# Lecture 2

# DIODES

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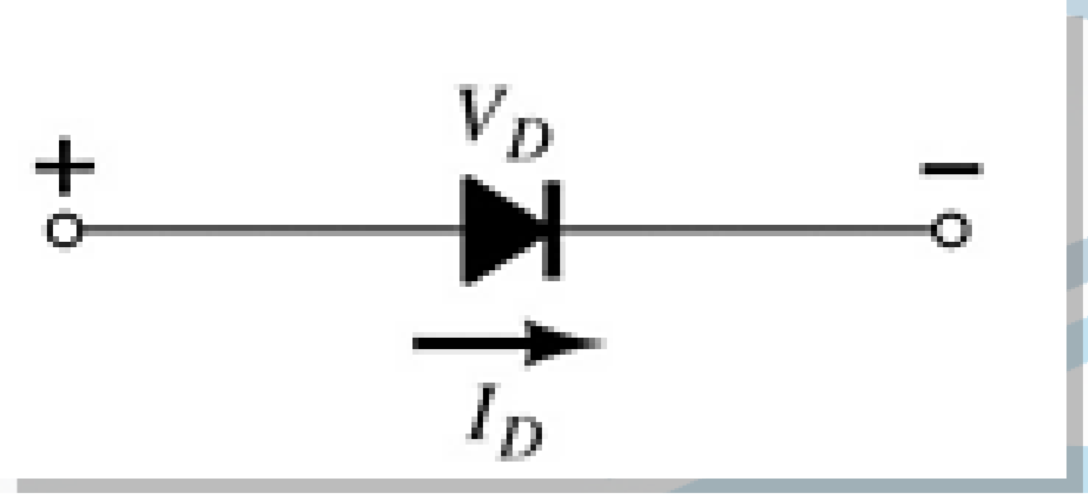
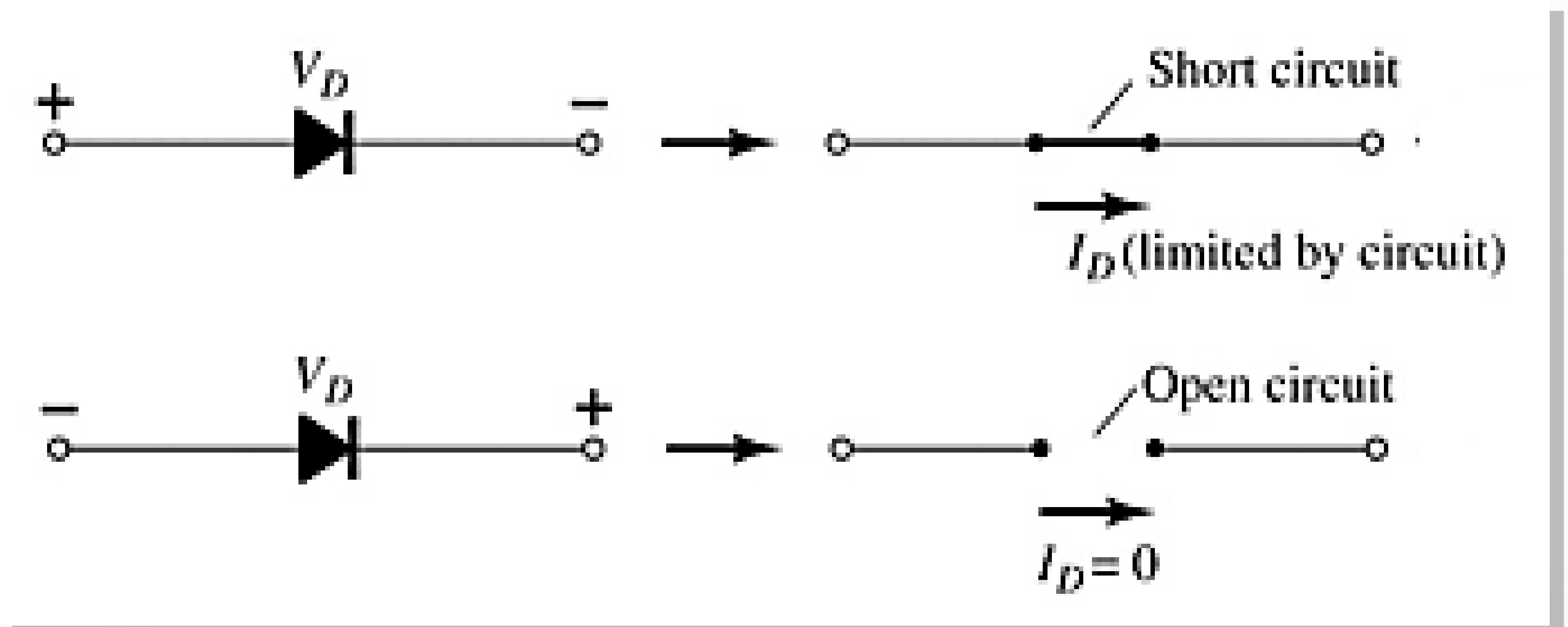
# Diodes

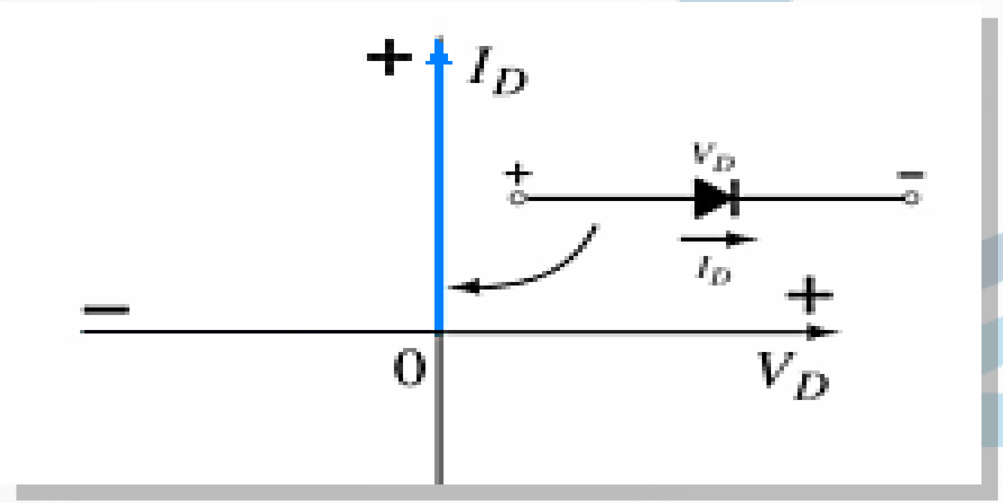



The diode is a 2-terminal device.

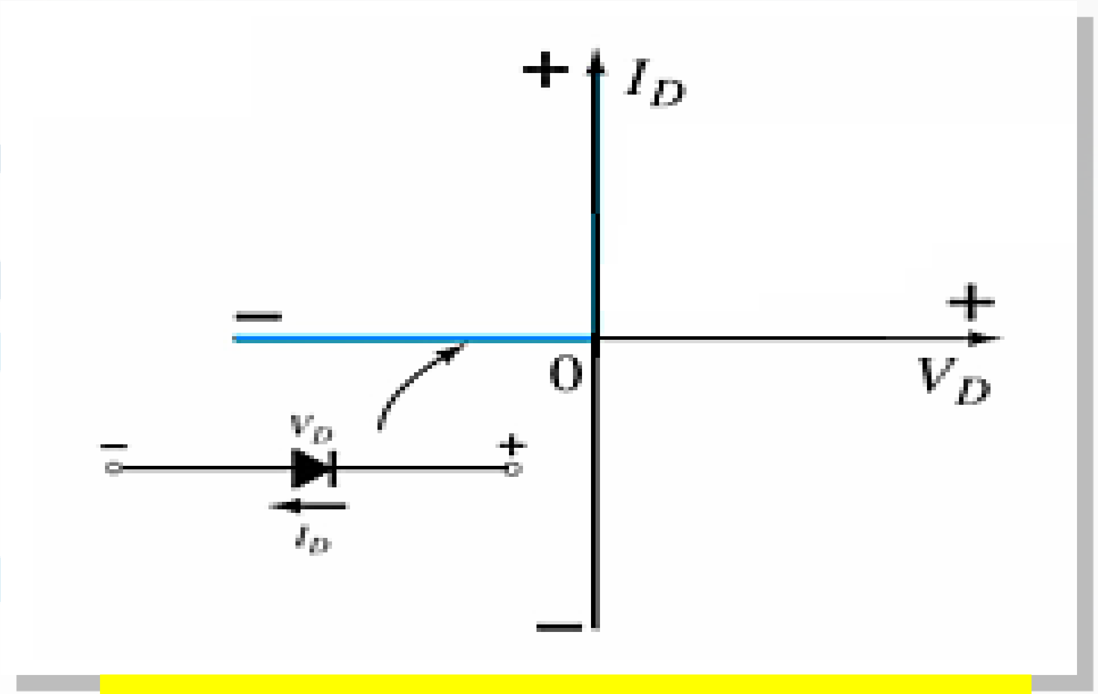



A diode ideally conducts in only one direction.

# Diode Characteristics




## Conduction Region




## Non-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

- 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

# Semiconductor Materials

**Materials commonly used in the development of semiconductor devices:**

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

# 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**

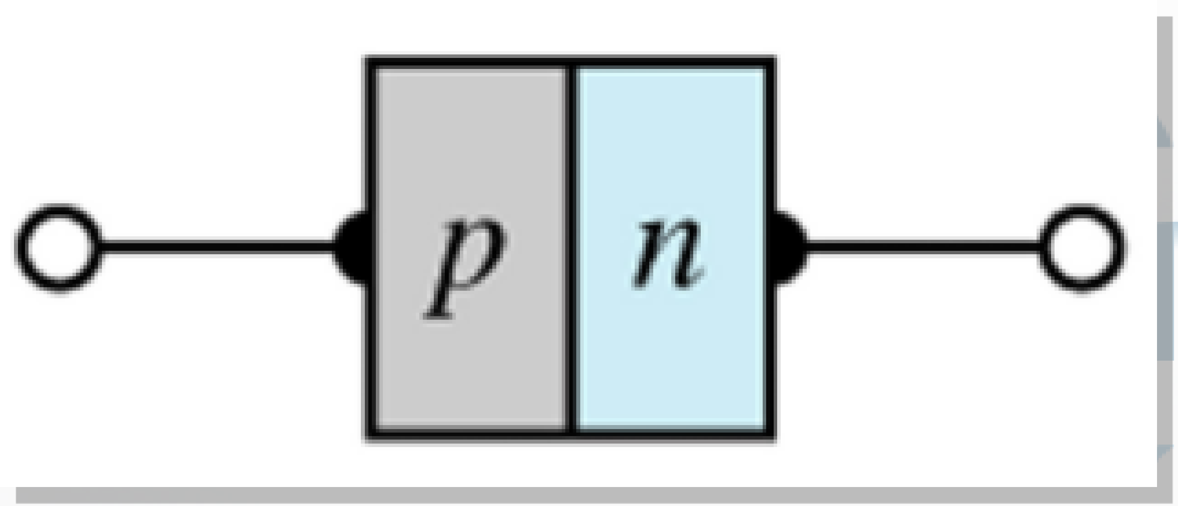
***p*-type**

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

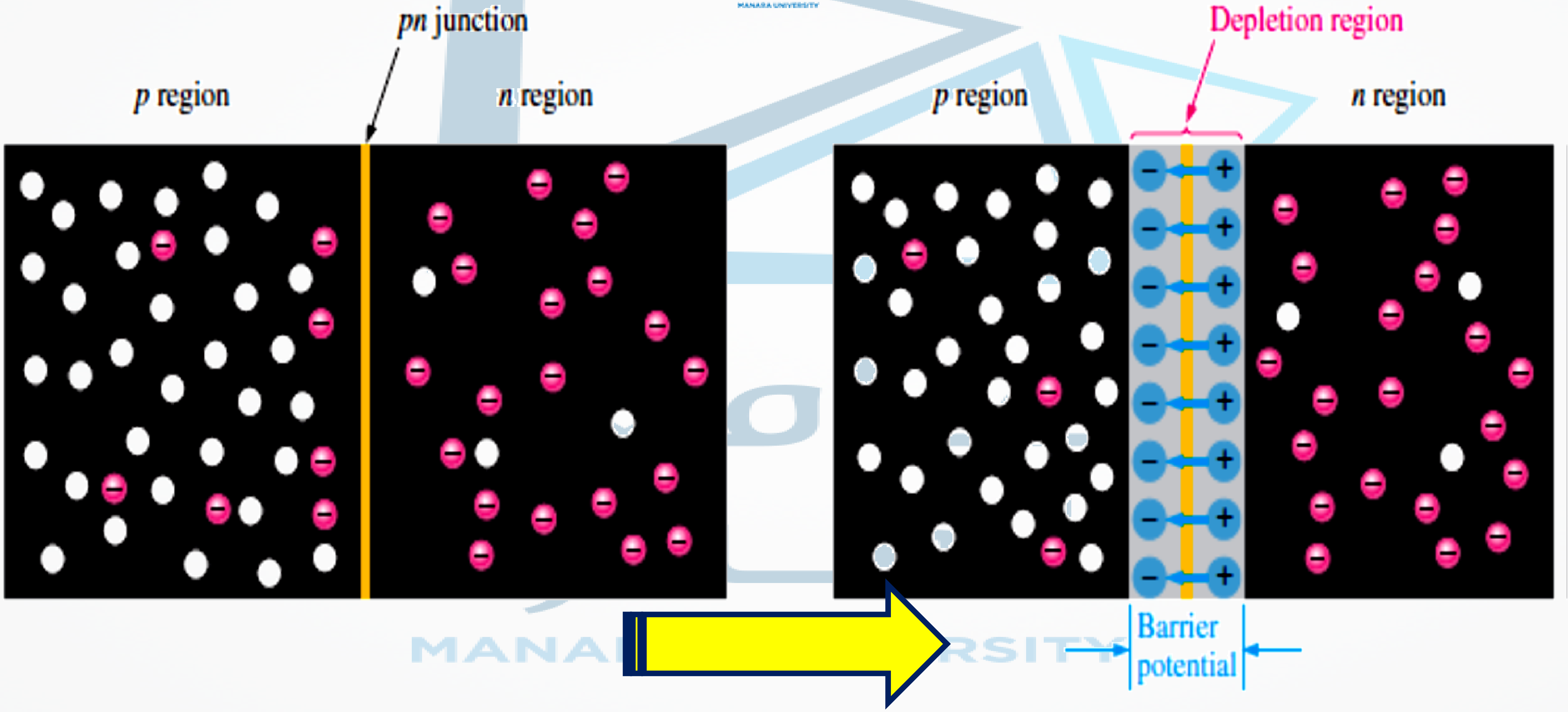
# p-n Junctions

**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.**



# Formation of the Depletion Region

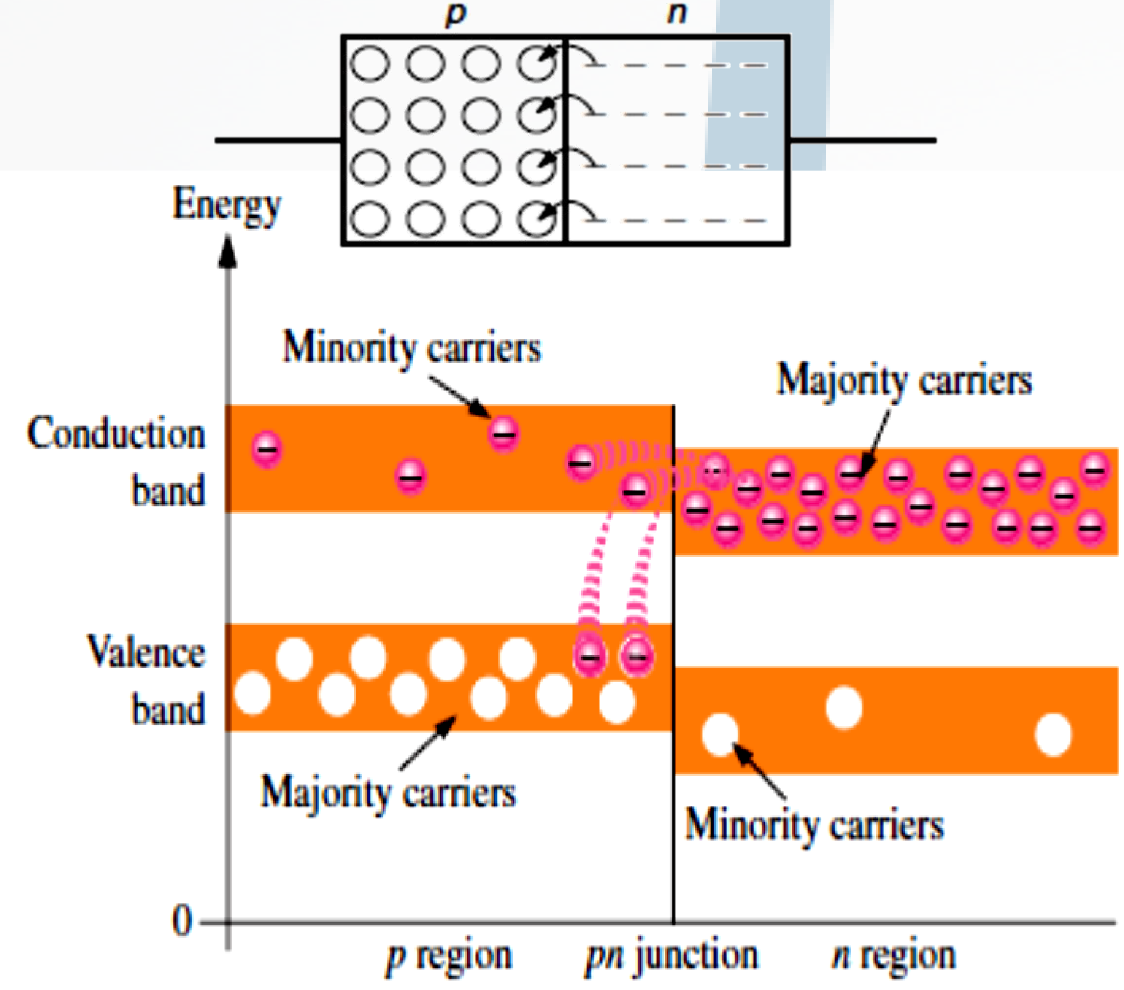


# Formation of the Depletion Region

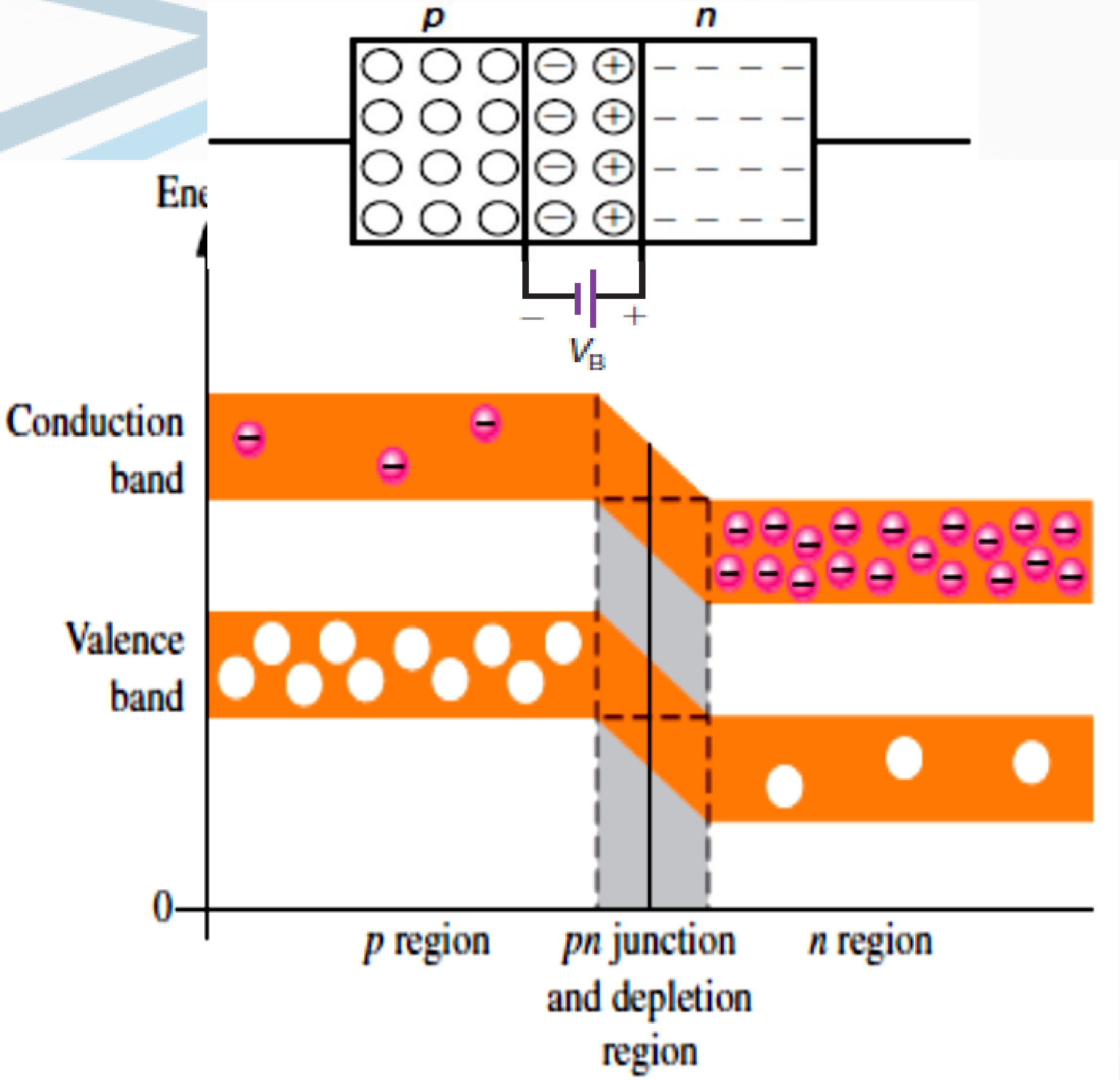
- The basic silicon structure at the instant of junction formation showing only the majority and minority carriers. Free electrons in the n region near the pn junction begin to diffuse across the junction and fall into holes near the junction in the p region.

- For every electron that diffuses across the junction and combines with a hole, a positive charge is left in the n region and a negative charge is created in the p region, forming a barrier potential. This action continues until the voltage of the barrier repels further diffusion. The blue arrows between the positive and negative charges in the depletion region represent the electric field.

# Energy Diagrams of the PN Junction and Depletion Region



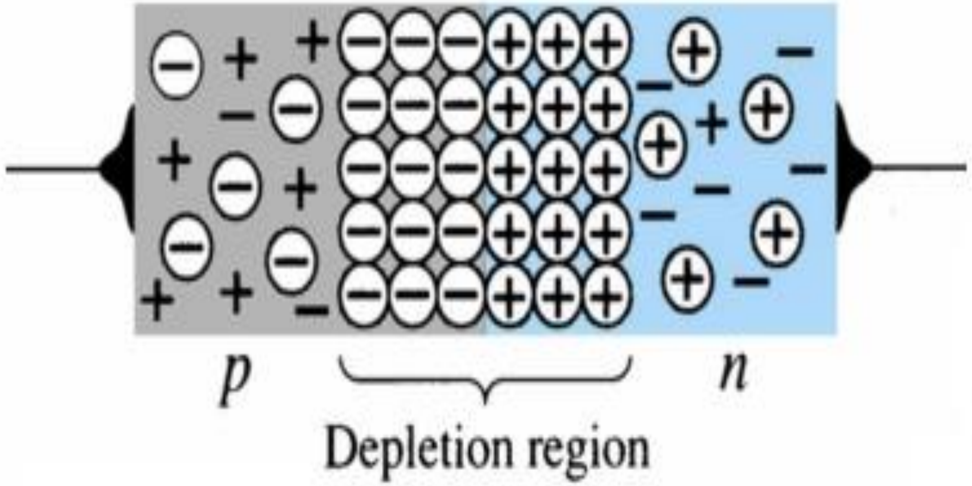

(a) At the instant of junction formation




(b) At equilibrium

# 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.**

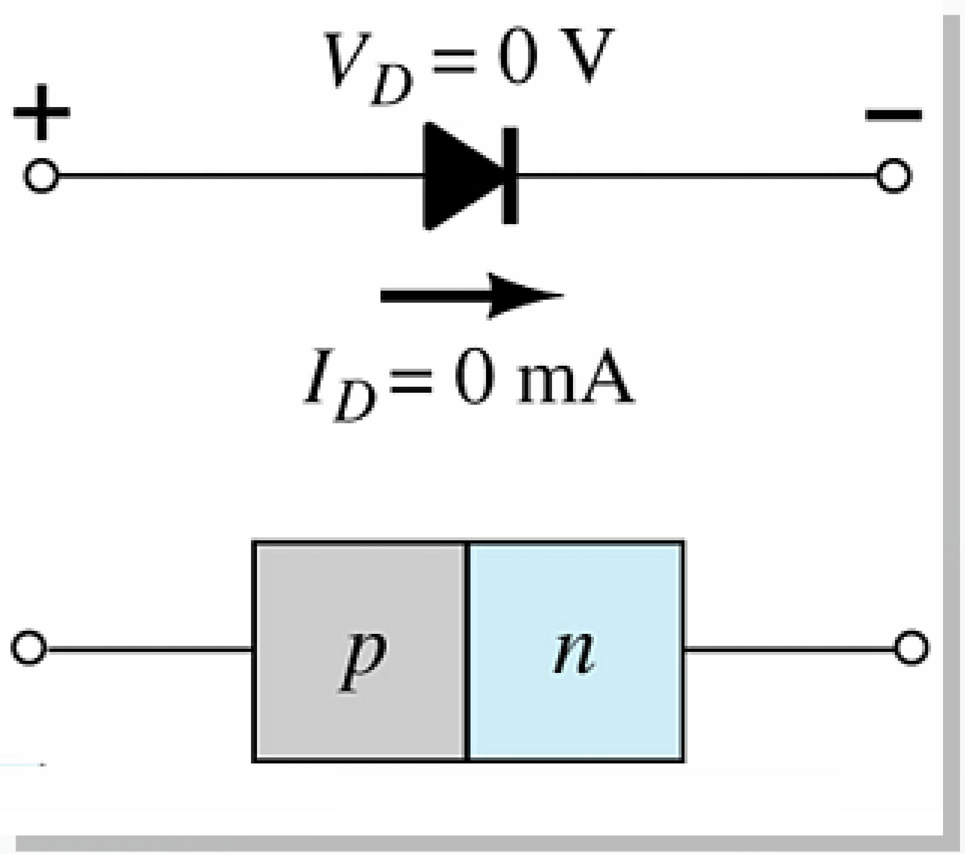
# Diode Operating Conditions

A diode has three operating conditions:

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

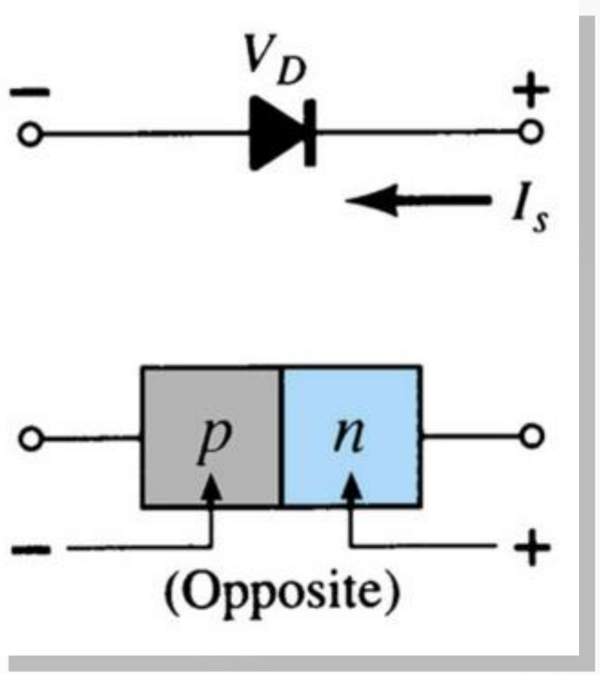
- **No Bias**

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

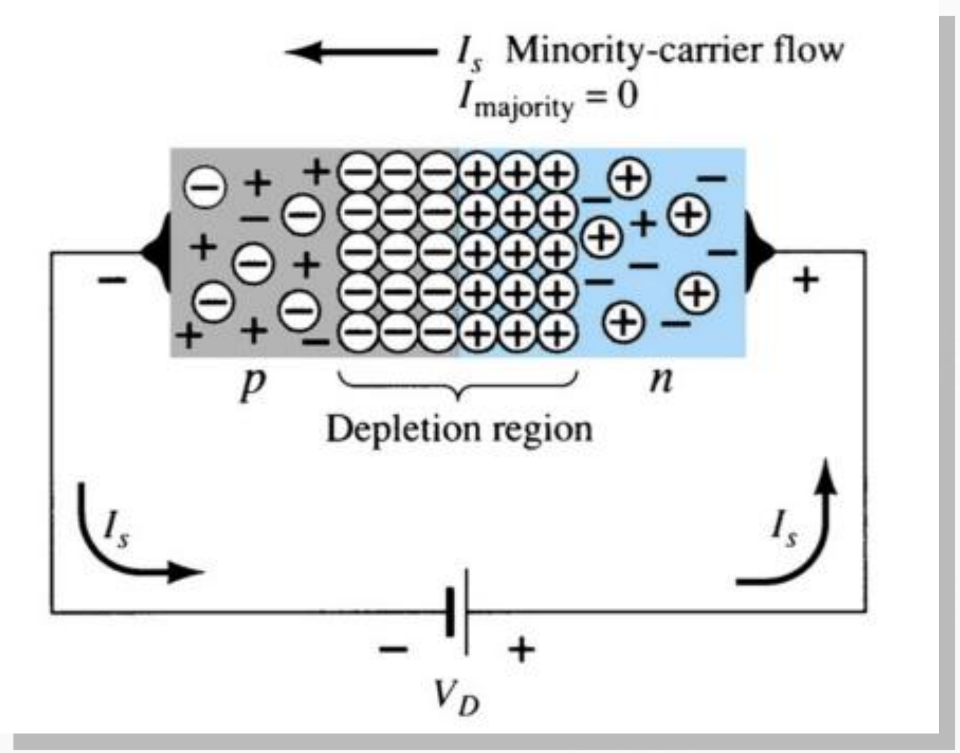


## • Reverse Bias

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

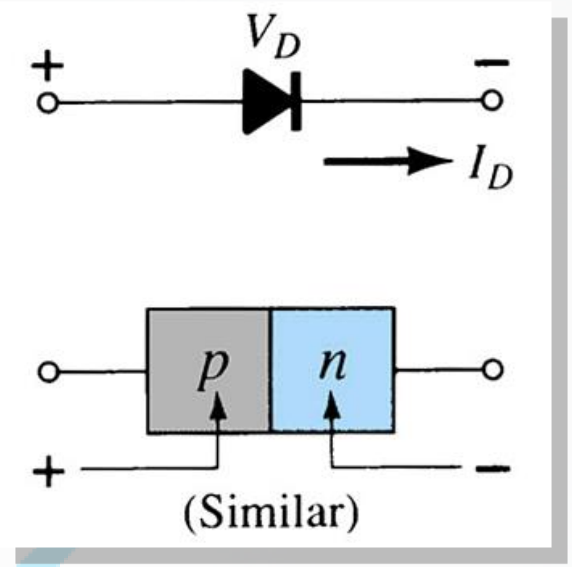



- The reverse voltage causes the depletion region to widen.
- The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.
- The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.

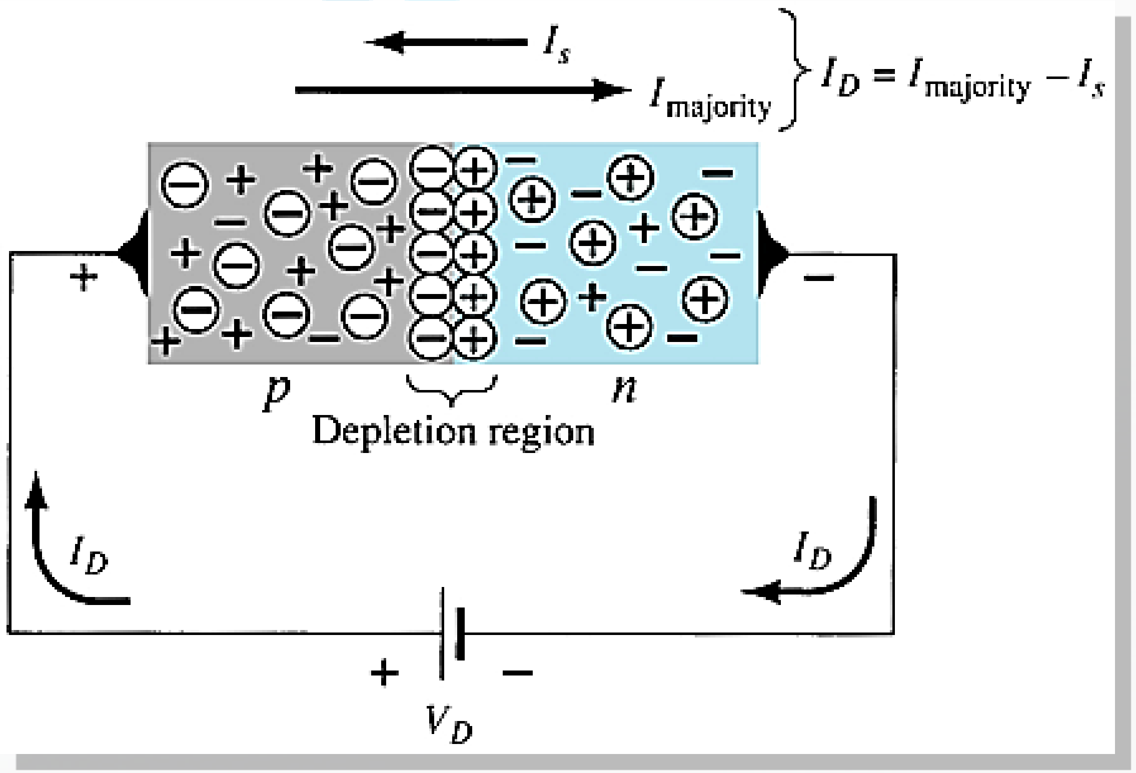


## • Forward Bias

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



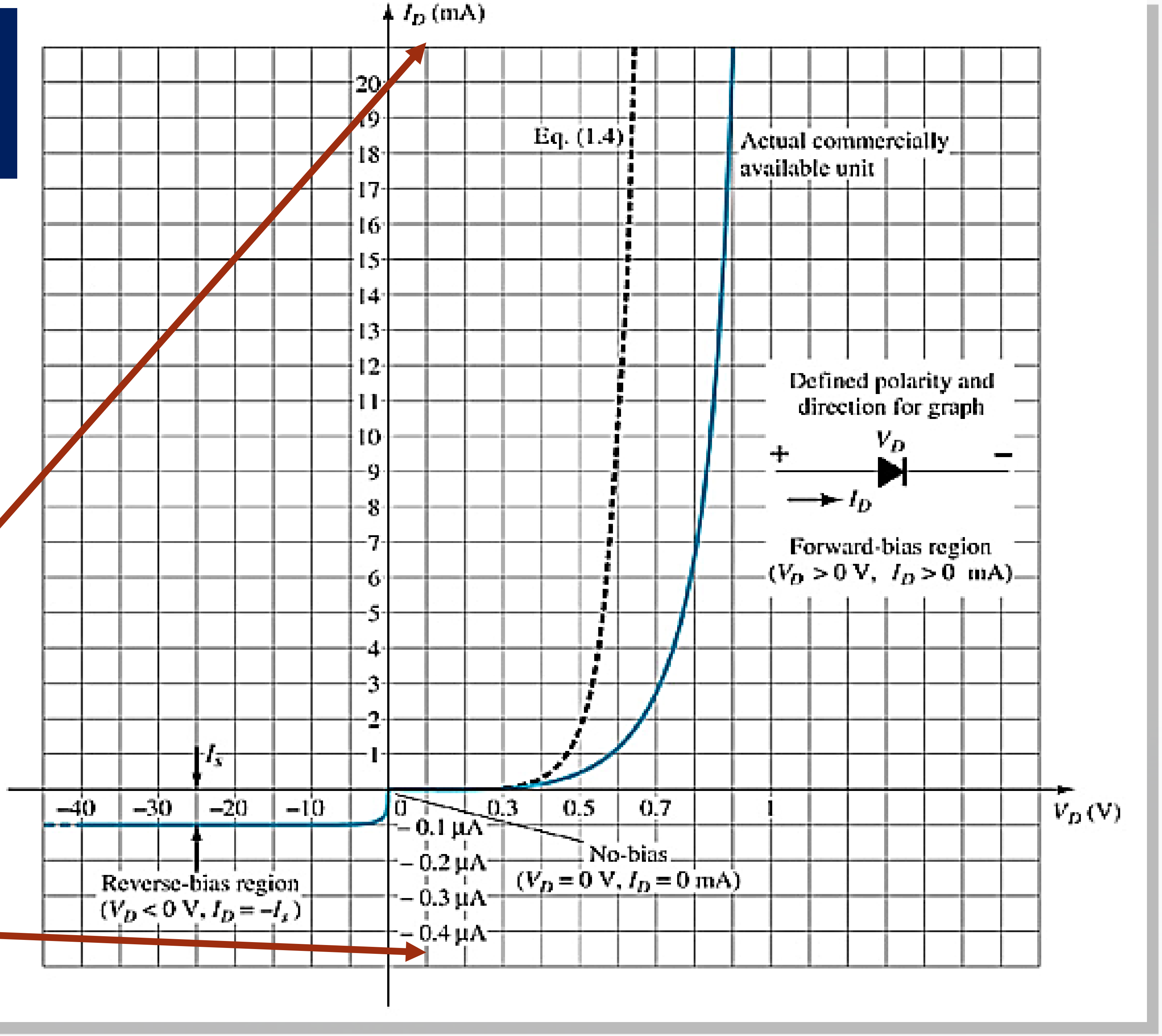

- **The forward voltage causes the depletion region to narrow.**
- **The electrons and holes are pushed toward the *p-n* junction.**
- **The electrons and holes have sufficient energy to cross the *p-n* junction.**



# 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

# حوامل الشحنات الاكثرية والاقلية

**Two currents through a diode:**

## Majority Carriers

## حوامل الشحنات الاكثرية

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

## Minority Carriers

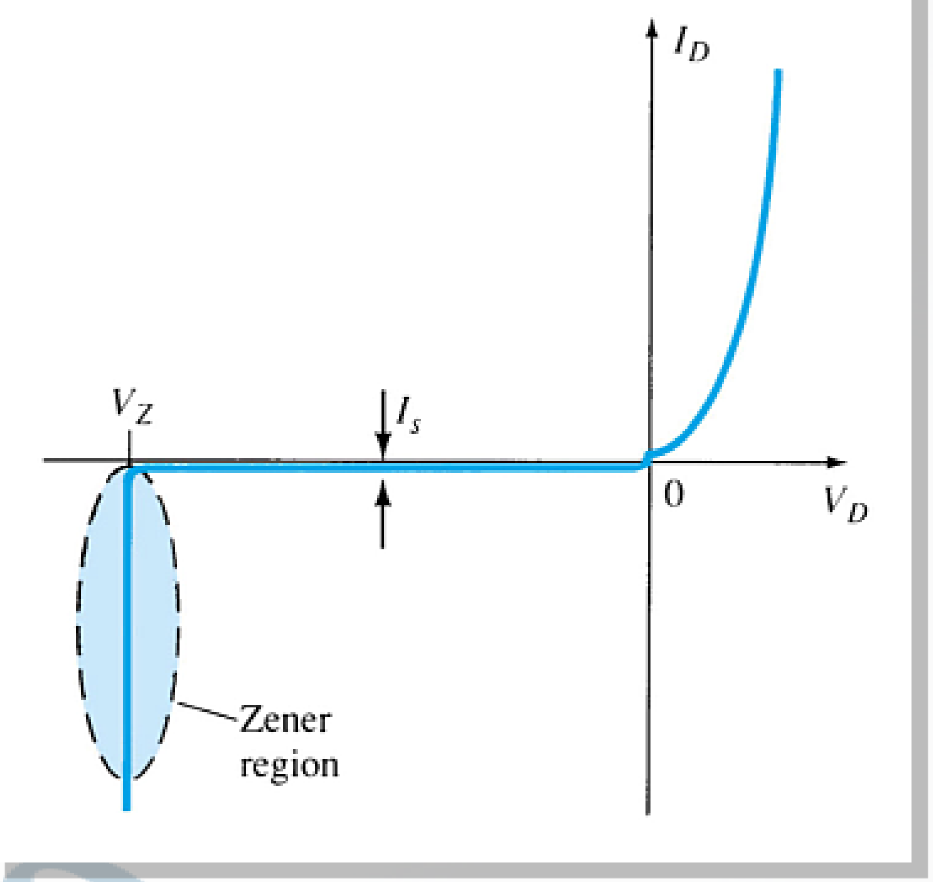
## حوامل الشحنات الاقلية

- **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.