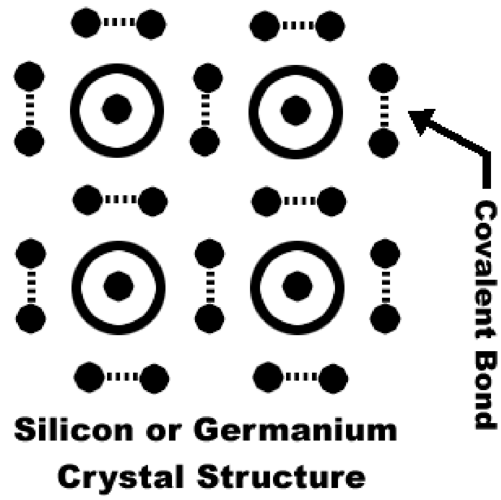
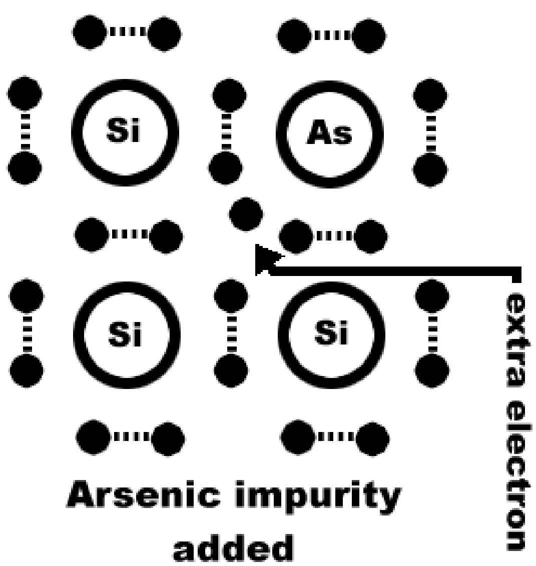
Chapter 2
Semiconductors

2.1 CRYSTAL STRUCTURES

We have discussed conductors and insulators, but there are also elements that are in between. These are called **Semiconductors**. These elements exhibit some characteristics of both conductors and insulators. The most common semiconductor today is Silicon (Si). In the early development of solid state electronics Germanium (Ge) was also used. Both of these elements form a **Crystal Lattice** structure. They both have 4 electrons in their outer orbit. These are called Valence electrons. In a crystal lattice the valence electrons are shared by adjacent atoms. These shared electrons form **Covalent bonds** that create a crystal.



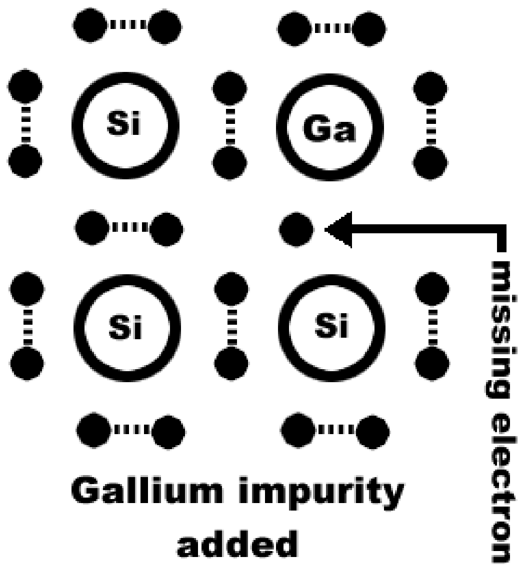
By themselves Silicon and Gallium are not of much use in electronics. They do have the benefit of being easily purified to a high degree. Once this is done impurities are added to form useful semiconductors in a process called **Doping**.



If an element such as Arsenic is added to Silicon, it will fit into the crystal structure. Arsenic, however, has five valence electrons. That leaves one electron that is not part of a covalent bond. This is called a **Pentavalent Impurity**. Antimony, bismuth and phosphorus are also pentavalent impurities. Because they have an extra electron, they are also called donor impurities. With the pentavalent or donor impurity added this becomes a negative or **N-type** crystal. The extra electron of the impurity doesn't fit into the lattice structure and is easily lost, making the material more conductive.

If a negative charge is put at one end of an N-type crystal and a positive is put at the other, the free electrons will be pushed from the negative end and pulled to the positive. Although this sounds like conductors we have already talked about, it does have one large difference. In a typical conductor, such as copper, an increase in temperature will increase resistance. In an N-type crystal, however, an increase in temperature causes a decrease in resistance.

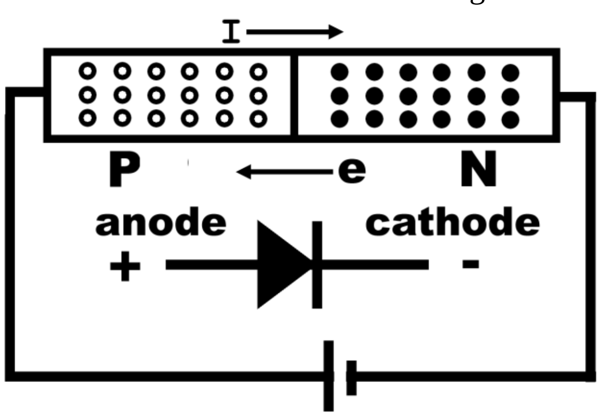
There are also impurities that have only three valence electrons. These are called **Trivalent Impurities** and Gallium is an element commonly used. Aluminum, indium, and boron are also used as trivalent impurities. Because these elements are lacking a valence electron to fit into the lattice they easily accept electrons from other atoms. Because of this they are also called acceptor impurities. With the trivalent or acceptor impurity added a positive or **P-type** crystal is formed.



If one end of a P-type crystal is given a negative charge and the other a positive, then it is said that the **Holes**, or missing electrons, move. Of course in actuality electrons move, filling in one hole and opening another.

2.2 SEMICONDUCTOR DIODES

When an N crystal and a P crystal are attached together a PN junction is formed. This creates a solid state **Diode**. The P crystal is called the **Anode** and the N crystal is called the **Cathode.** The schematic diagram is shown below with the crystals, charges and electron flow. If the charge on the Anode is more positive than the charge on the Cathode, electrons will be pulled from the N crystal and into the holes in the P crystal. We have current flow through the diode. This is called **Forward Biased**. What would happen if the Anode were more negative than the Cathode? The more positive charge on the N crystal would try to pull electrons from the crystal, but there is no way for electrons to move through the P crystal. There would be no electron flow through the diode. This is called **Reverse Biased**.

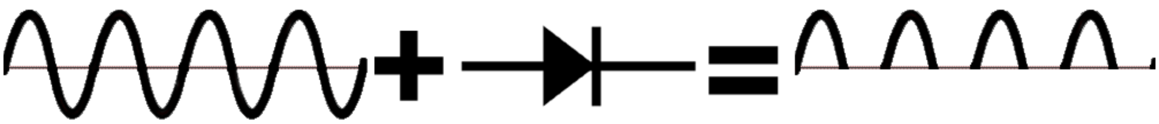


Diodes are rated for maximum voltage and current flow. The current flow rating is simple enough; it is the maximum current that can flow through the diode without destroying it. The voltage rating is **PIV** or **Peak Inverse Voltage**. This is the maximum voltage that can be reverse biased across the diode.

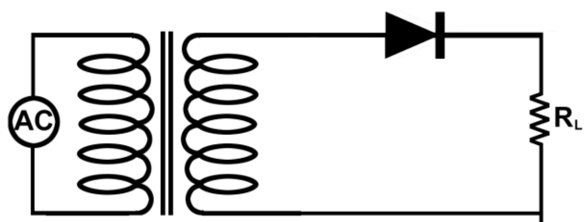
There is some energy used getting the electrons to move through the PN junction, in a Silicon junction this is typically 0.5 to 0.7 volts. For ease of math we will use 0.5 volts. This is called the **Breakover Voltage**. If you put a diode into a circuit with less than 0.5 volts there will be no current flow. If you use a circuit with 2 volts, you will be left with 1.5 volts; the diode has dropped 0.5 volts. Once the diode is forward biased it will always drop 0.5 volts (or it's specific breakover voltage). It is very important to remember that diodes do NOT follow ohms law.

2.3 DIODES AS RECTIFIERS

The most common use for a diode is as a rectifier. What happens if you put an AC signal through a diode? During a cycle, an AC signal is both positive and negative. Current will flow through the diode only when the anode is more positive than the diode.

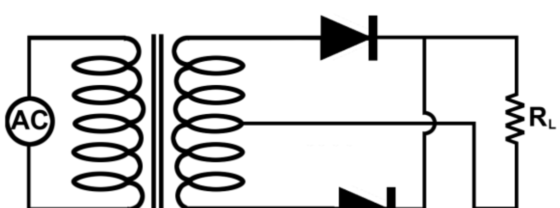


You will get current flow only during half of each AC cycle. The output voltage would then look like the drawing below. This is called a **Half Wave Rectifier** when used in the following power supply circuit.

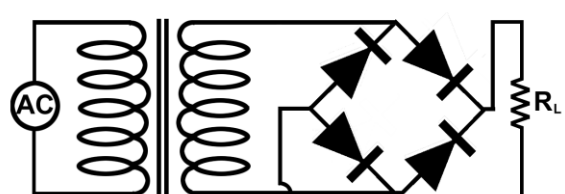


Half Wave Rectifier

Note that half of every wave is lost. There are two ways to construct a **Full Wave Rectifier** so that half of the wave is not lost. The simplest (though most costly) utilizes a center tapped power transformer and 2 two diodes. The center-tapped transformer is the reason for the high cost of this type of circuit. It is still not the most efficient rectification. The most common type of rectifier used today is the **Bridge Rectifier**. This consists of four diodes and is usually sold as a single component that contains all four diodes. The bridge rectifier does not require a center-tapped transformer. More specifics on rectifiers will be given in the next chapter.



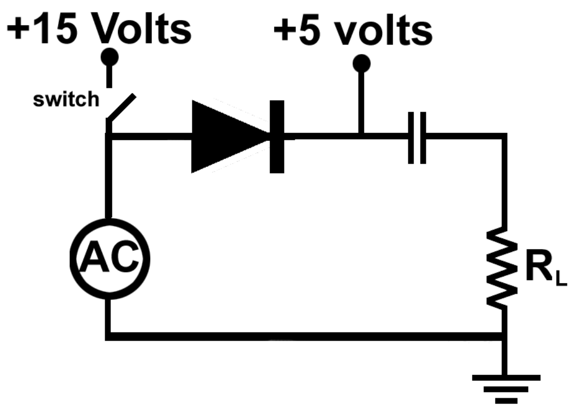
Full Wave Rectifier



Bridge Rectifier

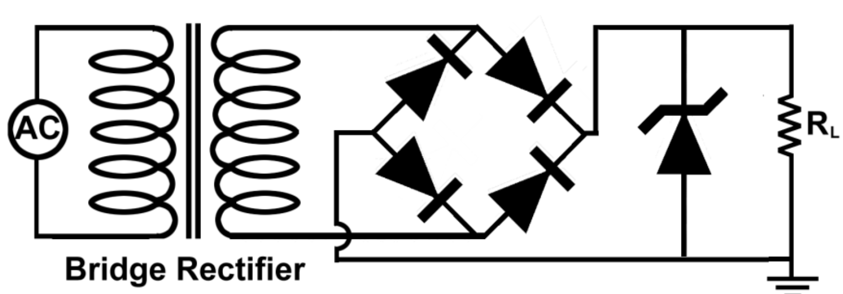
2.4 DIODE AS A SWITCH

You can also use a diode as a switch. A diode will only allow current to pass when it is forward biased. Look at the circuit shown to the left. When the switch is open the diode is reverse biased and the AC source does not reach the load. When the switch is closed the diode is forward biased and current passes. The AC source reaches the load. Is there any variable that would make this circuit not function as was just described? Yes, there is, if the AC source is large than 5 volts. With an AC source larger than 5 volts, the AC signal would be enough to forward bias the diode on the positive half of the cycle. This may not seem like a particularly useful circuit, but a circuit like this or a variation of it could be used as a remote controlled switch. If you place the switch and 15-volt source away from the rest of the circuit the AC signal could be controlled from a distance without running it through a long wire. The 15-volt source could also be very low current and control a very high current AC source.



2.5 ZENER DIODES

The most common special type of diode is the **Zener Diode**. With a conventional diode, when the PIV is reached, the PN junction is damaged and the diode stops working. In that case, it would be permanently damaged. If a conventional diode had a PIV of 1000 volts, you might be able to put 1001 volts on it without damaging the junction. The PIV rating is saying that you can put at least 1000 volts in reverse bias to the diode without damaging it. With a **Zener Diode** the PIV is a very accurate, specific voltage. In addition, when the PIV is reached, the junction is not damaged but allows current to flow. This current flow is reverse to direction current normally flows in a diode. So, with a Zener reverse biased over its PIV, current will flow from cathode to anode. Electrons would be flowing from anode to cathode. When it is forward biased a Zener diode functions just like any standard diode. The circuit to the right is the most common use of the Zener. If the bridge rectifier puts out roughly 18 volts, it will vary depending on the AC voltage and the current draw of the load. AC voltages from wall outlets in the U.S. care typically 115, 117or 120 volts. They can, however, be anywhere in a range from 108 to 130 volts. If you choose a 15-volt Zener diode you can regulate the voltage to the load as long as the



output of the bridge never drops below 15 volts. Whenever the voltage goes above 15 volts, current starts to flow through the diode to ground. At that point the Zener will drop 15 Volts. Since it is connected in parallel with the load it will keep the voltage across the load at a stable 15 volts. What happens if the voltage goes below 15 volts? Below 15 volts the Zener behaves like any normal reverse biased diode. This means that it is, in effect, invisible to the circuit. That is why the bridge output must be above 15 volts. In addition to the voltage of the Zener, the wattage must also be specified. Since all the excess voltage is removed with current flow through the diode, it must be able to dissipate all of that power.

2.6 LEDs

Another type of diode is the **LED or Light Emitting Diode.** When LEDs are forward biased, the current flow is indicated with a light. LEDs can be colored (red and yellow and green are common) and can also be non-visible light such as infrared. LEDs need more voltage than the typical diodes 0.5 volts. Common forward bias voltages for LEDs are from 1.6 to 2.3 volts. Blue light emitting LEDs require 5 volts.