Technical Operations Section

SEMI-CONDUCTORS

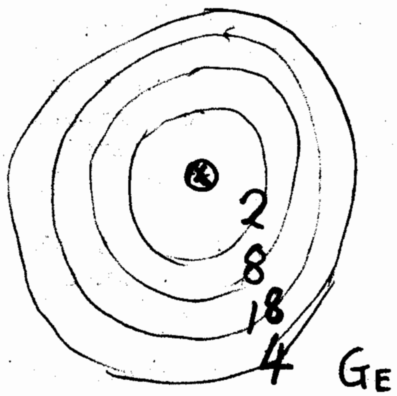
The ability of a substance to conduct electricity depends on the readiness with which electrons can become detached from their parent atoms. In the case of pure germanium, which is a crystalline substance, there are very few free electrons at room temperatures, and the material is classed as a Semi-Conductor.

(Insulator-glass-resistivity = 10^{12} ohm-cm^3)

(Conductor-copper " $1{\cdot}57 \times 10^{-6}$ ohm-cm^3).

(Semi-conductor " = 1 ohm-cm^3)

The electrons on which the conductive properties of the semi-conductor depend are those in the outer orbit or "valence band". These are called valence electrons.



1st Ring 2 electrons

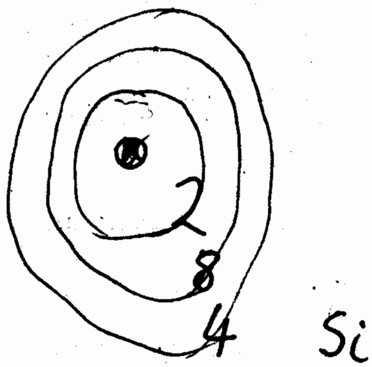
2nd Ring 8 electrons

3rd Ring 18 electrons

4th Ring 4 electrons

Structure of Germanium Atom

(Total electrons = 32 = atomic no.)



1st Ring 2 electrons

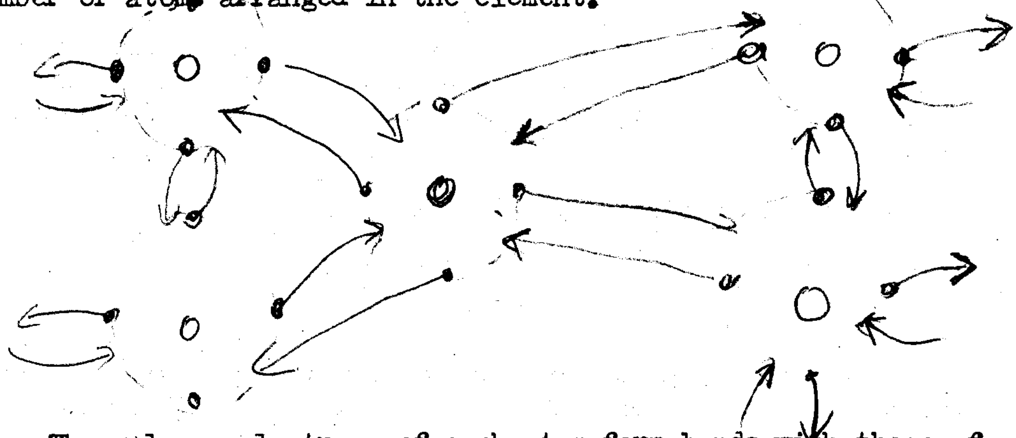
2nd Ring 8 electrons

3rd Ring 4 electrons

Stucture of Silicon Atom

(Total electrons = 14 = atomic no.)

On inspecting the structure of an atom of germanium or silicon it may be thought that some of the 4 electrons in the valence band could be easily displaced and that these elements would therefore be good conductors. Crystals of pure germanium and pure silicon are, in fact, very poor conductors and this is explained by looking at a number of atoms arranged in the element.



The valence electrons of each atom form bands with those of neighbouring atoms as shown. These are called co-valent bonds. Each outer shell electron orbits a neighbouring atom in addition to its parent atom. Thus the central nucleus "shares" its four valance electrons with four neighbouring nuclei, each of which contributes one electron from its outer shell in return so that effectively the central nucleus has eight electrons and is said to be "complete".

It is the electrons in the outer orbit that contribute to the conductivity of the material but before one can do this it must acquire sufficient energy to break away from its "bond".

In practice, germanium and silicon do have a small conductivity even when they are as pure as modern chemical methods can make them. This is partly due to the presence of minute traces of impurities and partly because some of the valence electrons do succeed in escaping from their co-valent bonds and thus become available as current carriers. This is because even at normal room temperatures they have sufficient energy to allow breakage of bonds. If their energy is increased by adding light or by increasing temperature, more valence electrons escape and conductivity increases.

If a valence electron does break away from its "bond" it will drift into the orbits of neighbouring atoms in a random way. Should a voltage be applied between two points on the substance, however, the movement of electrons becomes a general drift towards the positive pole of the applied voltage.

Each time an electron breaks away from its atom it leaves a vacancy or "hole", which remains until it is filled by another electron from a neighbouring atom. Thus the "hole" effectively moves in a direction opposite to that of the electron, and in general a flow of electrons in one direction may be regarded as a flow of "holes" in the reverse direction.

Improvement in Conductivity

The conductivity of germanium or silicon may be greatly improved by the addition of a small amount of impurity into the crystal. Two types of impurity may be purposely added in this way.

1. One having five valency electrons-called penta valent substance, e.g. arsenic. 'N' Type (free electrons Negative) DONOR

2. One having three valency electrons - called tri-valent substance, e.g. indium, boron. 'P' type (free holes. Positive) ACCEPTOR

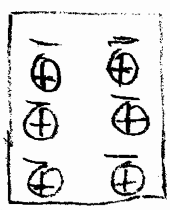
This addition of impurities is called "doping". An impurity of type (1) is said to be a "donor" since it adds an electron while type (2) is an "acceptor" since it will receive an electron from a neighbouring atom.

In case (1) an electron is made free to act as a "current carrier" while in case (2) a hole is made free and acts as a "current carrier".

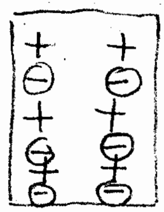
Germanium or silicon doped with a perta valent substance (i.e. (1) above), is called 'N' type material since it has a number of free negative charges.

Germanium or silicon doped with tri-valent substance (i.e. (2) above) is called 'P' type material since it has a number of free positive holes.

To show the operation of diodes and transistors it is convenient to neglect germanium or silicon atoms in our diagrams and show only the donor or acceptor atoms and the free electrons or holes they introduce, e.g.



'N' Type Germanium

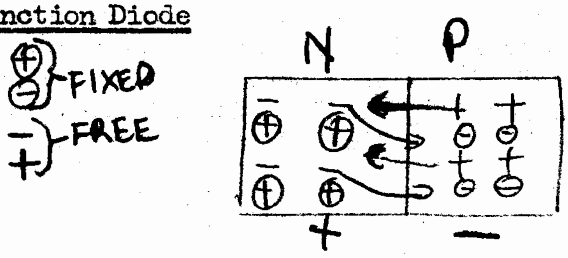


'P' Type Germanium

⊕ Fixed Donor Atoms HOLES
− Free Electrons

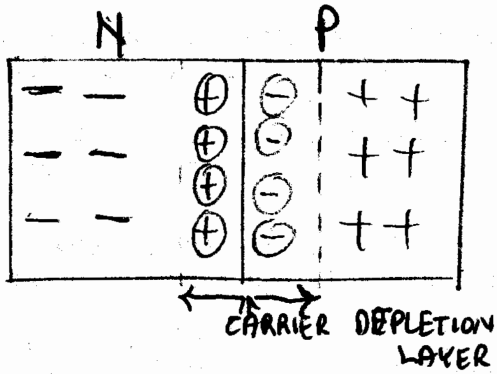
⊖ Fixed Acceptor Atoms
+ Holes FREE

Junction Diode



A single crystal of germanium or silicon may be produced which has been doped so that one half consists of n-type and the other p-type material. N.B. This is NOT obtained by simply butting a N type crystal to a P type. Initially such a crystal may be represented as shown.

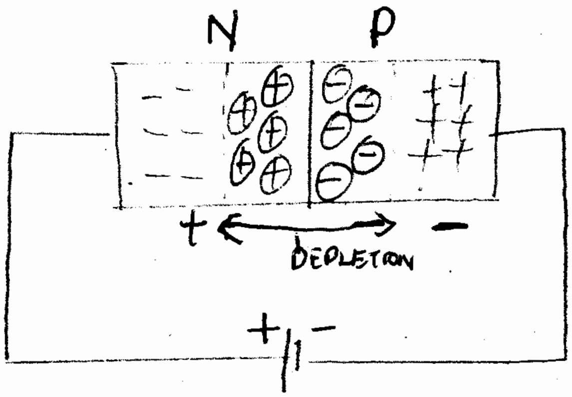
At the junction between the two regions, free electrons will move across from the 'N' region and begin to fill up "holes" in the 'P' region. This recombination process entails a flow of current carriers through the junction and therefore a potential is developed across the junction of such a polarity as to oppose the flow of carriers. A state of equilibrium is quickly reached when no more electrons will flow. This leaves a thin region in the vicinity of the junction which has no mobile carriers and is called the CARRIER DEPLETION LAYER.



A similar effect could be caused by connecting a battery as shown. The area in the vicinity of the junction is an area of high resistance since there are no free current carriers available.

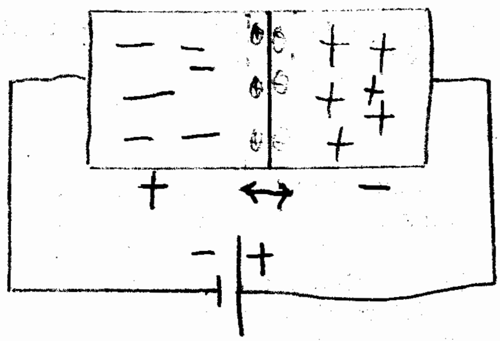
Application of E.M.F. Across P-N Junction

1. Reverse Bias

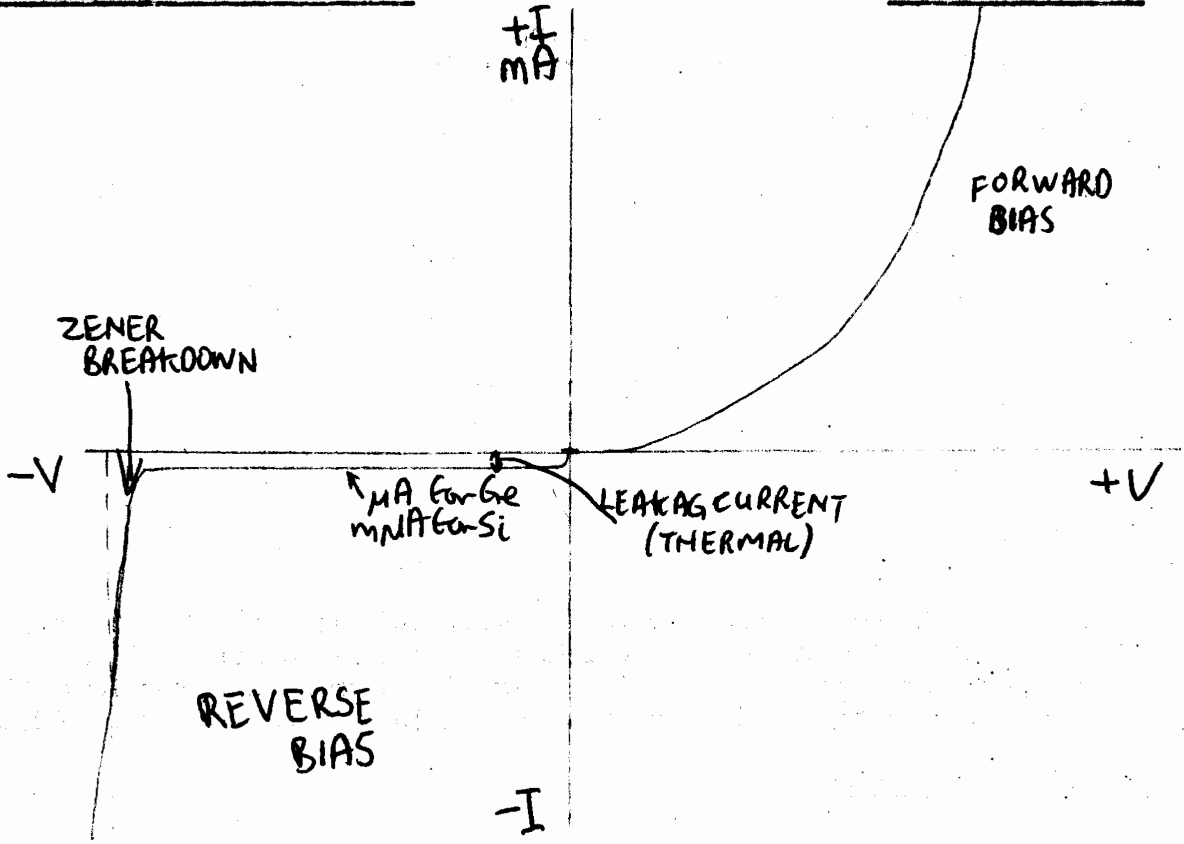


If an external battery is connected with the same polarity as the "Internal battery" the depletion layer will be increased in width and current carriers will still be unable to cross the junction. Thus the device acts as a high resistance and is said to be "reverse-biased".

2. Forward Bias



If the polarity of the external battery is reversed, it can be made to cancel the effect of the "internal battery" and reduce the depletion layer width. Current carriers may now move from N type to P type material and vice versa and the device has a relatively low resistance.



The small reverse current is due to thermally produced electron-hole pairs to which the depletion layer is not a barrier.

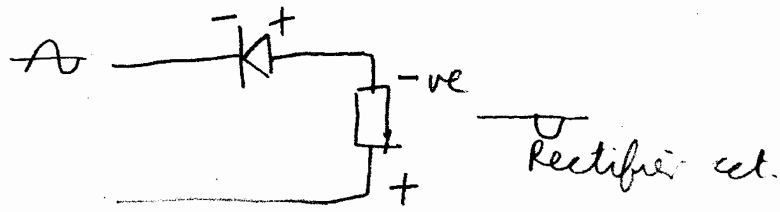
Uses of Semi-Conductor Diodes

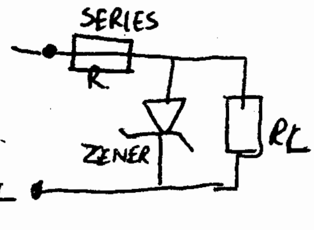
1. R.F. Detectors
2. Power rectifiers

Reverse resistance lower than valve but heater dispensed with saving heater supplies and current.

More robust than valve.
Smaller than valve
Cheaper than valve (except in specialised fields).
For high voltage and high current the valve still has the advantage.

3. Voltage Stabilisation - "Zener" diode used - a silicon diode with very steep reverse current characteristic.





4. Automatic Frequency Control, Frequency Modulation, etc.

"Capacitance" diode used - uses depletion layer as dielectric between two parallel plates (i.e. the 'P' and 'N' materials). Changes in reverse bias change thickness of depletion layer hence change capacitance.

e.g. Change from 5 to 90pF with voltage change of 125V

Change from 45 to 250pF with voltage change of 25V.

DGE/RAS
30.4.65.