MASKING

- In the fabrication of semiconductor devices, selective doping is often necessary. That is certain regions of the silicon wafers have to be protected against doping. This is usually done by covering the entire silicon wafer by a protective layer, and then removing this layer at selected regions of the silicon wafer. This is called **masking**.

PHOTOLITHOGRAPHY

- **Photolithography** is the process of transferring geometric shapes or images on a mask to the surface of a silicon wafer by the use of UV light and a photo resist.

  The steps involved in the photolithographic process are as follows:

1) Wafer Cleaning and Barrier Formation:

In the first step, the wafers are chemically cleaned to remove particulate matter on the surface as well as any traces of organic, ionic and metallic impurities. After cleaning, silicon dioxide, which serves as a barrier layer, is deposited on the surface of the wafer.

2) Photoresist Application (Spinning):

A drop of **light-sensitive liquid** called photoresist is applied on the surface of the oxidized silicon wafer. The wafer is then accelerated rapidly to a rotational velocity in the range of **3000 to 7000 rpm** for a period of **30 to 60 seconds**. This action spreads the solution in a thin, nearly uniform coat and spins off the excess liquid. The thickness of the coat so obtained is in the range **5000 to 10000**Å.

Photo resists:

- One of the major factors in providing increasingly complex devices has been improvement in photolithographic art. A large part of this improvement has been due to high quality photo resist, materials as improved techniques of coating, baking, exposing and developing photo resists.
- The principal constituents of a photo resist solution are a polymer, a sensitizer and a suitable solvent system. Polymers have properties of excellent film forming and coating. Polymers generally used are polyvinyl cinnamate, partially cyclised isoprene family and other types are phenol formaldehyde.
- When photo resist is exposed to light, sensitizer absorbs energy and initiates chemical changes in the resist. The sensitizers are chromophoric organic molecules. They greatly enhance cross linking of the photo resist.

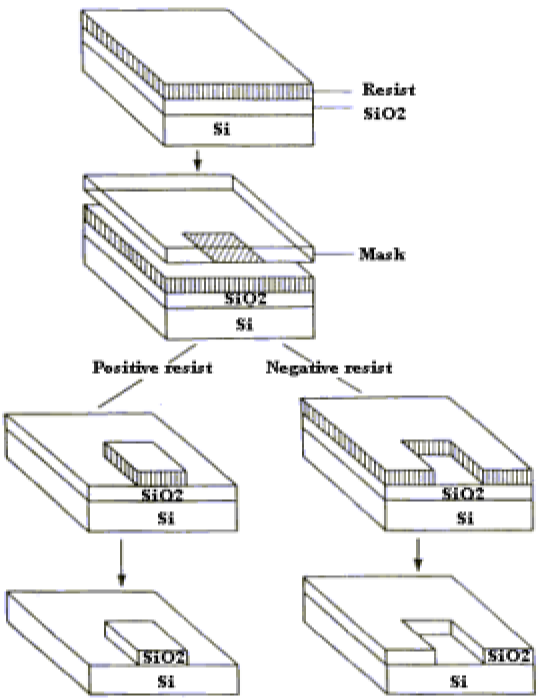
- Cross linking of polymer or long chain formation of considerable number of monomers makes high molecular weight molecules on exposure to light radiation, termed as photo-polymerization. Typical sensitizers are carbonyl compounds, Benzoin, Benzoyl peroxide, Benzoyl disulphide, nitrogen compounds and halogen compounds.
- The solvents used to keep the polymers in solution are mixture of organic liquids. They include aliphatic esters such as butyl acetate and cellulose acetate, aromatic hydrocarbons like xylene and Ethyl benzene, chlorinated hydrocarbons like chlorobenzene and methylene chloride and ketones such as cyclohexanone. The same solvents are used as thinners and developers.

Characteristics of Good Photoresist:

To achieve faithful registration of the mask geometry over the substrate surface, the resist should satisfy following conditions.

- Uniform film formation
- Good adhesion to the substrate
- Resolution
- Resistance to wet and dry etch processes

Types of Photo resist:



- **Positive Photo resist**

  For positive resists, the resist is exposed with UV light wherever the underlying material is to be removed. In these resists, exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer. The exposed resist is then washed away by the developer solution, leaving windows of the bare underlying material. In other words, "whatever shows, goes." The mask, therefore, contains an exact copy of the pattern which is to remain on the wafer.

- **Negative Photo resist**

  - Negative resists behave in just the opposite manner. Exposure to the UV light causes the negative resist to become polymerized, and more difficult to dissolve. Therefore, the negative resist remains on the surface wherever it is exposed, and the developer solution removes only the unexposed portions. Masks used for negative photo resists, therefore, contain the inverse (or photographic "negative") of the pattern to be transferred. The figure below shows the pattern differences generated from the use of positive and negative resist.

  - Negative resists were popular in the early history of integrated circuit processing, but positive resist gradually became more widely used since they offer better process controllability for small geometry features. Positive resists are now the dominant type of resist used in VLSI fabrication processes.

3) **Prebake:**

The silicon wafers coated with photo resist are now put into an oven at about 80°C for about 30 to 60 minutes to drive off solvents in the photo resist and to harden it into a semisolid film.

4) **Mask alignment and exposure:**

One of the most important step in the photolithography process is mask alignment. A mask or "photo mask" is a square glass plate with a patterned emulsion of metal film on one side. The mask is aligned with the wafer, so that the pattern can be transferred onto the wafer surface. Each mask after the first one must be aligned to the previous pattern.

Once the mask has been accurately aligned with the pattern on the wafer's surface, the photo resist is exposed through the pattern on the mask with a high intensity ultraviolet light. The exposure time is generally in the range 3 to 10 seconds and is carefully controlled in such a way that the total UV radiation dosage in watt-seconds or joules is of the required amount, and then developed in a developer.

5) **Post bake:**

After development and rinsing, the wafers are usually given a post bake in an oven at a temperature of about 150°C for about 30 to 60 minutes to toughen further the remaining resist on the wafer. This is to make it adhere better to the wafer and to make it more resistant to the hydrofluoric acid [HF] solution which is used for etching of the silicon dioxide.

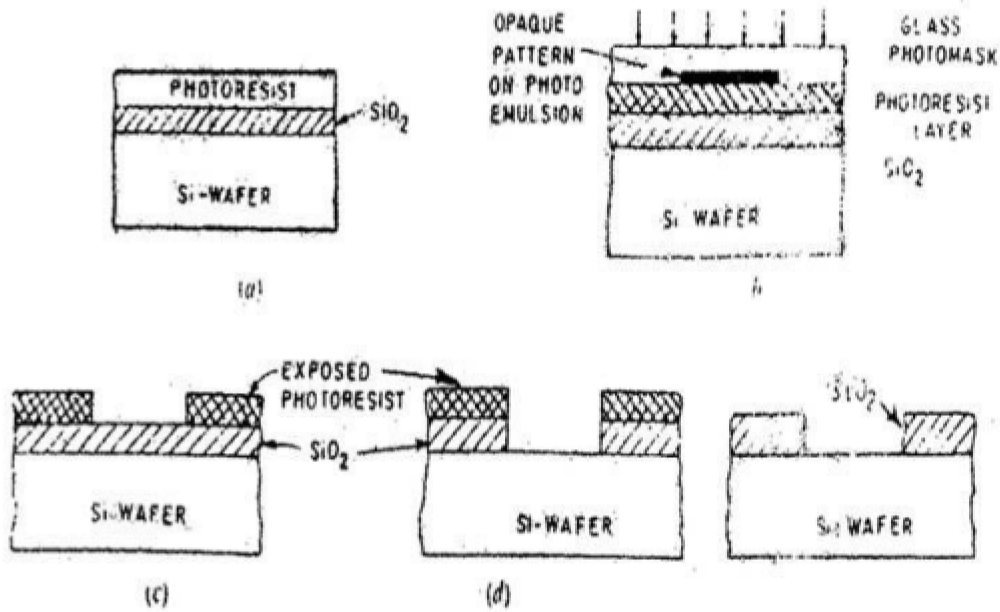
6) Oxide etching:

The remaining resist is hardened and acts as a convenient mask through which the oxide layer can be etched away to expose areas of semiconductor underneath. These exposed areas are ready for impurity diffusion.

For etching of oxide, the wafers are immersed in or sprayed with a hydrofluoric [HF] acid solution. This solution is usually a diluted solution of typically 10:1 - H_2O : HF or more often a 10 : 1 NH_4F [ammonium fluoride]: HF solution. The HF solutions will etch the SiO_2 but will not attack the underlying silicon nor will it attack the photo resist layer to any appreciable extent. The wafers are exposed to the etching solution ion enough to remove the SiO_2 completely in the areas of the wafer that are not covered by the photo resist

7) Photo resist Stripping:

Following oxide etching, the remaining resist is finally removed or stripped off with a mixture of sulphuric acid and hydrogen peroxide and with the help of abrasion process. Finally a step of washing and drying completes the required window in the oxide layer. The figure below shows the silicon wafer ready for next diffusion.



The Steps in photoresist patterning
(a) Photoresist coating ; (b) Contact printing ; (c) Developed Si-wafer
(d) After Oxide etching ; (e) After stripping

Photolithographic Process Steps

Negative photo resists are more difficult to remove. Positive photo resists can usually be easily removed in organic solvents such as acetone.

ETCHING

- Etching and cleaning process are involved at many points in the microcircuit fabrication process.
- The term etching is used to describe all techniques by which material can be uniformly removed from a wafer as in surface polishing, or locally removed as in the delineation of a pattern for a microcircuit.
- After a photo resist image has been formed on the surface of the wafer, the next process involves transferring that image into a layer under the resist. This is done by selective removal of material from the unmasked regions. The technique by which material can be uniformly or selectively removed is called **etching.**
- Some of the etching techniques used is wet chemical etching and plasma etching.

Wet chemical etching:

- In this process, the wafer is immersed in the etching solution at a predominant temperature and the solution reacts with the exposed film to form soluble by products.

- Wet chemical etching of any material can be considered as a consequence of three steps.
  1) Transport of the etchant species to the surface of the wafer.
  2) A chemical reaction with the exposed film that produces soluble by products and
  3) Movement of the reaction products away from the surface of the wafer into the volume of the etchant solution.
- A number of chemical reagents and their mixtures are used for etching purposes. Many of these are available in transistor grade purity and are preferred in order to minimize contamination of the semiconductor during processing .Water is an intrinsic component of all these reagents.
- A common Al etchant is 20% acetic acid, 77% phosphoric acid and 3% nitric acid.
- The main problem with wet etching is undercutting. Undercutting is the lateral extent of the etch under the photo resist mask. Undercutting limits the use of wet chemical etching to devices with dimensions larger than 2.5 µm.
- Other problems related to wet chemical etching are
  1) It is difficult to control
  2) It is prone to high defect levels due to solute particle contamination.
  3) Cannot be used for small features and
  4) Produces large volumes of chemical waste.

Plasma etching:

- It is a dry etching process. Integrated circuit fabrication processes that use reactive plasmas are common place in today's semiconductor production lines.
- The term reactive plasma is meant to describe a discharge in which ionization and fragmentation of gases takes place and produce chemically active species, frequently oxidizing and or reducing agents. Such plasmas are reactive both in the gas phase and with solid surfaces exposed to them.
- When these interactions are used to form volatile products so that material is removed or etched from surfaces that are not masked by lithographic patterns, the technique is known as **reactive plasma etching**.
- Plasma is a collection of electrons, singly and multiply charged positive and negative ions along with neutral atoms and molecules and molecular fragments. These particles are held in a reaction chamber and held at a pressure of 0.5 to 25 Pascal. The charged particles result from the interaction of the initially introduced etchant gas with an applied electric field.
- Plasma etching process proceeds in the following steps
  1) A feed gas introduced into the chamber must be broken down into chemically reactive species by the plasma.
  2) These species must diffuse to the surface of the wafer and be adsorbed.
  3) Once on the surface, they may move about (surface diffusion) until they react with the exposed film.
  4) The reaction product must be desorbed.
  5) The reaction product should be diffused away from the wafer.
  6) And finally the reaction product should be transported by the gas stream out of the etch chamber.
- Plasma etching is a dry etching process in which reactive gases are fed into the reaction chamber. This is excited by high strength RF field to form plasma of charged ions. These ions react with the material to be etched which evaporates off from the wafer. CF_4 is the commonly used compound for etching Si, SiO_2 and Si_3N_4.
- **Advantages of plasma etching**
  1) Plasmas are much easier to start and stop than wet etching.
  2) Plasma etch processes are much less sensitive to small changes in the temperature of wafer.
  3) There is less undercutting in plasma etching.
  4) This process produces less chemical waste than wet etching.