Fundamentals of Micro and Nanofabrication

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Lecture – 28
Pattern Transfer Basics

In this session, we will explore Pattern Transfer, i.e., patterning a surface of a material.

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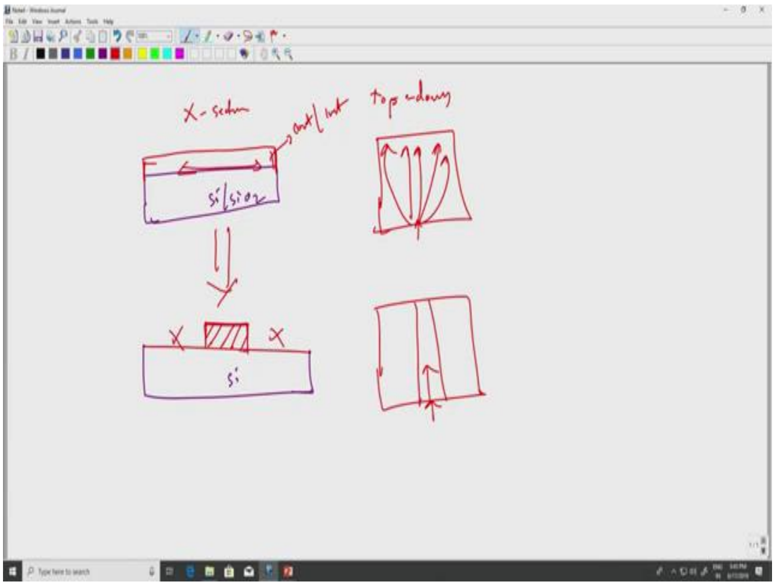

We will take a substrate, silicon, or silicon dioxide and then do a blanket material deposition. It can be conducting or insulating or can have multiple properties. The cross-section and top-down view show the film is flat. If the material is conducting, electrons can take various paths for flowing.

To restrict the flow of electrons in a particular direction, circuitry should be made with a conducting strip and non-conducting surrounding. For example, if we have metal in one region, it will be conducting; other regions without metal will act as insulators. From the top view, it will look like a line or strip of metal. Then on applying a potential across it, electrons will start flowing in that particular strip.

So, to restrict the electron flow from a continuous film to a restricted cross-section, we call pattern transfer. This can be exploited to realize various functionality that we want.

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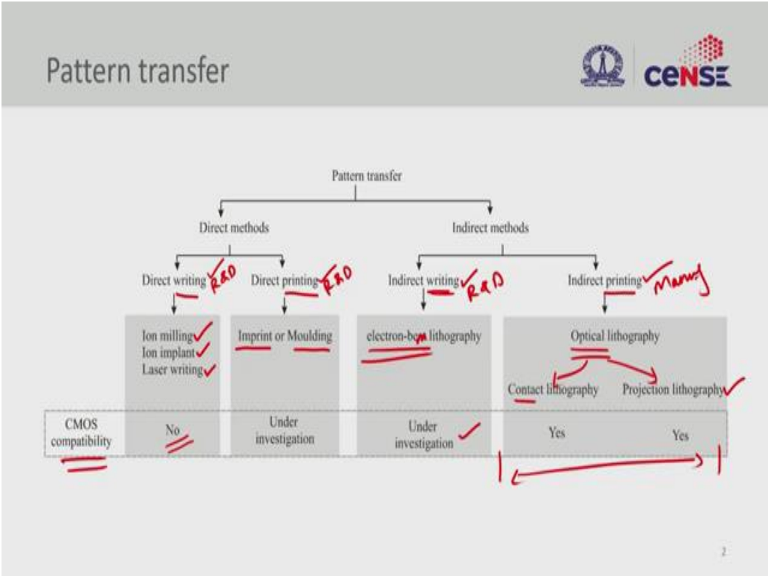

Pattern transfer can be classified into two broad categories; direct pattern transfer and indirect pattern transfer. In the direct pattering method, we can directly transfer pattern on the film, whatever the material is without any intermediate layer. While in the case of the indirect method we need an intermediate layer for pattern transfer. Here first, the patterns are transferred to the intermediate layer and then to the subsequent layer. Both direct and indirect patterning is subdivided into writing and printing.

Direct transfer method:

Like writing on a paper using a pen, a pattern is transferred bit by bit in the direct writing method. So if we have n number of structures, one by one, structures are written. Ion milling, ion implantation, or laser writing come under the category of direct writing. These are all serial patterning processes.

In contrast, direct printing is a parallel process. Here we have imprint patterning and mold patterning techniques. In imprint patterning, the template is used to print patterns—for example, cloth printing, screen printing. While in the case of molding, the material is filled in an existing mold, and the material will take the shape of the mold.

Indirect pattern method:

Here we pattern an intermediate material using energy, either electron or photon, and then the pattern from the intermediate material is transferred to the substrate. Depending on the exposure source, we have electron beam lithography and optical lithography. In electron beam lithography, using electrons, the intermediate layer is patterned. Since we are using a beam of electrons for rastering over a substrate for patterning, it is a writing technique, hence a serial process.

Optical lithography can either be writing or printing. Under printing optical lithography, we have contact lithography and projection lithography.

We are going to see contact litho and projection litho in detail in the subsequent sessions. We will look at the CMOS compatibility of these processes, i.e., whether these techniques can be used in CMOS fabrication or device fabrication.

Unlike printing, writing is a slow process. Writing is not preferred primarily because of low throughput and also the resolution in some cases. Direct printing and electron beam lithography is being explored for advanced patterning beyond 10 nm. Though electron beam lithography is a writing technique, later on in the lecture, it is interesting to see the modifications that we can bring to make this writing process parallelized, to get a reasonable throughput. The majority of patterning is done using an indirect pattern printing process; to be precise, projection lithography, but lately, for advanced integration techniques like backend integration, contact lithography is also used.

The indirect printing technique is primarily used for large volume manufacturing. While for R&D type of work, indirect writing process and direct printing are used. People are exploring these techniques for various applications, not just for electronics; for instance, direct printing and direct writing are explored for bio applications, MEMS type applications, and many more.

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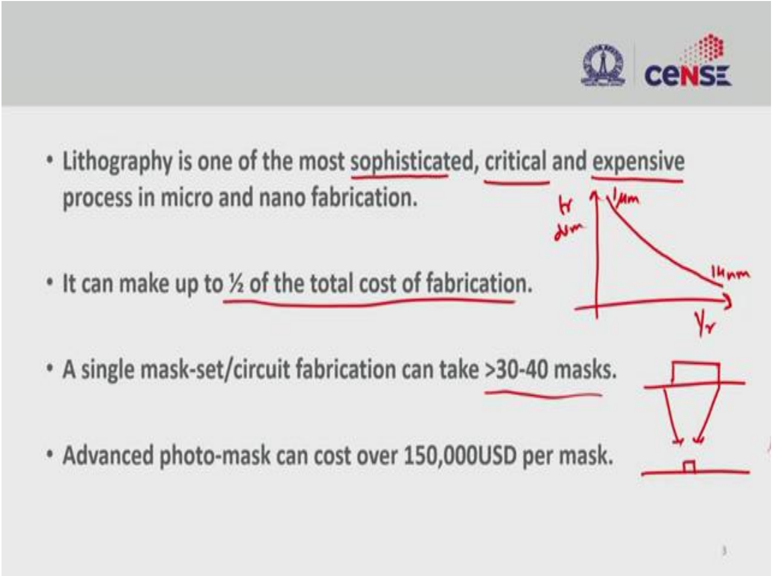

Lithography is one of the most sophisticated processes. We saw a decrease in the transistor dimension over the years if we look at the CMOS technology evolution. So, we started from 1 μm technology, and now we are at less than 14 nm node. So, the whole evolution of reduction of the size of the transistor is primarily driven by lithography.

Lithography became a vital part of micro and nano-fabrication technology, so it should be sophisticated and critical. Because of the nature of the process, it is expensive and comes up to half of the total fabrication cost. On one side, it adds technology to miniaturization; but on the other hand, it also adds cost. A single mask set or circuit fabrication will have 30 or 40 layers to make it functional; this will take up to 30 to 40 masks, one mask for each layer. The cost of each advanced mask is about 1.5 lakh US dollars. This increases as we move from lower mask technology to higher mask. As the functionality and sophistication increase, the cost will also increase.

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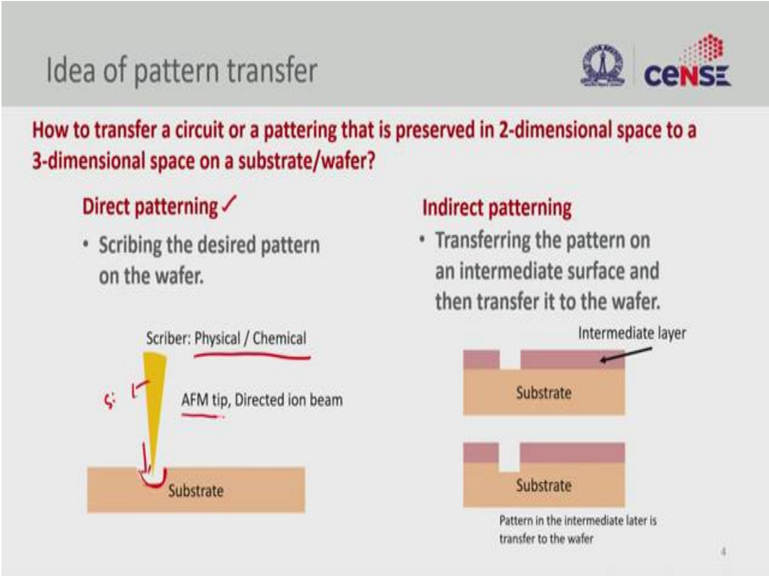

After understanding the importance of pattern transfer, let us examine how to direct patterning and indirect patterns are made. We will see how do we transfer a 2-dimensional structure into 3-dimensional features onto the wafer.

In direct patterning, we use a scribe, physical or chemical. A physical scribe can be a rigid solid tip, say silicon. Using these, we can apply pressure onto the substrate and remove the material that will form the surface profile. Chemical patterning uses some ion beam that reacts with the substrate or physically transfers its energy and knocks out the molecules and atoms sitting in the substrate; this results in pattern transfer.

In indirect patterning, we have an intermediate layer. Unlike the direct patterning case, where there is an interaction between the scriber and the substrate, the substrate remains untouched. We use an optical or electron beam for intermediate patterning to remove a part of the intermediate layer. The pattern is then transferred onto the substrate using some pattern transfer technique like etching the exposed portion. In this process, the pattern is first transferred to the intermediate layer, which is then transferred to the substrate.

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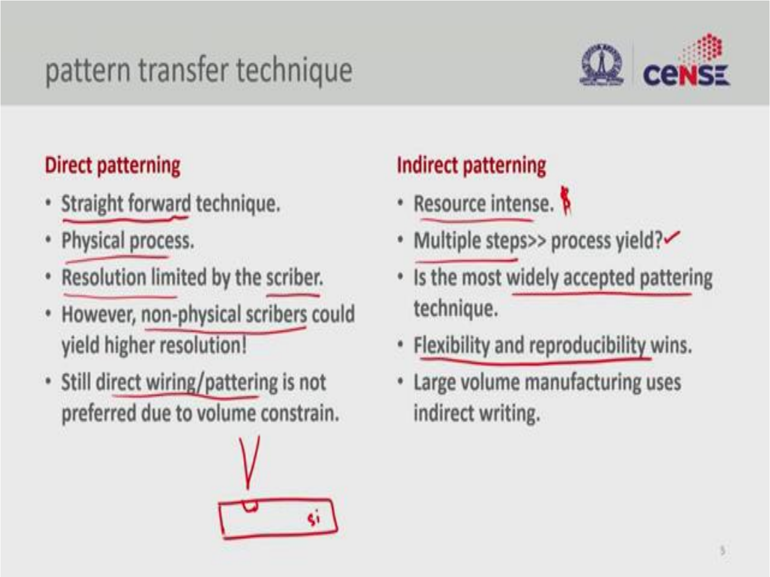

Now we will see the difference between direct patterning and indirect patterning. Direct patterning is a straightforward technique; there is no need for an intermediate layer and subsequent processes. We take the physical object or a beam to write onto the substrate directly. Similar to writing using a pencil, where the thinnest line can be drawn depends on the sharpness of the tip, the size of the scriber limits the resolution of direct patterning using a physical object. So to have a fine feature pattern, the scriber that we use should be very sharp; based on that sharpness, the resolution is limited. This process is destructive and can result in damage to the structure that we are defining.

Ion beam, a non-physical scriber technique, will interact with the substrate and patterns the substrate. It is a non-contact technique, which could yield a slightly higher resolution. The resolution depends on the mass of the ion particle, which we will see in the later lithography lectures. To increase the throughput of writing techniques, more number of devices should be fabricated in a short of period. Though using ions, we get better resolution; the direct writing process is always slow. Hence not preferred.

Indirect patterning is a resource-intense process. It needs an intermediate layer, optical or electron beam for exposure, etching process to remove the exposed part, and then removing the intermediate layer. When we have multiple steps, each step can bring in a yield reduction. In addition, if one of the steps fails, we have to reprocess the entire chip.

So, the multiple steps involved in the indirect process also will translate to expense. However, indirect patterning is preferred for the following reasons.

1. Indirect patterning is a parallel process; hence it is one of the widely accepted patterning techniques.

2. Despite multiple process steps, it is repeatable, flexible, and reproducible.

3. It is an extensive volume manufacturing process, including the CMOS or any MEMS processes.

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The tools used for indirect pattern transfer are ion beam milling, laser writing of polymer, scanning probe lithography. In the case of ion beam milling, an ion beam is used to transfer the pattern, while in laser writing, the laser is used to expose photosensitive material, i.e., polymer. In scanning probe lithography, we use a physical probe to transfer the pattern.

For indirect pattern transfer, optical lithography is predominantly used in industry and electron beam lithography in R&D but is now being explored for next-generation lithography, even in high-volume manufacturing.

Nano-imprint lithography is an optical process that combines optical and thermal processes. This is again primarily used in R&D. There are many more to list. These are all few to give you an idea about the different kinds of patterning techniques that one can use to realize the structures.

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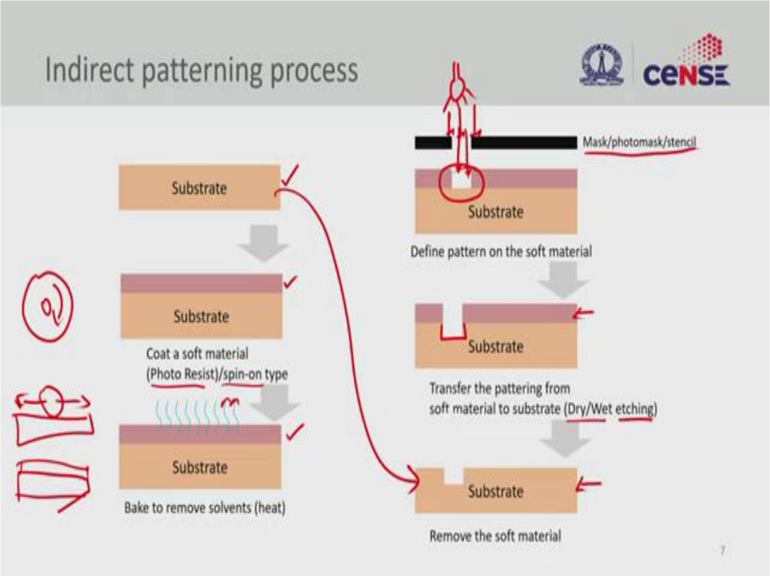

The above slide shows the process flow for an indirect pattern transfer. We start with a flat substrate, which has that has no profile. It is then coated with an intermediate layer. In this case, we call it a photoresist, a soft material, and we deposit this using the spin coating method. During spin-coating, we place the wafer on a chuck and drop the photoresist on the wafer. And then we rotate it at a particular speed; when we are spinning, it will spread the material on the surface of the wafer.

These photoresists are viscous liquids that on spinning at a particular speed will uniformly coat on the surface of the wafer. We then soft bake the coated wafer to solidify it by removing the solvent using heat. Over this solidified material, a photomask is placed and then illuminate with light.

An opaque photomask region prevents the light reach the substrate while transparent region will allow the light to go through. The light through the transparent region will cause chemical changes in the photoresist. This chemical change will allow few regions of photoresist to remove, which will expose the substrate. This exposed part can be removed using either wet or dry etching.

As mentioned earlier intermediate layer is just used to transfer the pattern. So, once the pattern is transferred, intermediate material is removed to get the final product. During the process, we transferred a uniform or without any topography to a substrate with a pattern. Here we have briefly seen pattern transfer using the indirect method.

In the subsequent lectures, we will discuss how optical lithography is used and what is the importance of photoresist, light source, and the intermediate processes involved in achieving the pattern onto the substrate.