# Chapter 41

## Conduction of Electricity in Solids

# 41.3: The p-n junction and the Transistor:

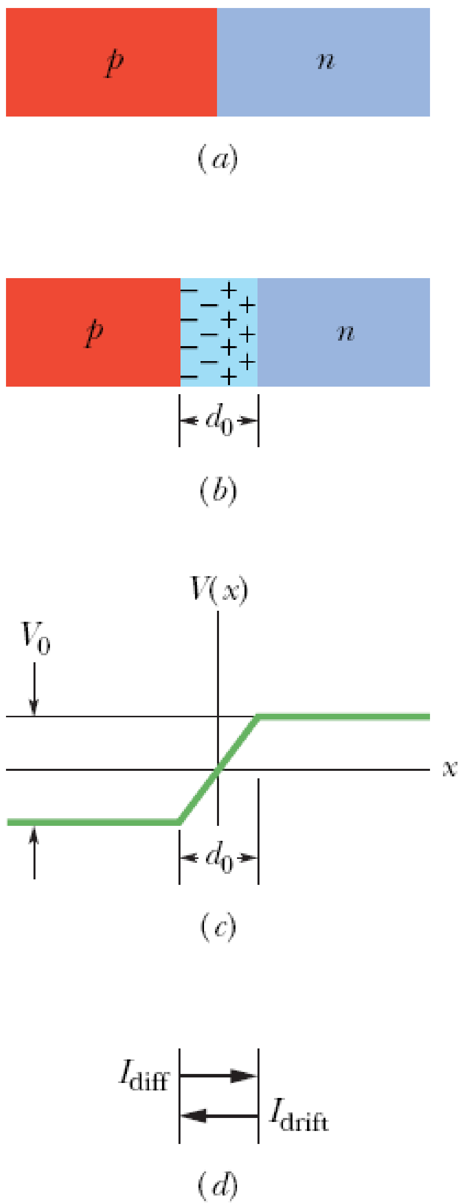


**Fig. 41-12** (*a*) A *p-n* junction. (*b*) Motions of the majority charge carriers across the junction plane uncover a space charge associated with uncompensated donor ions (to the right of the plane) and acceptor ions (to the left). (*c*) Associated with the space charge is a contact potential difference $V_0$ across $d_0$. (*d*) The diffusion of majority carriers (both electrons and holes) across the junction plane produces a diffusion current $I_{diff}$. (In a real *p-n* junction, the boundaries of the depletion zone would not be sharp, as shown here, and the contact potential curve (*c*) would be smooth, with no sharp corners.)

## Checkpoint 2

Which of the following five currents across the junction plane of Fig. 41-12*a* must be zero?

(a) the net current due to holes, both majority and minority carriers included
(b) the net current due to electrons, both majority and minority carriers included
(c) the net current due to both holes and electrons, both majority and minority carriers included
(d) the net current due to majority carriers, both holes and electrons included
(e) the net current due to minority carriers, both holes and electrons included

a, b, and c

# The Junction Rectifier:

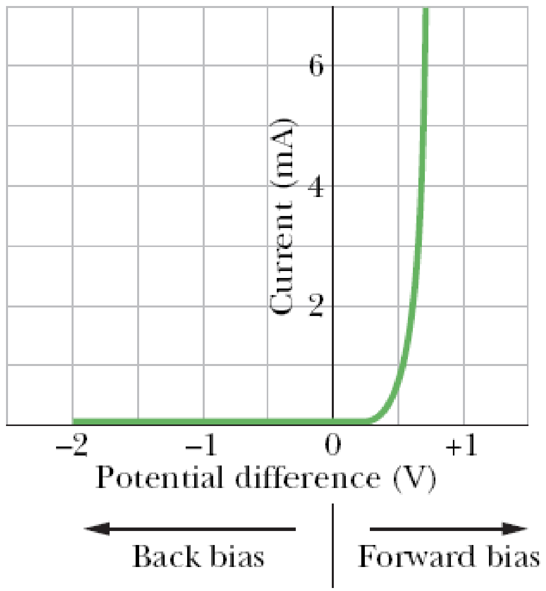


**Fig. 41-13** A current–voltage plot for a *p-n* junction, showing that the junction is highly conducting when forward-biased and essentially nonconducting when back-biased.

If a potential difference is applied across a *p-n junction* in one direction (here labeled and "Forward bias"), there will be a current through the junction.

However, if the direction of the potential Difference is reversed, there will be approximately zero current through the junction.

# The Junction Rectifier, An Example:

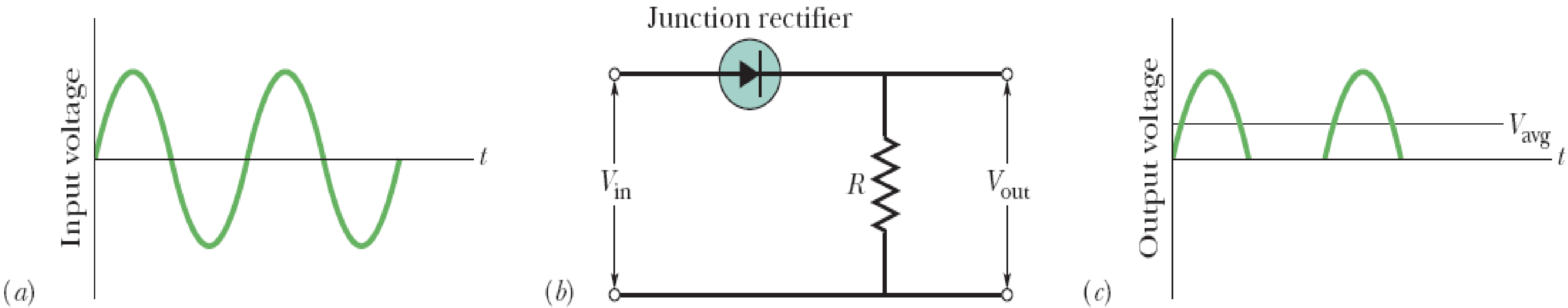


**Fig. 41-14** A *p-n* junction connected as a junction rectifier. The action of the circuit in (*b*) is to pass the positive half of the input wave form in (*a*) but to suppress the negative half. The average potential of the input wave form is zero; that of the output wave form in (*c*) has a positive value $V_{avg}$.

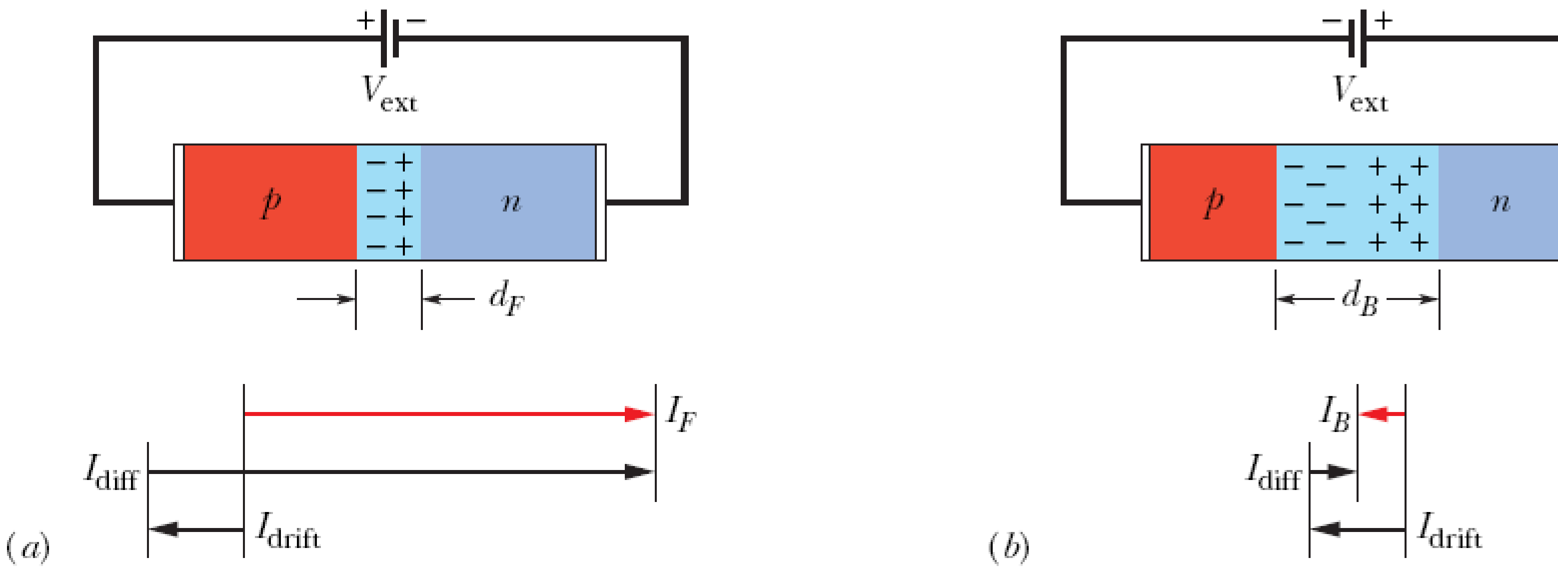


**Fig. 41-15** (*a*) The forward-bias connection of a *p-n* junction, showing the narrowed depletion zone and the large forward current $I_F$. (*b*) The back-bias connection, showing the widened depletion zone and the small back current $I_B$.

# The Light-Emitting Diode (LED):

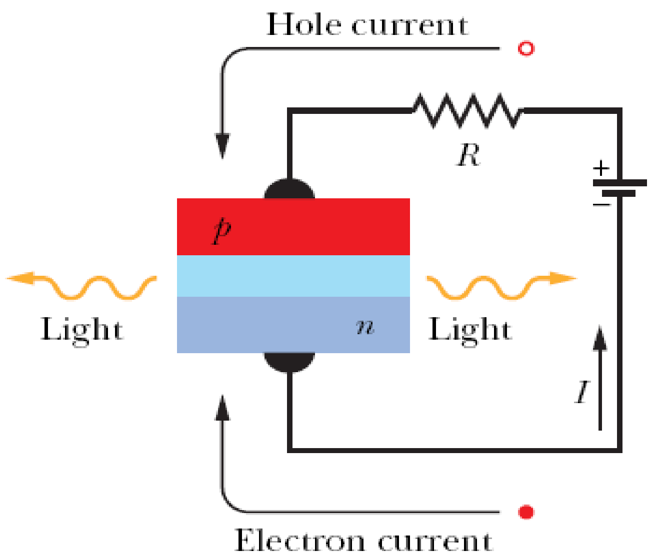


**Fig. 41-16** A forward-biased *p-n* junction, showing electrons being injected into the *n*-type material and holes into the *p*-type material. (Holes move in the conventional direction of the current *I*, equivalent to electrons moving in the opposite direction.) Light is emitted from the narrow depletion zone each time an electron and a hole combine across that zone.

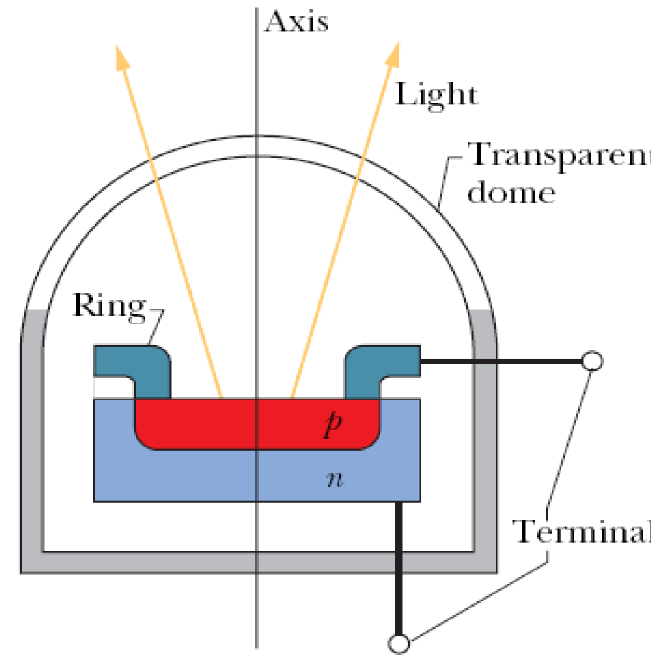


**Fig. 41-17** Cross section of an LED (the device has rotational symmetry about the central axis). The *p*-type material, which is thin enough to transmit light, is in the form of a circular disk. A connection is made to the *p*-type material through a circular metal ring that touches the disk at its periphery. The depletion zone between the *n*-type material and the *p*-type material is not shown.

In some semiconductors, including gallium arsenide, the energy can be emitted as a photon of energy $hf$ at wavelength

$$\lambda = \frac{c}{f} = \frac{c}{E_g/h} = \frac{hc}{E_g}.$$

# The Light-Emitting Diode (LED):

**Photodiode**

Shining light on a suitably arranged p-n junction can produce a current in a circuit that includes the junction. This is the basis for the photodiode.

**The Junction Laser**

A p-n junction can act as a junction laser, where its light output being highly coherent and much more sharply defined in wavelength than light from an LED.

**Fig. 41-18** A junction laser developed at the AT&T Bell Laboratories. The cube at the right is a grain of salt. *(Courtesy AT&T Archives and History Center, Warren, NJ)*

## Sample Problem 41.07 Light-emitting diode (LED)

An LED is constructed from a $p$-$n$ junction based on a certain Ga-As-P semiconducting material whose energy gap is 1.9 eV. What is the wavelength of the emitted light?

***Calculation:*** For jumps from the bottom of the conduction band to the top of the valence band, Eq. 41-11 tells us

$$\lambda = \frac{hc}{E_g} = \frac{(6.63 \times 10^{-34}\ \mathrm{J \cdot s})(3.00 \times 10^{8}\ \mathrm{m/s})}{(1.9\ \mathrm{eV})(1.60 \times 10^{-19}\ \mathrm{J/eV})}$$

$$= 6.5 \times 10^{-7}\ \mathrm{m} = 650\ \mathrm{nm}. \qquad \text{(Answer)}$$

Light of this wavelength is red.

# The Transistor:

A transistor is a three-terminal semiconducting device that can be used to amplify input signals.

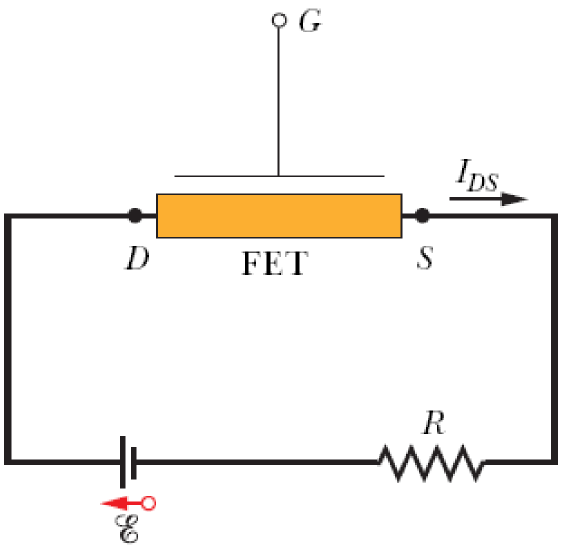


**Fig. 41-19** A circuit containing a generalized field-effect transistor through which electrons flow from the source terminal $S$ to the drain terminal $D$. (The conventional current $I_{DS}$ is in the opposite direction.) The magnitude of $I_{DS}$ is controlled by the electric field set up within the FET by a potential applied to $G$, the gate terminal.

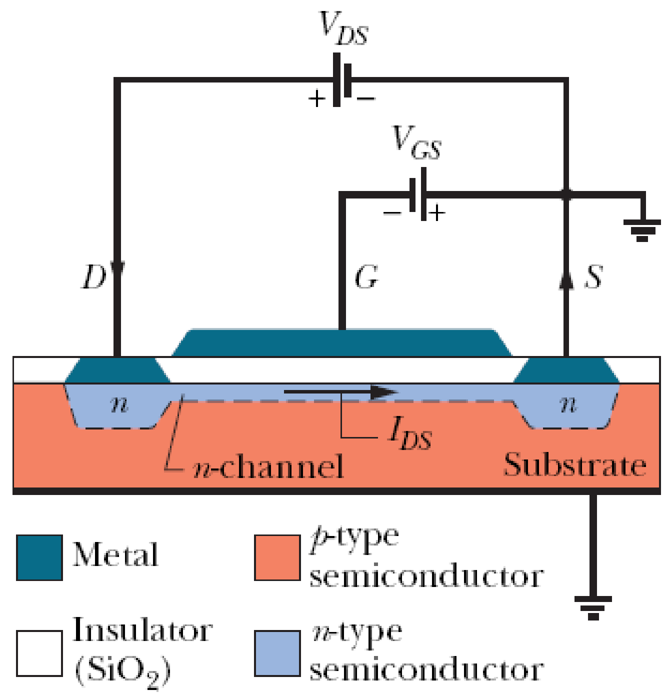


**Fig. 41-20** A particular type of field-effect transistor known as a MOSFET. The magnitude of the drain-to-source conventional current $I_{DS}$ through the $n$ channel is controlled by the potential difference $V_{GS}$ applied between the source $S$ and the gate $G$. A depletion zone that exists between the $n$-type material and the $p$-type substrate is not shown.