UNDERSTANDING SEMICONDUCTORS

By William R. Hoffman

Most of us at one time or another have built some of the projects published in the ELECTRONICS HANDBOOK, or elsewhere; a power supply, or a light dimmer, or any one of a multitude of other projects that have been published. Some of us have also found ourselves wondering about what the semiconductor devices that we commonly use are really like—what's inside them? For others, trying to design and/or fabricate a PC board for a project has been a problem because some of the parts must be measured for their dimensions and lead orientation before proceeding. This short series covering diodes, transistors, and FET's should help the reader have a better understanding of these very important, indeed integral, parts to almost every electronic project.

Start With Diodes

The diode is a passive device, very much like a resistor or capacitor, yet it has one very important difference—a unique property all its own—current, from a battery or other power source, normally passes through it in only one direction. Figure 1 shows the standard schematic symbol of a diode, sometimes called a rectifier. Note, at A, the flow of electrons, which is indicated by the arrow above the symbol, appears to be in the opposite direction that the symbol appears to be "pointing".

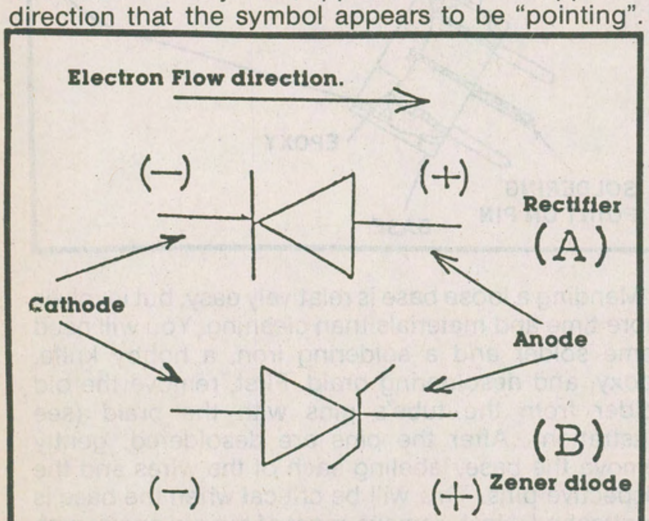


Figure 1. Standard rectifier diode and zener diode symbols.

This is because in the very early days of electricity, when the diode symbol originated, physicists did not understand what electricity really was, and thought that it "flowed" from the positive to the negative. But now, we all know that electricity is a flow of electrons, which have a negative charge and originate at the negative end of a battery and move toward the positive end. Therefore, our diode symbol appears to be backward.

A diode, which conducts in one direction, can only begin to conduct, once a minimum value of voltage is applied; that voltage, for the standard silicon diode, is about 0.5V, or for the earlier germanium type diodes, about 0.25V. Once this minimum voltage is applied in the normal "forward" direction, the diode will begin to conduct freely. See Figure 2.

However, what happens when a diode is subjected to a reverse voltage polarity? As Figure 2 also shows, although in the forward direction, about 0.5V causes the silicon diode to conduct in reverse. It does not have an infinite capacity to resist the force of an applied voltage. At some point the diode will stop blocking, and because of an internal breakdown, allow free and uncontrolled current to flow in the reverse direction. When this happens, the diode is usually destroyed; it shorts internally and appears physically cracked and burned. Therefore, a diode must not be used beyond its reverse voltage rating. In Figure 2, this is shown on the graph at about 50V. Actually, depending on the diode construction, this

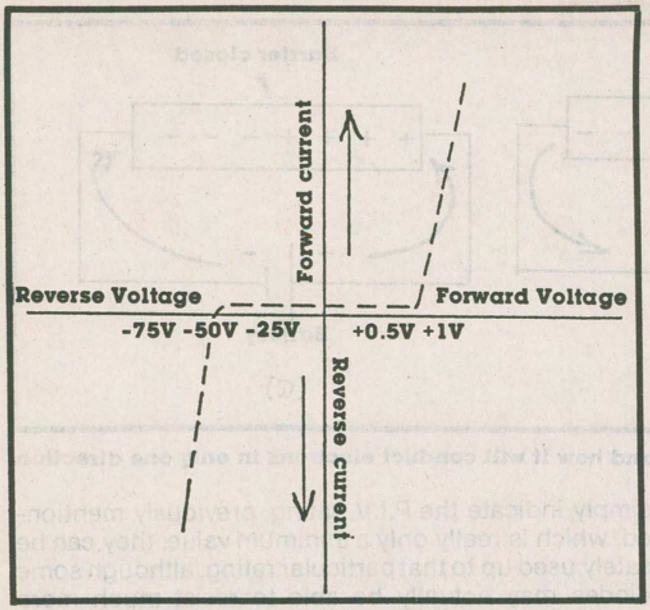


Figure 2. Graph of forward conduction and reverse breakdown characteristics of a typical diode.

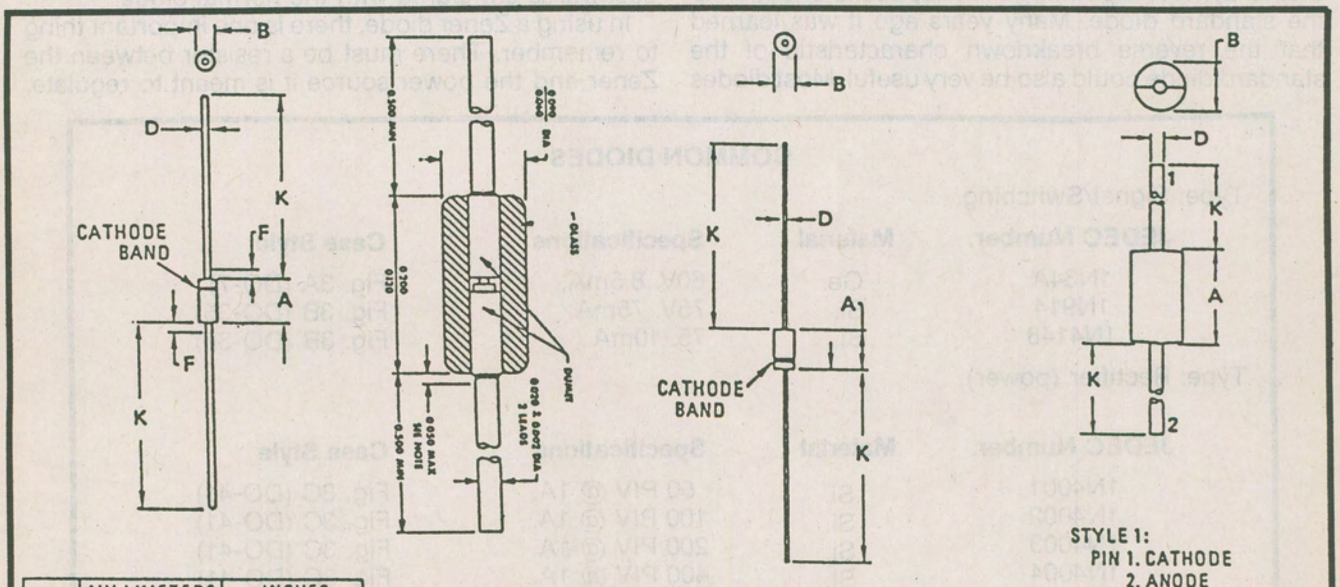
breakdown can take place anywhere from a few volts to several thousand volts, depending on how it is manufactured. This breakdown rating is called the "P.I.V." for Peak Inverse Voltage of the diode.

How A Diode Works

The construction of a diode is really quite simple. In Figure A, Illustration A, we start with just a small bar of very pure silicon (or germanium) which by itself is a very poor conductor. Then, in the manufacturing process, we heat up the bar of material, and surround it with a gaseous material whose atoms contain either an excess of electrons, or negative charges, (like phosphorus) or a shortage of electrons, or positive charges, (like boron), and let them "diffuse" into the material of the bar, one at each end. These create + or Positive regions, and - or Negative regions in the bar.

The key to making this bar a conductor, or having it resist conduction (as an insulator) is very simple. Studying Figure A again, look at Illustration B. Note that there is a battery connected with electrodes at each end of the bar. Because of the polarity of the battery, the Negative charges in the N region have been attracted to the Positive end of the battery, and the Positive charges in the P region have been attracted to the Negative end of the battery. This happens according to Coulombs Law, that states that opposite charges attract each other. The result is that there now exists a region in the middle of the bar (the barrier) where the bar material is just the pure silicon or germanium—which is a very good insulator, and no conducting through the bar is possible.

Going to C in Figure A, we see that the position of the battery has now been reversed, the Positive and Negative ends are opposite to what they were in B above, and things inside the bar are different now. From Coulombs Second Law, that like charges repel each other, we now see that since the Positive end of the battery is connected to the Positive end of the bar, and the Negative battery end to the Negative end of the bar, the charges are forced together in the middle of the bar and the barrier is closed up. Now, with the



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.84	7.62	0.230	0.300
B	2.16	2.72	0.085	0.107
D	0.46	0.56	0.018	0.022
F	–	1.27	–	0.050
K	25.40	–	1.000	–

(A)

(B)

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	4.70	5.20	0.185	0.205
B	2.54	2.71	0.100	0.107
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

(C)

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

(D)

Figure 3. Case styles and dimensions for the most popular diode types; signal, switching, rectifier, and Zeners

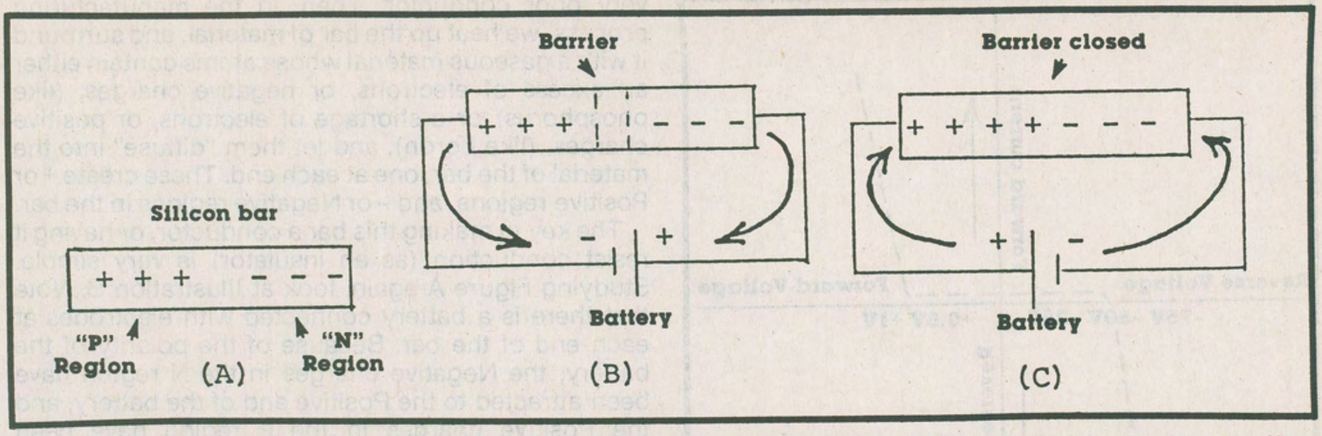


Figure A. Showing how a semiconductor diode is made, and how it will conduct electrons in only one direction

Positive and Negative charges in contact, conduction can begin; the Negative charges are attracted to and will flow through the Positive region, and electrons from the Negative battery terminal will flow through the bar to the other end of the battery completing a circuit. Relating this to Figure 2, the condition with the battery in reverse, or non-conducting state relates to the condition to the left of the vertical center line, which represents current flow; while with the battery in forward conduction direction, relates to the condition to the right of the center line.

The Zener Diode

Going back to Figure 1, at B we have the symbol for a special kind of diode, called a Zener Diode. Note that its symbol is pointing in the opposite direction to the standard diode. Many years ago it was learned that the reverse breakdown characteristic of the standard diode could also be very useful. Most diodes simply indicate the P.I.V. rating, previously mentioned, which is really only a minimum value; they can be safely used up to that particular rating, although some diodes may actually be able to resist much more reverse voltage than their specifications indicate. Nonetheless, if we made a diode with a very carefully controlled breakdown value, and specified it at the time it was sold, we could make use of this breakdown voltage in using the diode to act as a voltage regulator. For instance, a diode that had a breakdown rating of, say, 12V, could be used in a circuit to set the value of a particular voltage to just that value. This carefully controlled reverse breakdown voltage is what makes our diode a Zener type. Since we are using it in reverse, the symbol at B in Figure 1 seems backwards compared with the normal diode.

In using a Zener diode, there is one important thing to remember. There must be a resistor between the Zener and the power source it is meant to regulate.

COMMON DIODES

Type: Signal/Switching.

JEDEC Number.	Material	Specifications	Case Style
1N34A	Ge.	60V. 8.5mA.	Fig. 3A (DO-7)
1N914	Si.	75V. 75mA.	Fig. 3B (DO-35)
1N4148	Si.	75. 10mA.	Fig. 3B (DO-35)

Type: Rectifier (power).

JEDEC Number.	Material	Specifications	Case Style
1N4001	Si.	50 PIV @ 1A.	Fig. 3C (DO-41)
1N4002	Si.	100 PIV @ 1A.	Fig. 3C (DO-41)
1N4003	Si.	200 PIV @ 1A.	Fig. 3C (DO-41)
1N4004	Si.	400 PIV @ 1A.	Fig. 3C (DO-41)
1N4005	Si.	600 PIV @ 1A.	Fig. 3C (DO-41)
1N5400	Si.	50 PIV @ 3A.	Fig. 3D
1N5401	Si.	100 PIV @ 3A.	Fig. 3D
1N5402	Si.	200 PIV @ 3A.	Fig. 3D
1N5403	Si.	300 PIV @ 3A.	Fig. 3D
1N5404	Si.	400 PIV @ 3A.	Fig. 3D
1N5405	Si.	500 PIV @ 3A.	Fig. 3D
1N5406	Si.	600 PIV @ 3A.	Fig. 3D

Figure 4. Some popular diode types, and their specifications. Note: material is (Si) silicon or (Ge) germanium.

COMMON ZENER DIODES

JEDEC Number.	Zener Voltage Rating (±5%)	Case Style
1N4733A	5.1V @ 49mA.	Fig. 3C
1N4734A	5.6V @ 45mA.	Fig. 3C
1N4735A.	6.2V @ 41mA.	Fig. 3C
1N4737A	7.5V @ 34mA.	Fig. 3C
1N4739A	9.1V @ 28mA.	Fig. 3C
1N4742A	12V @ 21mA.	Fig. 3C
1N4744A	15V @ 17mA.	Fig. 3C
1N4749A	24V @ 10.5mA.	Fig. 3C
1N4751A	30V @ 8.5mA.	Fig. 3C
1N4753A	36V @ 7mA.	Fig. 3C
1N4756A	47V @ 5.5mA.	Fig. 3C
1N4757A	51V @ 5mA.	Fig. 3C

Figure 5. Some popular Zener Diode types, and their specifications. All are silicon. 10% tolerance parts have the same JEDEC part numbers, except the suffix "A" is omitted.

Otherwise, when it begins to conduct, it may draw too much current, and overheat and destroy itself.

Other Diode Types

Just as the carefully controlled breakdown makes a regular diode a Zener type, we can also optimize other characteristics for special purposes. Making the diode body large will allow it to handle many amperes of current, such as a power supply or battery charger. When a diode is used like this, to convert alternating current (AC) into direct current (DC), it is also referred to as a rectifier. Also, when acting as a radio detector, or for logic switching in computers, the diode must be made very small—hardly larger than the lead in a wooden pencil—and must be able to switch from "on" in forward conduction, to "off" in reverse, very rapidly. These are called "signals" or "switching" diodes. Finally, another diode type, called a varactor, is made to take advantage of the property of a diode to act like a small capacitor—one that can actually change its capacitance value with the amount of DC voltage applied to it. This is designed to be used in tuned radio circuits, where being able to change the frequency of an oscillator is important to tuning the radio.

Numbering Diodes

Most diodes are given an alphabetic and numeric part number. Most American made diodes have numbers that begin with 1N-, while Japanese made diodes usually start with 1S-. These numbers are assigned to a particular diode with a specific set of characteristics, that is, any diode with a certain standard type number, regardless of the manufacturer, will have the same characteristics regarding breakdown, voltage, current, etc. All standard American diodes will have a number assigned by JEDEC (Joint Electron Device Engineering Council). Figures 4 and 5 are lists of very popular rectifier, zener, signal, and switching diodes which should be readily available at any electronic supplier or mail order company. Their important specifications are also listed. These lists should provide the experimenter with the most common type diodes likely to be needed in building electronic projects.

Finally, Figure 3 shows the case styles and dimensions of all the most popular diodes—including the dimensions, for those interested in laying out a printed circuit board.

With this information, the reader should have a better understanding of the diode, where it can be used, and how to locate the one you need for a project you may be building. ■