الجامعة المصرية
للتعلم الإلكتروني الأهلية
EELU
THE EGYPTIAN E-LEARNING UNIVERSITY

Electronics

Section 07

Faculty of Information Technology Egyptian E-Learning University

Aswan Center & Assiut Center Fall 2021

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Covalent bonding and intrinsic materials

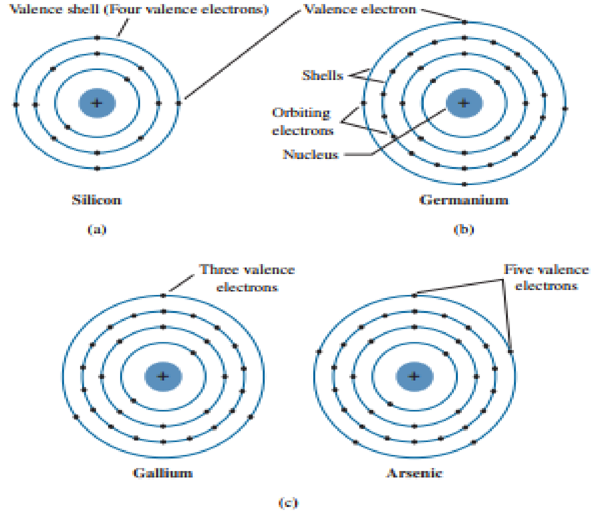


Figure: ***Atomic structure of (a) silicon; (b) germanium; and (c) gallium and arsenic.***

Energy levels

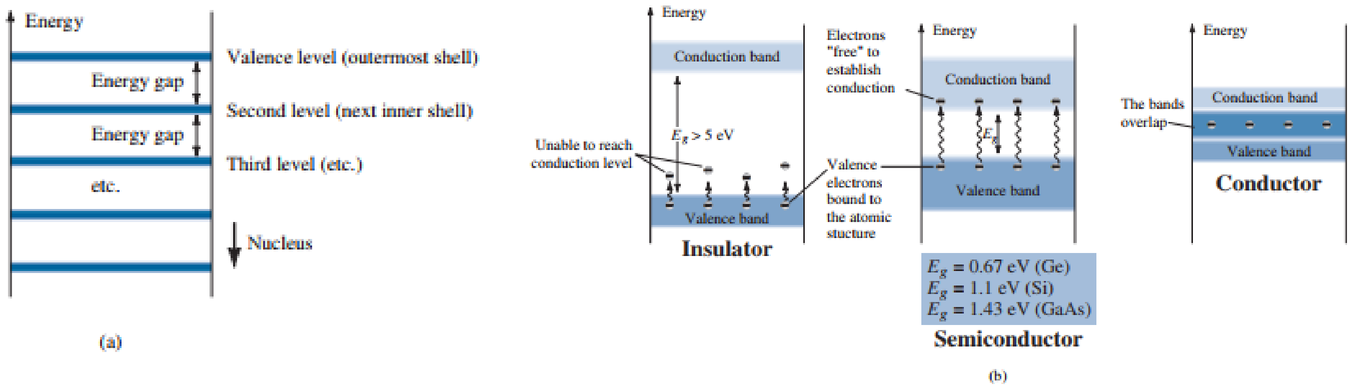
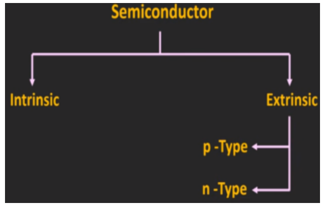


Figure: ***Energy levels: (a) discrete levels in isolated atomic structures; (b) conduction and valence bands of an insulator, a semiconductor, and a conductor.***

n-type and *p*-type materials



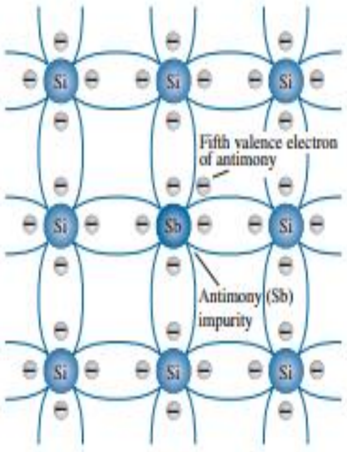


FIG. 7

Antimony impurity in n-type material.

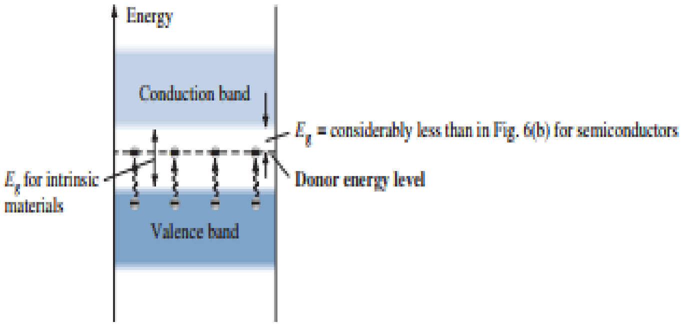


FIG. 8

Effect of donor impurities on the energy band structure.

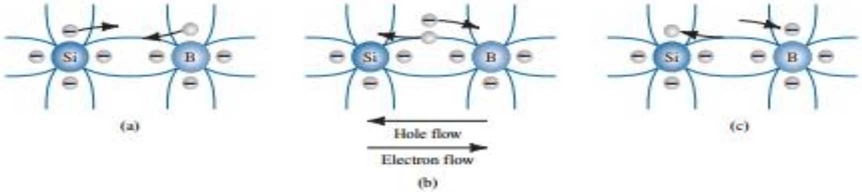


FIG. 10

Electron versus hole flow.

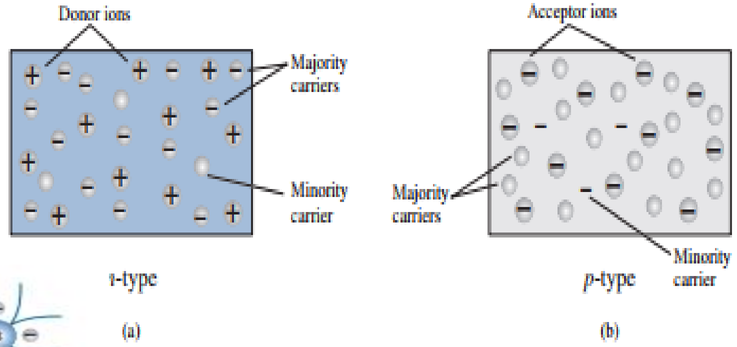


FIG. 11

(a) n-type material; (b) p-type material.

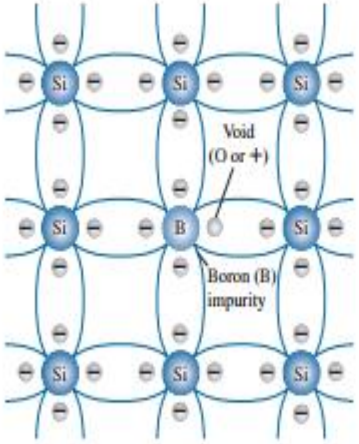


FIG. 9

Boron impurity in p-type material.

Semiconductor diode

no applied bias ($V = 0$ V)

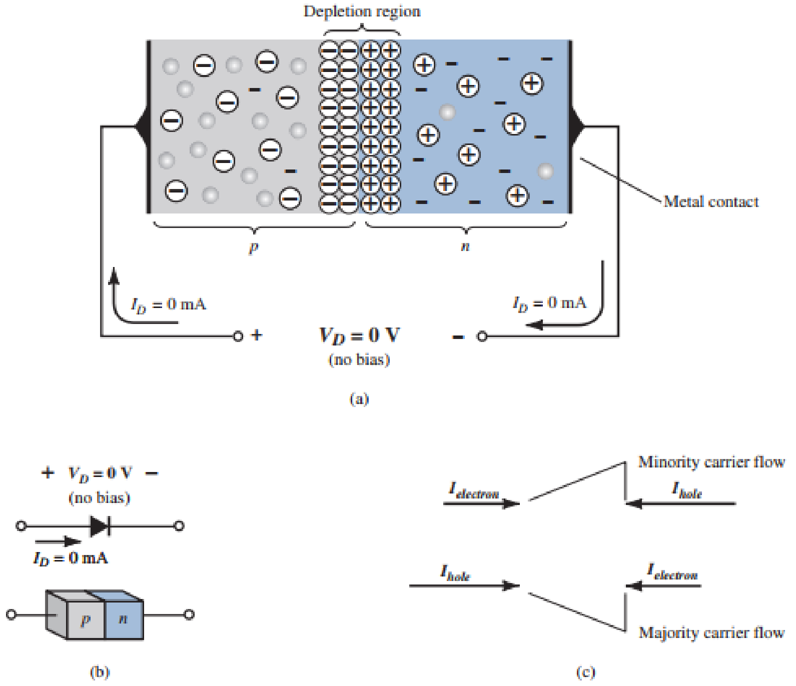


Figure: *A p–n junction with no external bias: (a) an internal distribution of charge; (b) a diode symbol, with the defined polarity and the current direction; (c) demonstration that the net carrier flow is zero at the external terminal of the device when $V_D = 0$ V.*

In the absence of an applied bias across a semiconductor diode, the net flow of charge in one direction is zero.

reverse-bias Condition ($V_D < 0$ V)

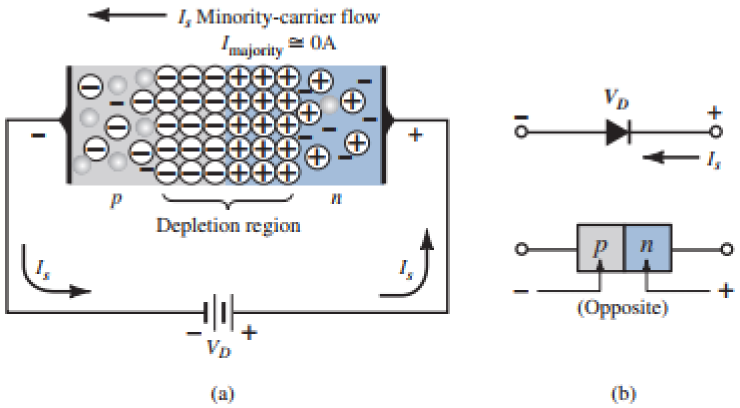


Figure: *Reverse-biased p–n junction: (a) internal distribution of charge under reverse-bias conditions; (b) reverse-bias polarity and direction of reverse saturation current.*

The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by Is.

Forward-bias Condition ($V_D > 0$ V)

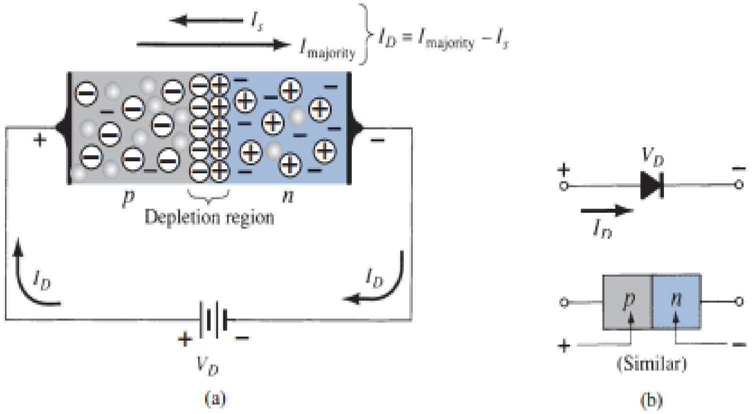


Figure: *Forward-biased p–n junction: (a) internal distribution of charge under forward-bias conditions; (b) forward-bias polarity and direction of resulting current.*

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

$$\boxed{V_T = \frac{kT_K}{q}}$$

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

Fahrenheit temperature conversion formula

	from Fahrenheit	to Fahrenheit
Celsius	[°C] = ([°F] − 32) × 5⁄9	[°F] = [°C] × 9⁄5 + 32
Kelvin	[K] = ([°F] + 459.67) × 5⁄9	[°F] = [K] × 9⁄5 − 459.67

Ideal versus practical

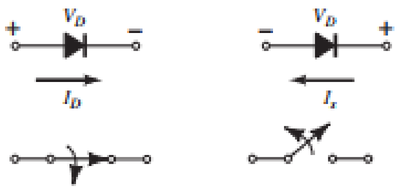
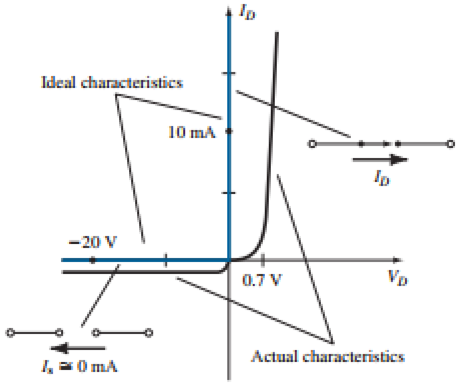


Figure: *Ideal semiconductor diode: (a) forward biased; (b) reverse-biased .*



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

In fact:

At any current level on the vertical line, the voltage across the ideal diode is 0 V and the resistance is 0 Ω.

For the horizontal section, if we again apply Ohm's law, we find

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

Again:

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.

Figure: *Ideal versus actual semiconductor characteristics.*

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.

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	I_D, $Q_{pt.}$, V_D
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	I_D, $Q_{pt.}$, ΔI_d, ΔV_d
Average ac	$r_{av} = \frac{\Delta V_d}{\Delta I_d}\Big\vert_{\text{pt. to pt.}}$	Defined by a straight line between limits of operation	ΔI_d, ΔV_d

Diode Equivalent Circuits (Models)

Type	Conditions	Model	Characteristics
Piecewise-linear model		V_K, r_{av}, Ideal diode	I_D, r_{av}, 0, V_K, V_D
Simplified model	$R_{\text{network}} \gg r_{av}$	V_K, Ideal diode	I_D, 0, V_K, V_D
Ideal device	$R_{\text{network}} \gg r_{av}$ $E_{\text{network}} \gg V_K$	Ideal diode	I_D, 0, V_D

Light emitting 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.

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

Q1. a. How much energy in joules is required to move a charge of 12 μC through a difference in potential of 6 V?

b. For part (a), find the energy in electron-volts.

Solution

a. $W = QV = (12\ \mu C)(6\ V) = 72\ \mu J$

b. $72 \times 10^{-6}\ J \left[\dfrac{1\ eV}{1.6 \times 10^{-19}\ J}\right] = 4.49 \times 10^{14}\ eV$

Q2. Describe the difference between *n*-type and *p*-type semiconductor materials.

An *n*-type semiconductor material has an excess of electrons for conduction established by doping an intrinsic material with donor atoms having more valence electrons than needed to establish the covalent bonding. The majority carrier is the electron while the minority carrier is the hole.

A *p*-type semiconductor material is formed by doping an intrinsic material with acceptor atoms having an insufficient number of electrons in the valence shell to complete the covalent bonding thereby creating a hole in the covalent structure. The majority carrier is the hole while the minority carrier is the electron.

Q3. Describe the difference between donor and acceptor impurities.

A donor atom has five electrons in its outermost valence shell while an acceptor atom has only 3 electrons in the valence shell.

Q4. Describe the difference between majority and minority carriers.

Majority carriers are those carriers of a material that far exceed the number of any other carriers in the material. Minority carriers are those carriers of a material that are less in number than any other carrier of the material.

Q5. Describe how you will remember the forward- and reverse-bias states of the *p–n* junction diode. That is, how will you remember which potential (positive or negative) is applied to which terminal?

For forward bias, the positive potential is applied to the *p*-type material and the negative potential to the *n*-type material

Q6. a. Determine the thermal voltage for a diode at a temperature of 20°C.

b. For the same diode of part (a), find the diode current if $I_s = 40$ nA, $n = 2$, and the applied bias voltage is 0.5 V.

Solution

a. $$V_T = \frac{kT_K}{q} = \frac{(1.38\times10^{-23}\ \text{J/K})(20°\text{C} + 273°\text{C})}{1.6\times10^{-19}\ \text{C}}$$

$$= \mathbf{25.27\ mV}$$

b. $$I_D = I_s(e^{V_D/nV_T} - 1)$$

$$= 40\ \text{nA}(e^{(0.5\ \text{V})/(2)(25.27\text{mV})} - 1)$$

$$= 40\ \text{nA}(e^{9.89} - 1) = \mathbf{0.789\ mA}$$

Q7. Given a diode current of 8 mA and n = 1, find I_s if the applied voltage is 0.5 V and the temperature is room temperature (25°C).

Solution

$$V_T = \frac{kT_K}{q} = \frac{(1.38\times10^{-23}\ \text{J/K})(25°\text{C} + 273°\text{C})}{1.6\times10^{-19}\ \text{C}}$$

$$= 25.70\ \text{mV}$$

$$I_D = I_s(e^{V_D/nV_T} - 1)$$

$$8\text{mA} = I_s(e^{(0.5\text{V})/(1)(25.70\ \text{mV})} - 1) = I_s(28\times10^8)$$

$$I_s = \frac{8\ \text{mA}}{2.8\times10^8} = \mathbf{28.57\ pA}$$

Q8. **Given a diode current of 6 mA, V_T = 26 mV, n=1, and I_s= 1 nA, find the applied voltage V_D.**

Solution

$$I_D = I_s(e^{V_D/nV_T} - 1)$$
$$6\text{ mA} = 1\text{ nA}(e^{V_D/(1)(26\text{ mV})} - 1)$$
$$6 \times 10^6 = e^{V_D/26\text{ mV}} - 1$$
$$e^{V_D/26\text{ mV}} = 6 \times 10^6 - 1 \cong 6 \times 10^6$$
$$\log_e e^{V_D/26\text{mV}} = \log_e 6 \times 10^6$$
$$\frac{V_D}{26\text{ mV}} = 15.61$$
$$V_D = 15.61(26\text{ mV}) \cong \mathbf{0.41\ V}$$

Q9. Given that E_g = 0.67 eV for germanium, find the wavelength of peak solar response for the material. Do the photons at this wavelength have a lower or higher energy level?

Solution

$$0.67\ \cancel{eV}\left[\frac{1.6\times10^{-19}\ \text{J}}{1\ \cancel{eV}}\right]=1.072\times10^{-19}\ \text{J}$$

$$E_g=\frac{hc}{\lambda}\Rightarrow\lambda=\frac{hc}{E_g}=\frac{(6.626\times10^{-34}\ \text{Js})(3\times10^{8})\ \text{m/s}}{1.072\times10^{-19}\ \text{J}}$$

$$=\mathbf{1850\ nm}$$

Very low energy level.

MCQ

(1) The term *electron current* means

(a) flow of free electrons
(b) flow of free holes
(c) flow of electrons or holes
(d) neither (a), (b), nor (c)

Answer: A

(2) To reverse-bias a diode,

(a) an external voltage source's positive terminal is connected at the anode and negative terminal at the cathode
(b) an external voltage source's negative terminal is connected at the anode and positive terminal at the cathode
(c) an external voltage source's positive terminal is connected at the *p* region and negative terminal at the *n* region
(d) both (a) and (c)

Answer: B

(3) When a diode is forward-biased,

(a) the only current is hole current
(b) the only current is electron current
(c) the only current is produced by majority carriers
(d) the current is produced by both holes and electrons

Answer: D

(4) Although current is blocked in reverse bias,

(a) there is some current due to majority carriers

(b) there is a very small current due to minority carriers

(c) there is an avalanche current

Answer: B

(5) For a silicon diode, the value of the forward-bias voltage typically

(a) must be greater than 0.3 V

(b) must be greater than 0.7 V

(c) depends on the width of the depletion region

(d) depends on the concentration of majority carriers

Answer: B

(6) Avalanche effect occurs

(a) in reverse bias

(b) in forward bias

(c) in both reverse bias and forward bias

(d) neither in reverse bias nor in forward bias

Answer: A

(7) A diode is normally operated in

(a) reverse breakdown
(b) the forward-bias region
(c) the reverse-bias region
(d) either (b) or (c)

Answer: D

(8) The dynamic resistance can be important when a diode is

(a) reverse-biased
(b) forward-biased
(c) in reverse breakdown
(d) unbiased

Answer: B

(9) The *V-I* curve for a diode shows

(a) the voltage across the diode for a given current
(b) the amount of current for a given bias voltage
(c) the power dissipation
(d) none of these

Answer: A

(10) Ideally, a diode can be represented by a

(a) voltage source (b) resistance (c) switch (d) all of these

Answer: C

(11) In the practical diode model,

(a) the barrier potential is taken into account

(b) the forward dynamic resistance is taken into account

(c) none of these

(d) both (a) and (b)

Answer: A

(12) In the complete diode model,

(a) the barrier potential is taken into account

(b) the forward dynamic resistance is taken into account

(c) the reverse resistance is taken into account

(d) all of these

Answer: D