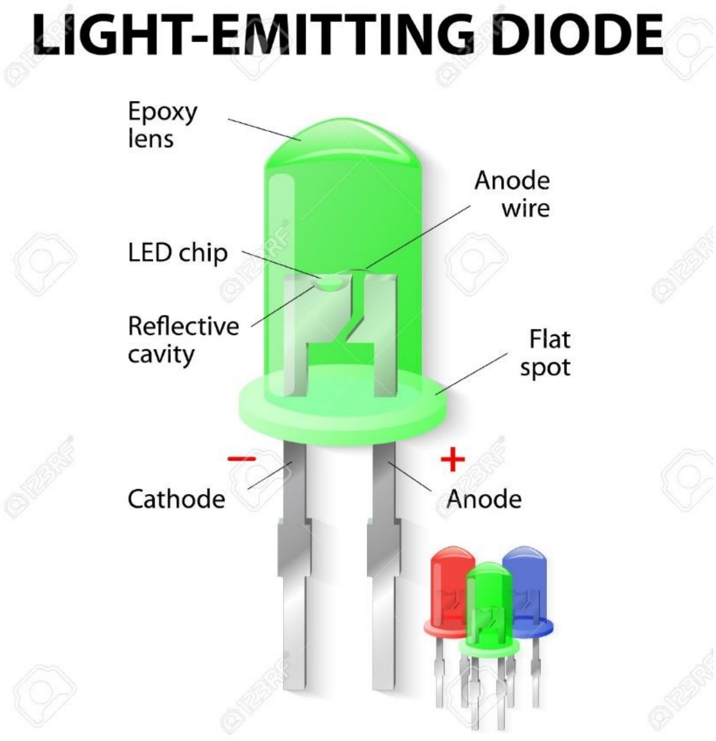
The anode is abbreviated A
The cathode is abbreviated K

Special-Purpose Diodes

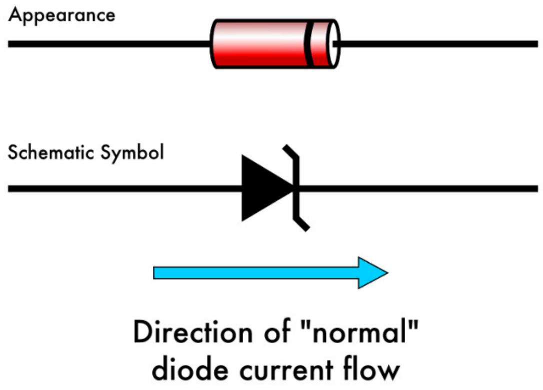


Light-emitting diodes



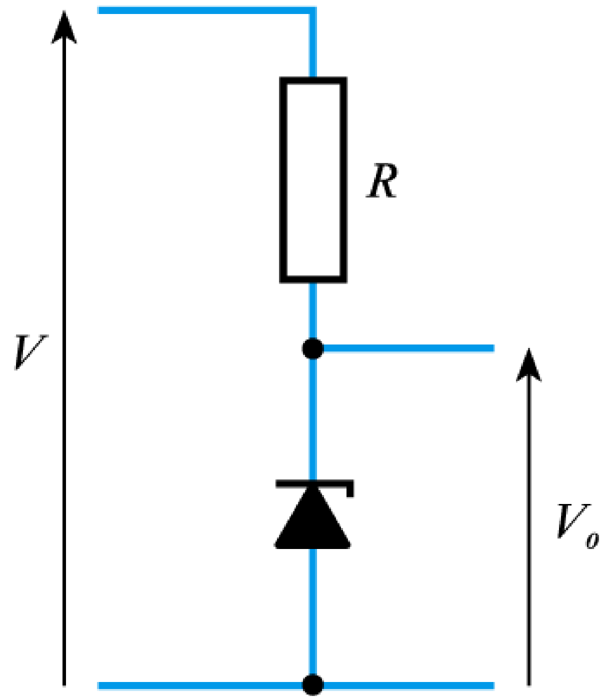


Special-Purpose Diodes



Zener diodes

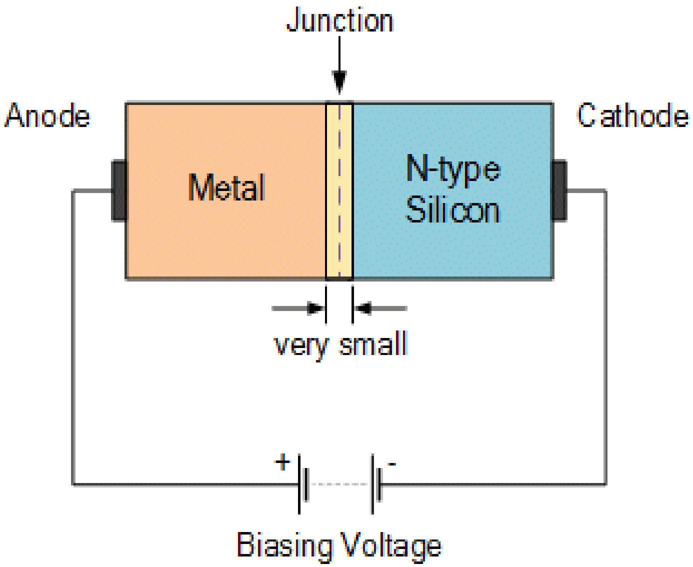
- uses the relatively constant reverse breakdown voltage to produce a voltage reference
- breakdown voltage is called the **Zener voltage**, V_Z
- output voltage of circuit shown is equal to V_Z despite variations in input voltage V
- a resistor is used to limit the current in the diode

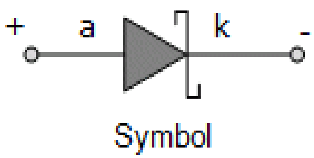


Special-Purpose Diodes

Schottky diodes

- formed by the junction between a layer of metal (e.g. aluminium) and a semiconductor
- action relies only on majority charge carriers
- much faster in operation than a *pn* junction diode
- has a low forward voltage drop of about 0.25 V
- used in the design of high-speed logic gates

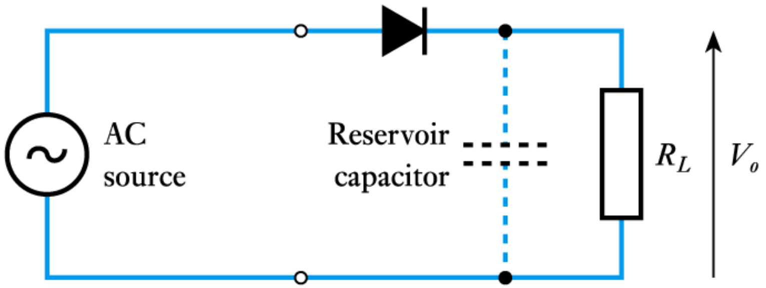


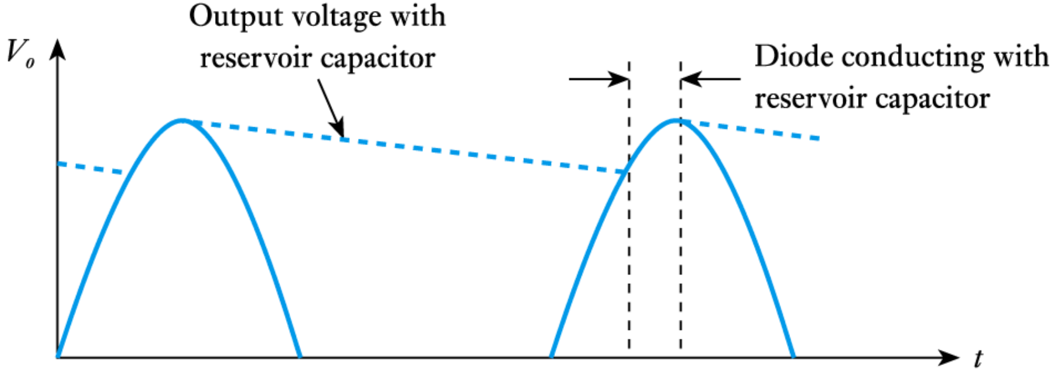


Diode Circuits

Half-wave rectifier

- peak output voltage is equal to the peak input voltage minus the conduction voltage of the diode
- reservoir capacitor used to produce a steadier output

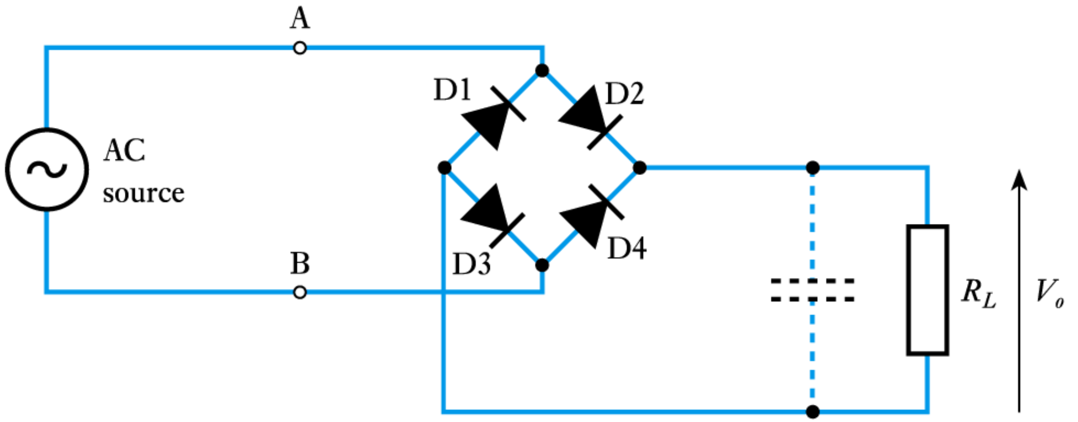


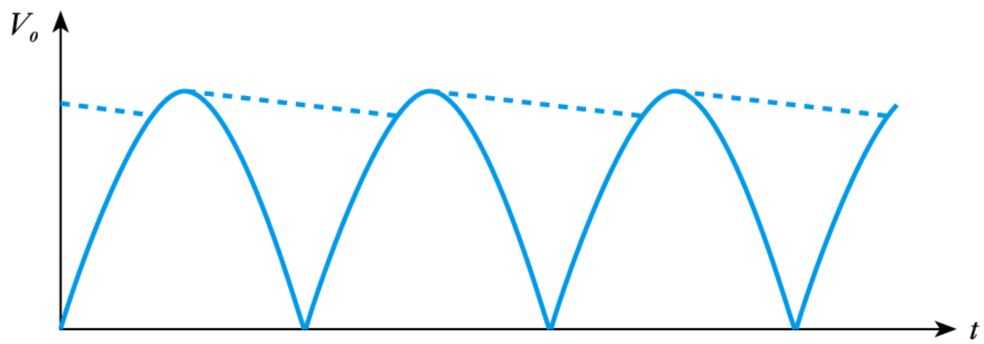


Diode Circuits

Full-wave rectifier

- use of a diode bridge reduces
  the time for which the capacitor has
  to maintain the output voltage
  and thus reduced the ripple voltage





Key Points

- Diodes allow current to flow in only one direction
- At low temperatures semiconductors act like insulators
- At higher temperatures they begin to conduct
- Doping of semiconductors leads to the production of *p*-type and *n*-type materials
- A junction between *p*-type and *n*-type semiconductors has the properties of a diode
- Silicon semiconductor diodes approximate the behaviour of ideal diodes but have a conduction voltage of about 0.7 V
- There are also a wide range of special purpose diodes
- Diodes are used in a range of applications

Note:

All material in these slides have been extracted from Chapter-1 of **Electronics Devices & Circuit Theory by Boylestad,** Pearson Education for the purpose of teaching.