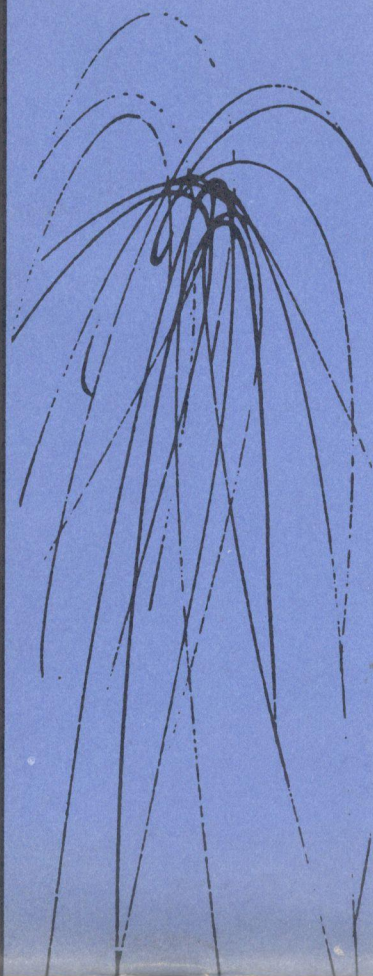




A Mullard minibook

semiconductor devices



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A MULLARD MINIBOOK

SEMICONDUCTOR DEVICES

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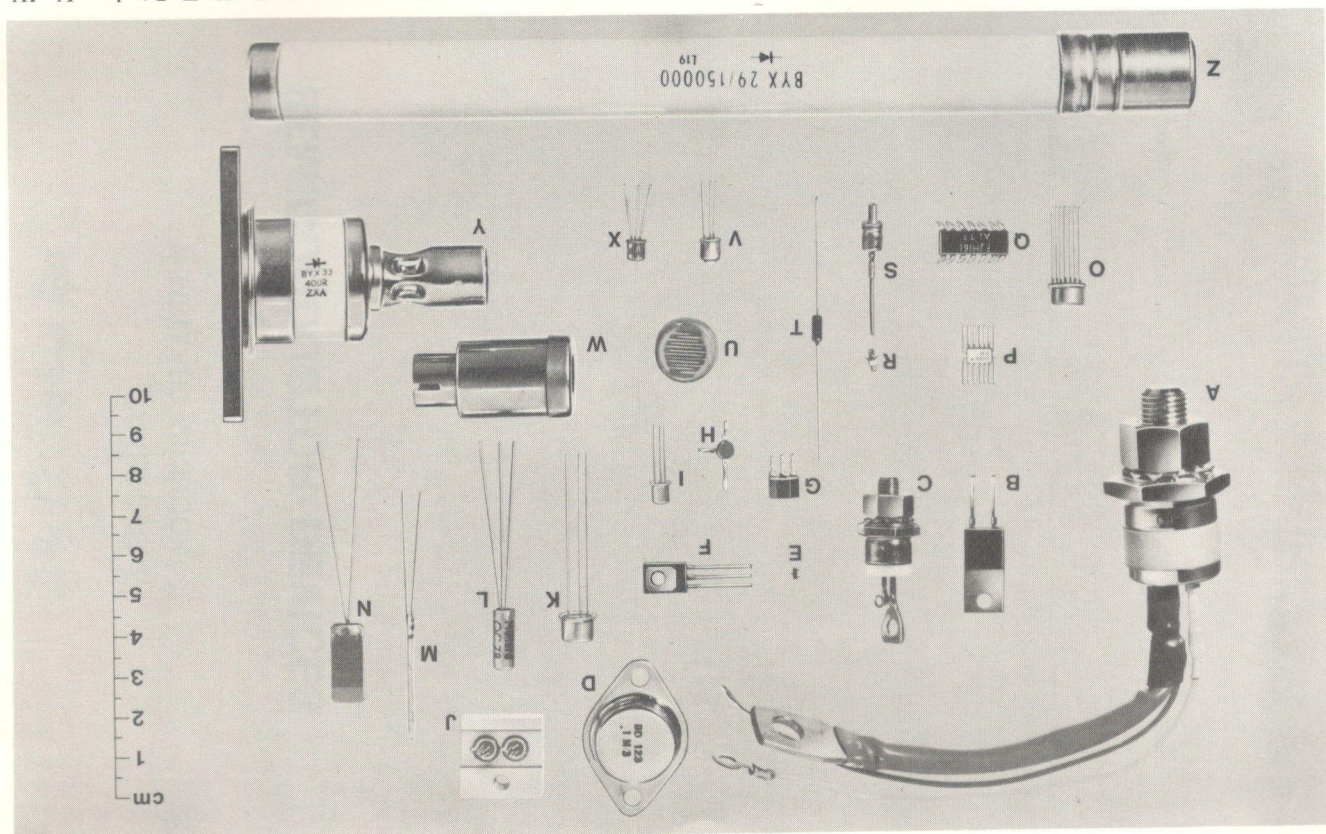
A, B, C Thyristors. D-L Transistors. M, N Thermistors. O, P, Q Integrated Circuits. R, S, T, Y, Z Diodes. U, W Photoconductive cells. V Phototransistor. X Electroluminescent diode.

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This book is an introduction to semiconductor electronics and its contents should be readily understood by anyone with a basic knowledge of electronics. The subject is treated non-mathematically and emphasis is placed on the nature, construction and performance of semiconductor devices.

Section 1 deals briefly with the crystal structure and preparation of silicon and germanium and mentions some of the other materials in common use. In Sections 2 and 3 the diode and transistor are treated as simply as possible. Section 4 describes the common types of construction including the alloy, alloy diffusion and planar techniques. In Section 5 the BC107 is used as an example to illustrate the essential characteristics and parameters of transistors. Section 6 deals simply with other semiconductor devices such as photo-transistors, thermistors, thyristors and integrated circuits.

In this second edition Section I has been re-arranged in order to up-date the parts dealing with the preparation of semiconductor materials. Minor alterations have been made to other sections.



SECTION 1 — SEMICONDUCTOR MATERIALS

Introduction

A very simple but somewhat superficial definition of semiconductors is that they are those materials whose resistivity lies between that of a perfect insulator and that of a good conductor. Thus glass (resistivity about $2 \times 10^{13} \Omega \cdot \text{cm}$) is an insulator, copper (resistivity about $1.7 \times 10^{-6} \Omega \cdot \text{cm}$) is a conductor, whereas germanium ($47 \Omega \cdot \text{cm}$ at 27°C) and silicon ($3 \times 10^5 \Omega \cdot \text{cm}$ at 27°C) are semiconductors.

Silicon and germanium are the best known semiconductor materials because it is from these that the most common devices, transistors and diodes, are made. These days there is a preference for silicon devices. Silicon has a lower leakage current, is less affected by temperature changes than germanium and the silicon planar technique now permits easier mass production of high quality devices. Many other semiconductor materials are also in common use, for example cadmium sulphide, lead sulphide, gallium arsenide and indium antimonide, but these tend to be found mainly in specialist devices such as photoelectric cells and electroluminescent devices. This section will be confined to the properties and preparation of silicon and germanium.

The Crystal Structure

The outer electrons of an atom are called the VALENCE electrons. Silicon and germanium are 'tetravalent', that is their atoms have four electrons in their outer orbits (tetra=4). The silicon atom, which is simpler than that of germanium, is represented in fig. 1. It is well known that the nucleus is positively charged and the electrons negatively charged and that the positive charge on the nucleus is equal to the total negative charge on all the electrons. The complete atom is therefore electrically neutral. Since it is the outer or valence electrons which take part in the flow of current, it is convenient to simplify the representation as shown.

When two atoms are close together there is often a tendency towards electron sharing. As a simple example consider two hydrogen atoms, fig. 2. The hydrogen atom has only one electron. When two atoms come close together the electrons orbit both nuclei and this electron sharing results in a bonding between the atoms that would not otherwise exist. The phenomenon is called 'covalent bonding'.

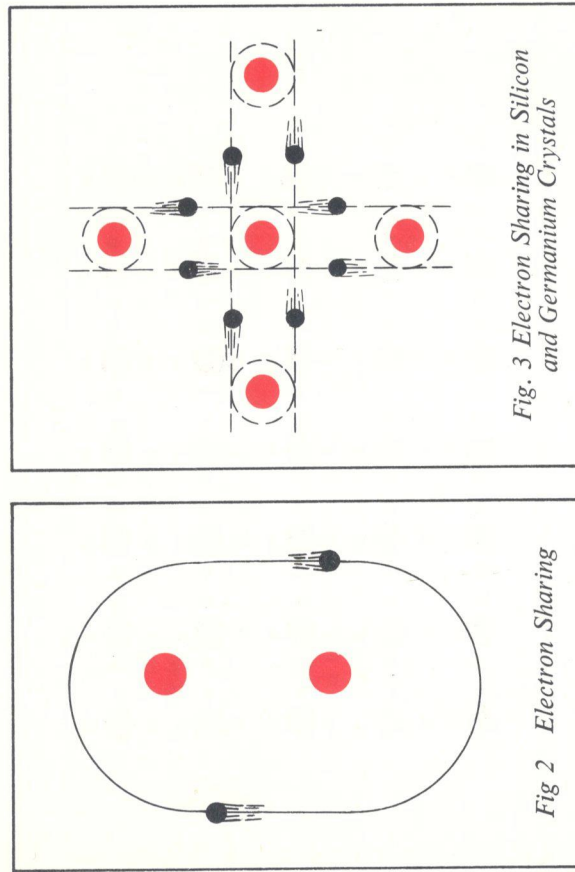
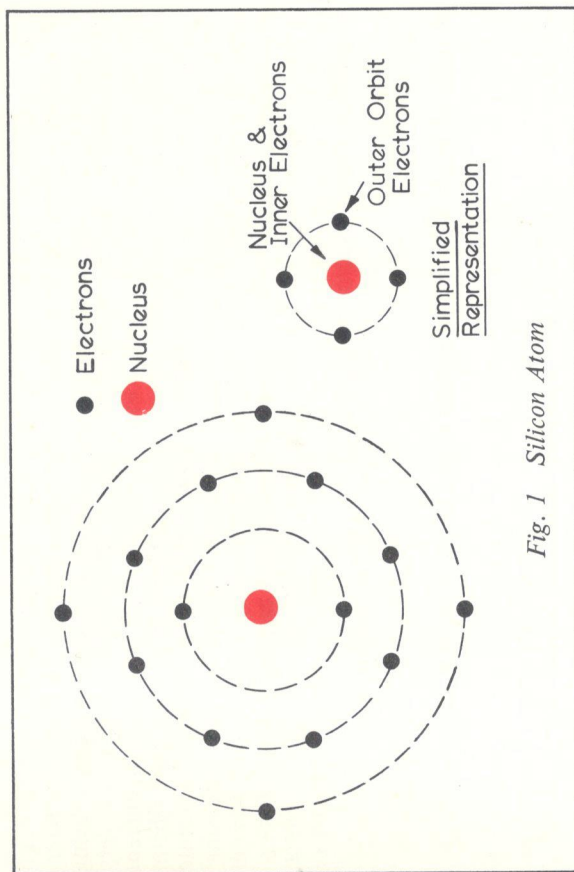


Fig. 3 illustrates what happens in tetravalent semiconductor crystals. Each of the four valence electrons of any one atom is shared with four neighbouring nuclei so that each nucleus is in effect orbited by eight electrons, causing strong bonds to exist between neighbouring atoms in the crystal. As it is very difficult for an electron to break away from its bonds to participate in current flow such crystals tend to be rather poor conductors. In practice pure silicon and germanium are perfect insulators only at a temperature of absolute zero. At room temperatures, owing to thermal agitation, the occasional electron is able to break away from the crystal lattice to carry a small current when a battery is connected across the crystal. The resistivity of germanium ($\rho = 47\Omega \cdot \text{cm}$ at 27°C) is far less than that of silicon ($\rho = 3 \times 10^5\Omega \cdot \text{cm}$ at 27°C). Fig. 4 illustrates simply and in two dimensions the crystal structure of tetravalent semiconductor materials.

P- and N-Type Semiconductors

In order to obtain the controlled flow of current required in transistors, diodes and other devices, minute traces of certain impurity elements are added to the INTRINSIC (i.e. pure) semiconductor crystal. For instance, if impurity atoms of a pentavalent element such as antimony or arsenic are

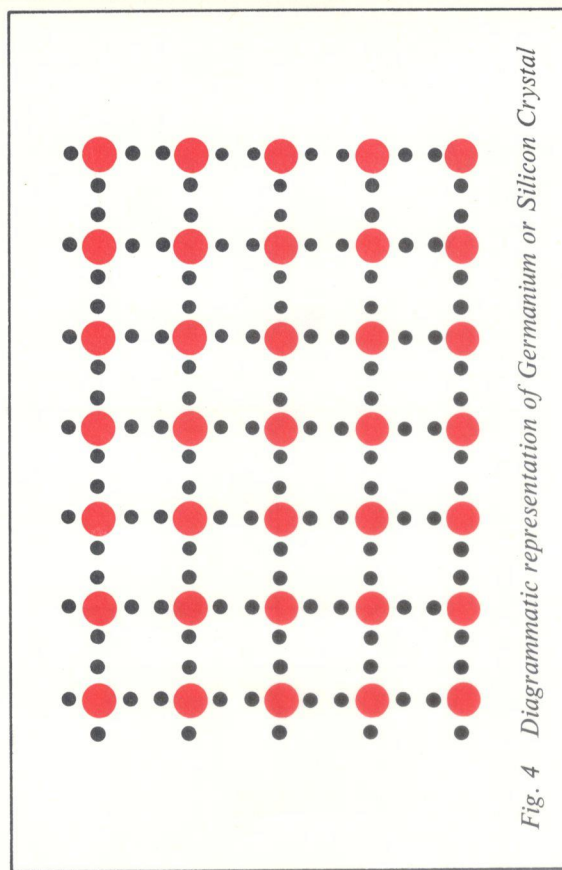


Fig. 4 Diagrammatic representation of Germanium or Silicon Crystal

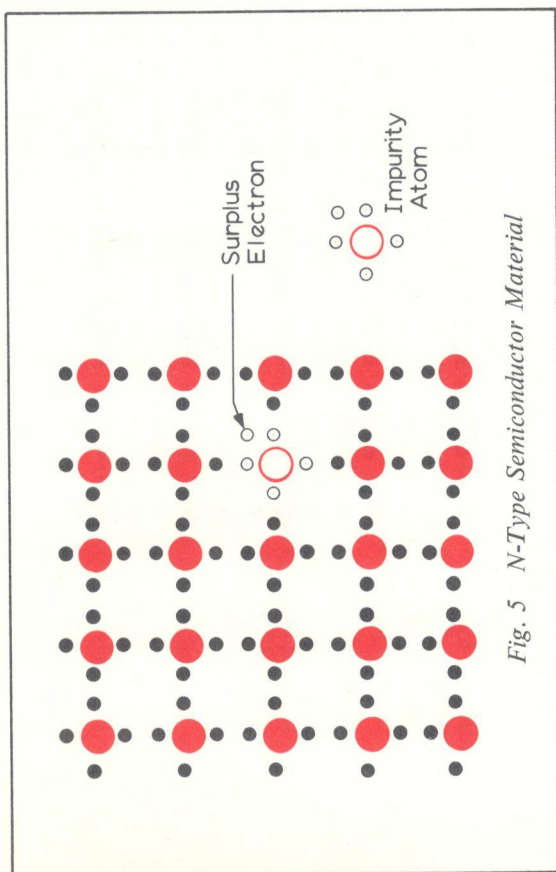


Fig. 5 N-Type Semiconductor Material

added, fig. 5, only four of the impurity's five outer electrons can 'fit' into the lattice and the surplus fifth electron becomes free to act as a current carrier. There will of course be a free electron for each atom of impurity added. A crystal treated in this way is called N-TYPE semiconductor material because it contains free electrons which are negative charge carriers. However, it should be noted that the overall charge on the crystal remains zero because each of the individual atoms present is electrically neutral. The overall effect is a large increase in the conductivity. The resistivity is reduced to only a few $\Omega \cdot \text{cm}$ by the addition of about one impurity atom to every 10^8 atoms of pure semiconductor. The pentavalent impurity atoms are called DONOR atoms since each donates one free electron to the lattice.

If on the other hand pure semiconductor crystal is contaminated or DOPED with atoms of a trivalent element such as aluminium or indium, fig. 6, a deficiency of electrons is introduced into the lattice. For each impurity atom there is a deficiency of one electron. These deficiencies are called HOLES. Because a hole exerts an attractive force on neighbouring electrons in the lattice, it constitutes a virtual positive charge and may be considered as a positively charged particle. A hole need not stay near the impurity atom which introduced it. An electron from a neighbouring atom can move in and cancel it so that the hole moves to the neighbouring atom. A semiconductor crystal which contains mainly holes is called P-TYPE (p for positively charged particles). Whilst the presence of holes increases the conductivity,