Introduction to Photolithography

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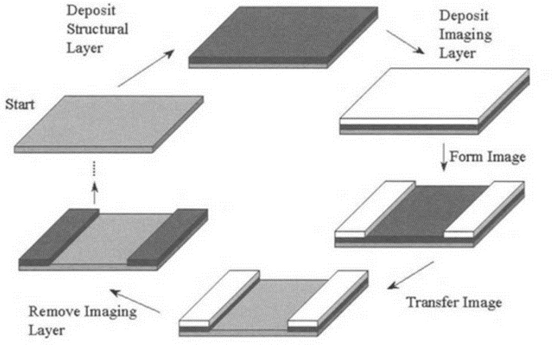
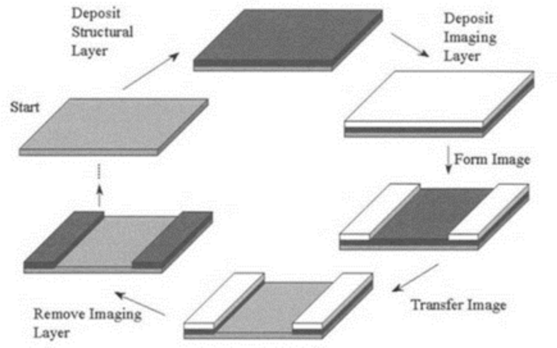


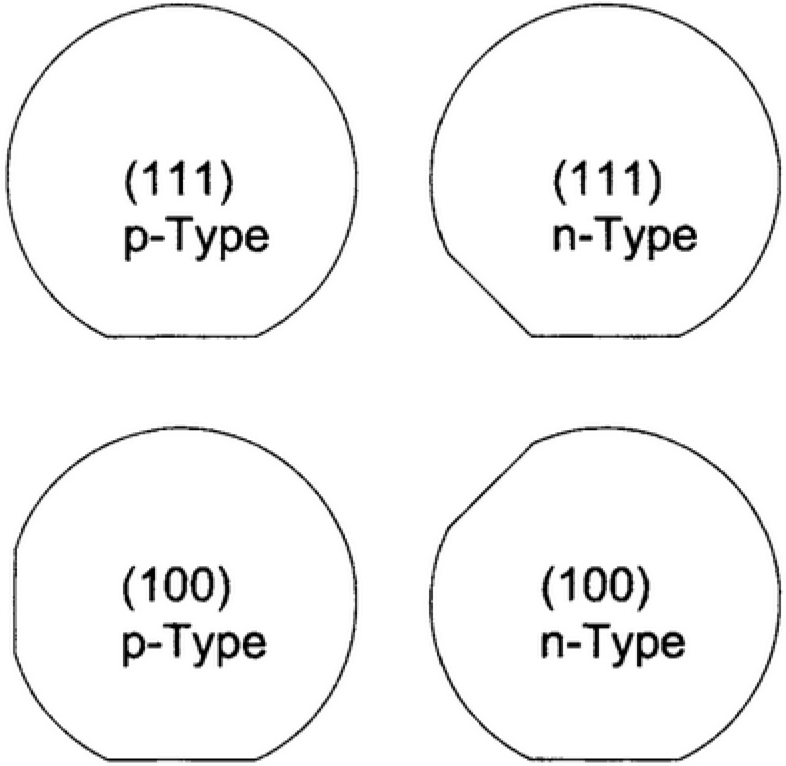
Photolithography



- The word lithography comes from the Greek *lithos*, meaning stones, and *graphia*, meaning to write. It is a printing method that uses light in a special way.
- It means quite literally writing on stones. In the case of semiconductor lithography (also called photolithography) our stones are silicon wafers and our patterns are written with a light sensitive polymer called a photoresist.
- To build the complex structures that make up a transistor and the many wires that connect the millions of transistors in a circuit, lithography and etch pattern transfer steps are repeated at least 10 times, but more typically are done 20 to 30 times to make circuit stack that is three dimensional.
- Each pattern being printed on the wafer is aligned to the previously formed patterns and layer by layer the conductors, insulators, and selectively doped regions are built up to form the final device.

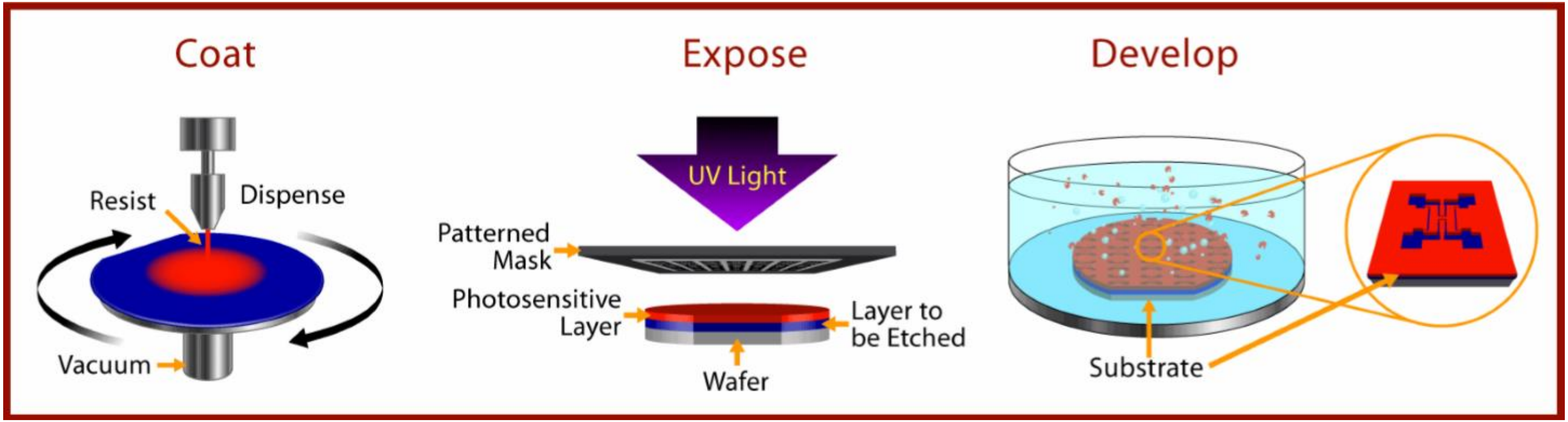
Silicon Wafers as Substrates

Wafer types and flat orientation that tells us the crystal structure of silicon in it



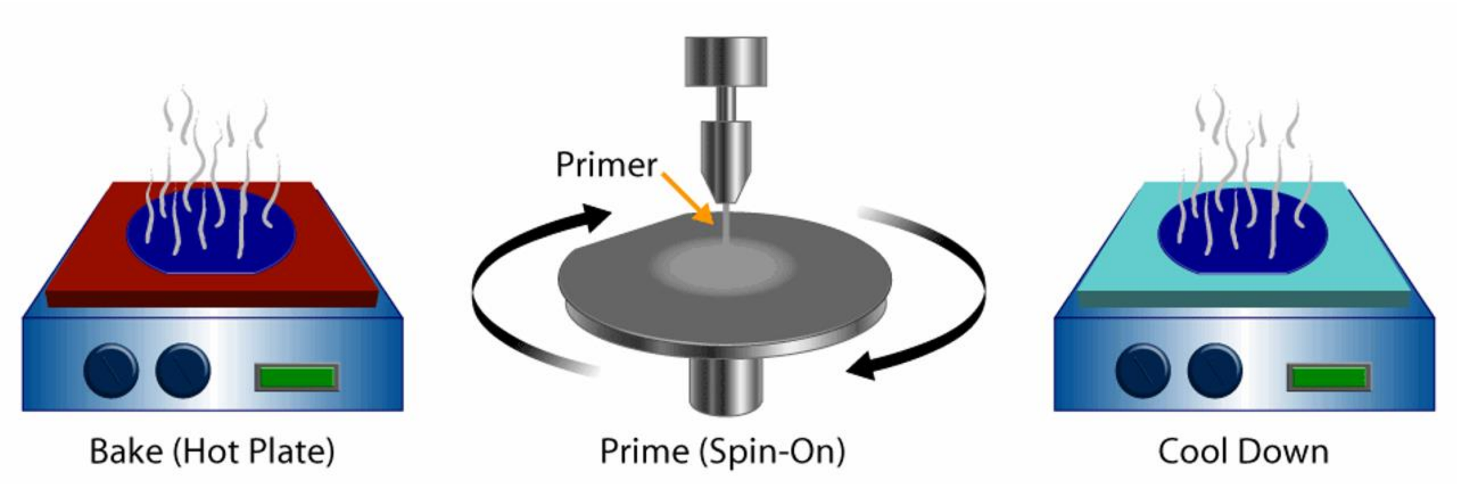
Photolithography is the core of all semiconductor and photonic fabrication processes since this step defines the geometry of the structures used in a micro-device.

Basic Photolithography Steps



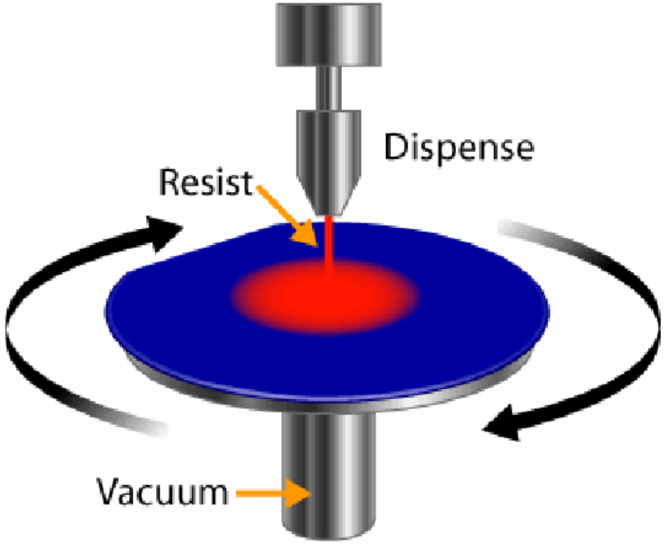
- Surface conditioning: prebake substrate to remove contaminants and/or apply adhesion promoter
- Spincoat photoresist (light sensitive polymer) on the substrate
- Softbake photoresist coated substrate to evaporate the solvent and help the film to set
- Cover the coated film with a patterned mask and expose it to UV light of appropriate frequency
- Develop exposed substrate that removes the uncrosslinked polymer to reveal the pattern

Surface Conditioning



- Surface conditioning prepares the silicon wafer or your substrate of choice (say glass) to accept the photoresist by providing a clean surface. This may involve:
  - Cleaning the surface with a solvent to remove dust, dirt and adhered contamination and even absorbed moisture
  - Heating/Baking the substrate to a high temperature removes moisture and organic contamination from the surface
  - Coating the substrate or wafer with an adhesion promoter or primer such as Hemxamethyldisilazane (HMDS) creates a hydrophobic surface
  - The substrate is then cooled to room temperature and is ready for spin coating

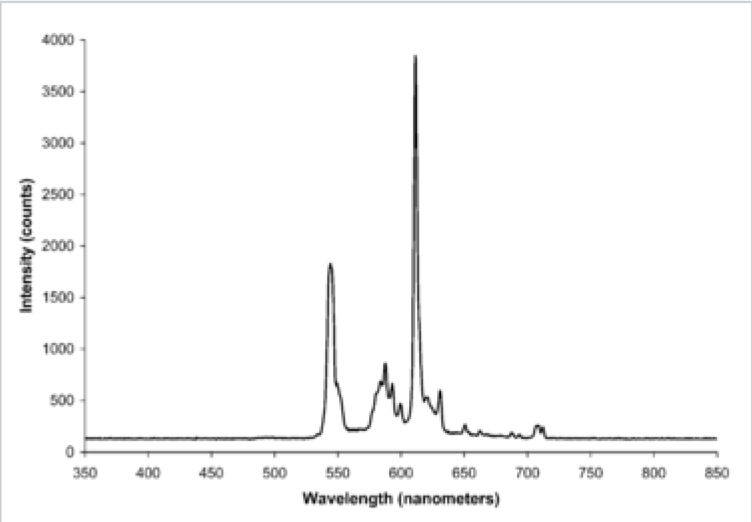
Spin Coating



- The wafer is mounted on a vacuum chuck where it is securely held down by vacuum
- Photoresist is dispensed with usually a dropper in the center of the sample
- The chuck is turned on and rotates the sample, allowing the centrifugal forces to thin the photoresist from the center towards the edge to form a film of desired thickness and covers the entire substrate with it. Excess resist simply spins off the substrate into the coater housing. Faster the chuck spins, thinner is the film of resist.
- The resist is further dried by giving the coated substrate an additional spin

Soft-bake or Pre-bake

- Primer coated sample is baked to remove any residual solvent from the sample. This step is to be done in the “dark” as the resist is sensitive to light, particularly ultra-violet light.
- Cleanrooms are fitted with lights that are covered with a film to filter out the UV light. This is why the light inside a cleanroom appears yellow.
- After the soft-bake the sample is cooled down to room temperature



The filtered fluorescent lighting, yellow LED or low-pressure sodium lighting in photolithography cleanrooms contains no ultraviolet or blue light in order to avoid exposing photoresists. The spectrum of light emitted by such fixtures gives virtually all such spaces a bright yellow color.

Mask and Alignment

- The mask for each step in the fabrication process is a pattern that is specially designed so the real estate on a given wafer can be used to produce maximum number of parts.
- Masks from one layer to the next are aligned accurately to ensure that we get a good yield at the end of the process.
- Aligning is the most critical step in the entire microsystem fabrication process
- Alignment accuracy of the mask on the substrate needs to be better than 1μm for each component on the wafer!
- A complete circuit is built by stacking several layers one over the other so each layer MUST be aligned properly and be within the specifications for layers above and below it for the device to work.

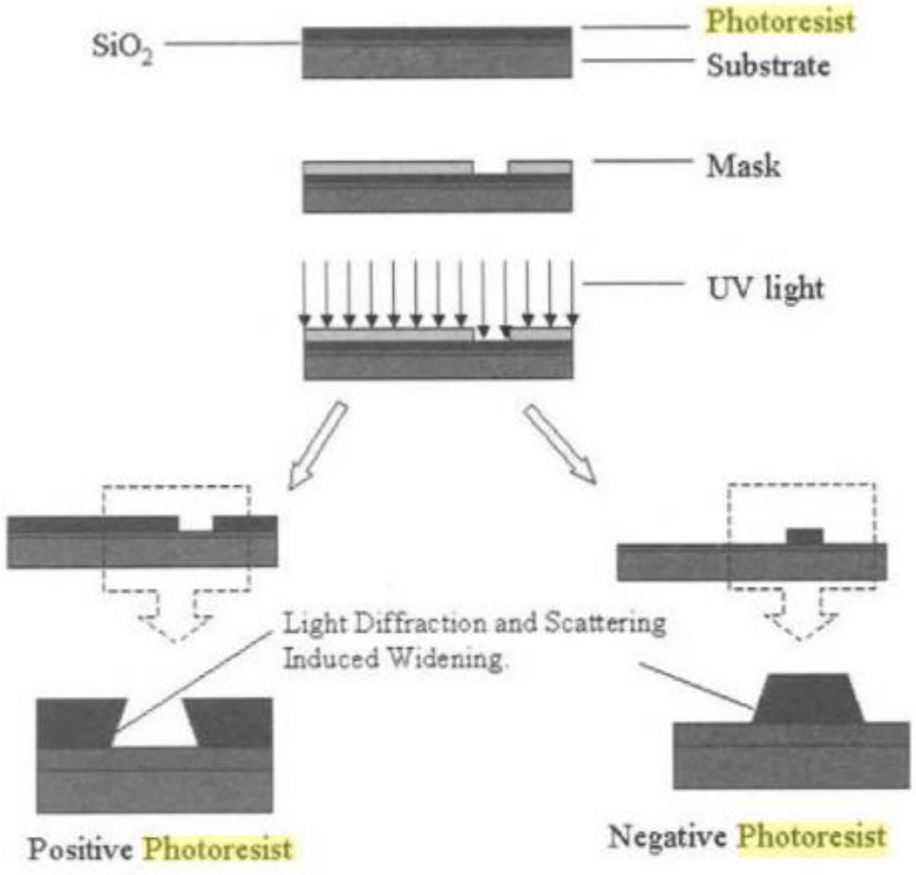
Photoresist or Resist:

There are two types of photoresists: positive and negative

In a positive photoresist the mask pattern and pattern on sample looks the same- in other words, the exposed areas become more soluble on exposure to UV light and are removed in the developing step.

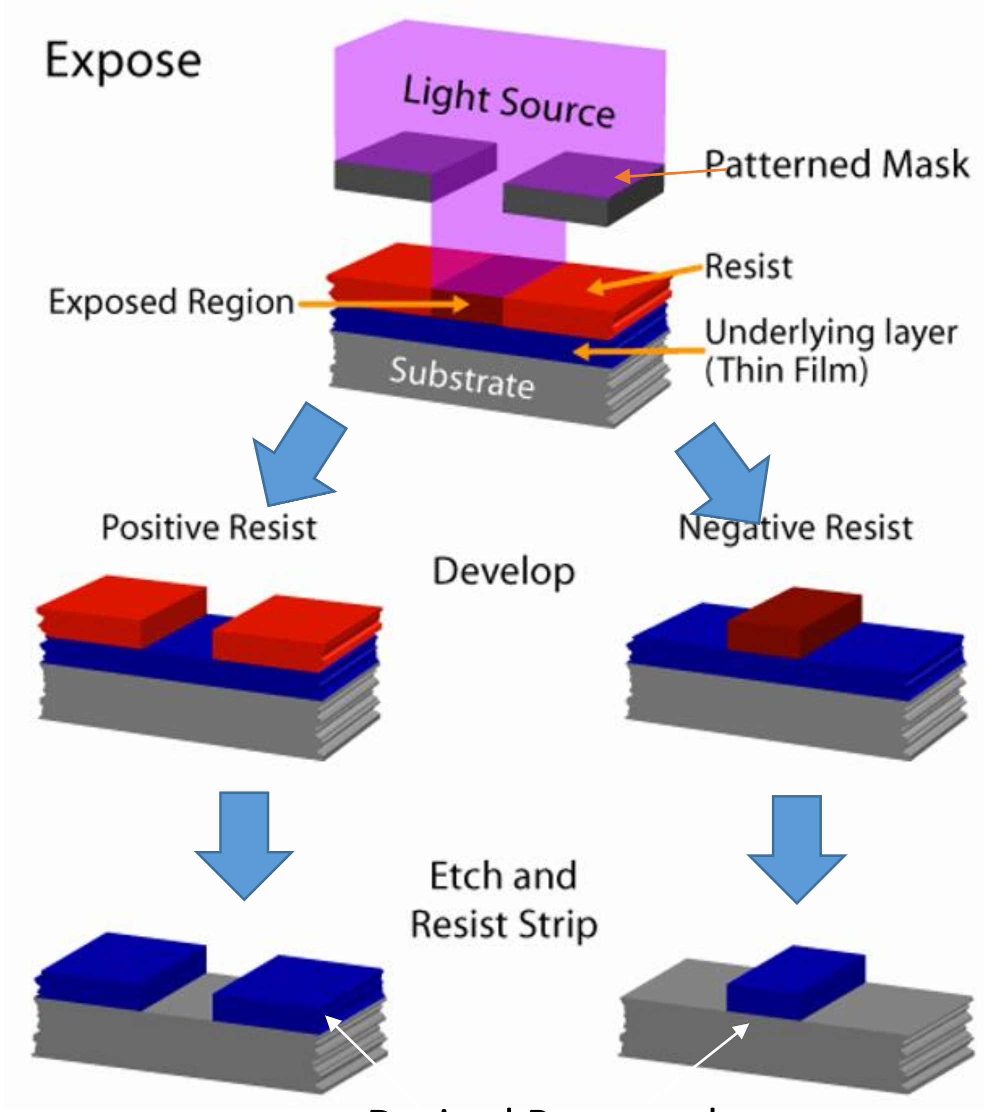
For a negative photoresist, the mask is a negative of the desired pattern on the substrate, so the exposed areas become crosslinked (harder) on exposure to UV light, while areas under the mask remain uncrosslinked. On developing this substrate the desired pattern emerges.

The either case, the resist thickness determines the resolution that can be achieved in the pattern.

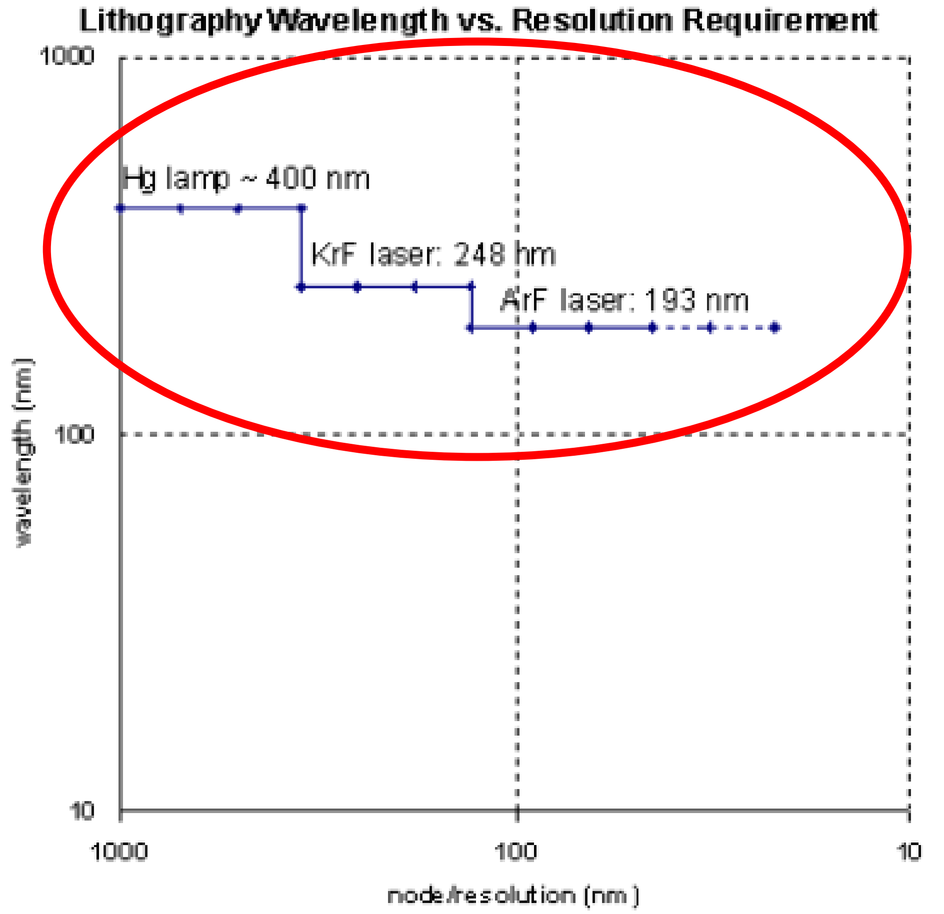


Exposure to UV Light

- A photoresist is a mixture of organic compounds in solvent
- These compounds are sensitive to UV light and react on exposure
- Typical wavelength: 254 nm
- Dose: depends on the chemistry of resist typically 130-170 mJ/cm^2
- Only those areas not protected by the mask undergo a chemical reaction.



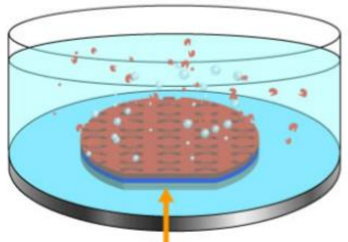
Desired Patterned Metal



One of the evolutionary paths of lithography has been the use of shorter wavelengths. It is worth noting that the same light source may be used for several technology generations.

In lithography shorter wavelengths lead to higher resolution

Developing Pattern



- The unreacted portions of photoresist are dissolved by a chemical developer
- With a positive resist, the exposed resist is dissolved while the unexposed resist remains on the wafer
- With a negative resist the unexposed resist dissolves leaving the exposed resist behind on the wafer.

Hard-bake or Post-bake (110-125°C)

- Hard-bake temperatures are often times higher than soft-bake temperatures and exposing the sample to this temperature removes the left over solvent and further hardens the photoresist and makes it resistant to chemical attack in subsequent steps.
- The wafer is then cooled down to room temperature.
- You will notice that the resist left behind on the wafer becomes an integral part of the wafer- in fact it becomes an isolation layer between say two metallic layers in the structure.

Final Stages:
Inspect, cut, bonded and packaged

- During inspection, alignment of the pattern at each step should be examined,
- Ensure that line width or critical dimension (CD) of the pattern are in focus and have the correct shape and size
- Defects: such as unintended inclusion of dust or dirt that would negatively impact the working of the device are marked on the wafer
- The successful parts are dissected, wire bonded and packaged as necessary for used in electronic circuits

Thin Film Deposition or Formation

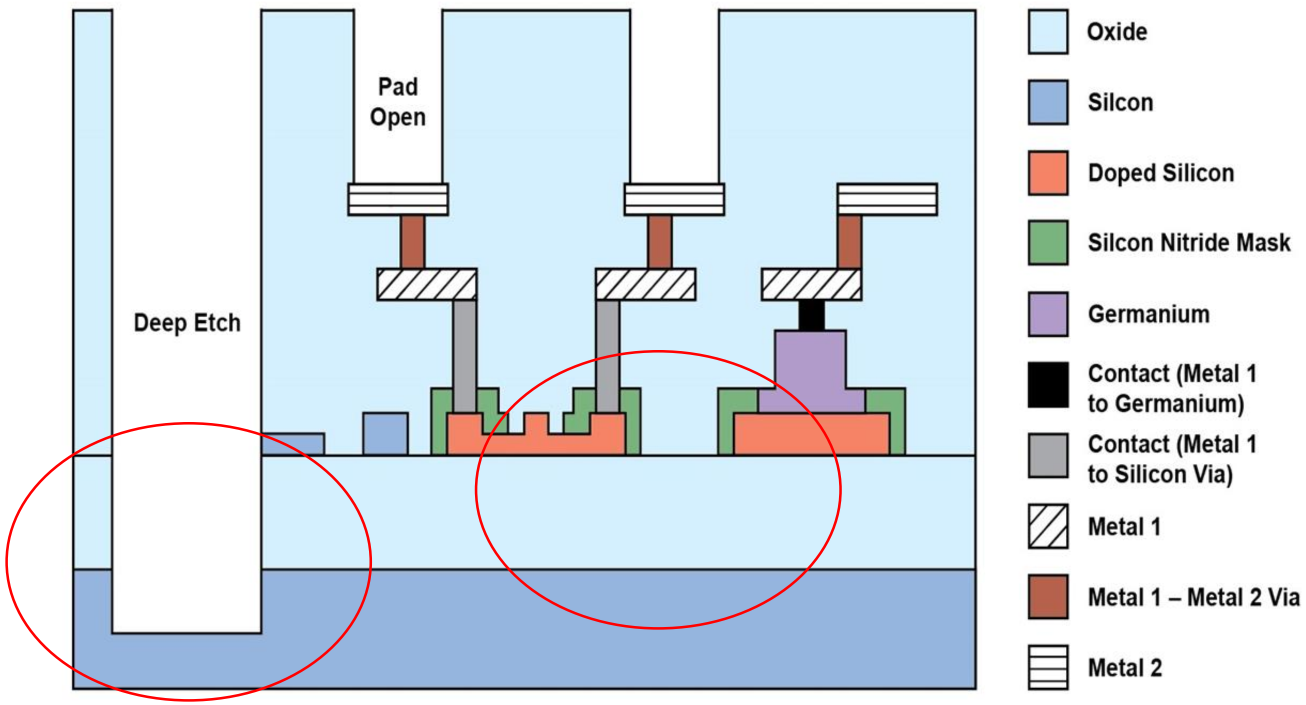
The photolithographic step is almost always preceded by a deposition step, which lays down the layer to be patterned. There are many deposition techniques currently in use in the fabrication of MEMS devices. The main ones used for the deposition of films less than 2-3 μm thick are physical vapor deposition (PVD) and chemical vapor deposition (CVD). Techniques producing thicker layers (above 4-5 μm) are electrodeposition (electroplating), polymer casting, spray coating, or high-pressure oxidation (HIPOX) of silicon.

3.3 Thermal Oxidation of Silicon

Thermally grown SiO_2 layers are the most important insulator in semiconductor devices. They serve as the gate insulator in CMOS transistors, dielectric in capacitive elements, as well as a masking material for a variety of process steps such as doping and etching. In micro electro-mechanical systems, the silicon dioxide (oxide) serves similar roles. There are many reasons behind the popularity of this dielectric in semiconductor device fabrication, the most important of which is its good electrical properties, ease of film growth, and its superior masking properties. The interested reader is referred to a monograph by Nicollian and Brews (1982) for an extensive discussion on the electrical properties of silicon dioxide and a variety of methods for its characterization.

The silicon dioxide is most commonly deposited via thermal oxidation in high-temperature quartz tubes under the supply of oxygen, steam, and possibly an inert carrier gas such as nitrogen or argon. Typical oxidation temperatures range from 850 °C to about 1272 °C. Figure 8 shows a cross section of the silicon wafer with a thin silicon dioxide film growing on its surface. As illustrated in the figure, the oxidation takes place at the interface between the single-crystal silicon surface and the already grown film,

Thin Film Deposition



- Typically a deposition or oxide formation step precedes a photolithographic step in a manufacturing process for device fabrication
- 2-3 μm thick films are coated using Physical Vapor Deposition (PVD) or by Chemical Vapor Deposition (CVD)
- 4-5 μm thick films are deposited using processes like electrodeposition (electroplating), polymer casting spray coating or high pressure oxidation of silicon, where oxidation temperatures are typically 850 °C to 1272 °C.

*C. Sorace-Agaskar, MIT LL Silicon Photonics Process Design Kit (PDK), 2015

References Used:

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