2-15 Reverse-Biased Diode

Let's discuss a few advanced ideas about a reverse-biased diode. To begin with, the depletion layer changes in width when the reverse voltage changes. Let us see what this implies.

Transient Current

When the reverse voltage increases, holes and electrons move away from the junction. As the free electrons and holes move away from the junction, they leave positive and negative ions behind. Therefore, the depletion layer gets wider. The greater the reverse bias, the wider the depletion layer becomes. While the depletion layer is adjusting to its new width, a current flows in the external circuit. This transient current drops to zero after the depletion layer stops growing.

The amount of time the transient current flows depends on the *RC* time constant of the external circuit. It typically happens in a matter of nanoseconds. Because of this, you can ignore the effects of the transient current below approximately 10 MHz.

Reverse Saturation Current

As discussed earlier, forward-biasing a diode raises the *n* band and allows free electrons to cross the junction. Reverse bias has the opposite effect: It widens the depletion layer and lowers the *n* band, as shown in Fig. 2-27.

Here is the energy viewpoint on reverse saturation. Suppose that thermal energy creates a hole and free electron inside the depletion layer, as shown in Fig. 2-27. The free electron at *A* and the hole at *B* can now contribute to reverse current. Because of the reverse bias, the free electron will move to the right, effectively pushing an electron out of the right end of the diode. Similarly, the hole will move to the left. This extra hole on the *p* side lets an electron enter the left end of the crystal.

The higher the junction temperature, the greater the saturation current. A useful approximation to remember is this: I_S doubles for each 10°C rise. As a derivation,

$$\textbf{Percent } \Delta I_S = \textbf{100\% for a 10°C increase} \tag{2-5}$$

In words, the change in saturation current is 100 percent for each 10°C rise in temperature. If the changes in temperature are less than 10°C, you can use this equivalent rule:

$$\textbf{Percent } \Delta I_S = \textbf{7\% per °C} \tag{2-6}$$

In words, the change in saturation current is 7 percent for each Celsius degree rise. This 7 percent solution is a close approximation of the 10° rule.

Figure 2-27 Thermal energy produces free electron and hole inside depletion layer.

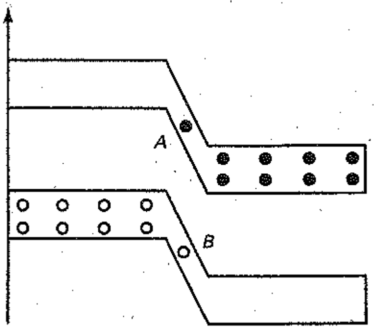
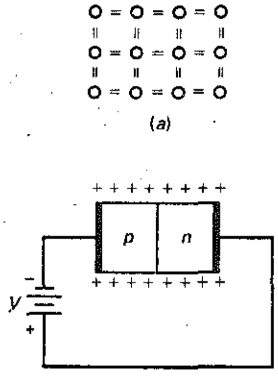


Figure 2-28 (*a*) Atoms on the surface of a crystal have no neighbors; (*b*) surface of crystal has holes.



(*a*) (*b*)

Silicon versus Germanium

In a silicon atom, the distance between the valence band and the conduction band is called the *energy gap.* When thermal energy produces free electrons and holes, it has to give the valence electrons enough energy to jump into the conduction band. The larger the energy gap, the more difficult it is for thermal energy to produce electron-hole pairs. Fortunately, silicon has a large energy gap; this means that thermal energy does not produce many electron-hole pairs at normal temperatures.

In a germanium atom the valence band is much closer to the conduction band. In other words, germanium has a much smaller energy gap than silicon has. For this reason, thermal energy produces many more electron-hole pairs in germanium devices. This is the fatal flaw mentioned earlier. The excessive reverse current of germanium devices precludes their widespread use in modern computers, consumer electronics, and communications circuits.

Surface-Leakage Current

We discussed surface-leakage current briefly in Sec. 2-10. Recall that it is a reverse current on the surface of the crystal. Here is an explanation of why surface-leakage current exists. Suppose that the atoms at the top and bottom of Fig. 2-28*a* are on the surface of the crystal. Since these atoms have no neighbors, they have only six electrons in the valence orbit, implying two holes in each surface atom. Visualize these holes along the surface of the crystal shown in Fig. 2-28*b*. Then you can see that the skin of a crystal is like a *p*-type semiconductor. Because of this, electrons can enter the left end of the crystal, travel through the surface holes, and leave the right end of the crystal. In this way, we get a small reverse current along the surface.

The surface-leakage current is directly proportional to the reverse voltage. For instance, if you double the reverse voltage, the surface-leakage current I_{SL} doubles. We can define the surface-leakage resistance as follows:

$$R_{SL} = \frac{V_R}{I_{SL}} \tag{2-7}$$

Example 2-6

A silicon diode has a saturation current of 5 nA at 25°C. What is the saturation current at 100°C?

SOLUTION The change in temperature is:

$$\Delta T = 100^\circ\text{C} - 25^\circ\text{C} = 75^\circ\text{C}$$

With Eq. (2-5), there are seven doublings between 25°C and 95°C:

$$I_S = (2^7)(5\ \text{nA}) = 640\ \text{nA}$$

With Eq. (2-6), there are an additional 5° between 95°C and 100°C:

$$I_S = (1.07^5)(640\ \text{nA}) = 898\ \text{nA}$$

PRACTICE PROBLEM 2-6 Using the same diode as in Example 2-6, what would be the saturation current at 80°C?