Lecture 2 Diode and Diode Application

Present by : Thawatchai Thongleam
Faculty of Science and Technology
Nakhon Pathom Rajabhat University

Diode and Diode Application

- Outline
  - 2.1 Basic Semiconductor
  - 2.2 Terminal Characteristics of Junction Diodes
  - 2.3 Analysis of Diode Circuit
  - 2.4 Clipper Diode
  - 2.5 Zener Diode

2.1 Basic Semiconductors

Diode

Symbol

Structure

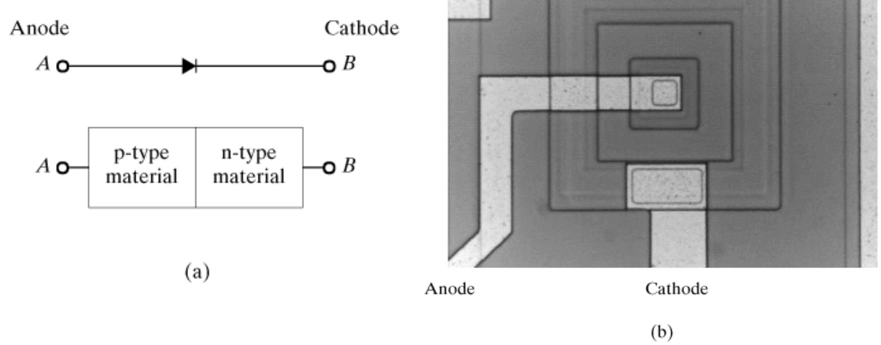


Fig. 2.1 Symbol and structure of diode.

Diode Device

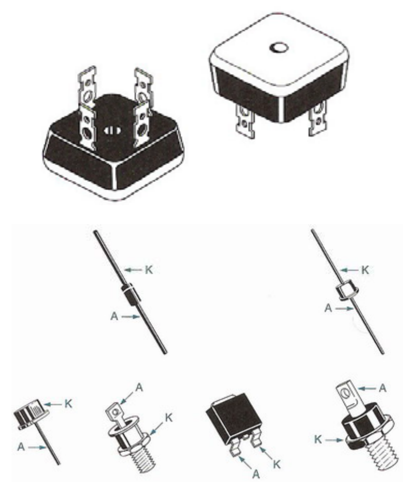


Fig. 2.2 Diode device.

Junction Physical Structure on PN

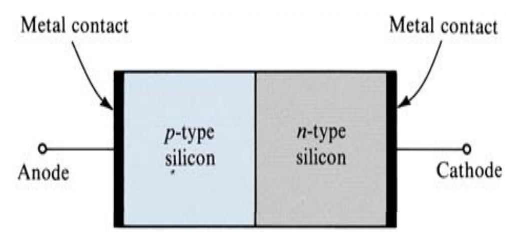
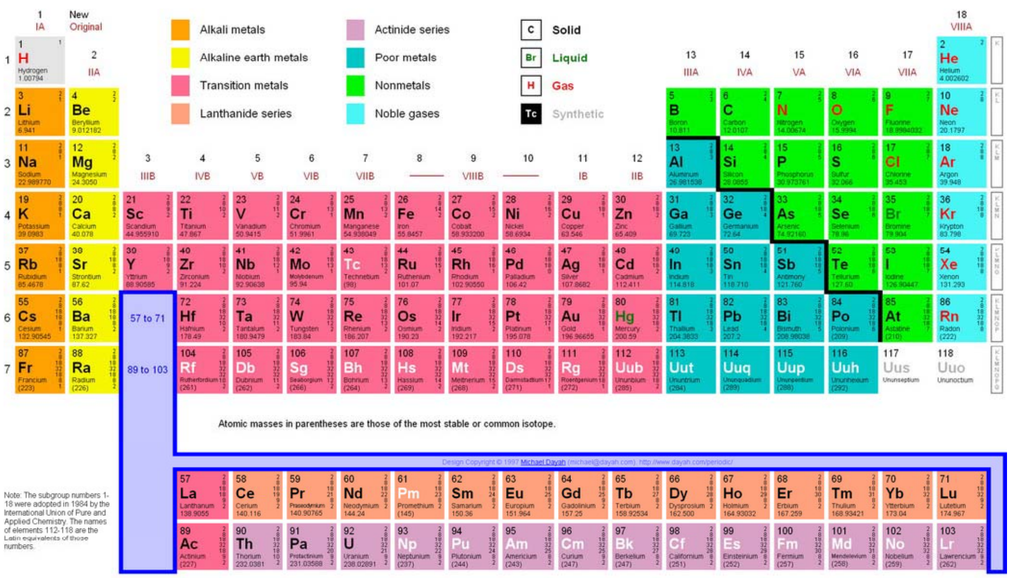


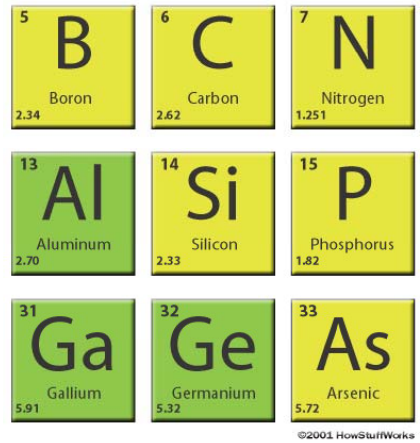
Fig. 2.3 Simplified physical structure of the junction diode. (Actual geometries are given on Appendix A.)

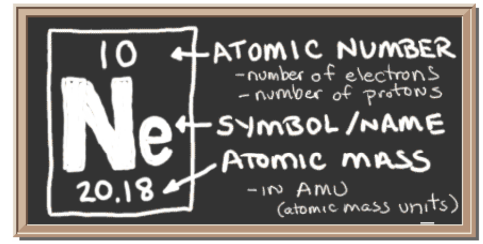
- We can simplify Diode physics by modeling it as a 2D PN junction

Periodic Table of the Elements

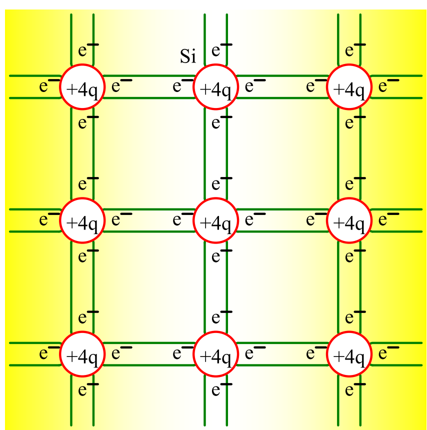


Valence Electron



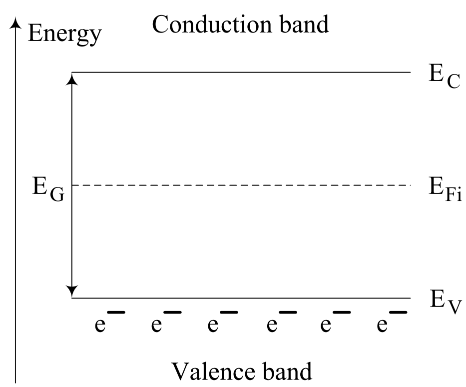


Intrinsic Semiconductor

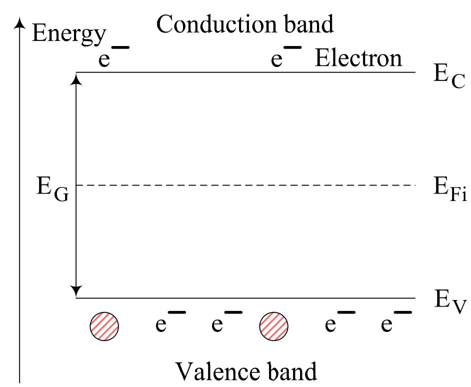


- มีคุณสมบัติเป็นกลาง (เป็นฉนวน)
- ถ้ามีพลังงานจากภายนอกที่มีขนาดเพียงพอมากระทำจะทำให้อิเล็กตรอนหลุดออก

Energy Band Model

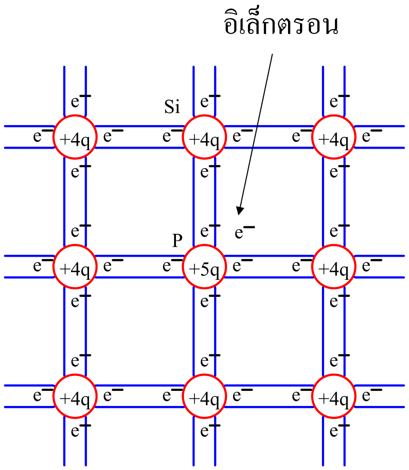


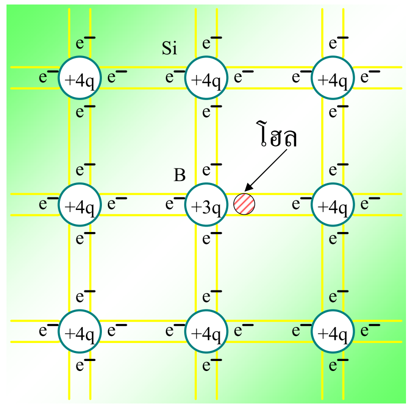
Energy band model for semiconductor



Creation of electron-hole pair by thermal excitation across the energy bandgap

Extrinsic semiconductor

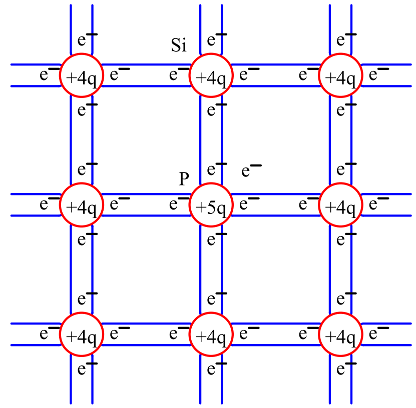




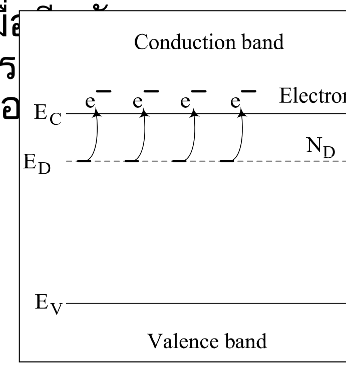
พันธะโควาเลนซ์

(N-Type) Semiconductor (P-Type) Semiconductor

(N-Type) Semiconductor

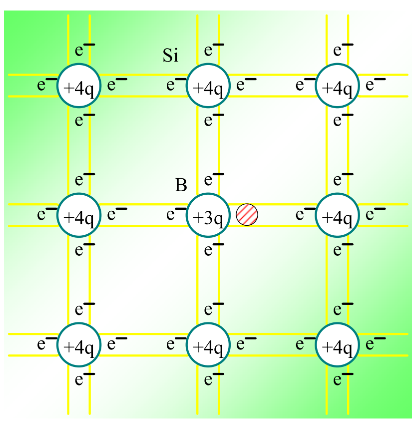


- มีการเจือด้วยสาร Phosphorus มีเลขอะตอม 15 และมีอิเล็กตรอนวงนอกสุด 5
- มีคุณสมบัติเป็นผู้ให้อิเล็กตรอน (Donor)
- เมื่อ ... กร ... รอนวง นอ ...

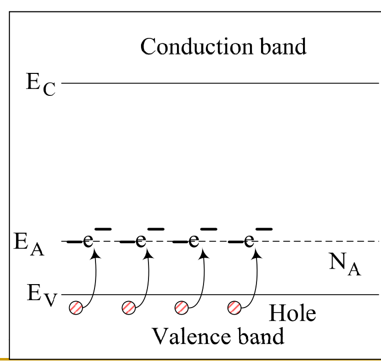


Donor level with activation energy (E_C-E_D)

(P-Type) Semiconductor

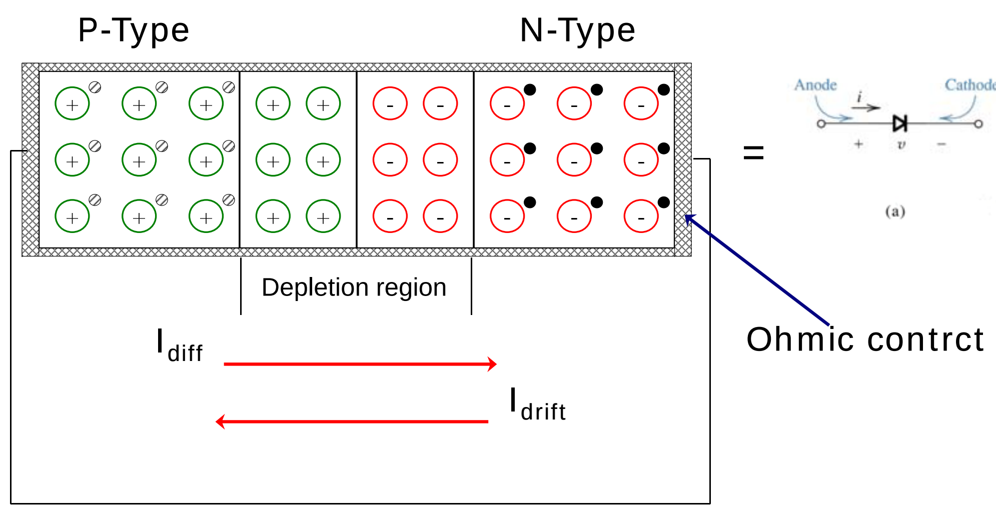


- มีการเจือด้วยสาร Boron มีเลขอะตอม 5 และมีอิเล็กตรอนวงนอกสุด 3
- มีคุณสมบัติเป็นผู้รับอิเล็กตรอน (Acceptor)
- เมื่อมีพลังงานภายนอกมากระทำ จะทำให้อิเล็กตรอนหลุดออก ไปยังที่ว่าง



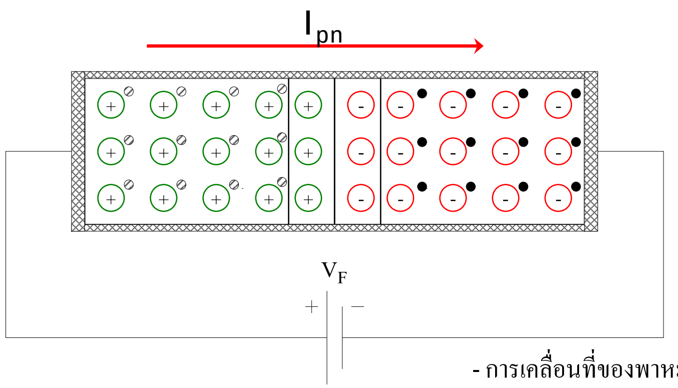
Acceptor level with activation energy (E_A-E_V)

Diode semiconductor



- I_{diff} ($I_{diffusion}$) คือกระแสแพร่ที่ไหลจาก p ไป n
- I_{drift} (I_{drift}) คือกระแสเลื่อนที่ไหลจาก n ไป p

Forward bias



$$I_{pn} = I_{diff} - I_{drift} \cong I_{driff}$$

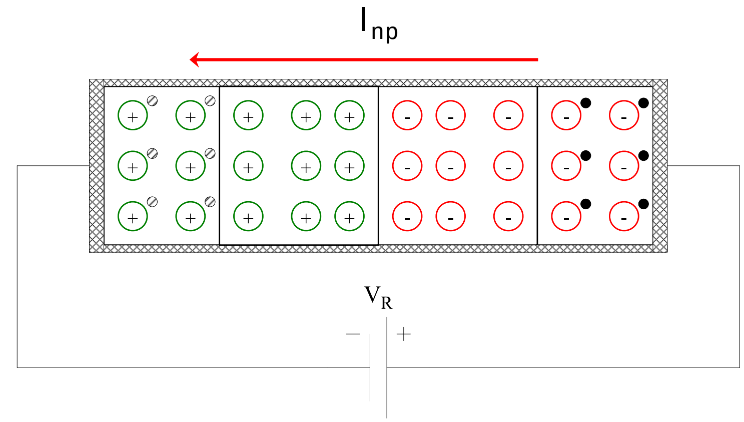
- การเคลื่อนที่ของพาหะ 2 ชนิด ทำให้ความกว้างของเขตปลอดพาหะลดลง

- แรงดันที่ตกคร่อมบริเวณเขตปลอดพาหะลดลง

- มีการแพร่ของอิเล็กตรอนและโฮลข้ามรอยต่อมากขึ้น

- กระแส I_{driff} ไหลมากขึ้น

Reverse bias



$$I_{np} = I_{drift} - I_{diff} \cong I_S$$

Diode Characterization

- ความสัมพันธ์ระหว่างแรงดันและกระแสของไดโอดได้ดังนี้

Forward Bias

$$i = I_s\left(e^{v/nV_T} - 1\right)$$

Reverse Bias

$$i \cong -I_s$$

$$i = I_s\left(e^{v/nV_T} - 1\right)$$

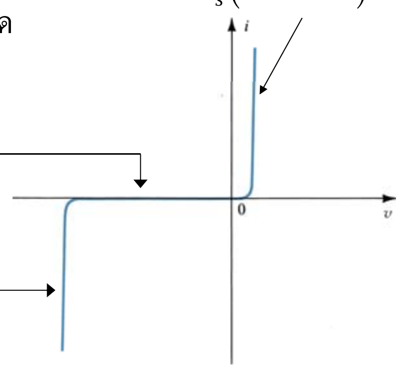


Fig. 2.4 The *i-v* characteristic of a silicon junction diode.

- เมื่อ I_s คือกระแสไหลย้อนกลับ~ 10^{-14}-10^{-15} A

  V_Tคือแรงดันอุณหภูมิ (Thermal Voltage) =25 – 26 mV

Diode Regions

- Thermal Voltage

$$V_T = kT/q$$

- T คืออุณหภูมิสัมบูรณ์ °K

  K คือค่าคงที่ของโบลต์แมนน์

  (Boltzmann's constant)

  = 1.38x10^{-23}

  q คือค่าประจุไฟฟ้าของอิเล็กตรอน

  = 1.6 x 10^{-19}

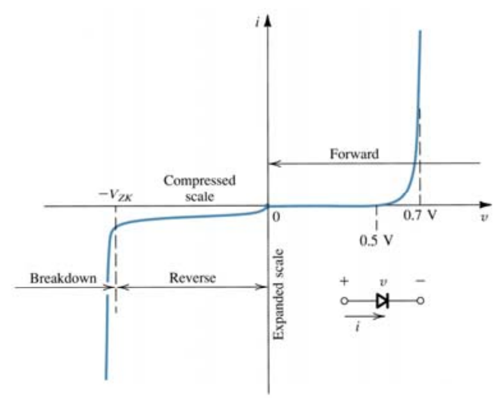


Fig. The diode *i-v* relationship with some scales expanded and others compressed in order to reveal details.

- Diodes have a 0.7V drop (thresholds voltage) in the forward direction

2.3 Analysis Diode Circuit

The Ideal Diode

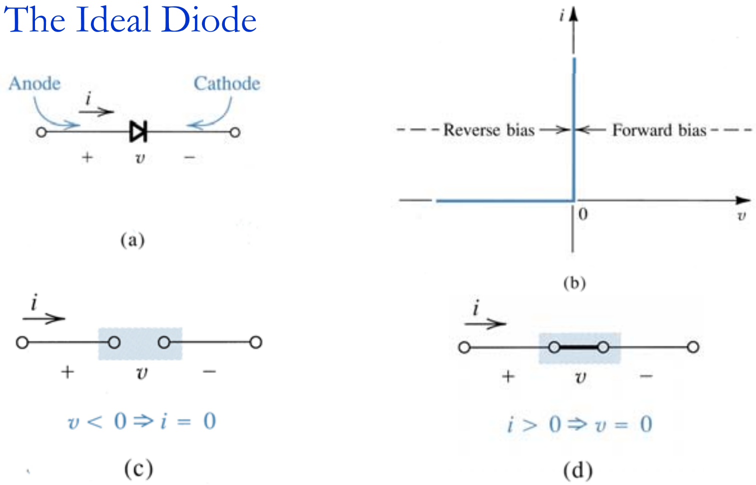
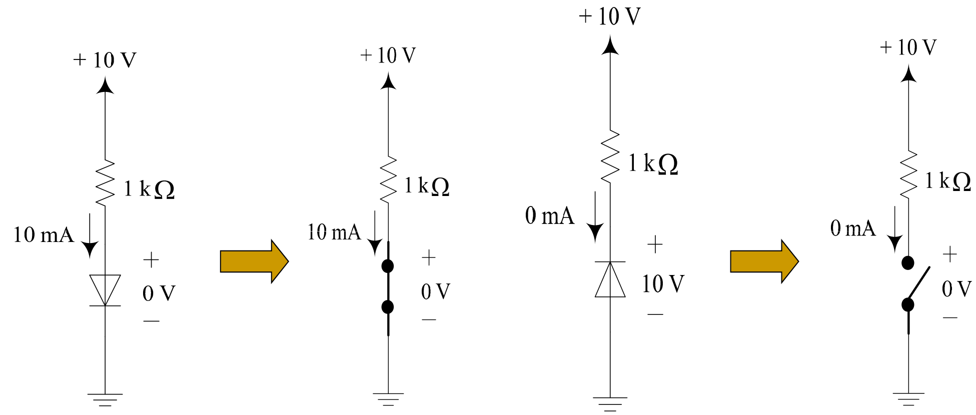


Fig. The ideal diode: **(a)** diode circuit symbol; **(b)** *i-v* characteristic; **(c)** equivalent circuit in the reverse direction; **(d)** equivalent circuit in the forward direction.

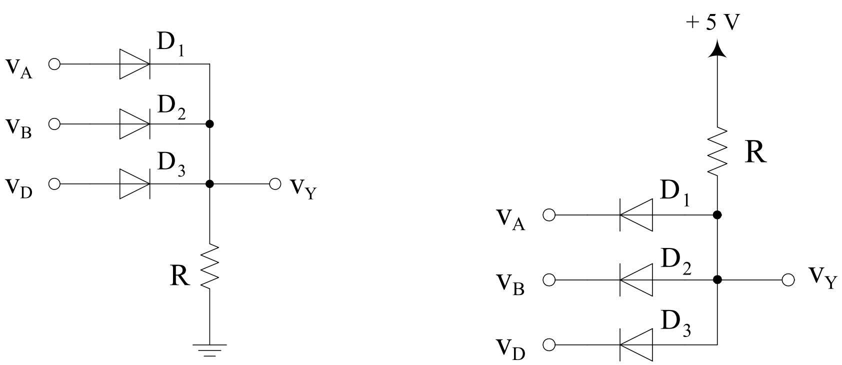
Diode Circuits



Forward bias

Reverse bias

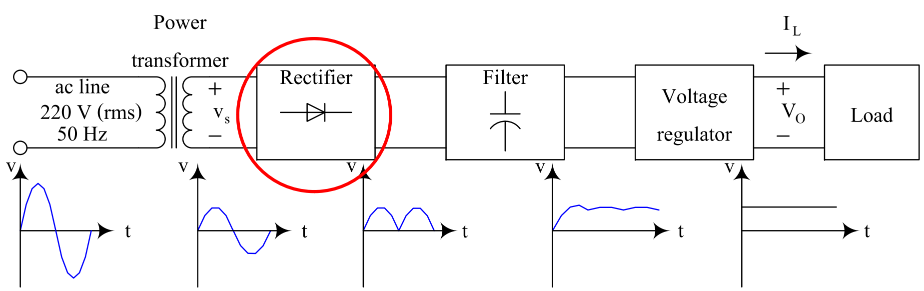
Diode Logic Gate



OR Gate

AND Gate

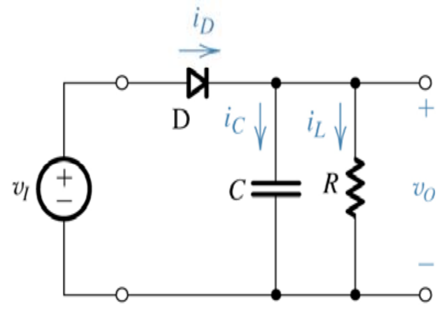
Rectifier



Practical Diode Circuit

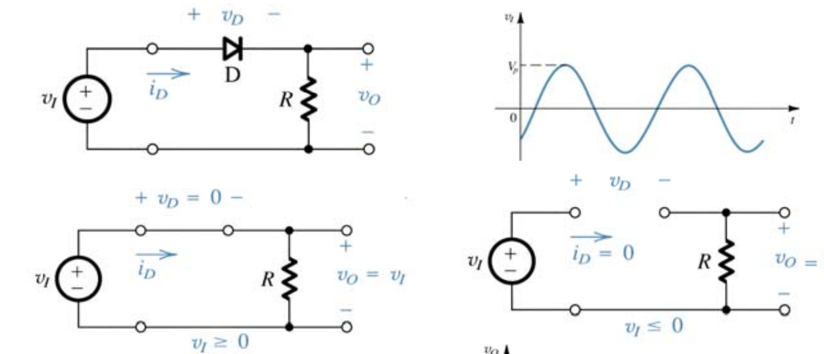
Diode charges capacitor.

The diode is assumed ideal. It will only conduct when v_I is more than v_o



(a)

Half-wave rectifier



During positive cycle, diode allow current to pass through and output voltage is positive

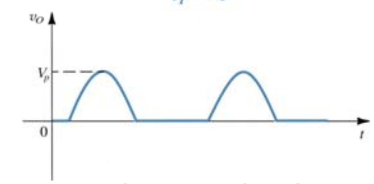
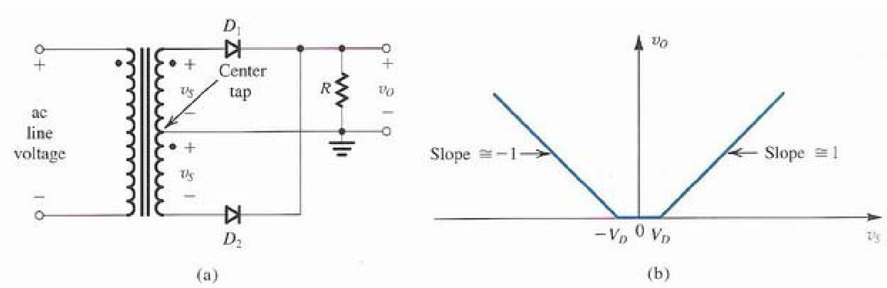
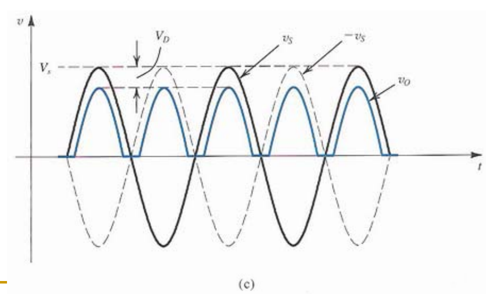


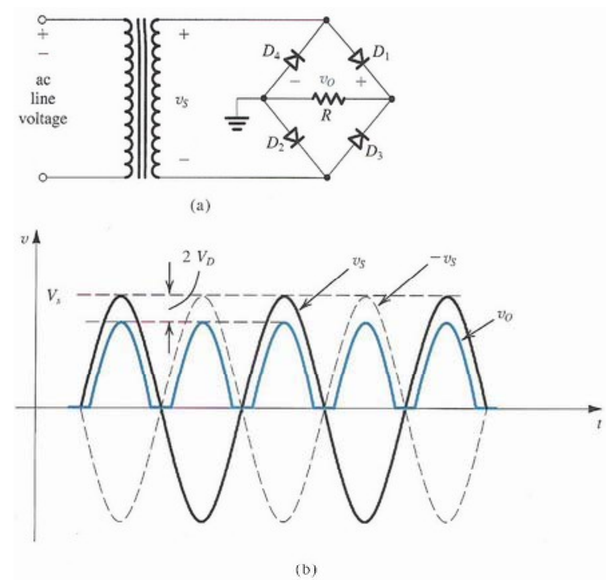
Fig. 2.3 **(a)** Rectifier circuit. **(b)** Input waveform. **(c)** Equivalent circuit when **(d)** Equivalent circuit when $v_I > 0$ **(e)** Output waveform.

Full-Wave Rectifier

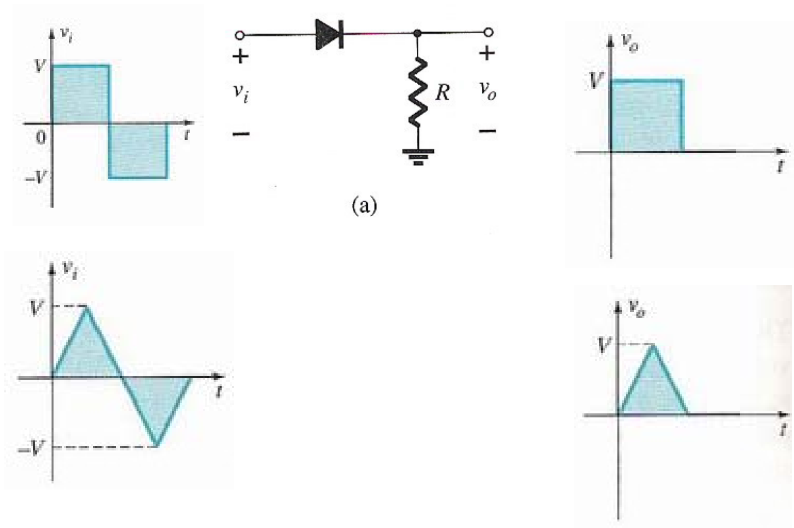




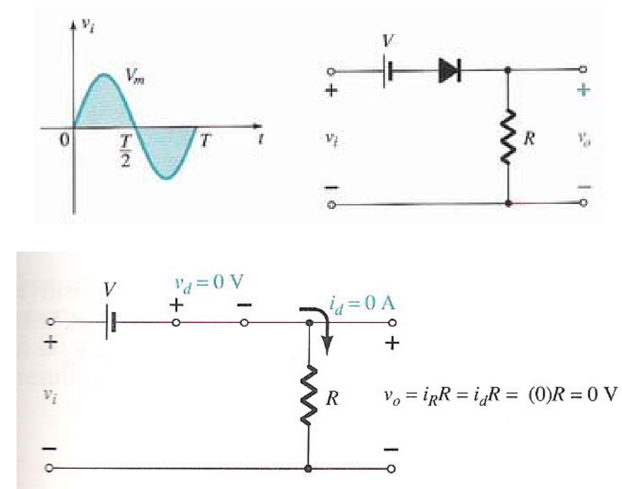
Full-Wave Rectifier



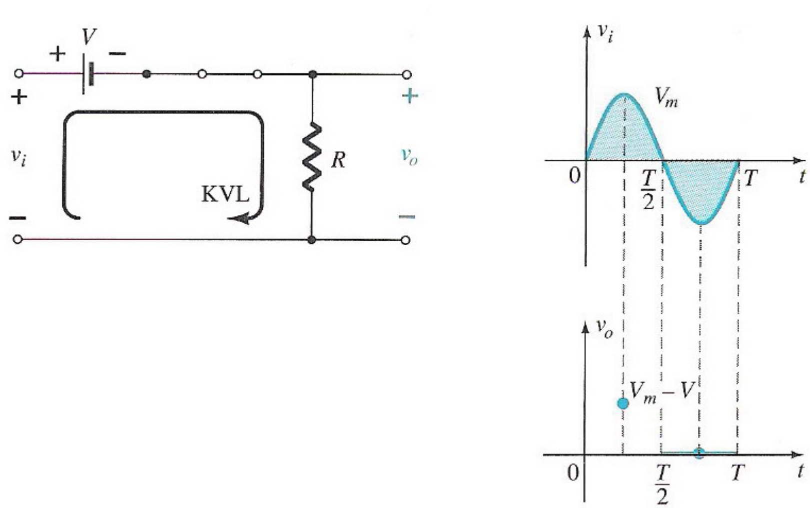
2.4 Clippers Diode



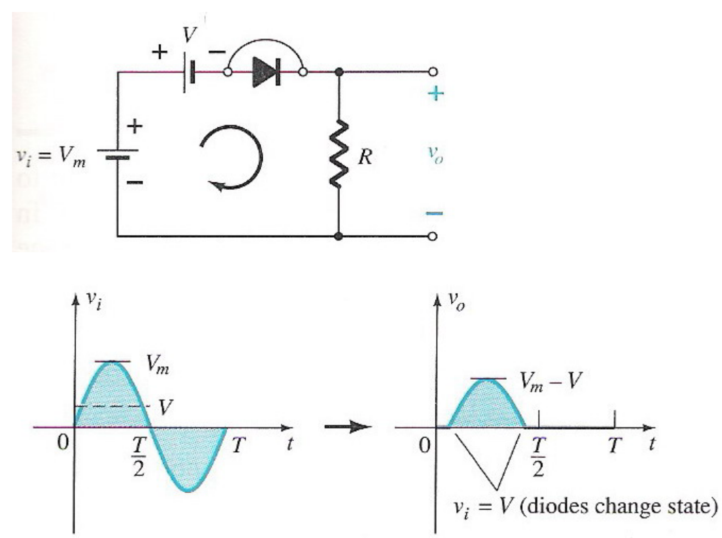
Clippers Diode (con)



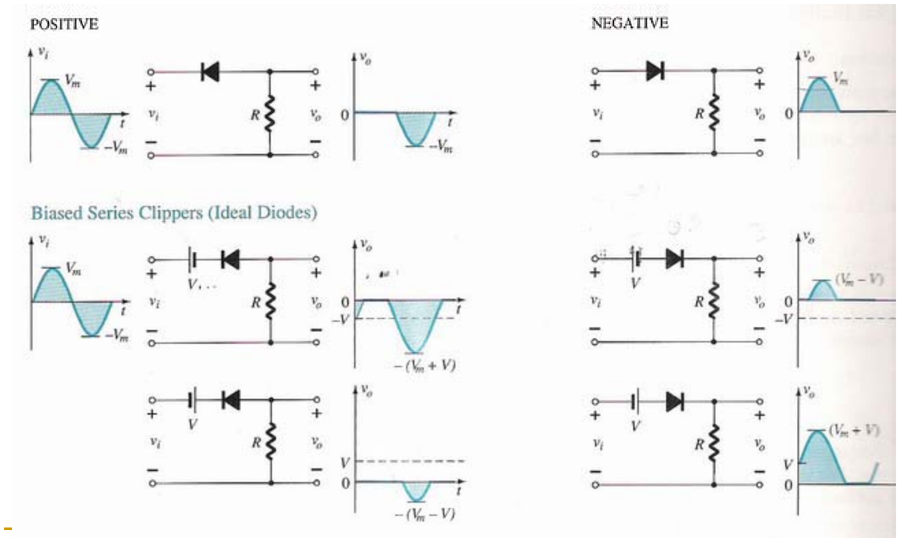
Clippers Diode (con)



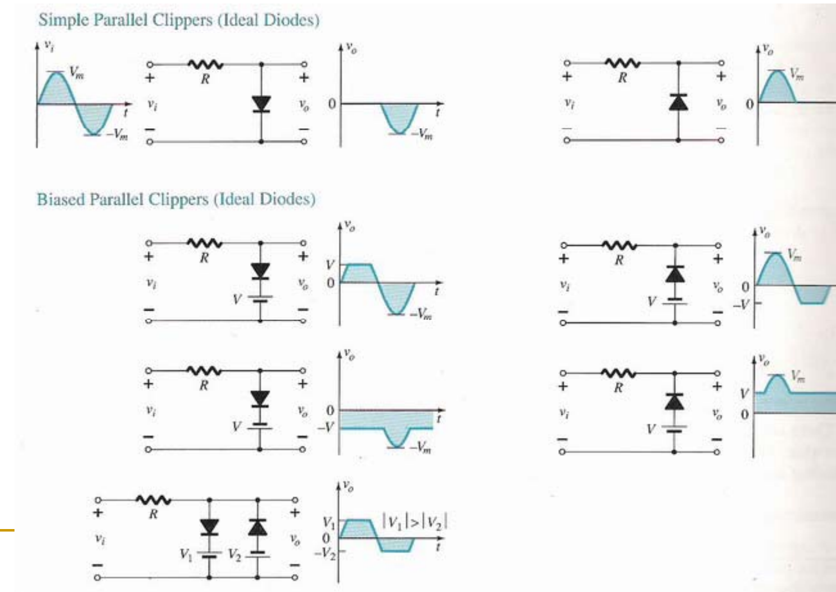
Clippers Diode (con)



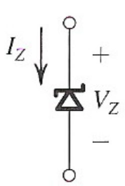
Clippers Diode (con)



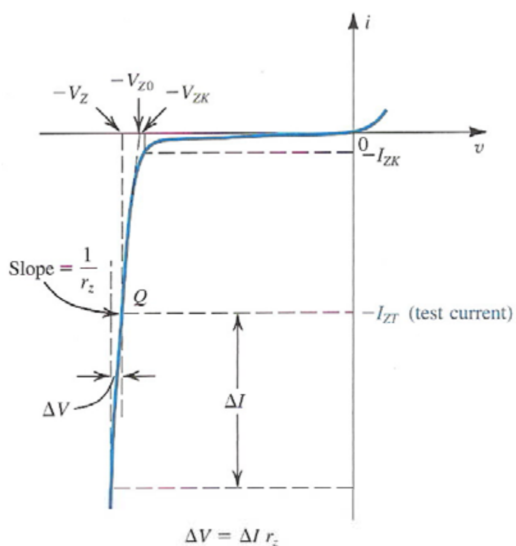
Clippers Diode (con)



2.5 Zener Diode

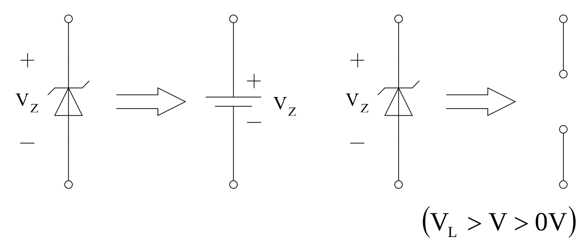


Symbol of Zener Diode



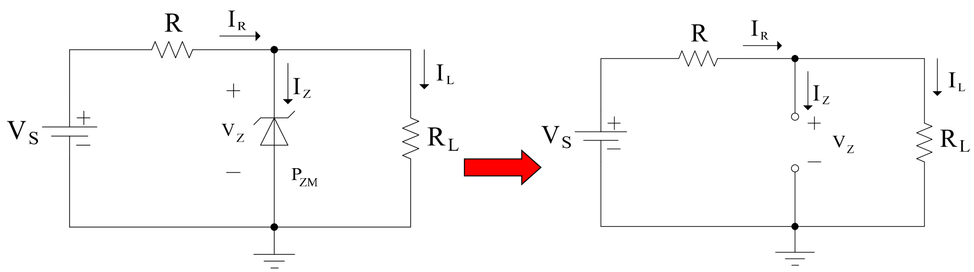
Characteristic of Zener Diode

Zener Diode



"on" "off"

Zener Diode



- If $V \geq V_z$ Zener Diode "on"
- If $V < V_z$ Zener Diode "off"

$$V = V_L = \frac{R_L V_S}{R + R_L}$$

Vs and R Fixed

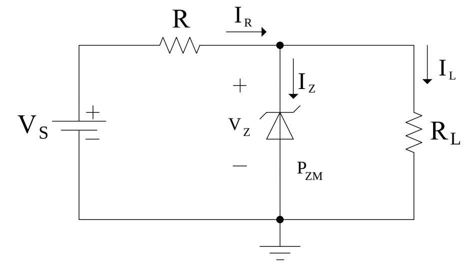


Fig Zener diode

$$V_L = V_Z$$

$$I_R = I_Z + I_L$$

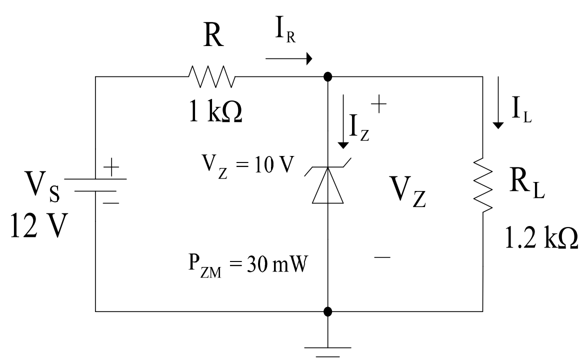
$$I_Z = I_R - I_L$$

$$I_L = \frac{V_L}{R_L}$$

$$I_R = \frac{V_R}{R} = \frac{V_S - V_Z}{R}$$

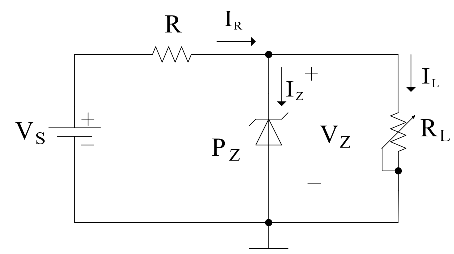
$$P_Z = V_Z I_Z$$

Ex1. Find V_L, V_R, I_Z and P_Z at figure



Zener Diode

Fixed V_S and Variable R_L



$$V = V_L = \frac{R_L V_S}{R + R_L}$$

$$R_{L_{min}} = \frac{R V_Z}{V_S - V_Z}$$

$$I_{L_{max}} = \frac{V_L}{R_L} = \frac{V_L}{R_{L_{min}}}$$

$$V_R = V_S - V_Z$$

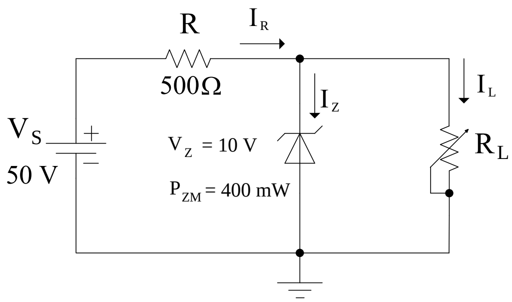
$$I_R = \frac{V_R}{R} = \frac{V_S - V_Z}{R}$$

$$I_Z = I_R - I_L$$

$$I_{L_{min}} = \frac{V_L}{R_L} = \frac{V_L}{R_{L_{max}}}$$

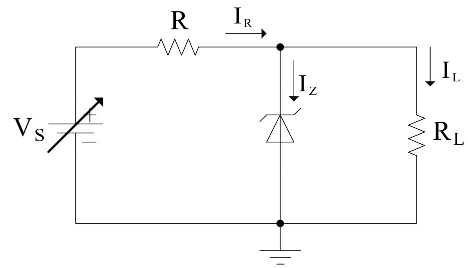
$$R_{L_{max}} = \frac{V_Z}{I_{L_{min}}}$$

Ex2. Find R_{Lmin} and R_{Lmax} at figure



Zener Diode

Fixed R_L and Variable V_S



$$V = V_L = \frac{R_L V_S}{R + R_L}$$

$$V_{S_{min}} = \frac{(R + R_L)V_Z}{R_L}$$

$$I_{ZM} = I_R - I_L$$

$$I_{R_{max}} = I_{ZM} + I_L$$

$$V_{S_{max}} = V_{R_{max}} + V_Z$$

$$V_{S_{max}} = I_{R_{max}} R + V_Z$$

Ex3. Find V_{Smin} and V_{Smax} at voltage regulation circuit