CHAPTER 13: More Diodes

In this chapter we'll look at four other types of diodes: Schottky diodes, Zener/avalanche diodes, light-emitting diodes (LEDs) and photodiodes.

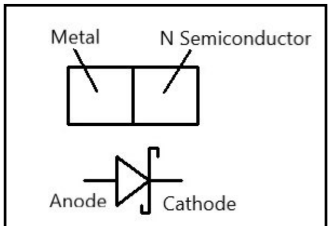

Figure 13.1. Schottky diode.

Schottky diodes. They work – and look – like standard diodes but are built differently. Instead of a P-N junction, the junction is between metal and doped semiconductor – usually N type (see Figure 13.1). The metal is the anode: the cathode is the N semiconductor. This is sort of like the old crystal radio detectors, where a "cat's whisker" wire touched the crystal. The standard symbol, seen in the figure, looks like the normal diode but with some extra lines added. P types also are made.

Schottky diodes have lower forward voltage drops and faster reverse recovery than P-N. At milliamp currents the forward drop may be around 0.4 V, versus around 0.7 V for P-N diodes. Lower voltage means higher efficiency. When used in the power rectifier circuits we saw in Chapter 12, smaller voltage drops means less power loss (V x I), less heating and a slightly higher rectified voltage. Another use is with photocells, placed between the cells and batteries to prevent reverse-current discharging when the photocells are dark. Again, smaller voltage drop means higher efficiency.

Faster reverse recovery means better operation in high-speed switching and RF circuits. Schottky and junction diodes both have capacitance, as mentioned in the last chapter. If the voltage to the diode is switched quickly from forward to reverse, the charge stored in the capacitance will supply reverse current for a very short time (nanoseconds or picoseconds). P-N junctions, though, also have another charge storage effect, called minority carrier recombination. We won't try to get technical, but just think of it as the time it takes to clear the holes and electrons out of the junction's depletion region. (See Figure 12.6 in the last chapter.) The total reverse recovery time is longer than for just capacitance. Schottkys are preferred in high frequency switching power supplies.

As always, there are tradeoffs. Most Schottky diodes have lower reverse breakdown voltage, often 50 volts or less. Schottkys with higher reverse breakdown also have higher forward voltage drop, reducing their efficiency advantage. For diodes rated above 100 V the forward voltage drops can be as great as, or greater than, standard P-N diodes. Schottky diodes also have higher reverse leakage current and lower maximum operating temperature than P-N diodes. Some diode design approaches used raise the maximum reverse voltage also increase the junction capacitance.

Like standard diodes, many styles, sizes and power ratings are available. Some are small, optimized for very high frequencies and picosecond recovery. Others are large, meant for power, and have higher capacitance. As always, consider which specifications are most important for you when choosing a diode, whether Schottky or standard.

Zener and avalanche diodes. They're made differently and serve a different purpose: voltage regulation and control. Figure 13.2 shows their symbol, similar to the standard diode symbol except the ends of the line are slanted. Zener and avalanche diodes both act the same but operate differently internally. Avalanche diodes usually are also called Zeners. We'll do that here.

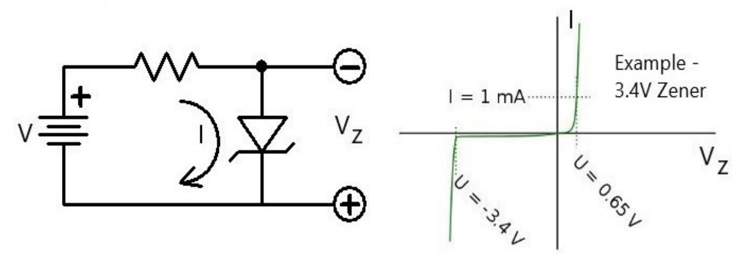

Figure 13.2. Zener diode. Forward conduction is shown. Zener breakdown occurs when the voltage and current are reversed. (Graph is from Wikipedia article on Zener diodes.)

In Zener diodes, the reverse breakdown voltage is carefully controlled. The circuit in Figure 13.2 shows the forward connection. Zener operation happens when the voltage and current are reversed. Look at the graph. If the source voltage, V, is reversed and is below the Zener voltage, the Zener will not conduct (except for a little leakage current). Once V exceeds Vz the Zener will conduct, holding a constant voltage. Raising V higher will increase the current but the Zener's voltage will stay constant - approximately. They're not perfect: the voltage will rise a bit as current increases. Available Zener voltages range from a few volts to over 200 V.

Also shown by the graph: in the forward direction, most Zeners will conduct like any other diode. There are exceptions: we'll touch on that in a bit. They also have maximum power or current ratings, always shown on the spec sheets. Remember that power equals voltage times current so, for any given power rating, higher voltage Zeners have lower current limits. Just like regular diodes, available types vary from micro size to large styles with high power ratings.

Zener Reference Diodes. Like most components, Zener diodes are affected by temperature. Low voltage Zeners have negative temperature coefficients or "tempcos" (voltage decreases with temperature); high voltage Zeners, positive tempcos. At around 5.6 volts, the tempco is just above zero.

For designs needing a voltage that doesn't change with temperature, manufacturers have created zero tempco reference Zeners. Remember that a P-N diode's *forward* voltage has a negative tempco, dropping about 2 millivolts per degree C. By integrating a forward-biased diode in series with a 5.6 volt Zener and using careful manufacturing processes, a 6.2 volt Zener is created having near-zero drift. Figure 13.3 shows the concept. The added diode blocks current in its reverse direction. This type of Zener will not conduct if its polarity is reversed.

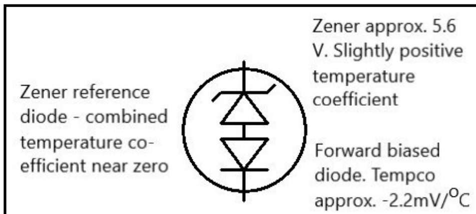

Figure 13.3. Voltage reference Zener.

Reference diodes have tight tolerance on the tempco but not on the voltage. Most reference diodes have $\pm$5% (5.9 to 6.5V) tolerance: 2% and 1% are available. Temperature coefficients from $\pm$100 ppm/^{O}C (0.01% change per degree C) to 5 ppm/^{O}C (0.0005%/^{O}C). are available.

Today's low-voltage circuits usually need references lower than 6.2V. Reference Zeners have largely been replaced by voltage reference ICs, which can be lower voltage, closer tolerance and less expensive. Some are adjustable. We may discuss them in a later chapter.

LEDs – Light Emitting Diodes. Good grief – how can a little piece of crystal emit light?

Most of us just accept the fact that LEDs work. We've all seen them everywhere, from LED watches to car headlights and more. However, here's an attempt at a brief, over-simplified explanation, maybe not 100% correct. (I've seen worse explanations, believe me.)

When a diode is forward biased the electrons gain energy to jump to a higher energy state (the valence band). They move into the junction, where they combine with holes. (For review, see Chapter 11.) When they combine they drop back to a lower state (a lower level electron shell). The energy difference is the "bandgap" – a voltage difference.

When they drop, they give off energy. The form of the energy is determined by the bandgap voltage. In regular diodes, the energy is heat. In LEDs, the bandgap is set to emit photons – light. The bandgap width, or voltage, determines the wavelength. This, in turn, is set by the materials and doping used. Most LEDs are not silicon: alloys of gallium and indium often are used. There also are organic LEDs, which we will not cover here.

Figure 13.4 (next page) shows an LED in a simple circuit. The LED's symbol is a diode with a couple arrows added to indicate light.

In this circuit the resistor sets the LED's current: I = (V - Vd) /R. Vd, the diode's voltage drop, is higher than for normal diodes – typically 2 volts or more. One other note: most LEDs have low reverse-voltage breakdown. If a reverse voltage higher than a few volts is applied, the diode will break down and conduct (no light) or possibly be damaged.

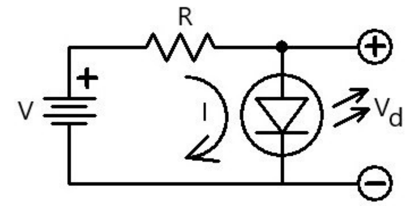

Figure 13.4. Simple LED circuit. Vd typically is 2 to 3 volts.

Two-color LEDs. A two-color LED is just two LEDs in the same package. The color is selected by changing the connections – see Figure 13.5. Two connection styles are available. 13.5a shows three terminals. The color is chosen by which anode connection is used. Connecting to both lights both LEDs which may, depending on how the LED is built, look like a third color.

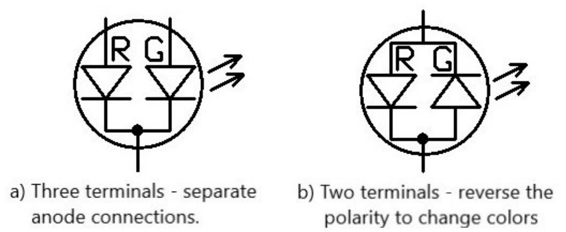

Figure 13.5. Two-color LEDs contain two individual LEDs.

13.5b has only two terminals. Only one LED can be lit at a time; however, if you apply an AC voltage the two will alternate and it will be as if both are lit at once.

White LEDs. Most white LEDs use phosphor coatings to create white light. The LED itself is blue: the phosphors absorb some of this light and give off colors from red through green, much of it yellowish. The colors combine with the blue to create white. Some do not use phosphors, but instead combine yellow and blue in series to look like white.

Electrically, they operate just like any other LED, with a voltage drop around 3 volts. If you search, you will find white LED components requiring 6, 9, 18 or more volts. These generally are two, three or several LEDs in series within a single package.

Photodiodes. A photodiode is the reverse of an LED – it converts light to current.

Figure 13.6 shows the symbol and its internal equivalent circuit. The symbol is like the LED except with the arrows reversed – incoming light instead of radiated.

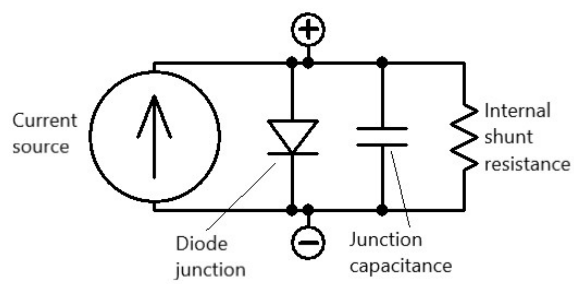

Figure 13.6. Photodiode equivalent circuit.

Light generates a current flowing out of the anode – anode positive. If the diode is open circuit, not connected to anything, it generates a voltage limited by the diode's forward voltage and internal shunt resistance.

Figure 13.7 shows two operating modes – photovoltaic and photoconductive. In the photovoltaic mode it acts much like a solar cell, generating a current. The load resistance should be small to keep the voltage below the diode's forward voltage. Op amp circuits often are used to create the equivalent of a short circuit (a subject for a later chapter).

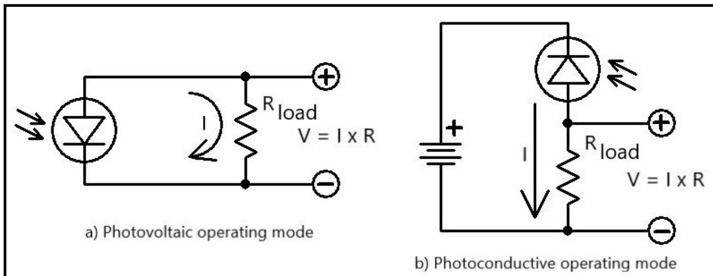

Figure 13.7. Photodiodes: two operating modes.

In the photoconductive mode the diode is reverse biased and the current flows through the load resistor. When dark, only a small leakage current flows. One advantage of reverse bias is, the junction's depletion region gets wider and its capacitance lower (see chapter 12). This increases the response speed when receiving high speed digital pulses.

There also are phototransistors, similar to photodiodes except that the transistor's gain can be used in circuits to amplify the current.

Footnotes:

1. Schottky – named for German physicist Walter H. Schottky, who did significant electronics work in the early 1900s.
2. Zener – named for Clarence M. Zener, an American physicist whose work included the physics of electrical insulator breakdown. Bell Labs used his findings and named the Zener diode after him.