Soft Nano Technology
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Lecture – 17
Photo Lithography – 6

Welcome back to the 17th lecture of the course and the 6 lecture of Photo Lithography this is the last one, we will wind up Photo Lithography now and as you can see in the content our next topic will do the more polymer specific so called soft patterned in technique or the Soft Photo Lithography we will take it up. Let us finish Photo Lithography so fast.

Hope you have a fear idea about Photo Lithography and it should be new to most of you, but see several simple techniques and whatever be your background I am pretty convinced, you should be able to follow it. Any problem you can always you can use post questions in the discussion forum. I and my T.S Nandini and Anuj will try to address to those questions, but you can also get a lot of lecture in the internet and I am sure with the outline knowledge that I have given you will be able to follow them.

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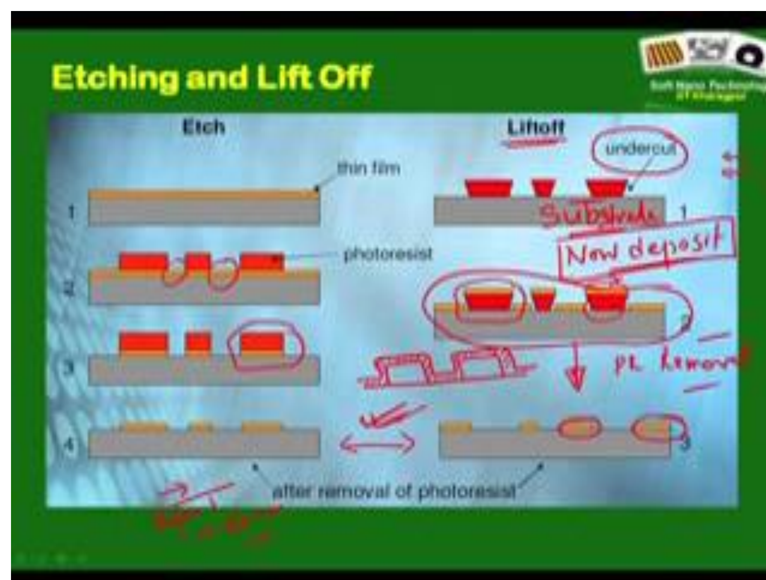

We are now close to the so called Etching step which we already discussed. So what is etching and dry etching any things like that? The way I have introduced the topic to Photo Lithography is obviously we will do etching because we have looked it from the

standpoint of microelectronic chip fabrication and where etching is standard because if then remove this on this configuration is now taken for Dopant diffusion, but there is another version that is available and particularly one uses that for making metallic nano structures often is what is known as Lift Off. So you see this schematics sort of tells you what you do the fundamental difference is that you do not have that so called barrier layer or whatever initially.

You start depositing the photo resist layers straight away or may be this figure even expense it better or may be this figure is good. So, this is the substrate and what you can see is that you sort of had the photo resist layers straight away on the substitute. Let me tell you I am mean if you have talking about a micro electronics chip fabrication this is not the route, but liftoff is used for many other settings and particularly if you liked to make metallic nano structures. So what you do? You do the photo resist processing, you do the development and as I was mentioning that during development and exposure you can cleverly manipulate the condition so that you can have under cart. So, what you do you may be beats of overexposure, beat of over development. So, far exposure would essentially lead to at transfer of energy in the red in deeper into the film and you can create undercut structures.

There is a rational efforts doing undercut structures and which is very clear form the next step. So, what you now do is, you now deposit the film and often this is metallic thin film. How does it undercut help? The undercut helps in creating discontinues metallic films, because see the next step now you sort of do a PR removal or Photo Resist removal something we will talk in 2 minutes time and see if you do not have an undercut, if your structures are like this, there is a possibility that the thin film you deposit might become continues.

And then how do you remove this photo resist layer you. In fact, today again put it in some sort of a chemicals solvent which eats up this and logic is that if the base here goes away, the metallic depositor over here also goes away, but if you get a continues thin film of a metal or whatever then you cannot strips the photo resist and you cannot achieve the patterns.

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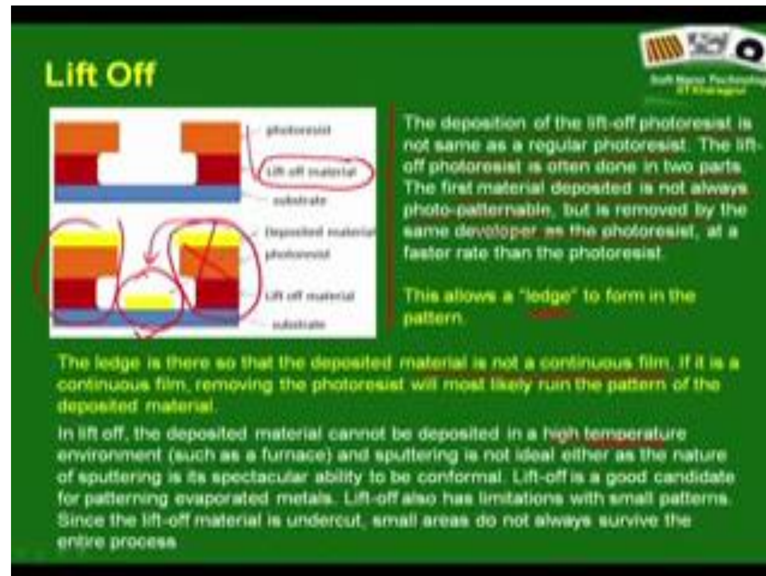

That is why you are for your lift off one of the necessary condition is the undercut. There is a bit of details which you can read, so here is essentially so called Lift Off material that you would like to have. It may not be a direct photo resist straight away. So, you might use the photo resist twice and lift off photo resist is not same as a regular photo resist. So, this is often one use as a lift off material, which is some sort of a photo resist, but new sort of the processing is done in 2 parts the first material is deposited it. It may not be a photo pattern able, but it may be removed by the same developer. So, you create a structure, then you create a photo resist layer on top of that and then you do the exposure and do the deposition.

The logic is when you remove the photo resist layer, this whole thing goes away and this is the only structure you are lift with. So, you need to have this type of an undercut or ledge that is mandatory for the lift off process. So, that the deposited layer as we have already discussed is not continues. Lift off process cannot be deposited a high temperature because that is a one of the limitations because after all you are depositing it on an existing photo resist layer.

If you go for a very high temperature you are bound to either damage or made this photo resist layer, which you do not want to have. So, this is another version lift off is a, as I mentioned lift off is a very good candidate for patterning evaporated metals, one can

create let us say strips of gold and silver and things like that. It is pretty regularly done for many experimental studies right.

And of course, making very small structure is very difficult because you need to have this undercut and if you try to create undercut structures with very small straights what will happen, there is a possibility that the whole structure collapses. So, those limitations are there, you are more than welcome to check out additional literature on lift off.

Irrespective of whether you do etching or lift off you either have this configuration or you have this configuration or this is the final thing you would like to have. Video doping or video other experiments or whatever you want to get rid of a photo resist layer. Because photo resists utility is now over, its utility was to transfer the pattern on the photo mask on to on to the barrier layer essentially and that you have achieved and now it is time you get rid of the photo resist.

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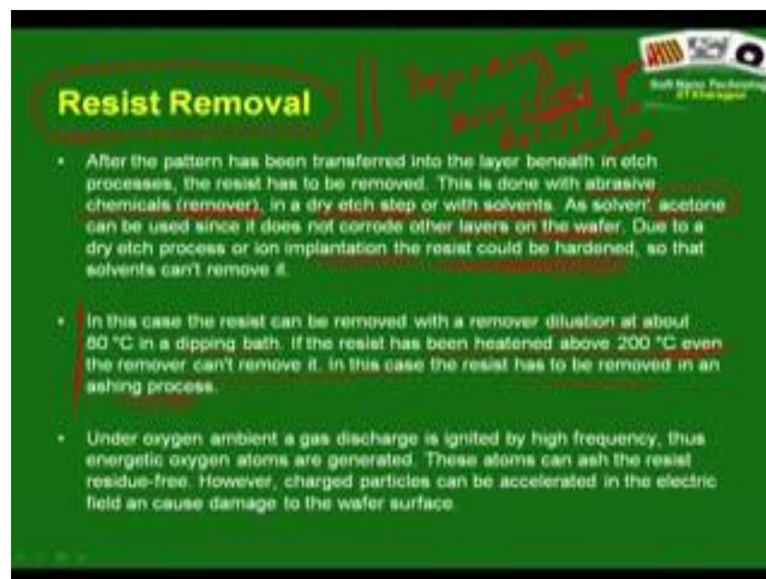

The next step is the Resist Removal Layer, Removal Step just should be a simple step. So this is done with some says are abrasive chemical it is again some sort of a solvent. It can be done in a dry etch step also or it can done with solvent. Acetone for example, is a good solvent which dissolves almost everything, but does not corrode the wafer layer. You can, I mean there are possibilities that you need to choose your resist removal mechanism based on what etching you have used.

If you have used let us say reactive ion etching type thing then you might need to do that there might be the resist the existing resist might have got hardened due to ion implantation and you need to worry about that. In case the resist cannot be remove it with the remover dilution at about 80 degree Celsius in a dipping bath, then it is heated at even higher temperature and then one goes for something that is known as the ashing process.

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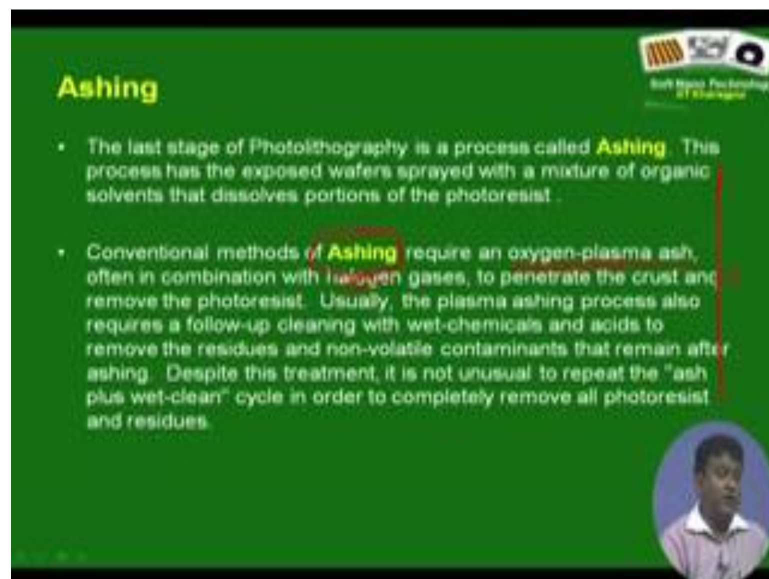

Ashing process, it is again and oxygen plasma ash of the existing resist layer. So, I will not like to go too much details of this resist removal. So, in a nutshell depending on, how strong your resist is, you may need to choose the resist removal process and how strong again is the function of the what is the etching methodology you have adopted. If you have typically adopted weight etching then the chances are the resist is not cross link to hardened, but if you have done reactive ion etching any things like that, you might need some stronger means to remove the resistant and that is done typically by ashing.

Why this is the mentioned as the industry standard? because in industry as I already told the industry level is always array or die, de array that is adopted for the etching step and that leads to hardening of the resist layer, so once the resist is removed.

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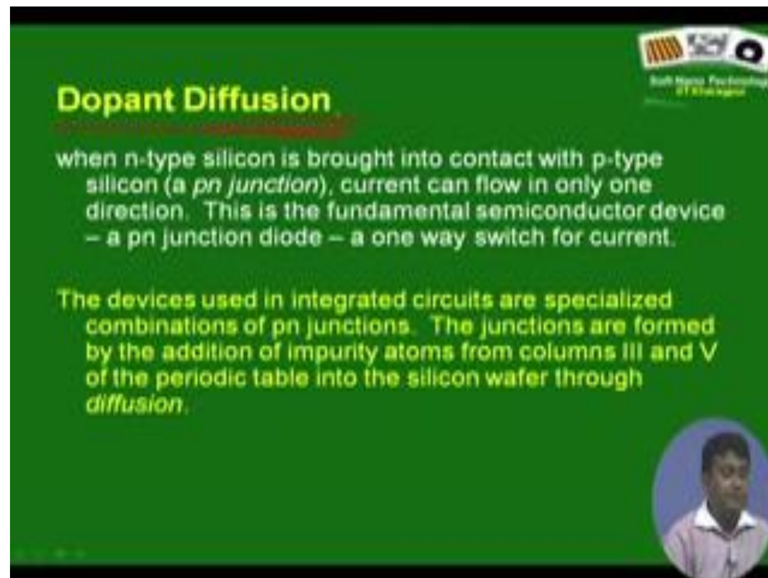

Now, the next step is the Dopant diffusion as I have already told that I will not worry about these because this itself is another area of research one can in fact have a semester long course on this one and then you just put it in the reactor chamber and you sort of achieve your Dopant diffusion. So, I will just read on this video now again and just to ensure that you can follow the entire process.

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This is the growth of the, let me just one some of you might get very bored that I am repeating the same thing again and again and again, but this is exactly how I teach in the

classrooms. So that everybody is following and please do not mind things will be repeated, it is important that you understand that is the most important thing.

You see you start off with this wafer you grow the barrier layer, you then spin coat the photo resist layer and now you see qualitatively or in a very simple manner you understand each one of the steps because we have discussed each one of the step in some sort of detail, after that you need to worry about your photo mask, you need to bring in your photo mask, of course what is not shown here or apparently this shows a contact printing, but you also know that there are additional complexities in the printing step.

You choose the printing mode, it can be contact printing, it can be proximity printing, or it can be projection printing depending on what you would like to do. Industrial it is always projection printing and then you can have issues like immersion lithography where between the lenses that is the reducer lens and the substrate Photo Resist coated film. You may introduce some high reflective index water or high in reflective index liquids which further enhances the numerical aperture of the system and therefore, you increase resolution. Of course in projection printing you have the option of using a Reticle that is essentially a reducer optics that allows you to miniaturize the patterns on the surface of the film.

You can have a mask which contains larger structures, but depending on the magnification or the reduction radically you choose you can create smaller size features and that is how you can in principle create structures which are smaller than lambda by 2, the diffraction limitation set by optics. So, lambda is ruffle of the order of 200 nanometers. So, theoretically direct Photo Lithography in contact approximate printing you should never is able to achieve features which are smaller than 100 nanometers. But projection printings sort of offer you that option that you have achieved some additional miniaturization.

So that you now understand of course, this is the simplistic cartoon and does no talk about the projection printing, the step and repeat process or the mask align and details, which is fine if you understand its better, it is good, but even if you do not understand you do not miss out on understanding the basics of Photo Lithography. And then you do the u v exposure. So, then again you know that it is a Photo Resists. So therefore, there will be changes in the structural changes.

This is an expose photo resist layer, what is being used is in fact a negative photo resist I think because it is strengthen in the areas that are exposed are in fact strengthening, but does not matter. So, an exposed photo resist layer has now specially wearing property of the photo resist, part of it is strong part of it is weak which part is strong and which part is weak. We have had a detailed discussion depending on what type of photo resist tone you are using.

Next step is doing the development. So, the developer solution in fact removes the weekend part of the photo resist and then again you know that industrially you may not be doing a ring zing, you might in fact be using cleverly using the spin coating platform itself to do the development. Of course, after you have applied the photo resist, after you have done the exposure, after you have done the development, it is very important to get rid or remove the any random solvent within the system and therefore you have different baking steps like which is not shown in this cartoon. You have soft bake, post exposure bake and hard bake steps. So once this is done, once development is done, then you need to worry about etching. Again this is very simplified picture. So, you talk about straight away ring zing in hydrofluoric acid.

And you have little idea that this in fact is Weight Etching. Weight Etching is simple, but weight etching is non selective and it can be isotropic. So, it might not create patterns in the barrier layer, exactly following the contours of the photo resist layer and that is not desirable in most cases at least in microelectronic fabrication therefore you have more complex and more advance etching steps which are an isotropic and selective like reactive ion etching and dry reactive ion etching any things like that, but so that is where you are do that etching step and then after you are etching is done you need to now get rid of the photo resist layer and that photo resist layer again it is very simply shown as that you do a solvent wash, but that may not be the case, you might have to use a plasma and you need to use a step or process called Ashing.

Depending on how strong your random photo resist layer is and how strong the layer is also depends largely on the etching protocol you have chosen. So, if you have chosen a simple weight etching probably a solvent wash as is shown in this cartoon is probably, but if you have done something like reactive ion etching and stop like that, probably you need to go for ashing. So, any way after ashing is done and now you see that, you have a patterned barrier layer and now it is ready for the doping reaction.

You the doping reaction and after the doping is done what you do is you get rid of the again you wash with the hydrogen fluoride to remove the barrier layer and then you create the PN junctions as we talked in the very first slide. So, this is an action Photo Lithographic process for creating patterns. Now, we are ruffle done with our discussion on Photo Lithography, but let us try to understand certain things. So, we may be some certain things for your information.

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Key requirement of lithography for manufacture integrated circuits; so critical dimension control, overlay defect control cost because please do not forget the process are ruffle 30 to 40 percent of process are cost actually is due to lithographic process.

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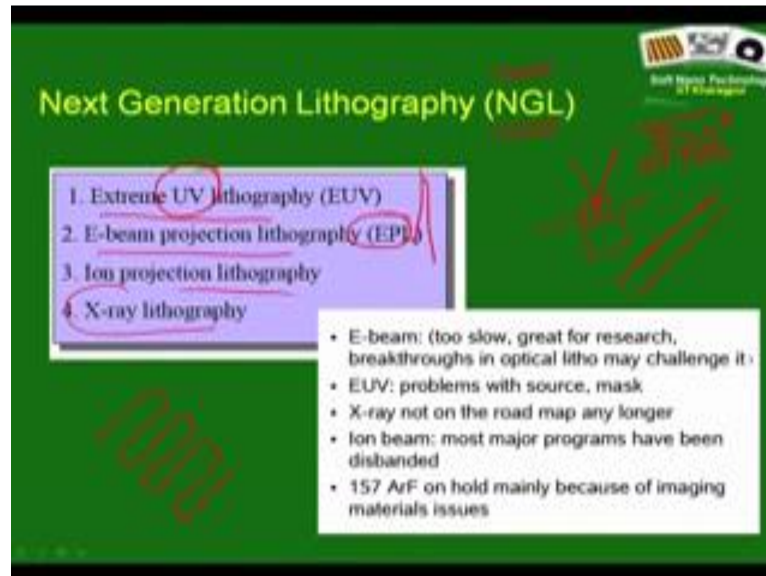

That is an important step in any mechanism for cost removal is, therefore welcome. There of course, this next generation lithography techniques to achieve even smaller sizes, this is something I will not touch upon in this course because these are completely these carry talk about completely different physics.

You have extreme UV lithography, electron beam lithography focused on beam ion projection lithography and stuff like that they follow in to the category of next generation lithography and most of them. In fact, use a ion gun or electron gun to sort of remove materials along the contours; so then these gun rafters so for the surface and it removes or creates structures along its contour. So, you can go down to let us say with electronic beam lithography it is possible to go down to 30 or 40 nanometer or may you can smaller focused on beam 100 nanometer or even smaller than that even we do at Kharagpur regularly.

This is something I will not write, but there are huge differences there, they are very expensive instruments and most importantly they are serial techniques, they are not parallel techniques. What is a parallel technique? Is like when you expose a photo resist layer under a photo mask, all those structures that is there on the mask get transfer on to the photo resist layer at once. However, this is like it is like writing. So, you serially write as the beam rustlers it make structures like this.

Therefore, immediately you can conclude that its very slow, but then there are cases where you just want to create one master which we will talk in great details in soft lithography and that is where one of the advantages of soft lithography, you create one of this structures following this ion lithography techniques and then using.

In fact, this dependence on something some writing technique is also there in Photo Lithography and Can you identify where it is? These are the techniques, let us say something like a focused and beam or electron projection lithography or something like that or exceed lithography is what is used to create the mask because what you initially had is a quadge play covered with a corneum layer and it is during this writing you actually get rid of some zones, which create your mask.

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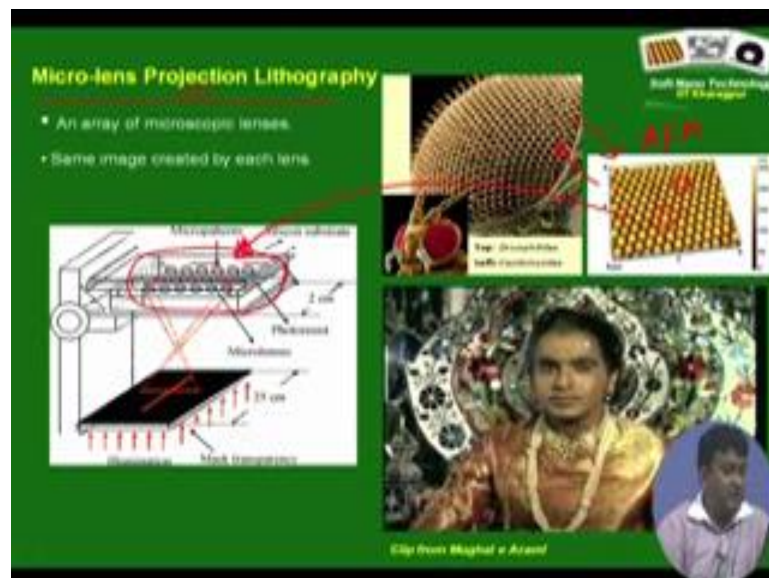

Again this is something that I will not touch up on, but there has been more fascinating developments in Photo Lithography. These are none of them had reached the commercial level, but they are very fascinating in terms of the science is very reach and people try to do many things.

1 of the things is that the micro lens projection lithography it is provide about 15 years back reported. It there is the clue from the eyes of insects, all of us know that insects have bug eyes their compound eyes. So, they have many of these lenses and they eventually focus at one place to create an image. So, what was considered, it sort of it takes clue from projection lithography, but instead of using a single reticle or a mask or 1

single lens for a miniaturization what it plans to do, is that use one pattern and you have an array of micro lenses, spherical small micro lenses do not.

Let us not get in to the details of how one can fabricate these micro lenses and how one can arrange these things these are very interesting, but here also some interesting is coming up. So, interesting things I would talk.

The idea is that you take an array of this micro lenses and create the same image on each one of them and then project it on the photo resist layer. So, I mean this is one ASSM image that I liked to show, these are not micro lenses, but these are spherical collides and when you under appropriate condition put this collides on a flat surfaces they again due to self assembly and energy minimization they in fact can get a arranged in a beautiful hexagonal close packed manner.

1 can take this. This you see, the ordering sort of resemble a bug eye and instead of colloidal partials one can now think of using micro lenses each one is a spherical micro lens and one can self organize them. So, all the mechanisms there they are in place and then what I am telling is that you try to create. So, this is the whole idea.

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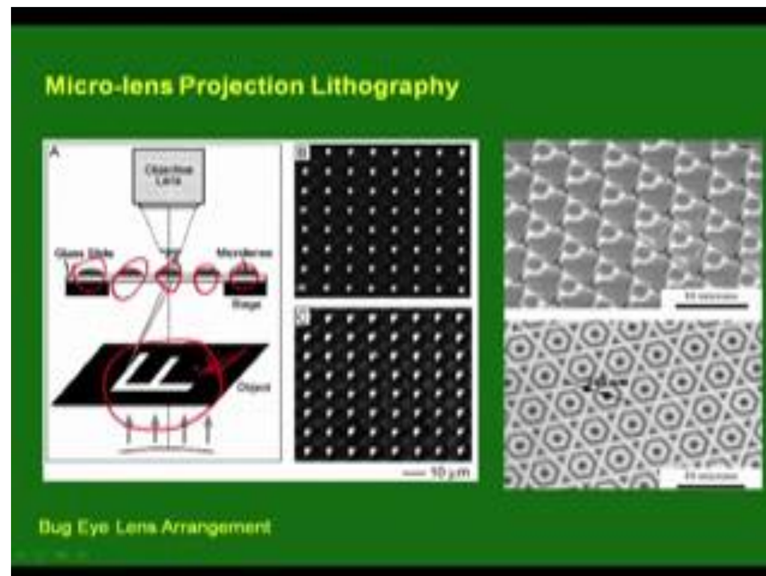

This is the original pattern and instead of the reducer lens, you have these micro lenses and each one of them sort of creates an image. So, you had one master and it goes on creating structures like this, does it make a sense, if it does not make a sense, I will give

you a strange clue on how it works. Let us have a look at this click from Mughal-e-azam. So it is not a lenses its mirror this is the effect this is known as array of mirrors.

Therefore, you are seeing reflected images on that all over the place, but if you now have a micro lenses here, you would be creating this multiple number of images of the same object on the photo resist layer and that is exactly what was the concept that was proposed in the micro lens projection lithography you can just enjoy the (Refer Time: 22:12) and I will decide a this is the same thing. 1 image, one object can be create multiple number of an images everywhere, the time that Prithviraj Chauhan, but that strengthful as per as micro lens projection lithography, but you enjoyed this example.

The last so this was consider to be a very big development about 15 years back, unfortunately it was very fascinating science because you very cleverly utilize self assembly of this was tiny lenses and then project it, but industrially somehow the things did not go, but I mean the concept was just amazing.

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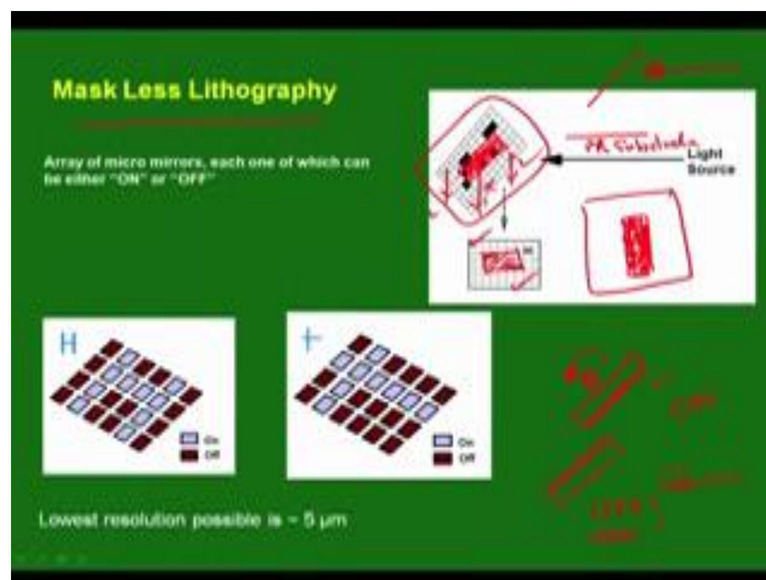

There is another development that in fact, took place about 10 years back now and that is the development of an instrument called Mask Less Lithography. So, what it does is instead of micro lenses it uses an area of micro mirrors and so. In fact, that each of the mirrors has a sweeful arrangement. So, this is the mirror, this is the shining side of the mirror and this mirror is attached to a holder which can be rotated by 180 degree. So, if the mirror is in this configuration its own but if you rotate it the shining side is on this

side light is coming from this side. So, this mirror appears to be off and that is the whole idea.

What they did was what was considered, I mean this development was around 2005. So, everything was computer controlled. So, the easy thing that did was they simply choose an array of number of the array mirrors chosen was in fact, identical to the resolution of a computer screen.

You simply draw a patterned on your computer screen. So, you a let us say you draw something like this on your computer screen. So, this will be black, this is your screen. So, once you connect the interfacing device, this is fully black. Within this mirror array what will happen these many mirrors because that the pattern you would like to create which simply turned off, while everything remains turned on. So, what is the advantage? Now they choose a very clever 45 degree angle for the light source the geometry was here was the photo resist sub strict and here was the light source.

You see that since these many mirrors are turned off the light will not reflect from here, but it will reflect from all other areas and therefore, the photo resist layer will not get exposed here, but it will exposed on all other area and therefore, whatever pattern you actually do on your computer screen using the simple software like AutoCAD or something like there are may be even paint I cannot be transfer on to a photo resist layer very cleverly.

I was lucky that I could actually see this instrument once it was under service there are several of these instruments and some of the institutes in India IIT Kanpur, Hyderabad JMC each one of them has this instrument.

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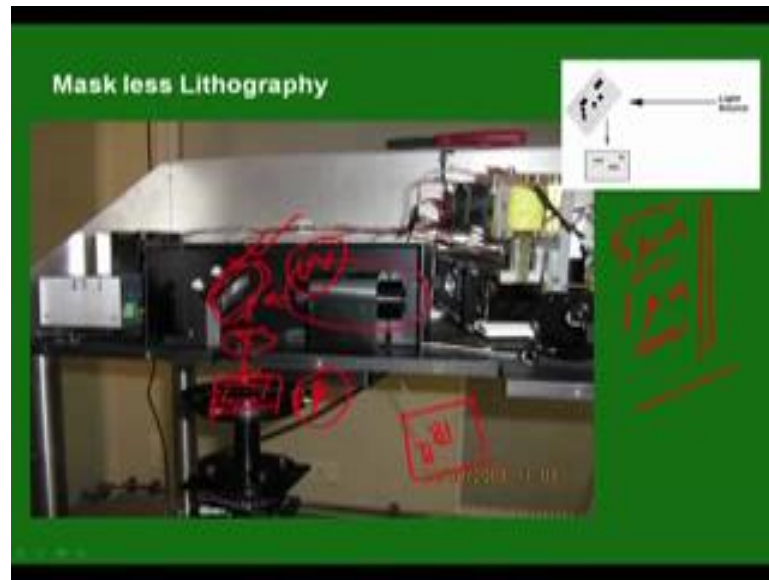

You see this is the light source, this is the mirror blank as I told that it is kept at a angle of a 45 degree and this is the substrate holder and this is not that because you what is the biggest advantage, you actually eliminate the requirement of a physical mask and you sort of use this mirror blank or this array of micro mirrors as a reconfigurable mask. So, one of the steps of sort of using a mask and fabricating a mask is straight away eliminated.

Of course, this cannot really give you anything like a chip fabrication because you need a mask aligners for that you do not have anything there this is for one step rapid fabrication for some other application areas like hydrophobic surfaces or some structure or may be some micro cantilevers, this is quite. This was good in the sense that initially it could give a resolution of 5 micron and then later models incorporated some reduction optics and they could go down to one micron any things like that.

With that, but essentially the basic I mean once the light falls again everything on the substrate was same you needed a photo resist idea is that the this light source of course, is an UV light source and then it the photo resist changes its structures along the contours of the patterns which transfers to the mirror array and then you can create structures.

With that I will stop my discussion on Photo Lithography. Please sort of go through these lectures and the resource materials in big detail and try to have a clear

understanding of Photo Lithography. From the next lecture onwards we will move on to a most polymer specific soft lithography based techniques.

Thank you.