Nano Structured Materials-Synthesis, Properties, Self Assembly and Applications
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Module - 2
Lecture - 13
Lithography – I

Welcome to this course on nano structured materials- synthesis, properties, self assembly and applications. We are in module 2 and this is the lecture 11 of module 2, and today we start lecture on lithography. We will have 2 lectures on lithography. Today, we will have the first lecture of lithography - lithography 1 and we will have lithography 2. Earlier we have look that several other techniques for the synthesis of nano structured materials, involving chemical methods, physical methods, various types of depositions like PVD, CVD and then spray pyrolysis, VLS methods, several techniques to make nanostructured materials, including template methods, have been discussed in the earlier lectures of this course. Today, we start the first lecture on lithography.

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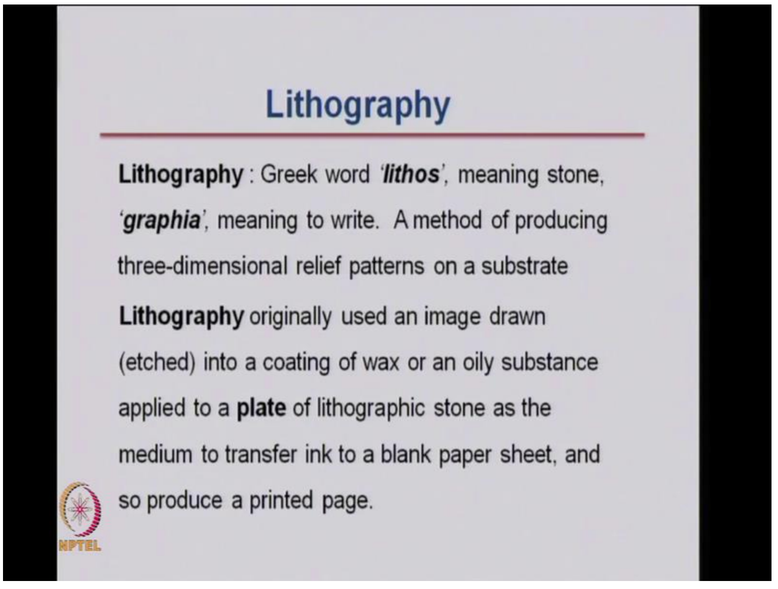

This is the lecture 11 of module 2. The term lithography involves two basic parts; litho and graphy. The greek word lithos means stone, and graphia means to write. Hence the term lithography ideally means, a method of producing patterns on a substrate. In modern terms, by lithography, we mean we make structures. It may be micron size structures or nano size structures on a substrate, which is very well designed, which has a particular pattern. That is the lithography of today. Originally, it started with the meaning as if to write on stone, and hence the term lithography came into existence. Earlier days, several centuries back, the lithography used to be an image, which is drawn or edged on to a coating of wax or any oily substance, which is then applied on a plate of lithographic stone as the medium, which will then transfer the ink on to a blank paper. Hence, it produces a particular design on that page, using this patterned stone on which you can add ink, and then transfer it on to a blank paper. That is how, centuries back, a return material was stored.

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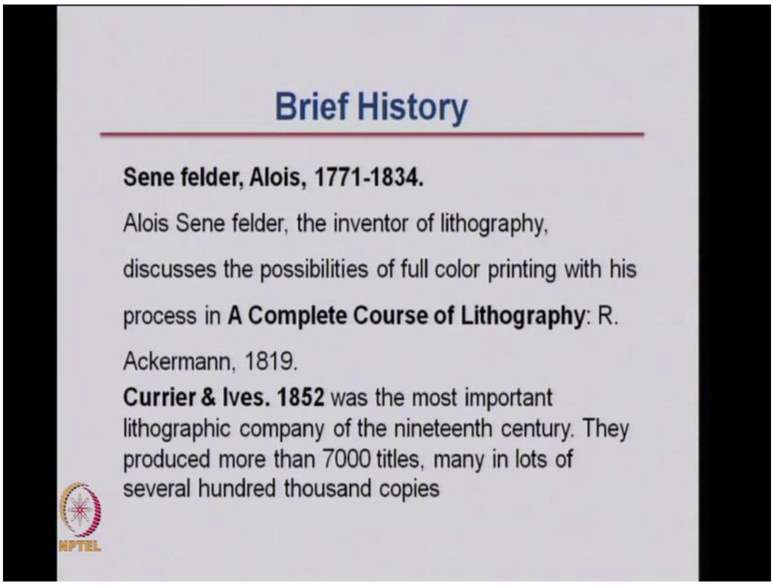

The history of lithography starts with the person Alois Sene Felder, who is the inventor of lithography. He has a full text on lithography, dated 1819, where he discusses all the possibilities of color painting, using this type of lithography, where you will have a mold made of wax, which is filled with ink and this pattern on the mold, is then transferred on a sheet of paper. This lithography was very useful in the 19th century.

The most important company, the Currier and Ives, in 1852, was one of the most important lithographic companies of the 19th century. They produced many prints, are called titles and several thousand copies have been made of individual titles, using this type of lithography, where you have a wax mold, which transfers an ink on to a sheet of paper, on a leaf or on a cloth. That was a kind of lithography in the 19th century.

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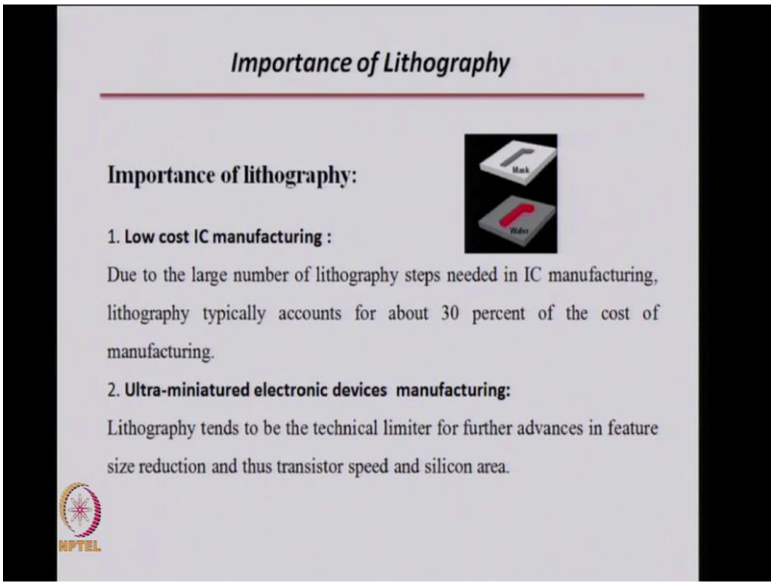

The importance of lithography today, especially, comes for our IC industry, for IC or integrated circuits or the key in all kind of computational devices, computers or any other electronic devices being used today. The manufacture of ICs requires several lithographic steps. This lithography is cost about 30 percent of the total cost of manufacturing of that IC. Hence, if the cost of IC manufacturing is lowered; that means, the cost of lithographic techniques is lowered ultimately, the electronic device or the product, will have much lower cost. So, it is very important to develop lithographic techniques, which can create patterns or here, create circuits which can be used in ICs at a very low cost and hence, can bring down the whole cost of the device.

Another important thing is the lithography has to go from one size to ultra miniatured size. So, if you want to make smaller devices, you have to make designs or patterns or circuit, which have very small dimensions. These devices, like the ICs, which we can call as features, have their size to be reduced; that means, we want low feature size in these devices. Lithographic techniques decide the size of these ultra miniatured devices.

Because, your technique; how you are making the patterns, will lead to the dimensions which ultimately, form the patterns. Hence, you may have to use certain types of lithography to make certain patterns, which are thick of several microns, and if you have to make smaller patterns, which are nanometer dimensions then you may have to use some other type of lithography. So, different types of lithography exist, which are important for different sizes of the patterns or the thicknesses of the nano patterns, which you are going to imprint in your device. This field restricts the ultimate size of your device.

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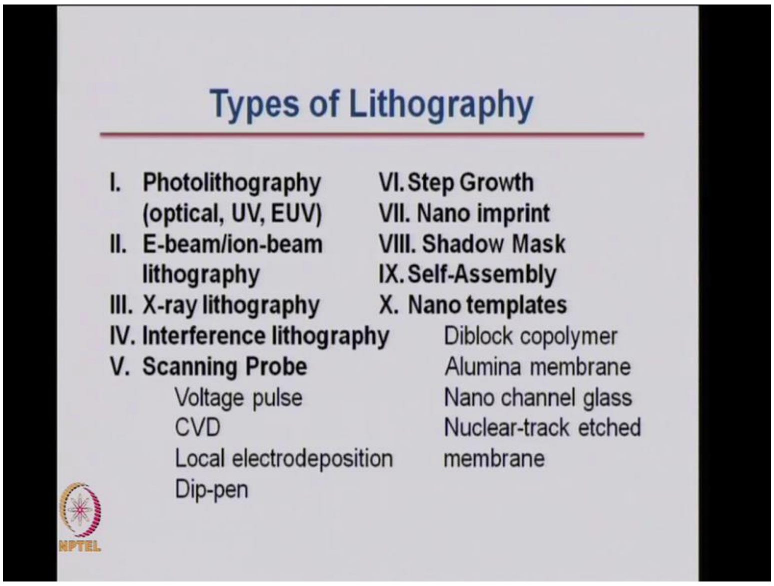

There is large number of types of lithography and each type of lithography has its advantages and its disadvantages. Of course, the primary thing is to get the pattern of your choice. If you need for a particular application, a device with certain dimensions, then you have to choose a lithography, which will create that kind of dimension. For that, if the costs are high you will have to use it. Ultimately, the product will be of course, expensive, but depends on your applications. What you want in you device, you have to use that kind of lithography.

You have photolithography, for example. From the term photolithography, you can understand that it involves light and light induced lithography. So, light can have various wave lengths. If you are normally in the visible region, you can call it, the solar radiations if you are using, or the optical lithography. If you are using UV light then it is UV lithography. If you want to use extreme UV it is call EUV, that is even lower wave lengths than UV. Lower wave lengths means higher energy. So, you are going from the visible region to ultraviolent region to extreme ultraviolent region. So, higher and higher energy of the incident, like beam can be used for making different types of lithographic patterns. This is photolithography.

You can also do E-beam or ion beam lithography; that means, you are making patterns or designs on your substrate, using an electron beam or using an ion beam. Then you can use X-rays. This is also a form of electromagnetic radiation. However, it has very low wave lengths compared to optical or UV radiation. X-rays have wave length in the order of 1 to 2 angstroms and that is like 0.1 to 0.2 nanometers, which is much smaller than the wave length of the UV or extreme UV radiation.

X-ray lithography has much lower wave length and hence, it can achieve certain things which UV and EUV photolithography cannot achieve. Then you have techniques called the interference lithography. From the term interference, you can understand that there will be mixing of waves; that means, you may have constructive or destructive interference of two beams, and that can be used to generate patterns. So, that is called interference lithography.

Then you have scanning probe techniques, which involve a variety of different. There are variations on the scanning probe technique; you have the voltage pulse technique; the CVD technique; the local electro deposition technique and the Dip-pen technique. These are all scanning probe techniques, like the scanning probe microscopy. Here, you are using the scanning probe to make patterns or designs on the substrate. You have different variations for the scanning probe technique. Then you can have other techniques like the step growth technique, the nano imprint technique, the shadow mask technique, the self assembly technique and the nano templates.

Several templates can be used to make lithographic patterns using these nano templates. Some of them can be made by using diblock copolymers or alumina membrane, or you have channels made in glass, and then you can have membrane, which has been made using a nuclear radiation. These are called nuclear track etched membranes. So, a variety of techniques is available to carry out different types of lithography, to maintain design patterns on substrates, which then can be used for certain devices. We will be discussing some of these lithographic techniques, but not all the techniques.

But, we will try to cover the important techniques like all the photolithography techniques, the X-ray lithography techniques, the interference techniques and may be, the nano imprint technique. These will be discussed in little bit more detail. The basic technique of lithography is that, you take a substrate. Your substrate becomes like the rock or the stone of early days, where people used one to write something. In the modern day, we call it the substrate. The substrate can be a glass or silicon or silica. It depends on what you want to do with it. Very important substrate is, of course, silicon.

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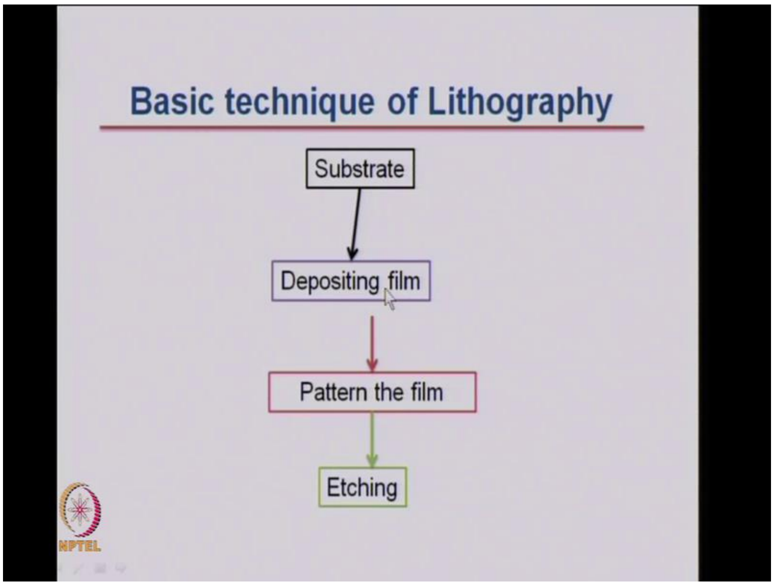

Then you want to deposit a film on the substrate. On that film, you should be able to pattern the film. One of the properties of this film is, it should be something where, you can make some impression or where, you can remove some parts of the film easily that it leaves behind the pattern. You take a start with a substrate. Then deposit a suitable film. Then you pattern the film. After you have patterned the film; that means, the design is there on the film with the substrate behind it. Then you etch this patterned substrate. So, the film is there on the substrate and the film has been designed or patterned.

When you etch, only the pattern that you made will remain on the substrate. Remaining parts of the film will be removed, that is called etching. This etching can be done using different chemicals or acids. So, lithography consists of these four basic steps that, you start with the substrate, deposit a film which is suitable for patterning and after you pattern using some technique, it may be light, electrons or ion beams or some scanning probe techniques. You pattern the film. Then you etch the film such that, only the design part of the film remains. The remaining part of the film should be removed and the substrate will have the pattern on top of it.

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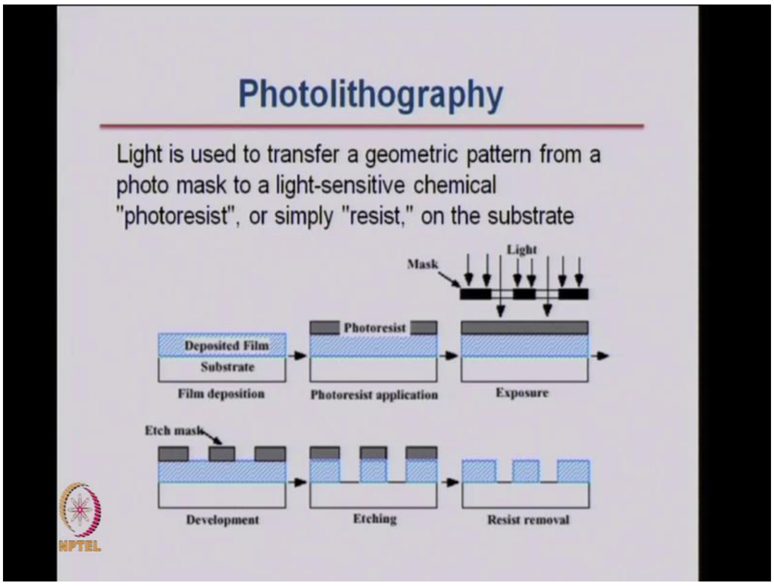

Now, if you consider photolithography, in photo lithography you use light to transfer the pattern, from a photo mask to a light sensitive chemical, which is called the photo resist or just a resist, on the substrate. You have a substrate. On that, you first have to deposit a film. That is the first step in photo lithography. You start with a substrate and then you deposit a film, after that, you deposit another layer of the photo resist. So, you have one layer of a film and then, you have one layer of the photo resist. Then, on top of the photo resist, you place a mask. So, this mask has a pattern.

It has this dark and white zones in the mask and then, when you shine light, the mask is such that, wherever it is having some material, it will not allow the light to pass through. However, in this region which is shown as white, the light will go through this and hit the photo resist. In this region, the photo resist is not having any light falling. Only in this region, the light will fall on the photo resist. So, selectively light is falling in this area and in this area on the photo resist. So, when that happens, this part of the photo resist the it gets removed.

This is a particular type of photo resist, which is called a positive photo resist, which we will discuss. Wherever light is falling, that part gets solvable or it dissolved away, and you are left with these gaps. After these steps, you have the substrate, then you have the film and the photo resist is at certain parts of the on top of the deposited film. Now, if you etch or remove this mask, then only you can see this. So, the mask was on the top of this. Light was passed and it creates this kind of holes. On top of this film, the mask has been removed and we etch the mask off. Then you can see, only the film on top of this substrate and the photo resist is removed at certain parts.

The next thing is, you have to etch this exposed part of the deposited film. This exposed part of the deposited film can be removed using certain chemicals and that is called etching, and once you etch, now you have a gap here. Wherever, the film did not have any covering of the photo resist, that part got removed completely. So, you are left with the structure which has got the film, and the photo resist on top of it, and then there is nothing here and then again you have. So, you generated a pattern of the film, but still now, you have this photo resist material on top of those columnar structures of the film. Next step is, you have to remove the resist from the top of that. So, use another set of chemicals to remove these photo resist, which is on top of your film. When you remove that, you get the final structures. This is what the pattern you wanted, starting from the film which is here, you designed a pattern, where the film exists only in certain parts and wherever you want, and the other parts do not have the film.

Of course, as you see that the pattern will depend directly on the mask. So, the mask has to be designed in such a way that ultimately, you get a pattern on the film, which is the pattern of your design. The design of the mask is very important because, ultimately, that will be the guide to the ultimate structure that you get. This structure has the pattern or design which you wanted. So, if you go through the steps: you have a substrate, a film deposited on it and then, a photo resist layer deposited on it, then you have a mask on top. You shine light on the mask and through the mask wherever, the light can go through it, will penetrate and remove the photo resist.

The remaining parts of the photo resist will remain and then, you remove the mask first, from top of this. When you remove the mask, you get this and then, when you remove the photo resist you finally, end up with this structure. So, you have made a pattern structure using photo lithography.

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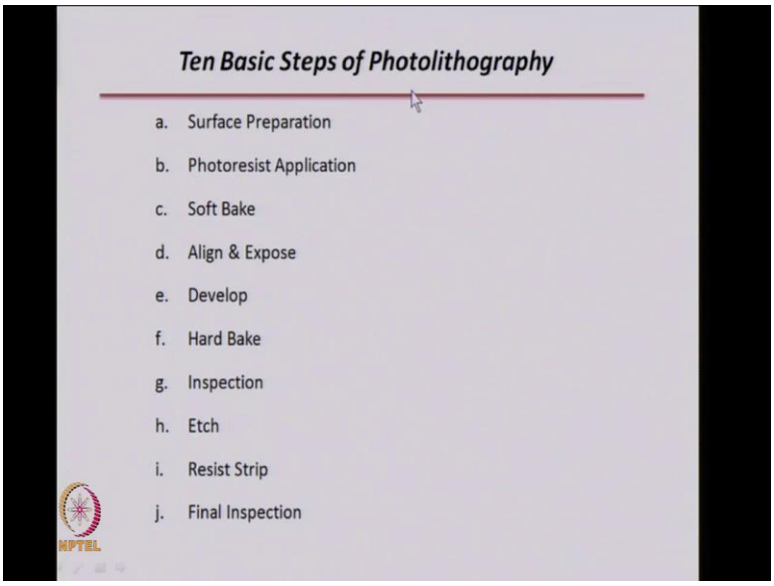

The various steps which we already got through, with some more details are that, you have to prepare the surface of the substrate; clean the substrate. Then you have to apply the photo resist, then you have to bake it; soft bake with little bit temperature and then you have to align the mask. The mask has to sit exactly on top of the film, where you want. You need what is called a mask aligner and then you align the mask and then you expose it to the light; whatever radiation you are using. After that you develop; that means, you add some chemicals which will remove the mask. When you add after you do the light, you use your light, you etch away the mask, which will be on top, and you will get this kind of structure. Then, you inspect if it is fine. Then, you etch further to remove the resist and then you get your final structure.

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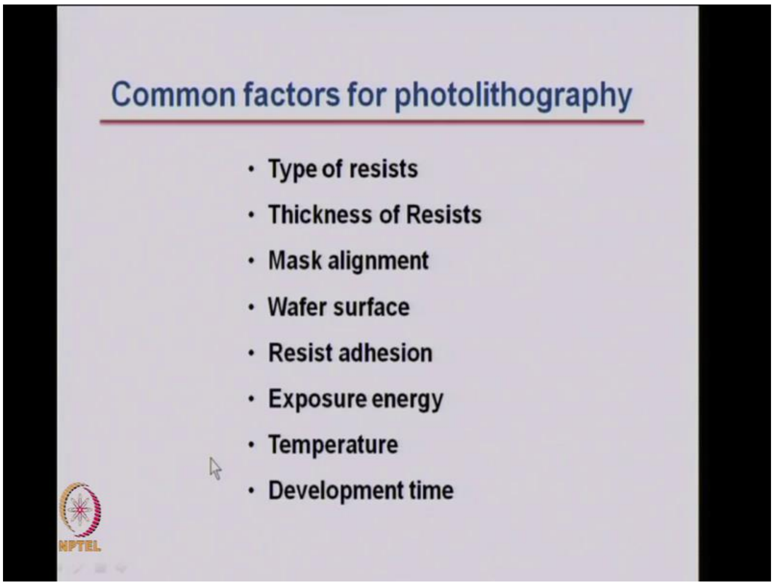

Common factors for photolithography: There are different types of resist. Then, what is the thickness of resist you want because, your resist, if it is too thick that light cannot penetrate completely, then you will not have this structure and some resist will remain. The thickness of the resist is also important that depends on what wavelength of light you are using; how much time you are exposing to the light and then the alignment of the mask, of course, is of ultimate importance. Because, if you misalign the mask, you will not get the structure which you want, because the mask actually guides the final structure. So, the mask alignment, which is done not by hand, but automatically through equipment, which is called the mask aligner. It is programmed and the mask is goes to the exact position on the resist.

Then, you do expose it to light. You have to know the wafer surface; the wafer is basically the substrate here. The substrate is silicon for IC chips. Most of the times, we are using silicon. The silicon wafer surface has to be very clean and then you have to bond the resist very carefully. So, the adhesion of the resist; this property of the resist material, whether it adheres to the surface or not properly, is important. Then you have to optimize the energy of the radiation that you are using, for exposure of this film. So, the exposure energy and temperature of baking is important.

The time that you allow for the development, using some chemicals is also important. So, there are several factors which you need to optimize to get a proper pattern, using photolithography.

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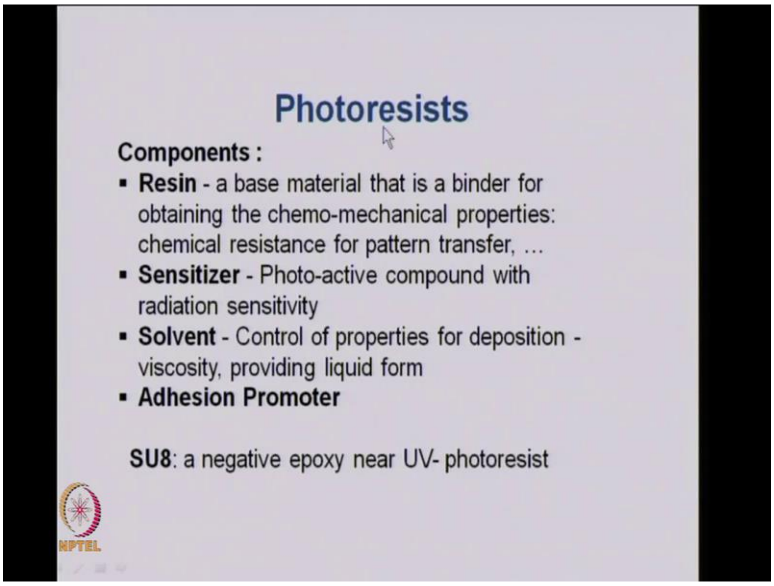

The different types of the photo resist, before we go to the different types of photo resist, a typical photo resist consist of the following components. One is the basic resin. It is a material that is a binder for obtaining certain property. Certain chemo-mechanical property; certain strains, certain flexibility and certain chemical resistance for pattern transfer. So, a good resin will have optimal properties, which you want and that is used for different. One resin may not be good for all the substrate.

So, you have to optimize the type of resin, depending on the sub straight because, the adhesion of the resin is important. Apart from the resin, you need a sensitizer because, you will expose it to light. You need a photo active compound; that means, a compound or chemical which becomes activated in the presence of light of the wavelength, which you are using. So, this chemical in the photo resist should get activated at the wavelength of the light that you are planning to use. That actually, we call it as a sensitizer because, it is sensitive to a particular band of energy or particular wavelength of light.

Then you need a solvent, and you have to control the properties of the solvent, for deposition, like the viscosity, the flow properties, etc. which provide the liquid form for this resin. The resin is in a liquid form when it flows and then it has to bind. To bind, you need adhesion promoter. So, together, all these four: the resin, sensitizer, solvent and the adhesion promoter make the photo resist. A very important and commercially successful photo resist is the SU8 photo resist. It is very popular and used extensively in lithographic techniques. This is a negative epoxy and it works in the near UV radiation. Near UV, there is some wavelength of light and that wavelength of light, it is most active or it is more sensitive. So, SU8 is a negative epoxy near UV photo resist and we will discuss, what is a positive and what is a negative photo resist. So, SU8 is a negative photo resist.

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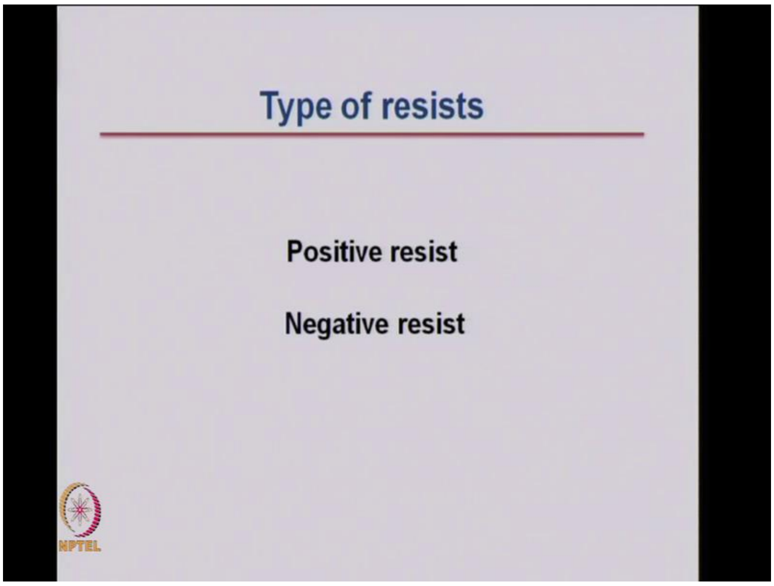

The types of resist are positive resist and negative resist. As you said, SU8 is a negative photo resist, but you can have both positive and negative resist. What is this positive and negative resist?

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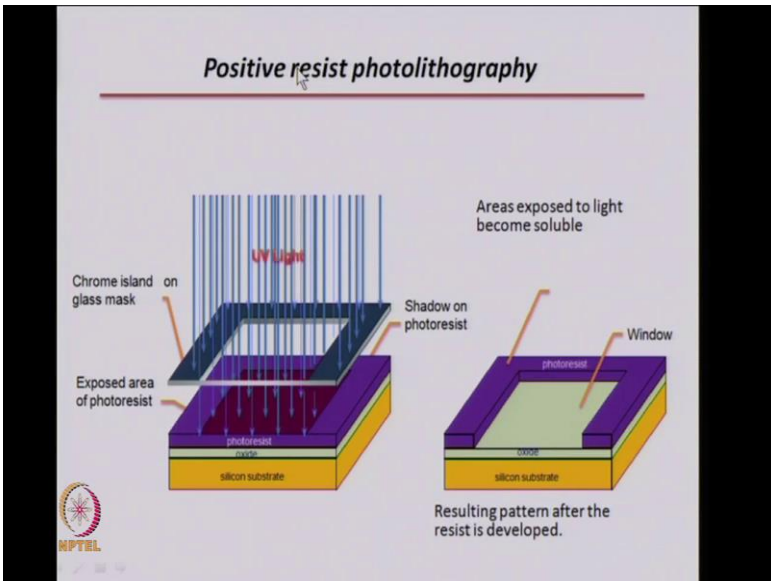

If you discuss this first, the positive resist photolithography, you have your substrate and then, this is your oxide layer; which is your film, in the previous slides we are talking of a film on a substrate. Here, that film is made of some oxide and then you have this photo resist on top of that, and then you have this mask. This mask can be some metal and which does not react, or is not sensitive to UV light.

If the mask is designed in such a way, that it allows UV radiation to go through in certain region; this rectangular or square region. Radiation falling on the photo resist in this region, will get dissolved and that is called a positive resist. Wherever, the light is falling, if this resist gets dissolved, those areas that are exposed to light become soluble. Then this kind of a resist is called a positive photo resist. Ultimately, you will get a structure like this, where the resist which was here is no more there because, it has been exposed to light and during that period, this part of the photo resist got dissolved.

And only this part, where no light was coming because, there was a mask on top, still remains. So, the photo resist part which remains is where, the mask actually was placed on top of it. The resulting pattern, based on a positive resist photolithography will look like that, if the shape of the mask is like this.

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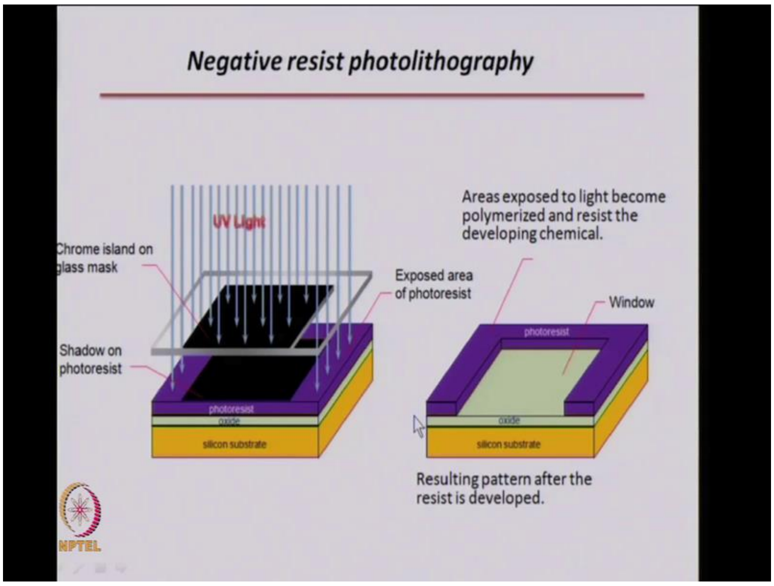

If you look at the negative resist photolithography, there it is just the opposite. It involves a photo resist, where if light falls on that photo resist that polymerizes. That will remain as such, it will polymerize. Wherever, light is not there, that can be moved. So, areas expose to light become polymerized and then when you add the whole thing to a developing chemical, the region where light was not falling, that does not resist the chemical and so, it will get dissolve.

Areas which were exposed to light, that will resist the chemical. Earlier, areas which were exposed to light become soluble. Now the area, where light falls, become polymerized and will remain; the area where light did not fall will actually get dissolved. It is just the opposite of the positive resist photolithography. This is a negative photolithography. Here, the region, where the light did not fall because, the mask was designed like this; did not allow the light to fall on this region. Since, light did not fall on this region, when you put it in the chemical, it removes the photo resist and the part, where light fell, the photo resist polymerized and now the chemical cannot remove that part. The final structure looks like this. So, this is the negative resist photolithography.

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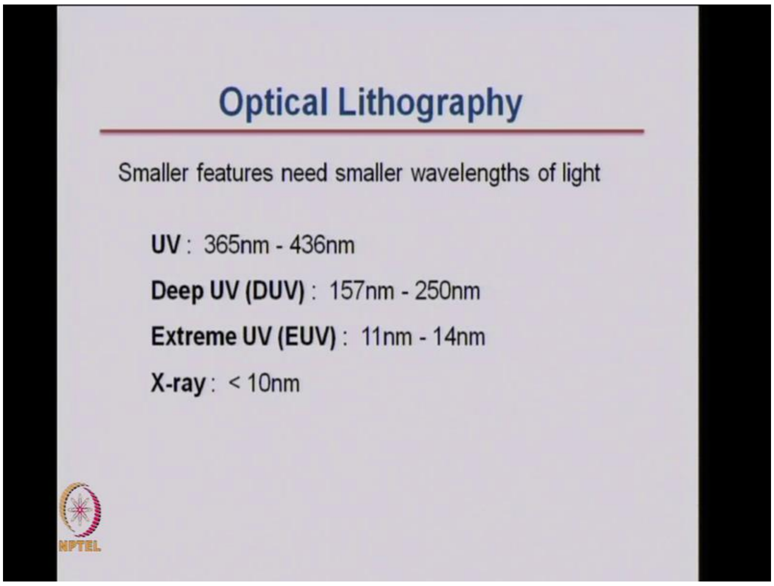

You can do optical lithography with visible light, with ultra violet radiation, which has wavelengths in the order of 365- 436 six nanometers, when you go from visible to ultra violet, you are going to smaller wavelengths. As you are going to smaller wavelengths, you can make smaller features. If you want to make smaller and smaller features, you go to smaller and smaller wavelengths. You can go to UV, which is 365 to this 436 nanometers. If you want still smaller structures, you go to deep UV that is, deep ultra violet, which is much smaller wavelength and much higher energy, that is 157- 250 nanometers.

If you want even smaller wavelength; that means, even higher energy, you go to extreme UV, which is called EUV, where the wavelength has the values of 11 nanometers to 14 nanometers. Ultimately, if you want to go to even higher energies and much lower wavelengths, to obtain very small feature sizes, then you go to X-ray radiation, which has wavelength less than 10 nanometers. It is normally, of the order of 1 to 2 nanometers. So, you can make feature sizes much smaller than what you can get using UV or deep UV lithography. So, extreme UV lithography, you can use, when using UV lithography you are at the limit of the minimum feature size. That means; you cannot make designs or feature smaller than the UV radiation, but you need them.

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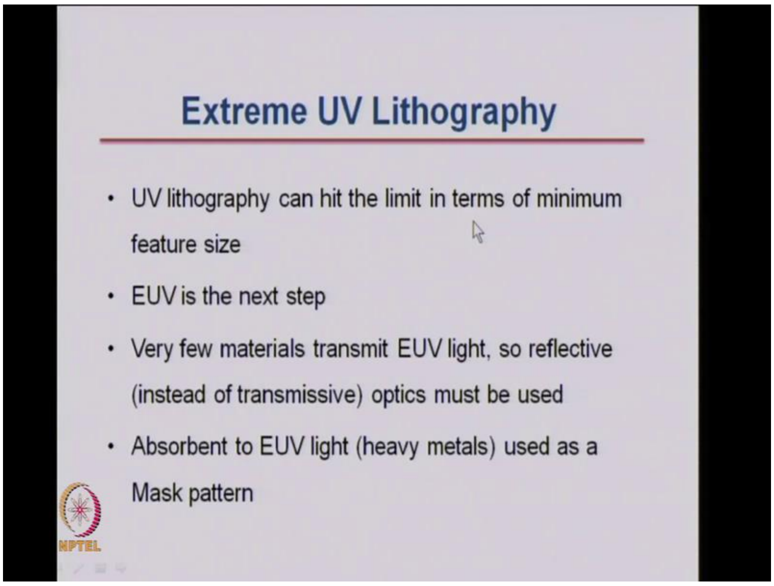

Then you go to EUV, which is the extreme UV. Since, very few materials transmit extreme UV light, you have to use reflective, instead of transmissive optics, because most of the materials, reflect the light instead of transmitting the light. Your optics has to be changed. The masks used for lithography, using such extreme UV radiation, uses heavy metals for forming the mask patterns, because those absorb the EUV radiation. Heavy metals may be gold or platinum. They can be used for forming masks, which will absorb the extreme UV light and wherever, in that pattern; there is a hole or a gap, the light can penetrate and will affect the film underneath the mask and hence, your patter will be generated.

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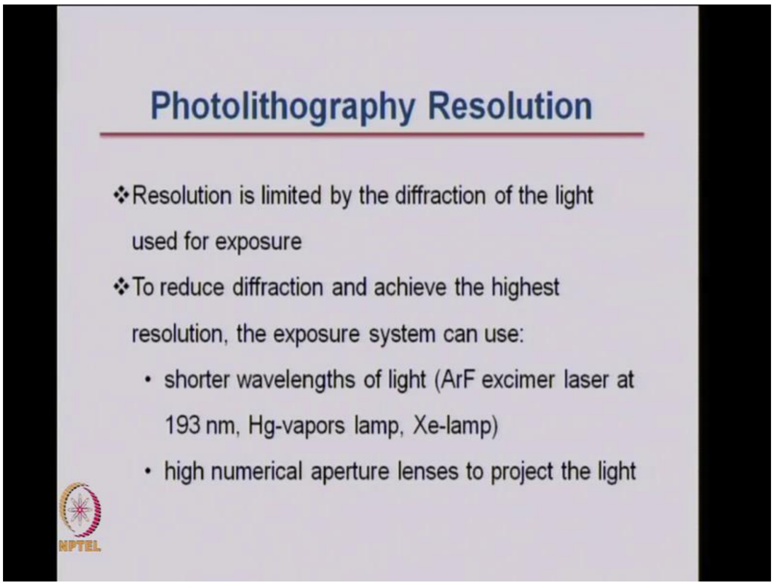

The resolution of such a photolithographic process is limited, mainly by the diffraction of the light used for exposure. So, to reduce the diffraction and achieve the highest resolution, you can use shorter wavelengths. As we discussed, you can use deep UV, extreme UV and you can use different sources for them for example, you can use an excimer laser, which uses radiation of the wavelength of 193 nanometers. You can use mercury vapor lamp or xenon lamp. So, you can use shorter wavelength to avoid the resolution, which is limited by diffraction. Of course, you are going down below the UV limit. The other thing is you can choose high numerical aperture lenses to project the light. So, the higher the numerical aperture your resolution; that means, your ability to see two points close together, will improve. You can come down to much smaller dimensions between two points and dissolve them, if you use a very high numerical aperture.

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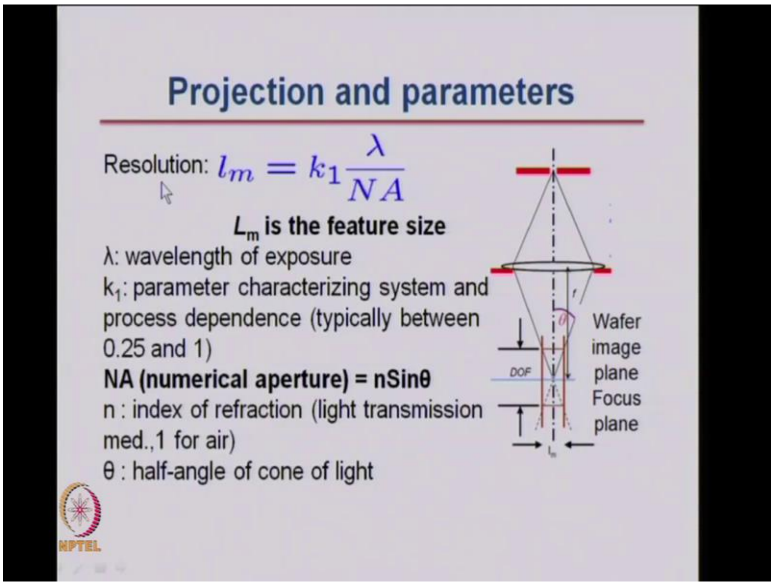

That will become clear, if you look at this equation, where the resolution, you want are very small numbers here. So, Lm which is your resolution, should be very small. This can be very small if either lambda is very small, which is the wavelength; that means, you keep decreasing the wavelength. That is why you go from UV to deep UV to extreme UV and then, you go to X-rays. In the other thing that you can do is, you can increase the numerical aperture NA here. If you have very high numerical aperture then also, you will have a very small number for the resolution; that means, your resolution is very good.

These are typical optics for any microscope or optical; either optical microscope or electron microscope, where you have your source which may be an optical beam, a light rays, or it can be an electron beam and then you have lenses to focus the beam. When it is focused, there is this angle. This angle, which is actually should be discussed as a solid angle, but we are now looking at half of that angle. And that angle theta, if you take the sign of the half angle theta, multiplied by n which is the refractive index, you calculate the numerical aperture. So, the numerical aperture you want is a very large number.

This numerical aperture will be large, if you have a very large theta value or very large n value. Because, you will have the maximum value sin theta equal to 1, when theta is equal to 90 degrees, but of course, you cannot do that. This theta, you can vary to increase the aperture to a certain extent. You can change the refractive index by changing

n. So, you can control the numerical aperture and you can get a better resolution, if you have a high numerical aperture. So, the wavelength of light and the numerical aperture; both control the resolution and you want a low wavelength and high numerical aperture to achieve the best resolution.

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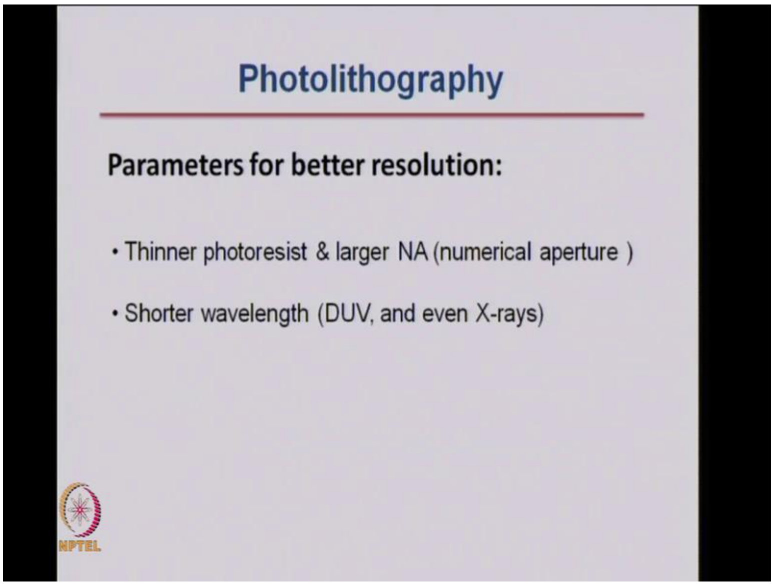

One thing is, which I already said that you need, for better resolution in photolithography, you need a large numerical aperture and short wavelength. In short wavelength you can go to deep UV extreme UV or even X-rays.

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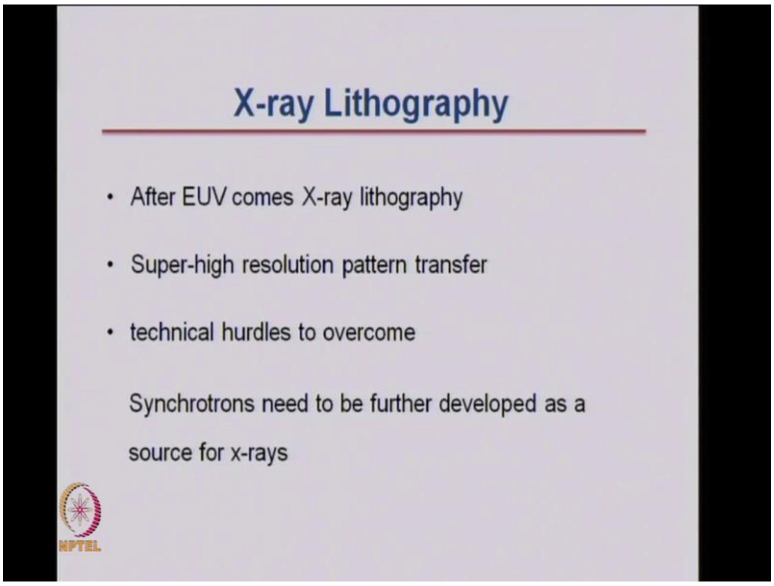

If you want to go to X-rays then we come into the term, what is called X-ray lithography. You are going to use X-rays as your source of radiation to make patterns on the films. This methodology, the X-ray lithography technique, allows you to have a very high or super high resolution pattern transfer. When you are transferring the pattern of very high resolution, then this technique is very important. There are other techniques like the UV lithography, etc. have a limit to what kind of resolution or pattern can be transferred onto the film. But, X-ray lithography has technical hurdles. Most of the time you need synchrotrons X-rays. Synchrotrons are not available everywhere. You cannot have synchrotrons in every laboratory. So, synchrotrons need to be further developed. It is expensive and you need these synchrotrons because, they will give you qualimeted X-rays and those are normally use for X-ray lithography. That makes this x ray lithography technique, little expensive.

It has to be used for very high end product design. X-ray lithography is similar to photolithography, except that, you are using X-ray radiation, instead of visible light or ultraviolet light. You have to keep a gap between the silicon wafer or substrate and the mask. In the earlier techniques, you use to put the mask right on top of the film, which was on the top of the substrate. But in X-ray lithography, there is a gap between the substrate or the film, on top of the substrate and the mask. Then you have to have X-ray resists; that means certain materials which will not allow X-rays to pass. X-ray masks are always thinner. So, there are certain differences between X-ray lithography techniques and normal optical lithography techniques.

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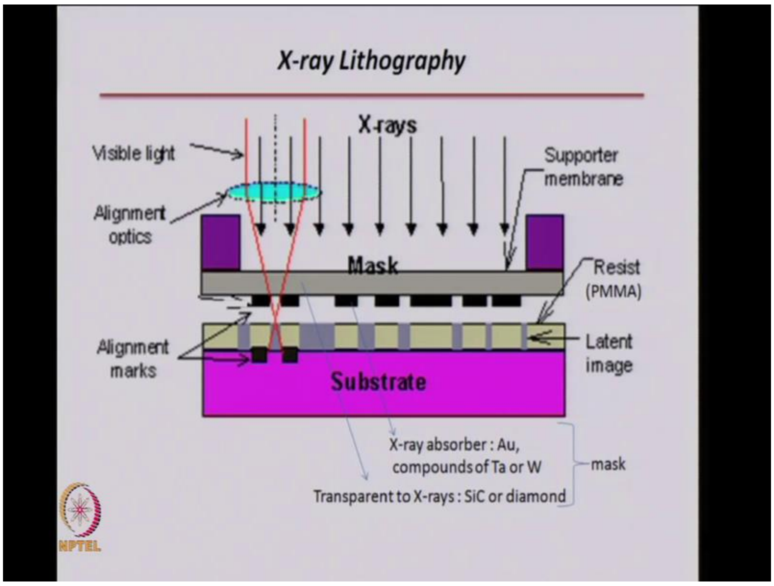

This is a typical diagram to show you an X-ray lithography process. You have your substrate and, on top of the substrate, you will have your image of the pattern, which you have on the mask. This mask, which is kept little bit away from the substrate; there is a gap between the mask and the substrate. The mask is of two parts; the mask is made up of an X-ray absorber, which is patterned on this mask. So, these are X-ray absorbers and in between, these are gaps, where the X-ray is not absorbed. You have an X-ray absorber and there is a material of film, which is transparent to X-rays. Wherever, the material is transparent to X-rays and there is no absorber behind it, then the X-rays will pass on through this material, and then hit the film. This film on the substrate is typically, a polymer, like poly PMMA we call. It is used very commonly in many photo resists.

So, what you have is your X-rays falling on the mask and the mask is made up of two parts. You have an X-ray absorber, which will absorb the X-ray, if the X-ray comes in its path. There is the resists, which is transparent to X-rays. You get feature on the PMMA, which is the PMMA is where; you will get the final image. You transfer the X-ray whatever, the pattern on the mask on top of the PMMA, using these X-rays. Now, the materials which are used for X-ray absorption, are typically metals with high atomic numbers like gold, or compounds of tantalum tungsten, which are also of high atomic masses. The layer which is transparent to X-rays in the mask, this layer is typically silicon carbide or diamond. As we already discuss, the film on which the image will be formed is typically, a polymer which is PMMA.

So, whatever be the design here, that design is recreated on the film. This is called the latent image. You will see that wherever, there is a gap here the film here. This film of PMMA has been removed by the X-ray, but wherever, you have this absorber, that part of the film is intact. So, you can make a pattern using X-rays. You use a visible light and some alignment optics to align your mask and you see, such that you have the right positioning of the X-ray absorbers to create right pattern on the PMMA. So, this is a typical lithographic technique, where you are using X-rays. There are couples of differences with the earlier techniques. The mask is kept away from the film of the polymer.

There is a gap and this is an important thing. Then the materials that you used are different, you need to make the mask in such a way, that you have some X-ray absorbing materials on the mask and these X-ray absorbing materials are made up of either gold or some compounds of tantalum or tungsten. So, this is the X-ray lithographic technique and with this technique, you can make very fine features, because the wavelength of X-rays is very small. It is 0.1 to 0.2 nanometers and it resolves the diffraction problem of normal UV radiations.

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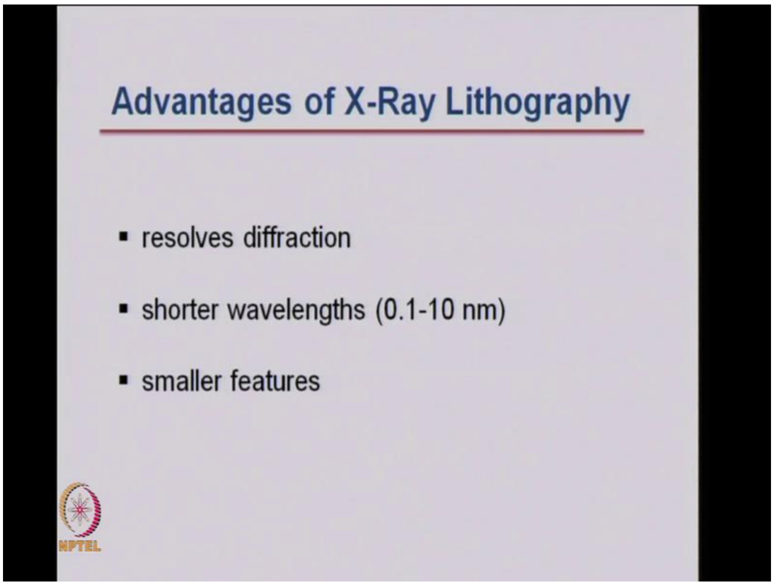

In photolithography, using UV, when we come across the problems of the diffraction limit, then if you use the X-ray techniques, which resolves that diffraction limit. Because, you can go to shorter and shorter wavelength like 0.1 to 10 nanometers and hence, you can generate much smaller features using X-ray lithography technique. There are certain disadvantages too of X-ray techniques. One, as I already mentioned that it may be expensive. We may have to use synchrotrons sources and then you have to use thin X-ray masks and those are expensive. Then, there can be deformations in the polymeric film. There can be vibrations and this process is also a time consuming. So, these are some disadvantages. Of course, if you want to have very precise and small features then you have to go for X-ray lithography.

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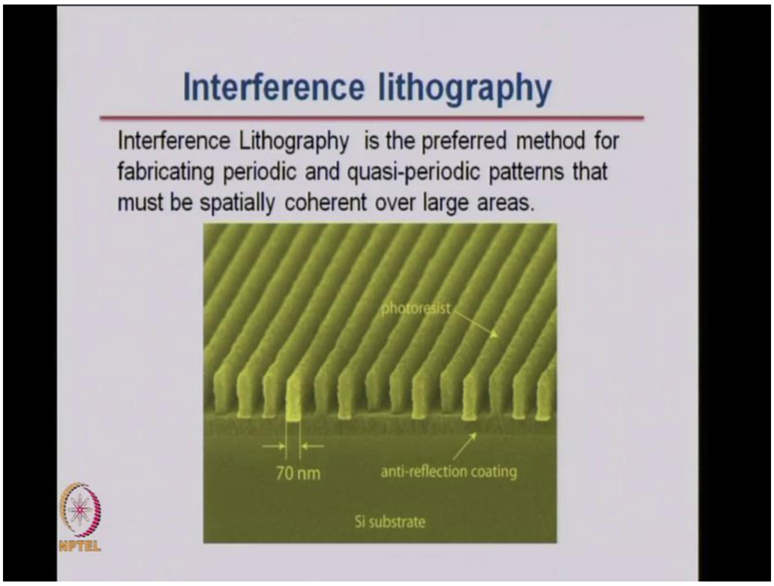

Now, we move on to what is called interference lithography. The term interference, as commonly studied in physics, as you know, you have two different waves and they are interfering to create either constrictive or destructive regions. Somewhere, the amplitude of the resultant radiation or the resultant wave will become higher, and some places it will become lower. So, this technique interference lithography, is the preferred method where, you want large scale pattern formation and where, the periodic or quasi periodic patterns are coherent over large areas. So, this is a very good technique for making such large area patterns. Here, you can see that you have silicon substrate, on which you have anti reflection coating and then you have this photo resist. You can have negative photo resist or a positive photo resist and accordingly, you can get the patterns on top of them.

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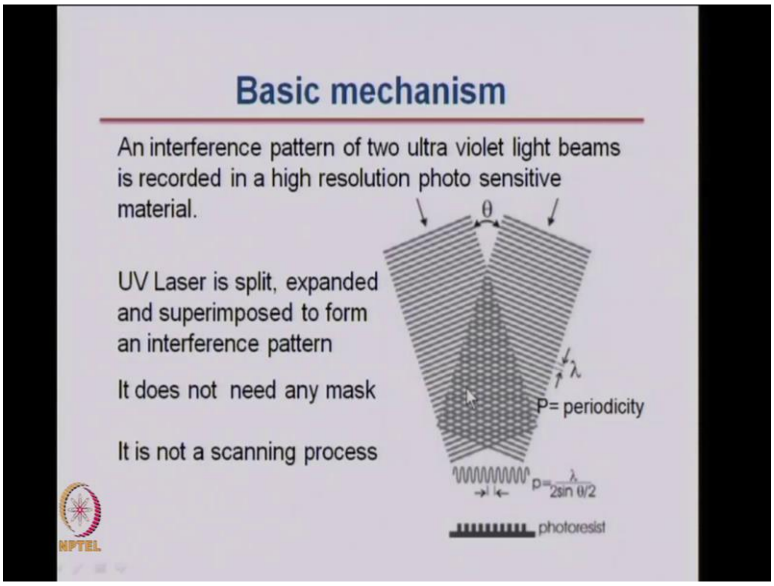

So, the basic mechanism of this interference lithography is, you make an interference pattern between two light beams. Here, if you chose the ultra violet or UV light then you have two beams of UV light. So, this is one beam and this is another beam and they are kind of tilted at an angle theta and they will interfere. When they interfere, they will generate this pattern. If you look at the variation of their amplitude, then you will see a periodic variation of this amplitude, which is related to the wavelength and of course, the angel at which, the two radiations or meeting. You normally, use a UV laser, which is split, expanded and superimposed to form the interference pattern. Now, this technique is very good because we do not need a mask and it is not a scanning process.

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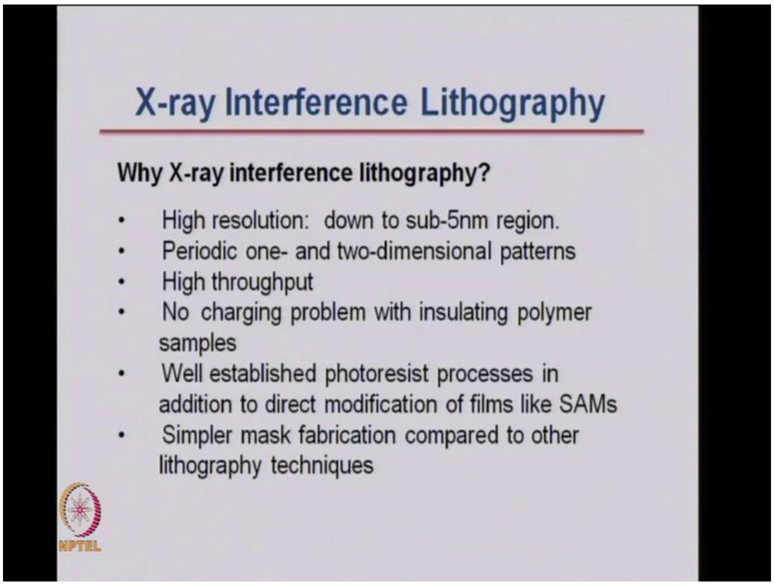

If you use X-rays, that is you passed two beams of X-rays, instead of UV then you get what is called X-ray interference lithography. Now, if you use X-ray interference then you get high resolution. You can go to sub-5 nanometer region. You can get periodic structures of less than 5 nanometers. You have high throughput; that means, you can make many nanostructures very quickly. There are no charging problems in this technique and you can use other photo resist processes, in addition to direct modification of films just like, these kinds of SAMs, which are called self assemble mono layers. The mask fabrication is much easy compared to other lithographic techniques. So, X-ray interference lithography is a very advance form of lithography, where you are using two X-ray beams to interfere and creating periodic patterns, and these periodic patterns are at a level of less than 5 nanometers periodicity. Using this you can generate very large scale periodicities.

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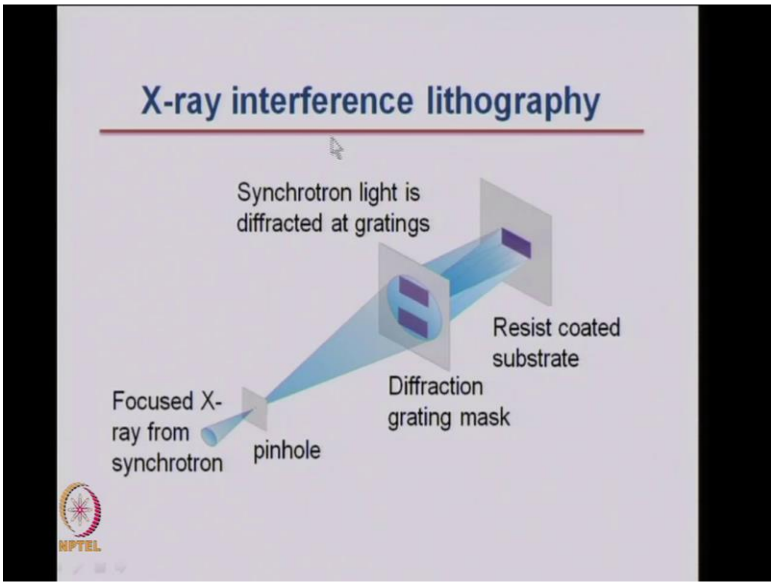

The X-ray interference lithography is shown here. You have an X-ray from synchrotron going through a pin hole and this synchrotron light is then diffracted at a grating. That grating is basically, a mask and the pattern on this mask will result in the ultimate image that you want. You have this substrate and this substrate is coated with resist. On the top of the substrate you have the resist, when the X-ray, after interfering here, it creates a pattern here. Then that pattern will be edge on the substrate. So, you are using X-rays going through a mask, which has a particular pattern and then diffraction is occurring and you are getting a periodic structure, based on the interference of the two beams, which is, the two beams are being generated by this grating and you get a structure of your choice by the design, which you made in the mask. This is the way that you generate X-ray interference lithography based on two X-ray beams, which are interfering with each other.

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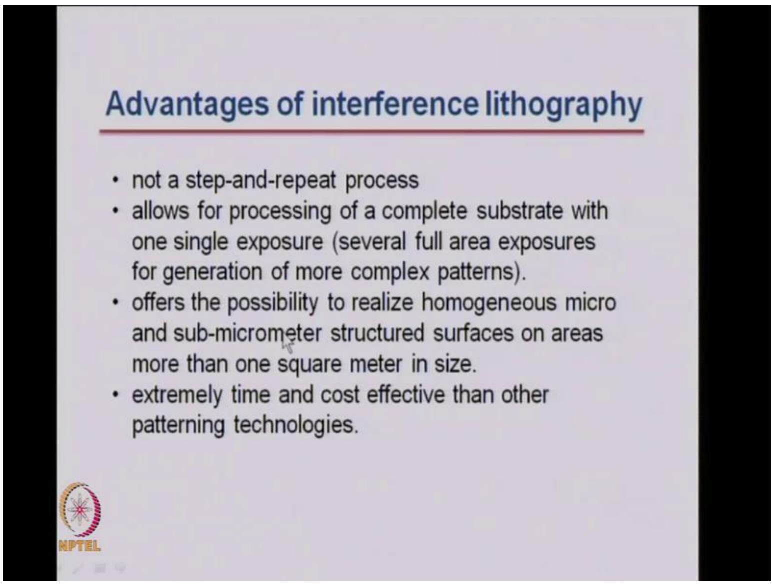

The advantages of interference lithography are that, it is a one step process. It is not that you have to repeat steps after steps. It allows for processing of a complete substrate with one single exposure. So, very large pattern can be generated using a single exposure. Of course, if we have a very complicated pattern then we have to do several exposures. It is possible to make very small sub micrometer structure surfaces on area, which are more than one square meter in size. It is very effective for large scale structures. It is time and cost effective compared to many other pattern technologies. So, these are the advantages of X-ray interference lithography. With that, we come to the end of today's lecture, is lecture 11 of module 2. I thank you all for your patience and we meet again for the 12th lecture, which will be the second lecture on lithography.

Thank you very much.