4.7.2 Varactors

In Chapter 3 we learned that reverse-biased *pn* junctions exhibit a charge-storage effect that is modeled with the depletion-layer or junction capacitance C_j. As Eq. (3.49) indicates, C_j is a function of the reverse-bias voltage V_R. This dependence turns out to be useful in a number of applications, such as the automatic tuning of radio receivers. Special diodes are therefore fabricated to be used as voltage-variable capacitors known as **varactors**. These devices are optimized to make the capacitance a strong function of voltage by arranging that the grading coefficient m is 3 or 4.

4.7.3 Photodiodes

If a reverse-biased *pn* junction is illuminated—that is, exposed to incident light—the photons impacting the junction cause covalent bonds to break, and thus electron-hole pairs are generated in the depletion layer. The electric field in the depletion region then sweeps the liberated electrons to the n side and the holes to the p side, giving rise to a reverse current across the junction. This current, known as photocurrent, is proportional to the intensity of the incident light. Such a diode, called a photodiode, can be used to convert light signals into electrical signals.

Photodiodes are usually fabricated using a compound semiconductor[7] such as gallium arsenide. The photodiode is an important component of a growing family of circuits known as **optoelectronics** or **photonics**. As the name implies, such circuits utilize an optimum combination of electronics and optics for signal processing, storage, and transmission. Usually, electronics is the preferred means for signal processing, whereas optics is most suited for transmission and storage. Examples include fiber-optic transmission of telephone and television signals and the use of optical storage in CD-ROM computer discs. Optical transmission provides very wide bandwidths and low signal attenuation. Optical storage allows vast amounts of data to be stored reliably in a small space.

Finally, we should note that without reverse bias, the illuminated photodiode functions as a **solar cell**. Usually fabricated from low-cost silicon, a solar cell converts light to electrical energy.

4.7.4 Light-Emitting Diodes (LEDs)

The light-emitting diode (LED) performs the inverse of the function of the photodiode; it converts a forward current into light. The reader will recall from Chapter 3 that in a forward-biased *pn* junction, minority carriers are injected across the junction and diffuse into the p and n regions. The diffusing minority carriers then recombine with the majority carriers. Such recombination can be made to give rise to light emission. This can be done by fabricating the *pn* junction using a semiconductor of the type known as direct-bandgap materials. Gallium arsenide belongs to this group and can thus be used to fabricate light-emitting diodes.

The light emitted by an LED is proportional to the number of recombinations that take place, which in turn is proportional to the forward current in the diode.

[7]Whereas an elemental semiconductor, such as silicon, uses an element from column IV of the periodic table, a compound semiconductor uses a combination of elements from columns III and V or II and VI. For example, GaAs is formed of gallium (column III) and arsenic (column V) and is thus known as a III-V compound.

LEDs are very popular devices. They find application in the design of numerous types of displays, including the displays of laboratory instruments such as digital voltmeters. They can be made to produce light in a variety of colors. Furthermore, LEDs can be designed so as to produce coherent light with a very narrow bandwidth. The resulting device is a **laser diode**. Laser diodes find application in optical communication systems and in DVD players, among other things.

Combining an LED with a photodiode in the same package results in a device known as an **optoisolator**. The LED converts an electrical signal applied to the optoisolator into light, which the photodiode detects and converts back to an electrical signal at the output of the optoisolator. Use of the optoisolator provides complete electrical isolation between the electrical circuit that is connected to the isolator's input and the circuit that is connected to its output. Such isolation can be useful in reducing the effect of electrical interference on signal transmission within a system, and thus optoisolators are frequently employed in the design of digital systems. They can also be used in the design of medical instruments to reduce the risk of electrical shock to patients.

Note that the optical coupling between an LED and a photodiode need not be accomplished inside a small package. Indeed, it can be implemented over a long distance using an optical fiber, as is done in fiber-optic communication links.

FROM INDICATION TO ILLUMINATION:

Light-emitting diodes (LEDs), which once served only as low-powered status indicators, are now lighting our way! Increasingly, automotive lighting uses LEDs; increasingly, too, LED bulbs of higher and higher power are replacing both incandescent and fluorescent lighting in homes and offices. Incandescent bulbs are only 5% efficient in the conversion of electricity into light—the other 95% is dissipated as heat. The light conversion efficiency of LEDs, however, is 60%. Moreover, LEDs last 25 times longer (25,000 hours) than incandescent bulbs and 3 times longer than fluorescents.

Summary

- In the forward direction, the ideal diode conducts any current forced by the external circuit while displaying a zero voltage drop. The ideal diode does not conduct in the reverse direction; any applied voltage appears as reverse bias across the diode.
- The unidirectional-current-flow property makes the diode useful in the design of rectifier circuits.
- The forward conduction of practical silicon-junction diodes is accurately characterized by the relationship $i = I_S e^{v/V_T}$.
- A silicon diode conducts a negligible current until the forward voltage is at least 0.5 V. Then the current increases rapidly, with the voltage drop increasing by 60 mV for every decade of current change.
- In the reverse direction, a silicon diode conducts a current on the order of 10^{-9} A. This current is much greater than I_S because of leakage effects and increases with the magnitude of reverse voltage.
- Beyond a certain value of reverse voltage (that depends on the diode), breakdown occurs, and current increases rapidly with a small corresponding increase in voltage.
- Diodes designed to operate in the breakdown region are called zener diodes. They are employed in the design of voltage regulators whose function is to provide a constant dc voltage that varies little with variations in power-supply voltage and/or load current.