the gas flow sequence, automatic insertion and removal of wafers and the furnace temp.

Once the SiO_2 layer has been formed on the surface of the wafer, it is selectively removed (etched) from those surface where impurities are to be introduced and kept as a shield for underlying Si surface where dopants are to be allowed.

(B) Vapour phase / chemical vapour deposition (CVD) - It is used when the oxide layer is required on the top of a metal layer such as in multi level metallization structure.

(C) Plasma oxidation - It is a low temp. vacuum process carried out in a pure oxygen discharge. This process allows to grow high quality oxides on the surface of Si wafer compared to other techniques.

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(5) ETCHING:

It is a process in which the material which is not masked by lithographic process is removed uniformly or selectively.

(A) Wet Etching: the unmasked regions on the wafer are etched using wet etchants (i.e. chemicals) such as nitric acid, hydrofluoric acid at a predetermined temperature. The material to be (20) etched is removed equally in all direction (isotropic). It has high throughput i.e. large no. of wafers can be immersed in the etchants. Other advantages are higher selectivity, minimum lateral removal of resist and overetching of the substrate material.

(B) REACTIVE PLASMA ETCHING (Dry etching)

The wafer is kept in reaction chamber filled with reactive gas like argon. The chamber is excited by high value r.f. field producing a plasma discharge which is collection of electrons, positive ions, negative ions and molecules generated due to interaction of gas introduced in the chamber. These gas ions react with wafer and remove the unmasked material.

Advantages: (i) less sensitive to temperature.

(ii) the process can be controlled easily.

(iii) the pattern obtained is superior

(C) REACTIVE ION ETCHING (Dry etching)

Here wafers are kept in a reaction chamber between two electrodes anode

and cathode. Using high electric field (21)
between two electrodes, plasma is produced
between these electrodes. The plasma
consists of different ions which remove
the material by ion bombardment. This
process has highest selectivity & uniformity

(5) DIFFUSION

The process consists of introduction of impurities into selected regions of a wafer to form junctions.

It occurs in 2 steps

(i) Predeposition: High concentration of dopant atoms is introduced on the surface of Si by a vapour that contains the dopant at a temperature of 1000°C. The bonds between neighbouring atoms of the Si in the lattice are broken and Si atoms move out of the lattice structure. Hence high density of vacancies is created. When the dopant is added at 1000°C, the impurity atoms diffuse into the Si at location of vacancies.

A shallow, heavily doped layer of impurities is formed at the surface. It is called constant source diffusion.

(ii) Drive-in: Here impurity atoms are redistributed without adding new impurity. The present impurity atoms are driven deep into the Silicon. Surface concentration is reduced and junction depth is increased. It is also called constant dose diffusion (22)

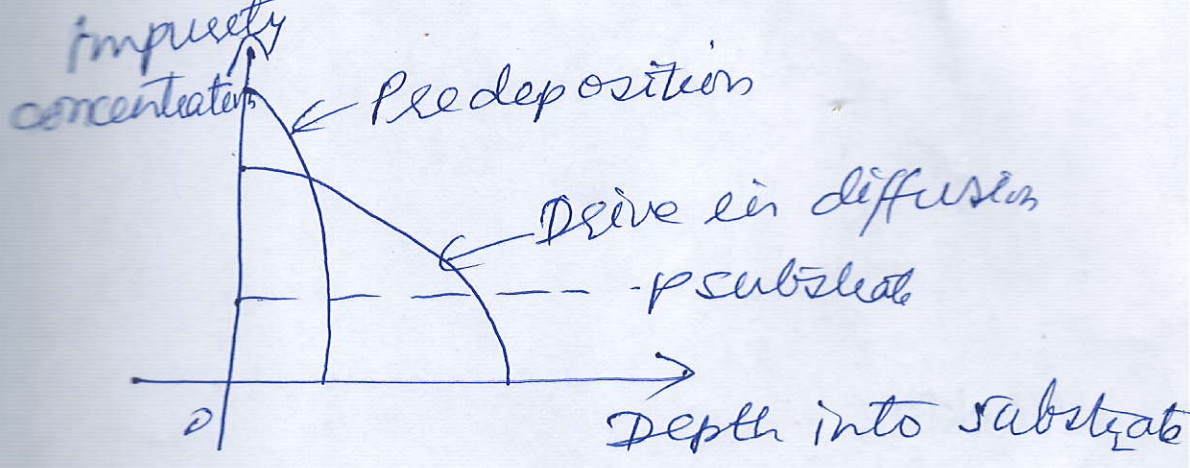
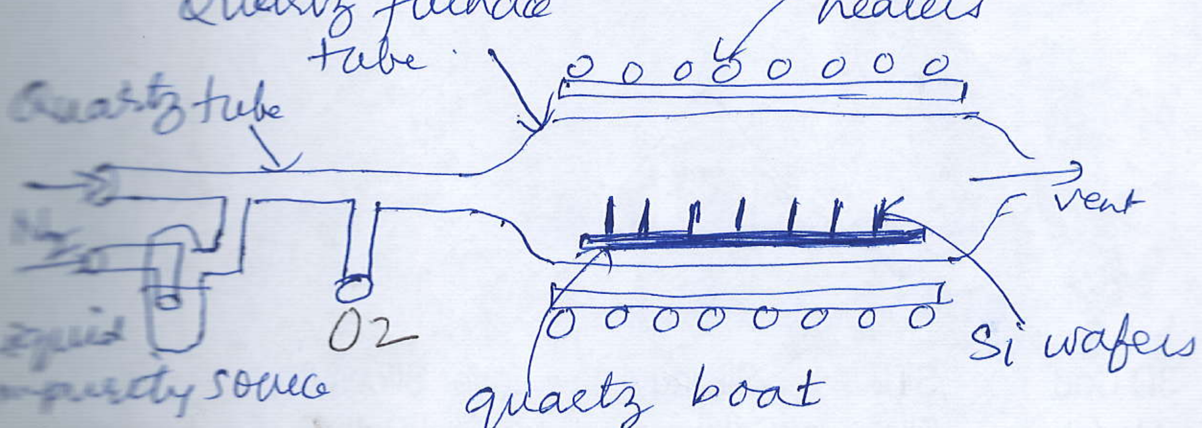


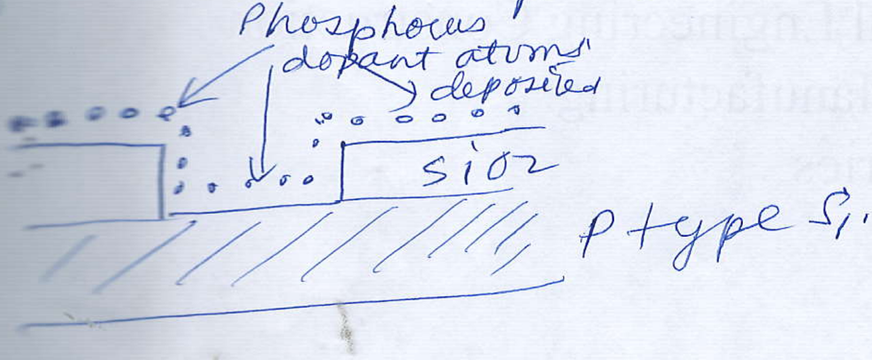
Fig: N impurity distribution in P substrate.

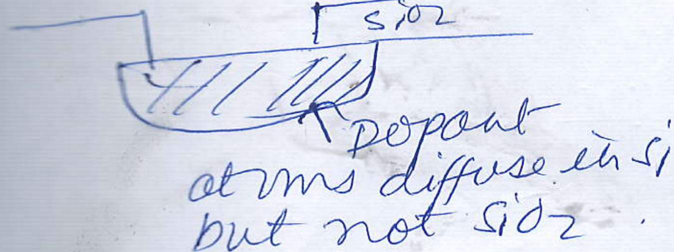
<u>Diffusion process</u>



The Si wafers are stacked vertically on a movable quartz boat inside quartz furnace tube. The temp. of the quartz furnace tube is increased with the help of resistance heaters. The dopant to be introduced is kept in a container. The dopant in liquid form may be placed inside the quartz tube ~~at~~ in low temp. region or preferably outside the tube with precisely controlled temp.

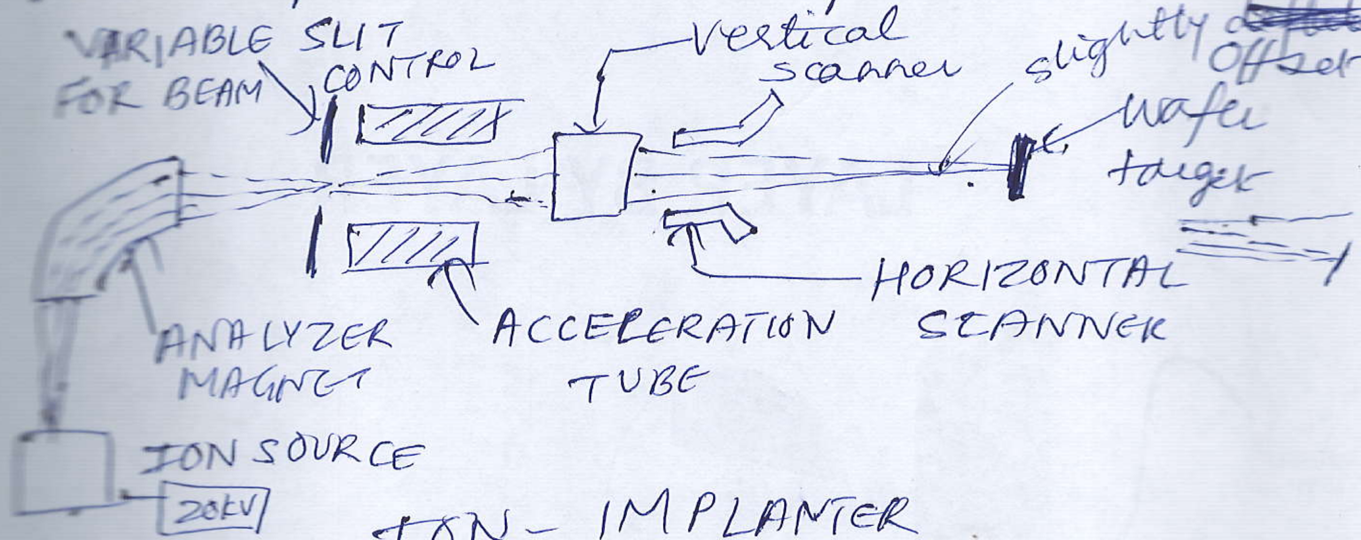
to maintain dopant in the liquid form.
Typically N_2 and O_2 are used as carrier gases.
When the carrier gases pass over the container, they carry dopant vapour into the furnace. In furnace, the gases are deposited on the Si surface. The layer containing Si, O_2, P (dopant) is formed on the surface. At high temp. such as 900°c to 1000°c, the dopants get diffused into silicon. For drive in deposition, the temp. is further increased to 1100°c so that dopant gets diffused with more depth in Si. Diffusion depth is controlled by the time and temp, ~~accurate~~ of the drive-in process





(6) ION-IMPLANTATION

This is a process of introducing dopants into selected areas of the surface of the wafer by bombarding the surface with high energy ions of the particular dopant.



ION-IMPLANTER

A gas source delivers a small amount of gas into ~~gas~~ ion source. The gas used is BF_3. The molecules break into charged particles due to heating element. The ion source contains desired ions alongwith charged particles. Due to high voltage about 20kV the charged ions are pulled out of the ion-source into the bending magnet analyzer. The bending magnet analyzer selects the ions with desired charge to mass ratio with the help of properly applied magnetic field. Thus the desired ions ~~can~~ only can travel through the analyzer while the others impinge on the analyzer walls. In the acceleration tube the ions are accelerated to the sufficiently high implantation energy.

The aperature (slit) focuses the beam of ions. The X-Y scanner (horizontal & vertical scanner) plates adjust the sweep of the beam over the wafer placed in the target chamber.

The wafer is slightly offset to the axis of the accelerator tube so as to avoid deflection of ions onto the wafer. Accelerator voltages range from few KV to MeV.

<u>Advantages of ion implantation over diffusion</u>

1. doping levels can be precisely controlled.
2. Depth of the dopant can be easily regulated.
3. Extreme purity of dopant is guaranteed
4. Doping uniformity across the surface can be accurately controlled.
5. As the ions enter the solid as a directed beam there is very little spread of beam thus the doping area can be clearly defined.
6. Since ion-implantation is carried out at room temp, wafers do not face temperature stress.

Disadvantages of ion-implantation over diffusion.

1. The ion implantation may create considerable damage to the crystal structure because of the collisions of the high energy ions with the Si. Such damage results in inferior performance of ICs made by this process. If the damage is not extensive, the process of annealing restores the structure.
2. High initial investment and operational cost of the equipment
3. Uses very toxic gases for some of the dopants such as phosphorus and arsenic

(5) PHOTOLITHOGRAPHY

This process is subdivided into 2 processes

(A) Photomask generation

(B) Lithography i.e. pattern generation

(A) PHOTOMASK GENERATION:

It is necessary to identify regions of each circuit so as to carry out selective doping i.e. some areas protected against doping. This requirement can be fulfilled by use of mask (protective layer pattern) during fabrication process where different masks are used for different fabrication processes.

Generation of photomask means designing a desired pattern for each device. A mask is simply a glass plate consisting a pattern for complete wafer. The mask is generated using computer controlled system. The pattern to be generated is stored in the digital form. Using proper commands from computer, a pattern generator is activated which uses an electron beam to draw pattern. This is called photoengraving. The pattern is drawn on high quality glass which is coated with chromium.

After obtaining mask ~~from~~ for each layer, individual mask is photographed. Then using step and repeat camera, photorepeating is done which means obtaining successive images in array on the photographic plate which is moved in equal steps during exposure. After developing the exposed plate, final mask is prepared called master mask. From this master mask, working copies are made which are called reticles, which are used for actual pattern transfer on a semiconductor wafer.

The reticle consists of 2 types of regions namely transparent region (with no metal) and opaque region (with metal) when the light is passed through the reticle on photoresist coated wafer only the shadow of the reticle is projected onto the surface of the wafer.

(B) LITHOGRAPHY.

It is a process in which the pattern generated on the photomask is transferred or imaged on the wafer covered with photoresist.

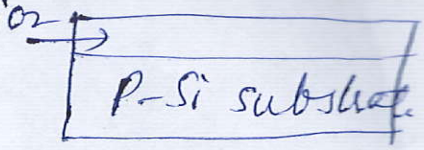
To transfer the pattern the wafer is coated with light sensitive material called photoresist.

After this following steps are ~~done~~ taken to open a window on the surface of the wafer. (2)

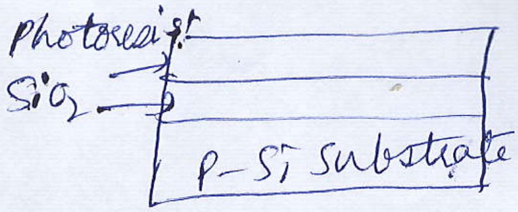
1. Wafer is baked at 100°c to solidify the photoresist on the wafer.
2. Glass plate is placed on the wafer and aligned by computer control.
3. Glass plate is exposed to ultraviolet light with the transparent parts of the glass plate passing light on the wafer. The photoresist under the opaque regions of the glass plate is unaffected.
4. The exposed photoresist is chemically removed by dissolving it in an organic solvent and exposing the SiO_2 underneath.
5. The exposed SiO_2 is then etched away using hydrofluoric acid. The Hydrofluoric acid dissolves SiO_2 and not photoresist.
6. The photoresist under the opaque regions of glass plate is removed using proper solvent and SiO_2 is exposed.

The surface covered by SiO_2 do not permit entry of dopants.

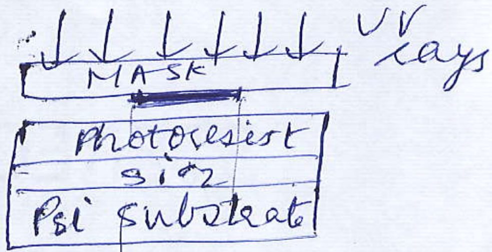
(a) P Si substrate & oxide film.



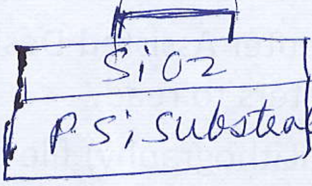
(b) Photoresist applied



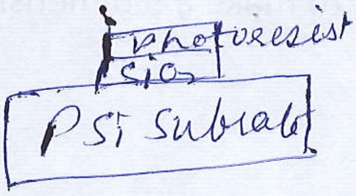
(c) Mask placed above photoresist & UV light directed at it



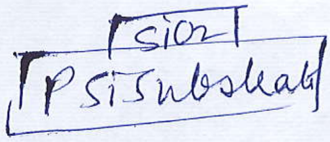
(d) photoresist etched away under transparent regions of mask



(e) SiO_2 etched away



(f) remaining photoresist etched away



Here positive photoresist is used which allows the windows to be opened wherever the UV light passes through the transparent parts of the mask.

When windows are opened under opaque parts of the mask it is called negative photoresist.

Other methods use

(i) X ray lithography – size of 0.1 µm is possible but the process is slow & cost of equipment high.

(31)

(4) Electron beam lithography.
Used for feature size less than 1 μm. offers high resolution but exposure time is more and equipment cost is high.

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(6) EPITAXY
Epitaxy means 'arranged upon'. It is the process of controlled growth of a crystalline doped layer of Si on a single crystal substrate. This method produces a layer of lower concentration than the existing one whereas diffusion and ion-implantation produce a layer at the surface that is of higher density than that which existed before the dopant was added.

The epitaxial layer formed on the substrate may be either n doped, p doped or intrinsic. P type doping uses bi-borane (B_2H_6) and n type doping uses phosphine (PH_3) with the stream of silicon tetrachloride gas + Hydrogen gas.

$$SiCl_4 + 2H_2 \rightleftharpoons Si + 4HCl.$$

There are 2 types of epitaxy.
1 Homoepitaxy: Here epitaxial layer and the substrate are of same material Eg Si ~~formed~~ grown on Si substrate.