3–4 OPTICAL DIODES

In this section, three types of optoelectronic devices are introduced: the light-emitting diode, quantum dots, and the photodiode. As the name implies, the light-emitting diode is a light emitter. Quantum dots are very tiny light emitters made from silicon with great promise for various devices, including light-emitting diodes. On the other hand, the photodiode is a light detector.

After completing this section, you should be able to

- **Discuss the basic characteristics, operation, and applications of LEDs, quantum dots, and photodiodes**
- Describe the light-emitting diode (LED)
  ◆ Identify the LED schematic symbol ◆ Discuss the process of electroluminescence ◆ List some LED semiconductor materials ◆ Discuss LED biasing ◆ Discuss light emission
- Interpret an LED datasheet
  ◆ Define and discuss radiant intensity and irradiance
- Describe some LED applications
- Discuss high-intensity LEDs and applications
  ◆ Explain how high-intensity LEDs are used in traffic lights ◆ Explain how high-intensity LEDs are used in displays
- Describe the organic LED (OLED)
- Discuss quantum dots and their application
- Describe the photodiode and interpret a typical datasheet
  ◆ Discuss photodiode sensitivity

The Light-Emitting Diode (LED)

The symbol for an LED is shown in Figure 3–28.

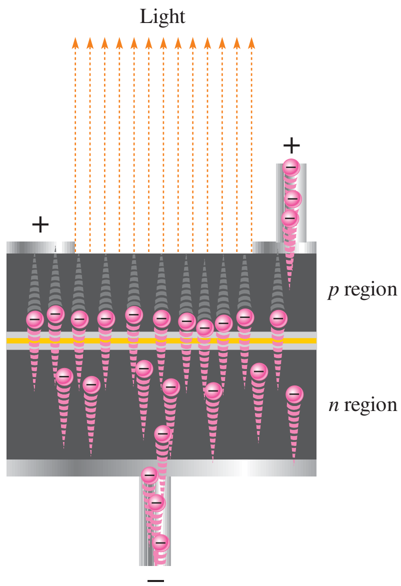
▲ FIGURE 3–28

Symbol for an LED. When forward-biased, it emits light.

The basic operation of the **light-emitting diode (LED)** is as follows. When the device is forward-biased, electrons cross the *pn* junction from the *n*-type material and recombine with holes in the *p*-type material. Recall from Chapter 1 that these free electrons are in the conduction band and at a higher energy than the holes in the valence band. The difference in energy between the electrons and the holes corresponds to the energy of visible light. When recombination takes place, the recombining electrons release energy in the form of **photons.** The emitted light tends to be monochromatic (one color) that depends on the band gap (and other factors). A large exposed surface area on one layer of the semiconductive material permits the photons to be emitted as visible light. This process, called **electroluminescence**, is illustrated in Figure 3–29. Various impurities are added during the doping process to establish the **wavelength** of the emitted light. The wavelength determines the color of visible light. Some LEDs emit photons that are not part of the visible spectrum but have longer wavelengths and are in the **infrared** (IR) portion of the spectrum.

LED Semiconductor Materials The semiconductor gallium arsenide (GaAs) was used in early LEDs and emits IR radiation, which is invisible. The first visible red LEDs were produced using gallium arsenide phosphide (GaAsP) on a GaAs substrate. The efficiency was increased using a gallium phosphide (GaP) substrate, resulting in brighter red LEDs and also allowing orange LEDs.

Later, GaP was used as the light-emitter to achieve pale green light. By using a red and a green chip, LEDs were able to produce yellow light. The first super-bright red, yellow, and green LEDs were produced using gallium aluminum arsenide phosphide (GaAlAsP). By the early 1990s ultrabright LEDs using indium gallium aluminum phosphide (InGaAlP) were available in red, orange, yellow, and green.



▶ FIGURE 3–29

Electroluminescence in a forward-biased LED.

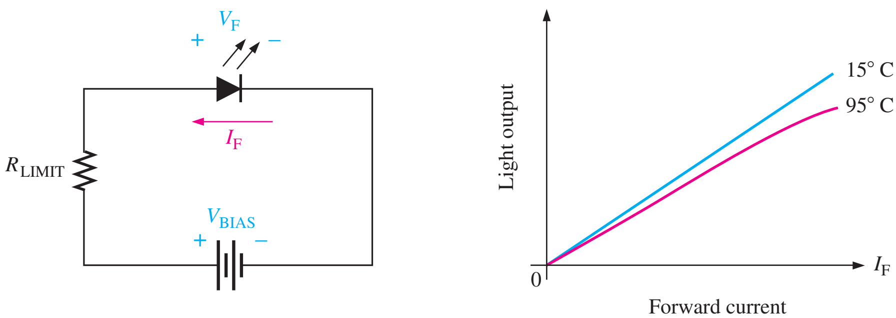
FYI

Efficiency is a term used in many fields to show how well a particular process works. It is the ratio of the output to the input and is a dimensionless number, often expressed as a percentage. An efficiency of 100% is the theoretical maximum that can never be achieved in real systems. For lighting, the term *efficacy* is used with units of lumens per watt and is related to the efficiency of converting input power (in watts) to light that can be seen by the human eye (lumens). The theoretical maximum efficacy is 683 lumens/watt.

Blue LEDs using silicon carbide (SiC) and ultrabright blue LEDs made of gallium nitride (GaN) became available. High intensity LEDs that produce green and blue are also made using indium gallium nitride (InGaN). High-intensity white LEDs are formed using ultrabright blue GaN coated with fluorescent phosphors that absorb the blue light and reemit it as white light.

LED Biasing The forward voltage across an LED is considerably greater than for a silicon diode. Typically, the maximum V_F for LEDs is between 1.2 V and 3.2 V, depending on the material. Reverse breakdown for an LED is much less than for a silicon rectifier diode (3 V to 10 V is typical).

The LED emits light in response to a sufficient forward current, as shown in Figure 3–30(a). The amount of power output translated into light is directly proportional to the forward current, as indicated in Figure 3–30(b). An increase in I_F corresponds proportionally to an increase in light output. The light output (both intensity and color) is also dependent on temperature. Light intensity goes down with higher temperature as indicated in the figure.



(a) Forward-biased operation

(b) General light output versus forward current for two temperatures

▲ FIGURE 3–30

Basic operation of an LED.

Light Emission An LED emits light over a specified range of wavelengths as indicated by the **spectral** output curves in Figure 3–31. The curves in part (a) represent the light output versus wavelength for typical visible LEDs, and the curve in part (b) is for a typical infrared LED. The wavelength (λ) is expressed in nanometers (nm). The normalized output of the visible red LED peaks at 660 nm, the yellow at 590 nm, green at 540 nm, and blue at 460 nm. The output for the infrared LED peaks at 940 nm.