Fundamentals of Micro and Nanofabrication
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Lecture – 41
Emerging lithography techniques

In this lecture on lithography, I would like to discuss alternate lithography processes. So, so far, we discussed a lot about optical lithography, and then we also discussed about electron beam lithography, but there are other competing lithography techniques that is being explored primarily to achieve a better resolution on one hand, and also look at unconventional way for various applications. So, let us look at a few of those examples.

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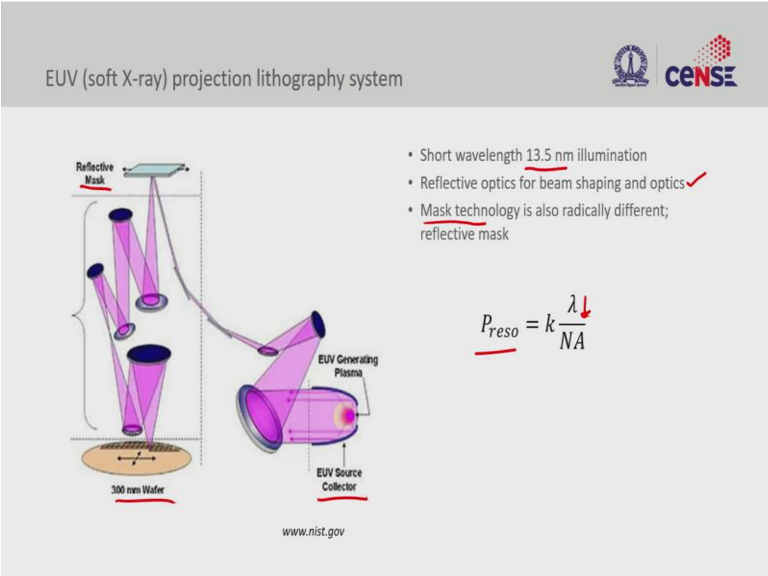

So, the continuation to optical lithography in terms of resolution is extreme UV lithography. So, this extreme UV lithography is being considered as the next step towards addressing the resolution needs by reducing the wavelength. So, here we are looking at 13.5 nm illumination wavelength. So, this is a soft X-ray type. So, the rays are generated from a plasma source, and then used in reflective optics which is very different from the transmission optics that we have seen in optical lithography.

So, by reducing lambda, we are trying to achieve better resolution. We all know when you go down in wavelengths, the materials become transparent and X-ray is a good example. So, X-ray on one hand where you can see through most of the things. So, you cannot use a regular transmission lens optics, so that is the reason why we use reflective optics. All the beam shaping and optics here are going to be reflective right. And the other important thing is the mask is also going to be reflective.

So, the whole idea of this now the diffraction through transmission is now going to be completely different. So, it is going to be reflection. So, the diffraction is going to be very different, and the optics are also going to be very different. So, here we use reflective mirrors in order to get the light from the source right through the mask, and then on to the wafer. So, all these lenses are reflective lenses now. The mask technology is also reflective.

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So, this is just a cartoon of illumination tool from ASML extreme UV illumination tool, where you can see the source, it is beamed to various optics. So, this is all beam optics, this trying to make the beam expand, and then profile the beam, so that we could expose it to the mask right. So, there should be a uniform exposure to the mask. And once it is exposed to the mask, then you do also required optics in order to get it to the wafer. You can see here the complexity in getting the beam to the mask and also getting the beam onto the wafer.

So, another interesting point here is this whole chamber should be in vacuum. So, if you look at this lower wavelengths, the spectral efficiency of this sources are very low. So, the amount of photons that you get is low, so you want to make it very efficient. So, in order to reduce dispersion of the photons, you should operate these optics inside a vacuum chamber.

And that again is a very technically challenging task, where you have highly sophisticated reflective optics that need to be aligned, at the same time this should be in a chamber. And that is the reason, why, you know all these challenges including source stability, the alignment stability, the mass technology, and the resist technology, the extreme UV hitting the production scale that is required is still being delayed.

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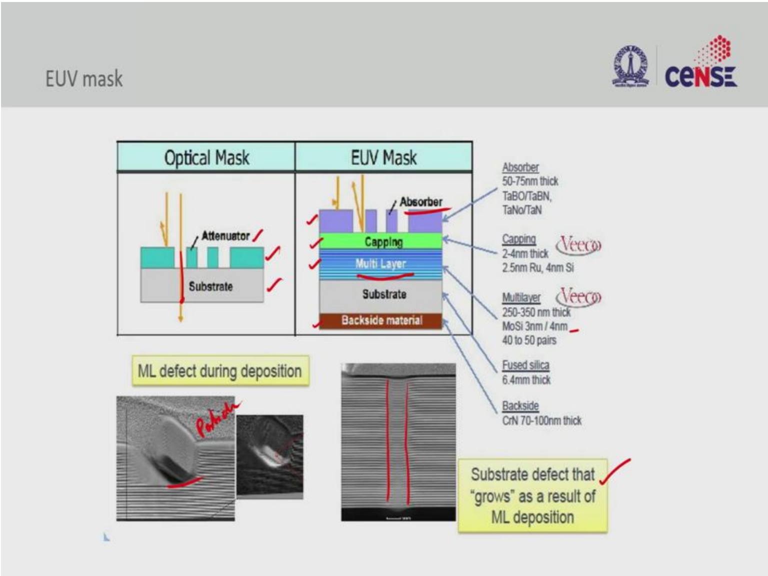

And this is the mask technology. So, the regular optical mask uses an attenuator, let us say a chrome like layer and then you have a transparent layer where it goes through. In EUV or extreme UV mask, this is slightly different because here it is reflective. So, you also have absorber, but then instead of you know transmission you have multilayer reflectors. So, this multilayer reflectors use a combination of molybdenum and silicon. So, multiple layers of molybdenum and silicon creates this reflection, and that reflection is again captured through the optics. And this is protected by a capping layer.

So, all these layers need to be transparent. So, you want these layers to be transparent not absorbing, at the same time they should also be responsive to the wavelength, so that is how you create this reflection. So, as you can see here, it is very hard to make this complex structure unlike optical mask where you have only two elements that is substrate and attenuator.

Here you have absorber, a capping layer, multilayer stack, and then you have a back side material to protect any transmission and so on. So, it is very important to make all these layers meet the specification. And in case of any misalignment or non-uniformity, you will transfer that non-uniformity on to your feature.

Just to give you an example you have this dislocation in the multi layer stack will quickly result in deformation of your reflection. So, the substrate defects could directly translate into reflection effect. So, during a multi layer deposition, you also want to make sure that you do not incorporate any defects.

So, this is a particle defect, and you do not want to have this particles there, because your light source wavelength is 13.5 nm. So, you need to look at the scattering cross section. So, any dust particles which are in the order of wavelengths that is, 10 nm or 5 nm will scatter, and that will create undesirable imaging problems.

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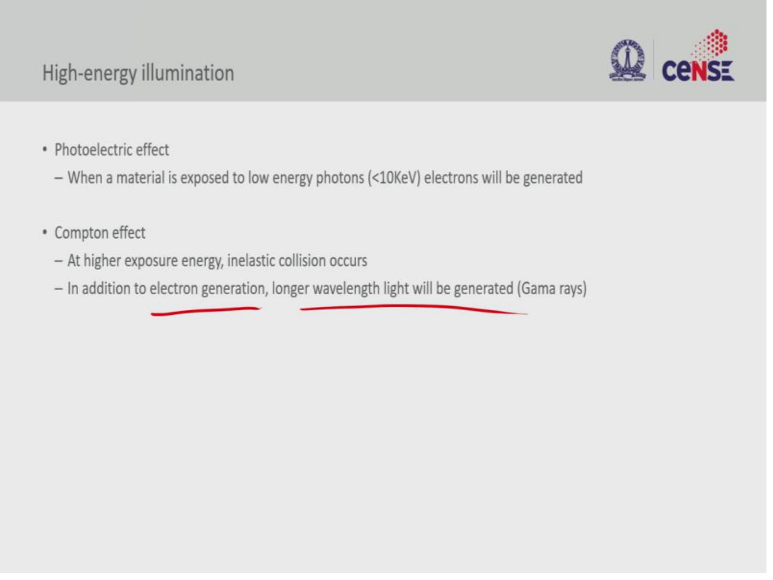

And there are other problems related to using high energy, the few of the two predominant once are photoelectric effect and compton effect: where a continuous exposure to this high energy radiation will degrade the material right, and it will create elastic and inelastic collisions at very high exposures. And this will create you know electrons and also you create longer wavelength light which is very dangerous.

So, you want to make sure that your exposure is under control that is again a reason why keeping it in a vacuum and sealed tool is really important, because this can create health hazard if you do not take care of all these protections.

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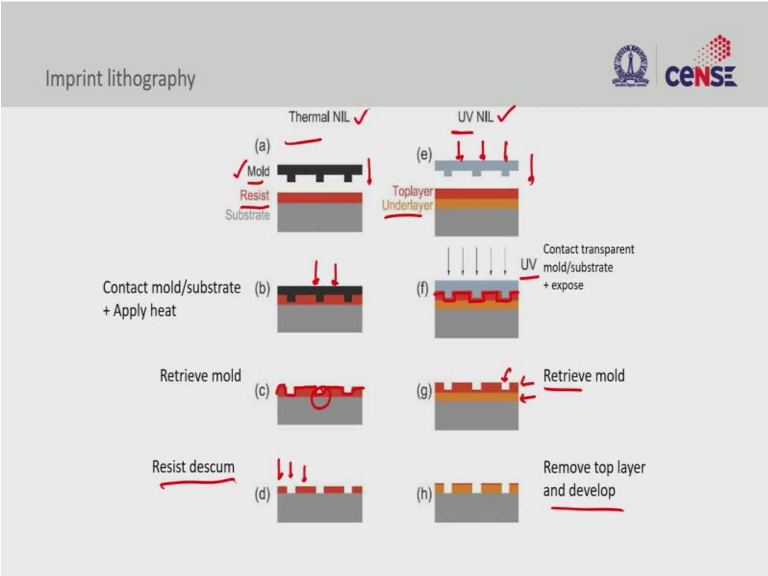

And the alternate form of lithography is the imprint lithography, which is used quite a lot in research and development, academia and also for a lot of fluidics. So, this type of lithography is used, where we use a mold. Instead of a mask, that is used to transfer the pattern to the resist, here we use a mold. There is a template. And we press this template against a resist, and or a layer can take the shape of the mold.

So, there are two ways to transfer, one is once you press this mold on top of the layer, the soft layer, you either apply thermal energy to transform the pattern or you do UV exposure. So, when you expose it with light, there is a cross linking that happens. And the soft polymer takes the shape of the mold. So, the polymer will take the shape of the mold. Even after retrieval you see the shape preserved.

On the other hand, you have thermal nano imprint lithography where you heat after putting it together. When you heat it, the polymer takes the shape of the mold, and then you should cool it down. And then after cooling it down, and then retrieval, you will see soft layer on the wafer takes the shape of the mold.

So, after removing it we always do descum right and removal of the layer (soft material) that is left here, cannot be completely removed. You need to do a short plasma etch in order to remove it. And then in case of UV, you can have a both soft layer that is photo definable, and then you have a underlying layer that can be used to transfer the pattern by either using a developer or you use some kind of plasma process.

So, both can be used. And based on the application you either use thermal or UV. One of the main difference in using thermal or UV is the type of mold. In thermal nano imprint lithography, the mold need not be transparent. You can even take a steel mold, and then press it against the soft material and then heat it up. But in a UV nano imprint lithography, mold should be transparent, because you are illuminating from the top right. So, because you are illuminating that mold should be transparent. So, more often quartz is used as a mold. While in thermal nano imprint lithography you can even use silicon wafers. So, you can make a mold in silicon wafer and then use that mold to transfer the pattern.

One of the important thing is the force that we apply because this is hard contact. We can use the proximity printer or contact lithography tool to do this lithography. We do not need any special equipment to do this. This the same contact lithography tool that can be used, but the only thing is you may need a nano imprint lithography attachments either with heated chuck, a transparent mask or a transparent mold here. So, this is a very popular lithography technique among academic community which is very cheap. Once you make the mold you can repeatedly use that, if you apply the right force and not break the mold right.

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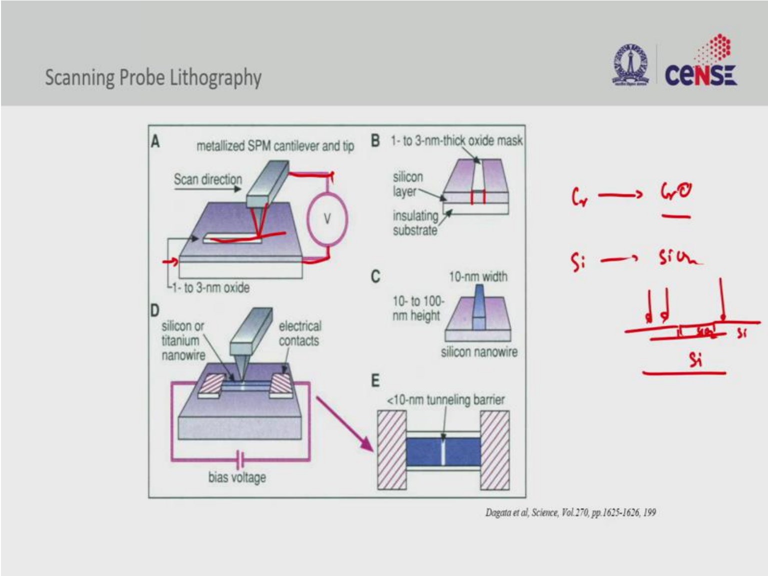

And the next type of litho is scanning probe lithography. Here we can define very fine features order of you know 10s of nm by using a tip right. This is a physical process that we saw in the first lecture, where we can directly transfer the pattern. Here we use a very sharp tip like a atomic force microscope tip or scanning probe tip, a cantilever tip, and then we apply a voltage between your substrate and your tip. And the important thing is the substrate should be coated with a material that you can change the property when you apply this field.

For instance, take chromium. Chromium in the presence of a high electric field in atmosphere can create can oxidize. This oxidation can result in a electron migration. So, you can either oxidize this surface or you can create electron migration. So, there is electron migration lithography which is using the same type of process, where you apply a high electric field that creates oxide which creates electron migration. So, you can also oxidize the surface. For instance, if you take a material, for instance silicon, and then you apply very high electric field and then you can create silicon dioxide. And this silicon dioxide can be used as a mask.

So, now you have oxide sitting on silicon, and you use that silicon as a mask and then transfer the pattern. So, we can use dry etching process, where you write a very thin layer of silicon dioxide and then you can etch silicon. So, you oxidize this layer and the other parts are still silicon, and then you can etch this layer while silicon is etched and silicon dioxide can stay. And this is how you transfer the pattern if you are using a scanning probe lithography.

So, a conventional scanning probe tool or AFM tool can be converted to the scanning probe lithography tool. But the important thing here is you should make a high electric field between the tip and your substrate. And you want the substrate also to be conducting to some extent, so that you can create light field. You can either do it by small semiconducting coating or a very thin layer of metal coating that will help you to create this.

And the other important thing is there should be some chemical change that should happen because of this electric field. Just a field alone is not good enough. The field should either create electron migration or it should oxidize the film, so that there is a chemical change that happens on the surface which we could exploit for pattern transfer. So, this is another interesting way of pattern transfer.

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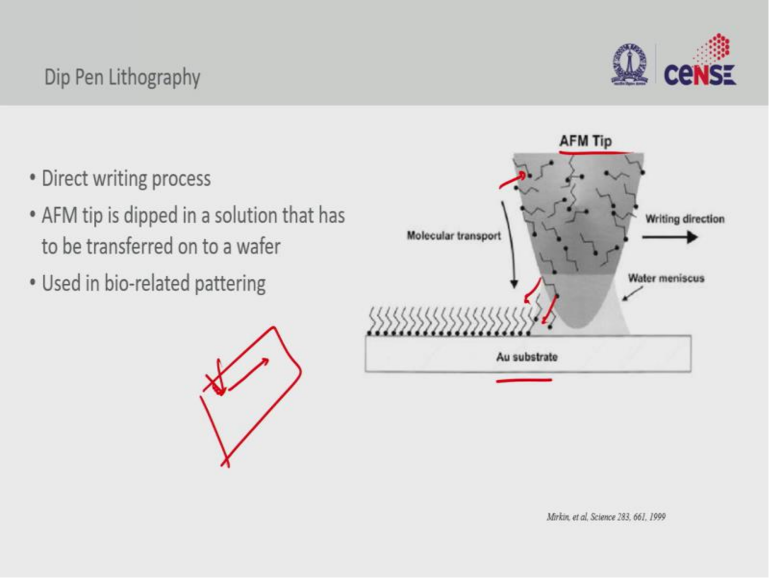

And again using a AFM tip, this is slightly towards a biological pattern writing, where you want to align molecules in a certain fashion on a substrate. So, there are you know bulk processes where you dip coat a certain layer, but the problem there is you will coat all over the wafer. But if you want to pattern, if you want to align few of this molecules in a certain fashion, you need this dip pen lithography where you take a AFM tip, and then first you coat it with the molecule that you want right. So, you first dip it into a solution that has this molecules right, and then you lift it up and then bring it to the substrate that you want these molecules to be transported to and then you slowly move.

So, you take the substrate and then you take the dip pen with all these molecules, and then you move this pen on top of this substrate. And as you move along the substrate, you will see all this molecules come and attach to the substrate. Of course you need to make sure that the wettability of this surface is also taken into account where you should be able to transfer these molecules. So, this is primarily used for bio-related patterning where you want to transport molecules and arrange molecules in a certain fashion. So, that is a brief summary of alternate lithography that is existing.

There are many number of lithography techniques that is available in literature and a lot of demonstrations are there. We would not be able to cover all of it. I just gave you a few hints about how you can use probes for a pattern transfer, how you can use mold imprint lithography can be done, and also you can use X-rays for instance for transferring this pattern. And for instance, you can take contact lithography and replace the mercury vapor lamp with X-ray source.

You need to think about what kind of mask you are going to use, because most of the material are transparent to X-rays. So, you need to think about what kind of material and what kind of thicknesses one need to use. You can actually use X-rays for contact lithography and that will give very high resolution. So, there are lot of adaptations one can do to the existing tools that you have and also adapt; for instance AFM for pattern transfer, and also scanning probe for pattern transfer.

So, all these are alternate techniques and people get creative when there is a need to look for pattern transfer technique that is cheap and it should operate in vacuum, and also achieve the right kind of a dimension one wants. There are many as I mentioned so just explore and then see whatever pattern is useful for your own research. So, with that I hope you got a feel for many alternate techniques, it is up to the you to decide exactly what to go, whether my process is compatible with the substrate or whether my critical dimensions that I am going to achieve are going to be compatible with my design patterns or not right. So, the need dictates the solution.

So, with that we come to the end of the lithography lecture series. Hope you had a complete understanding of this lithography process, the importance of various elements in the lithography process, and how the imaging happens in both optical and electron beam lithography, and the importance of each process step right. It is not just the writing; it is about what kind of resist we choose and the development process that we use, the baking process you use.

Each and every process in lithography is important; we cannot skip processes and expect the result that we are trying to achieve with this high resolution process. So, I hope you will use this information in your research program and also for general understanding as well.