Nanomanufacturing

Manufacturing at the nanoscale is known as nanomanufacturing. Nanomanufacturing involves scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems. It also includes research, development, and integration of top-down processes and increasingly complex bottom-up or self-assembly processes.

Top-down vs. bottom-up

Top-down methods:
1. Begin with a pattern generated on a larger scale, then reduced to nanoscale.
2. Top-down fabrication reduces large pieces of materials all the way down to the nanoscale, like someone carving a model airplane out of a block of wood. This approach requires larger amounts of materials and can lead to waste if excess material is discarded.
3. By nature, aren’t cheap and quick to manufacture.
4. Slow and not suitable for large scale production.

Bottom-up methods:
1. Start with atoms or molecules and build up to nanostructures.
2. Which can be time-consuming.
3. Fabrication is much less expensive
Lithography (Top-Down):

Lithography is a method of printing originally based on the principle. There are different methods of Lithography

1. **Photolithography**
2. **Electron beam lithography**
3. **Scanning probe lithography**
4. **X-ray lithography**
5. **Soft Lithography**
6. **Ion beam lithography**
7. **Others.**

At the moment, the most used top-down approach is **photolithography**.

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**Photolithography**

Also termed **optical lithography** or **UV lithography**, is a process used in **microfabrication** and **nanofabrication** to pattern parts of a thin film or the bulk of a substrate. Typically, features smaller than 10 **micrometers** are considered microlithography, and features smaller than 100 **nanometers** are considered nanolithography.

**Application**

**Photolithography** is one of these methods, often applied to semiconductors manufacturing of microchips. For example, in complex **integrated circuits**, and produce structures smaller than 100 nm. Photolithography is also commonly used for fabricating **Microelectromechanical systems** (MEMS) devices and **Nanoelectromechanical systems** (NEMS).
**How to make?**

Typically, an oxidized silicon (Si) wafer is coated with a 1µm thick photoresist layer. It uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical "photoresist". After exposure to ultraviolet, photoresist undergoes a photochemical reaction. Subsequently, when the wafer is rinsed in a developing solution, the exposed areas are removed. A series of chemical
treatments then either engraves the exposure pattern into, or enables deposition of a new material in the desired pattern upon, the material underneath the photo resist as shown in figure below

**Advantages**

1. Though the concept of photolithography is simple.
2. Large production.
3. Consume less Time.

**Its main disadvantages (drawbacks) are:**

1. The actual implementation is very complex and expensive.
2. It requires a flat substrate to start with, it is not very effective at creating shapes that are not flat,
3. It can require extremely clean operating conditions.
4. It requires optical mask.
5. Nanostructures significantly smaller than 100 nm are difficult to produce due to diffraction effects of light wave length.
6. Masks need to be perfectly aligned with the pattern on the wafer.
7. The density of defects needs to be carefully controlled.
8. Photolithographic tools are very costly, ranging in price from tens to hundreds of millions of dollars.
These techniques have been developed as alternatives to photolithography. In the case of electron beam lithography, the pattern is written in a polymer film with a beam of electrons. Since diffraction effects are largely reduced due to the wavelength of electrons, the resolution is greatly improved. However, the electron beam technique is very expensive and very slow. In the case of X-ray lithography, diffraction effects are also minimized due to the short wavelength of X-rays, but conventional lenses are not capable of focusing X-rays and the radiation damages most of the materials used for masks and lenses.

Here are two systems of electron-beam lithography:

1. **Scanning lithography**
2. **Projection lithography**.

In *scanning electron beam lithography* the resist is exposed (scanned) by a focused beam of electrons consistently moving in the plane of the pattern. The electron beam is controlled by a computer in accordance with a predefined program; therefore there is no need for templates or masks. However such sequential scanning of the image increases the exposure time.
In *projection electron beam lithography* a wide unfocused flow of electrons is used to obtain the entire image through one exposure. In this system, the optical mask with a given pattern is putted. As a result, the mask image is created on the entire area of the substrate through one exposure.

![Projection Electron Beam Lithography Diagram](image)

**X-ray lithography**, is a process used in electronic industry to selectively remove parts of a thin film. It uses X-rays to transfer a geometric pattern from a mask to a light-sensitive chemical *photoresist*, or simply "resist," on the substrate. A series of chemical treatments then engraves the produced pattern into the material underneath the photoresist.

- It is principle like photolithography but the difference is the wave length of x-ray (below 1 nm) shorter than UV wave length.

<table>
<thead>
<tr>
<th>The Electromagnetic Spectrum</th>
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<tbody>
<tr>
<td>1m</td>
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<tr>
<td>1m</td>
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<tr>
<td>radio waves</td>
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<tr>
<td>visible light: 0.4 to 0.7 um</td>
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<tr>
<td>long wavelength low frequency</td>
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The most recent lithography methods, which its steps:

(Printing, stamping, and molding) use mechanical processes instead of photons or electrons. These methods are normally called soft lithography methods because they involve the use of polymers.

As shown in figure below:

Mold or mask fabrication

Soft printing lithography
Focused ion-beam (FIB) machining

FIB machining offers the greatest resolution, with the ability to make features as small as 20 nm, but it is very slow. In FIB a beam of gallium ions from a liquid metal ion source is accelerated, filtered, and focused with electromagnetic lenses to give a spot size of 5–8 nm. The beam is tracked across the surface, contained in a chamber under high vacuum.

The high-energy ions blast atoms from the surface, allowing simple cutting of slots and channels or the creation of more elaborate 3-D shapes. Secondary electrons are emitted when the gallium ions displace the surface atoms. These can be used to image the surface, allowing observation and control of the process as it takes place. Dual-beam FIBs have an additional electron gun that is used as an alternative way of imaging. The precision is extraordinary.
Nanosphere lithography (NSL) is an effective method to grow large-area and periodic nanostructure, which uses self-assembled polystyrene nanospheres as templates. Combining related techniques, various ordered arrays of nanoparticles, nanotubes and template structures can be prepared.
Ball Milling

Principle: Small hard balls are allowed to rotate inside a container and then it is made to fall on a solid with high force to crush the solid into nanocrystal. Hardened steel or tungsten carbide balls are put in a container along with powder of particles (50mm) of a desired material. The container is closed with tight lids. When the container is rotating around the central axis, the material is forced to press against the walls. The milling balls impart energy on collision and produce smaller grain size of nano particle.
**Advantages of Ball Milling**

- Few mg to several kgs of nanoparticle can be synthesized in a short time.
- This technique can be operated at large scale.

**Disadvantage**

1. Time consume when require very fine powder
2. Very wide average size of obtained particles that very difficult to separate to the desired size by sieving.
3. Very difficult to obtain very fine powder.

**Applications**

- Ball milling method is useful in preparation of elemental and metal oxide nano crystals like Co, Cr, Al-Fe, Ag-Fe and Fe.
- Variety of intermetallic compounds of Ni and Al can be formed.
- Ball milling method is useful in producing new type building materials, fire-proof materials, glass ceramics, etc.