Semiconductor Diodes

The diode is the simplest type of semiconductor device. Its most significant feature is that it conducts current in only one direction. In terms of water models, it can be thought of as a one-way water valve, or *check valve*, that only lets water flow in one direction and only once the pressure of the water is sufficient to overcome the spring that holds the valve shut.

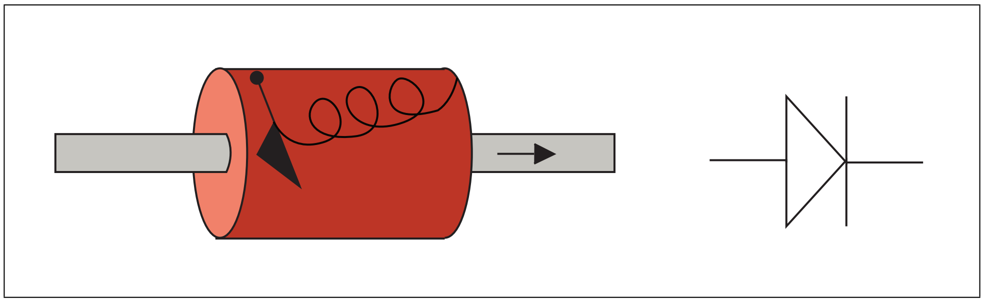

Figure 1: Diode Water Model

If a voltage source is oriented in a circuit so that the intended current flows in the direction of the diode arrow, current will flow. If the source is oriented oppositely, no current flows. When the diode is passing current we say it is *forward biased*. In this mode, the diode exhibits only a small resistance to the current flow. When the arrow is oriented in opposition to current flow, the diode appears as a very high resistance and essentially no current flows. In this case, we say the diode is *reverse biased*.

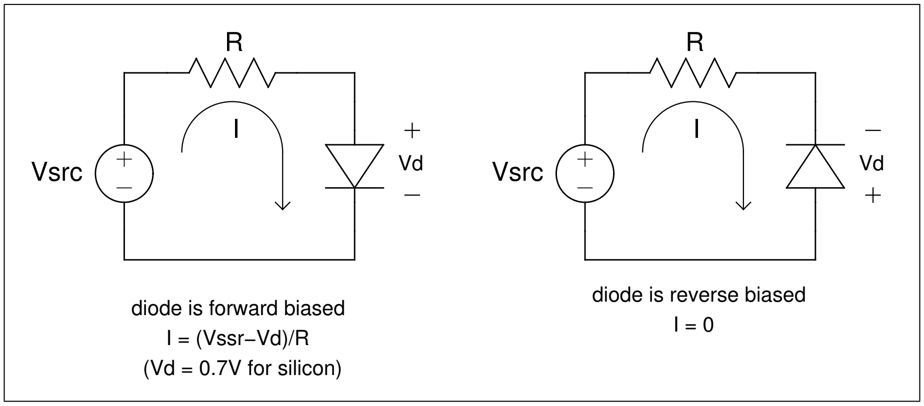

Figure 2: Diode In Forward and Reverse Modes

Almost all diodes are used in such a way that they are forward biased. If too much voltage is placed across the diode in the reverse direction, the diode will begin to conduct, but in a non-controlled and damaging way. There are a few exceptions to this however. A *Zener diode* is used in a special non-damaging *reverse breakdown* mode in which it acts as a voltage regulator. A *varactor diode* is a diode constructed in such a way that it acts as a electrically variable capacitor that is adjusted by the reverse voltage across its terminals.

The forward and reverse regions for a diode is shown in 3 as its VI characteristic curve.

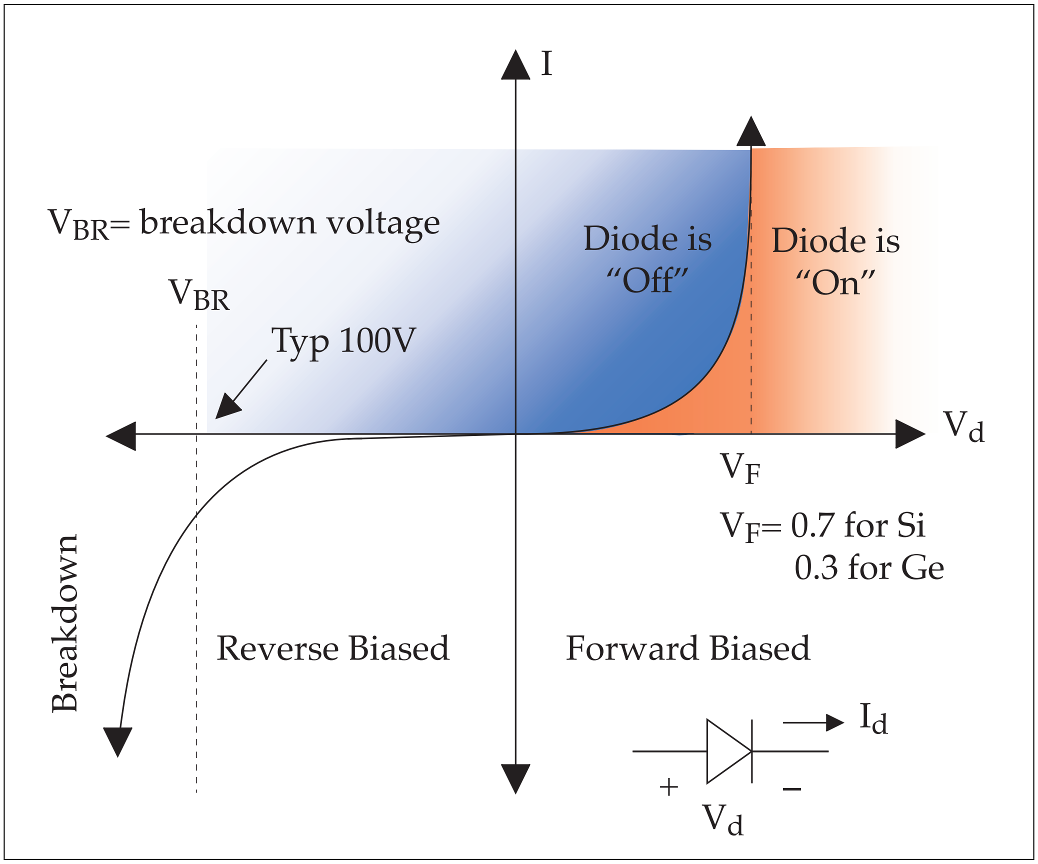

Figure 3: Diode Regions of Operation

As can be seen, the VI characteristic for a diode is a fairly complex, exponential relationship. The Shockley ideal diode equation describing its operation is roughly:

$I_d = I_s(e^{\frac{V_d}{V_t}} - 1)$
where
I_d is the diode current
I_s is the reverse bias saturation current
V_d is the voltate across the diode
V_t is the thermal voltage which is approximately 25.85mV at 300 degrees K.

However, in many applications, an approximation to the behavior can be made. It can be assumed that if the diode is on, it exhibits a forward voltage V_f from anode to cathode. If the diode is off, it appears as an infinite resistance. This approximation is shown in figure 4

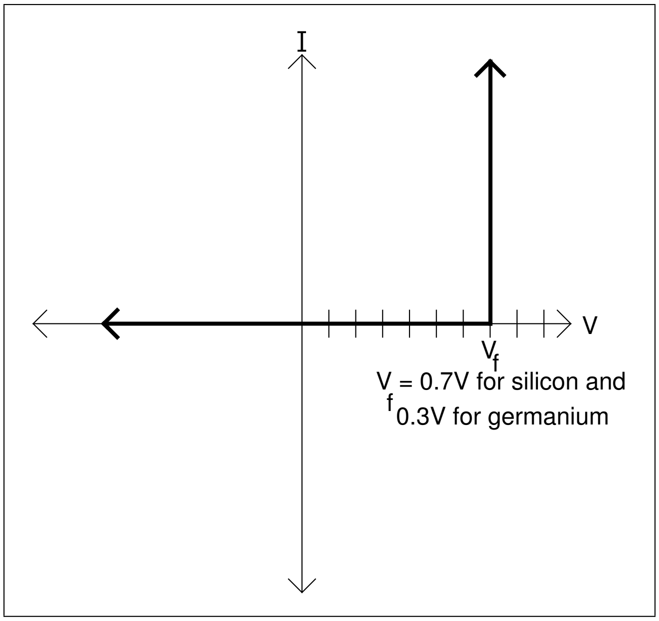

Figure 4: Diode IV Approximation

Physical Construction

The diode is constructed of n-type an p-type material sandwiched together with a connection made at each end. The connection to the n-type material is called the *cathode* and the connection to the p-type material is called the *anode*. The n-type material has extra negatively charged electrons that are free to move while the p-type material has extra places where electrons could go called "holes". Holes appear to move and are spoken of, as if they were particles themselves.

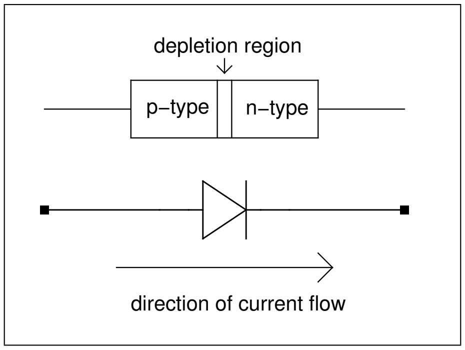

Figure 5: N and P Type Regions Form the Cathode and Anode Respectively

Operation

Prior to voltage being applied to the diode, at the junction of the p-type and n-type regions, free electrons from the n-type side move to the p-type side and fill holes. This essentially annihilates them both leaving region at the junction depleted of any charge carriers. This region is called the depletion region. There are no charge carriers to allow current to move through the junction.

For current to flow across the depletion region, a voltage potential must be created across the junction. To do this, the n-type side is connected to a negative potential and the p-type side to a positive potential. When the negative potential becomes high enough, electrons will be pushed across the boundary and current will flow. The potential at which this occurs is called the *forward voltage* and is approximately 0.7 volts for silicon and 0.3 volts for germanium.

The forward voltage drop across the diode stays roughly the same regardless of how much current is passing through it. In fact, a good approximation of the diode in its forward bias region is simply a independent voltage source equal to the forward voltage. Although the actual current voltage relationship for the diode is far more complicated we can make this approximation for most circuits.

For more information, see: `http://www.allaboutcircuits.com/vol_3/chpt_3/1.html`. There are also a number of good animations on the internet that can be helpful in understanding current flow across an pn junction.

Common Diode Packages and Markings

Diodes often have their cathode end marked with a band. However, there are many different packages for diodes and others are marked differently. In figure 6 are shown a number of diodes. The two diodes to the far left are different from the others in that the semiconductor they are made with is germanium. Germanium has a much lower forward voltage than silicon and makes for a more sensitive detector in crystal radios. At the far right are diodes that are used to convert AC current to DC in power supplies. They are much bigger in size so that they may more easily dissipate heat when they conduct large currents.

The small black diode at top middle is called a varactor diode. This diode is used as an electrically tuned capacitor. By varying the reverse voltage across its terminals (no current flows through the diode) the capacitance formed by the depletion region grows or shrinks forming a variable capacitor.

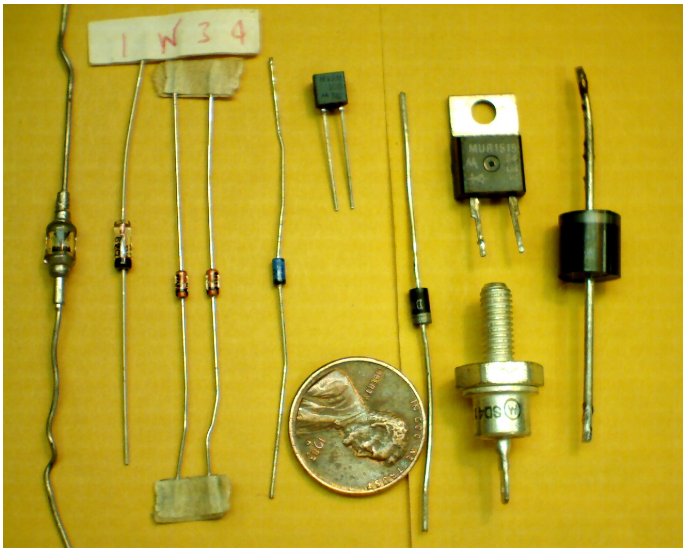

Figure 6: Various Diodes, From left:
Vintage (1960) 1N34A
newer 1N34 (germanium)
high-speed 1N4148
BAT41 schottky diode
MVAM108 varactor
1N4001 rectifier
MUR1515 15A rectifier
SD41 power rectifier
high voltage diode