THERMIONIC AND GASEOUS STATE DIODES

Thermionic and gaseous state (vacuum tube) diodes

Thermionic diodes are thermionic-valve devices (also known as vacuum tubes, tubes, or valves), which are arrangements of electrodes surrounded by a vacuum within a glass envelope. Early examples were fairly similar in appearance to incandescent light bulbs.

In thermionic valve diodes, a current through the heater filament indirectly heats the cathode, another internal electrode treated with a mixture of barium and strontium oxides, which are oxides of alkaline earth metals; these substances are chosen because they have a small work function. (Some valves use direct heating, in which a tungsten filament acts as both heater and cathode.) The heat causes thermionic emission of electrons into the vacuum. In forward operation, a surrounding metal electrode called the anode is positively charged so that it electrostatically attracts the emitted electrons. However, electrons are not easily released from the unheated anode surface when the voltage polarity is reversed.

Hence, any reverse flow is negligible.

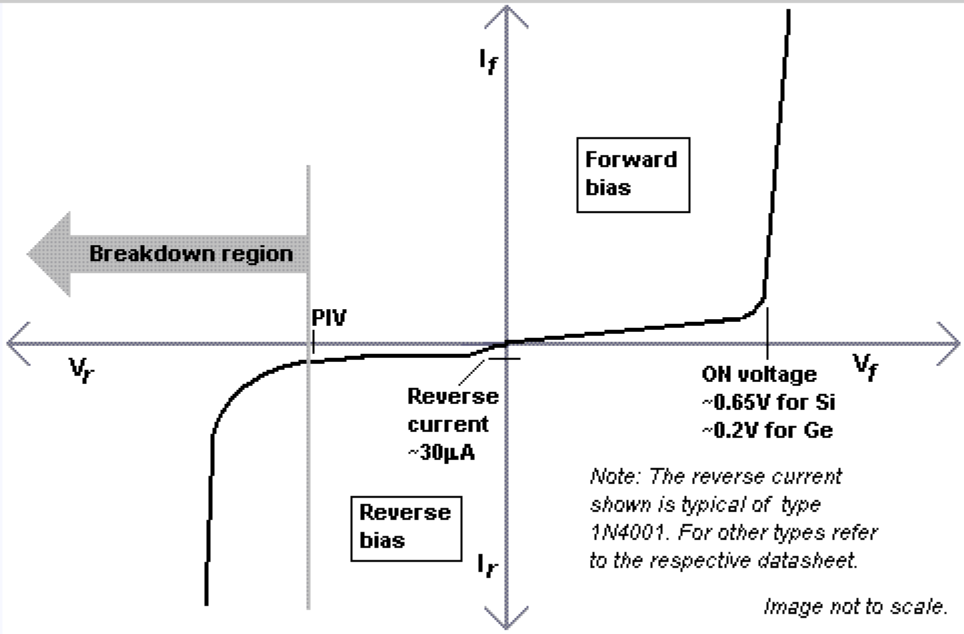
For much of the 20th century, thermionic valve diodes were used in analog signal applications, and as rectifiers in many power supplies. Today, valve diodes are only used in niche applications such as rectifiers in electric guitar and high-end audio amplifiers as well as specialized high-voltage equipment.

Semiconductor diodes

A modern semiconductor diode is made of a crystal of semiconductor like silicon that has impurities added to it to create a region on one side that contains negative charge carriers (electrons), called n-type semiconductor, and a region on the other side that contains positive charge carriers (holes), called p-type semiconductor. The diode's terminals are attached to each of these regions. The boundary within the crystal between these two regions, called a PN junction, is where the action of the diode takes place. The crystal conducts conventional current in a direction from the p-type side (called the anode) to the n-type side (called the cathode), but not in the opposite direction.

Another type of semiconductor diode, the Schottky diode, is formed from the contact between a metal and a semiconductor rather than by a p-n junction.

Current–voltage characteristic



I–V characteristics of a P-N junction diode (not to scale).

A semiconductor diode’s behavior in a circuit is given by its current–voltage characteristic, or I–V graph (see graph at right). The shape of the curve is determined by the transport of charge carriers through the so-called depletion layer or depletion region that exists at the p-n junction between differing semiconductors. When a p-n junction is first created, conduction band (mobile) electrons from the N-doped region diffuse into the P-doped region where there is a large population of holes (vacant places for electrons) with which the electrons “recombine”.

When a mobile electron recombines with a hole, both hole and electron vanish, leaving behind an immobile positively charged donor (dopant) on the N-side and negatively charged acceptor (dopant) on the P-side. The region around the p-n junction becomes depleted of charge carriers and thus behaves as an insulator.

However, the width of the depletion region (called the depletion width) cannot grow without limit. For each electron-hole pair that recombines, a positively-charged dopant ion is left behind in the N-doped region, and a negatively charged dopant ion is left behind in the P-doped region. As recombination proceeds more ions are created, an increasing electric field develops through the depletion zone which acts to slow and then finally stop recombination. At this point, there is a "built-in" potential across the depletion zone.

If an external voltage is placed across the diode with the same polarity as the built-in potential, the depletion zone continues to act as an insulator, preventing any significant electric current flow (unless electron/hole pairs are actively being created in the junction by, for instance, light. see photodiode). This is the reverse bias phenomenon.

However, if the polarity of the external voltage opposes the built-in potential, recombination can once again proceed, resulting in substantial electric current through the p-n junction (i.e. substantial numbers of electrons and holes recombine at the junction).. For silicon diodes, the built-in potential is approximately 0.6 V. Thus, if an external current is passed through the diode, about 0.6 V will be developed across the diode such that the P-doped region is positive with respect to the N-doped region and the diode is said to be “turned on” as it has a forward bias.

A diode’s 'I–V characteristic' can be approximated by four regions of operation (see the figure at right).

At very large reverse bias, beyond the peak inverse voltage or PIV, a process called reverse breakdown occurs which causes a large increase in current (i.e. a large number of electrons and holes are created at, and move away from the pn junction) that usually damages the device permanently. The avalanche diode is deliberately designed for use in the avalanche region. In the zener diode, the concept of PIV is not applicable.

A zener diode contains a heavily doped p-n junction allowing electrons to tunnel from the valence band of the p-type material to the conduction band of the n-type material, such that the reverse voltage is “clamped” to a known value (called the zener voltage), and avalanche does not occur. Both devices, however, do have a limit to the maximum current and power in the clamped reverse voltage region. Also, following the end of forward conduction in any diode, there is reverse current for a short time. The device does not attain its full blocking capability until the reverse current ceases

The second region, at reverse biases more positive than the PIV, has only a very small reverse saturation current. In the reverse bias region for a normal P-N rectifier diode, the current through the device is very low (in the µA range). However, this is temperature dependent, and at suffiently high temperatures, a substantial amount of reverse current can be observed (mA or more).

The third region is forward but small bias, where only a small forward current is conducted.

As the potential difference is increased above an arbitrarily defined “cut-in voltage” or “on-voltage” or “diode forward voltage drop (Vd)”, the diode current becomes appreciable (the level of current considered “appreciable” and the value of cut-in voltage depends on the application), and the diode presents a very low resistance.

The current–voltage curve is exponential. In a normal silicon diode at rated currents, the arbitrary “cut-in” voltage is defined as 0.6 to 0.7 volts. The value is different for other diode types — Schottky diodes can be rated as low as 0.2 V and red or blue light-emitting diodes (LEDs) can have values of 1.4 V and 4.0 V respectively.

At higher currents the forward voltage drop of the diode increases. A drop of 1 V to 1.5 V is typical at full rated current for power diodes.

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