

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

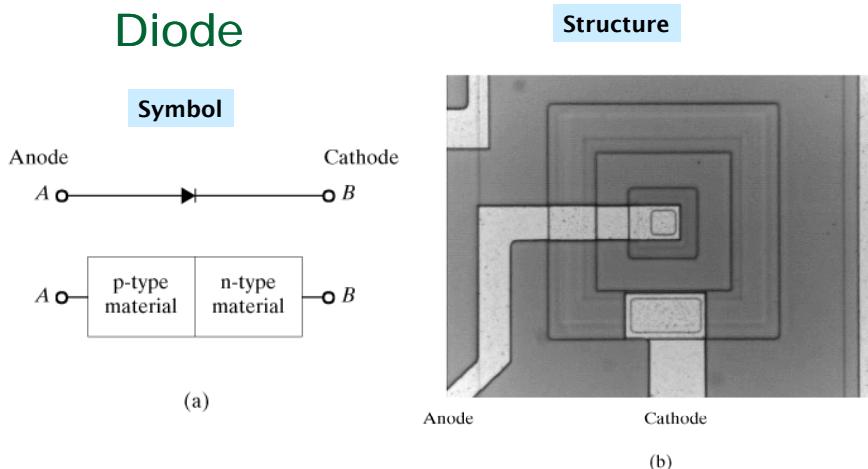


Fig. 2.1 Symbol and structure of diode.

Diode Device

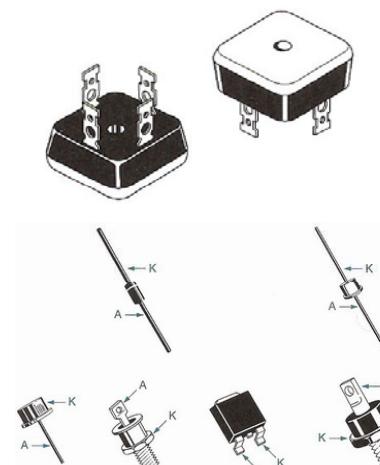


Fig. 2.2 Diode device.

Junction Physical Structure on PN

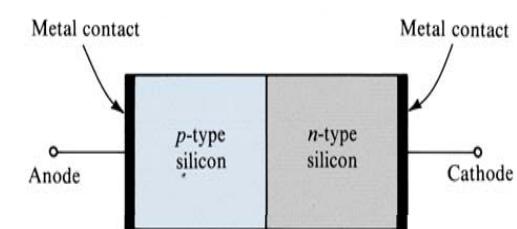


Fig. 2.3 Simplified physical structure of the junction diode. (Actual geometries are given on Appendix A.)

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

Periodic Table of the Elements

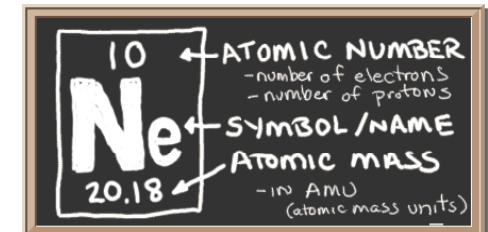
1 IA 1 H Hydrogen (1.00714)	2 IIA 2 Li Lithium (6.941)	3 IIIA 3 Na Sodium (22.98977)	4 IVB 4 Be Boron (8.01219)	5 VB 5 Mg Magnesium (24.306)	6 VIIB 6 Al Aluminum (26.98156)	7 VIIIB 7 Sc Scandium (44.95570)	8 IB 8 Ti Titanium (47.867)	9 IIB 9 V Vanadium (50.9415)	10 VIIIB 10 Cr Chromium (52.00205)	11 IB 11 Mn Manganese (54.93818)	12 IIIB 12 Fe Iron (55.847)	13 IIIA 13 Co Cobalt (58.93200)	14 IVA 14 Ni Nickel (58.697)	15 VA 15 Cu Copper (63.546)	16 VIA 16 Zn Zinc (65.402)	17 VIIA 17 Ga Gallium (69.720)	18 VIII 18 Ge Germanium (70.901)														
19 IA 19 K Potassium (39.0983)	20 IIA 20 Ca Calcium (40.078)	21 IIIA 21 Sc Scandium (44.95570)	22 IVB 22 Ti Titanium (47.867)	23 VB 23 V Vanadium (50.9415)	24 VIIB 24 Cr Chromium (52.00205)	25 IB 25 Mn Manganese (54.93818)	26 IIIB 26 Fe Iron (55.847)	27 IVA 27 Co Cobalt (58.93200)	28 VA 28 Ni Nickel (58.697)	29 VIIB 29 Cu Copper (63.546)	30 IIA 30 Zn Zinc (65.402)	31 IIIA 31 Ga Gallium (69.720)	32 IVA 32 Ge Germanium (70.901)	33 VA 33 As Arsenic (75.00)	34 VIA 34 Se Selenium (78.97)	35 VIIA 35 Br Bromine (79.904)	36 VIIA 36 Kr Krypton (83.798)														
37 IA 37 Rb Rubidium (85.467)	38 IIA 38 Sr Strontium (87.62)	39 IB 39 Y Yttrium (88.907)	40 IIIB 40 Zr Zirconium (81.224)	41 IVB 41 Nb Niobium (95.906)	42 VIIB 42 Tc Technetium (98.905)	43 IB 43 Ru Ruthenium (101.07)	44 IIIB 44 Rh Rhodium (101.07)	45 VIIB 45 Pd Palladium (106.42)	46 IB 46 Ag Silver (107.866)	47 IIIB 47 Cd Cadmium (112.411)	48 VIIB 48 In Indium (113.818)	49 IA 49 Hf Hafnium (178.49)	50 IVB 50 Ta Tantalum (180.919)	51 IB 51 W Tungsten (183.84)	52 IIIB 52 Re Rhenium (192.207)	53 VIIB 53 Os Osmium (192.203)	54 IA 54 Sb Antimony (191.769)	55 VIIA 55 Te Tellurium (192.411)	56 VIIA 56 Xe Xenon (131.293)												
57 to 71																															
72 IA 72 Cs Cesium (132.9045)	73 IIA 73 Ba Barium (137.327)	74 IB 74 Ta Tantalum (180.919)	75 IIIB 75 W Tungsten (183.84)	76 IA 76 Os Osmium (192.207)	77 IB 77 Ir Iridium (192.203)	78 IIIB 78 Pt Platinum (191.07)	79 IA 79 Au Gold (196.678)	80 IA 80 Hg Mercury (200.59)	81 IA 81 Tl Thallium (204.9645)	82 IA 82 Pb Lead (207.2)	83 IA 83 Bi Bismuth (208.00)	84 IA 84 Po Polonium (209.00)	85 IA 85 At Astatine (212.00)	86 IA 86 Rn Radon (222.00)	87 IA 87 Fr Francium (223.00)	88 IA 88 Ra Radium (226.00)	89 IA 89 Ac Actinium (227.00)	90 IA 90 Th Thorium (232.0381)	91 IA 91 Pa Protactinium (231.03568)	92 IA 92 U Uranium (231.02891)	93 IA 93 Np Neptunium (237.00)	94 IA 94 Pu Plutonium (244.00)	95 IA 95 Am Americium (243.00)	96 IA 96 Cm Curium (247.00)	97 IA 97 Bk Berkelium (247.00)	98 IA 98 Cf Californium (251.00)	99 IA 99 Es Einsteinium (252.00)	100 IA 100 Fm Fermium (257.00)	101 IA 101 Md Mendelevium (258.00)	102 IA 102 No Nobelium (259.00)	103 IA 103 Lr Lawrencium (262.00)
Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.	Atomic masses in parentheses are those of the most stable or common isotope.													

Note: The subgroup numbers 1-10 were adopted in 1989 by the International Union of Pure and Applied Chemistry. The names of elements 112-115 are the Latin equivalents of their numbers.

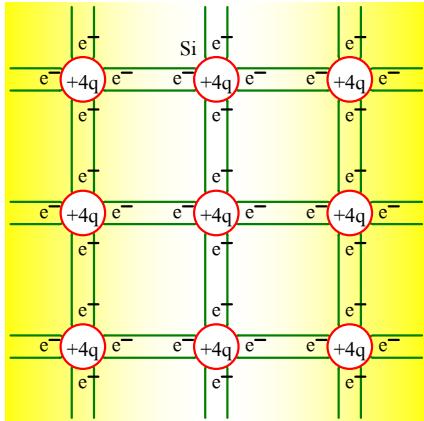
Valence Electron

5 B Boron 2.34	6 C Carbon 2.62	7 N Nitrogen 1.251
13 Al Aluminum 2.70	14 Si Silicon 2.33	15 P Phosphorus 1.82
31 Ga Gallium 5.91	32 Ge Germanium 5.32	33 As Arsenic 5.72

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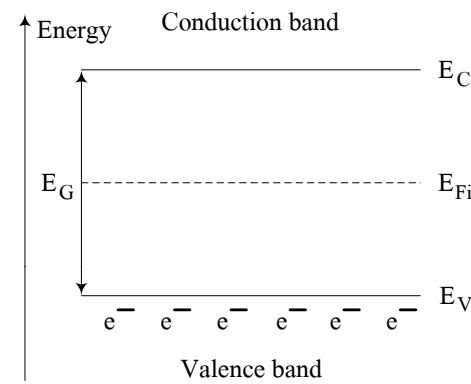
Intrinsic Semiconductor



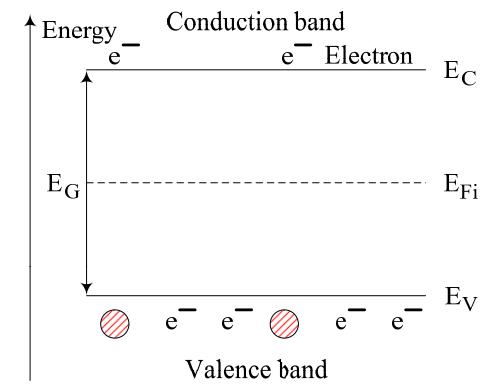
■ มีคุณสมบัติเป็นกลาง (เป็นฉนวน)

■ ถ้ามีพลังงานจากภายนอกที่มีขนาดเพียงพอมากระทำ จะทำให้อิเล็กตรอนหลุดออก

Energy Band Model

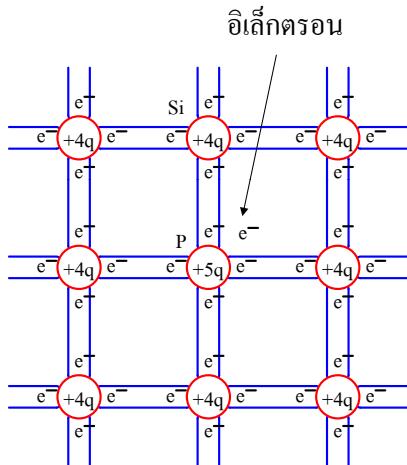


Energy band model for semiconductor

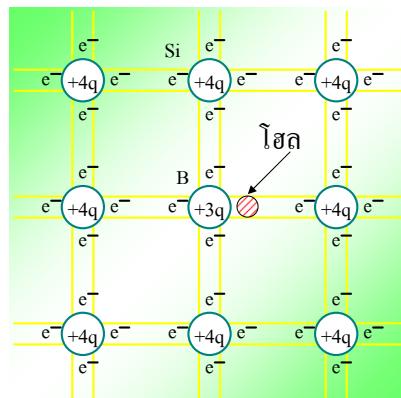


Creation of electron-hole pair by thermal excitation across the energy bandgap

Extrinsic semiconductor



(N-Type) Semiconductor



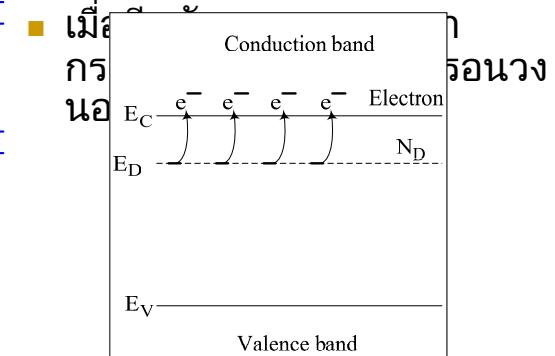
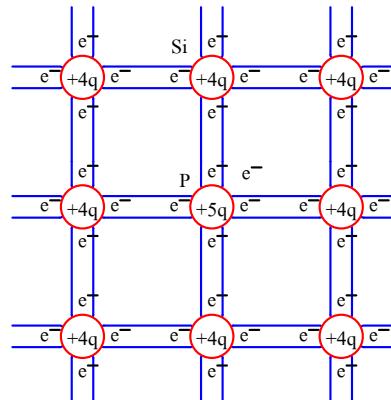
(P-Type) Semiconductor

(N-Type) Semiconductor

- มีการเจือด้วยสาร Phosphorus มีเลขอะตอม 15 และมีอิเล็กตรอนวงนอกสุด 5

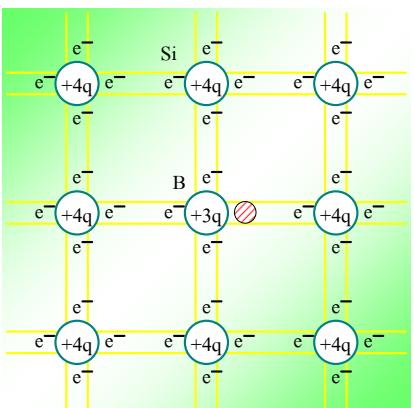
- มีคุณสมบัติเป็นผู้ให้อิเล็กตรอน (Donor)

- เมื่อหัวเข็มขัดนำไฟฟ้าไปต่อ กระแสไฟฟ้าจะไหลในทิศทางเดียวกัน

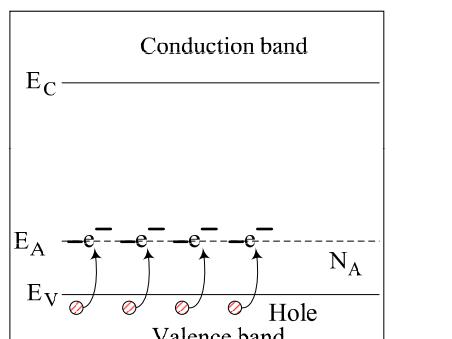


Donor level with activation energy ($E_C - E_D$)

(P-Type) Semiconductor



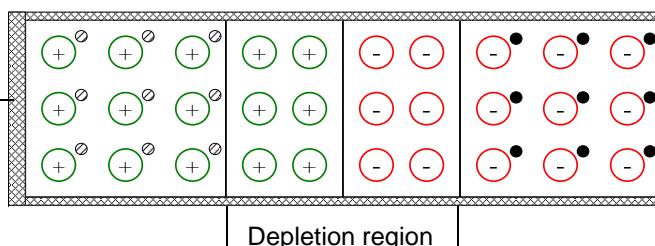
- มีการเจือด้วยสาร Boron มีเลขอะตอม 5 และมีอิเล็กตรอนวงนอกสุด 3
- มีคุณสมบัติเป็นผู้รับอิเล็กตรอน (Acceptor)
- เมื่อมีพลังงานภายนอกมากการทำ ทำให้อิเล็กตรอนหลุดออก ไปยังที่ว่าง



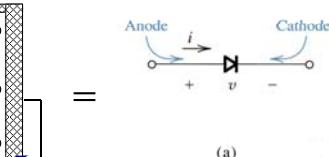
Acceptor level with activation energy ($E_A - E_V$)

Diode semiconductor

P-Type



N-Type

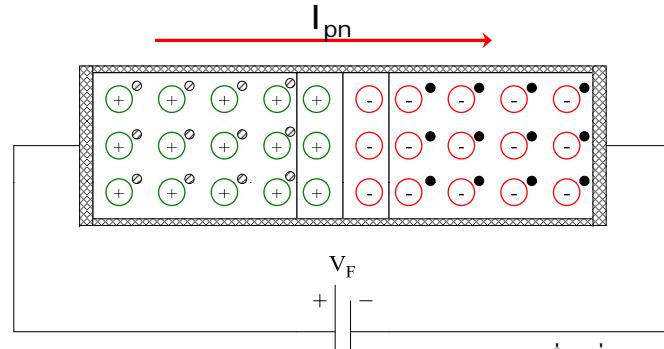


(a)
Ohmic contact

- $I_{\text{diff}} (I_{\text{diffusion}})$ คือกระแสแพร่ที่ไหลจาก p ไป n

- $I_{\text{drift}} (I_{\text{drift}})$ คือกระแสเลื่อนที่ไหลจาก n ไป p

Forward bias



- การเกลี้ยงที่ของพานะ 2 ชั้นิด ทำให้ความกว้างของเขตปลดพาราหะลดลง

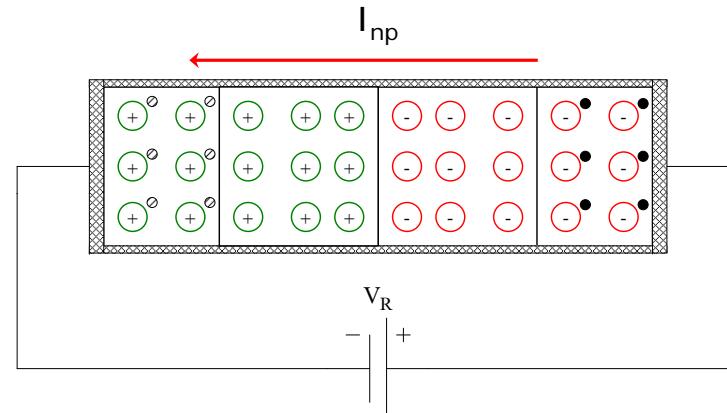
- แรงดันที่ตอกคร่อมบริเวณเขตปลดพาราหะลดลง

- มีการแพร์ของอิเล็กตรอนและโโซลข้ามรอยต่อมากขึ้น

- กระแส I_{drift} ใหญ่มากขึ้น

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

Reverse bias



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

Diode Characterization

- ความสัมพันธ์ระหว่างแรงดันและกระแสของไคโอดไดดังนี้

Forward Bias

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

Reverse Bias

$$i \cong -I_s$$

- เมื่อ I_s คือกระแสไฟหล่อ่อนกลับ $\sim 10^{-14} - 10^{-15} \text{ A}$

V_T คือแรงดันอุณหภูมิ (Thermal Voltage) $= 25 - 26 \text{ mV}$

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

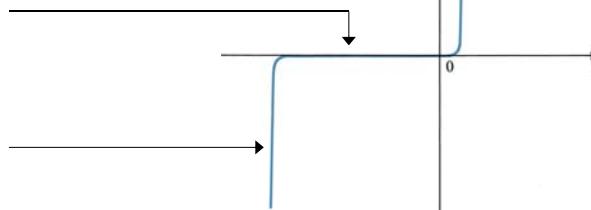


Fig. 2.4 The i - v characteristic of a silicon junction diode.

Diode Regions

- Thermal Voltage

$$V_T = kT/q$$

- T คืออุณหภูมิสัมบูรณ์ 0K

- K คือค่าคงที่ของโบลต์มันน์ (Boltzmann's constant)

$$= 1.38 \times 10^{-23}$$

- q คือค่าประจุไฟฟ้าของอิเล็กตรอน

$$= 1.6 \times 10^{-19}$$

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

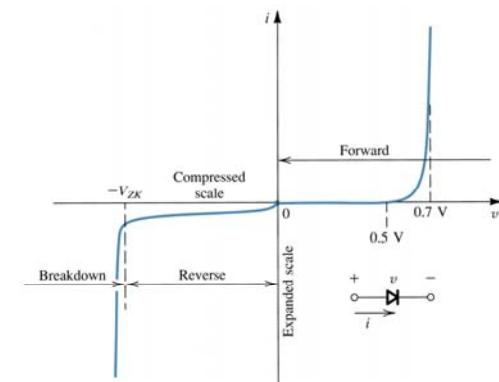


Fig. The diode i - v relationship with some scales expanded and others compressed in order to reveal details.

2.3 Analysis Diode Circuit

The Ideal Diode

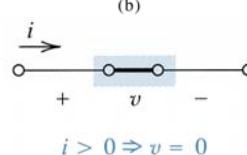
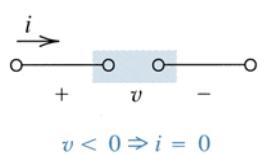
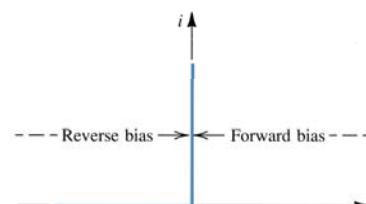
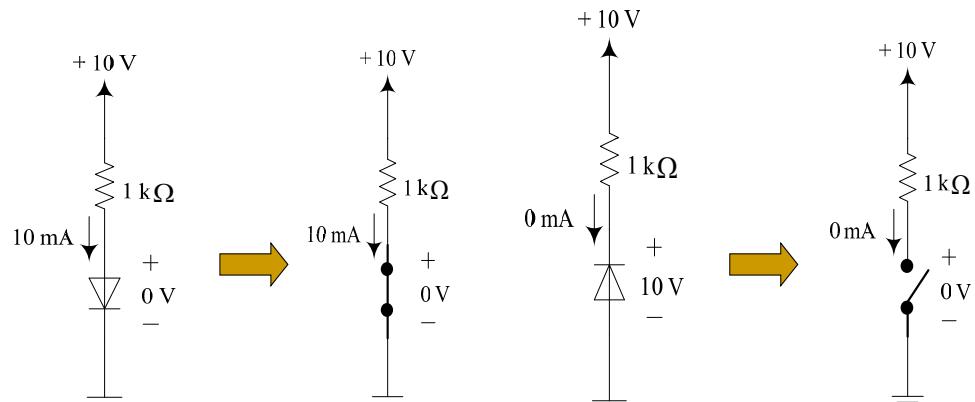
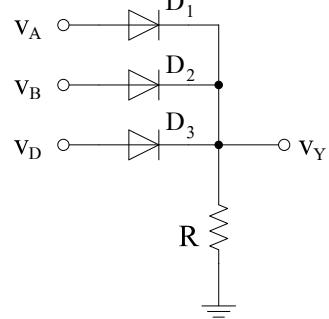


Fig. The ideal diode: (a) diode circuit symbol; (b) i - v characteristic; (c) equivalent circuit in the reverse direction; (d) equivalent circuit in the forward direction.

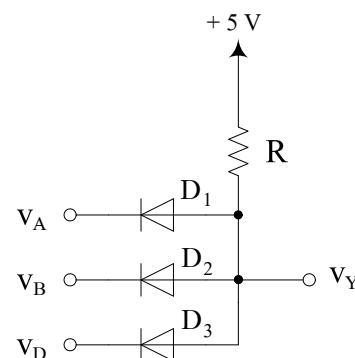
Diode Circuits



Diode Logic Gate

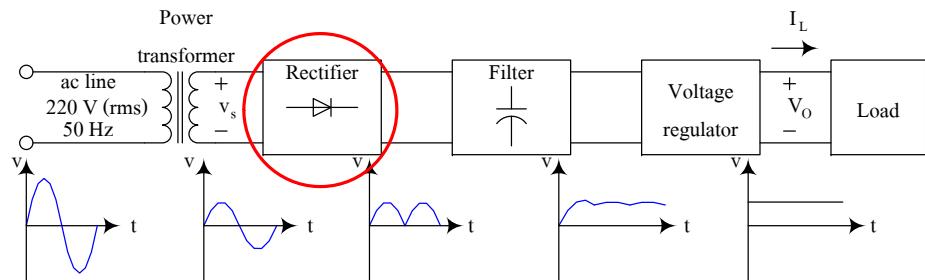


OR Gate



AND Gate

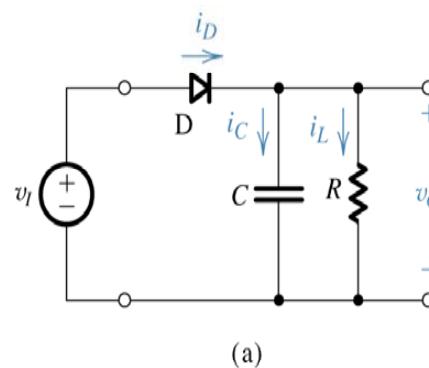
Rectifier



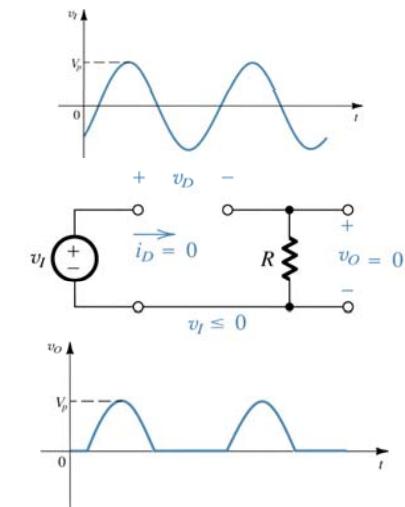
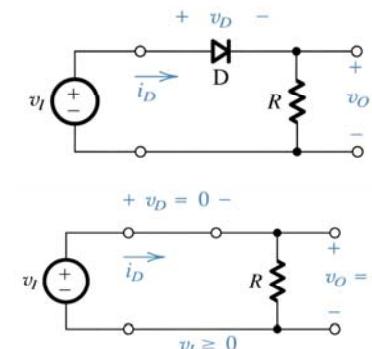
Practical Diode Circuit

Diode charges capacitor.

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



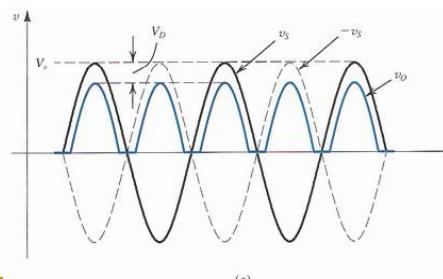
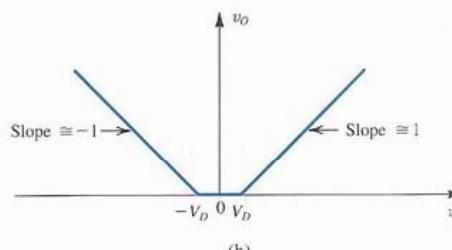
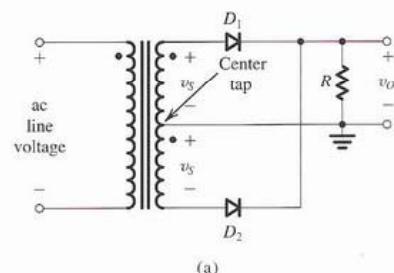
Half-wave rectifier



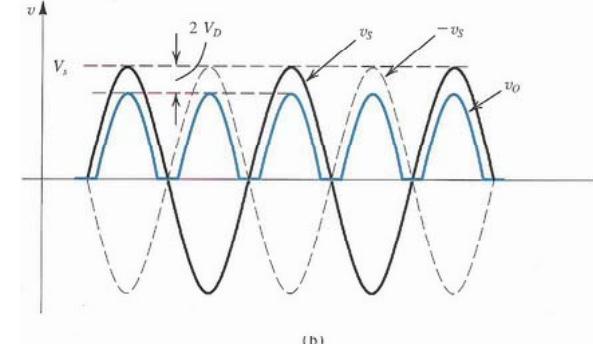
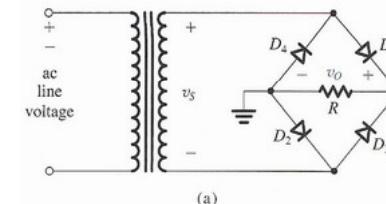
During positive cycle, diode allow current to pass through and output voltage is positive

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

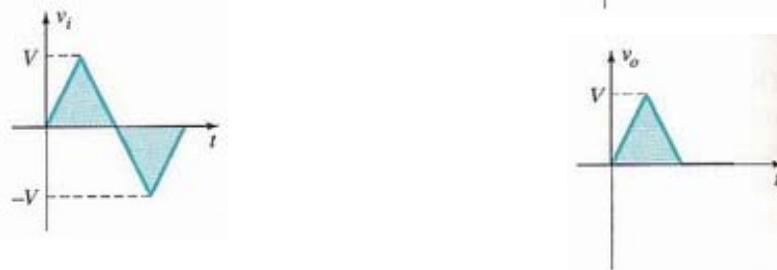
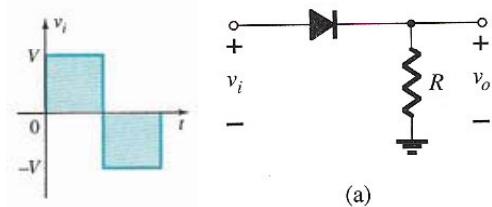
Full-Wave Rectifier



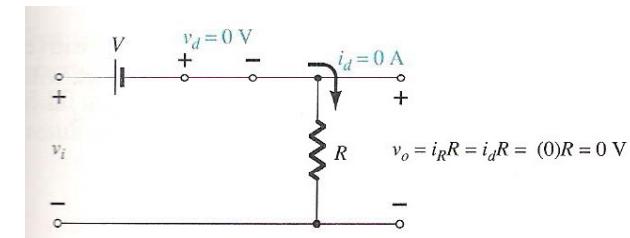
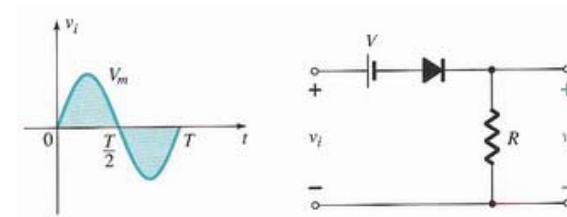
Full-Wave Rectifier



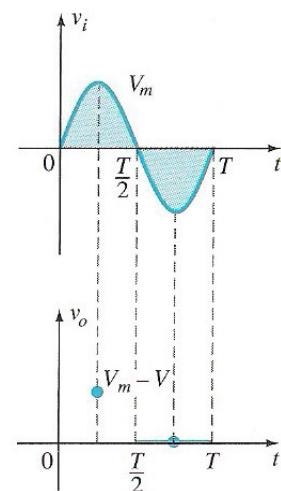
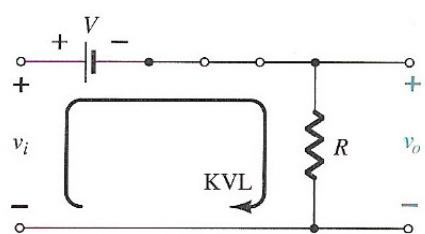
2.4 Clippers Diode



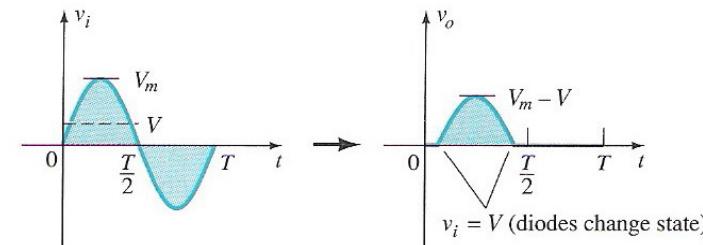
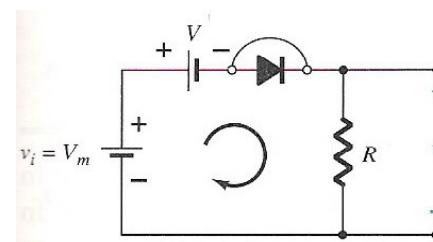
Clippers Diode (con)



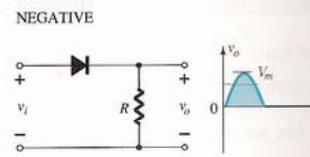
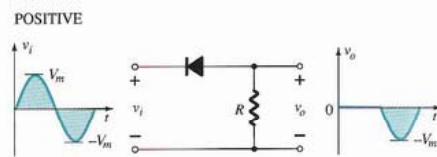
Clippers Diode (con)



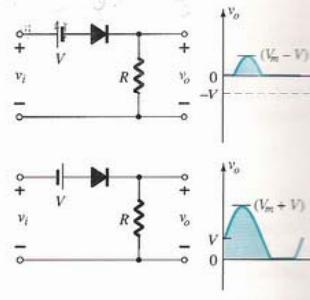
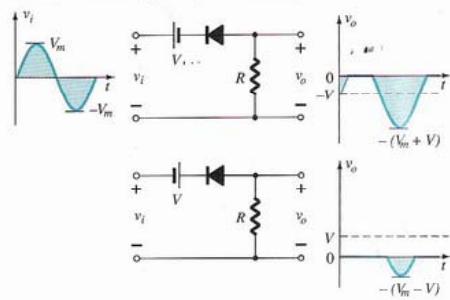
Clippers Diode (con)



Clippers Diode (con)

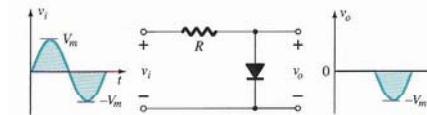


Biased Series Clippers (Ideal Diodes)

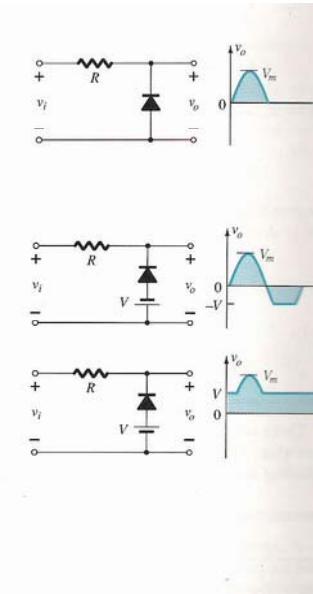
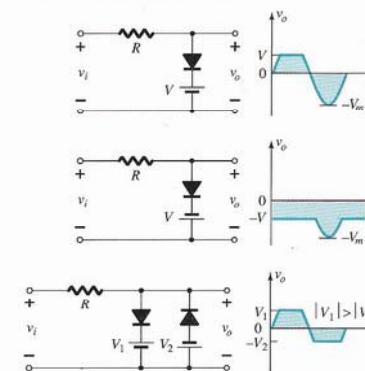


Clippers Diode (con)

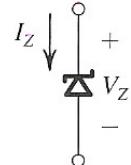
Simple Parallel Clippers (Ideal Diodes)



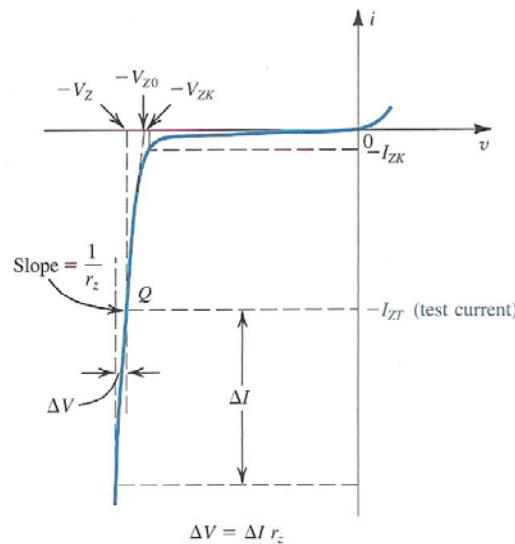
Biased Parallel Clippers (Ideal Diodes)



2.5 Zener Diode

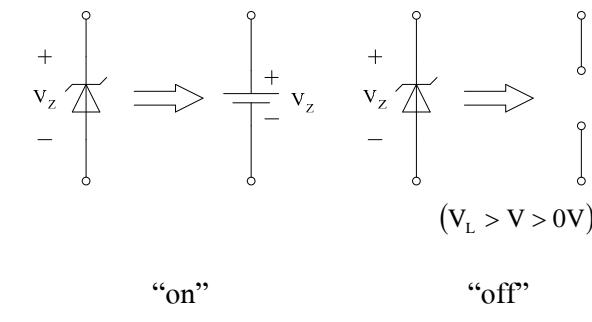


Symbol of Zener Diode

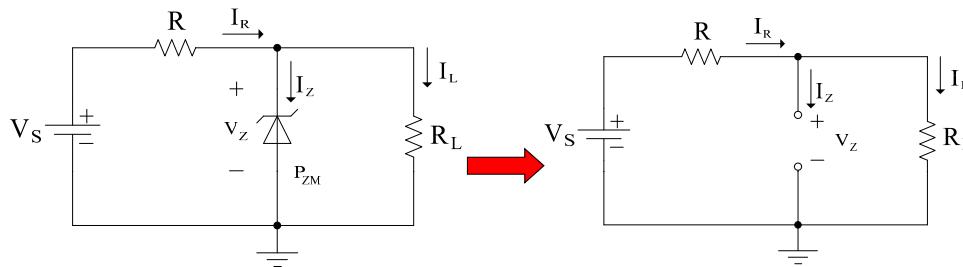


Characteristic of Zener Diode

Zener Diode



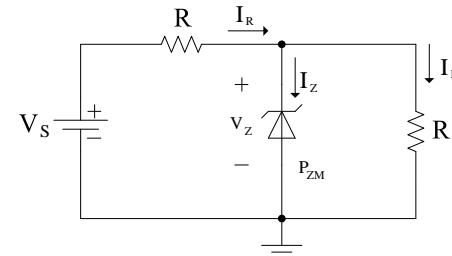
Zener Diode



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

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

V_S and R Fixed



$$I_Z = I_R - I_L$$

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

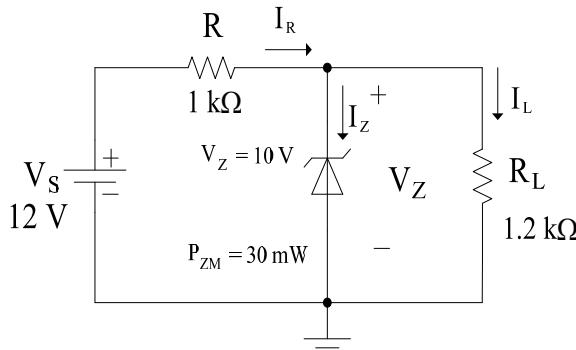
$$I_R = \frac{V_R}{R} = \frac{V_S - V_Z}{R}$$

Fig Zener diode

$$V_L = V_Z$$

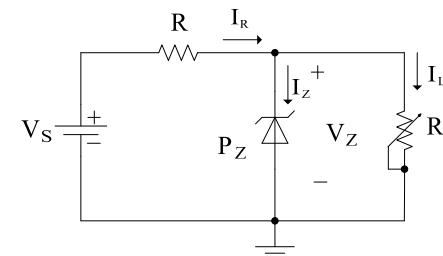
$$I_R = I_Z + I_L$$

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



Zener Diode

Fixed V_S and Variable R_L



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

$$V_R = V_S - V_Z$$

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

$$I_Z = I_R - I_L$$

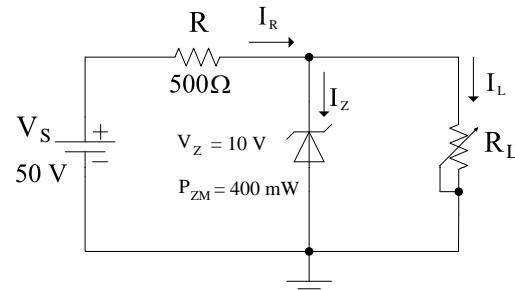
$$I_{L_{\min}} = \frac{V_L}{R_L} = \frac{V_L}{R_{L_{\max}}}$$

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

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

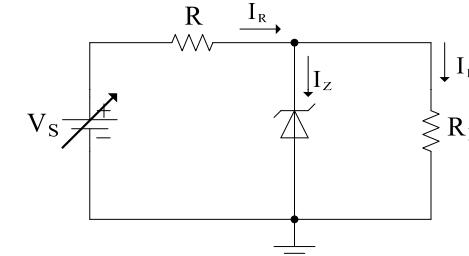
$$R_{L_{\max}} = \frac{V_Z}{I_{L_{\min}}}$$

Ex2. Find $R_{L\min}$ and $R_{L\max}$ at figure



Zener Diode

Fixed R_L and Variable V_S



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

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

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

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

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

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

Ex3. Find $V_{S_{\min}}$ and $V_{S_{\max}}$ at voltage regulation circuit

