JADAVPUR UNIVERSITY

IC DESIGN AND FABRICATION CENTRE

SUMMER TRAINING ON MICRO-ELECTRONICS TECHNOLOGY AND VLSI DESIGN

PRACTICAL REPORT
ON
MICROELECTRONICS(ME) LAB

BY~

INSTITUTE OF ENGINEERING AND MANAGEMENT, KOLKATA(IEM)

GROUP – 1

TEAM MEMBERS

NAMES	STREAM/ YEAR
SOMAK KUMAR	ECE/ 3rd Year
ABHISHEK ANAND	ECE/ 3rd Year
SAYANTAN SARKAR	ECE/ 3rd Year
APARAJITA ROY	ECE/ 3rd Year
SOURAJIT NAYAK	ECE/ 3rd Year
LAWAZ ISLAM	ECE/ 3rd Year
DEBAYAN SENGUPTA	ECE/ 3rd Year
VISHWAVIJAY SINGH	ECE/ 3rd Year

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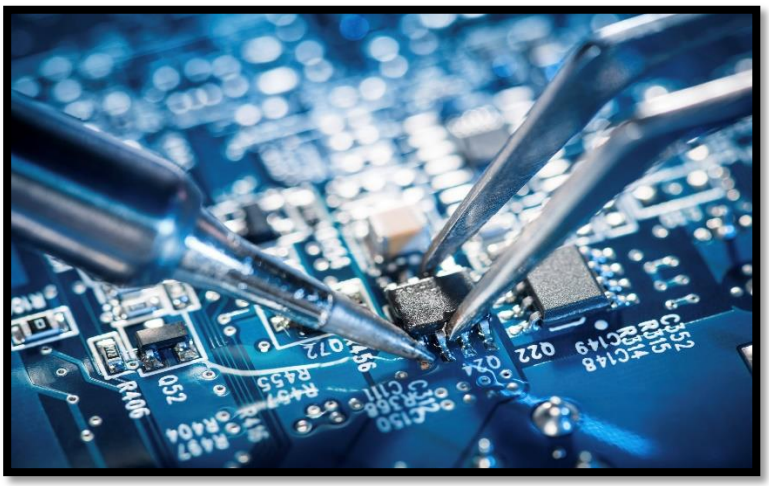
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INTRODUCTION

What does Microelectronics mean?

Microelectronics is a field in electronics that utilizes tiny, or **microscopic**, components to manufacture electronic components. Microelectronics has been rapidly evolving as the most in-demand field of electronics because of **the ever-increasing demand for inexpensive and lightweight equipment**. The main areas of focus generally are **research, reliability** and **manufacture**.



Semiconductor material such as silicon and graphite are the most commonly used elements in the manufacturing of microelectronic devices. These include **transistors, capacitors, inductors, resistors and diodes as well as insulators and conductors**. Equipment and expertise used in manufacturing of microelectronic devices is not widely available, causing microelectronic devices to generally be more expensive than devices that do not utilize microelectronics.

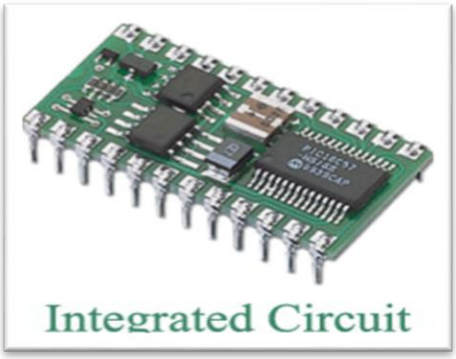
INTEGRATED CIRCUIT (IC) and its HISTORY

Integrated circuit (IC), also called **microelectronic circuit**, **microchip**, or chip, an assembly of electronic components, fabricated as a single unit, in which miniaturized active devices (for example, transistors and diodes) and passive devices (for example, capacitors and resistors) and their interconnections are built up on a thin substrate of

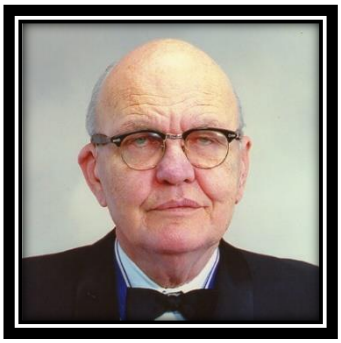
semiconductor material (typically silicon). Transistor is the main component in IC.

❖ HISTORY of ICs:

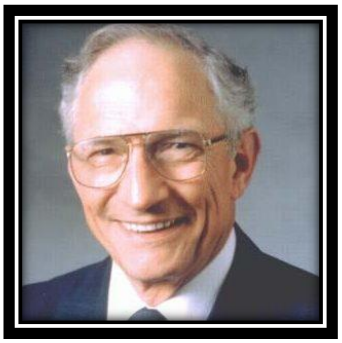
Before the discovery of ICs, the basic method of making circuits was to select the components like diodes, transistors, resistors, inductors and capacitors and connect them by shouldering. But due to size and power consumption issues, it was necessary to develop a small size circuit with less power consumption, reliability and shockproof. Thus, the invention of transistors and semiconductors paved the way for the development of ICs that changed the face of electronics technology's face.



Jack Kilby from **Texas Instruments** and **Bob Noyce** from **Intel** invented the *first integrated circuit* in **12 sep,1959**. But *he didn't get the Nobel prize* for that because as per rule no engineer can get a Nobel prize. When Jack Kilby started work as a physicist in 1998 then **he got the Nobel prize in 2000**. The first IC was consisted of only 12 transistors in it.



Jack Kilby



Robert Noyce

India, first started their research on '**Microelectronics**' from **1986**. It has only 7 research centres including the five premium IITs i.e.,

(**IIT KGP, IIT D, IIT B, IIT M, IIT K**) and two universities (**Jadavpur University** and **BHU**). **Jadavpur University** was the *first* Indian Institute to invent a device – **TFT (Thin Film Transistor)** in 1988 and also, they were the *first* to invent the **Solar Cell** and **Plain Paper X-Ray**.

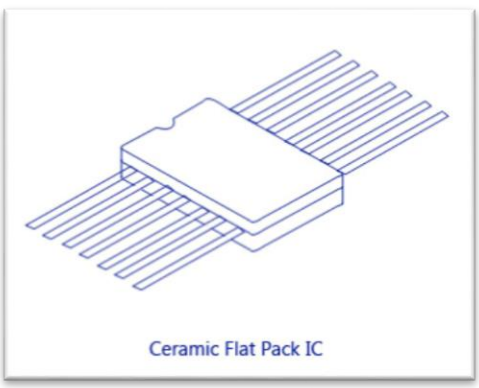
ADVENT of MODERN-DAY ELECTRONICS

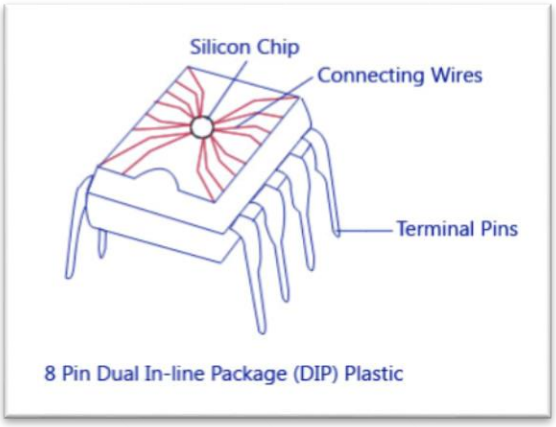
❖ Advantages of Integrated Circuits:

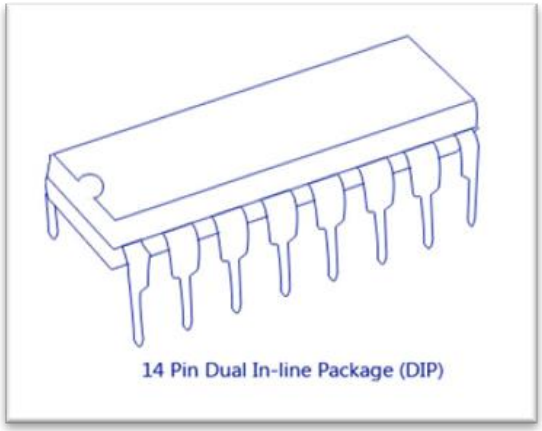
Integrated circuits (IC) offer many advantages. They are discussed below –

- **Compact size** - For a given functionality, a circuit of smaller size can be obtained using ICs, compared to that built using a discrete circuit.
- **Lesser weight**- A circuit built with ICs weighs less when compared to the weight of a discrete circuit that is used for implementing the same function of IC.
- **Low power consumption** - ICs consume lower power than a traditional circuit, because of their smaller size and construction.
- **Reduced cost** - ICs are available at much reduced cost than discrete circuits because of their fabrication technologies and usage of lesser material than discrete circuits.
- **Increased reliability** - Since they employ lesser connections, ICs offer increased reliability compared to digital circuits.
- **Improved operating speeds** - ICs operate at improved speeds because of their switching speeds and lesser power consumption.


Metal Can IC


Ceramic Flat Pack IC

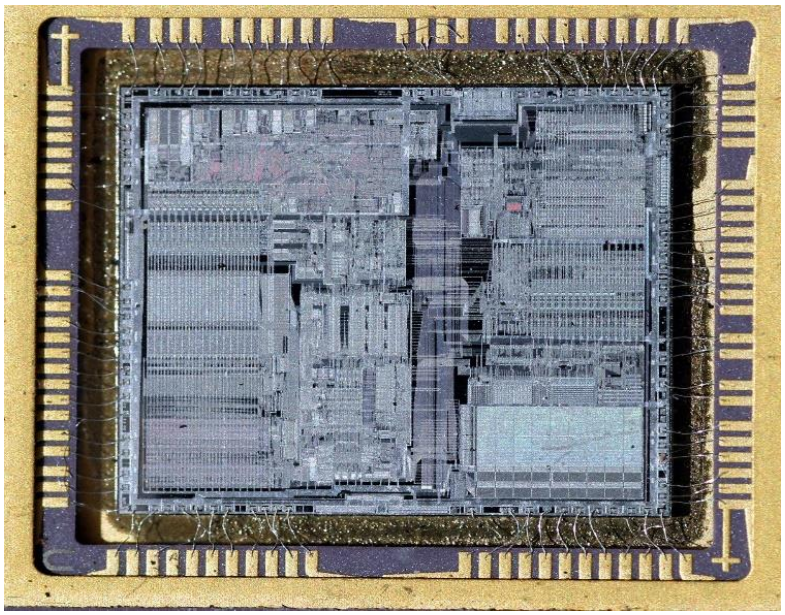




❖ Generation of ICS:

ICs are classified into 4 types based on the no. of components(transistors) used:

- **Small-scale integration (SSI)** - A SSI IC consists of some tens of transistors on a chip. SSI ICs played a critical role in early aerospace projects.
- **Medium-scale integration (MSI)** - A MSI IC consists of some hundreds of transistors on the IC chip. They achieved better economy and advantages compared to the SSI ICs.
- **Large-scale integration (LSI)** - A LSI IC consists of thousands of transistors on the chip. The first microprocessor, calculator chips and RAMS of 1Kbit developed in the 1970s had below four thousand transistors. (Fig. **PHOTO OF SILICON CHIP)**



- **Very large-scale integration (VLSI)** - A VILSI IC consists of transistors from hundreds to several billions number. VLSI ICs are developed between 1980-2009.

  Modern day ICs contain 2 layers:

  (i) **Lateral Layer**,

  (ii) **Vertical Layer**.

  Width of each IC is in the range **(400 – 500) micron**.

❖ Micro-electronics Lab Setup:

The Lab set up specifically for Fabrication work is called **Dust-Free Lab**. Some precautionary measures are taken, to keep the microelectronics lab free from dust particles which are as follows.

- The Lab **should not have any window** inside it, and all the doors should be **Push-Out** in nature, so that when someone enters the room, air only comes out and comparatively less dust enters.

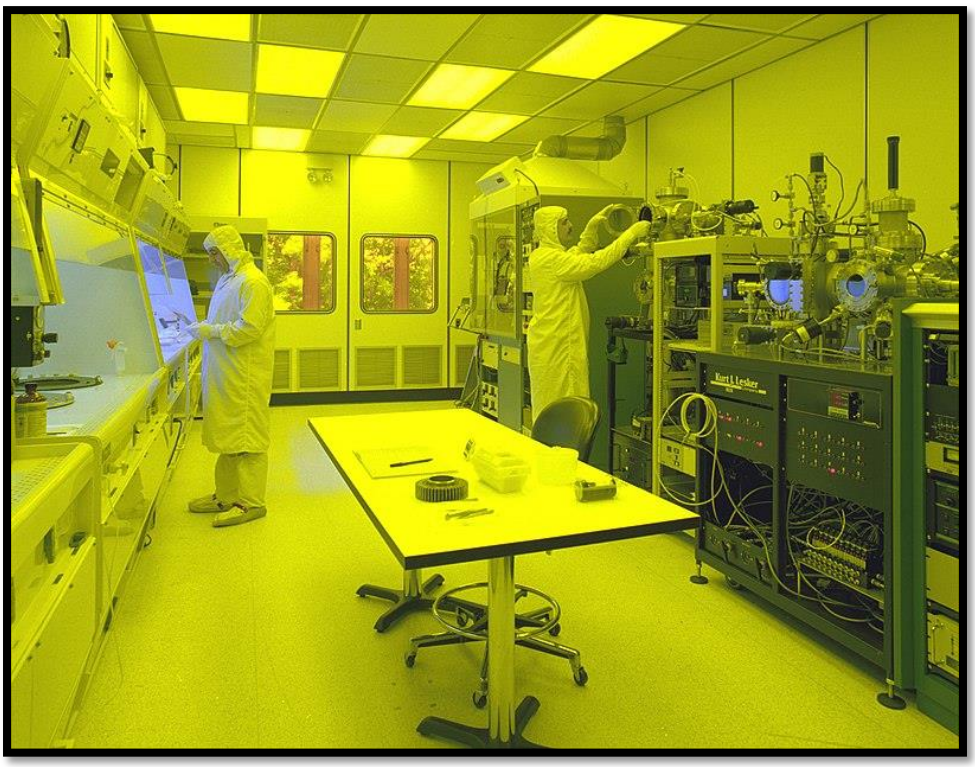
- The Staffs should enter and leave through airlocks and everyone should wear **protective clothing** such as hoods, face-masks, gloves and boots to protect themselves from harmful obnoxious gasses during fabrication of IC and also to avoid the contamination of dust, from their clothes, with the fresh air inside the room.



- A **basin** should be used for cleaning and washing hands and face.

- **Fan-filters** are installed in the lab to the ceiling ground. The air entering the lab from outside is filtered to exclude dust and the air inside is constantly re-circulated through High Efficiency Particulate air (FHFPA)and/or Ultra-Low Particulate Air (ULPA) to remove internally generated contaminants. The number of Fan-Filters installed to ventilate air outside is compensated with same number of Fan-Filters circulating air inside.

- Clean rooms are classified according to number and size of particles permitted per volume of air. These are:
  a) **10 class** (which means 1 cubic feet area has only 10 particles),
  b) **100 class** (100 particles exist in 1 cubic feet area),
  c) **1000 class** (1000 particles exist in 1 cubic feet area).



Microelectronics Laboratories

Bangalore is the dust-free city in India, which has the maximum number of Dust-Free labs in India.



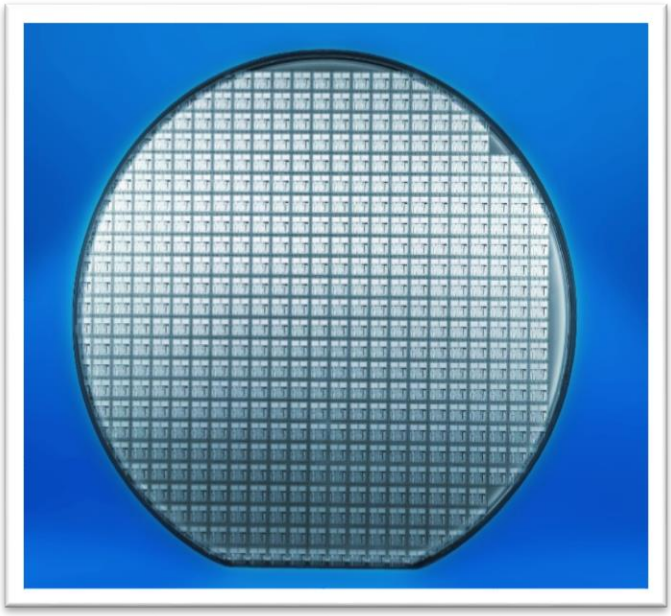
Microelectronics Laboratories

❖ Specification Of Silicon Wafer:

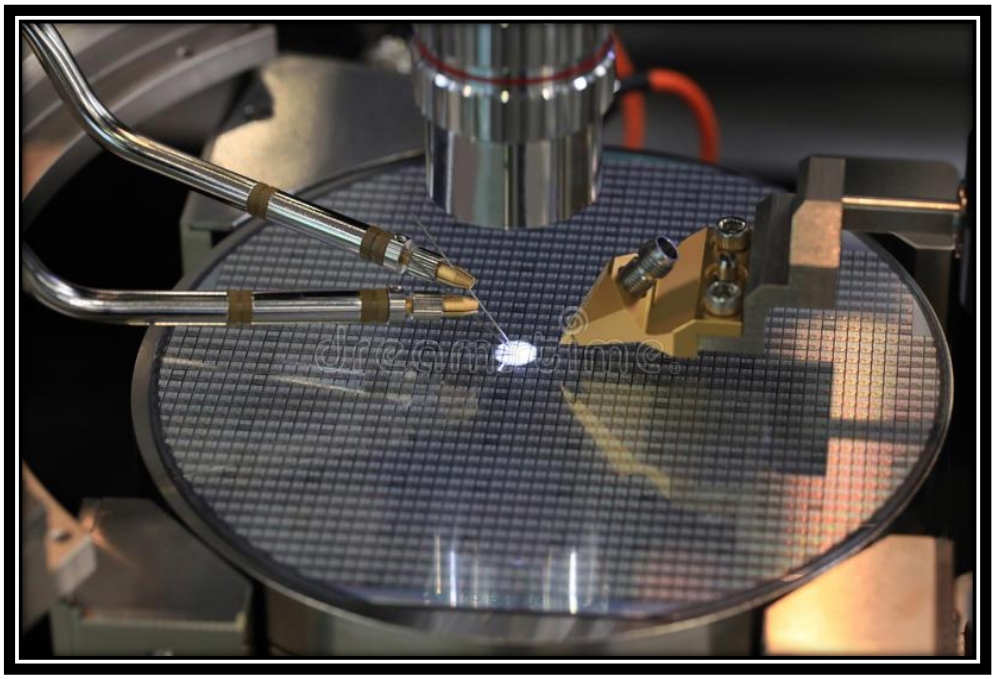
- **Nature** - There are three types of silicon wafer available in the market. These are:
  a) Both sides **Mirror Polish** (use for *IC fabrication*)
  b) One side Mirror Polish and one side As-Cut
  c) Both sides **As-Cut** (use for *Solar cell production*).

- **Orientation of wafer** - There are two types of orientation present in a silicon wafer. These are:
  a) **Major Cut & Minor Cut [Single Wafer, Multiple Device]** - This Type of wafer can be cut Horizontally as well as Vertically and the orientation of this type of wafer is **<100>**.
  b) **Only Major Cut [Single Wafer, Single Device]** - This type of wafer can be cut Horizontally only and the orientation of this type of wafer is **<111>**. For Example, **Solar cells** are made of this kind of wafer. It consists of some **pyramidal undulations** which helps in the consumption of more light to convert it into electricity.

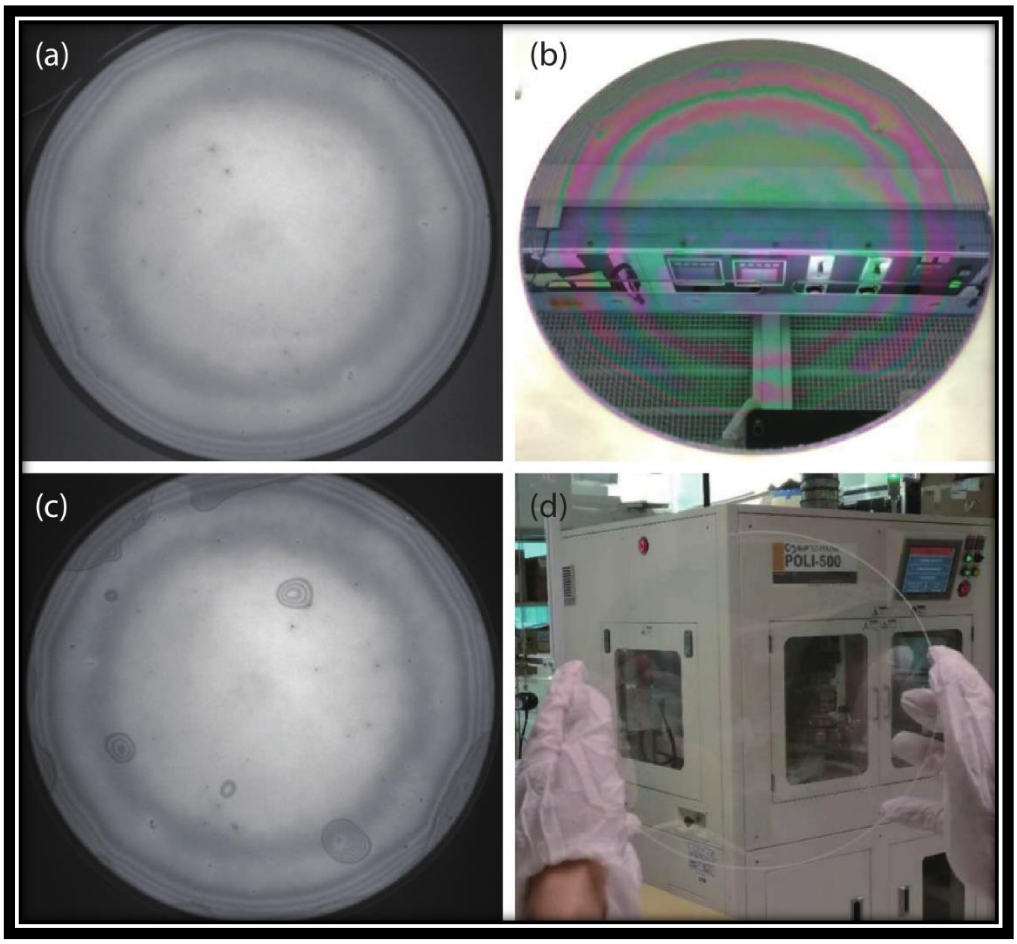
- **Thickness** - The average thickness of a silicon wafer is (400-500) micron.
- **Resistivity** - The resistivity of a silicon wafer is 0.50 ohm/cm.
- **Diameter** - The diameter of the silicon wafer should be 1inch less than the diameter of the furnace tube.



DOUBLE SIDE POLISHED WAFER



SILICON WAFER with UNCUT CHIPS STOCK



SILICON-BASED WAFER BONDING PROCESSES

PROCESSES OF SILICON FABRICATION

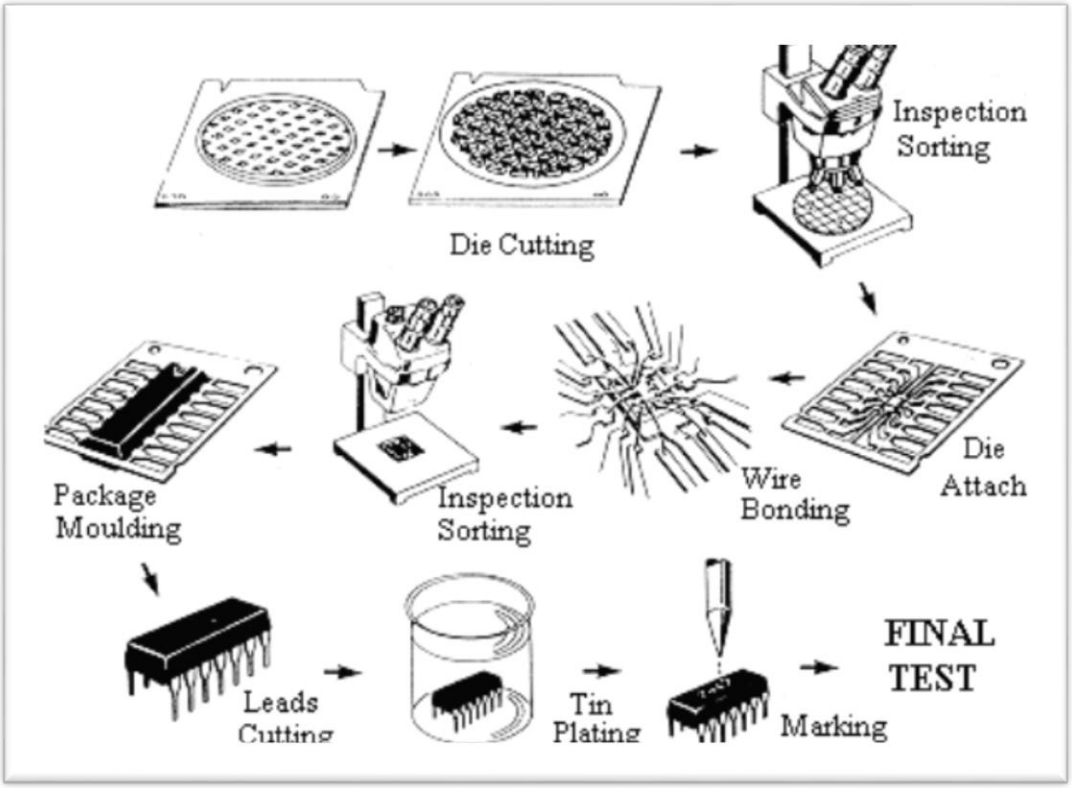
Fabrication is the process of constructing products by combining typically standardised parts using one or more individual processes.

For example, steel fabrication is the production of metal structures using a range of processes such as cutting, bending and assembling. Metal fabrication will often form a complete assembly made from smaller sub-assemblies for use with readily available standard sections. This is achieved with computer-aided designs (CAD) that are often programmed using computer numerical control (CNC) technology which communicates directly with machinery on the factory floor. By using these technologies, the quality standards of production are increased and higher quality assemblies are produced. This ensures a more accurate and quicker steel erection time on site, which is vital in high volume

production, reducing cost for the customer through better material utilisation and faster assembly times.

The fabrication process can involve a range of different steps, depending on what is being produced and from what materials. However, the first stage in any fabrication is design.

Although it is possible to use hand-drawn diagrams for simpler work, more complex or detailed designs can be created and tested with computer aided design (CAD) programs. More complex fabrications will also often involve prototyping, which helps with visualising and testing product iterations. Fabricators use a range of different processes according to the product specification and materials.



There are 5 steps of silicon fabrication:

1) ***Cleaning***
2) ***Oxidation***
3) ***Photolithography***
4) ***Diffusion***
5) ***Metallization***

CLEANING

Cleaning process in IC Fabrication is carried out in two different ways:

i) Acidic Cleaning Process
ii) Plasma Dry Cleaning Process

The former is usually followed because it is less expensive and more convenient than the latter. Here also, we are using the Acidic Process for the removal of impurities from the wafer surface.

Cleaning process takes place to remove different types of impurities from the Silicon wafer. These impurities can be listed in the next page:

i) Dust

ii) Oil and Grease

iii) In-Organic Compound

iv) Alkaline Organic Compound

v) Acid-Organic Compound

vi) SiO_2

❖ **Acidic process:**

The process of removal of Dust Particles includes the following steps:

I) Sample + Tri-Chloro Ethylene → Removes Dust Particles

Boil the sample for 5 min and then keep it in ultrasonic vibrator (which is used to vibrate the sample at or greater than 20,000 Hz frequency) for 3 min. This ultrasonic vibrator helps in cleaning the sample.

II) Sample + Acetone → Removes oil and grease

Boil it again for 5 min and then keep it in ultrasonic vibrator at or greater than 20,000 Hz frequency for 3 min. This is performed again for further cleaning the sample.

III) To remove the In-Organic compounds:

The constituents used here is **H_2SO_4 and H_2O_2**, but are present in an equal proportion of **1:1**.

Process of the reaction:

First of all, H_2SO_4 of 20 cc is put in the beaker and then the sample is added to it and then 20cc of H_2O_2 is added to it and then we wait until the reaction stopped. This reaction is exothermic in nature and in this reaction gas and heat is released. After the reaction is stopped the sample is cleaned in deionised water, also termed as **DI water**.

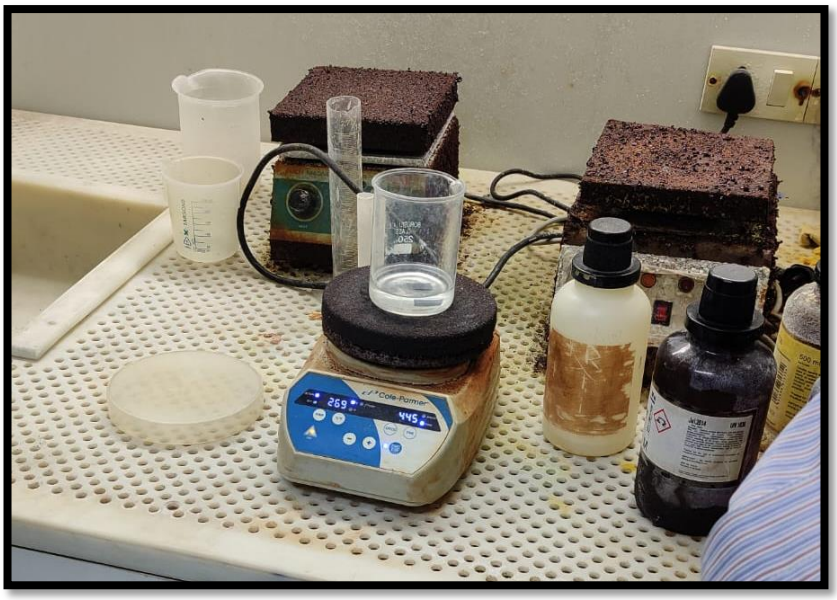


IV) To remove Acidic Organic compound:

Process of the reaction:

The constituents used here are **H_2O, H_2O_2 and $(NH_4)OH$** and these are present in the ratio **5:1:1**. These constituents are heated at 70^0 C for 10 min and then passed into cold water. The ***Ammonium hydroxide used here is volatile in nature.***

Here, firstly, 25 cc of H_2O is used and then 5cc of H_2O_2 is added to the H_2O. The mixture of H_2O and H_2O_2 is heated up to 70^0C. After the mixture is heated up to 70^0C the sample is added to the mixture and then NH_4OH is added to it. Then we just wait for 10 min.



Sample in container being heated over a Heater

V) To remove Alkaline Organic compound:

Process of the reaction:

In this reaction all the components HCl, H_2O_2, H_2O all the three are mixed together and its temperature is rose up to 70^0C. Then the sample is added to the mixture and then we wait for 10 min so that the sample is cleaned completely.



Different Samples Preserved for Various Chemical Processes in IC Fabrication

VI) To remove SiO_2 from the sample:

Process of the reaction:

After the sample is almost cleaned and gone through all the process, we dip the sample in 10% concentrated HF for 2 to 3 min. This is done to completely remove the dirt from the sample and get it cleaned 100% (theoretically).

NOTE:

- **HF** *has a strong itching property because of which it is available as of 40% concentrated in the market.*
- ***How to understand whether the Wafer is completely cleaned?***

After the process is completely over the silicon wafer becomes completely hydrophobic in nature which means that the sample will not let the water stay on it by any chance.

OXIDATION

❖ Why is Oxidation needed?

Usually SiO_2 layer (impurity) on the wafer is non uniform in nature. Thus, to produce a uniform layer of SiO_2 on the wafer, oxidation is required.

❖ Requirements to form an oxide layer on the wafer:

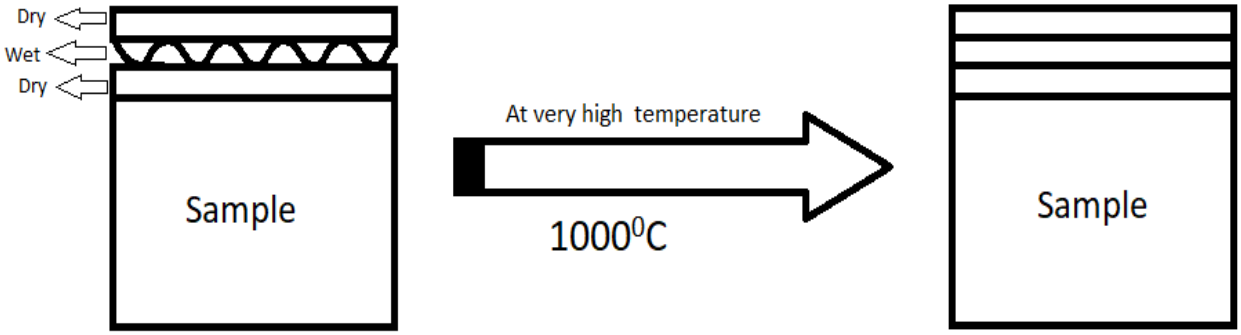
- ***Temperature*** → 1000^0C (arbitrary)
- ***Gas*** → (i) O_2 (0.8 L/min)
  (ii) N_2 (1 L/min)
- ***Time*** → (i) Dry Oxidation: (for 30 minutes)
  (ii) Wet Oxidation: (for 1 hour)
  (iii) Dry Oxidation: (for 30 minutes)

NOTE:

We can make the oxide layer only by using dry process but here we are using first the dry then, wet and then again the dry process, in spite of the fact that the dry oxidation gives a completely uniform layer of oxide. The reason behind this is that the ***dry oxidation takes too much time as it is a very slow***

process hence it takes more man power and cost of device also increases, which is not needed. Hence this set up is done.

But, when we use dry-wet-dry process, at a very high temperature (1000^0C), the non-uniform layer atoms arrange themselves to a uniform layer. So, here, the cost also reduces and the time consumed is also less compared to only the dry process. Hence, it is used.



<u>During dry Oxidation</u>:

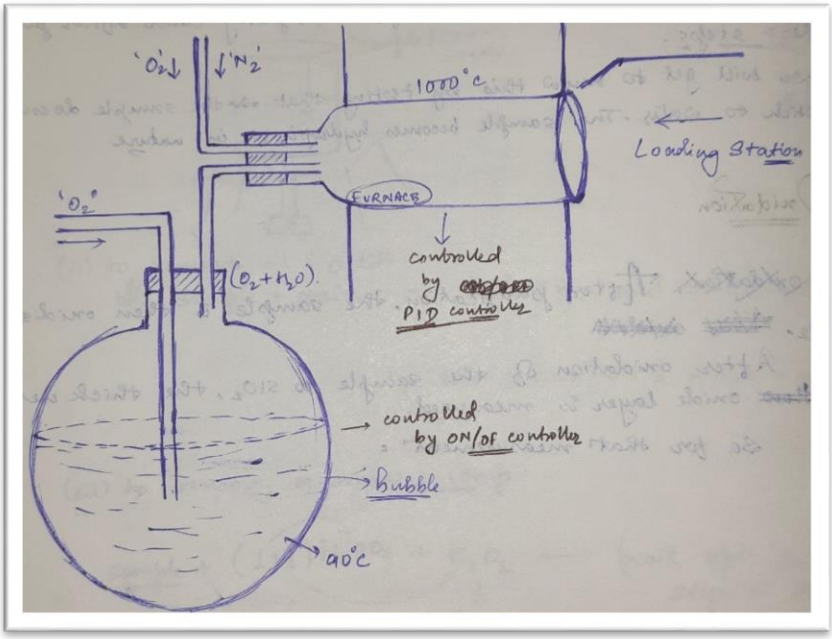
O_2 (1 mole) + **Si** → SiO_2 (1 mole)

<u>During wet Oxidation</u>:

O_2 (1 mole) +H_2O (from bubbler) → $O_2 + H_2 + O_2$

$2O_2 + 2Si \rightarrow 2SiO_2$

Therefore, ***1mole O_2 gives $2SiO_2$*** .



Furnace and Bubbler

NOTE:

We are aware of the fact that the temperature of the bubbler is 90^0C. But if its temperature is:

i) **89^0C:** Then the temperature is decreased hence the density of the water increases, hence O_2 cannot carry H_2O molecule with it and hence, ***SiO_2 will not form***.

ii) **91^0C:** Then H_2O gets easily evaporated at this temperature and hence does not require O_2 to go up. Hence, if O_2 molecule is not present, ***$2SiO_2$ is not formed***.

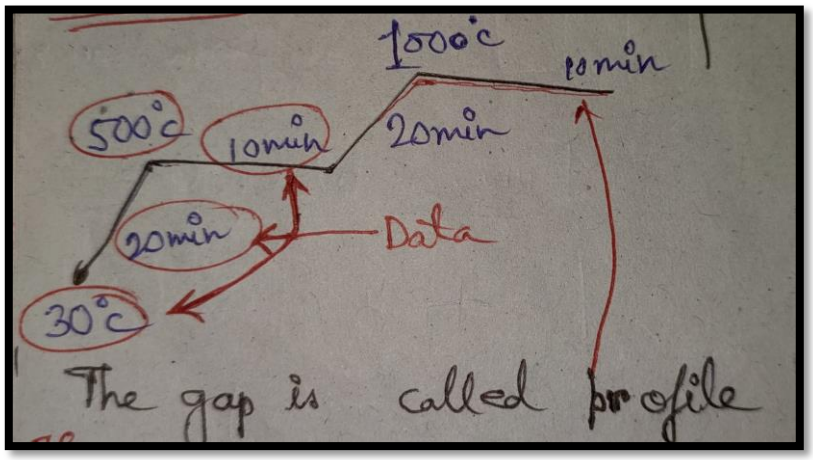
- **What is the difference between a Furnace and an Oven?**

Ans:

Oven	Furnace
In this device, the temperature should be up to 500^0C and this is controlled by an ON and OFF controller.	This is a device controlled by a PID controller and hence temperature should be greater than 500^0C (maximum ~ [4000-5000] **^{0}C. (Image is attached below)**



- **ON and OFF controller**: This is an automatic temperature controller, where the temperature is either high or low depending on the controller switch (either on or off).
- **PID controller:** PID stands for ***Proportional Integral Derivative***. Its purpose is to force feedback to match a setpoint, such as a thermostat that forces the heating and cooling unit to turn on or off based on a set of temperature.



❖ **Process of making the Oxide Layer in lab:**

- First of all, the temperature is rose up to a level of 1000^0C through a PID controller in the furnace.
- Then we pass N_2 for 10 min at a rate of 1L/min. Because of this the furnace is full of N_2 ambient which we want.
- Now we are ready for loading the sample in the loading station.
- Once the loading is done, we pass O_2 for 30 min at a rate of 0.8L/min. This is the Dry Oxidation process which is discussed earlier.
- Now the same O_2 is passed but this time through the bubbler at the same rate of 0.8L/min and for 1 hour. This process is the Wet Oxidation process.
- Once this is done, we move again to perform the Dry Oxidation for 30 min as discussed earlier.

- When all these processes are complete then we unload the sample from the furnace and then we are ready with a sample with an oxide layer on it. Here the sample is Si and the oxide layer which we did form on it is the SiO_2 layer.
- Now the sample is ready to check its thickness and its thickness can be measures in various ways which are listed below but during our experiment we used the colour chart process to check its thickness.



FURNACE and the entire Machine required for OXIDATION

NOTE:

Only N_2 is used as a gas to create an ambient in the furnace because ***N_2 acts as an inert gas*** and it creates an inert atmosphere in the furnace making it completely ready for the experiment and most importantly it is very cheap and easily available. So only N_2 is used for this purpose.

❖ **Different Ways to Check the Oxide Layer:**

Once the oxide layer is formed there can be many ways to measure its thickness. Some of its ways are:

- ✓ **Process 1**:

We can take out area of the area of the sample and let us assume it to be A, now we can also take out the density of the sample and let us say that the density of it to be D. So, if w1 be the weight of the wafer before oxidation and w2 be the weight of the wafer after oxidation, the thickness will become:

Thickness(t): (w2 -w1)/(A^2*D)

- ✓ **Process 2**:

The second process is the one in which we measure the thickness with the help of a microscope which makes it more accurate than the previous process.

- ✓ **Process 3**:

The third process is a computer aided process in which we give the specifications in a software and the software gives us the thickness of the sample of which we have desired specifications.

- ✓ **Process 4**:

In this process we are given an oxide layer chart and the chart consists of the colour and its corresponding value for its thickness. With the help of this a microelectronics engineer performs an experiment and with that experiment we get to see a colour combination and in that combination the colour which is in the middle is considered and is then checked in the chart for its corresponding value as its thickness.

One very important thing to note is that, we have to look at the sample at an angle of 90^0 with the sample which is completely upright. In that way we can get the most accurate value of the thickness of the oxide layer.

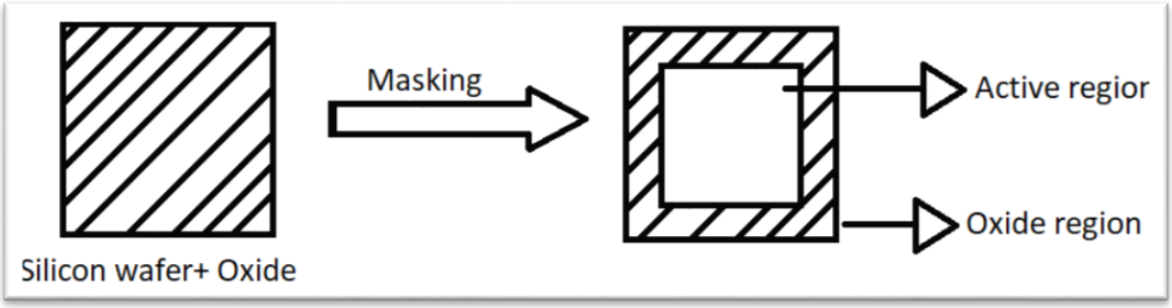
- **In MOSFET, dry oxidation is done, as it is thin** and it is the middle layer of the semiconductor.

PHOTOLITHOGRAPHY

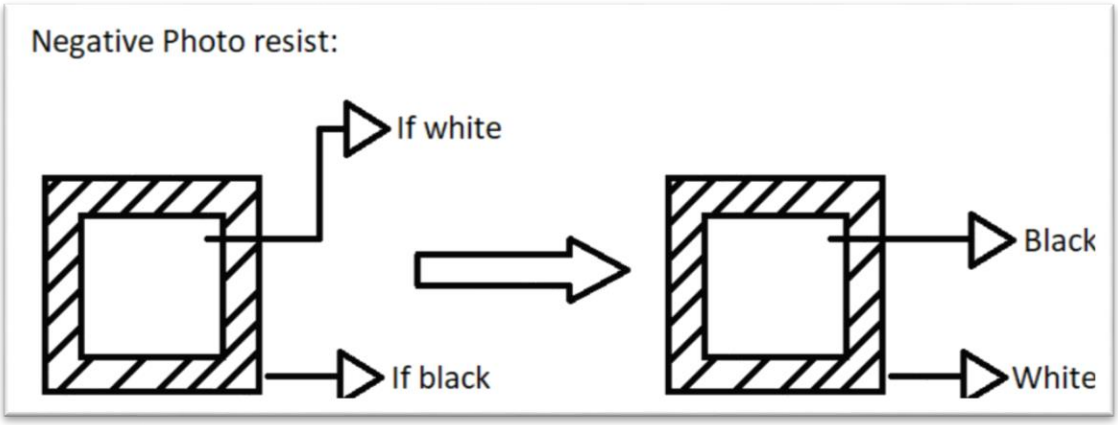
The terms used here, are: '***Photo' meaning 'image***'; '***Litho' meaning 'stone/rock***' and '***Graphy' meaning 'design***'. So, completely it stands for "**Designing of the Image on Silicon**".

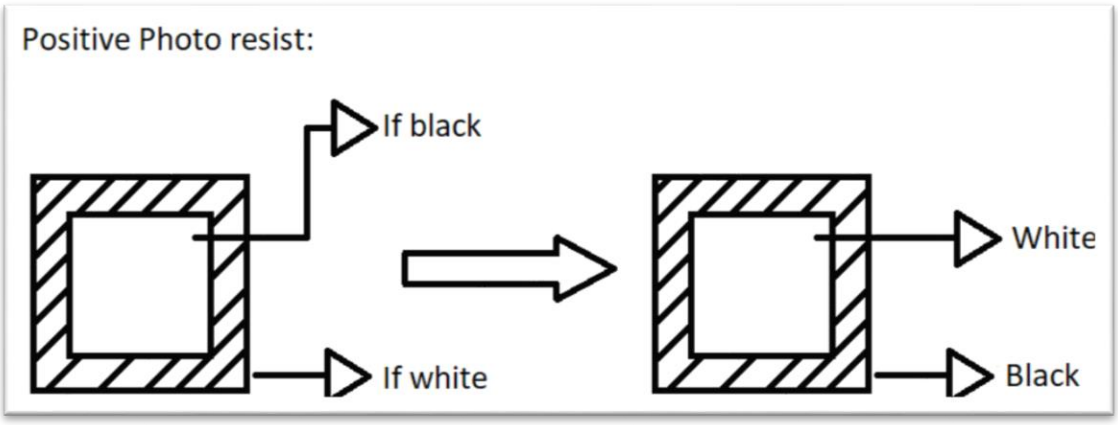
Process:

I) **Masking**: This is done using AutoCAD

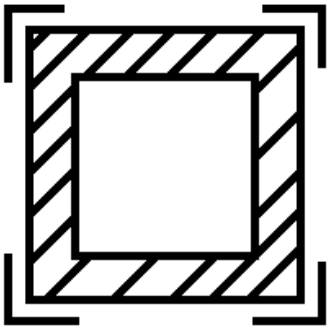


II) **Photo Resist**: There are two types of photo resist. One is the ***negative photo resist*** and the other is the ***positive photo resist***.





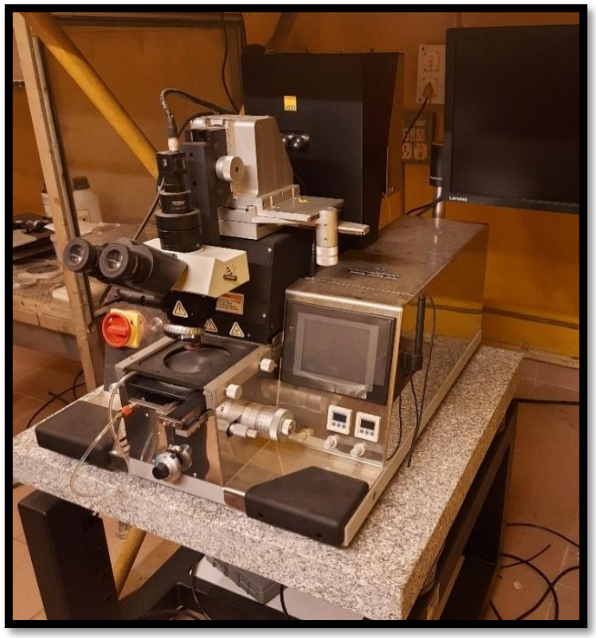
- **Alignment Sign:**



This alignment sign can be of any type and it is given just to match it with other wafers. Here the alignment sign is corners of a square but it can be of any shape just to give a symbol.

- **Mask Aligner** is used to align all the wafers one below the other.

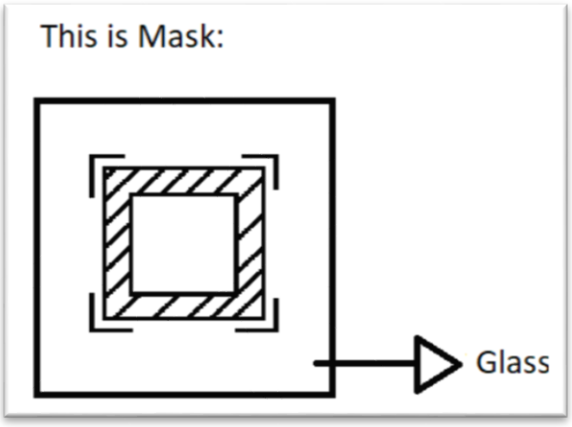
This sample is put on a glass and then the printing is done on the glass itself.



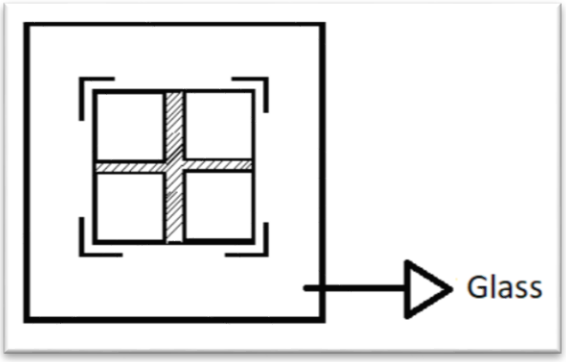


MASK ALIGNER

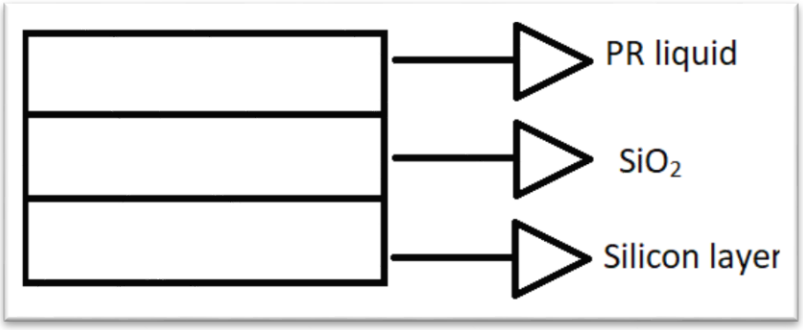
- **Mask Printer** is used to print the design on the glass.



III) Depending upon the number of devices to be placed on the mask, the division happens on the device in AutoCAD.



IV) Once the design is complete and is printed by the AutoCAD software then it is taken out of the machine and then it is given a heat treatment at a temperature of 200^0C for 2 hours. This is done for removing of moisture from the oxide coated sample.



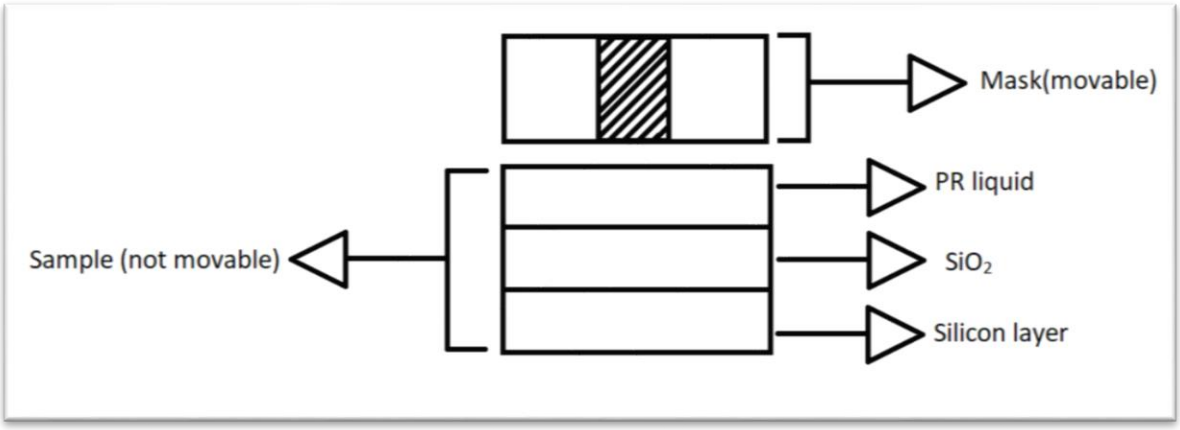
V) Then the sample is spin by the spinner at an rpm of 2000-3000 and then a coating of a photoresist on the oxide coated sample is done. The photoresist is termed as PR.



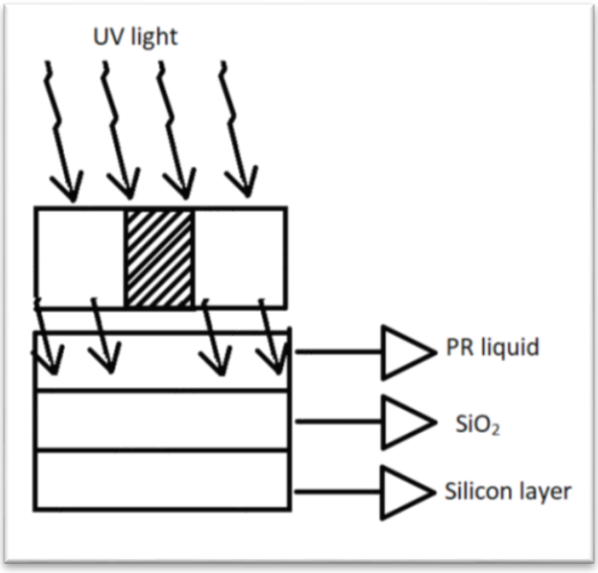
SPINNER

VI) Thereafter, the **Pre-heat** is done at a temperature of 90^0C for a duration of 20 min. This is done to solidify the PR layer. This is a primary process.

VII) **Aligning/Alignment**: Mask Aligner is used over here. A gap is maintained between the mask (which is fixed) and the sample (which is movable). This is done to avoid the scratches on the sample layer.

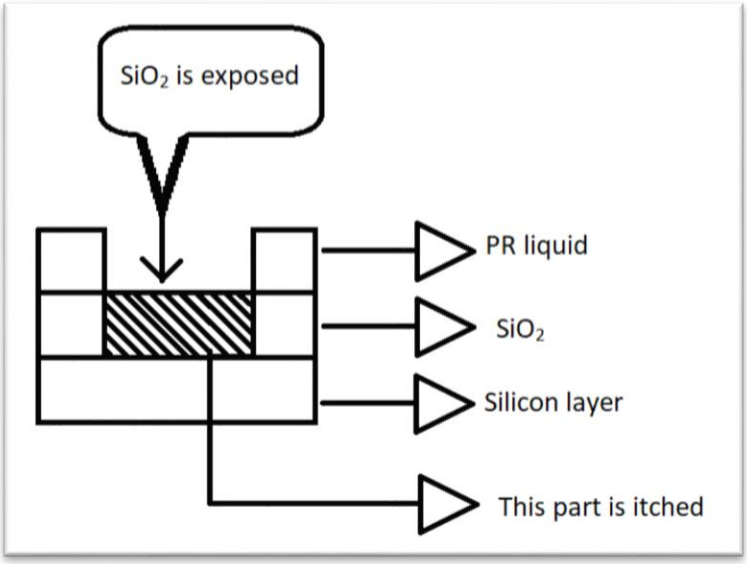


VIII) **Exposed by UV for 8sec:** This is used to fill up the gap between the mask and the sample because of which it is merged. UV cannot penetrate the block part which is in the middle of the mask region.

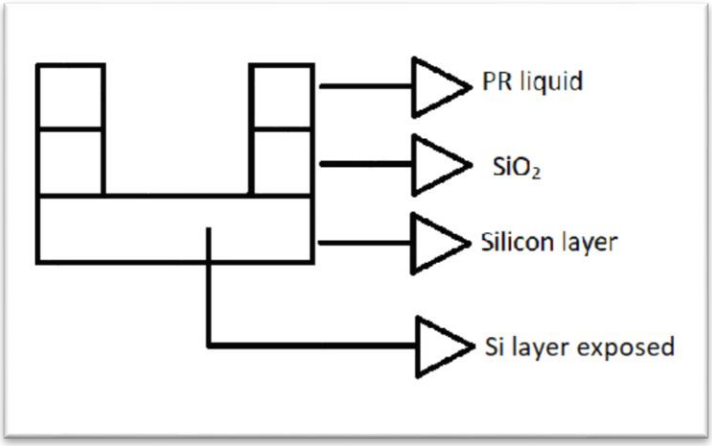


IX) The places where UV falls on the PR, the solubility of PR changes and in the remaining places the solubility of the PR remains the same.

X) **Develop by the Developer by 40 sec**: The places on the PR where UV falls and gets undissolved and the places where UV is not falling gets dissolved. Hence when we take an image of anything and take out its negative, then the black region appears to be as white and vice versa. This is an example by which we can relate this experiment.



XI) **Itching with 10% HF**: This process dissolves the SiO_2 layer exposed and hence the diagram becomes to look like this:



XII) **Stipping by Acetone**: Dissolves the PR layer on the top and then this experiment gets complete. So, the result look like:

DIFFUSION

The process of ***diffusion*** begins by determining whether the silicon wafer is doped with p – type or n – type impurity. This process of identification was previously done by using **HALL EFFECT** Method, but due to the consumption of more time, it was rejected. The alternative method, introduced is **HOT PROBE** Method.

❖ Hot Probe Method:

A voltmeter (or ammeter) is attached to the sample and a heat source such as a soldering iron is placed on one of the leads. The heat source will cause charge carriers (electrons in case of an n-type semiconductor material and holes in case of a p-type) to move away from the lead. The heat from the probe causes an increased number of higher energy carriers to diffuse away from the contact point. Thereby, creating a space or gap on the surface. This will cause a voltage difference. Thereafter, electrons flow from positive electrode to negative and thus, current flows in opposite direction. After that, if the voltmeter reads negative, then the doping is confirmed to be p-type and if the reading is positive then the doping is n-type.

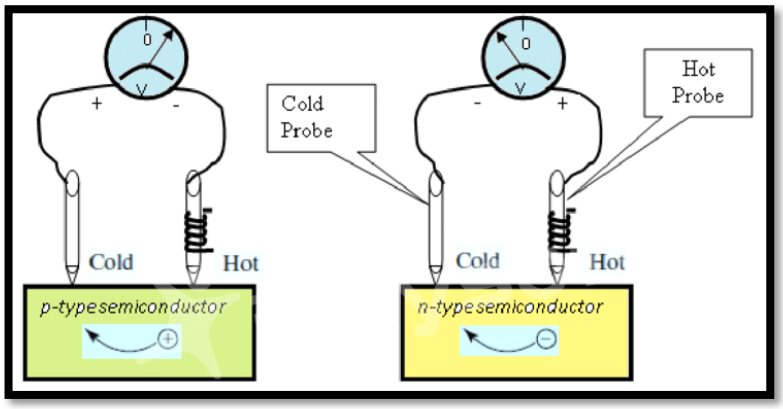
#Note:

- **For p-type Doping**:

  Pure Boron is not used, instead, **Boron Nitride** (BN) is used.

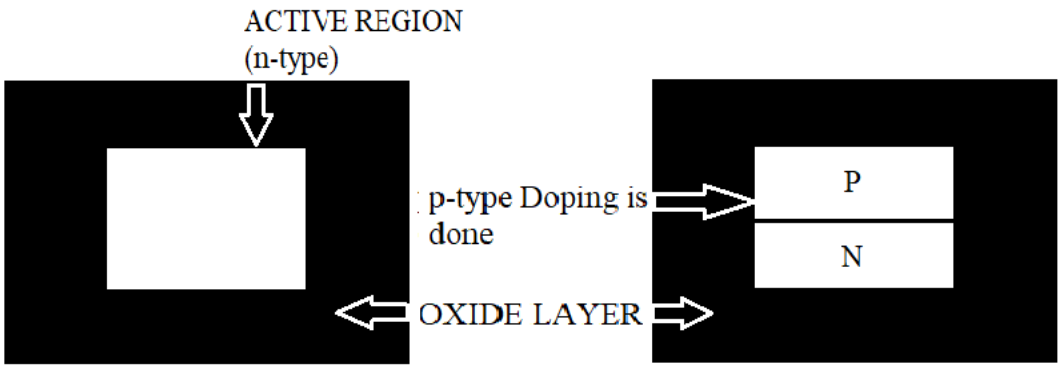
- **For n-type Doping**:

  Pure Phosphorus is not used, instead, **Phosphoryl chloride** ($POCl_3$) is used.



❖ Requirements for diffusion:

- *Temperature*: **1000°C**
- *Gas*:
  a. **N_2 (1L/min)** [for 10mins]
  b. **O_2 (1L/min)**
- *Time*:
  a. **Pre-dip** [Primary Diffusion] (15 minutes)
  b. **Driving** (Minimum 3 Hours)
- *Itching*: **10% HF**



DIFFUSION PROCESS

A Group 3 element (such as 1Boron) can be added to the Silicon wafer. In this case, Boron will try to bond with four Silicon atoms but it only has three electrons to bond with. This means that there is an incomplete bond with one of the Silicon atoms, a hole where an electron would normally be. This hoc behaves much like an electron and can move around the wafer but with an opposite charge. So, a different type of charge carrier is present in the wafer that increases the wafers conductivity. This type of Silicon doped with Boron (Group3) element is called p-type semiconductor. By adding impurities to Silicon its conductivity increases.

❖ The Process of Diffusion:

(i) ACTIVATION:

Boron Nitride is used because Boron can be easily extracted from it. The characteristics of Boron Nitride is to absorb lots of moisture. Thus, it reacts with water vapour to create Boron Hydroxide [$B(OH)_3$], which acts as a gum. So, 'Activation' is done. In this process, BN should be heated for (20-25) hours at 1000°C in ambient N_2. Boron Hydroxide is formed on its surface which prevents it from reacting. Then, it is kept in an oven at a temperature 110°C until it is used.

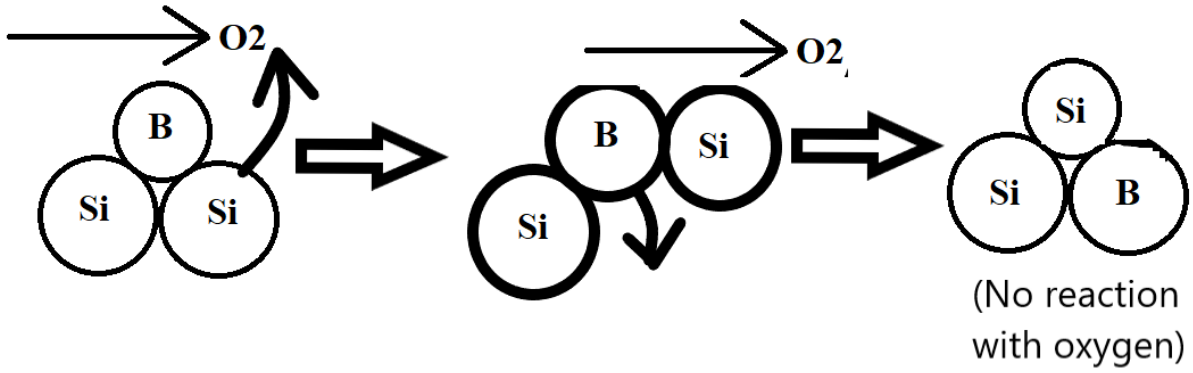
(ii) Dopant Diffusion-[Pre-dip]:

The objective of the dopant pre-deposition diffusion is to move dopant atoms from a source to the wafer and then allow the dopants to diffuse into the wafer. The source of dopants can be in several forms like solid, liquid or gas. In order, for the dopant atoms (Boron), to move into Silicon they must be given energy usually in the form of heat. Temperature must be kept reasonably high i.e. (~1000°C). At this temperature, the dopant reacts with the exposed Silicon surface to form junctions selectively on the wafer through the highly doped glass formed by photolithography. It is from this glass that the dopants can then diffuse into the wafer openings in the oxide. The experiment is performed in the presence of ambient N_2 because nitrogen carries boron from BN and deposits on the

silicon surface. Thus, at the end of this process, Silicon crystal is occupied by Boron.

(iii) Dopant diffusion-[Drive]:

After the pre-deposition step of diffusion process, the dopants are situated close to the wafer surface. However, they must diffuse even farther to lower the overall concentration, in order to make some of the devices work properly. The pre-deposition process introduces dopants into the wafer. The diffusion redistributes the dopants and allows them to diffuse into the wafer more deeply. In addition, oxygen and water vapor are introduced into the drive process. Silicon is very much reactive towards O_2. Therefore,



in this way Boron atoms move deep inside the silicon layer. This oxygen is also used to grow a new oxide over the area which is exposed to bare silicon during the processes that can be performed to create other types of devices. This new oxide can be patterned again so that other selective diffusion processes can occur easily. During the process, sometimes Silicon and Boron both reacts with oxygen to form a layer of Boron Silicate [$BSi(O_3)_2$] is formed over the p-type region of the wafer. It acts as an insulator.

(iv) Itching:

The Boron Silicate formed over the wafer surface is removed by reacting it with 10% HF for few seconds. This process is called *Itching*.

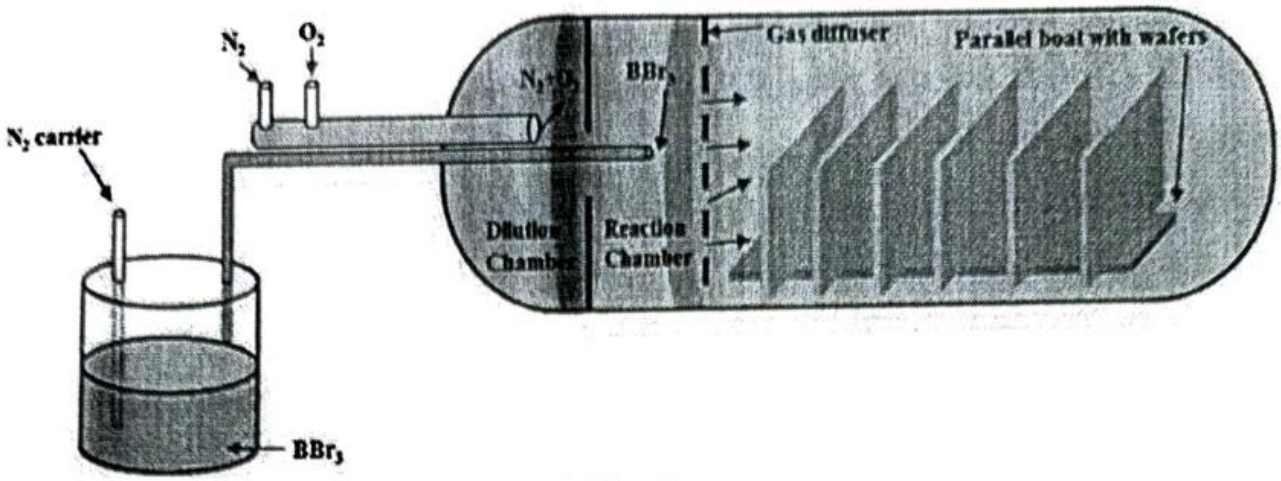
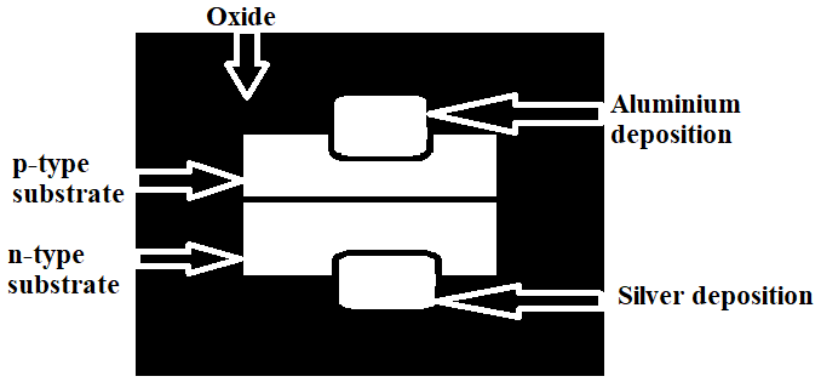


Fig: Diffusion

METALLIZATION

The process of metallization begins with the testing of the metal that will be deposited on the wafer surface. The criteria include the metal should have **Ohmic contact**, i.e., its V-I Characteristics should be linear. Silver (**Ag**) is a good Ohmic conductor for ***n-type substrate*** and similarly, Aluminium (**Al**) is a good conductor for ***p-type substrate***.



Silicon wafer after Metallization

In Microelectronics, 'Metallization' is conducted by a method called **Vacuum Evaporation Method (VES)**. This method is used because of two reasons: (i) To avoid the oxide of the metal, and (ii) Mean free path (shortest distance between two paths) should be free. Systems are classified into four different parts depending upon the Power supply. These are:

- ***Thermal Vacuum Evaporation System (VES),***
- ***Electron Beam VES,***
- ***Radio Frequency VES,***
- ***Plasma Chemical Vapour Deposition VES.***

(i)Thermal Vacuum Evaporation System:

Deposition of metals with low melting point (like Al, Ag, Cu, Au etc.) occur in this process.

(ii)Electron Beam Vacuum Evaporation System:

Deposition of metals with high melting point (like Pt, Si, Mo etc.) occur in this process.

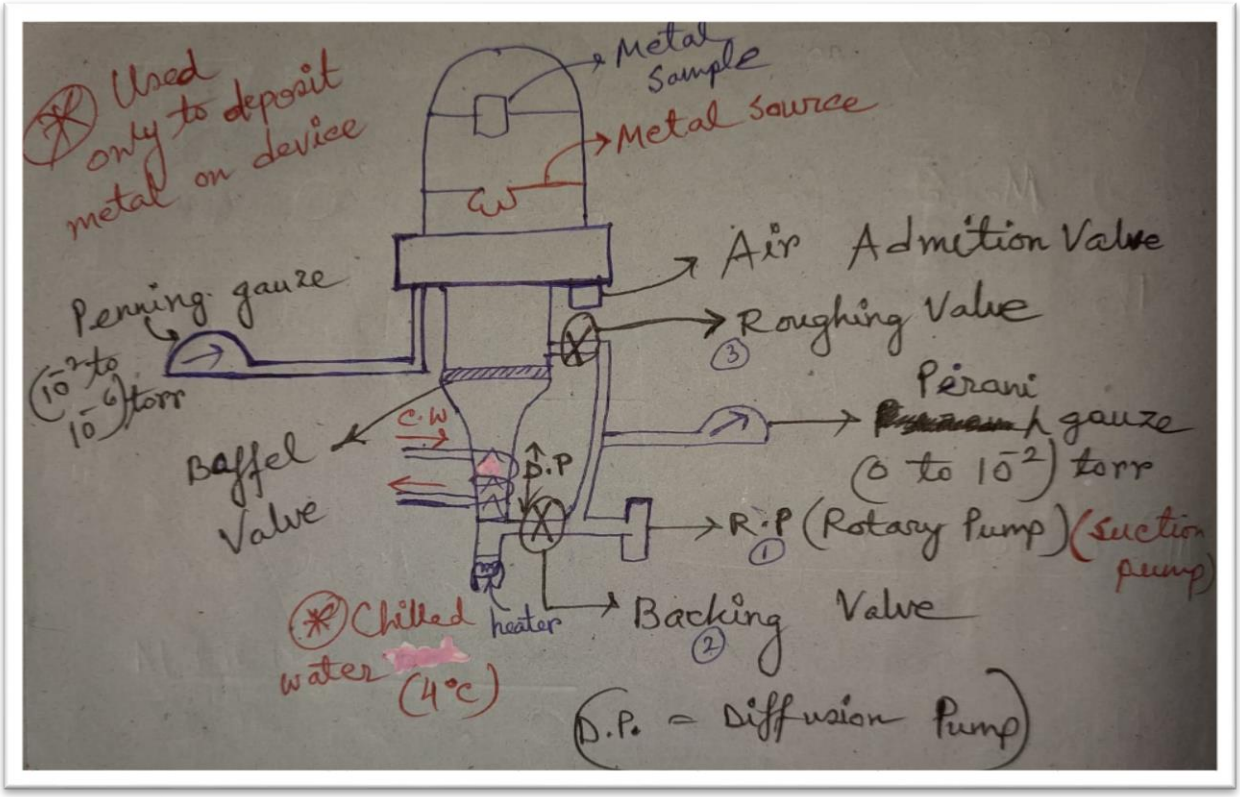
(iii)Radio Frequency Vacuum Evaporation System:

Deposition of bi-metals (like toxic gases) occur in this process.

(iv) Plasma Chemical Vacuum Evaporation System:

Deposition of metals, like graphene, occur in this process.

❖ **Vacuum Evaporation System Process**:



1) At first to open the vacuum chamber, it has to be filled with gases and for that the '**Air Admission Valve**' has to be opened. Thereafter, the *vacuum chamber is opened*.
2) A metal (**Al/Ag**) is placed inside the **Tungsten Filament** and after that the sample is placed over a levelled chamber on a boat, such that **a *small portion of it is opened, where the metal deposition will occur***.

3) Thereafter, the '**Rotary Pump**' is opened to vacuum the area above it and the process continues until the **Pirrani Gauze** measures **10^{-2} torr**.
4) After that, the **Backing Valve** is opened and the *Rotary pump is closed* and the same suction process continues until the *Pirrani Gauze* measures **10^{-2} torr**.

5) Now, the *Backing Valve is closed* followed by ***opening the line for the* cold water *to enter***. Thereby, **Diffusion Valve** is opened.
6) Followed by this, the *Roughing Valve* and the **Baffle Valve** is opened. This process of suction continues until the '**Penning Gauze**' measures 10^{-6} torr (this usually takes a long time to perform).

7) Thereafter, **metal deposition starts**. Meanwhile, sufficient amount of heat is also provided from the heater, causing the Aluminium or Silver to melt and evaporate. The evaporate of the metal will solidify into a thin film, when it has touched the silicon.
8) After this, the *Backing Valve, Roughing Valve* and *Baffle Valve is closed* and **'HT & LT'** button is switched **ON**.
9) There are two display screens present, one shows the current of **Primary HT&LT** values (value is less usually less than 1) and the other of **Secondary LT** values. Initially, the value of current in Secondary LT display is less, which increases when the metal melts and its resistivity decreases. The value increases upto 30A and then starts decreasing as the metal melts and its resistivity increases. Finally, the current is reduced to zero (when the process is over).

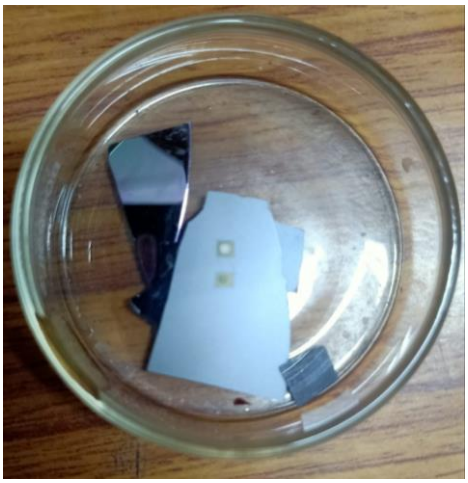


Thermal Vacuum Evaporation Machine

#**Note**:

In case of **Aluminium**, heat treatment is done at **550°C for 45 seconds** and in case of **Silver**, heat treatment is done at **700° C for 45 seconds**.

Usually, ***at first 'Ag' is deposited***, thereafter '***Al***' because Ag needs higher temperature to melt.

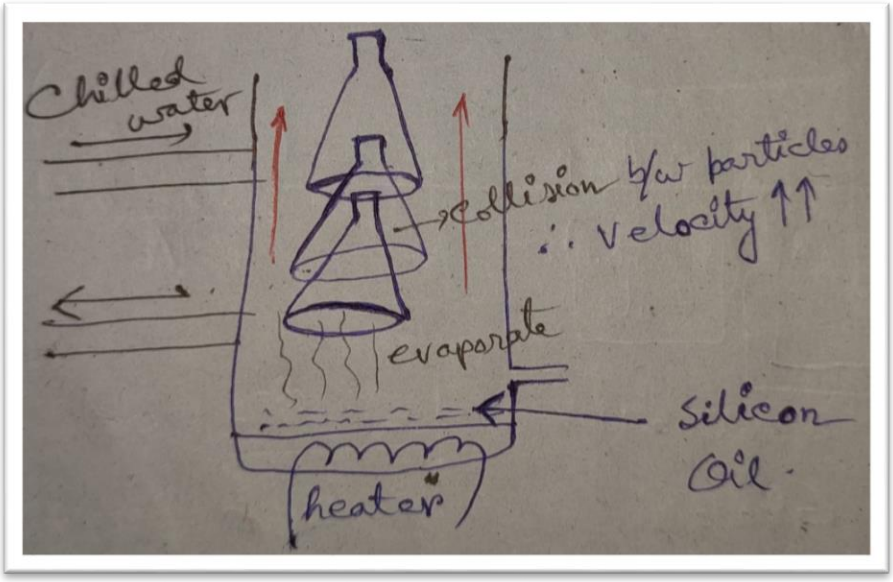


Sample



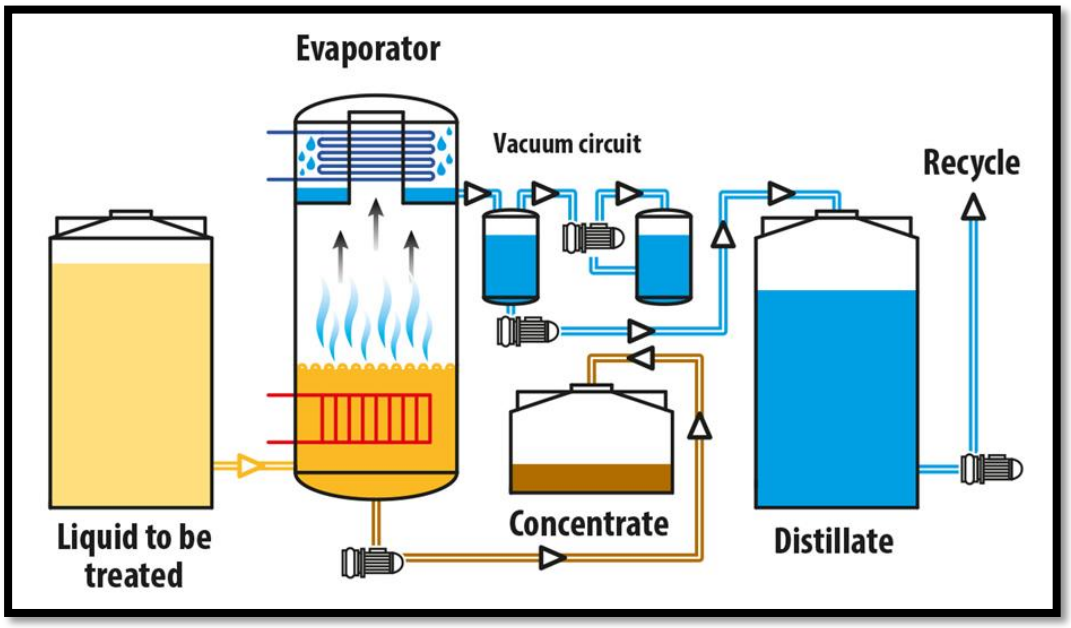
Masked Wafer

❖ Working of Diffusion Pump:



Diffusion Pump Diagram

When the heater is on, the temperature of Diffusion Pump increases and the silicon oil inside it, starts evaporating. The oil particles enter the flasks and starts colliding with each other. Thereafter, it come out of the funnel and moves up towards the container, having the metal and sample. Over there, these oil particles (because of their air particle capturing ability) captures each and every air particle and thereafter become heavy and fall down. Due to the contact of the cold water, they condense easily and precipitates. Thereby, making the top container air free (or vacuum).



CONCLUSION

Initially, ten transistors' functionalities could be integrated in a single chip around 1960. With the gradual improvement in studies and technologies, nowadays billions of transistors can be embedded in a single chip. Doping, vapour positions and itching processes, requires ultra-clean rooms with fewer than three dust particles per litre of air, and operates in geometrical dimensions close to the wavelength of light. May seem hypothetical in the 60s but this is the reality. After 1965, the field of informatics witnessed an unprecedented boom. For large-scale research, huge mainframe systems and supercomputers came into existence. Transistors are much more efficient and cost effective. The electronics in your smartphone use less electricity in a year than the ENIAC computer uses in one minute back, while performing billions more calculations per second back in 1950s. It's impossible to overstate the impact that personal computing has had on our modern world, and all of that innovation is only possible due to the invention of the transistor. It's tough to say whether it was the most important invention in human history, but it definitely completely changed the world.