Advanced Neural Science for Engineers
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Lecture 11
Lab 03 Lithography: Demonstration

Hello, today I will be discussing about lithography today. So you might have already seen the processes where we have silicon wafer on which we might have spin coated a thin layer of polyimide which is a flexible substrate and it is baked and cured. So that it can be used for the next step which is electrode fabrication, now, when we talk about a neural interface, mostly it will have a substrate which can be silicone or an electrode base of gold or platinum or one of them metals like that.

Now, the substrate can be silicone or polyamide and the conductive lines through which the data is collected can be gold or platinum or any other conducting material. Now, there are a lot of other surface modifications that can be done as well, if we are planning for stimulation of the brain as well. Now for our course, we will be showing mostly for device fabrication that can be used for neural recording mostly. So we will see how the process is happening.

Now, if we have a substrate. And we need to create electrodes which can be used for recording there are multiple steps involved in it. So first the substrate will be there one approach could be which Crosser Hardwick might have already taught you is that on the substrate, we can deposit metal say gold or platinum or titanium gold or titanium platinum, that metal can be deposited followed by pattern transfer using lithographic process.

Once this pattern is transferred, we can etch of the excess metal to realize the electrodes. Now, that is one approach to do lithography and creation of electrodes or the features that we need. Another alternative approaches what we can do is to have the substrate we can do lithographic first, and transfer the pattern followed by deposition of metal.

Now, what happens in this case, is that when we transfer the pattern before metal deposition, the patterns will be designed such that that will be opening will be there where the metal can get deposited, which forms the electrode later on, and wherever there is no opening of the photoresist and the metal is there, which will be removed during the next step which is known as liftoff.

So there are two alternative methods during lithography where we can realize metal acontacts, one is a lift-off approach where we do photolithography first and pattern de-photoresist followed by metal deposition, and then do the lift-off process where the excess metal is removed.

By removal of photoresist alternate approaches is deposit metal first then go for photolithography, so that you can use the photoresist as a mask for etching. So either of this process can be done. Now, when we are using a flexible substrate it is ideal to use, one approach over the other. So based on our device requirement, we are doing a lift-off process.

So what you would see today is that on the polyamide substrate that we have or polyamide substrate, which was encoded on the silicon wafer, we will be doing photolithography for transferring the pattern. Then we will see how e-beam evaporation can be used for depositing metal and which further can be, taken to liftoff, so that we will get the metal lens.

So we will see the process. Now, we have earlier seen the processes where we have seen how the wafer is cleaned and, processes like that are the pre-processing, and which you might have observed that that happens in a room which is white or there is white light like the where place, place where I am standing. Now behind me, you can see a room which is yellow in color.

So this is known as a Yellow Room, where the lithography has to happen. Now why this room is necessary. So if you think about it, photo lithography itself means that, there is some light dependence there. Photo lithography. Now lithography is basically patterning, and photolithography means patterning with the help of light. So this is a process that have been evolved long back.

So one of the example, that you might be aware already, is where photography is used. So there used to be filmed based photography back in the days. And there used to be a film where there is negative, and other things like that you might have seen, before, may be like 20 years back those kinds of photographic films were there.

Now for processing that film to the photograph that we need or the printed paper on the printed paper, a similar principle was used and you would have seen in movies or something where, they show a photographer processing their photo, they might have used a room like this, yellow room. So why we do this or even for photography or photolithography why do we need a Yellow Room?

So the thing is that for photolithography to happen, we use a specific material known as photoresist, which you might be already aware through the other lectures that you had already. So this photoresist is this light sensitive. So what light sensitive means is this photoresist is the material if light falls on it, especially if UV, light fall on it is property changes.

So consider this like a, a fluid kind of material, which is like a paint assume photoresist like a paint, which we coat on a substrate using a process known as spin coating, so we have a thin fluid coating over the substrate that we need. Now we dry it, so that is not a soft bake. or pre bake. So that is one step.

Now, after that, after the pre bake, what we have to do is, we will do the lithographic process. Now, after pre bake when you do the lithography, the areas where the light falls can become soft, or hard based on the property of the photoresist. Now, say when I say, photoresist becomes hard. What it means is that when you put in a solution known as developer, the photoresist that is hard remains there, and rest of the soft photoresist, will go away.

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So it is like, if this is a finger, and I have the substrate with photoresist coated kept here, and the light source comes from here, then the light passes through these gaps in the fingers and falls on the substrate. Now, wherever the light fell might have a different property than that of wherever light has not fallen. So this is the principle of photolithography. And we will further see how this actually happens. Now, as I said, the photoresist might have different properties, it can they are mostly classified into positive photoresist and negative photoresist.

Now, when I say positive photoresist, what it means is that say if this is this, my fingers are the mask, so this is the opaque region. And this is the transparent region, the light can pass through, the light cannot pass through, and I have the substrate here with the photoresist, which is positive, then if the light passes through here and falls on the substrate here, what we would have is, if it is a positive photoresist, wherever light has fallen, it will become a soft region.

When I say it is soft region, what means is later on during a process named as development, the photoresist which was exposed to light will go away, or the we will get removed, now, if it is a negative photoresist, if it is a negative photoresist, what happens is wherever light has fallen, will become strong, and it stays there. So this is two different types of photoresist that we will be using. Now for our specific use case we will be using a positive photoresist that means if light falls, it will get removed or it is it will become soft.

Now, we will see two different types of masks. And I will also show you maybe a couple of types of photoresist in the bottle, but for our use case, we will be using a positive photoresist now let us go to the yellow.

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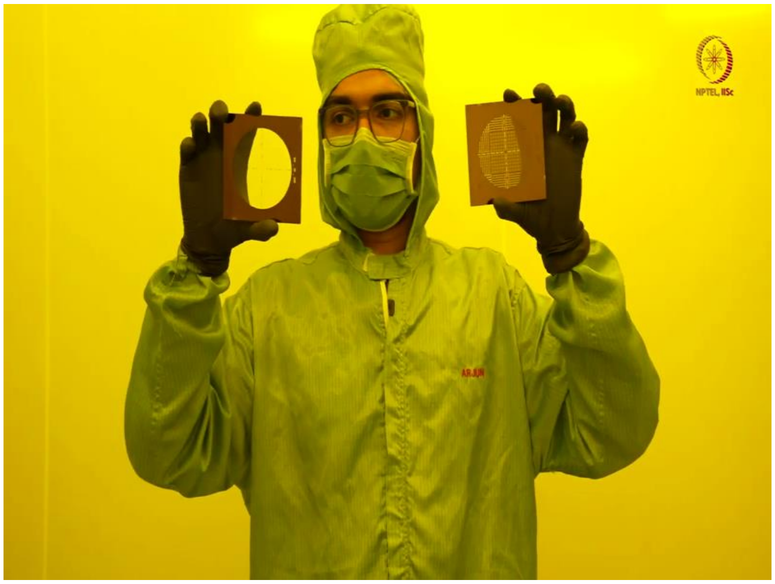

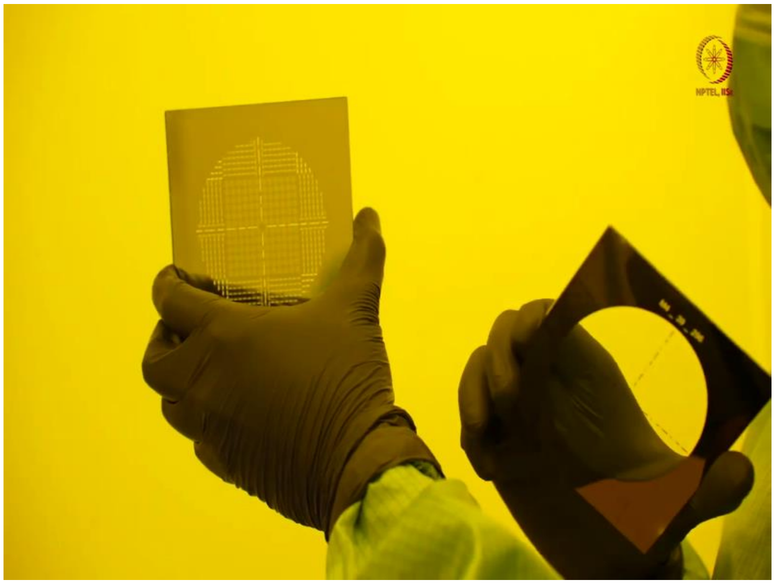
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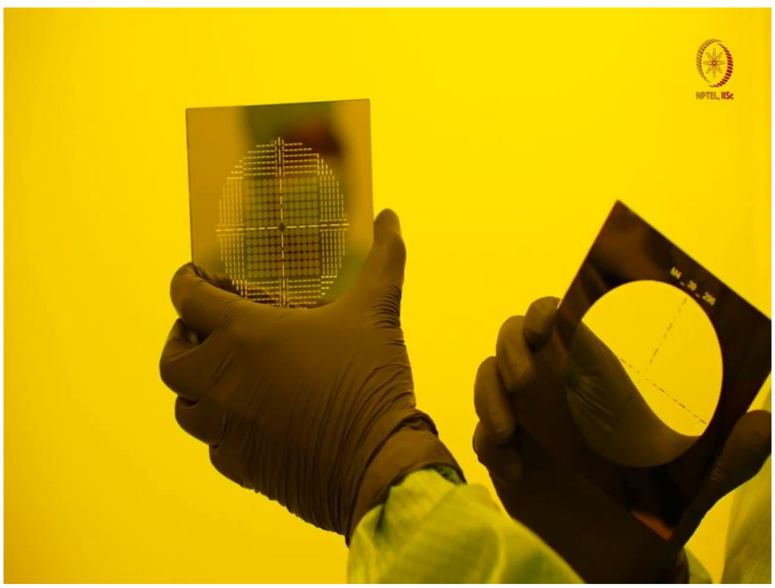
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So now we are inside the Yellow Room, you can see the overall color difference. So now I have talked about positive and negative photoresist. Now I will show you something known as a bright field and dark field mask, so these are masks, or photo mask, see during notice the difference between these two maybe I can show it against a surface, do you see the difference between these two? So if you look here, you can see, the within the circle is more or less transparent. You might be able to see small features there as well.

So those are the patterns that we need. So these are the patterns that we need, but most of the area is kind of transparent. Now if you look at this mask, you can see that most of the areas are dark, and some patterns are there which are transparent in nature. So what is the difference between these two masks? So we would call this this one as a bright field mask and this one as a dark field mask. Alright, so we have seen a bright field mask and a dark field mask.

So depending on the requirement that we have, we will change the mask. Now think about it like this. We have a two different types of masks which is like bright field and dark field and then we have two different types of photoresist this can be positive or negative. So you can think of the possible combinations in which you can create a pattern onto the wafer or the substrate or the photoresist. So if you think it like this.

So this is a bright field mask, this is a bright field mask and we have a wafer with photoresist here, which is a negative photoresist, if it is a negative photoresist what happens the light passes through the transparent area and falls on to the photoresist which is negative. Now, you know that negative photoresist what happens is if the light falls, that area becomes hard, so wherever the transparent areas where there, there you will have hard photoresist and wherever the light did not pass, it will have soft photoresist.

Now, this combination that a bright field mask, and a negative photoresist can be used for liftoff, why so because the patterns that we need is where the metal should come. So when we have photoresist and it is exposed. So the soft areas, which are the patterns will get removed during the development process, and when we deposit the metal in those gaps in photoresist, the metal will get a positive. So that is a liftoff process.

Now, if you look at the dark field mask, to get the same effect what we have to use is a dark field mask coupled with a positive photoresist then what happens the light passes through the pattern and falls on the positive photoresist and wherever light is there, there the photoresist becomes soft. So the pattern areas that we need will get the photoresist, get removed and we can deposit metal.

So in today's process, we will be using this photomask coupled with a positive photoresist so as to get the liftoff feature that we need. Now, I will show you two different types of photoresist so that you will understand what they are.

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So I told you there are positive and negative photoresist, and this is an example of a positive photoresist, which is AZ 4562, this is a positive photoresist and what, most of the photoresist this number like this a 4562 has something associated with this this number 4562 has something associated with this properties. So what it means is that the coating procedure or the spin coating procedure that we use for this photoresist is somewhat evident from this number.

So the six two at the end means that when we spin coat this photoresist at the recommended RPM or rotation speed, you will get the thickness of photoresist equal to 6.2 micron. So this is a very repeatable process. Now, when we are spin coating depending on the speed at which we rotate or the acceleration that we do and the duration at which we do the spin coating, the thickness might vary, but for the recommended speeds it will be 6.2 micron.

Now, then we have a negative photoresist which is nLOF 2020. So this is another photoresist which is negative in nature. So for our today's use case we will be using a positive photoresist which is known as 3012. So I will show you that now.

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So this is a 3012 photoresist. So as you might already know now 1.2 micron, is for thickness that we will get if we spin coat this photoresist at the recommended RPMs. Now these photoresist, is the bottles has to be stored between 0 to 25 degrees Celsius, preferably in a freezer. And for the convenience we will be transferring the photoresist on to a smaller dark bottle where, the light does not go in. So here we can store and use it for the later use. So I will be using photoresist from this bottle during the experimentation that I will be showing.

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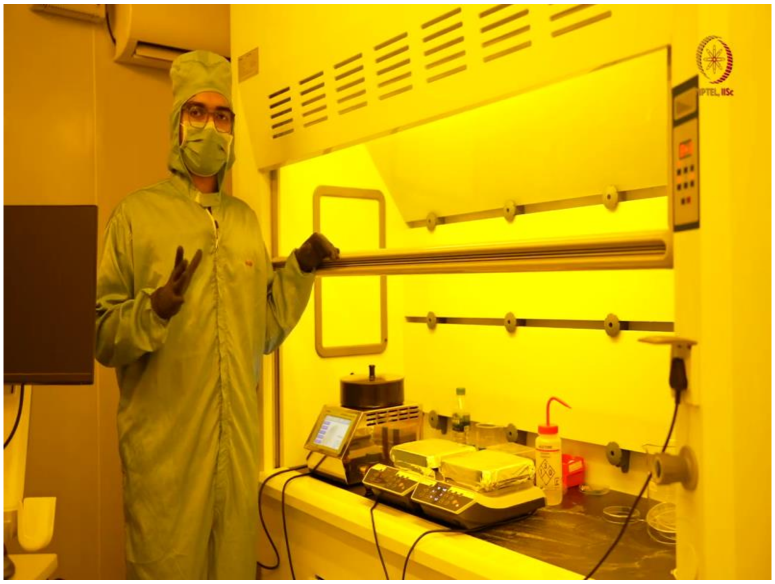

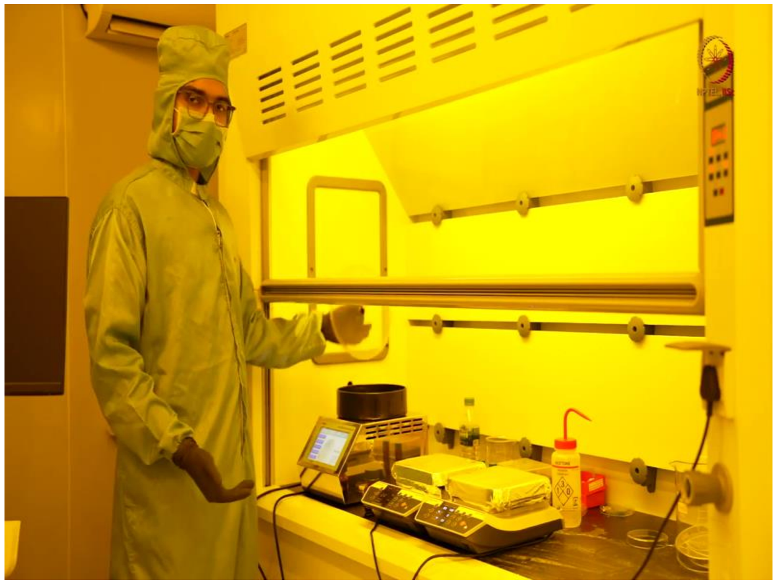

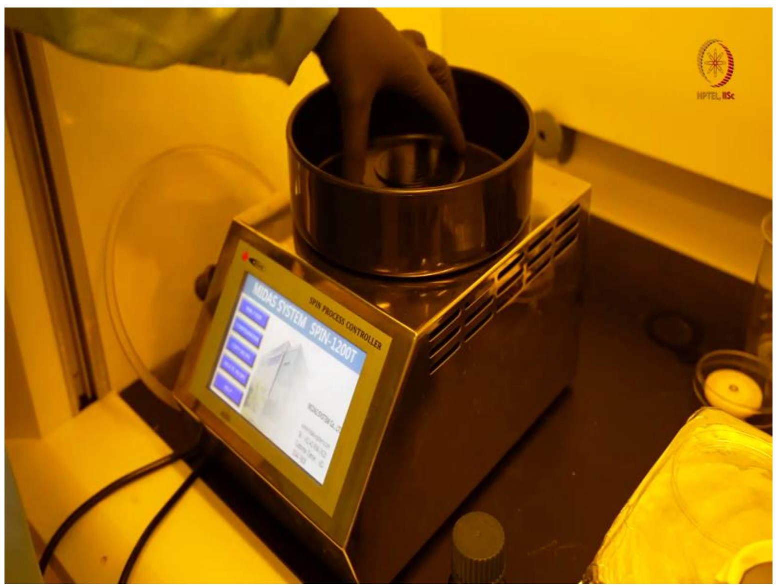
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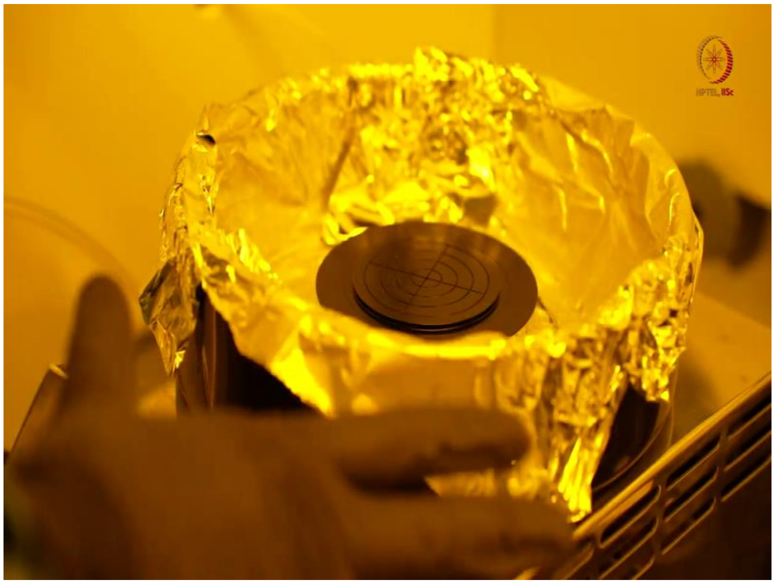
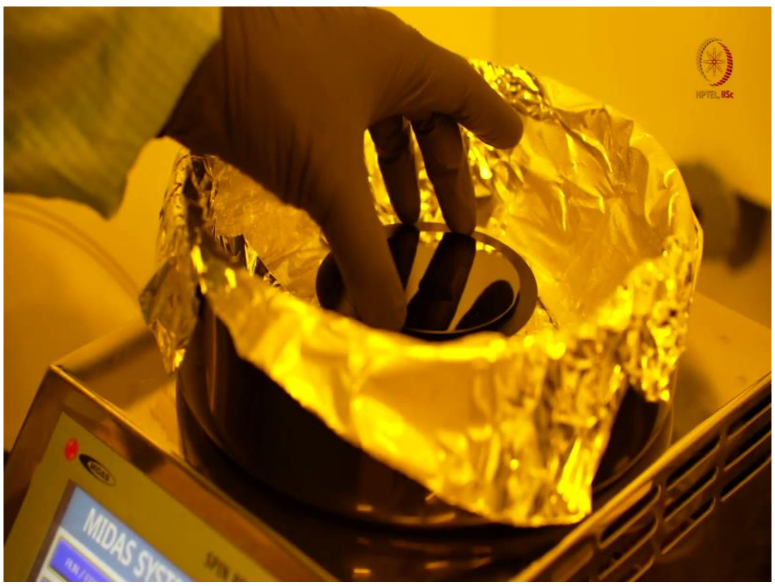
SPIN PROCESS CONTROLLER

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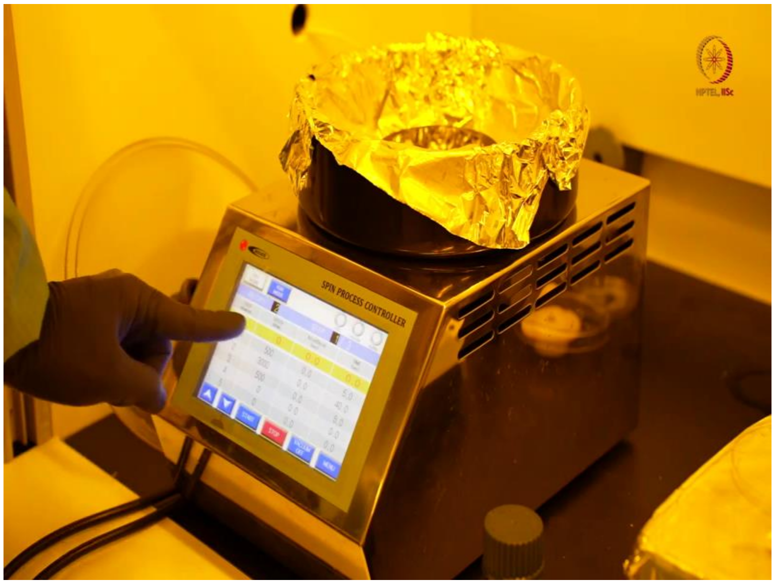
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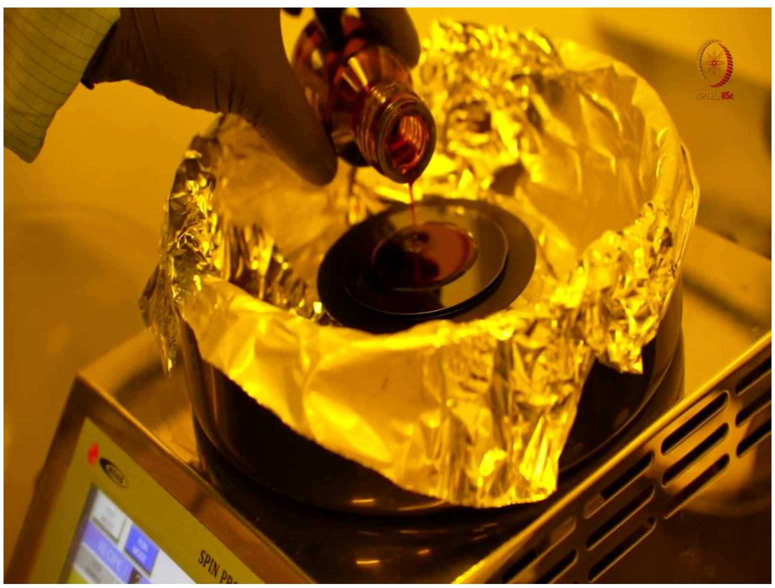

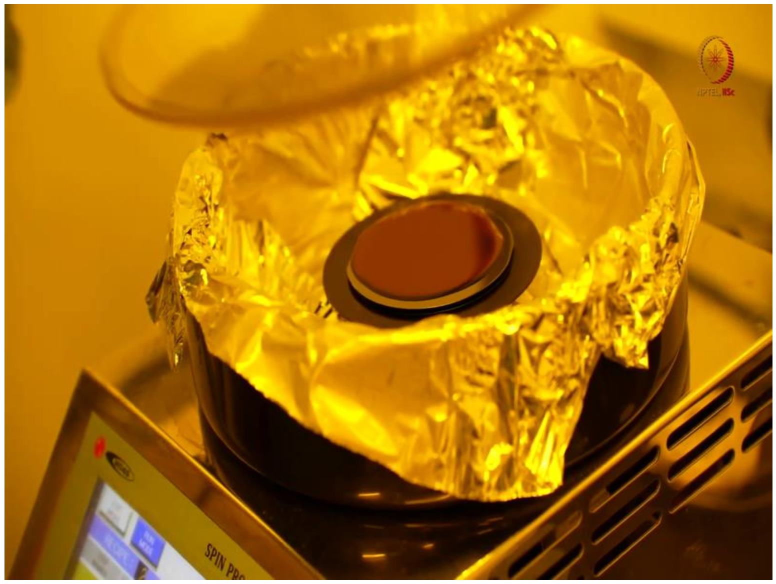

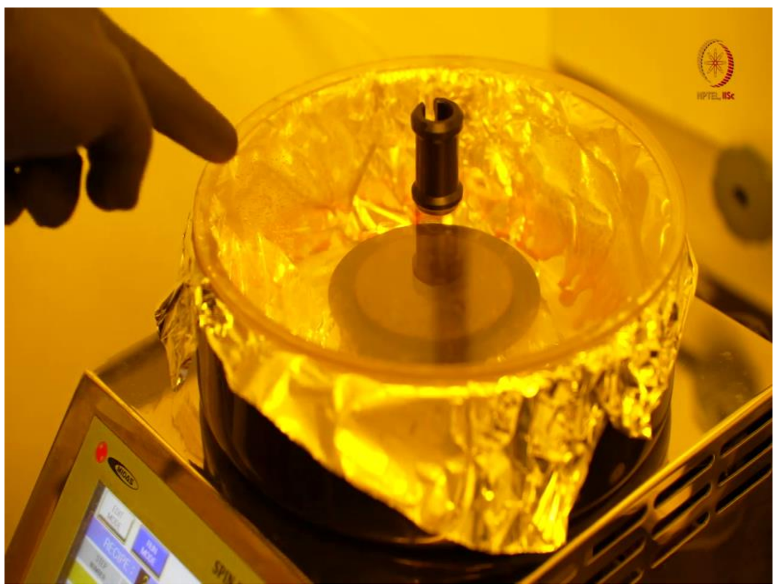

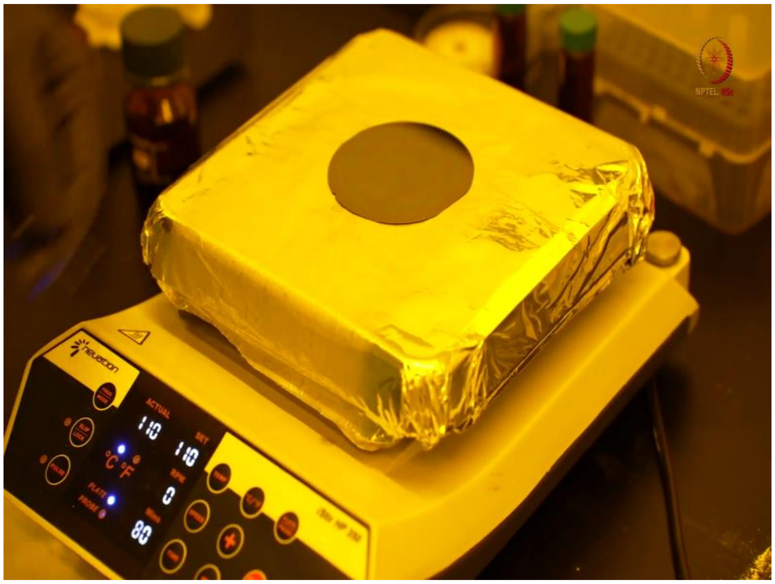

So now this is the fume hood where we have to do the spin coating of the photoresist, now photoresist is a biohazardous material and which can which is reported to be carcinogenic. So we need to take enough prevention or precautions to, so that there is no help us out to us. So this is a fume hood if we close the fume hood lid this, the laminar flow that is installed within the fume hood will prevent any volatile gases to come outside. So there are the photoresist as I said is a fluid like materials.

So the solvent will evaporate so that it gets hard, or the photoresist gets hard by the evaporation of solvent. So to prevent ourselves from breathing in the solvent we use a fume hood all the time. Now Right now, we are we have an spin coated photoresist, so if you look here the main tools that we need for spin coating are, one this is the spin coater that we have, then we also have for plates for baking the photoresist I will talk about the processes in on the way. Now we will first prepare the spin coater for spin coating.

So this is the lid of the spin coater, which I am keeping it over here, and this is where we load the samples. Now we can see that, there is a chuck, this is known as the chuck, which is able to rotate, and you can see a few grooves here, circular grooves with a central hole here. Now, the point of the chuck is when we load the wafer onto the circular chuck, through vacuum suction, this the sample will be held here since we are going to rotate the wafer at very high RPM, like 3000 RPM we need to make sure the wafer stays there.

So that is why we use vacuum suction to make sure the sample stays on the chuck. Now first we will cover the inside of spin coater so that spillage of the photoresist will be minimal. So we will see after that let me I am going to cover. Now that we have covered the spin coater with aluminum foil, we will load the samples. So this is the silicon wafer which we spin coated last time, it is a 3-inch silicon wafer that we have. So now we will load it onto the chuck.

So now I have placed the wafer centrally. Now we will switch on the vacuum and also get into program for spin coating. So what we can go to is there is this run or edit option where you can click it. So we already have a recipe set which means the rotation will start at 0 or some stationary speed, it will accelerate to 500 RPM, in five seconds and stays there then followed by rotation at 3000 RPM for 40 seconds.

And again deceleration to 500 RPM for five seconds forward by coming back to rest. So this is the recipe or speed at which we had to spin code this 3012 photoresist. Now since I have loaded the wafer, I am going to create the vacuum. So I have switched on the vacuum. Now if you see the wafer will not move, if we try to push it that is because the vacuum is on, now we can go to run mode, where the if we press start, we start rotating. Now before that we have to pour the photoresist over the silicon wafer.

Now we will see how the photoresist is coated, before pouring the photoresist and switching it on we need to make sure once again that vacuum is on, it is on now so you can see the photoresist, so I am going to pour the photoresist o the silicon wafer, see it is a very liquid kind of medium. 4 to 5ml of photoresist is enough to cover the inch wafer. So you can see that it spreads it is not as fluid as water but more like an oil kind of consistency.

Now we can close the lid, so that while spin coating it does not spill out. Now we will start the spin coating process. If you look at the wafer, it will start rotating now. So you can see the excess photoresist that spilled over to the sides, that is why we have put aluminum foil. And you can see now the wafer is rotating at very high speed will rotate for 40 seconds at 3000 rpm.

Then we deaccelerate back to rest, now the vapor is decelerating. Now it has come to rest. So now we will move the wafer, from the spin coater to the hot plate, so that we can pre bake it.

Now, the spin coating is complete, so I will take the wafer out. So first we switch off the vacuum, so that we can take it, alright I have taken out the sample wafer.

And now we have to keep it for baking for one minute in the hot plate. So we need to make sure that the photoresist is pre bake for exactly one minute at 110 degrees Celsius. So that is the pre bake procedure. We will see how it is done, so I am keeping the wafer. So we will look for countdown for one minute. Now the pre bake step is done. So that the solvent which was fluid in nature is evaporate.

The prebake also helps in better addition to the silicon wafer or substrate that we use, the addition between the photoresist and the wafer, it also improves the chemical resistance and also improves the light dependent behavior of the photoresist which is very crucial for the next step, which is our lithography process. So now I am taking out the wafer because it is one minute. So now, we have taken out the sample after one minute. So pre bake is done. So now, we will go for the lithographic process.

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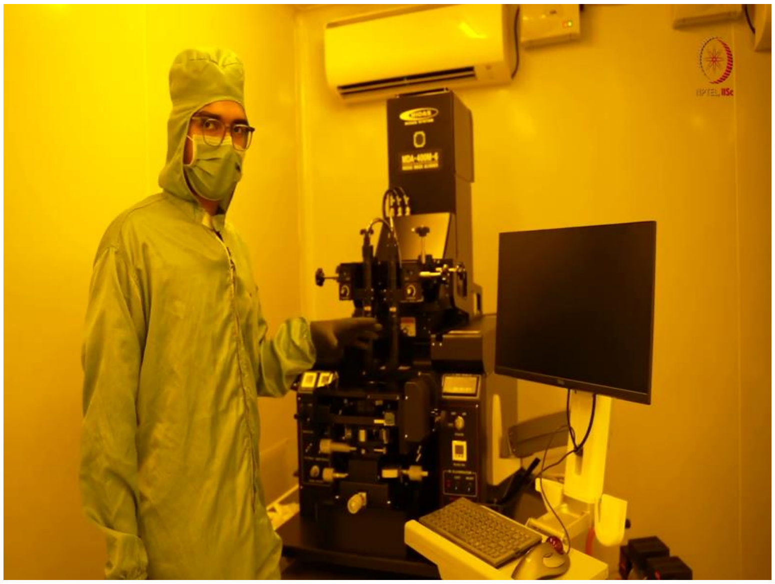
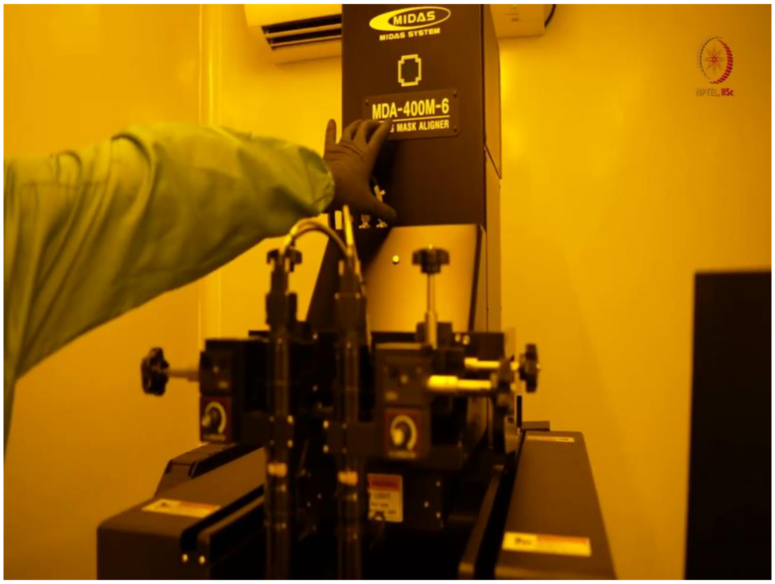
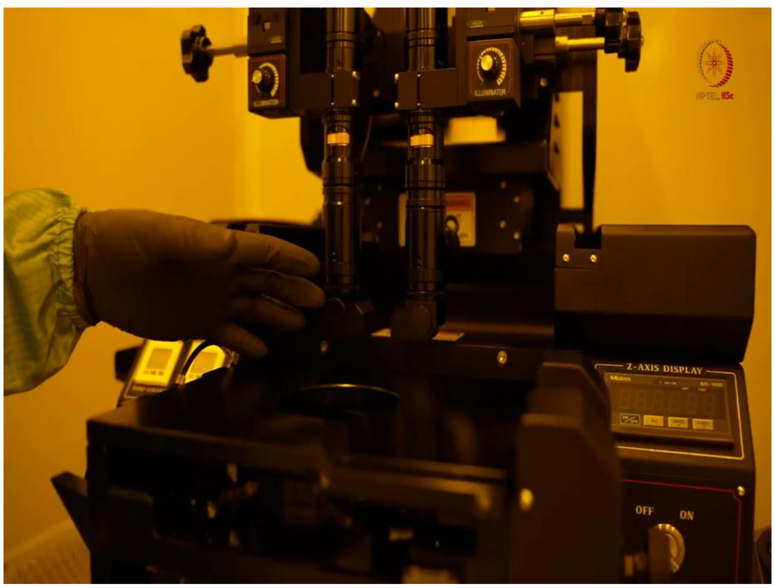



MIDAS
MIDAS SYSTEM
MDA-400M-6
MASK ALIGNER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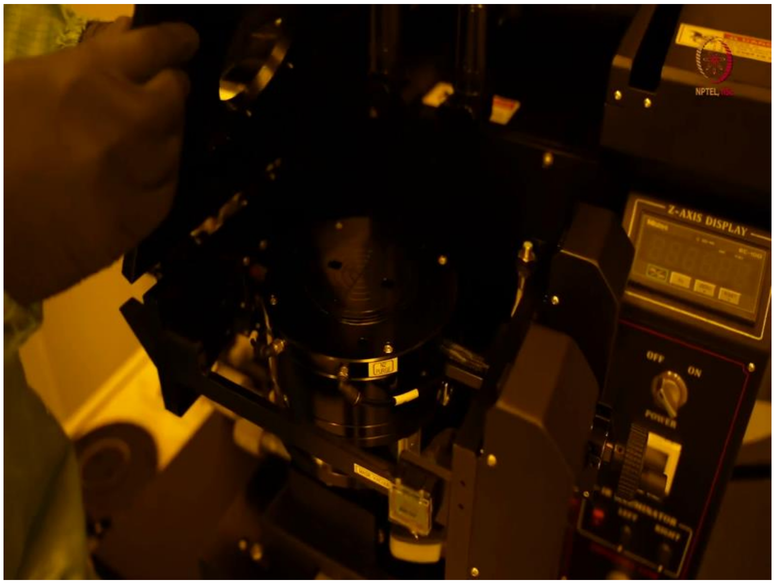
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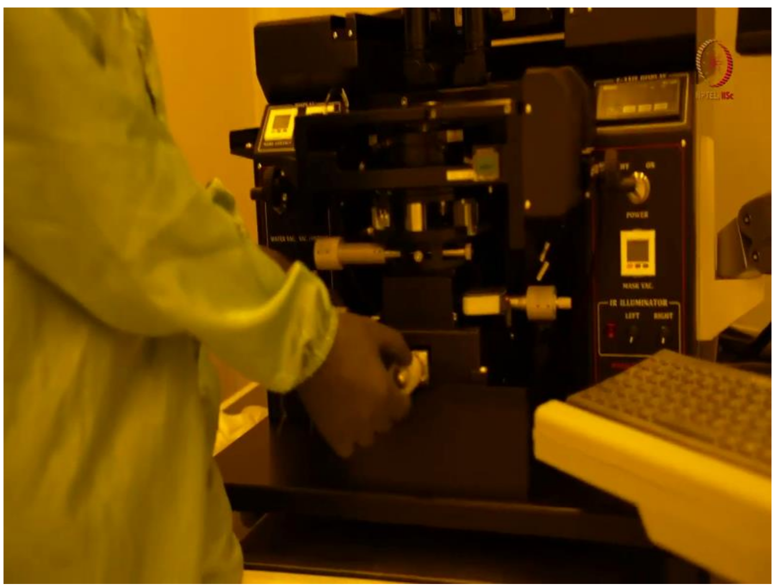
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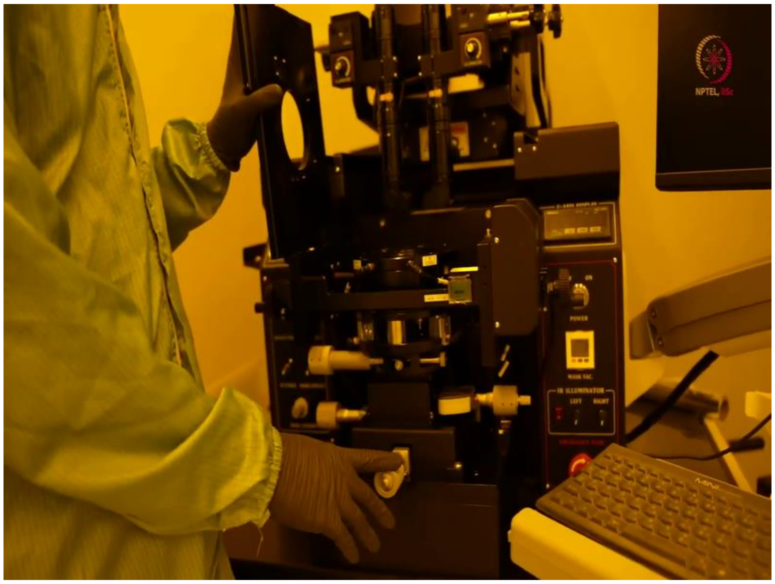

So what we have here is the Mask Aligner equipment, the name suggests Mask Aligner. So that means, the photomask that we have with the pattern can be aligned with the wafer or substrate in which we have the photoresist. So it is an alignment process. Now, we have the UV source Ultra-violent source that is within this chamber. So this is the UV source that is used to expose the photoresist 365 nanometer. Then we also have a microscope which we use for alignment.

So the display from the or the camera output from the microscope can be shown on the display in the system. So that we will be able to see the features very accurately. So in the Mask Aligner or in micro in the micro fabrication process, all the features are in the range of micrometers. So we need to make sure the alignment happens properly, that is why we have microscopes with variable zoom and focusing features to align the mask with the wafer properly then, we also have the mask holder here, you can see the cavity here.

So the mask or the photo mask actually sits here in between the slots here. So the photo mask can be inserted here and then we can close it like this. Now, if you look here, we have a wafer holder which is a circular diameter. I mean, it is like a circle. So the circular wafer can be placed here. Now, you think about it this way and the wafer is here and the mask holder is close like this with the mask they aligned together. Now, if there are some small misalignments we will use these adjustments Vernier's, to aligned the mask and wafer.

Now, when we rotate this the wafers, the chuck or the chuck with the wafer moves and that is how we can do that alignment. Now the chuck has some special behavior properties that we will see later. And similar to the spin coater you can see the grooves here for vacuum section. So once the wafer is kept here, it will not move now we will see the operation of the Mask Aligner.

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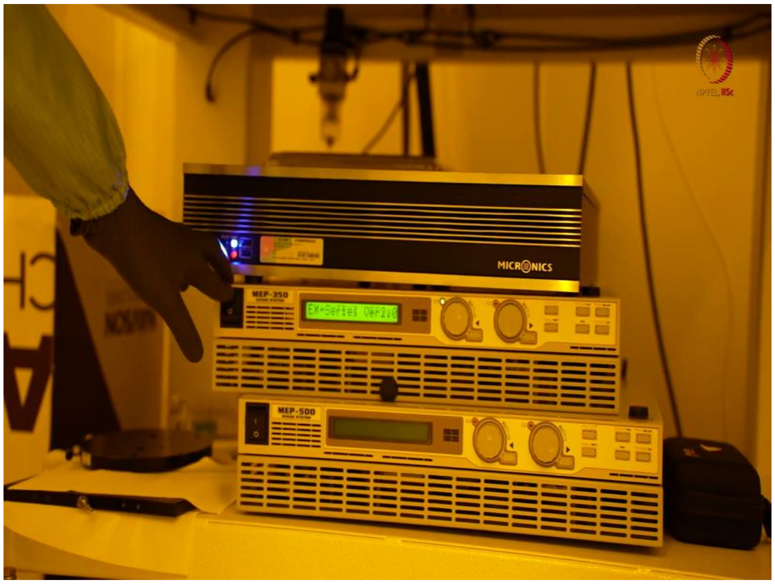

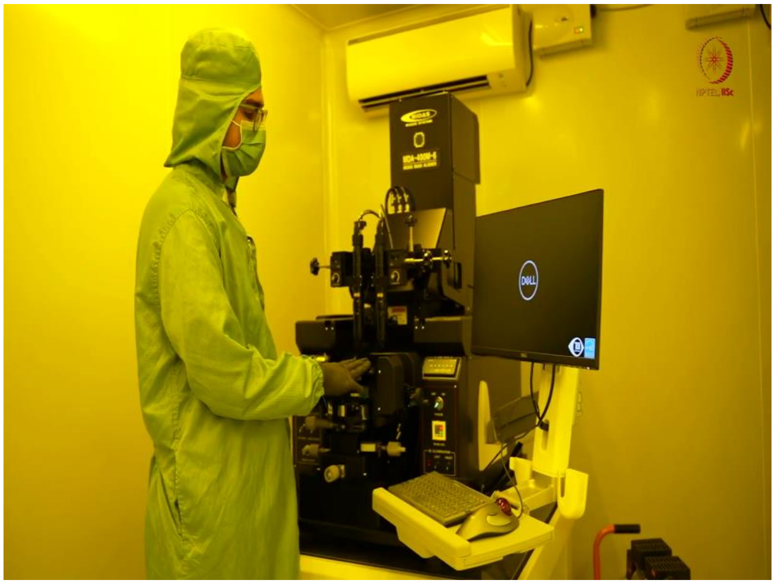

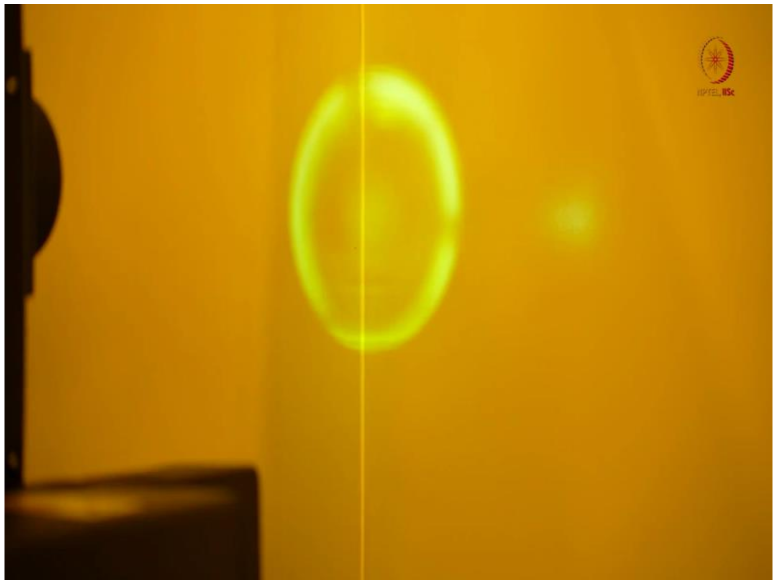


MDA-400M-6
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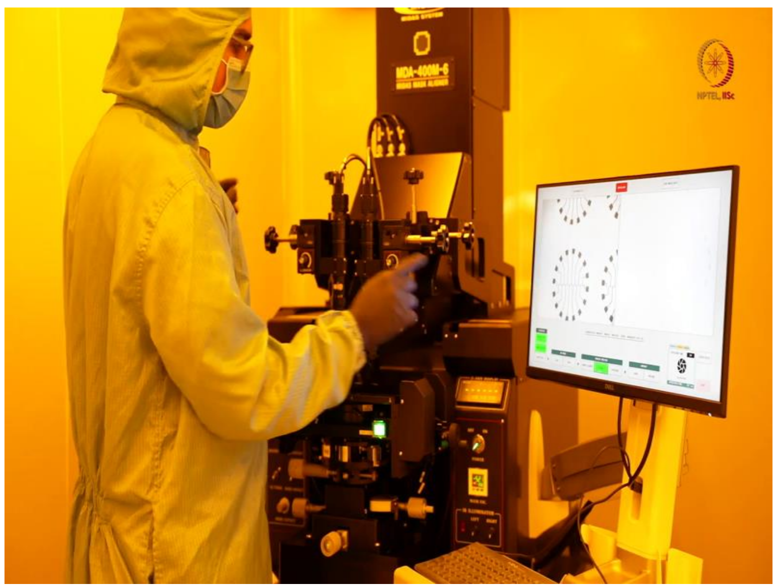
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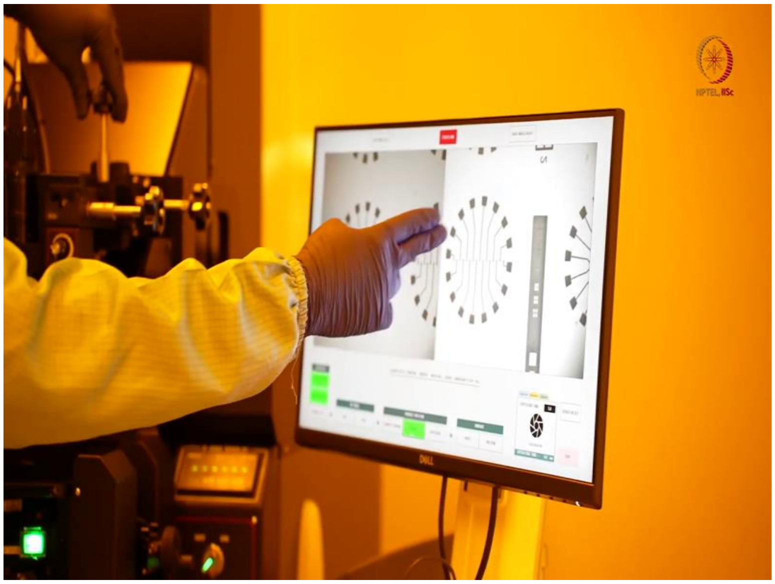

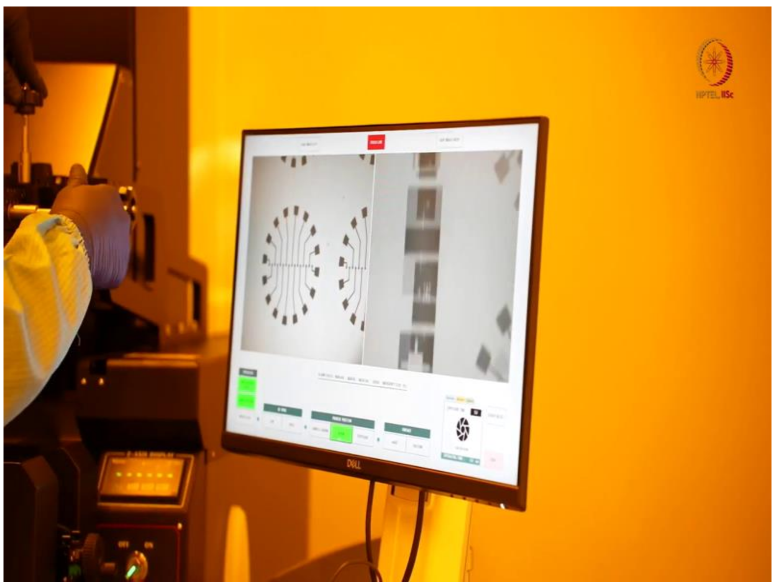

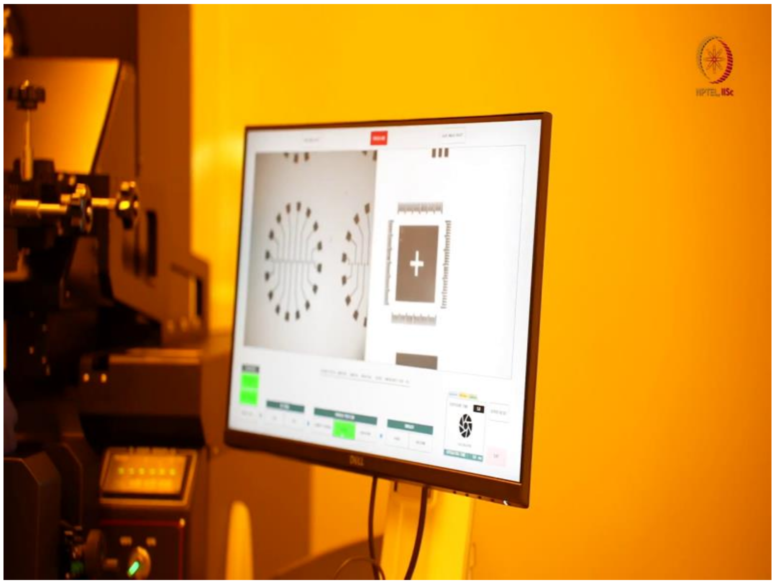

So this is the PC that controls the Mask Aligner, so I am switching it on, then followed by the power supply for the UV lamp ultraviolet lamp and fixing that as well on Now, we need to switch on the lamp power supply as well here. So when I proceed you can see some numbers written here, which corresponds to the current rating, voltage rating and the power. So now that the lamp is on we are going to switch on the equipment, so now the equipment is initializing.

So this is the UV light that you see this circular rings. So there is a slot here through which the light is permitted so we know that the lamp is on. Now we will switch on the user interface so that we can control the equipment, so this is the user interface, now, we can switch off this mask holder lock, so that we can load the mask. So now I am going to load the mask. So there is a mask holder.

As I have explained, now, you can load the mask once it is loaded, I can press this button here, this is the vacuum switch for the mask holder so that the mask does not move. So now I have it is on the vacuum for the sample. Now the wafer will not be able to move. Now I am closing the mask holders. So it automatically locks here and you can see it on the green button here.

Now, what we can do is to align the wafer and the mask for which will go to the alignment mode. When it goes to the alignment mode, you can see that the microscope comes and aligns with the mask here. So now you have to adjust the microscopes, so that you will be able to see the features. Now you can see there is a dark area here, and these white bright region here. So this is the right microscope that you see here.

And the left microscope that you see here, here, it is like this because of the low illumination, so I am increasing the brightness slightly. And I am adjusting the field of view for the microscope. So I am reducing the zoom then illumination is too much. Now I am going to you are able to see some very slight features here. Now, you can clearly see the features that we have.

So these are electrodes, as you can see circular device with a linear ray of electrodes that you can see, you can even reduce the elimination further so that you can see clearly on the right side as well. I am reducing elimination. So you can see different patterns on the mask, on one quadrant of the mask, we have this kind of a design on the other we have different designs you might also have another design here.

So depending on our requirements, we can have different designs on the mask. And these designs that you see here are known as alignment marks. So if we have a multi-step process or multiple deposition, lithography and etching steps or multiple lithography, liftoff and other steps, we will need to align one process step with the others. So for that we use the alignment marks.

Now it is kind of visible, we will be able to zoom in as much as we need, if you see here we just have to move it, adjust the focus the way we need so it will get, you will get a very clear image. So you can see different kinds of features that are available, there are different types of designs that are available for alignment as well. So these are called Vernier alignment marks. So that we can see slightest of the misalignments.

Now that we have these samples here, what we can do is to do the error compensation, which includes lifting up of the wafer, to a stage where it touches the mark. So you can actually see in the display here, so since this is a dark field mask the white region that you see is the opaque region. And what you see through the greater slot is the transparent region and you can see the wafer there. Now, if we zoom in clearly or maybe you can see it here.

So this was the transparent area and this is opaque region. Now this is blurry here. When you move it closer, you can see the, I am slowly lifting the wafer up. And you can see that there is a change in shape. Now, that area is has also focused clearly, see if you look here, see, you will be able to see the shadow of this plus mark very slightly here.

But once you bring the wafer close enough that shadow goes away that means, both the mask and the wafer have touched now, but we do not want them to touch. So for that now, we will do the wedge lock. So now they are parallels and then we can switch on the, easter axis display that we have here, we can set it to zero because they have touched now, and then we can move it down by say 50 microns.

So that there will be a 50-micron gap between the wafer and the mask. So this is known as proximity lithography, where you do not really have to have the mask and wafer in contact. So why give a gap between the mask and the wafer is there, this small gap will prevent any photoresist to remain on the mask surface.

So we can have a long activity in the mask aligner. And then there are other optical properties which is out of the scope of this lecture. But, yeah, so now we have the wafer and the mask aligned, since this is a first mask process we do not have an alignment processor set, but we just have made sure that the wafer is sitting almost on top of the or the mask is almost aligned with the vapor that we have. Now, next step is to go for exposure.

Now, before exposures, we need to calculate the exposure time. So that is something you can set it here for the power requirements. So the photoresist has to be exposed with UV lamp for specific intensity. So you can calculate it here as well. So the UV lamp that we have here has a power of 22 milli watt, but the overall energy that we have to supply for developer for the patterning of photoresist is 100 milli joule per second.

So that is why we have to expose close to 4.5 seconds to get the overall energy of 100 milli Joule. So that we have set here. Now, we can go to the exposure mode, so that the exposure can happen. We can see here the system has moved up. So that the ultraviolet chamber has come over the wafer now. Now, we will go to the monitor and press this press the symbol here which looks like a shutter. So once we press this the UV exposure will happen.

Now, you do see here you will see the UV exposure being happening and pressing the shutter button. So this, this is ultraviolet light exposure that is happening. Now, once the exposure is done, the device will go back. Now the next step is to unlock the mask holder. So that we can take out the wafer for the next step. So then before that we have to make sure we sample vacuum is off and we can we have taken out the wafer, now the next step after lithography or the exposure for a positive photoresist that we use is something known as hot bake, sorry soft bake.

So we did prebake already when we did exposure, and now we are going for soft bake, after soft bake that which happens at 110 degrees Celsius for one minute or 60 seconds, we are then we will go for the development process. So in the development process is the time where we expose photoresist, which since this is a positive photoresist, the exposed data becomes soft. So the exposed area will get removed. Now that we will see that.

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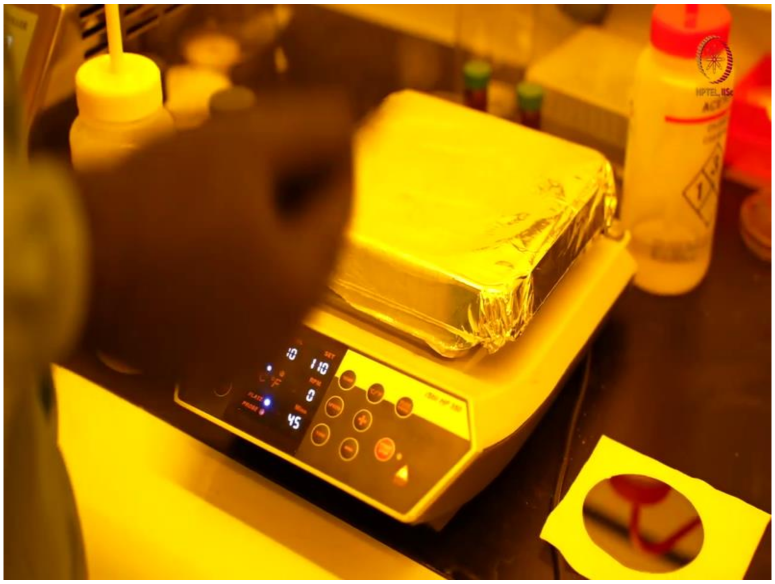

So now I will keep the wafer onto the hot plate. So the wafer is being kept at 110 degrees Celsius for one minute. So this process is known as soft bake. So I am taking out the wafer, it is been one minute. Now the next step is development.

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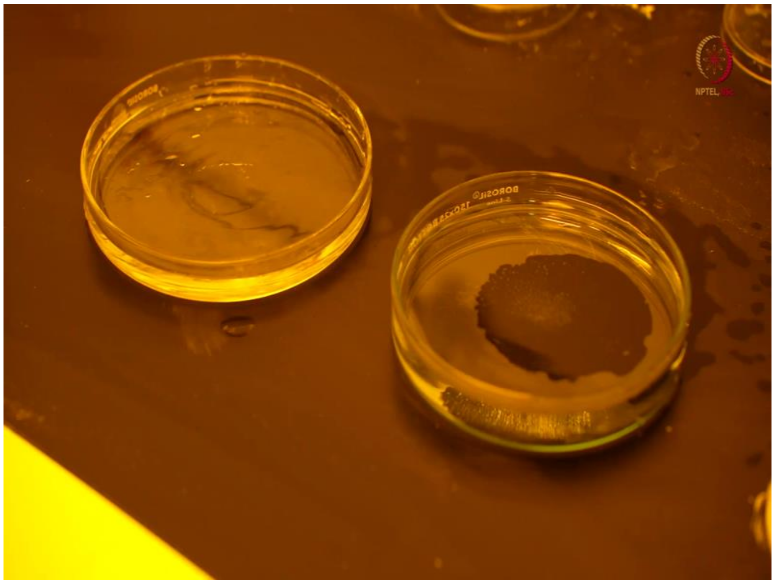

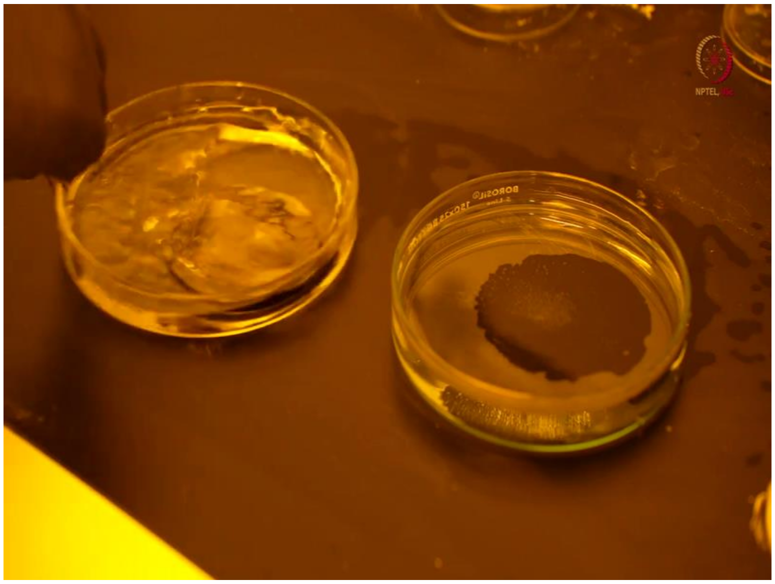

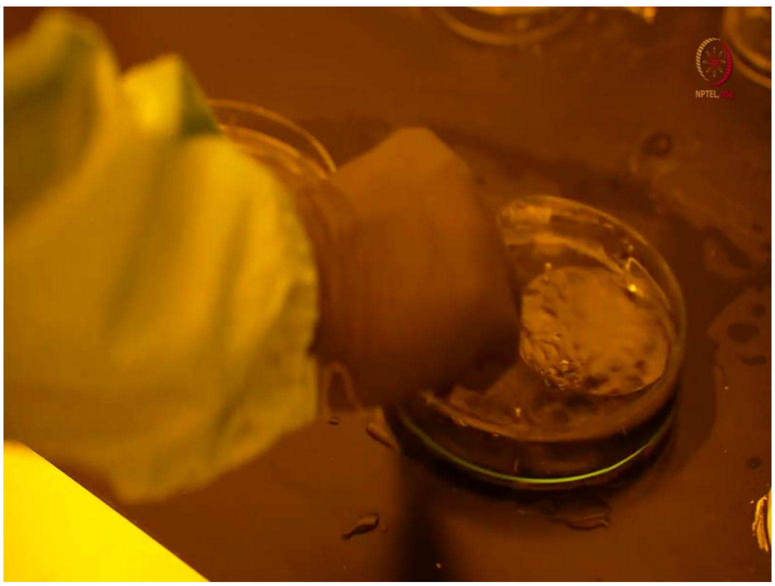

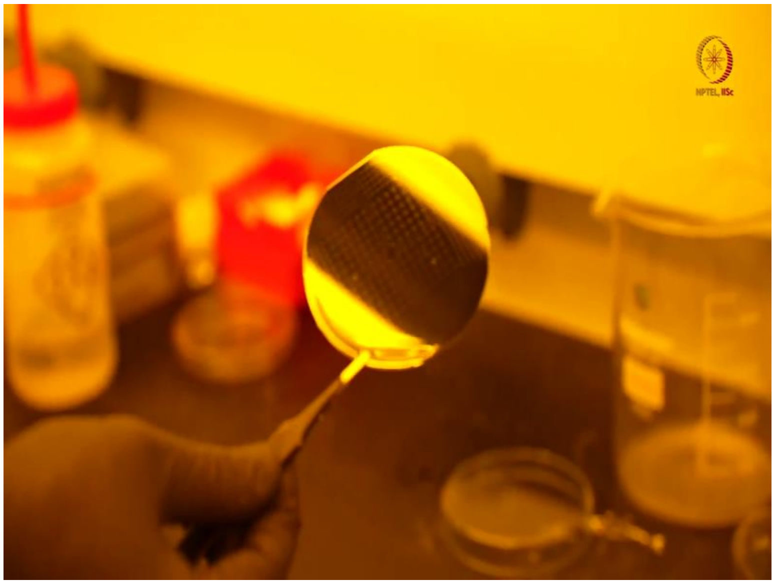

So now I am pouring the solution named as developers. So developer is the solution, which removes the soft photoresist, as I told you before, so and then we also have another petri dish with DI water. So after, so the development is time dependent. If you keep it in developer or wafer in developer for a long time, the required photoresist also will get removed, or the hard photoresist will also get removed.

So after our process here we have optimized to close to 30 seconds, and as soon as the development is complete we have to transfer the wafer to the DI water birth about so that the reaction stops so now I am placing the wafer on to the developer, and agitating it. Now we can see kind of patterns here and putting onto DI water so that the pattern is preserved so now the development is complete. So if you zoom in closer, you will be able to see patterns here.

So that shows the lithography is successful. You can see the patterns. Now the next step is to dry the wafer and then go for hot baking.

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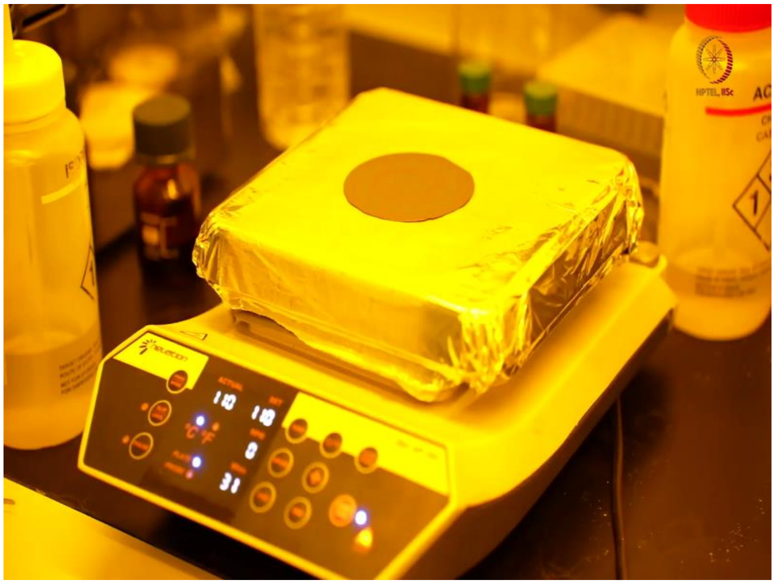

Another wafer is right. So the next step is to hot bake the wafer for three minutes at 110 degree Celsius, the hot baking step will harden the photoresist that remains so that it can sustain the metal deposition process that is going to happen next. Now the hot bake is complete. I am taking out the wafer, and now the wafer is ready for metal deposition.

So now, so the lithographic process is complete. And what you are going to see next is the metal deposition process using e-beam, where we will be depositing titanium platinum which will be the electrode material. So goodbye.