Integrated Technical Education Cluster
At AlAmeeria

J-601-1448
Electronic Principals

Lecture #1
Introduction to the semiconductors

Instructor:
Dr. Ahmad El-Banna

October 2014

Agenda

- Course Objectives
- Course Information
- Semiconductor Diodes
- Zener Diodes and LED

Course Objectives

- ***Applying testing procedures for semiconductor devices and circuits.***
- ***Understand the characteristics and operation of amplifier circuits.***
- ***Understand the types and effects of feedback on circuit performance.***
- ***Understand the operation and applications of sine wave oscillators.***

Course Information

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Lectures:	Sunday, 12:30 -14:15 Prerequisite: ECE-121 & ECE-222
Office Hours:	Sunday (14:15~15:30) Tuesday (12:00~13:00)
T.A.:	Eng. Mena
Texts/Notes:	• R. Boylestad, **Electronic Devices and Circuit Theory**, 11th edition, Prentice Hall. • T. Floyd, **Electronic devices** - Conventional Current Version, 9th edition, Prentice Hall.

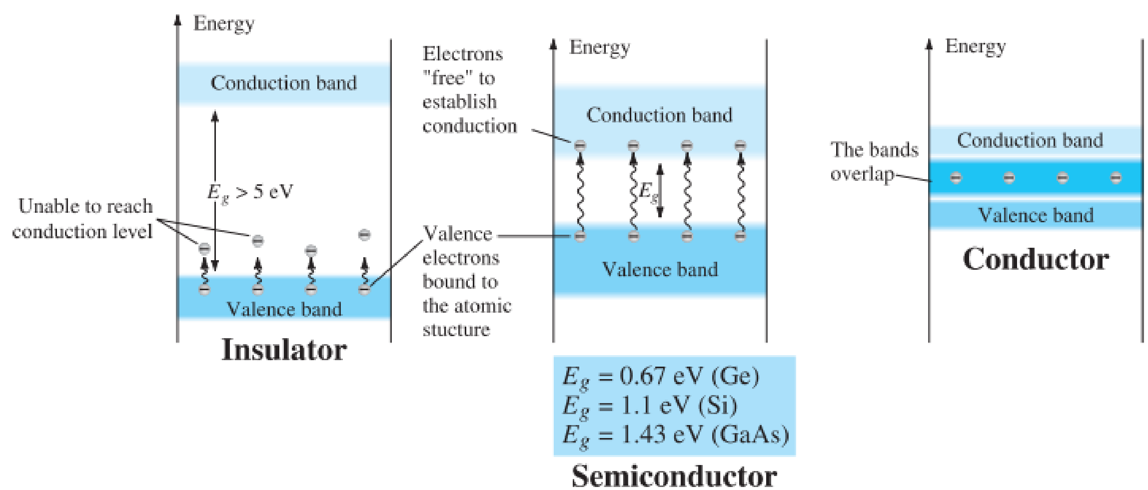
Lectures List

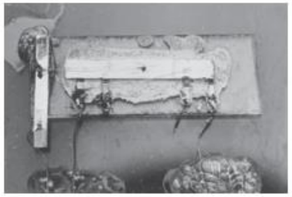
- **Weeks 1:6**
  - *Applying testing procedures for semiconductor devices and circuits.*
- **Weeks 7:10**
  - *Understand the characteristics and operation of amplifier circuits.*
- **Weeks 11:12**
  - *Understand the types and effects of feedback on circuit performance.*
- **Weeks 13:14**
  - *Understand the operation and applications of sine wave oscillators.*
- **Week 15**
  - *Course close and feedback*

SEMICONDUCTOR DIODES

Semiconductor Materials

- Semiconductors are a special class of elements having a conductivity between that of a good conductor and that of an insulator.
- The three semiconductors used most frequently in the construction of electronic devices are Ge, Si, and GaAs.

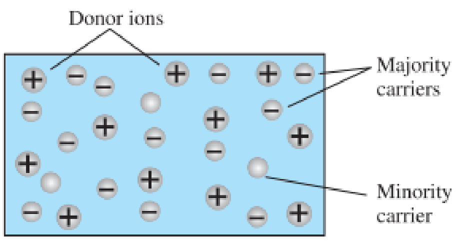




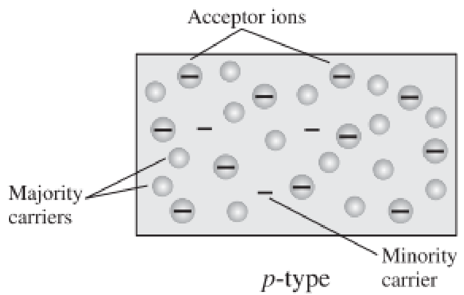
The first integrated circuit, a phase-shift oscillator, invented by Jack S. Kilby in 1958. (Courtesy of Texas Instruments.)

N-type and P-type materials

- A semiconductor material that has been subjected to the doping process is called an extrinsic material.
- N-type:
  - Diffused impurities with five valence electrons are called donor atoms.
  - In an n-type material the electron is called the majority carrier and the hole the minority carrier.
- P-type:
  - The diffused impurities with three valence electrons are called acceptor atoms.
  - In a p-type material the hole is the majority carrier and the electron is the minority carrier.



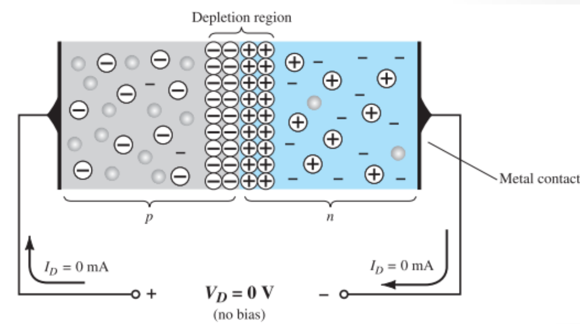
n-type

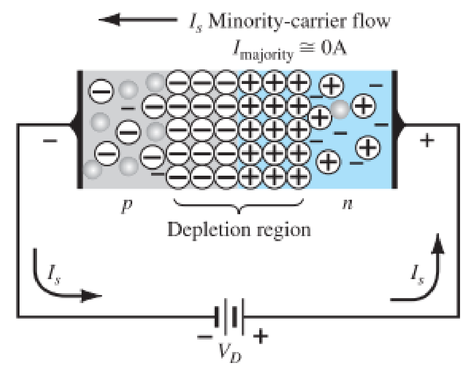


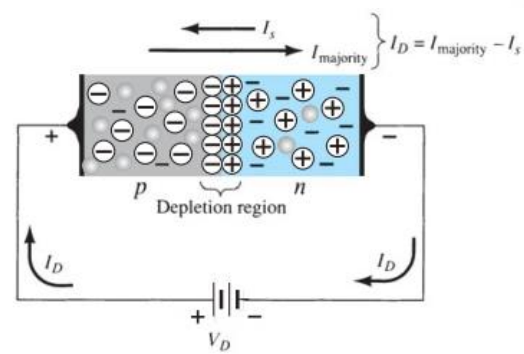
p-type

Semiconductor Diode

- No applied bias:
  - This region of uncovered positive and negative ions is called the depletion region due to the "depletion" of free carriers in the region.
  - In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.
- Reverse-Bias condition:
  - The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by I_s .
- Forward-Bias condition:
  - A forward-bias or "on" condition is established by applying the positive potential to the p -type material and the negative potential to the n -type material







Semiconductor Diode..

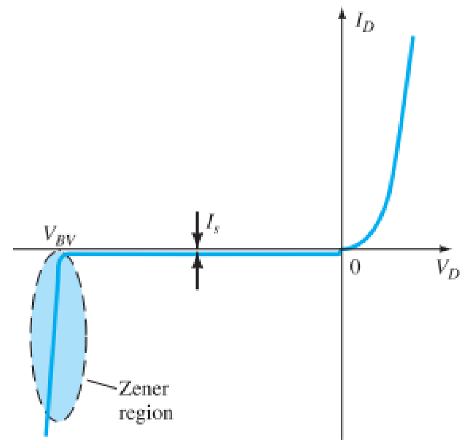
$$I_D = I_s(e^{V_D/nV_T} - 1) \quad \text{(A)}$$

where I_s is the reverse saturation current
V_D is the applied forward-bias voltage across the diode
n is an ideality factor, it has a range between 1 and 2

$$V_T = \frac{kT_K}{q} \quad \text{(V)}$$

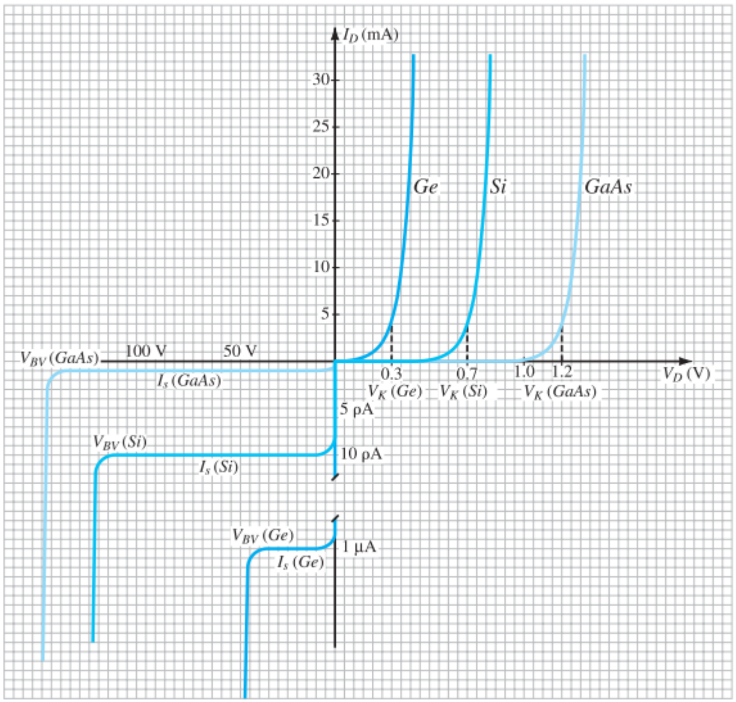
k is Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K
T_K is the absolute temperature in kelvins $= 273 +$ the temperature in °C
q is the magnitude of electronic charge $= 1.6 \times 10^{-19}$ C

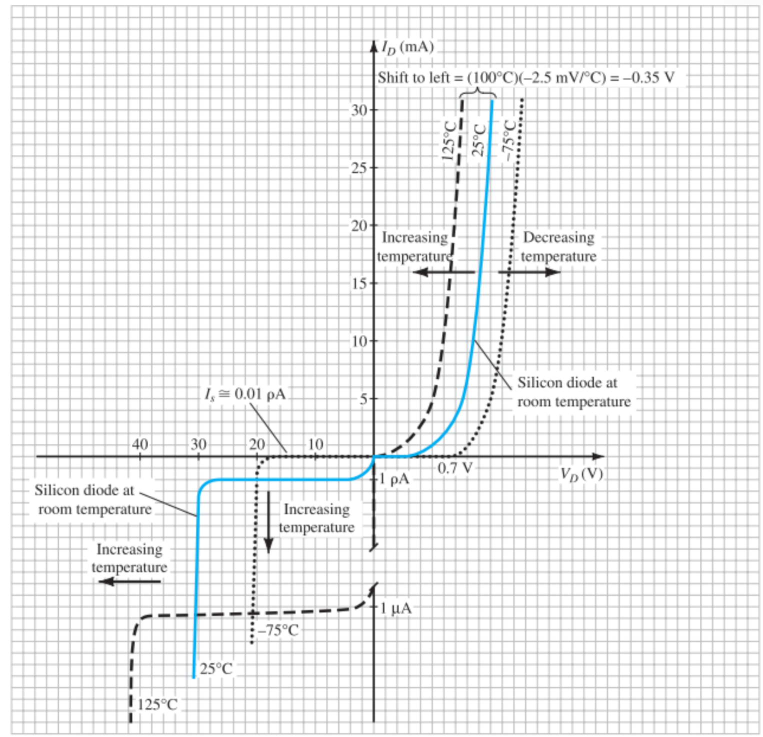
- The defined direction of conventional current for the positive voltage region matches the arrowhead in the diode symbol.
- The actual reverse saturation current of a commercially available diode will normally be measurably larger than that appearing as the reverse saturation current in Shockley's equation.



- The maximum reverse-bias potential that can be applied before entering the break-down region is called the peak inverse voltage (referred to simply as the PIV rating) or the peak reverse voltage (denoted the PRV rating).

Ge/Si/GaAs & Temperature Effect





- In the forward-bias region the characteristics of a silicon diode shift to the left at a rate of 2.5 mV per centigrade degree increase in temperature.
- In the reverse-bias region the reverse current of a silicon diode doubles for every 10°C rise in temperature.
- The reverse breakdown voltage of a semiconductor diode will increase or decrease with temperature.

Ideal vs. Practical

- The semiconductor diode behaves in a manner similar to a mechanical switch in that it can control whether current will flow between its two terminals.
- The semiconductor diode is different from a mechanical switch in the sense that when the switch is closed it will only permit current to flow in one direction.
- At any current level on the vertical line, the voltage across the ideal diode is 0 V and the resistance is 0 .
- Because the current is 0 mA anywhere on the horizontal line, the resistance is considered to be infinite ohms (an open-circuit) at any point on the axis.

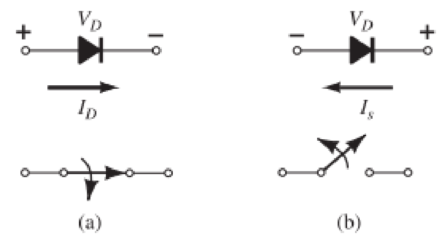
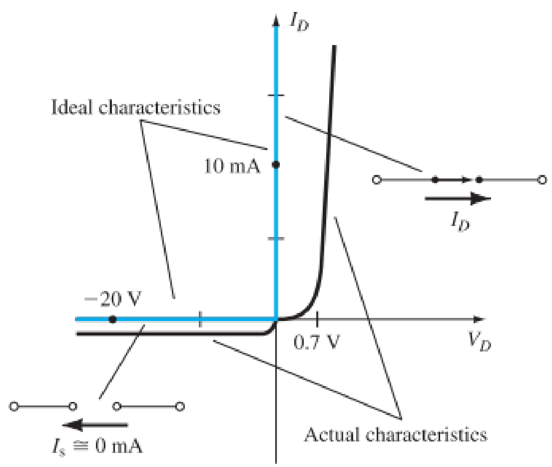


FIG. 1.21
Ideal semiconductor diode: (a) forward-biased; (b) reverse-biased.



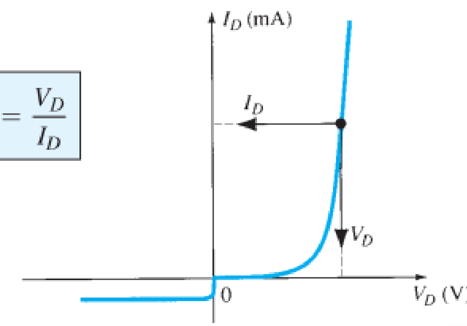
$$R_F = \frac{V_D}{I_D} = \frac{0\text{ V}}{5\text{ mA}} = \mathbf{0\ \Omega} \quad \text{(short-circuit equivalent)}$$

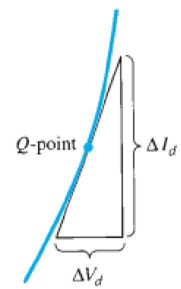
$$R_R = \frac{V_D}{I_D} = \frac{20\text{ V}}{0\text{ mA}} \cong \infty\,\Omega \quad \text{(open-circuit equivalent)}$$

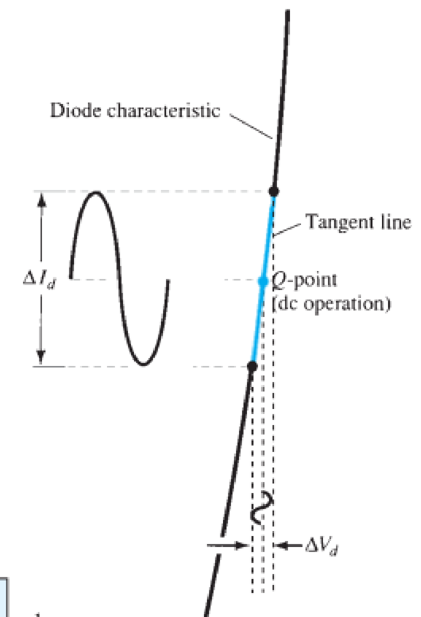
Resistance Levels

- DC or Static Resistance:
  - In general, therefore, the higher the current through a diode, the lower is the dc resistance level.
  - the dc resistance of a diode is independent of the shape of the characteristic in the region surrounding the point of interest.
- AC or Dynamic Resistance:
  - If a sinusoidal rather than a dc input is applied, then the varying input will move the instantaneous operating point up and down a region of the characteristics and thus defines a specific change in current and voltage.
  - A straight line drawn tangent to the curve through the Q –point will define a particular change in voltage and current that can be used to determine the *ac* or *dynamic* resistance for this region of the diode characteristics.
  - In general, the lower the Q-point of operation (smaller current or lower voltage), the higher is the ac resistance.

$$R_D = \frac{V_D}{I_D}$$







$$r_d = \frac{\Delta V_d}{\Delta I_d}$$

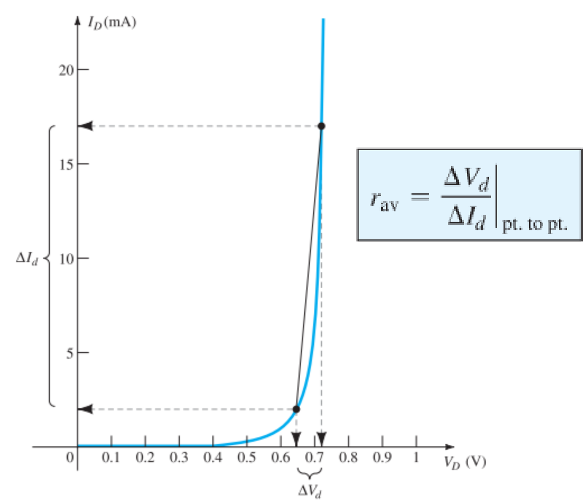
$$r_d = \frac{26 \text{ mV}}{I_D}$$

$$r'_d = \frac{26 \text{ mV}}{I_D} + r_B \quad \text{ohms}$$

body resistance

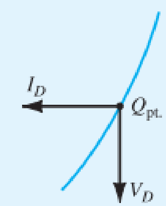
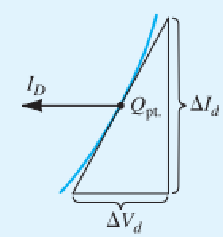
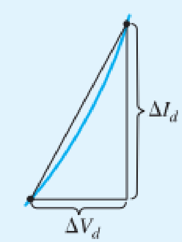
Resistance Levels..

- **Average AC resistance**
  - If the input signal is sufficiently large to produce a broad swing, the resistance associated with the device for this region is called the average ac resistance.
  - The average ac resistance is, by definition, the resistance determined by a straight line drawn between the two intersections established by the maximum and minimum values of input voltage.



- Summary table

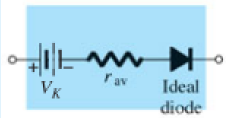
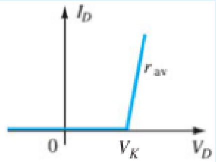
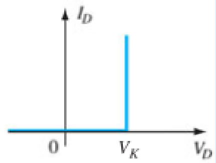
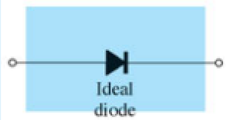
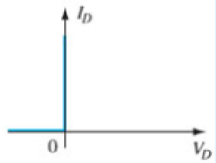
Resistance Levels

Type	Equation	Special Characteristics	Graphical Determination
DC or static	$R_D = \frac{V_D}{I_D}$	Defined as a point on the characteristics	
AC or dynamic	$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{26\text{ mV}}{I_D}$	Defined by a tangent line at the Q-point	
Average ac	$r_{av} = \frac{\Delta V_d}{\Delta I_d}\Big\|_{\text{pt. to pt.}}$	Defined by a straight line between limits of operation	

Diode Equivalent Circuit

- An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device or system in a particular operating region.
- If the characteristics or specification sheet for a diode is not available the resistance r_{av} can be approximated by the ac resistance r_d .

Diode Equivalent Circuits (Models)

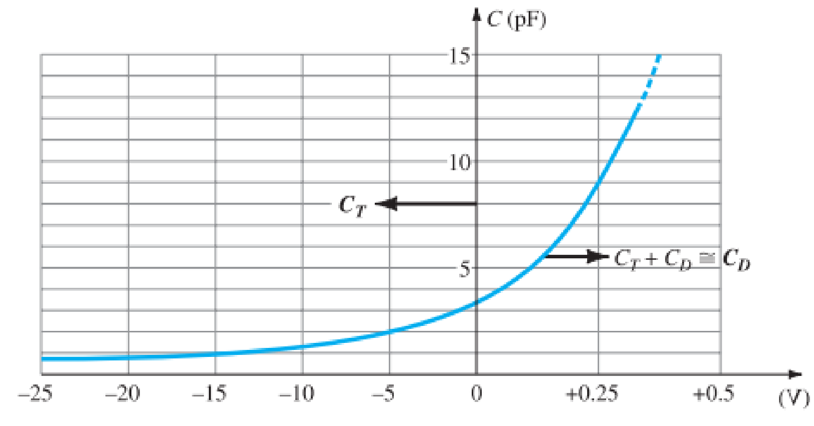
Type	Conditions	Model	Characteristics
Piecewise-linear model			
Simplified model	$R_{network} \gg r_{av}$		
Ideal device	$R_{network} \gg r_{av}$ $E_{network} \gg V_K$		

Transition and Diffusion Capacitance

- Every electronic or electrical device is frequency sensitive.
- As we approach high frequencies, stray capacitive and inductive effects start to play a role and will affect the total impedance level of the element.
- the transition capacitance C_T, barriers, or depletion region capacitance, is the predominant capacitive effect in the reverse-bias region whereas the diffusion capacitance is the predominant capacitive effect in the forward-bias region.
- the diffusion capacitance C_D a capacitance effect directly dependent on the rate at which charge is injected into the regions just outside the depletion region.

$X_C = 1/2\pi f C$,

$C = \epsilon A/d$,



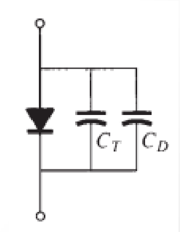
$$C_T = \frac{C(0)}{(1 + |V_R/V_K|)^n}$$

$C(0)$ is the capacitance under no-bias conditions

V_R is the applied reverse bias potential

$$C_D = \left(\frac{\tau_T}{V_K}\right) I_D$$

τ_T is the minority carrier lifetime

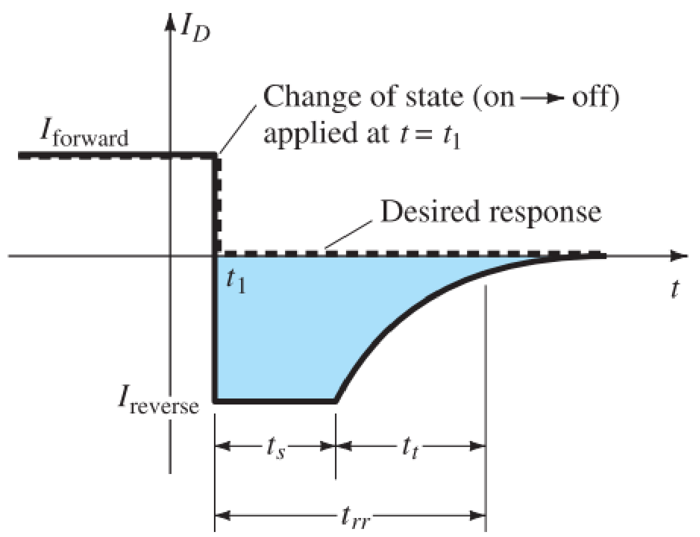


Reverse Recovery Time

- The period of time t_s (storage time) required for the minority carriers to return to their majority-carrier state in the opposite material.
- When this storage phase has passed, the current will be reduced in level to that associated with the non conduction state. This second period of time is denoted by t_t (transition interval).
- The reverse recovery time is the sum of these two intervals:

$$t_{rr} = t_s + t_t$$

- Most commercially available switching diodes have a t_{rr} in the range of a few nanoseconds to 1 us.



Diode Specification Sheets

They include:

1. The forward voltage V_F (at a specified current and temperature)
2. The maximum forward current I_F (at a specified temperature)
3. The reverse saturation current I_R (at a specified voltage and temperature)
4. The reverse-voltage rating [PIV or PRV or V(BR), where BR comes from the term “breakdown” (at a specified temperature)]
5. The maximum power dissipation level at a particular temperature
6. Capacitance levels
7. Reverse recovery time t_{rr}
8. Operating temperature range

$$P_{D\max} = V_D I_D$$

$$P_{\text{dissipated}} \cong (0.7\text{ V})I_D$$

Diode Specification Sheets..

DIFFUSED SILICON PLANAR

A — • BV . . . 125 V (MIN) @ 100 μA (BAY73)

ABSOLUTE MAXIMUM RATINGS (Note 1)

Temperatures

B —
Storage Temperature Range	−65°C to +200°C
Maximum Junction Operating Temperature	+175°C
Lead Temperature	+260°C

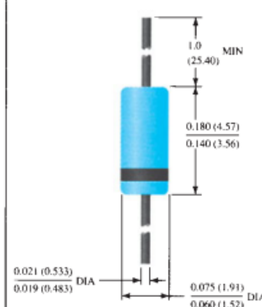
Power Dissipation (Note 2)

C —
Maximum Total Power Dissipation at 25°C Ambient	500 mW
Linear Power Derating Factor (from 25°C)	3.33 mW/°C

Maximum Voltage and Currents

WIV	Working Inverse Voltage	BAY73	100 V
I_O	Average Rectified Current		200 mA
D — I_F	Continuous Forward Current		500 mA
i_f	Peak Repetitive Forward Current		600 mA
$i_{f\,(surge)}$	Peak Forward Surge Current		
	Pulse Width = 1 s		1.0 A
	Pulse Width = 1 μs		4.0 A

DO-35 OUTLINE

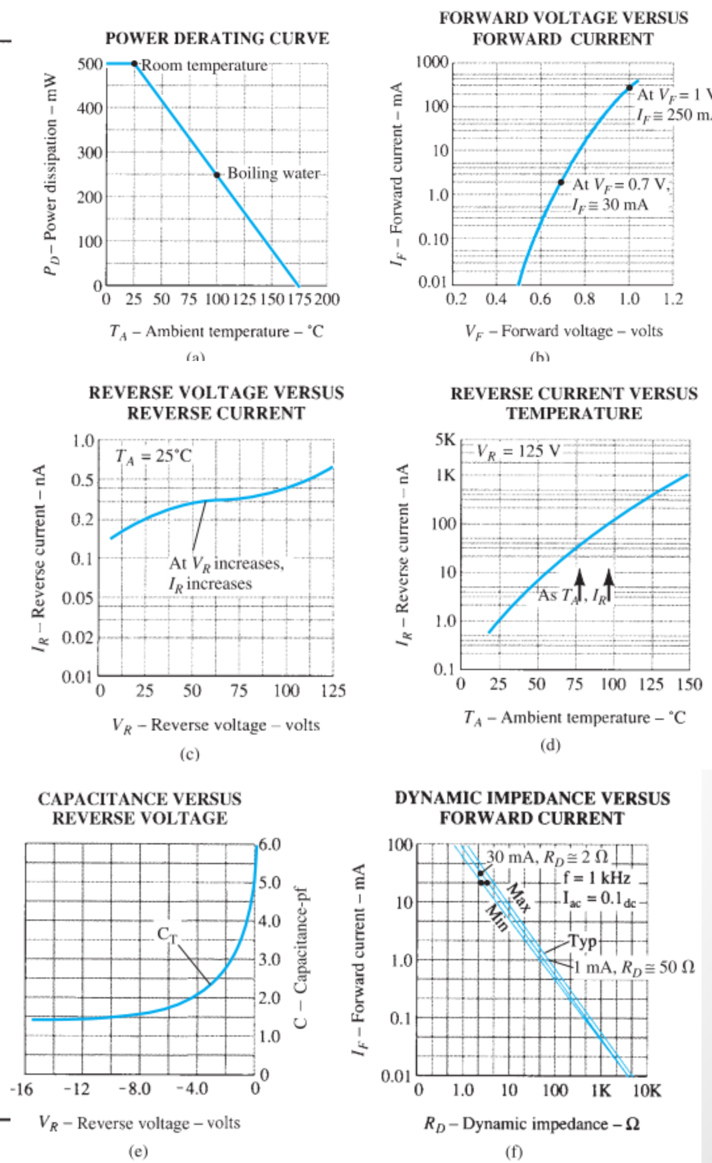


NOTES:
Copper clad steel leads, tin plated
Gold plated leads available
Hermetically sealed glass package
Package weight is 0.14 gram

ELECTRICAL CHARACTERISTICS (25°C Ambient Temperature unless otherwise noted)

	SYMBOL	CHARACTERISTIC	BAY73 MIN	BAY73 MAX	UNITS	TEST CONDITIONS
E	V_F	Forward Voltage	0.85	1.00	V	I_F = 200 mA
			0.81	0.94	V	I_F = 100 mA
			0.78	0.88	V	I_F = 50 mA
			0.69	0.80	V	I_F = 10 mA
			0.67	0.75	V	I_F = 5.0 mA
			0.60	0.68	V	I_F = 1.0 mA
F	I_R	Reverse Current		500	nA	V_R = 20 V, T_A = 125°C
				1.0	μA	V_R = 100 V, T_A = 125°C
				0.2	nA	V_R = 20 V, T_A = 25°C
				0.5	nA	V_R = 100 V, T_A = 25°C
	BV	Breakdown Voltage	125		V	I_R = 100 μA
G	C	Capacitance		5.0	pF	V_R = 0, f = 1.0 MHz
H	t_{rr}	Reverse Recovery Time		3.0	μs	I_F = 10 mA, V_R = 35 V; R_L = 1.0 to 100 kΩ; C_L = 10 pF, JAN 256

NOTES
1 These ratings are limiting values above which the serviceability of the diode may be impaired.
2 These are steady state limits. The factory should be consulted on applications involving pulses or low duty-cycle operation.



Semiconductor Diode Notation

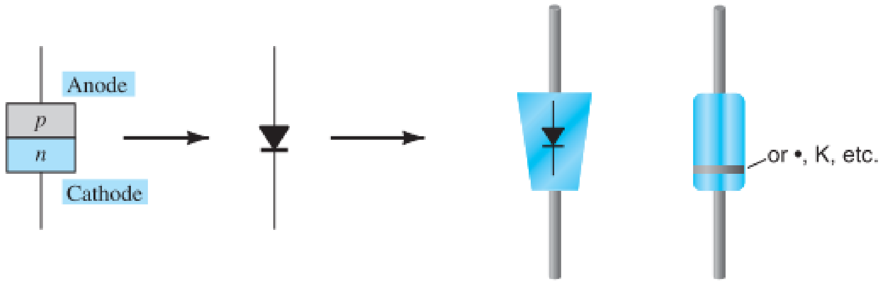


FIG. 1.38
Semiconductor diode notation.

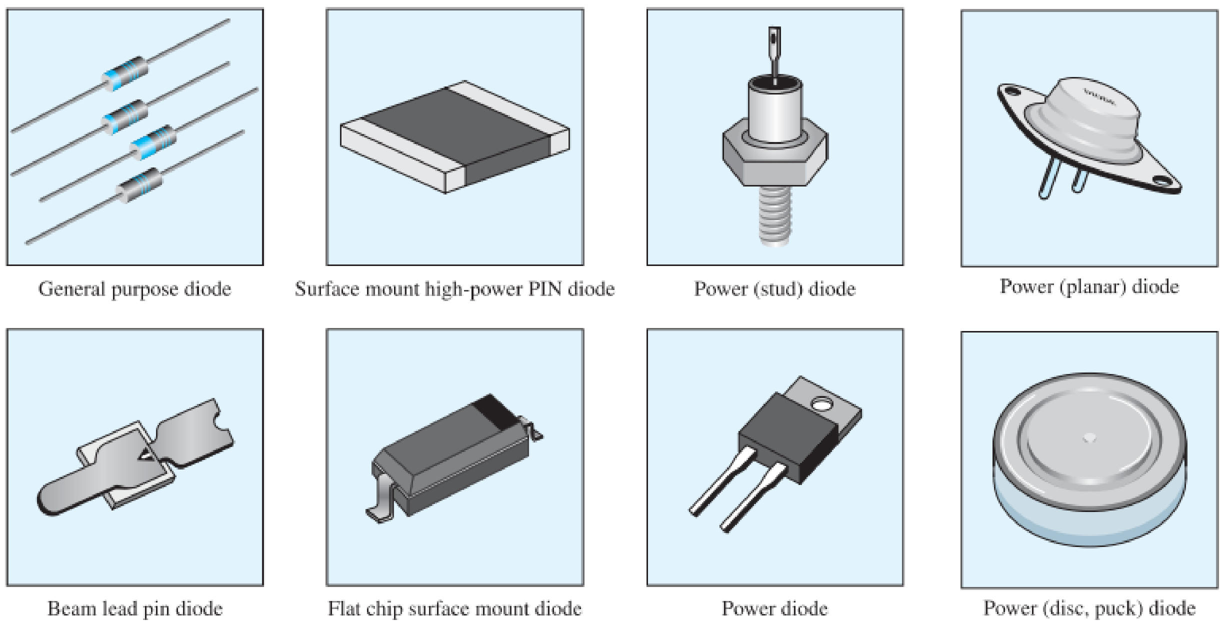
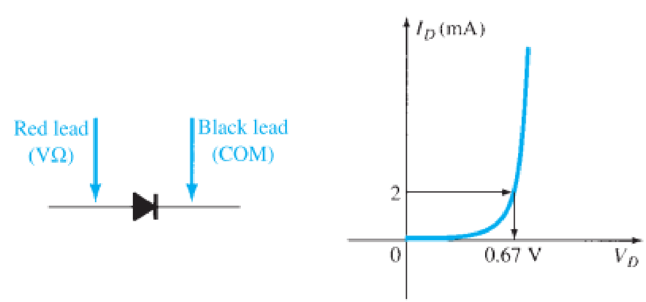


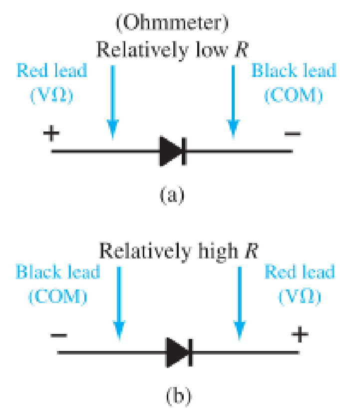
FIG. 1.39
Various types of junction diodes.

Diode Testing

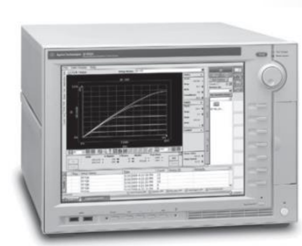
- Diode Checking Function



- Ohmmeter Testing



- Curve Tracer



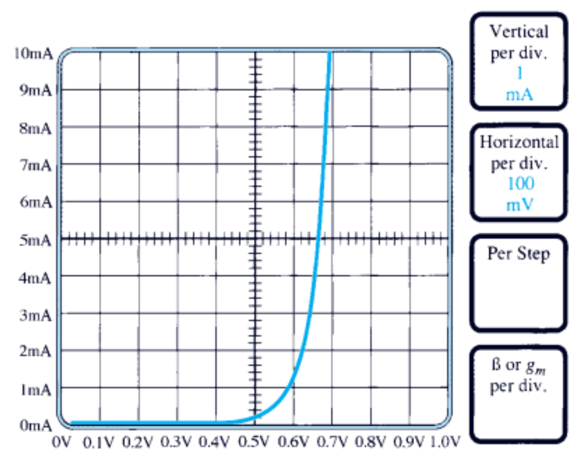
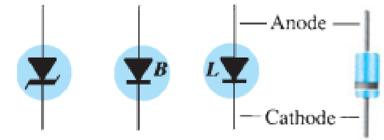


FIG. 1.44
Curve tracer response to IN4007 silicon diode.

ZENER DIODES AND LED

Zener Diodes



$$P_{Z_{max}} = 4 I_{ZT} V_Z$$

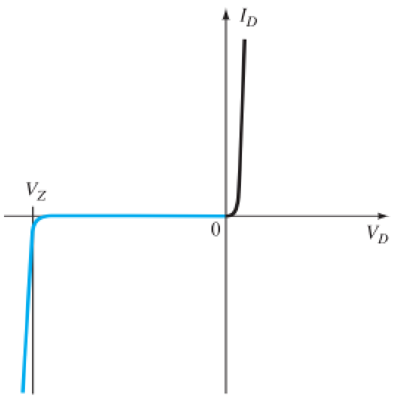


FIG. 1.45
Reviewing the Zener region.

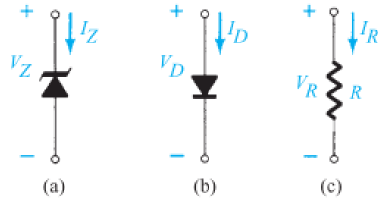


FIG. 1.46
Conduction direction: (a) Zener diode; (b) semiconductor diode; (c) resistive element.

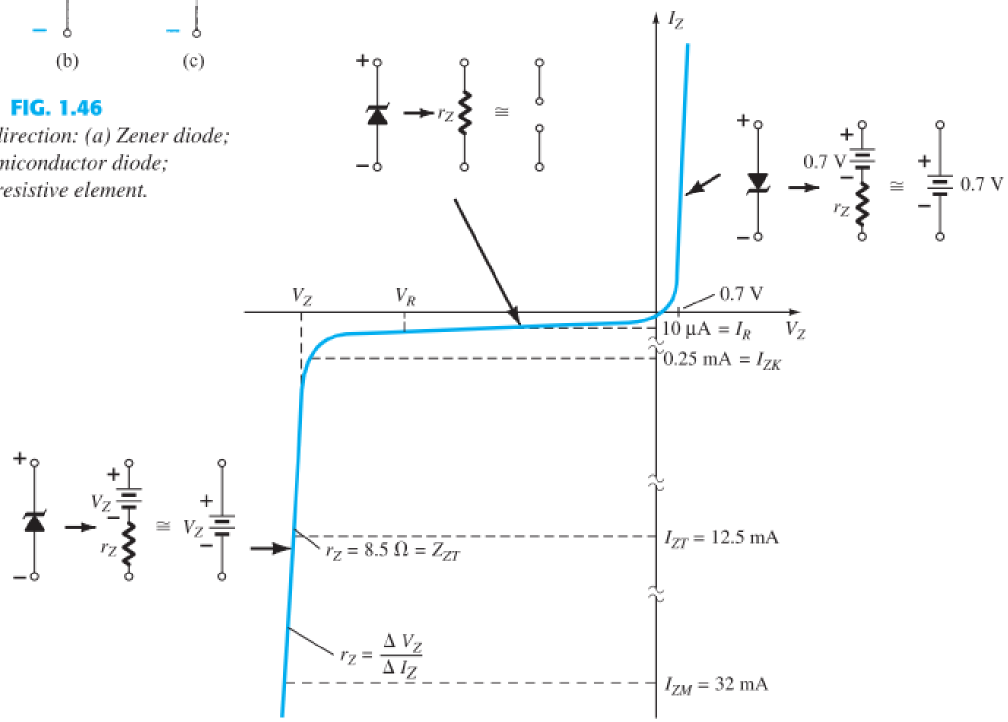


FIG. 1.47
Zener diode characteristics with the equivalent model for each region.

- The characteristic drops in an almost vertical manner at a reverse-bias potential denoted V_Z.
- The fact that the curve drops down and away from the horizontal axis rather than up and away for the positive- V_D region reveals that the current in the Zener region has a direction opposite to that of a forward-biased diode.

LED

- In Si and Ge diodes the greater percentage of the energy converted during recombination at the junction is dissipated in the form of heat within the structure, and the emitted light is insignificant.
- Diodes constructed of GaAs emit light in the infrared (invisible) zone during the recombination process at the p–n junction.

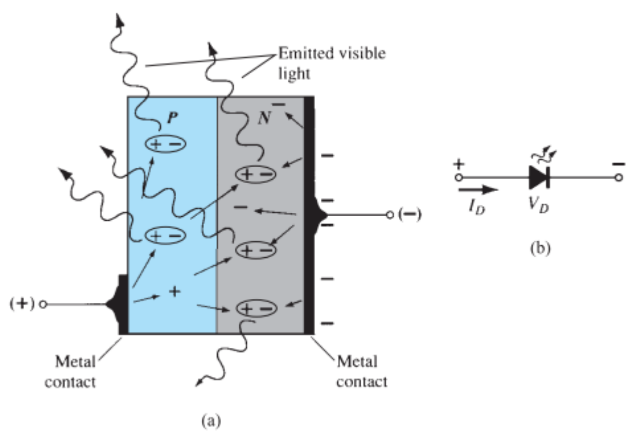


FIG. 1.50
(a) Process of electroluminescence in the LED; (b) graphic symbol.

TABLE 1.9
Light-Emitting Diodes

Color	Construction	Typical Forward Voltage (V)
Amber	AlInGaP	2.1
Blue	GaN	5.0
Green	GaP	2.2
Orange	GaAsP	2.0
Red	GaAsP	1.8
White	GaN	4.1
Yellow	AlInGaP	2.1

LED..

- The frequency spectrum for infrared light extends from about 100 THz (T = tera = 10^{12}) to 400 THz, with the visible light spectrum extending from about 400 to 750 THz.
- The response of the average human eye extends from about 350 nm to 800 nm with a peak near 550 nm.
- The wavelength and frequency of light of a specific color are directly related to the energy band gap of the material.
- A first step in the production of a compound semiconductor that can be used to generate light is to come up with a combination of elements that will generate the desired energy band gap.

$$\lambda = \frac{c}{f} \quad \text{(m)}$$

where $c = 3 \times 10^8$ m/s (the speed of light in a vacuum)
f = frequency in Hertz
λ = wavelength in meters.

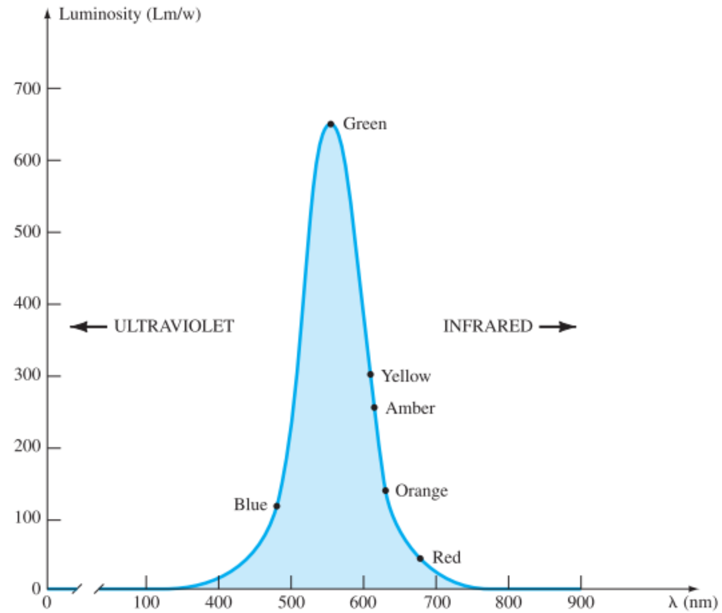
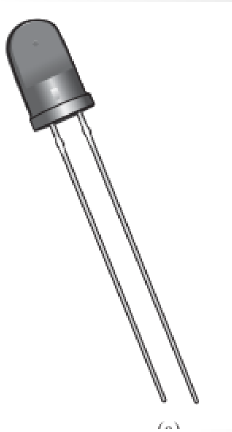


FIG. 1.51
Standard response curve of the human eye, showing the eye's response to light energy peaks at green and falls off for blue and red.

$$E_g = \frac{hc}{\lambda}$$

with E_g = joules (J) [1 eV = 1.6×10^{-19} J]
h = Planck's constant = 6.626×10^{-34} J • s.
$c = 3 \times 10^8$ m/s
λ = wavelength in meters

LED…

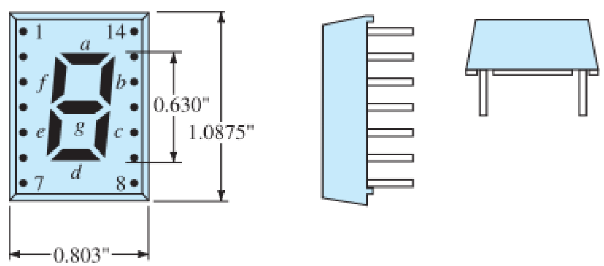


- The light intensity of an LED will increase with forward current until a point of saturation arrives where any further increase in current will not effectively increase the level of illumination.
- One of the major concerns when using an LED is the reverse-bias breakdown voltage, which is typically between 3V and 5V.
- For many years the only colors available were green, yellow, orange, and red, permitting the use of the average values of V_F=2 V and I_F =20 mA for obtaining an approximate operating level.

LED….

Applications

FIG. 1.53
LED residential and commercial lighting.

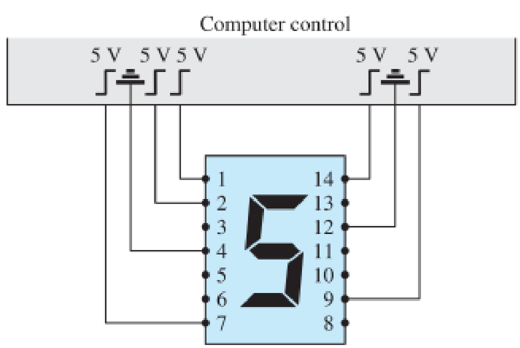


(a)

COMMON CATHODE

PIN #	FUNCTION
1.	Anode f
2.	ANODE g
3.	NO PIN
4.	COMMON CATHODE
5.	NO PIN
6.	ANODE e
7.	ANODE d
8.	ANODE c
9.	ANODE d
10.	NO PIN
11.	NO PIN
12.	COMMON CATHODE
13.	ANODE b
14.	ANODE a

(b)



(c)

- For more details, refer to:
  - Chapter 1, Electronic Devices and Circuits, Boylestad.
- The lecture is available online at:
  - https://speakerdeck.com/ahmad_elbanna
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