# *3* Transistors and Diodes

Transistors and diodes are wonderful devices. They are the basic elements of modern electronic circuits that made possible the rapid development of computer and information technologies we experience today. The TRANSISTOR was invented in 1947 at Bell Laboratories (AT&T), a mere 15 miles from NJIT. Initially, its importance was not fully appreciated, but years later the impact of this invention was recognized by awarding its authors (John Bardeen, Walter Brattain, and William Shockley) a Nobel Price. The full power of the transistor was unleashed with the invention of the INTEGRATED CIRCUIT (Texas Instruments, in 1958), which combines many transistors (a few initially, billions today) in one integrated device. It is this device that literally changed the way we work and live. The inventor of the integrated circuit, Jack Kilby, has also been recognized with the Nobel Prize.

Transistors and simpler elements, DIODES, belong to the class of so called SOLID STATE devices, because they are made of a solid semiconductor material, most of them crystalline silicon (earlier electronics used vacuum tubes). There are two types of semiconductors, n-type, and p-type. These symbols stand for negative (n) or positive (p) charges (electrons and holes) that carry electric current in these materials. Electronic devices are made by combining p and n semiconductors. We will first examine the simpler device, the diode, before moving to more complex transistors.

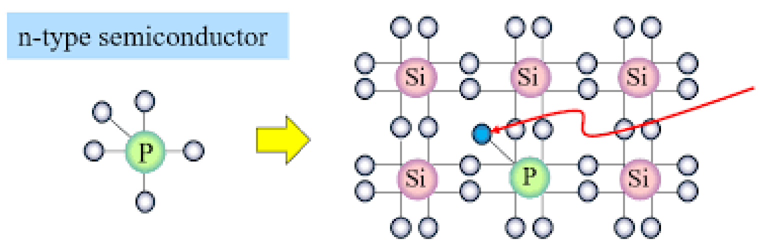


Figure 3.1: The atomic structure of an n-type semiconductor material.

## *3.1 Diodes*

Diodes, like resistors, have two terminals for connecting to electrical circuit. Unlike resistors, however, diodes are so called NONLINEAR ELEMENTS. It means the current through them is not proportional to the voltage applied across them; they do not obey Ohm’s law. Moreover, they have polarity. That is, their terminals can be assigned positive and negative signs since they are connected to p – type and n – type semiconductors, as shown schematically in Figure 3.2.

 

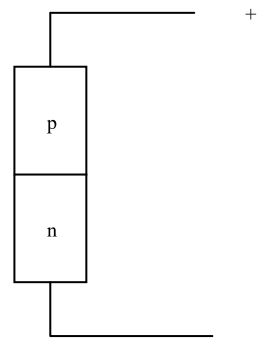


Figure 3.2: A diode as a junction of p – type and n – type semiconductors

When the positive terminal of the diode is connected to the positive terminal of a power source, a current flows with very low resistance. This is called the forward bias of a diode. If the diode is connected in reverse, practically no current flows. The diode acts like a valve, passing the current in one direction. You may recall a different device, also called a valve, found on bicycle or car tires. The valve passes the air only in one direction allowing you to pump a tire, while it cannot escape in the reverse direction.

The curve representing the relationship between the current and the voltage across a typical diode is shown in Figure 3.3. With the values of current on the vertical axis and voltage on the horizontal scale it is called the I-V characteristic on the I-V curve. The current increases exponentially for the positive voltage values and the graph really shoots up when the voltage exceeds about 0.7 V (Silicon diode). For the negative voltage value, the graph shows zero current, but only because of the scale on the vertical axis. Expanding this scale would reveal that there is in fact some current for the reverse bias, the so-called reverse current. Only an ideal diode has zero reverse current but in real diodes this current is usually orders of magnitude smaller than the forward current.

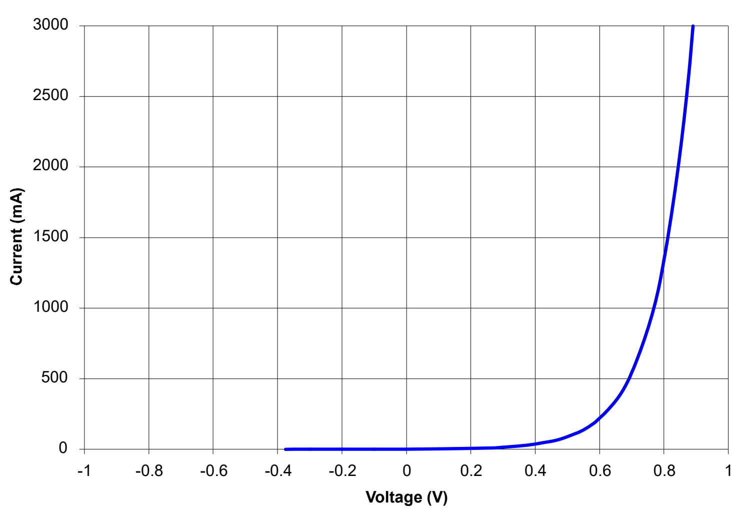


Figure 3.3: The characteristic of a typical diode (I-V curve)

 

The diodes are very useful in rectifiers, circuits that convert AC to DC power. They are used in all electronic devices, such as desktop PCs, which require DC to operate but are supplied by the household current (AC). Battery operated devices, such as quartz watches run on batteries and do not need rectifiers, but laptops still need them to recharge their batteries. Diodes can also be used in digital devices to form basic logic gates, as we will see in laboratory experiments. A special type of diode, the light emitting diode or LED, is used in light communication and display panels. The symbols representing diodes in electric circuit schematics are shown in Figure 6.3. The forward current direction is from left to right. The arrows in the LED symbol represent emitted light.

Figure 3.4: Schematic representation of a diode (left) and an LED (right).

## *3.2 Transistors*

There are two most common transistor types today: the Metal-Oxide-Semiconductor or MOS and the Bipolar Junction Transistor or BJT. The MOS is also designated as MOSFET because it is a field effect transistor (FET). A great majority of both types are made from silicon (Si) and a small fraction (about 2%) from gallium arsenide (GaAs). Depending on the type of semiconductor materials used in making transistors (n-type or p-type semiconductors) there are n-type or p-type MOSFETs or n-p-n and p-n-p BJTs. The BJT dominated the market initially but now most of the transistors, particularly in integrated circuits, are of the MOS type. The BJT still holds its own, particularly in some analog and high-power circuits.

The big difference between transistors and diodes is that transistors have three terminals, not two. The additional terminal controls the current flowing through the other two. This creates important functional possibilities, namely, one circuit can control (or switch on or off) the current flowing in another circuit. Another important feature of the transistor is that the controlling current can be much smaller than the current that is controlled. This leads to amplification, a very useful effect in devices such as stereo amplifiers or the control of the speed of electric motors. MOSFET transistors are voltage driven, and BJT transistors are current driven.

 

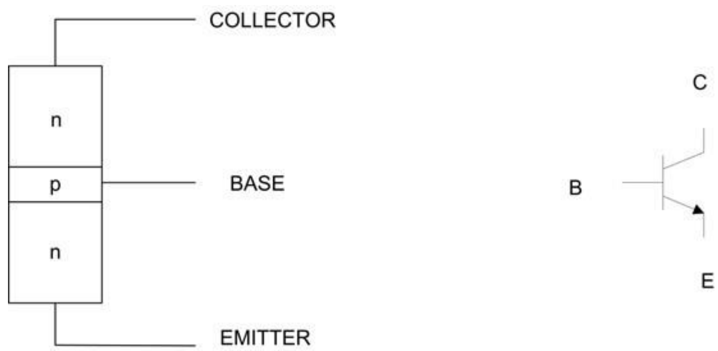


Figure 3.4: The structure of an n-p-n BJT (left) and its representation in electrical schematics (right)

The structure and the schematics of connections to a BJT are shown in Figure 6.4. An np-n type transistor consists of two n-type regions (the emitter and the collector) with a thin p – type layer (the base) between them. Note that the transistor consists of two p-n junctions connected by the common p-type base. In normal operation the collector is positive and the current flows between the collector (C) and the emitter (E) while the base (B) is the control electrode. There are also less often used p-n-p transistors with opposite types of semiconductor layers. In MOS transistors the electrodes have different designations: source instead of emitter, gate instead of base and drain instead of collector. There are also n-type and p-type MOSFETs. In the n-type, the current flows between source (S) and drain (D), while gate (G) is the control electrode.

Most transistors of any type are made today as elements of integrated circuits (ICs), which can contain many millions of circuit elements. Such a combination of many interrelated circuits can result in an extremely complex and powerful system such as the Intel i9 microprocessor, which has over 4 billion transistors. Single or discrete transistors, however, are still useful in many applications such as high frequency or power units.

 