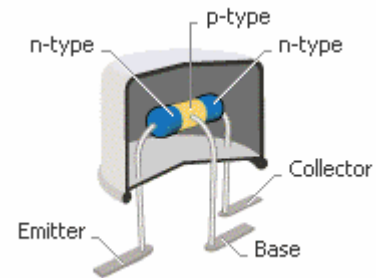


# The Transistor

## I. Introduction

A transistor is an electronic device used as amplifiers or oscillators in communications, controlling and computer systems. The first transistor was developed in 1948. Until that date, development depended on the use of thermion vacuum tubes, magnetic amplifiers, specialized rotating machinery and special capacitors.

In electronic circuits, the transistor can substitute many functions of the vacuum tube. It consists of a small crystal of semi-conducting materials, such as germanium or silicon, and has three electrical connections. The basic components of a transistor – basis, emitter and collector – are comparable to those of a triode vacuum tube. For example the emitter corresponds to the heated cathode of a triode and is also a source of electrons.



The transistor was developed by William Bradford Shockley, Walter Houser Brattain, and John Bardeen, three physicists of Bell Laboratories. In 1956, the three received the Nobel Prize for physics for their achievement. Shockley is known to be the initiator and director of this research program on semiconductors, which led to the development of this group of electronic devices. Brattain and Bardeen invented the point-contact transistor, an important type of transistors.

## II. The Structure of Semiconductors

The atomic structure of a semiconductor is responsible for its electrical properties. Each atom in a crystal of pure germanium or silicon has four valence electrons, which leads to a periodic arrangement of the atoms in the crystal. Thus, there are no electrons that are free to move and the material acts, at low temperatures, as an insulator.

## III. Function of Impurities (Doping)

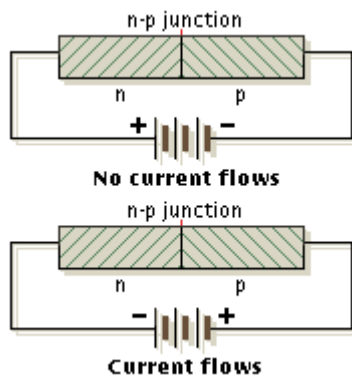
Germanium or silicon crystals containing small amounts of certain impurities can conduct electricity even at low temperatures. The process of targeting impurification is called doping. Such impurities in the semiconductor crystal can work in two ways. An impurity element, such as phosphorus, antimony, or arsenic, is called a donor impurity because it contributes excess electrons. This group of elements has five valence electrons, but only four of them enter a divalent bonding with the germanium or silicon atoms. Thus, when an electronic field is applied, the remaining electron in donor impurities is free to move through the crystalline material.

In contrast, impurity elements, such as gallium and indium, have only three valence electrons, lacking one to complete the interatomic-bond structure within the crystal. Such impurities are known as acceptor impurities because these elements accept electrons from neighbouring atoms to fill in the missing electrons in the valence-bond structure. The resulting absence of electrons, or so-called holes, in the structure of atoms are filled by other neighbouring electrons. These holes behave as positive charges and appear to move in the direction opposite to that of the electrons under an applied voltage.

## IV. n-Type and p-Type Semiconductors

A germanium or silicon crystal, containing donor-impurity atoms, is called an **n-type** semiconductor to indicate the presence of excess **negatively** charged electrons. The use of an acceptor impurity produces a **p-type** semiconductor, so called because of the presence of **positively** charged holes.

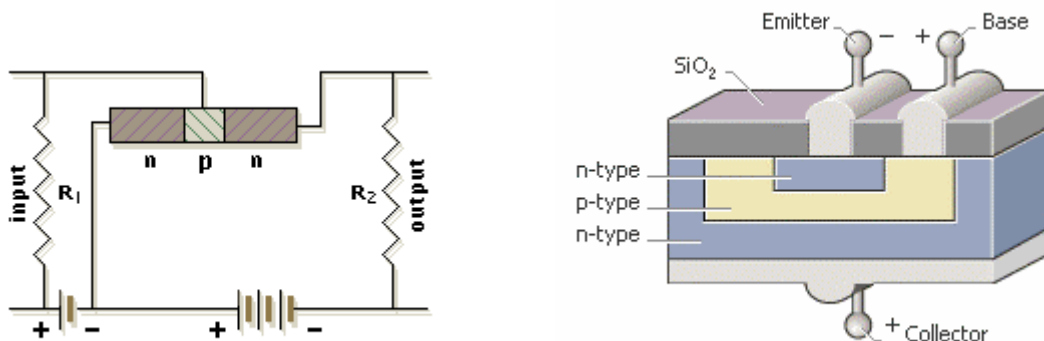
A single crystal containing both n-type and p-type regions can be created by putting the donor and acceptor impurities into molten germanium or silicon at different stages of crystal formation. The resultant crystal has two specific regions of n-type and p-type material. The boundary area of the n-type and the p-type region is known as an n-p junction. Another way to produce such a junction can be by placing a piece of donor-impurity material against the surface of a p-type crystal or a piece of acceptor-impurity material against an n-type crystal. Under heat the impurity atoms diffuse through the outer layer.



When an external voltage is applied, the n-p junction acts as a rectifier, permitting current to flow in only one direction. If the p-type region is connected to the positive terminal of a battery and the n-type to the negative terminal, a large current flows through the material across the junction. If the battery is connected in the opposite way, as shown in the diagram on the left, current does not flow.

## V. Transistor Operations

In the transistor, a combination of two junctions may be used to achieve amplification. One type, called the n-p-n junction transistor, consists of a very thin layer of p-type material between two sections of n-type material, arranged in a circuit as shown in the diagram on



the left. The n-type material at the left of the diagram is the emitter element of the transistor, functioning as the electron source. To permit the forward flow of current across the n-p junction, the emitter has a small negative voltage with respect to the p-type layer, or base component, that controls the electron flow. The n-type material in the output circuit serves as the collector element, which has a large positive voltage with respect to the base to prevent reverse current flow. Electrons moving from the emitter enter the base, are attracted to the positively charged collector, and flow through the output circuit. The input impedance, or resistance to current flow, between the emitter and the base is low, whereas the output

impedance between collector and base is high. Therefore, small changes in the voltage of the base cause large changes in the voltage drop across the collector resistance, making this type of transistor an effective amplifier.

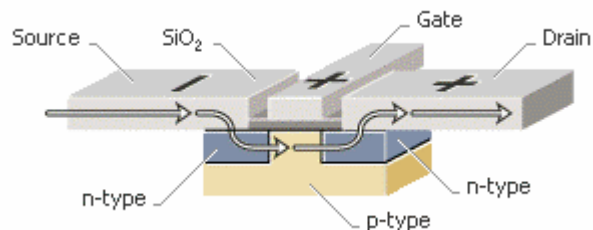
Similar in operation to the n-p-n type is the p-n-p junction transistor, which also has two junctions and is equivalent to a triode vacuum tube. Other types with three junctions, such as the n-p-n-p junction transistor, provide greater amplification than the two-junction transistor.

## VI. Transistors In Information Technology

During the late 1960s a new electronic technique, the integrated circuit, began to replace the transistor in complex electronic equipment. Although roughly the same size as a transistor, an integrated circuit performs the function of 15 to 20 transistors. A natural development from the integrated circuit in the 1970s has been the production of medium-, large-, and very large-scale integrated circuits (MSI, LSI, and VLSI), which have permitted the building of a compact computer, or minicomputer, containing disk storage units and the communication-control systems on the same frame.

The microprocessor, which came into use in the mid-1970s, is a refinement of the LSI. As a result of further miniaturization, a single microprocessor can incorporate the functions of a number of printed-circuit boards and deliver the performance of the central processing unit of a much larger computer in a hand-held, battery-powered microcomputer.

The transistor used most commonly in the microelectronics industry is called a metal-oxide semiconductor field-effect transistor (MOSFET). It contains two n-type regions, called the source and the drain, with a p-type region in between them, called the channel. Over the channel is a thin layer of nonconductive silicon dioxide topped by another layer, called the gate. For electrons to flow from the source to the drain, a voltage (forward bias) must be applied to the gate. This causes the gate to act like a control switch, turning the MOSFET on and off and creating a logic gate that transmits digital 1s and 0s throughout the microprocessor.



## VII. Further Transistor Development

At its present stage of development, the transistor is as effective as a vacuum tube, both of which can amplify to an upper limit of about 1000 megahertz. Among the advantages of the transistor are its small size and very small power requirements. In contrast to the vacuum tube, it does not need power for heating the cathode. Therefore, transistors have replaced most vacuum-tube amplifiers in light, portable electronic equipment, such as airborne navigational aids and the control systems of guided missiles, in which weight and size are prime considerations. Commercial applications include very small hearing aids and compact portable radio and television receivers.

Transistors are also used in miniaturized diagnostic instruments, such as those used to transmit electrocardiograph, respiratory, and other data from the bodies of astronauts on space flights. Nearly all transmitting equipment used in space-exploration probes employs transistorized circuitry. Transistors also aid in diagnosing diseases. Miniature radio transmitters using transistors can also be implanted in the bodies of animals for ecological studies of

feeding habits, patterns of travel, and other factors. A recent commercial application is the transistorized ignition system in automobiles.