

TOWARD MEMS!

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Students are presented with aspects of general production and manufacturing of integrated circuit (IC) products to enable them to better liaise with and participate in the manufacturing industry sector. The design for manufacture of various products is presented with emphasis on: IC design approaches, to packaging, to printed wiring board technologies, to quality and reliability, to test, to production and to assembly.

Integrated Circuits

- Integrated circuits (ICs) form a branch of the general field of microelectronics, which originated in the late 1950s.
- The main advantage of ICs over discrete components is the reduced size and increased reliability.
- ICs evolved from the miniaturization program. The first effort was to miniaturize discrete components. This was followed by developing printed circuit boards (single and double-sided) to eliminate bulky wiring and tie points. Discrete components were then placed on the board.

What is a Semiconductor?

- A number of elements are classified as semiconductors including silicon, zinc, and germanium. These elements have the ability to conduct electrical current, and they can be regulated in the amount of their conductivity.
- Silicon is the most widely used semiconductor material because it is easily obtained. Silicon is basically extracted from sand. It has been used for centuries to make cast iron, bricks, and pottery. In ultra-pure form, the controlled addition of minute amounts of certain impurities (called dopants) alters the atomic structure of the silicon. The silicon can then be made to act as a conductor or a nonconductor, depending upon the polarity of an electrical charge applied to it. Hence, the generic term semiconductor.

Early Developments

- Semiconductor materials were studied in laboratories as early as 1830. The first materials studied were a group of elements and compounds that were usually poor conductors if heated. Shining light on some of them would generate an electrical current that could pass through them in one direction only.
- By 1874, electricity was being used not only to carry power, but to carry information. The telegraph, telephone, and later the radio were the earliest devices in an industry that would eventually be called electronics.
- Radio receivers required a device called a rectifier to detect signals. Ferdinand Braun used the rectifying properties of the galena crystal, a semiconductor material composed of lead sulfide, to create the cat's whisker diode for this purpose. Thus was born the first semiconductor device.

The terminology of Microelectronics

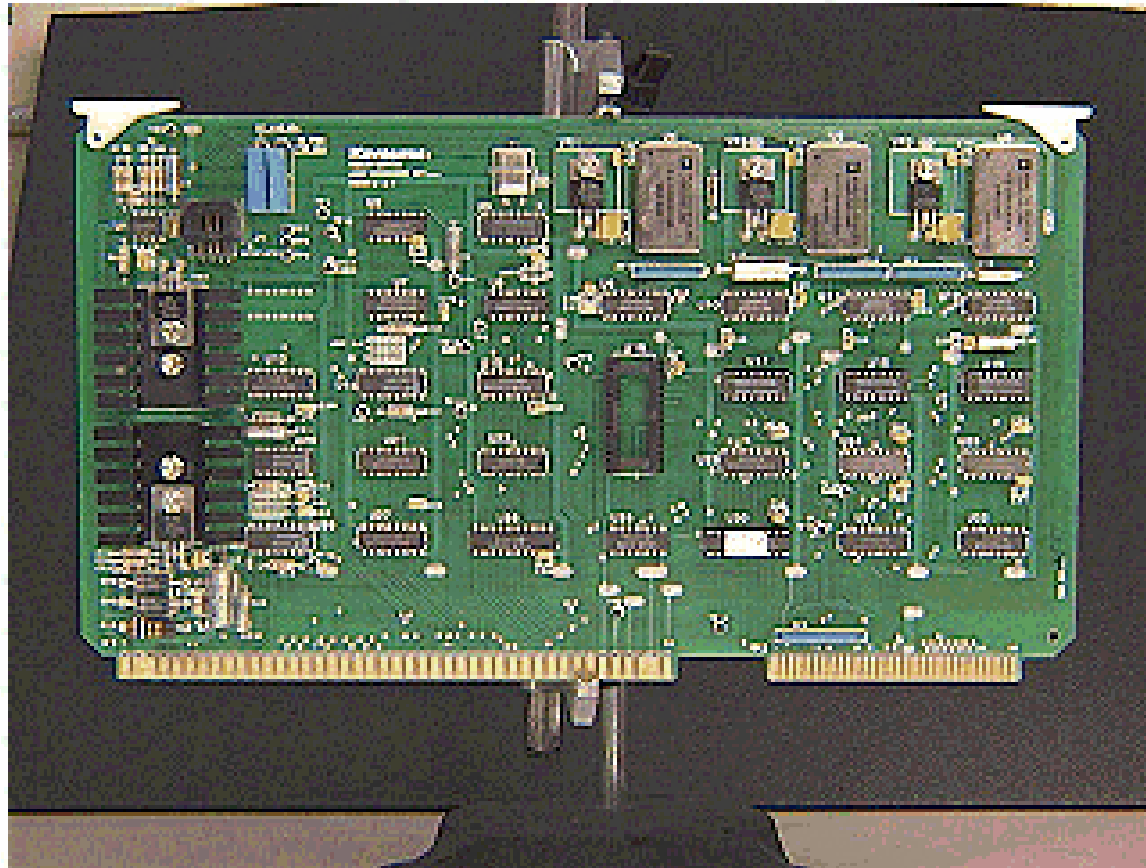
- Miniature Discrete Components.
- Functional Devices.
- Integrated Circuits.
 - Silicon Monolithic (Active and Passive).
 - Film Circuits (Passive):
 - Thin.
 - Thick.
 - Hybrid:
 - Thin Film and Discrete Active Devices
 - Compatible Silicon-thin Film
 - Multichip Interconnections.

LSI and VLSI

- VLSI is the results of improvements in microelectronics production technology. In the VLSI, the entire SUBSTRATE WAFER (slice of semiconductor or insulator material) is used instead of one that has been separated into individual circuits.
- In LSI and VLSI, a variety of circuits can be implanted on a wafer resulting in further size and weight reduction. ICs in modern computers, such as home computers, may contain the entire memory and processing circuits on a single substrate.
- Large-scale integration is generally applied to integrated circuits consisting of from 1,000 to 2,000 logic gates or from 1,000 to 64,000 bits of memory. A logic gate, as we know from digital electronics is an electronic switching network consisting of combinations of transistors, diodes, and resistors. Very large-scale integration is used in integrated circuits containing over 2,000 logic gates or greater than 64,000 bits of memory.

Back to the PCB

But This Time We emphasize on the fabrication of the solid state components



Integrated Circuit

- Until 1959, all electronic components were discrete: that is, they performed only one function, and many of them had to be wired together to create a functional circuit. Although a great number of identical discrete transistors could be fabricated on a single wafer, they then had to be cut up and individually packaged in tiny cans. Packaging each component and hand wiring the components into circuits was extremely inefficient. The military sought more efficient methods of making circuits. New technologies emerged and integrated circuits were soon developed with various components (transistors, resistors, and capacitors) formed on the same chip, but interconnection of the various components still required tedious hand wiring.
- In 1959, Jean Hoerni and Robert Noyce developed a new process called planar technology at Fairchild Semiconductor which enabled them to diffuse various layers onto the surface of a silicon wafer to make a transistor, leaving a layer of protective oxide on the junctions. This process allowed metal interconnections to be evaporated onto the flat transistor surface and replaced the hand wiring. The new process used silicon instead of germanium, and made commercial production of ICs possible. 1960s, nearly 90% of all the components manufactured were integrated circuits.

Monolithic Integrated Circuits

Monolithic means “one stone” from which the whole circuit is manufactured using only diffusion method and no “add ons”.

The following are steps of fabricating simple monolithic integrated circuits:

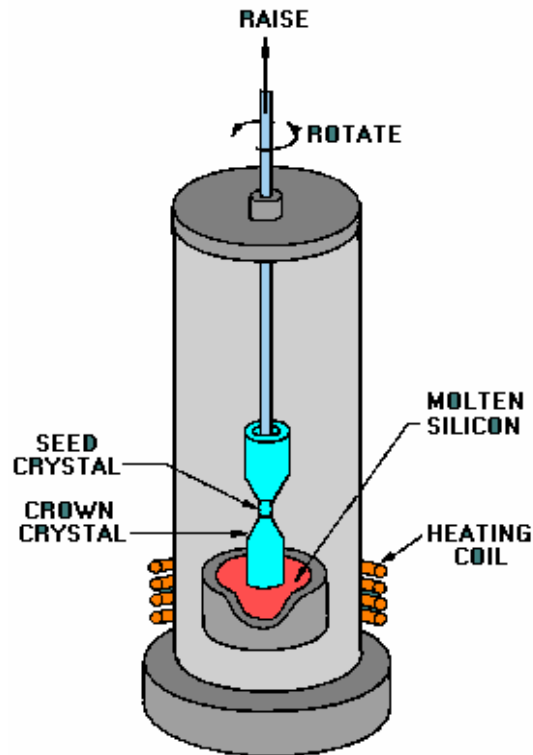
- Wafer Preparation
- Epitaxial Growth
- Diffused Isolation
- Base Diffusion
- Emitter Diffusion
- Pre-ohmic Etch
- Metallization
- Circuit Probing
- Dicing
- Mounting and Packaging
- wire Bonding
- Encapsulation.

Substrate Production

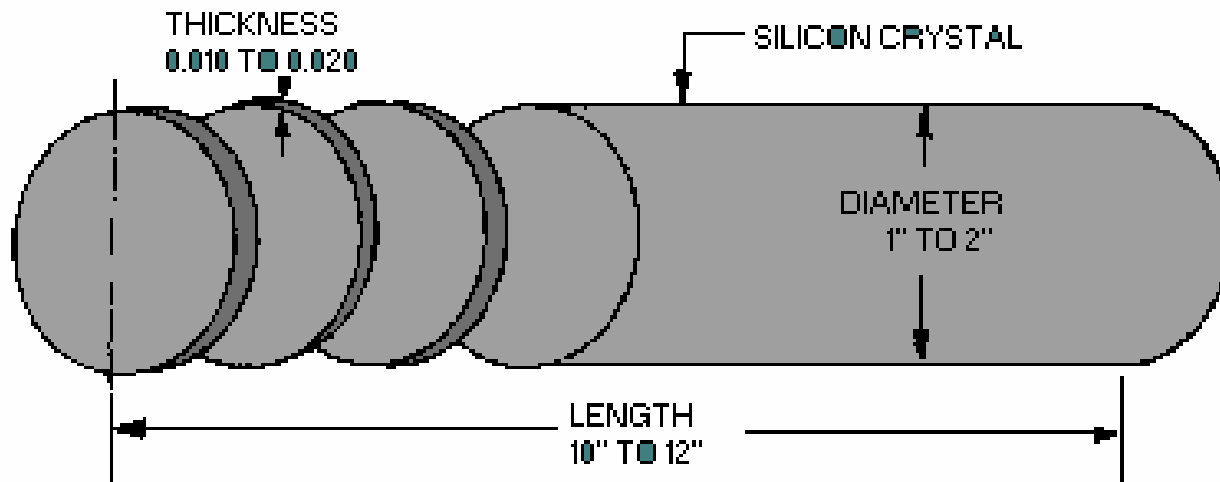
Substrates used in monolithic ICs are of semiconductor material, usually silicon. In this type of IC, the substrate can be an active part of the IC.

Glass or ceramic substrates are used only to provide support for the

components.



The cylinder of semiconductor material that is grown is sliced into thicknesses of 0.010 to 0.020 inch in the first step of preparation. These wafers are ground and polished to remove any irregularities and to provide the smoothest surface possible. Although both sides are polished, only the side that will receive the components must have a perfect finish.

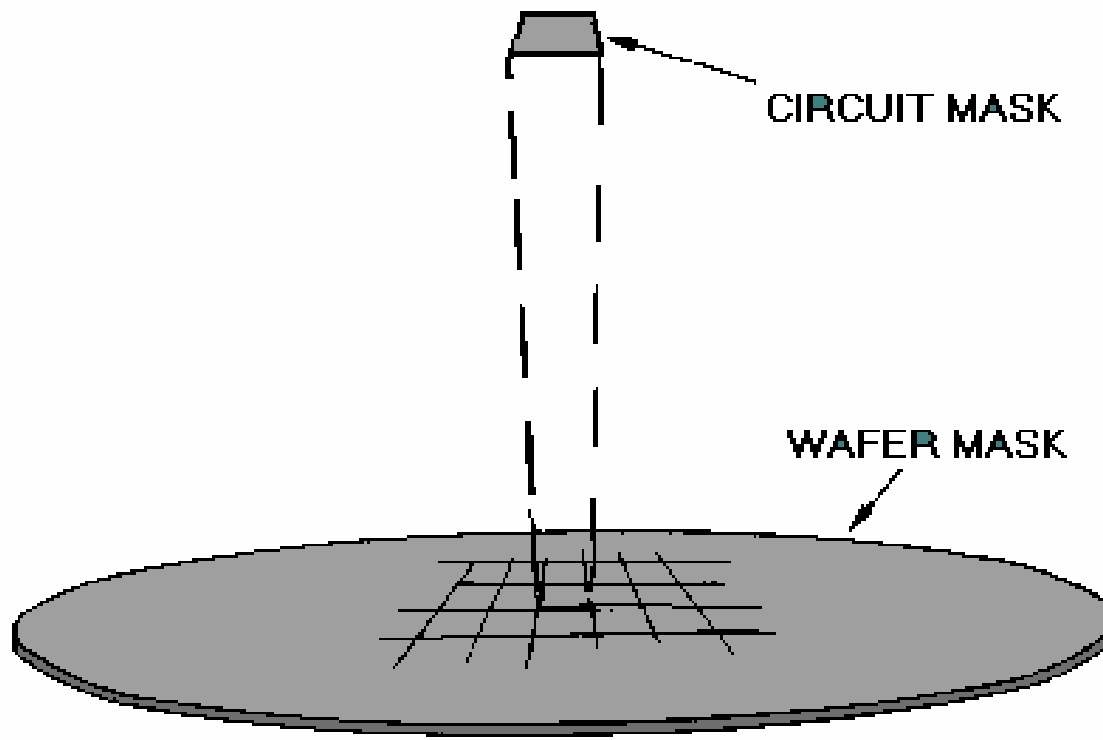


Silicon Wafer

1 1/4 inch diameter

See the little 40-mil square die

The wafer could be cut into 625 40-mil dice

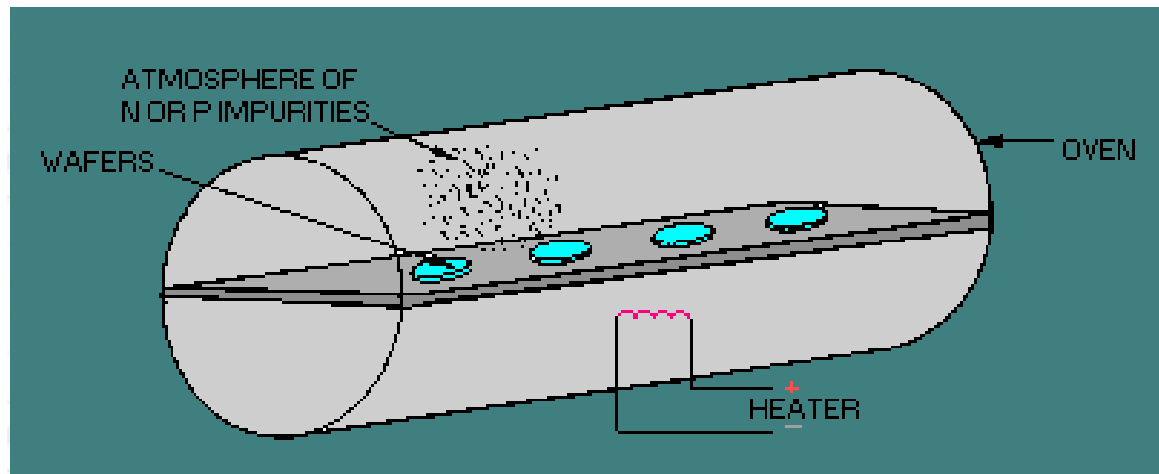


Wafer Preparation

- A single crystal of extremely pure P-type silicon is sliced into wafers 10 to 15 mils thick.
- These wafers after being lapped and polished to a mirror finish, are approximately 5 mils thick.
- The silicon crystal has a flat ground on one side, which is used to position the wafer in succeeding operations.
- The lightly doped P-type wafer provides the base or substrate on which the transistor and other elements are built.

Wafers in Diffusion Oven

The DIFFUSION process begins with the highly polished silicon wafer being placed in an oven. The oven contains a concentration impurity made up of impurity atoms which yield the desired electrical characteristics. The concentration of impurity atoms is diffused into the wafer and is controlled by controlling the temperature of the oven and the time that the silicon wafer is allowed to remain in the oven. This is called DOPING. When the wafer has been uniformly doped, the fabrication of semiconductor devices may begin. Several hundred circuits are produced simultaneously on the wafer.



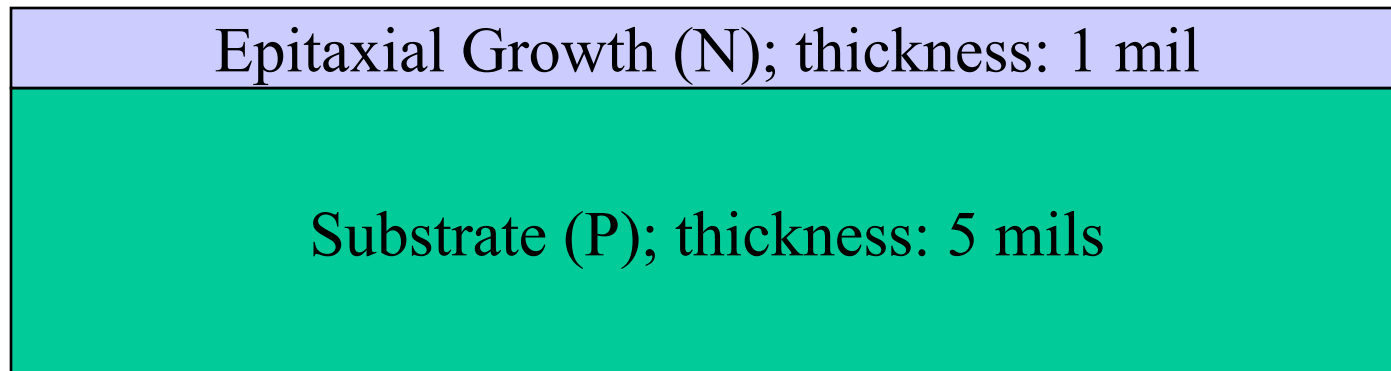
Doping

The conductivity of silicon and germanium may be drastically increased by the controlled addition to the intrinsic (pure) semiconductor material. This process is called doping. It means increasing the number of current carriers (electrons or holes). The two categories of impurities are N-type and P-type.

- N-type Semiconductor: To increase the number of conduction-band electrons in intrinsic silicon, pentavalent impurity are added such as arsenic (As), phosphorus (P), bismuth (bi) and antimony (sb).
- P-type Semiconductors: To increase the number of holes in intrinsic silicon, trivalent impurity atoms are added. Examples like aluminum (Al), boron (B), indium (In), and gallium (Ga).

Epitaxial Growth

An N-type layer of silicon, typically 1 mil thick, is now grown on the P-type substrate by placing the wafer in a furnace at 1200 °C and introducing a gas with a phosphorus content (donor material). This provides the collector material for the NPN transistors. A cross-sectional view of part of the wafer is shown in the following figure.



Diffused Isolation

The N-type epitaxial layer is now isolated into islands, so that on each island a transistor or some other component may be fabricated.

This is done by diffusing P-type material through the epitaxial layer to the substrate by a series of steps that is common in all diffusion processes.

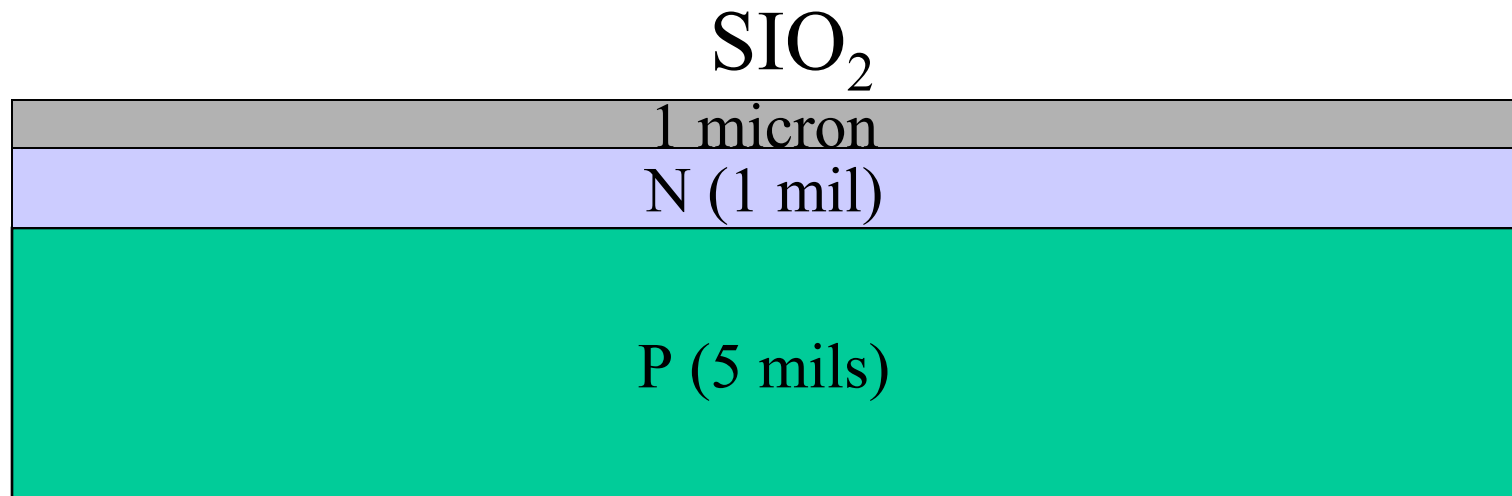
First,

a thin layer of silicon dioxide (approximately 1 micron thick) is formed on the N-type by oxidizing the wafer in dry oxygen.

Units:

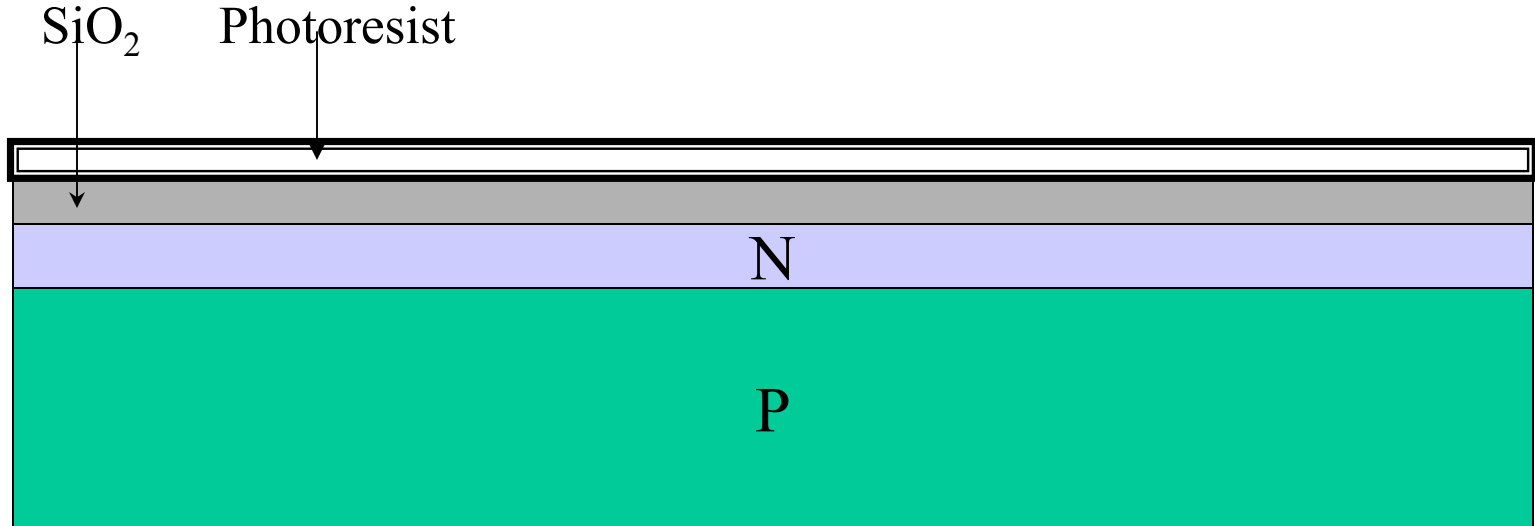
1 mil = 25.4 micron

1000 mils = 1 inch = 25.4 mm exactly



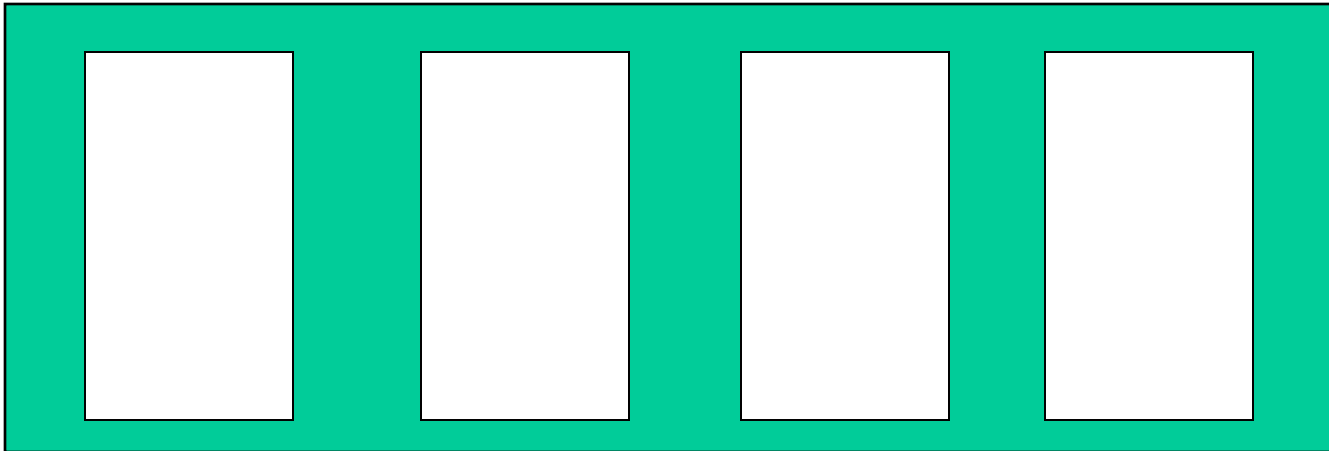
Second,

a thin uniform coating of a chemical called photoresist is now deposited on the SiO_2 layer. This is liquid that will harden when exposed to ultraviolet light.

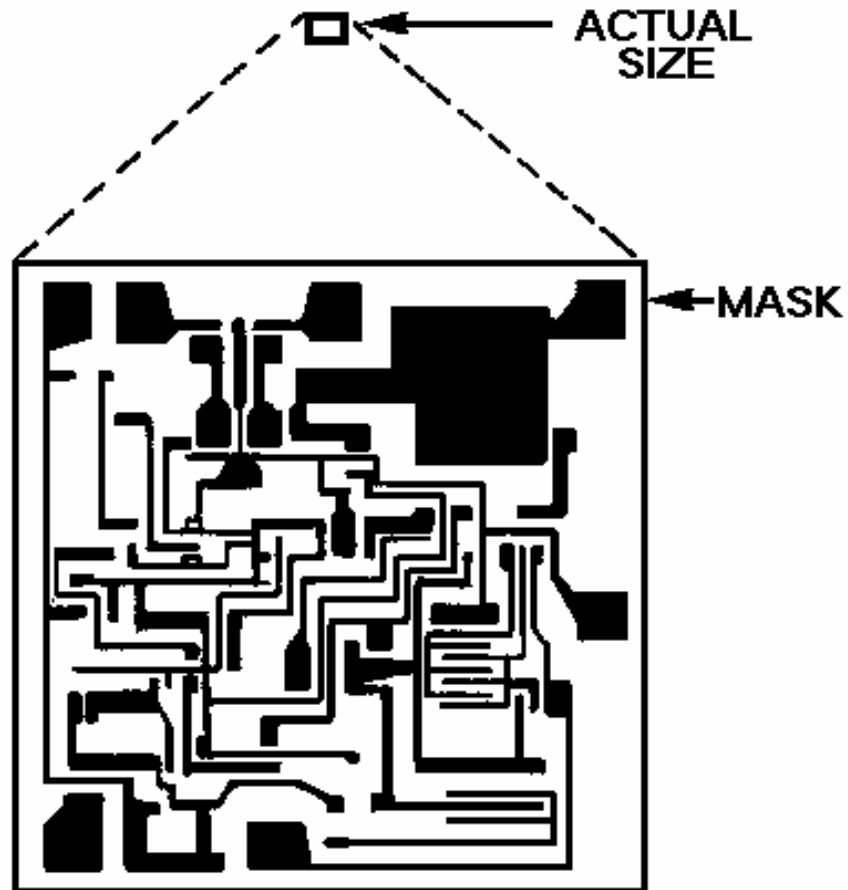


Third,

A mask (which is a glass plate with a pattern drawn on it) is now placed over the photoresist surface. The purpose of the mask is to select the areas through which ultraviolet light may be directed to cause a hardening of the photoresist.

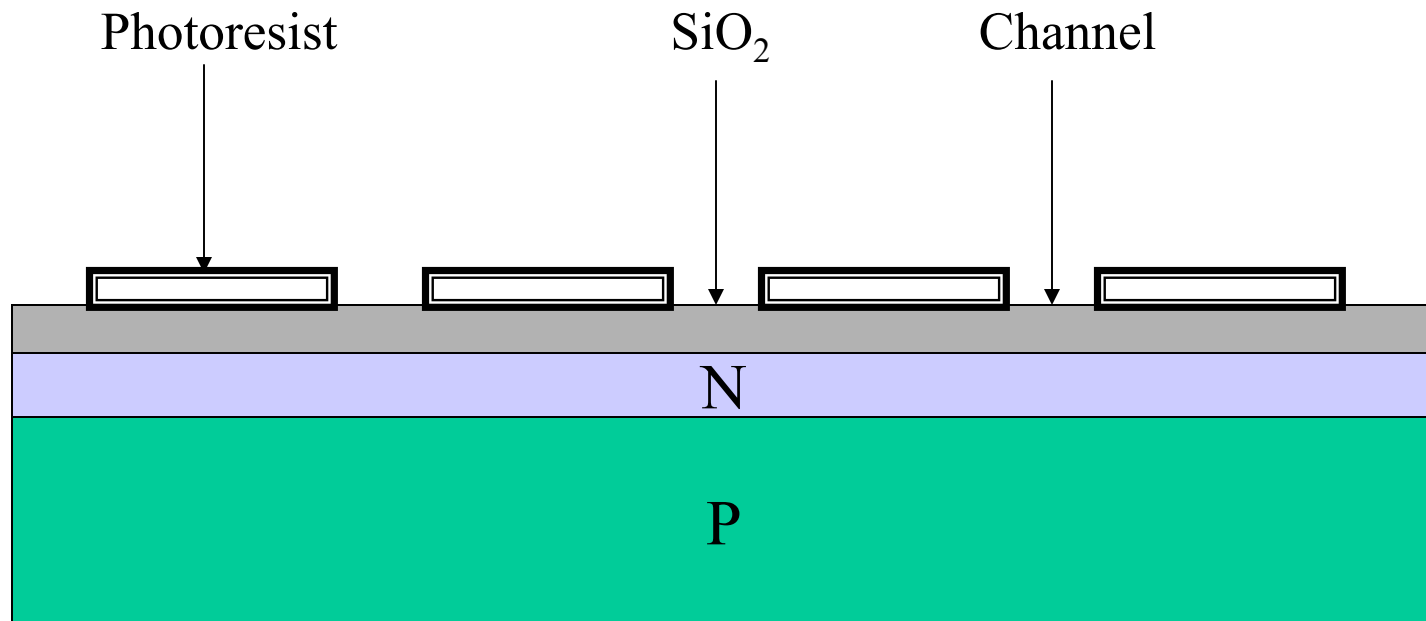


IC Mask Pattern



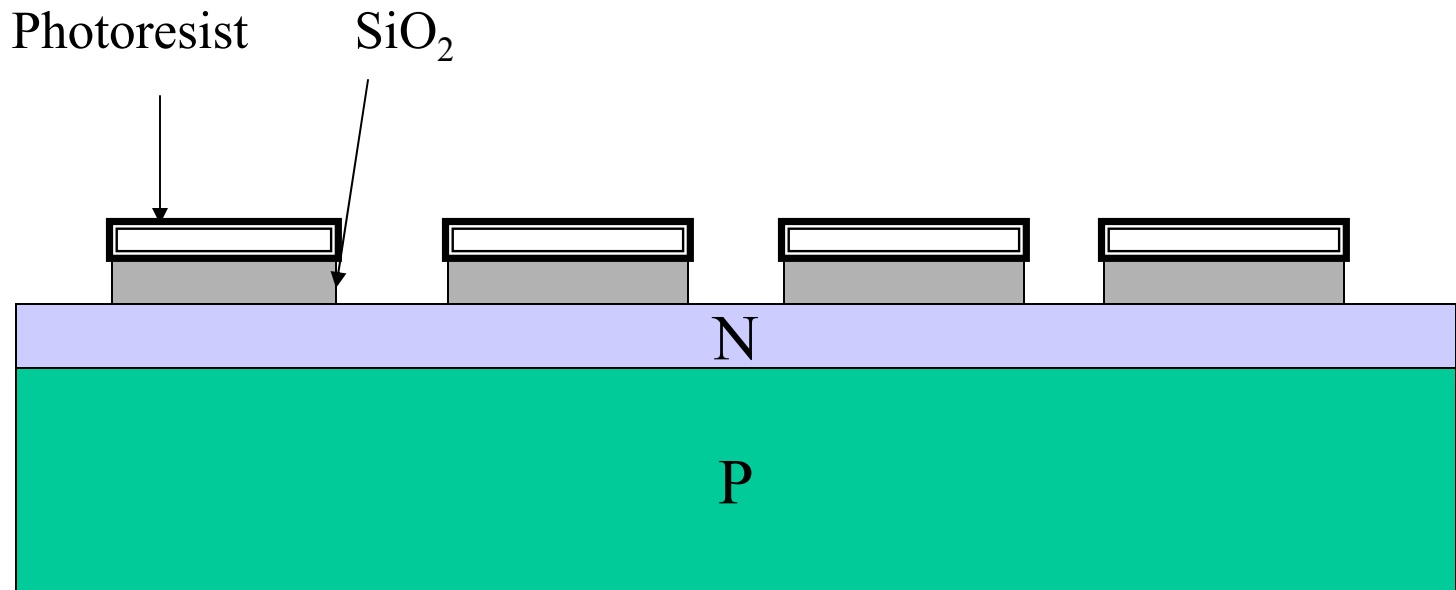
Fourth,

After the wafer and masks have been exposed to ultraviolet light and the unexposed areas washed away, the wafer will have the appearance



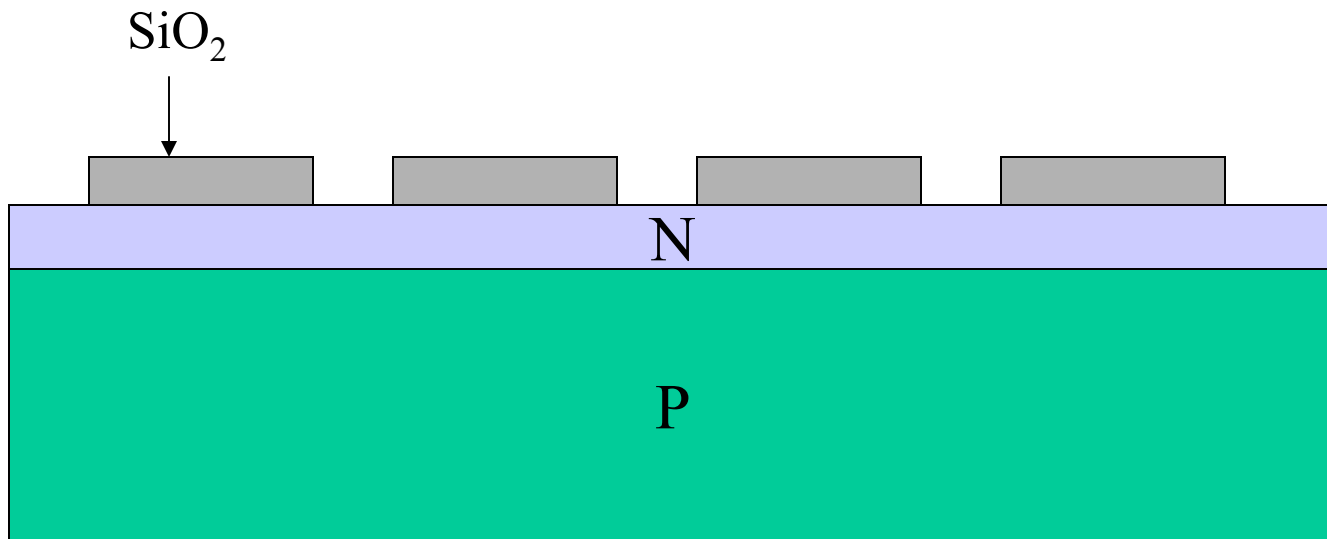
Fifth,

The SiO_2 coating may then be removed by an etching process from the areas not protected by the photoresist.

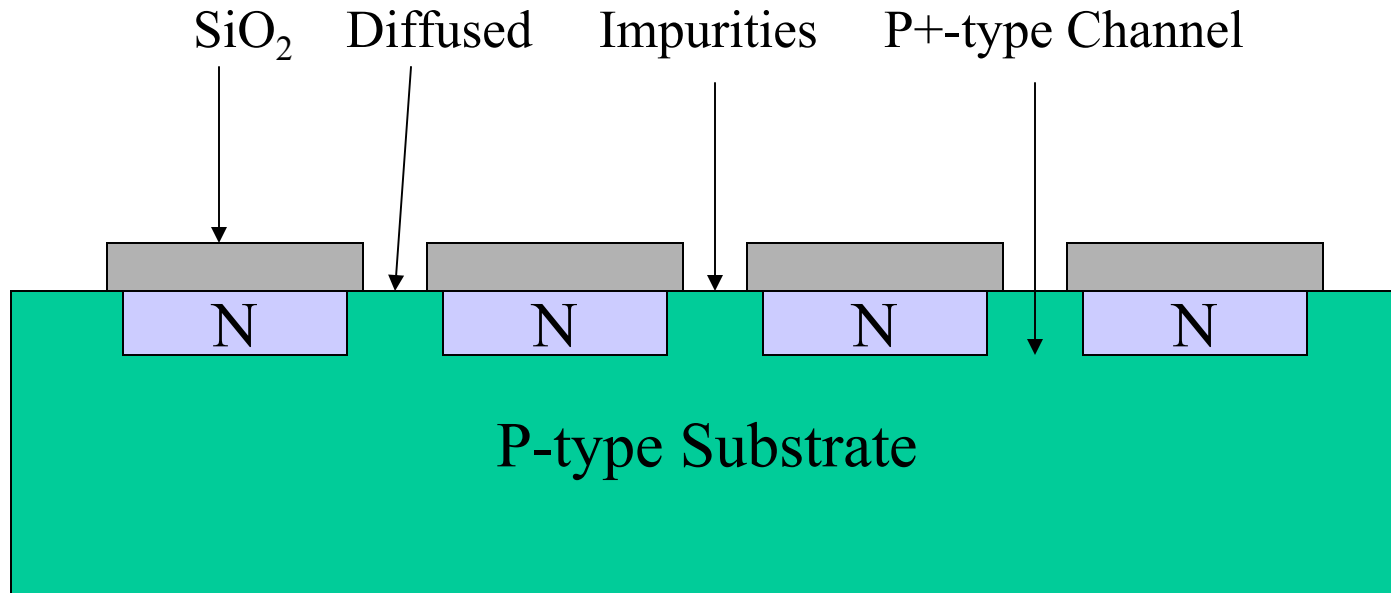


Sixth,

The photoresist is now removed completely by scrubbing with heated solvents. It was used mainly for providing selective etching of the SiO_2 .

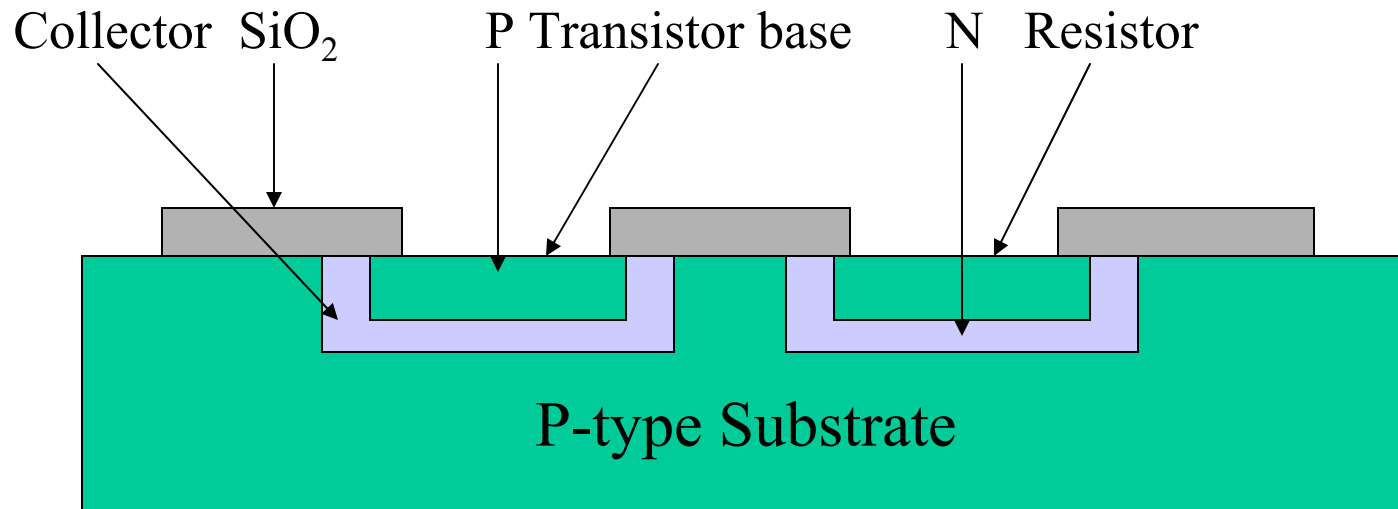


The silicon wafers are now placed in a boat and passed through a furnace containing a gaseous boron (acceptor material) atmosphere. The P impurities will diffuse into the silicon (like water being absorbed by a sponge), turning the N-type material into a P-type channel down to a depth extending to the P-type substrate. This will result in islands of N-type material resting on the P-type substrate under the SiO_2 layer.



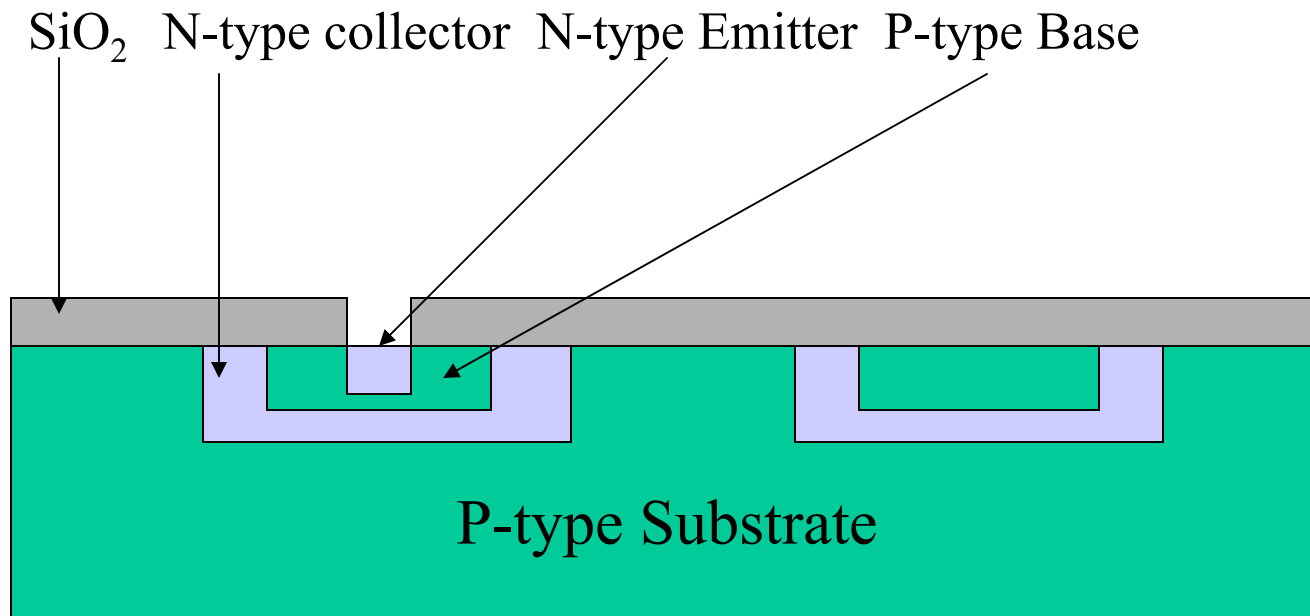
Base Diffusion

The P-type base of the transistor now needs to be diffused into the collector. At the same time, diffusion of the resistor takes place in the adjoining island. First a complete layer of SiO_2 is provided, after which the photoresist and masking process is repeated



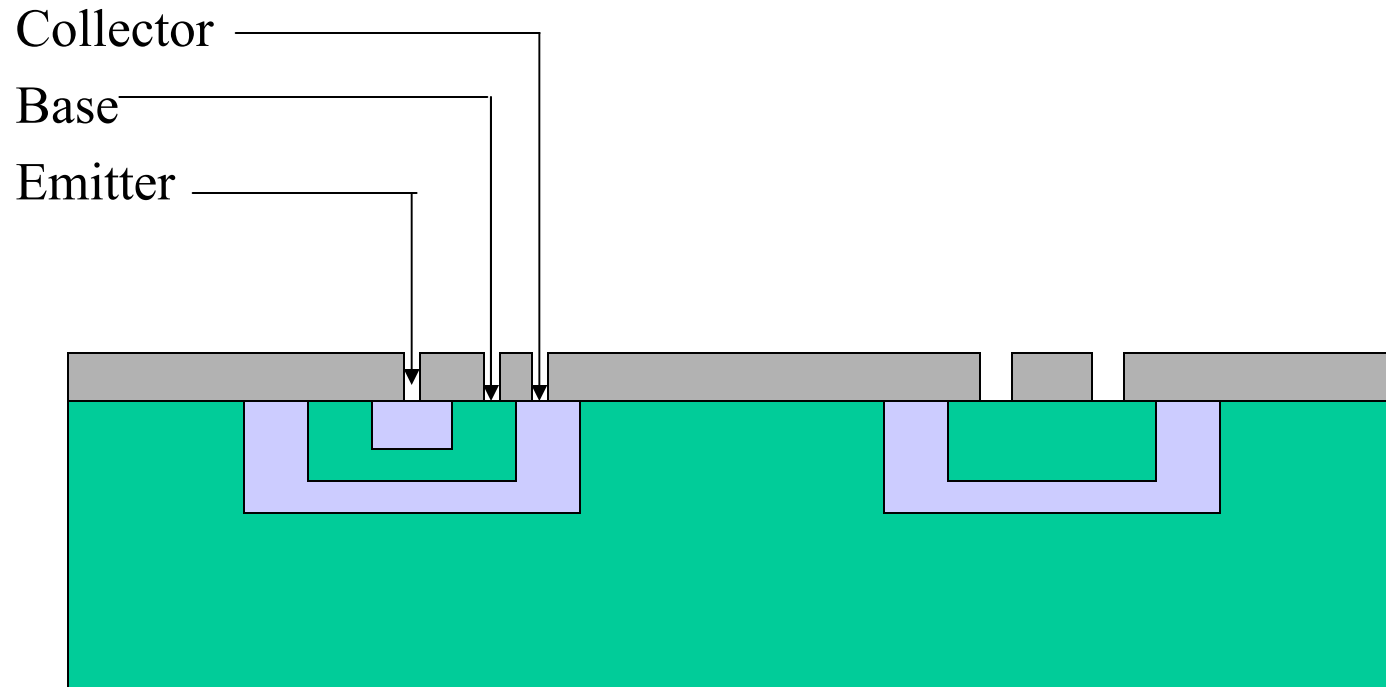
Emitter Diffusion

The N-type emitter is now diffused into the base following the photoresist and masking process.



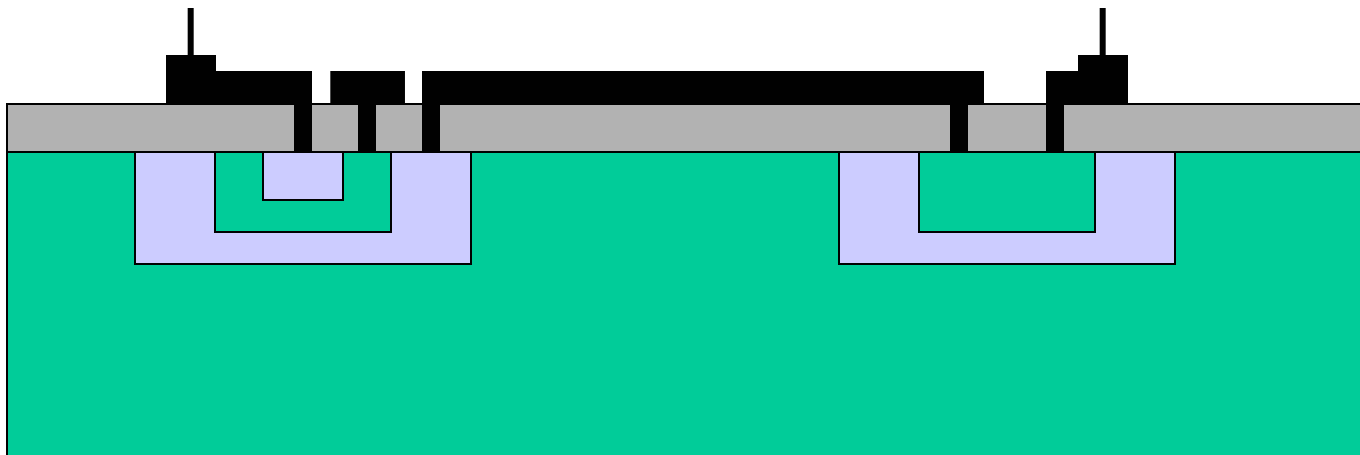
Pre-ohmic Etch

It then remains to make provision for metal ohmic (nonrectifying) contacts with the diffused areas. This is done again by the SiO_2 layer, photoresist, and masking process to provide access to the layers.



Metallization

Ohmic contacts and interconnections are now made, using aluminum for good adhesion to the silicon and silicon dioxide. Bonding pads are provided around the circumference of the die (with the 40 mil square area) for later connection of wires. This process is carried out by evaporating aluminum over the entire surface (approximately 1 micron thick) and then selectively etching away the aluminum to leave the desired interconnections and bonding pads.



Circuit Probing

Each integrated circuit on the wafer is now checked electrically for proper performance characteristics by placing probes on the bonding pads and performing some test. Faulty circuits are marked and discarded after dicing.

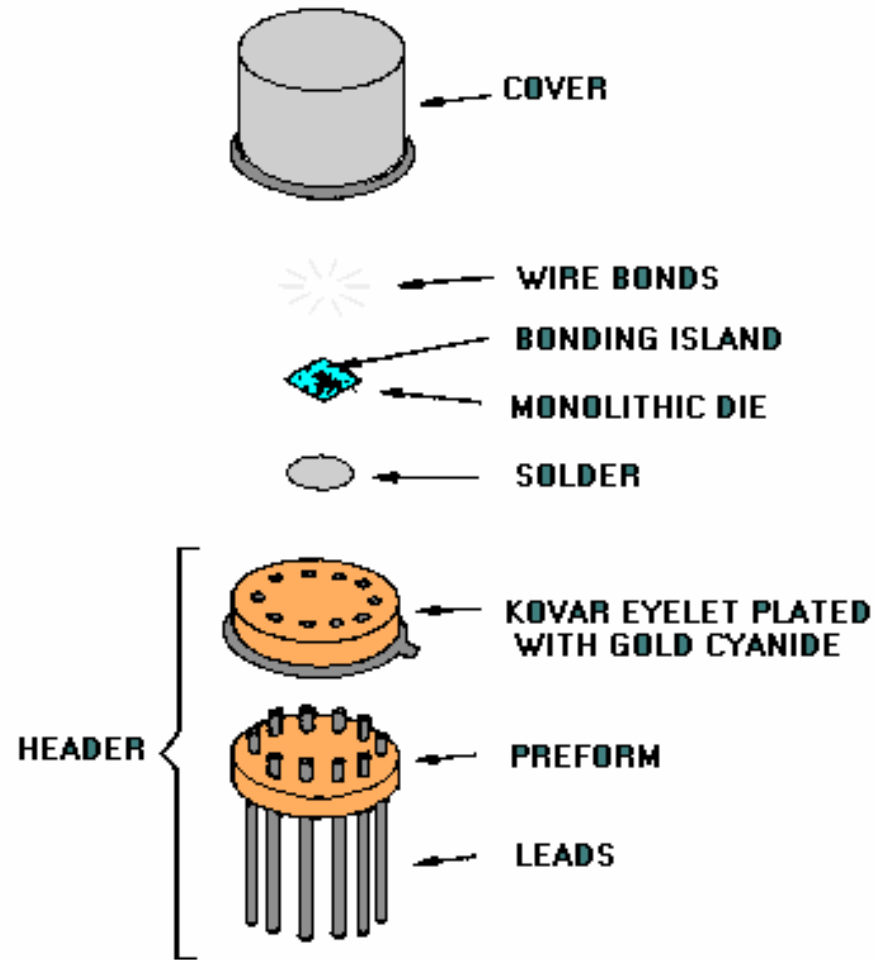
Dicing

Dicing is the process of separating the wafer into individual chips or dice by scribing the wafer and breaking.

Mounting and Packaging

The individual die is very small and must be cemented or soldered to a gold-plated header through which leads are already connected.

Transistor-Outline Package



Wire Bonding

Connections between the IC die and the package leads is done by thermal compression method using either aluminum or gold wire (under a microscope) as shown below.

Encapsulation

A cap is now placed over the circuit, and sealing takes place in an inert atmosphere.

Integrated Circuit Components

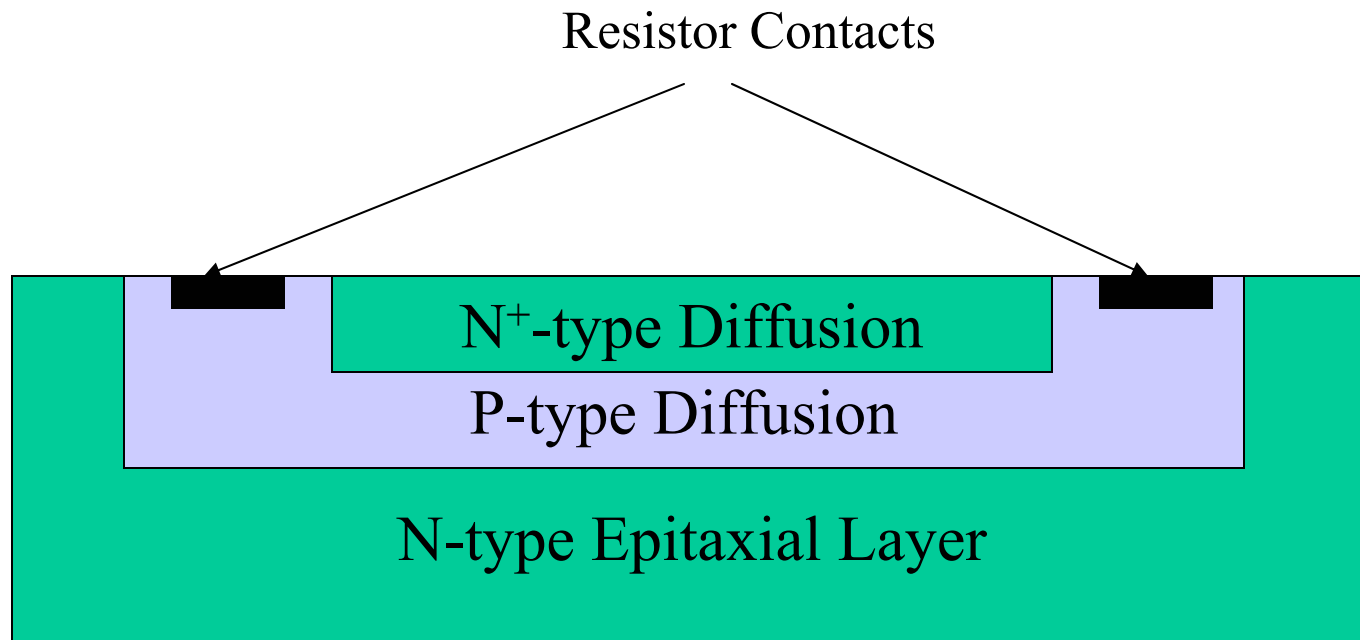
- Resistors
 - Diffused
 - Thin-film
 - Thick Film
 - Pinch
- Capacitors
 - Diffused
 - Thin Film
- Inductors (exterior to the IC)
- Diodes (Diffused)
- Field-effect Transistors (Diffused)
- Bipolar Transistors (Diffused)

Resistors

- Resistors are obtained either by utilizing the resistivity of diffused area (usually P-type) or films of metal laid on a substrate. In either case, a term “sheet resistance” is useful in describing the values obtainable. For a given thickness, we can refer to the “ohms per square” of a sheet. Typical values run from 50 to 250 ohms per square, depending upon the thickness for a P-type diffused material, and from 50 to 10 K ohms per square for thin films.
- Thin films are only a few microns thick, however, thick films are several microns thick (resistances up to 20,000 ohms per square are available). Both are less temperature-sensitive than the diffused resistors.
- In the IC fabrication, for example) it is required 70 km to provide a resistance of 10 K ohms.

Pinch Resistor

This consists of normal P-type diffusion with a N^+ -type layer on top. This reduces the effective cross-sectional area of the resistor by eliminating the conductivity paths near the surface of the P-type diffusion.



Capacitors

Capacitors may be obtained in essentially two ways:

- Diffused PN Junction:
400 pF Maximum
5-20 V Breakdown
Tolerance $\pm 20\%$
- Thin Film (Al_2O_3):
5000 pF Maximum
20-30 V Breakdown
Non-polarized.

Inductors

To date, no satisfactory method of fabricating appreciate values of inductance or transformer has been found.

Therefore, they are found exterior to the IC where their use cannot be designed out of the circuit.