Photoresists for microchip fabrication

Patterning is one of the basic operations in the fabrication of a microchip. A photoresist is the heart of the patterning process. It is a suspension of light sensitive polymers, sensitizers and additives in a solvent. The light sensitive polymer is the material responsible for patterning.

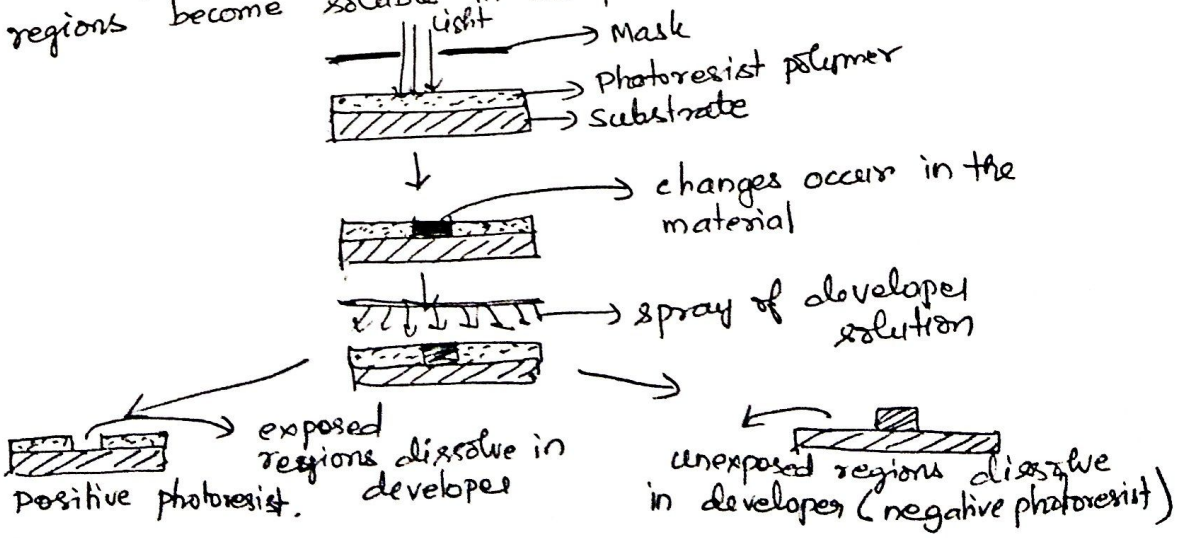
Photoresist is a material, which after exposure to light, resist the action of certain chemicals in desired areas.

Types of photoresists :-

Let us consider a substrate which is covered by a thin layer of photoresist material. When the coating is selectively irradiated with light through a mask, the irradiated regions undergo changes (like cross-linking or polymerization or degradation). Depending on the type of photoresist material used, it is possible to wash away either the exposed or unexposed regions selectively, using a fluid, called the developer.

In positive photoresist, the light exposed areas become more soluble in the photoresist developer and the portion of photoresist unexposed to light remain insoluble.

In negative photoresist, the light exposed regions become relatively insoluble in the photoresist developer and unexposed regions become soluble in the photoresist developer.



The role of photoresists is to transfer the required circuit pattern on to the substrate and also act as an etch barrier on the substrate when subjected to etching in the required regions. ~~Therefore~~

The requirements for best performance of a resist material are as follows.

Exposure speed and sensitivity:-

→ The primary action of a photoresist is a change in structure in response to an exposing light.

The rate of the reaction should be high so that the wafers can be processed faster.

Negative photoresists require 5 to 15 seconds exposure time, whereas positive resists take three to four times longer.

Adhesion capability:-

→ Since photoresists also act as etch barriers, the materials should be strongly adherent on the substrate. The layer should be free from pin holes and also should have a certain thickness for mechanical strength.

If the layer does not adhere strongly to the substrate, the pattern will be distorted leading to defect.

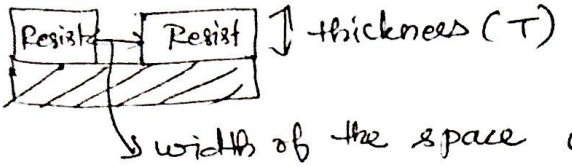
→ Resolution capability:-

For fabrication of VLSI circuits the resolution capability of a photoresist should be ~~high~~ as small as possible.

The smallest opening or space that can be produced on a photoresist is called as resolution capability. The smaller the opening produced, the better the resolution capability.

Generally, smaller line openings are produced with thinner resist film thickness. However, a resist layer must be thick enough to function as an etch barrier and be pinhole free.

Thus, the capability of a particular resist relative to resolution and thickness is given by its aspect ratio which is the ratio of the resist thickness to image opening.



$$\text{Aspect ratio} = \frac{T}{W}$$

Higher aspect ratios are preferred. i.e., forming small openings with thicker layers. Positive photoresists have higher aspect ratios compared to negative photoresists.

→ Viscosity :-

Usually photoresists are coated on substrates by spin coating. The viscosity of the photoresist suspension plays an important role in obtaining layers of the required thickness in short process time.

→ Retain dimensional stability

During patterning the photoresist is subjected to two heating steps. The first heating is called soft bake which evaporates solvents from the resist. The second one is the hard bake, which is done after the image has been developed in the resist layer. The purpose of the hard bake is to increase the adhesion of the resist to the wafer surface.

Since the resist is a polymer, it may soften and flow (Depending on its Tg) during the hard bake step. Such dimensional changes may lead to defect. Therefore, the resist has to maintain its shape and structure during the hard-bake step.

→ Contaminant free :-

Resists, like other process chemicals, must be meet stringent standards for particle content, sodium and trace metal contaminants and water content.

Precautions to be taken during storage and use of photoresists:-

→ Since photoresists are light sensitive materials, they have to be protected during storage and handling. This is why masking areas use yellow light and resists are stored in brown bottles.

→ To maintain photoresist viscosity, resist bottles must be capped prior to use. Otherwise, solvents will evaporate and viscosity would increase.

→ Each photoresist has a shelf life. As time passes, changes in the polymer will take place, altering the resist performance.

→ For proper adhesion of the photoresist to the substrate, the substrate should be free from contaminants and moisture. The relative humidity in the wafer fabrication area is kept under control so that moisture does not collect on the substrate.

A dehydration baking is done on the wafer to remove moisture and a hydrophobic coating is given on the substrate to promote adhesion of photoresist.

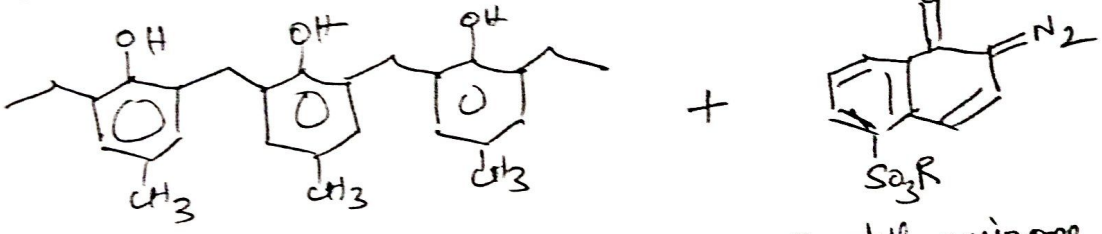
→ The resist dispensing tube must be free from solid resist materials, ~~that on~~ Thus periodic cleaning is required.

~~Comparision between positive e~~
Material chemistry of photoresists:-

Positive photoresists:-

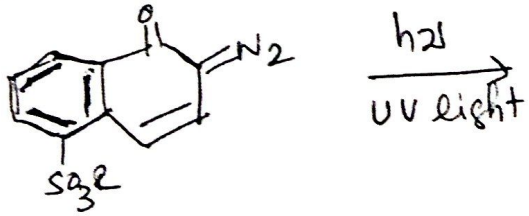
Material which shows an increase in solubility of the resist in the light exposed region relative to the unexposed regions.

Eg 1 : A photoresist that is widely used in the electronics industry is a two-component system comprising a short chain Novolac resin, which acts as the film forming agent, mixed with 20 to 50 wt% of a naphthaquinone diazide photosensitive compound. This sensitizer is insoluble in basic solutions and ~~acts by inhibition~~ also inhibits the dissolution of the novolac resin in base (novolac itself is soluble in alkali).



naphthaquinone diazide (insoluble in base)

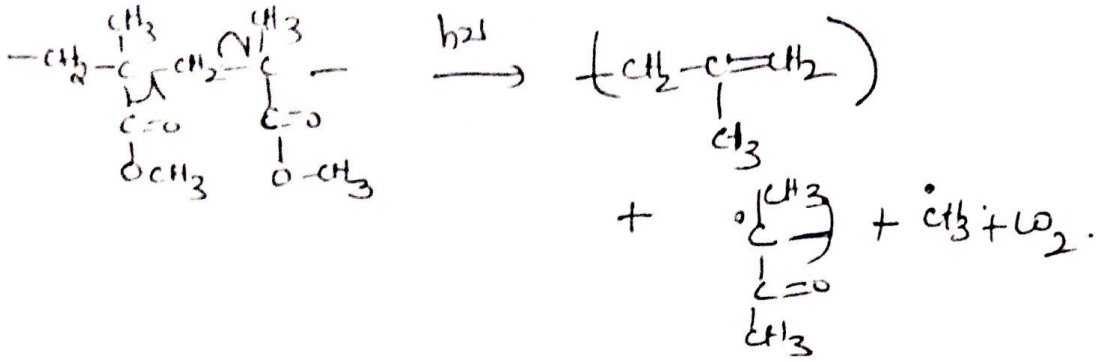
on exposure to light, the sensitizer gets converted to indene carboxylic acid.



Indene carboxylic acid becomes soluble in base.

Therefore at the light exposed region, novolac & the indecarboxylic acid ~~dissolve~~ formed, dissolve in alkali.

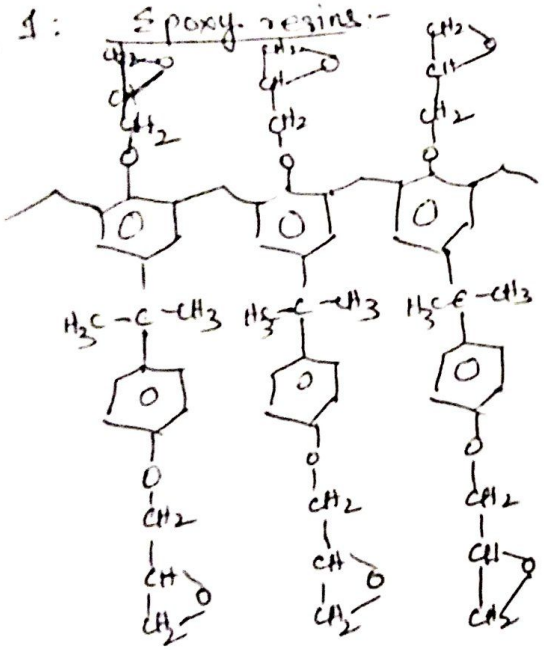
Eg.(2) Polymethylmethacrylate (PMMA):- In this case, the carbonyl groups absorb at 215nm, and this leads to chain scission and degradation.

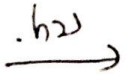


Negative photoresist:-

Material shows increased solubility in unexposed regions.

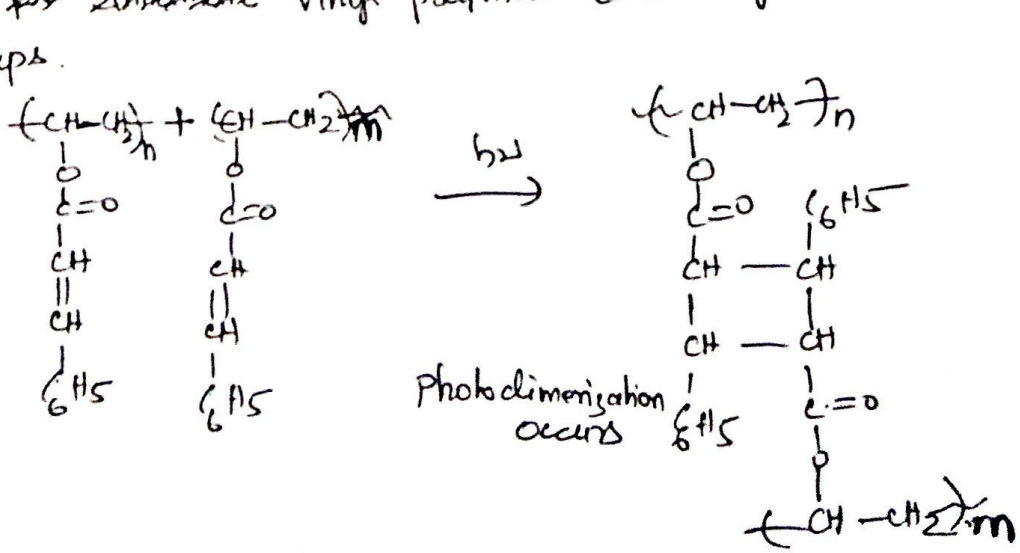
Eg 1: Epoxy resins:-





crosslinking occurs between epoxy groups of neighbouring chains.

Eg. 2. ~~poly~~ cinnamate vinyl polymers containing cinnamate groups.



Photodimerization occurs

Comparison between positive and negative photoresists

→ Positive photoresist is preferred for image sizes in the 2 to 5 μm or lower range because they have higher resolution capability than negative resists.

→ Negative resists are more sensitive to O_2 in atmosphere. thinning of the films take place.

→ Positive resists are more expensive than negative.

→ the difference in solubility ~~of the resist material~~ between the exposed and unexposed regions of the resist material in the developer is large, in the case of negative photoresist. ∴ the dimensions of images formed is stable even after developing step.

But the difference in solubility between the exposed and exposed regions is less in the case of Positive photoresists. ∴ carefully prepared developer solutions are required or dissolution inhibitors are required.

→ Generally, the removal of positive potoresist in unexposed region is easier and takes place in chemicals that are more ecofriendly.