Physics of Nano Technology

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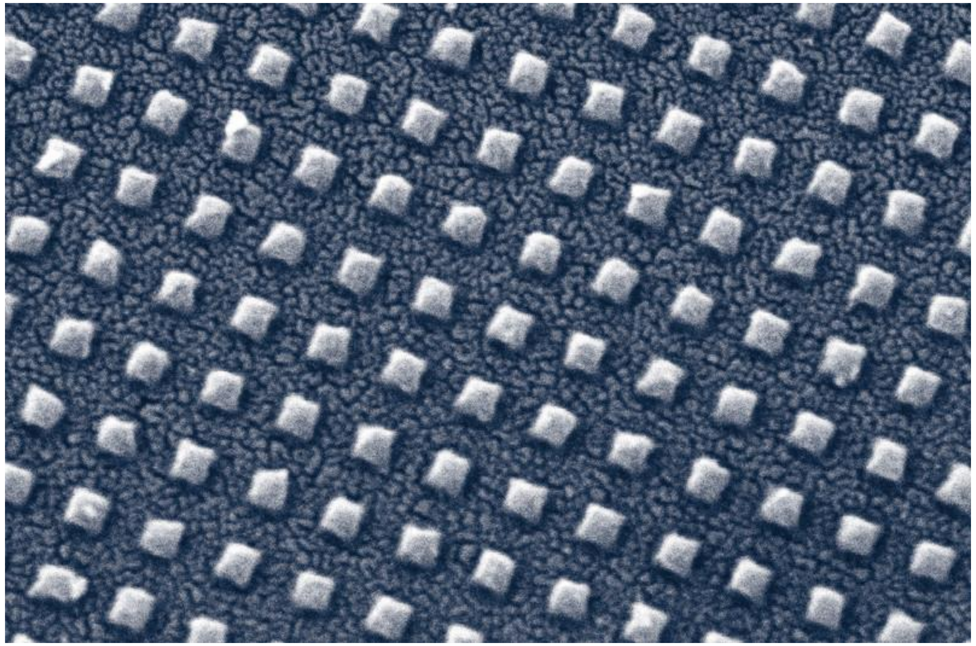
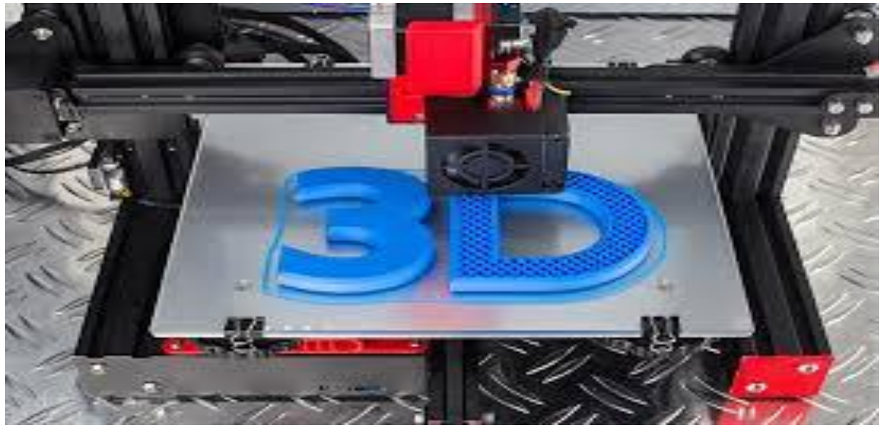
Nanolithography

- **Nano Lithography is process of Printing/writing Nanoscale structurs.**
- **Nanolithography** is a growing field of techniques within nanotechnology dealing with the engineering (etching, writing, printing) of nanometer-scale structures.
- From Greek, the word can be broken up into three parts: "nano" meaning dwarf, "lith" meaning stone, and "graphy" meaning to write, or "tiny writing onto stone." Today, the word has evolved to cover the design of structures in the range of 10^{-9} to 10^{-6} meters, or structures in the nanometer range. Essentially, field is a derivative of lithography, only covering significantly smaller structures.
- All nanolithographic techniques can be separated into two categories: those that etch away molecules leaving behind the desired structure, and those that directly write the desired structure to a surface (similar to the way a 3D printer creates a structure).

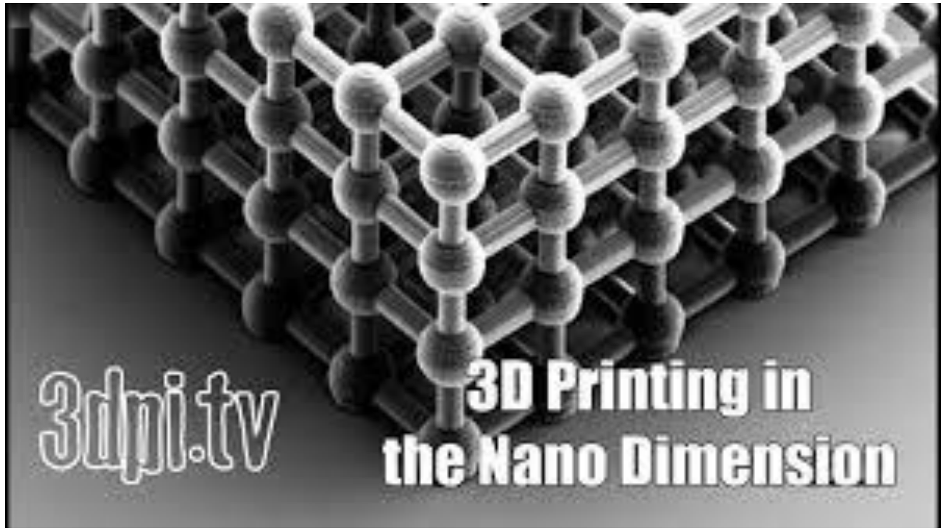
Nano Patterns



Printing by Etching



3d Printer at large scale



Nano 3d Printing

History of Nanolithography

- The field of nanolithography was born out of the need to increase the number of transistors in an integrated circuit in order to maintain Moore's Law.
- lithographic techniques have been around since the late 18th century, none were applied to nanoscale structures until the mid-1950s.
- With evolution of the semiconductor industry, demand for techniques capable of producing micro- and nano-scale structures skyrocketed. Photolithography was applied to these structures for the first time in 1958 beginning the age of nanolithography. Since then, photolithography has become the most commercially successful technique, capable of producing sub-100 nm patterns.There are several techniques associated with the field, each designed to serve its many uses in the medical and semiconductor industries.

Important techniques

- 1.1Optical lithography
- 1.2Electron-beam lithography
- 1.3Scanning probe lithography
- 1.4Nanoimprint lithography
- 1.5 Focused ion beam lithography

Optical lithography

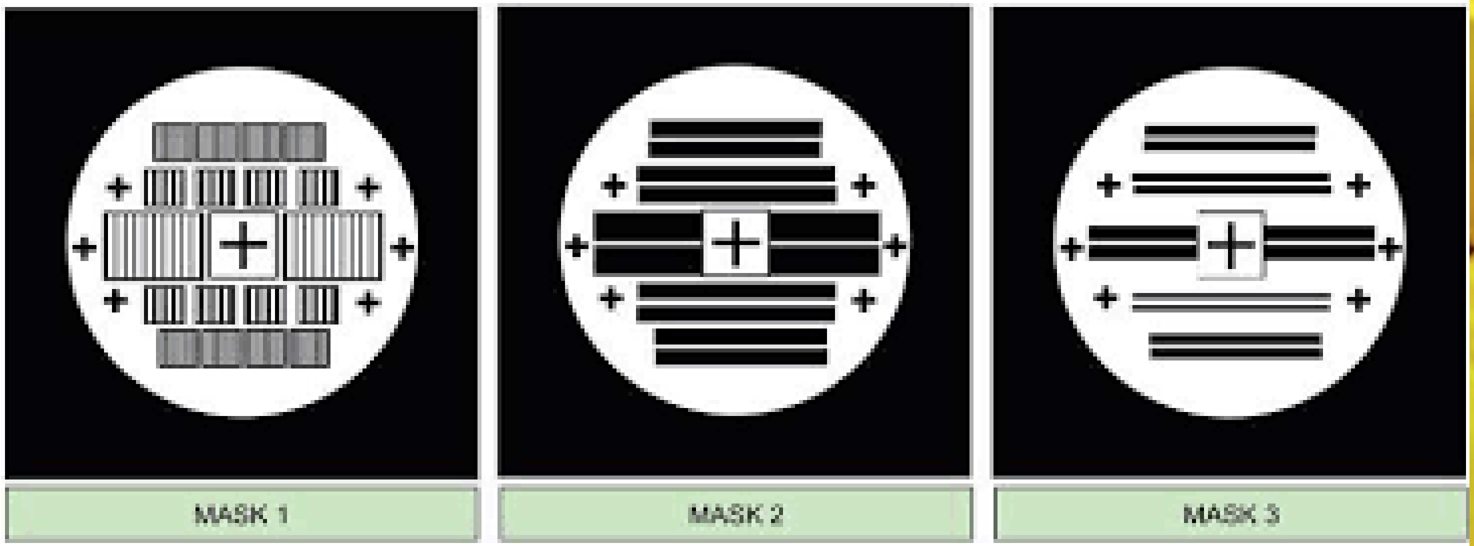
- **Photolithography**, also called **optical lithography** or **UV lithography**, is a process used in microfabrication to pattern parts on a thin film or the bulk of a substrate (also called a *wafer*). It uses light to transfer a geometric pattern from a photomask (also called an *optical mask*) to a photosensitive (that is, light-sensitive) chemical photoresist on the substrate. A series of chemical treatments then either etches the exposure pattern into the material or enables deposition of a new material in the desired pattern upon the material underneath the photoresist. In complex integrated circuits, a CMOS wafer may go through the photolithographic cycle as many as 50 times.

Optical lithography

- Photolithography shares some fundamental principles with photography in that the pattern in the photoresist etching is created by exposing it to light, either directly (without using a mask) or with a projected image using a photomask. This procedure is comparable to a high precision version of the method used to make printed circuit boards. Subsequent stages in the process have more in common with etching than with lithographic printing. This method can create extremely small patterns, down to a few tens of nanometers in size. It provides precise control of the shape and size of the objects it creates and can create patterns over an entire surface cost-effectively. Its main disadvantages are that it requires a flat substrate to start with, it is not very effective at creating shapes that are not flat, and it can require extremely clean operating conditions. Photolithography is the standard method of printed circuit board (PCB) and microprocessor fabrication.

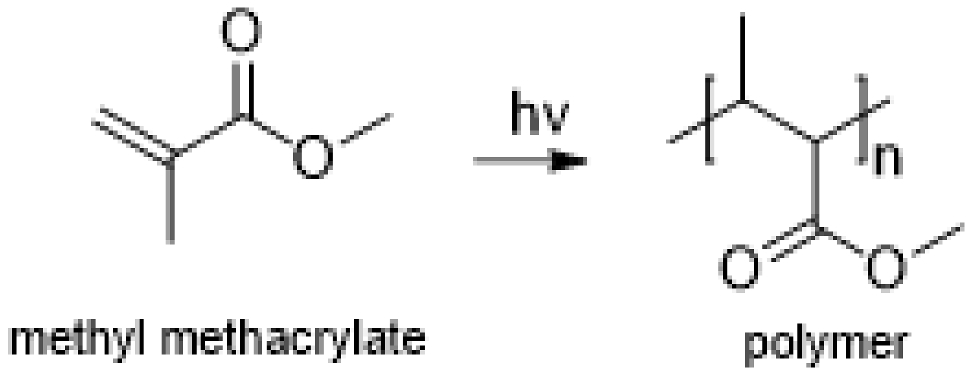
What is Photolithography Mask?

A **photolithography mask** is an opaque plate or film with transparent areas that allow light to shine through in a defined pattern. It is commonly **used in photolithography** processes, but is also **used** in many other applications by a wide range of industries and technologies



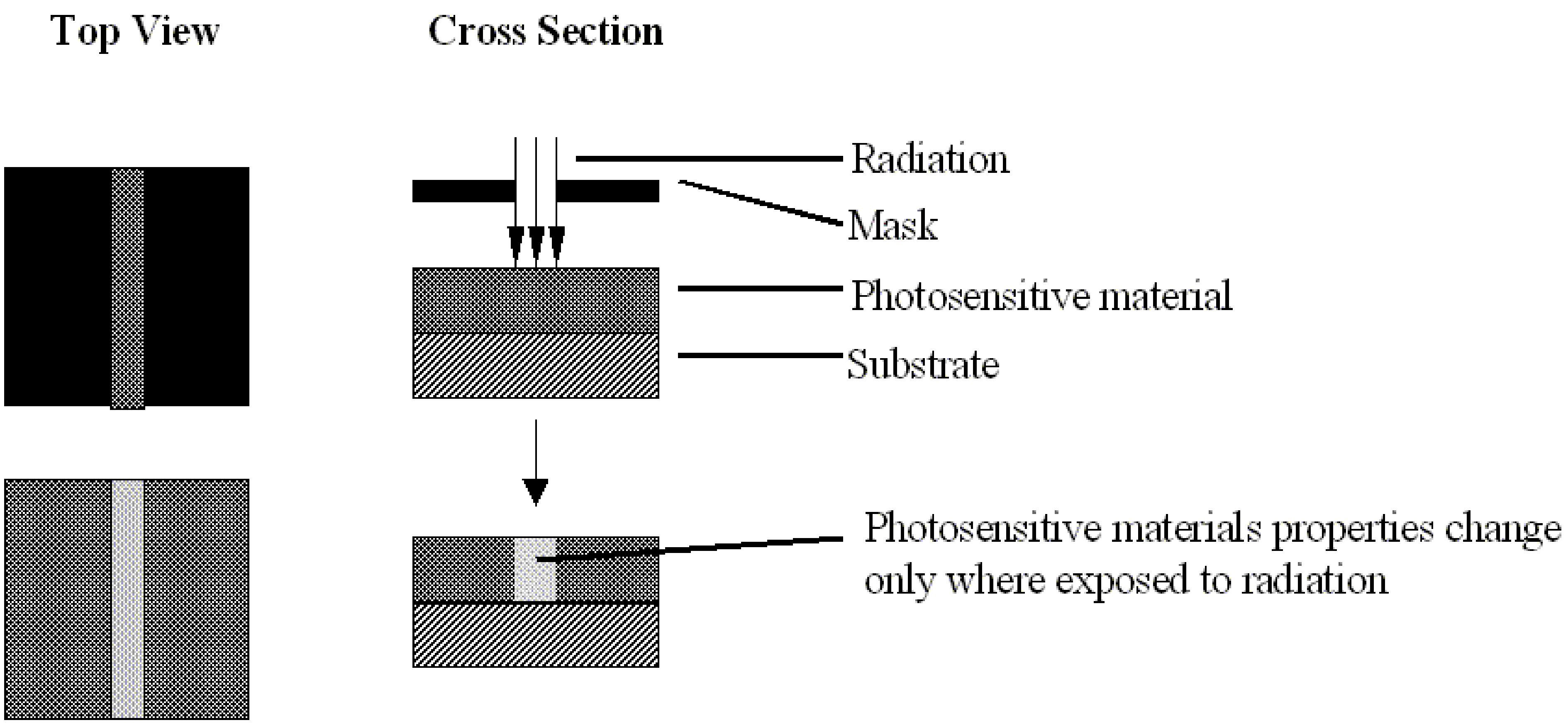
What is Photoresist?

- A **photoresist** (also known simply as a resist) is a light-sensitive material **used** in several processes, such as **photolithography** and photoengraving, to form a patterned coating on a surface.



Photopolymerization of methyl methacrylate monomers under UV that resulting into polymer

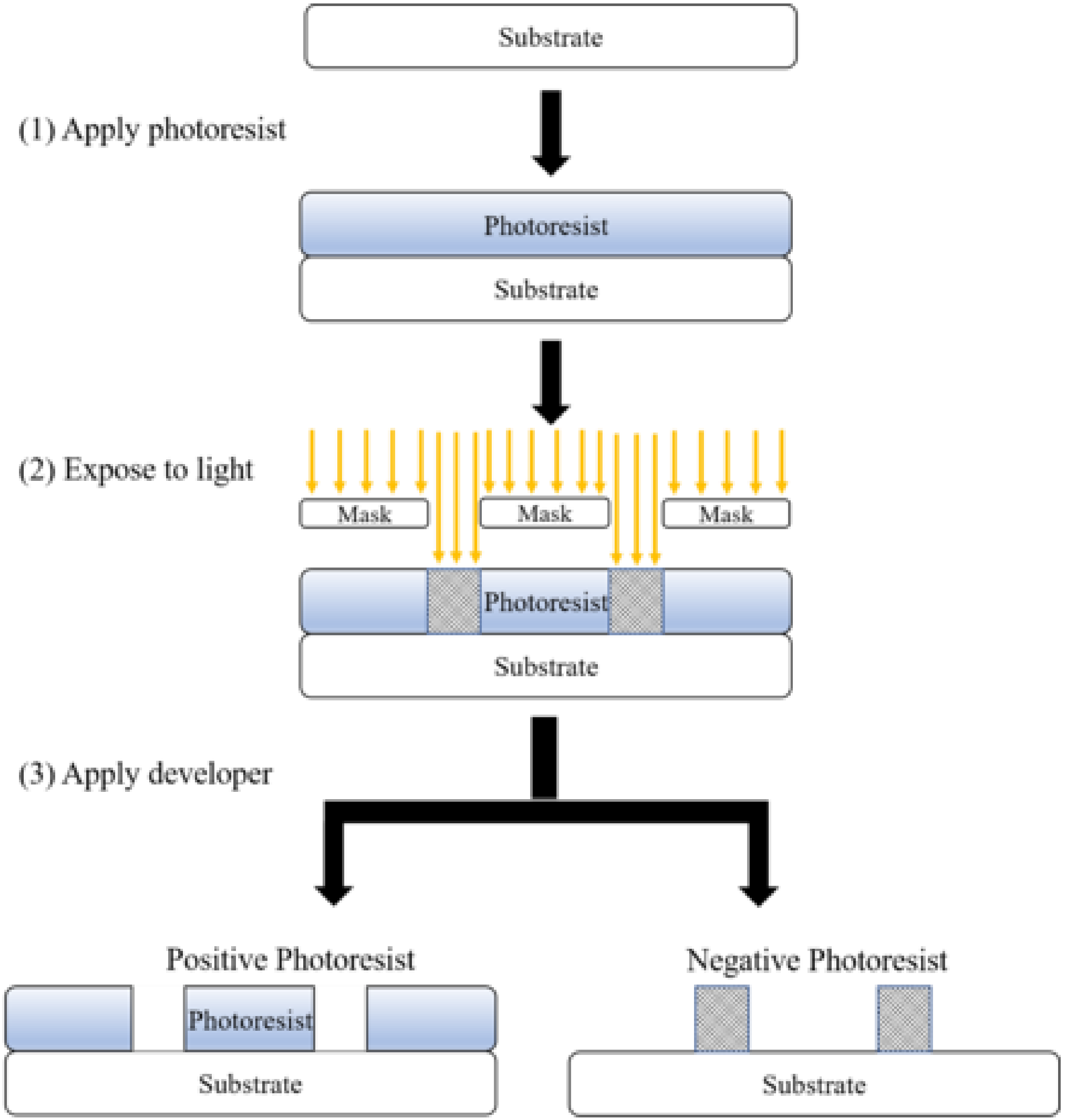
What is Photoresist?



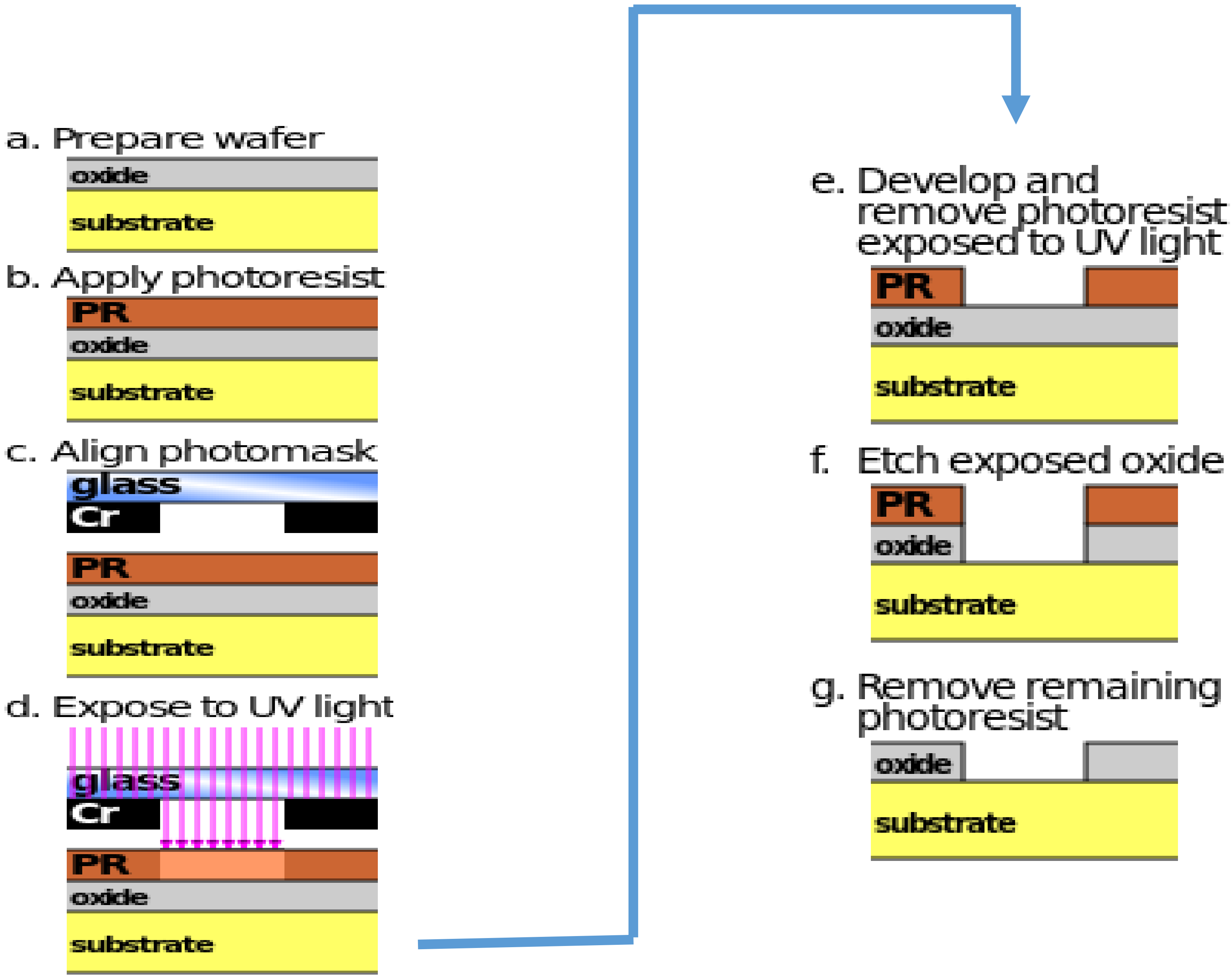
What is Photoresist?

Two Types

- **Negative Photo Resist**
- **Positive Photo Resist**



Basic procedure



Basic procedure

- **Cleaning**

If organic or inorganic contaminations are present on the wafer surface, they are usually removed by wet chemical treatment, e.g. the RCA clean procedure based on solutions containing hydrogen peroxide. Other solutions made with trichloroethylene, acetone or methanol can also be used to clean.

- **Preparation**

The wafer is initially heated to a temperature sufficient to drive off any moisture that may be present on the wafer surface; 150 °C for ten minutes is sufficient. Wafers that have been in storage must be chemically cleaned to remove contamination.

Basic procedure

- A liquid or gaseous "adhesion promoter", such as Bis(trimethylsilyl)amine ("hexamethyldisilazane", HMDS), is applied to promote adhesion of the photoresist to the wafer. The surface layer of silicon dioxide on the wafer reacts with HMDS to form tri-methylated silicon-dioxide, a highly water repellent layer not unlike the layer of wax on a car's paint. This water repellent layer prevents the aqueous developer from penetrating between the photoresist layer and the wafer's surface, thus preventing so-called lifting of small photoresist structures in the (developing) pattern.

Basic procedure

- Prebake

In order to ensure the development of the image, it is best covered and placed over a hot plate and let it dry while stabilizing the temperature at 120 °C.

Basic procedure

- **Exposure and developing**

After prebaking, the photoresist is exposed to a pattern of intense light. The exposure to light causes a chemical change that allows some of the photoresist to be removed by a special solution, called "developer" by analogy with photographic developer. Positive photoresist, the most common type, becomes soluble in the developer when exposed; with negative photoresist, unexposed regions are soluble in the developer.

Basic procedure

- A post-exposure bake (PEB) is performed before developing, typically to help reduce standing wave phenomena caused by the destructive and constructive interference patterns of the incident light. In deep ultraviolet lithography, chemically amplified resist (CAR) chemistry is used. This process is much more sensitive to PEB time, temperature, and delay, as most of the "exposure" reaction (creating acid, making the polymer soluble in the basic developer) actually occurs in the PEB.[14]

Basic procedure

- The develop chemistry is delivered on a spinner, much like photoresist. Developers originally often contained sodium hydroxide (NaOH). However, sodium is considered an extremely undesirable contaminant in MOSFET fabrication because it degrades the insulating properties of gate oxides (specifically, sodium ions can migrate in and out of the gate, changing the threshold voltage of the transistor and making it harder or easier to turn the transistor on over time). Metal-ion-free developers such as tetramethylammonium hydroxide (TMAH) are now used.

Basic procedure

- The resulting wafer is then "hard-baked" if a non-chemically amplified resist was used, typically at 120 to 180 °C[15] for 20 to 30 minutes. The hard bake solidifies the remaining photoresist, to make a more durable protecting layer in future ion implantation, wet chemical etching, or plasma etching.
- From preparation until this step, the photolithography procedure has been carried out by two machines: the photolithography stepper or scanner, and the coater/developer. The two machines are usually installed side by side.

Basic procedure

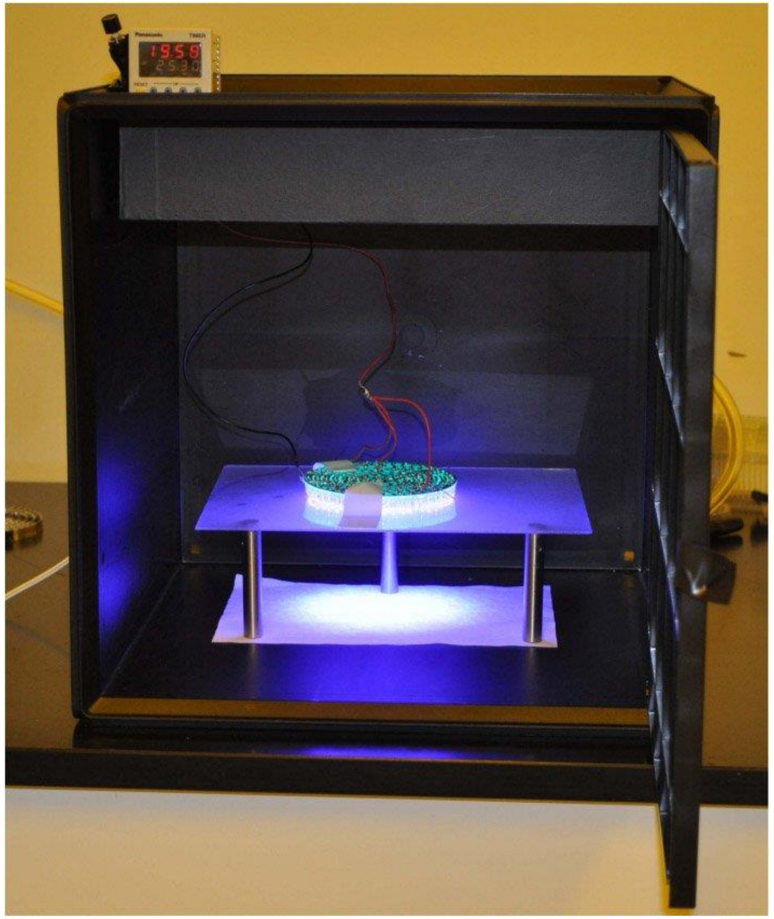
- **Etching**

In etching, a liquid ("wet") or plasma ("dry") chemical agent removes the uppermost layer of the substrate in the areas that are not protected by photoresist. In semiconductor fabrication, dry etching techniques are generally used, as they can be made anisotropic, in order to avoid significant undercutting of the photoresist pattern. This is essential when the width of the features to be defined is similar to or less than the thickness of the material being etched (i.e. when the aspect ratio approaches unity). Wet etch processes are generally isotropic in nature, which is often indispensable for microelectromechanical systems, where suspended structures must be "released" from the underlying layer.

Basic procedure

- The development of low-defectivity anisotropic dry-etch process has enabled the ever-smaller features defined photolithographically in the resist to be transferred to the substrate material

Basic procedure



Lithographic Mashine

Basic procedure

- **Photoresist removal**

After a photoresist is no longer needed, it must be removed from the substrate. This usually requires a liquid "resist stripper", which chemically alters the resist so that it no longer adheres to the substrate. Alternatively, photoresist may be removed by a plasma containing oxygen, which oxidizes it. This process is called ashing, and resembles dry etching. Use of 1-Methyl-2-pyrrolidone (NMP) solvent for photoresist is another method used to remove an image. When the resist has been dissolved, the solvent can be removed by heating to 80 °C without leaving any residue.[16]

Basic procedure

- **Exposure ("printing") systems**

Basic procedure

- The wafer track portion of an aligner that uses 365 nm ultraviolet light
- Exposure systems typically produce an image on the wafer using a photomask. The photomask blocks light in some areas and lets it pass in others. (Maskless lithography projects a precise beam directly onto the wafer without using a mask, but it is not widely used in commercial processes.) Exposure systems may be classified by the optics that transfer the image from the mask to the wafer.
- Photolithography produces better thin film transistor structures than printed electronics, due to smoother printed layers, less wavy patterns, and more accurate drain-source electrode registration.[17]

Basic procedure

Contact and proximity

- A contact printer, the simplest exposure system, puts a photomask in direct contact with the wafer and exposes it to a uniform light. A proximity printer puts a small gap between the photomask and wafer. In both cases, the mask covers the entire wafer, and simultaneously patterns every die.
- Contact printing is liable to damage both the mask and the wafer, and this was the primary reason it was abandoned for high volume production. Both contact and proximity lithography require the light intensity to be uniform across an entire wafer, and the mask to align precisely to features already on the wafer. As modern processes use increasingly large wafers, these conditions become increasingly difficult.

Basic procedure

- Research and prototyping processes often use contact or proximity lithography, because it uses inexpensive hardware and can achieve high optical resolution. The resolution in proximity lithography is approximately the square root of the product of the wavelength and the gap distance. Hence, except for projection lithography (see below), contact printing offers the best resolution, because its gap distance is approximately zero (neglecting the thickness of the photoresist itself). In addition, nanoimprint lithography may revive interest in this familiar technique, especially since the cost of ownership is expected to be low; however, the shortcomings of contact printing discussed above remain as challenges.

Basic procedure

- **Projection**

Very-large-scale integration (VLSI) lithography uses projection systems. Unlike contact or proximity masks, which cover an entire wafer, projection masks (known as "reticles") show only one die or an array of dies (known as a "field"). Projection exposure systems (steppers or scanners) project the mask onto the wafer many times to create the complete pattern. The difference between steppers and scanners is that, during exposure, a scanner moves the photomask and the wafer simultaneously, while a stepper only moves the wafer. A mask aligner does not move the photomask nor the wafer during exposure. Immersion lithography scanners use a layer of Ultrapure water between the lens and the wafer to increase resolution. An alternative to photolithography is nanoimprint lithography.

❑ Contact Printing:

In contact printing wafer is brought into physical contact with photo mask. Because of the contact between the resist and mask, very high resolution is possible. The problem with contact printing is that fragments trapped between the resist and the mask, can damage the mask and cause defects in the pattern.

❑ Proximity Printing:

The proximity exposure method is similar to contact printing except that a small gap, 10 to 25 microns wide is maintained between the wafer and the mask. This gap minimizes (but may not eliminate) mask damage. Approximately 2 to 4 micron resolution is possible with proximity printing.

❑ Projection Printing:

Projection printing avoids mask damage entirely. An image of the patterns on the mask is projected onto the wafer, which is many centimetres away. To achieve high resolution, only a small portion of the mask is imaged it has about 1-micron resolution.

Electron Beam Lithography

- Electron Beam Lithography is a specialized technique for creating extremely fine patterns. It is derived from the scanning electron microscope. Electron beams can be focused to a few nanometres in diameter.
- The basic idea behind electron beam lithography is identical to optical lithography. The substrate is coated with a thin layer of resist, which is chemically changed under exposure to the electron beam, so that the exposed/non-exposed areas can be dissolved in a specific solvent.
- Electron beam lithography is the most power full tool for the fabrication of feathers as small as 3nm to 5 nm.

The EBL system is normally referred to as the column. An EBL column (Fig. 4) typically consists of following components;

✓ **Electron source:**

Electrons may be emitted from a conducting material either by heating or by applying an electricfield.

✓Stigmators:

A stigmator is a special type of lens used for the alignment of e-beam. Stigmators may be either electrostatic or magnetic and consist of four or more poles.

✓ **Electron Lenses:**

Electron lenses can be made only to converge, not diverge. Electrons can be focused either by electrostatic forces or magnetic forces.

✓ **Apertures:**

Apertures are small holes through which the beam passes on its way down the column. There are several types of apertures. A blanking aperture is used to turn the beam on and off. A beam limiting aperture has two effects: it sets the beam convergence angle through which electrons can pass through the system, controlling the effect of lens aberrations and thus resolution.

✓ **Blanking Plates:**

Blanking plates are use to modify the e-beam, these are simple electrostatic deflector. One or both of the plates are connected to a amplifier with a fast response time.

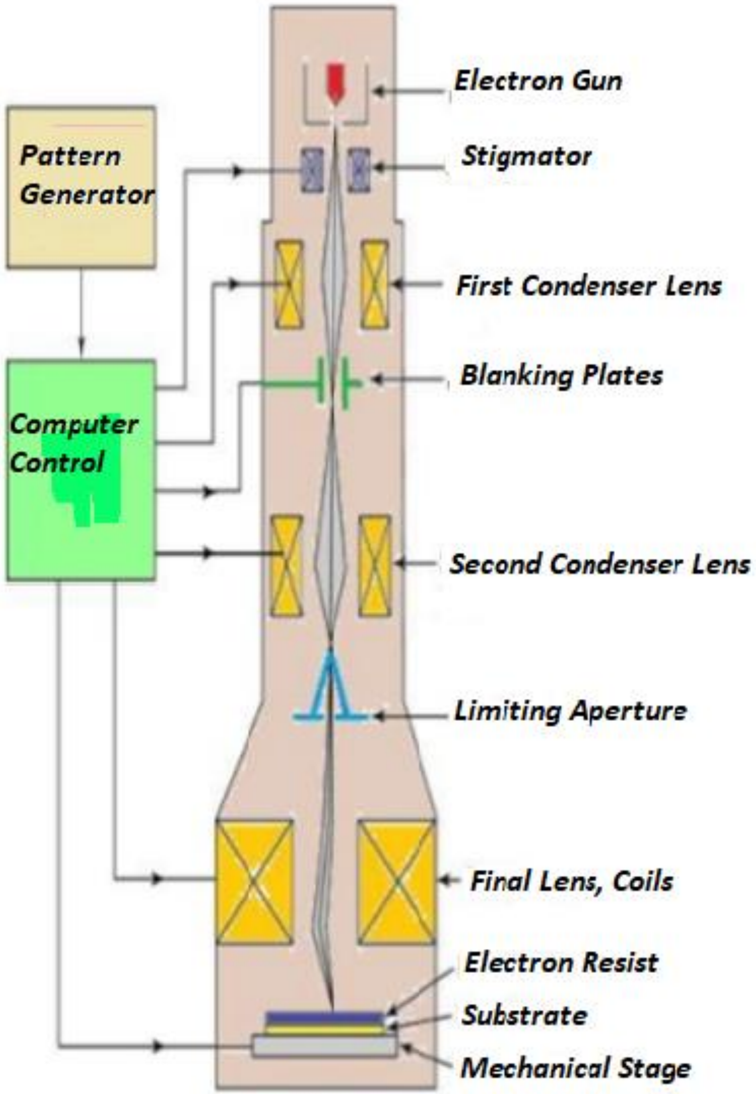


Fig.4

Advantages of EBL

- Print complex patterns directly on wafers
- Eliminates the diffraction problem
- High resolution up to 20 nm(photolithography ~50nm)
- Flexible technique

Disadvantages of EBL

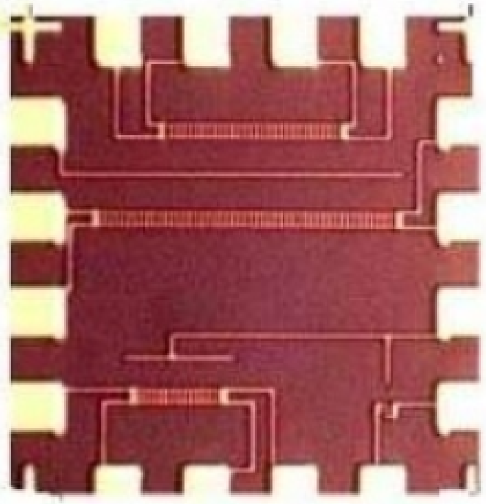
- Slower than optical lithography (approximately 5 wafers / hour at less than 0.1 μ resolution).
- Expensive and complicated
- Forward scattering
- Backward scattering
- Secondary electrons

Applications of EBL

Electron beam Lithography (EBL) is used primarily for two purposes

❖ Very high resolution lithography.

❖ Fabrication of masks.



Sample fabricated
by E-beam lithography

Nanoimprint Lithography (NIL)

Nano-imprint lithography (NIL) is a lithography technique that combines the speed of optical lithography with the resolution of EBL, we use NIL to make nanostructured substrates.

Special stamps contain the nanoscale designs to be fabricated on the substrate *fig: a)*.

- ✓ The stamps are pressed into a polymeric material *(resist)* that was previously deposited on the substrate *fig: b)*.
- ✓ When the stamp is filled with polymer, it is treated by UV light through the stamp, obtaining the stamps shape *fig: c)*.
- ✓ A residual layer of resist is left and can be removed *fig: d)*.

Fig: a)


Fig: b)

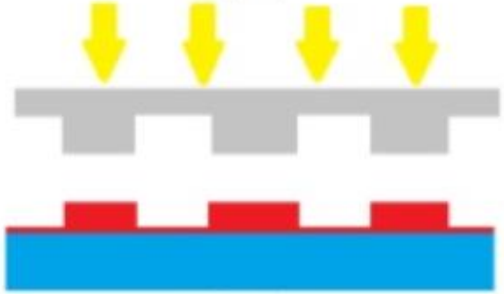


Fig: c)

✓A metal layer can be deposited on the sample as shown in *fig: e)*

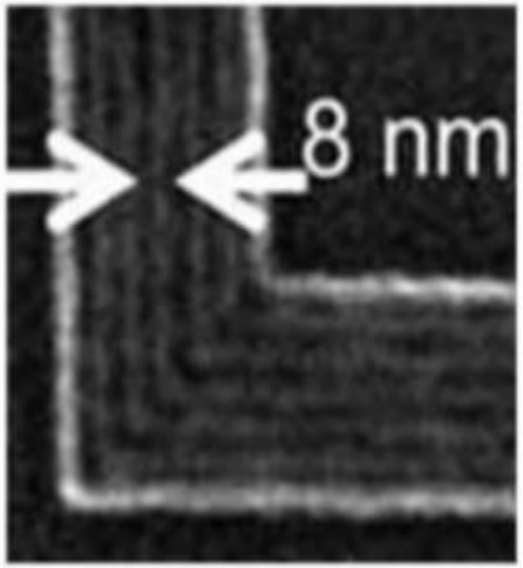
✓When the resist is removed, the nanoscale metal structures are left on the substrate *fig: f)*.

Fig: e)


Fig: f)

Applications

- ❑It can be used to make optical, photonic, electrical and biological devices.
- ❑Advances in mould manufacturing will have wide application of NIL in smaller devices.



Sample fabricated by nanoimprint lithography