Integrated Circuits

Active and Passive Components:

An electronic circuit is composed of various types of components. Some of these components are termed as active components because they take part in the transformation of the energy while other components, which only dissipate or store energy, are called as passive elements. The vacuum tubes, rectifier, transistors are some of the common active while the resistances, which dissipate the power and energy storing elements such as capacitances and inductances are known as passive elements. The transformers may be regarded as a matching device.

The elements which supply energy to the network are known as active elements. The voltage sources like batteries, DC generator, AC generator, and current sources like Photoelectric cells fall under the category of active elements.

Active components can be further classified as

Semiconductor Devices: Semiconductor diode, zener diode, and varactor diode, uni-junction transistor, Bipolar junction Transistor (BJT), FET, silicon, Controlled rectifier etc.

Vacuum Tube Devices: Vacuum tube diode, triode, Tetrode, Pentode, Hexode etc.

Gas Tube Devices: Gas diodes, Thyratons etc.

Photo Sensitivity Devices: Gas photodiodes, photo multiplier tubes, photodiodes, light emitting diode, photosensitive transistor etc.

The components which dissipate or store energy are known as passive components. Resistors, inductors, and capacitors fall under the category of passive elements.

Linear and Non-linear circuits:

Resistive elements for which the volt-ampere characteristic is a straight line are called linear and the electric circuits containing only linear resistances are called linear circuits.

Resistive elements for which the volt-ampere characteristic is other than straight line are called non-linear and the electric circuits containing non-linear resistances are called non-linear circuits.

Passive and Active Networks:

A network is said to be passive if it contains no source of e.m.f. it.

When a network contains one or more sources of emf or current is called active network.

Integrated Circuit

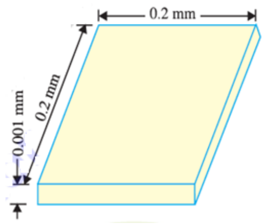
An **integrated circuit** is one in which circuit components such as transistors, diodes, resistors, capacitors etc. are automatically part of a small semiconductor chip.

An integrated circuit consists of a number of circuit components (e.g. transistors, diodes, resistors etc.) and their inter connections in a single small package to perform a complete electronic function. These components are formed and connected within a small chip of semiconductor material. The following points are worth noting about integrated circuits:

(i) In an IC, the various components are automatically part of a small semi-conductor chip and the individual components cannot be removed or replaced. This is in contrast to discrete assembly in which individual components can be removed or replaced if necessary.

(ii) The size of an *IC is extremely small. In fact, ICs are so small that you normally need a microscope to see the connections between the components. Figure shows a typical semi-conductor chip having dimensions 0.2 mm × 0.2 mm × 0.001 mm. It is possible to produce circuits containing many transistors, diodes, resistors etc. on the surface of this small chip.

(iii) No components of an IC are seen to project above the surface of the chip. This is because all the components are formed within the chip.



Advantages and Disadvantages of Integrated Circuits

Integrated circuits free the equipment designer from the need to construct circuits with individual discrete components such as transistors, diodes and resistors. With the exception of a few very simple circuits, the availability of a large number of low-cost integrated circuits have largely rendered discrete circuitry obsolete. It is, therefore, desirable to mention the significant advantages of integrated circuits over discrete circuits. However, integrated circuits have some disadvantages and continuous efforts are on to overcome them.

Advantages: Integrated circuits possess the following advantages over discrete circuits:

(i) Increased reliability due to lesser number of connections.

(ii) Extremely small size due to the fabrication of various circuit elements in a single chip of semi-conductor material.

(iii) Lesser weight and **space requirement due to miniaturized circuit.

(iv) Low power requirements.

(v) Greater ability to operate at extreme values of temperature.

(*vi*) Low cost because of simultaneous production of hundreds of alike circuits on a small semiconductor wafer.
(*vii*) The circuit lay out is greatly simplified because integrated circuits are constrained to use minimum number of external connections.

Disadvantages : The disadvantages of integrated circuits are :
(*i*) If any component in an *IC* goes out of order, the whole *IC* has to be replaced by the new one.
(*ii*) In an *IC*, it is neither convenient nor economical to fabricate capacitances exceeding 30 *pF*. Therefore, for high values of capacitance, discrete components exterior to *IC* chip are connected.
(*iii*) It is not possible to fabricate inductors and transformers on the surface of semi-conductor chip. Therefore, these components are connected exterior to the semi-conductor chip.
(*iv*) It is not possible to produce high power *ICs* (greater than 10 W).
(*v*) There is a lack of flexibility in an *IC i.e.*, it is generally not possible to modify the parameters within which an integrated circuit will operate.

IC Classifications

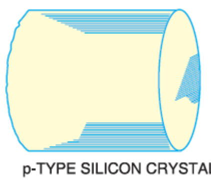
Four basic types of constructions are employed in the manufacture of integrated circuits, namely;
(*i*) mono-lithic **(*ii*)** thin-film **(*iii*)** thick-film **(*iv*)** hybrid.

Monolithic *ICs* are by far the most common type used in practice. Therefore, in this chapter we shall confine our attention to the construction of this type of *ICs* only. It may be worthwhile to mention here that regardless of the type of method used to fabricate active and passive components, the basic characteristics and circuit operation of an *IC* are the same as for any of their counterparts in a similar circuit using separate circuit components.

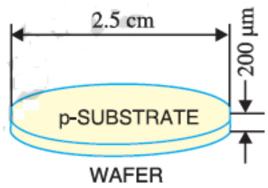
Making Monolithic IC

A **monolithic IC** is one in which all circuit components and their inter-connections are formed on a single thin wafer called the substrate.

The basic production processes for the monolithic *ICs* are as follow:
(*i*) p-Substrate. This is the first step in the making of an *IC*. A cylindrical *p*-type *silicon crystal is grown having typical dimensions 25 cm long and 2.5 cm diameter [See Fig.(*i*)]. The crystal is then cut by a diamond saw into many thin wafers like Fig.(*ii*), the typical thickness of the wafer being 200 μm. One side of wafer is polished to get rid of surface imperfections. This wafer is called the substrate. The *ICs* are produced on this wafer.

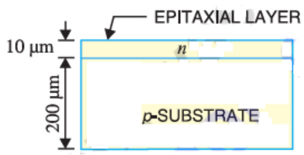


(*i*)

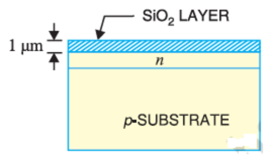


(*ii*)

(*ii*) Epitaxial n layer. The next step is to put the wafers in a diffusion furnace. A gas mixture of silicon atoms and pentavalent atoms is passed over the wafers. This forms a thin layer of *n*-type semi-conductor on the heated surface of substrate [See Fig. (*i*)]. This thin layer is called the **epitaxial layer* and is about 10 μm thick. It is in this layer that the whole integrated circuit is formed.

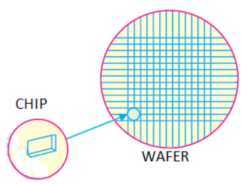


(i)



(*ii*)

(*iii*) Insulating layer. In order to prevent the contamination of the epitaxial layer, a thin *SiO*2 layer about 1μm thick is deposited over the entire surface as shown in above Fig. (*ii*).This is achieved by passing pure oxygen over the epitaxial layer. The oxygen atoms combine with silicon atoms to form a layer of silicon dioxide (*SiO*2).
(*iv*)Producing components. By the process of **diffusion, appropriate materials are added to the substrate at specific locations to produce diodes, transistors, resistors and capacitors. The production of these components on the wafer is discussed in the next topics.
(*v*) Etching. Before any impurity is added to the substrate, the oxide layer (*i.e. SiO*2 layer) is etched. The process of etching exposes the epitaxial layer and permits the production of desired components. The terminals are processed by etching the oxide layer at the desired locations.
(*vi*) Chips. In practice, the wafer shown in figure is divided into a large number of areas. Each of these areas will be a separate chip. The manufacturer produces hundreds of alike *ICs* on the wafer over each area. To separate the individual *ICs*, the wafer is divided into small chips by a process similar to glass cutting.



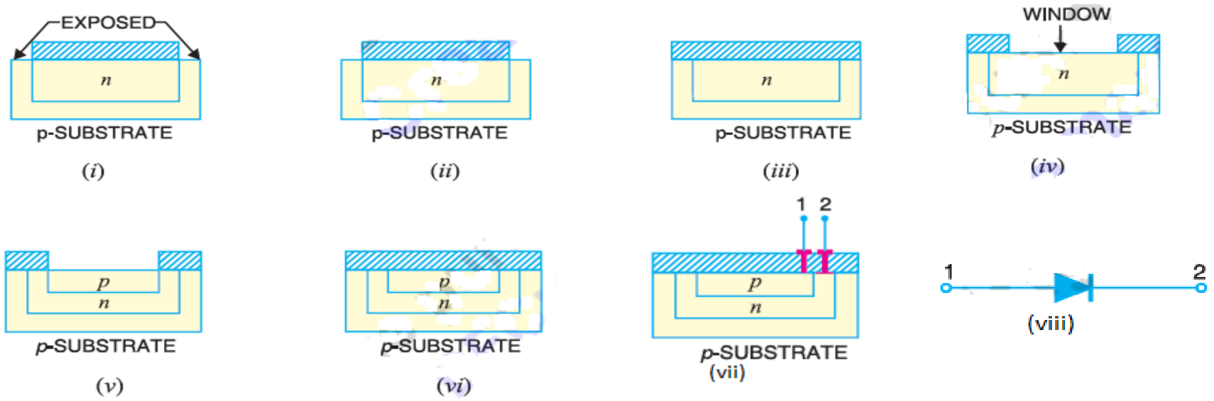
Fabrication of Components on Monolithic IC

The notable feature of an *IC* is that it comprises a number of circuit elements inseparably associated in a single small package to perform a complete electronic function. This differs from discrete assembly where separately manufactured components are joined by wires. We shall now see how various circuit elements (*e.g.* diodes, transistors, resistors etc.) can be constructed in an *IC* form.

(*i*) Diodes. One or more diodes are formed by diffusing one or more small *n*-type deposits at appropriate locations on the substrate. Fig. 23.5 shows how a diode is formed on a portion of substrate of a monolithic *IC*. Part of *SiO*2 layer is etched off, exposing the epitaxial layer as shown in Fig.(*i*).The wafer is then put into a furnace and trivalent atoms are diffused into the epitaxial layer. The trivalent atoms change the exposed epitaxial layer from *n*-type semi-conductor to *p*-type. Thus we get an island of *n*-type material under the *SiO*2 layer as shown in Fig.(*ii*).

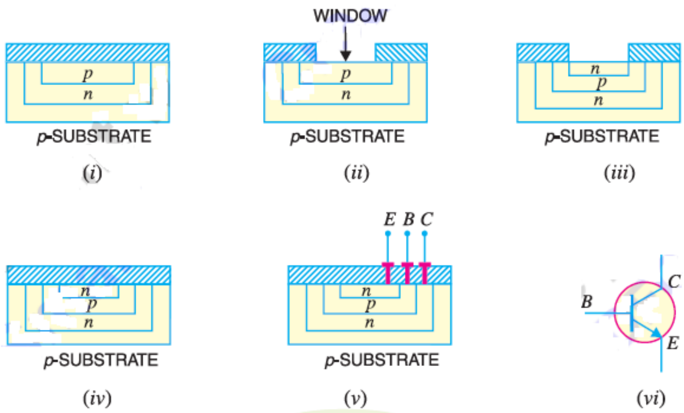
Next pure oxygen is passed over the wafer to form a complete *SiO*2 layer as shown in Fig.(*iii*). A hole is then etched at the centre of this layer ; thus exposing the *n*-epitaxial layer [See Fig.(*iv*)]. This hole in *SiO*2 layer is called a **window**. Now we pass trivalent atoms through the window. The trivalent atoms diffuse into the epitaxial layer to form an island of *p*-type material as shown in Fig.(*v*). The *SiO*2 layer is again formed on the wafer by blowing pure oxygen over the wafer [See Fig.(*vi*)]. Thus a *p-n* junction diode is formed on the substrate.

The last step is to attach the terminals. For this purpose, we etch the *SiO*2 layer at the desired locations as shown in Fig.(vii). By depositing metal at these locations, we make electrical contact with the anode and cathode of the integrated diode. Fig.(viii) shows the electrical circuit of the diode.



(*ii*) Transistors. Transistors are formed by using the same principle as for diodes. The figure shown below shows how a transistor is formed on a portion of the substrate of a monolithic *IC*. For this purpose, the steps used for fabricating the diode are carried out upto the point where *p* island has been formed and sealed off [See Fig.(*vi*) above]. This Fig. is repeated as Fig.(*i*) and shall be taken as the starting point in order to avoid repetition.

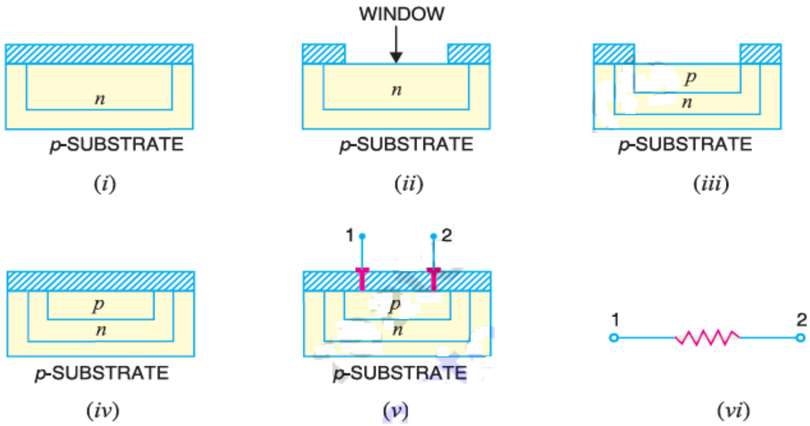
A window is now formed at the centre of *SiO*2 layer, thus exposing the *p*-epitaxial layer as shown in Fig.(*ii*). Then we pass pentavalent atoms through the window. The pentavalent atoms diffuse into the epitaxial layer to form an island of *n*-type material as shown in Fig.(*iii*). The *SiO*2 layer is re-formed over the wafer by passing pure oxygen [See Fig.(*iv*)]. The terminals are processed by etching the *SiO*2 layer at appropriate locations and depositing the metal at these locations as shown in Fig.(*v*). In this way, we get the integrated transistor. Fig.*vi*) shows the electrical circuit of a transistor.



(*iii*) Resistors. Figure shows how a resistor is formed on a portion of the substrate of a monolithic *IC*. For this purpose, the steps used for fabricating diode are carried out upto the point where *n* island has been formed and sealed off [Refer back to Fig. (*iii*) above]. This figure is repeated as Fig. (*i*) and shall be taken as the starting point in order to avoid repetition.

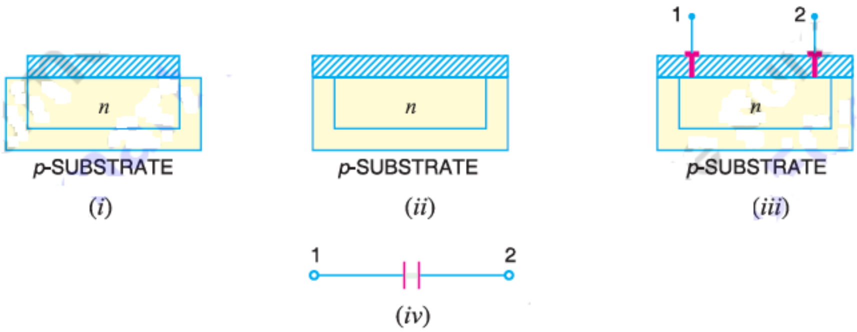
A window is now formed at the centre of *SiO*2 layer, thus exposing the *n*-epitaxial layer as shown in Fig.(*ii*). Then we diffuse a *p*-type material into the *n*-type area as shown in Fig.(*iii*). The *SiO*2 layer is re-formed over the wafer by passing pure oxygen [See Fig.(*iv*)]. The terminals are processed by etching *SiO*2 layer at two points above the *p* island and depositing the metal at these locations [See Fig.(*v*)]. In this way, we get an integrated resistor. Fig.(*vi*) shows the electrical circuit of a resistor.

The value of resistor is determined by the material, its length and area of cross-section. The high-resistance resistors are long and narrow while low-resistance resistors are short and of greater cross-section.



(*iv*) Capacitors. Fig. shows the process of fabricating a capacitor in the monolithic *IC*. The first step is to diffuse an *n*-type material into the substrate which forms one plate of the capacitor as shown in Fig.(*i*). Then *SiO*2 layer is re-formed over the wafer by passing pure oxygen as shown in Fig.(*ii*).

The *SiO*2 layer formed acts as the dielectric of the capacitor. The oxide layer is etched and terminal 1 is added as shown in Fig.(*iii*). Next a large (compared to the electrode at terminal 1) metallic electrode is deposited on the *SiO*2 layer and forms the second plate of the capacitor. The oxide layer is etched and terminal 2 is added. This gives an integrated capacitor. The value of capacitor formed depends upon the dielectric constant of *SiO*2 layer, thickness of *SiO*2 layer and the area of cross-section of the smaller of the two electrodes.



Classifications of IC Technologies:

The traditional method of combinational circuit design involves simplification and realization of logic functions using logic gates. This method of designing combinational circuit is effective for small circuit. When circuit complexity is more, more number of gates are required with more number of wires between them. Designing of such circuits may be time consuming and less reliable.

To avoid these problems a collection of one or more gates are fabricated on a single silicon chip. Such a circuit is called Integrated Circuit (IC). The number of electronic components which can be fabricated on a standard size of silicon chip is called Scale of Integration. There are 4 types of scale of integration:

1. Small Scale Integration (SSI)
2. Medium Scale Integration (MSI)
3. Large Scale Integration (LSI)
4. Very Large Scale Integration (VLSI)

Small Scale Integration (SSI):

The simplest types of digital ICs are placed in the small scale integration (SSI) category. These ICs have up to 20 equivalent gate circuits on a single chip. These include basic gate functions and flip-flops. SSI ICs are fabricated in one of the two main configurations:

(i) Dual-in Line Package (DIP) and
(ii) Flat Pack

The fig. 6.26 shows these packages for 14-pin and 16-pin ICs.
The fig.6.27 shows a cutaway view of a DIP with the IC chip within the package. Leads from the chip are connected to the package pins to allow input and output connections to the outside world.

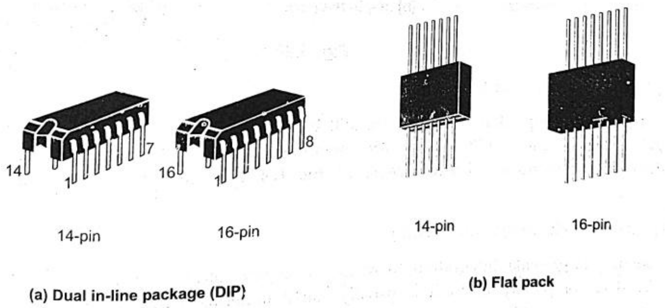


Fig. 6.26 Some common IC packages

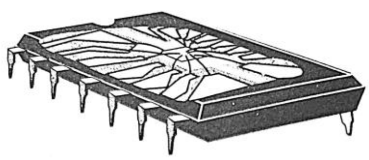
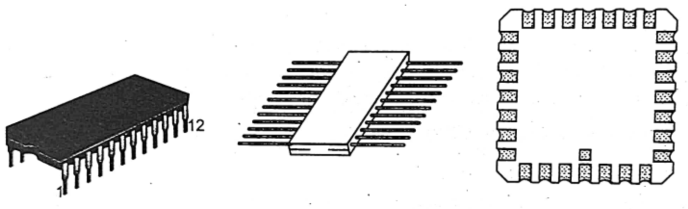


Fig. 6.27 Cutaway view of a dual-in-line 14-pin package

Medium Scale Integration (MSI):

The next larger commercially available ICs are called medium scale integration (MSI). In this case, number of components contained in one IC package is between 20 to 200 gates. MSI circuits include the more complex logic functions such as encoders, decoders, counters, multiplexers, demultiplexers, registers, arithmetic circuits, small memories and others. The fig.6.28 shows a 24-pin DIP and flat pack and a 28-pin chip carrier in which MSI functions are packaged.



(a) 24-pin dual-in-line (b) 24-pin flat pack (c) 28-pin ceramic chip carrier package

Fig. 6.28

Large Scale Integration (LSI):

Large scale integration (LSI) ICs are still bigger and contain the equivalent of 200 to 200,000 gates or more. LSI ICs include memories, microprocessors, programmable logic device and customized devices. Most of the LSI ICs are fabricated in dual-in line packages.

Very Large Scale Integration (VLSI):

Beyond large scale integration there is a category called very large scale integration (VLSI). The complexity in VLSI is usually stated in terms of transistor count that gate count. Any IC with over 1000000 transistors is VLSI IC. It includes advance microprocessors, large memories, larger programmable logic devices and customized devices.

The digital ICs reduce system cost, size, power and the number of external wire connections improving reliability of the system.