Advanced Machining Processes
Prof. Shantanu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur
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Lab session - Photolithography

Hello, and welcome to the microsystem's fabrication laboratory. I am Shantanu Bhattacharya, and I will be teaching today, I will be demonstrating some experiments on photolithography, which is a very essential component of MEMS for MEMS fabrication essentially. So, let us go step by step in this, the first thing I would like to enhance and like to emphasize in such a laboratory is that you have to be really maintaining the cleanliness, and there is a certain attire which is useful for processing, and basically one needs to cover almost entire portion of the body, and take the proper safety measures. So, that the particular operator in question who is doing the experiment is not affected, and also the experiment is done in a dust-free environment. So, let us look at the components one by one, this right here is one of the fundamental components used in such a laboratory, it is known as the fume hood. Essentially it provides a class 1000 clean space or clean area, which is just underneath or behind this particular panel.

There is essentially a blower unit which circulates and causes a laminar flow of air inside this particular hood. So, that typically all the dust which is around goes passes through a set of HEPA filters, and the air is recirculated back, and there is absolutely no entry of dust particles from outside into the clean space. Most of the dust particles exit, because of this continuous laminar flow operation. So, other components important components of the fume hood is basically an air track, a compressed air track which is kept for the purpose of cleaning wafers, once we process these wafers.

There is essentially a water connection which is used for again washing samples as you do the processing. And the very important component which is useful, or which is the most, which is the primary component where all the processing is done is actually a silicon wafer. So, the silicon wafer is commercially manufactured by only a few manufacturers all around the world, one of them being MEMC which is located in St. Louis. And essentially the wafer manufacturers have standardized processes wherein they produce different diameter wafers, including a 3 inches wafer, a 4 inches, 6 inches so on so forth.

Now, this right here is such a package or a box which comes from a wafer manufacturer, and it houses about 30 to 40 wafers in one of such packages. Let me give you a closer look as to how the wafers really look like. The wafers are all stacked in as you can see here in this particular fashion, and this again is packed in a super clean environment, so that there is absolutely no dust on the wafer surface. So, what we do right here is first take out a single-piece silicon wafer, and I would like to illustrate how that wafer really looks like. So, if you look at such a wafer, so as you see here in this particular fume hood, we have several components which we have kept inside.

Normally in order to maintain the cleanliness of the process, we use these aluminum foils which you can see here is the silver foil which is actually a clean surface, and it is reusable. So, it is actually a one-time use-and-throw basis, we can I can actually you know cut several pieces and cover this area, and keep it as a base, and all the processes typically would happen on the top of such a foil. These components as you are seeing here, some of the glassware which is around or these tweezers which are meant for handling such wafers have been already cleaned prior to this and heated in an oven, so that you get rid of all the water around it. So, they are actually adequate for handling these silicon wafers. So, the first thing I am going to do is to actually unload a wafer from its box and make a separate container or take a separate container of a wafer box and transfer this wafer.

As you are seeing here, this right here really is a wafer box which is meant for containing a single wafer. For microfabrication, it is very important that specially when the wafer is moving between workstations, we need to cover the wafer adequately, so that we do not have any contamination as the workpiece is moving between stations, so in coating. So, basically the first thing we have to do here is to transfer the wafer from this box into a separate carry box which is meant for holding just a single wafer. One of the reasons why we do that is that because we have to actually really protect the silicon wafer specially when it is transferred between different workstations. So, this is a carry box which is meant for that purpose, wherein there is a lid and then there is a small filter paper which is covered at the bottom, and this is used for handling wafer between workstations, particularly during the various process steps of photolithography.

So, we also use these aluminum foils to make super clean flooring while doing the processes. All the components like this glassware as you have seen has to be thoroughly washed and clean and then dried in an oven so that there is no moisture because essentially microfabrication is a lot about cleanliness. So, let us transfer the wafer from the box here as you have seen this is the wafer box. This process only has to be done within a fume hood because this prevents the chances of the wafer getting contaminated by the dust particles of the air. So, we take a wafer out using a tweezer as you can see here.

Tweezer also is a very clean tweezer and then essentially, we use this box to load this wafer and later on all the handling will be done using this particular box in the subsequent process steps and then cover this with the lid. We close the silicon wafer box and keep it in a separate area. One of the reasons is that we have to be extremely careful while handling silicon wafers because they are very fragile and essentially can crack even on little impact of stress. So, we have to make sure that this wafer box is far away from the experimental setup that is the main box is far away from the experimental setup. So, the next step basically is the clean wafer although it is very clean, but we still need to do a surface treatment of the wafer.

So, that number one it can be made hydrophilic. Number two is that whatever organic contamination is there on the top of the silicon wafer gets removed. So, one of the methods of doing that is by using an acidic solution called piranha which is essentially a mix of H_2SO_4 and H_2O_2 or sulfuric acid and hydrogen peroxide. Essentially the piranha is prepared by mixing three parts by volume of sulfuric acid with one part by volume of H_2O_2 or hydrogen peroxide. So, highly exothermic process and results in a lot of heat release and fumes.

Once the solution stabilizes a little bit after mixing, typically use a glass rods to stir the solution and put the wafer on the solution and clean it for several minutes about 6 to 7 minutes. So, that everything which is organic on the top goes away and then the idea is to kind of extract the wafer back and rinse it using DI water for a few times. So, that you can remove the acidic impurities and then dehydrated is in an oven set at 95 to 100 degree Celsius. So, let us look at that process now. Piranha is a very dangerous process as you as I have already illustrated and therefore, you need to use a special protective covering.

We are already wearing a safety glass as you have seen before. Now, what I am going to do is to wear a set of polypropylene gloves. These are acid-resistant essentially and highly anti corrosive and it essentially prevents any kind of damage or contamination to the operator in case of spillovers. As you see here, you know you can just wear it over the secondary gloves that you are already wearing, and which is a clean gloves and for doing processing. Once this is worn, we are almost ready for preparing the Piranha solution.

So, what we do is basically pour about in this case about 90 ml of sulfuric acid 98 percent. As you can see this is a very, very dangerous chemical and it has to be very carefully used and then we will mix about 30 ml of hydrogen peroxide. So, what we do here is the following. We use all this spill, all this pouring etcetera over this drain. So, that in case there is a spill over everything goes down the drain.

So, essentially opening this sulfuric acid bottle is also to be done very carefully. You use these gloves. So, basically, you open the acid bottle and keep the cap in safe place, safer area, and essentially now what you do is basically take this bottle and pour it in this beaker here very carefully and very slowly. As you are seeing here, pouring this is not a very easy job. Do it just about close to 100 ml and essentially again keep this back in its place.

So, you can actually spill over this properly. So, that there is no chance of any spillover and essentially close the lid and we need to actually do a secondary measurement to ensure that the volume that you are using is proper. So, use a measuring cylinder for that and we need to pour exactly 90 ml here. So, what we will do is we will transfer this sulfuric acid into this measuring cylinder and go all the way up to 90 ml. So, it is just about complete now.

So, we take a new container in which we have to prepare the piranha and slowly pour from the measuring cylinder the sulfuric acid. One thing we have to ensure is to identify the components which have already been used for containing sulfuric acid because we have to wash them later on properly. So, that there is no risk of any experimental is getting burnt because of improper usage that. Now, we have to pour about 30 ml of hydrogen peroxide. So, this right here is the container for H2O2, and the reaction is essentially an equilibrium reaction where there are lot of hydrogen ions and hydroxides which are generated.

And essentially it is an equilibrium process which codes a layer of hydroxide onto the silicon dioxide, the nascent oxide surface and also creates a lot of heat. So, basically, we need 30 ml of hydrogen peroxide. So, we open this and pour exactly 30 ml of hydrogen peroxide into the secondary container here and keep it separately in this particular zone. We close this because it is a highly volatile material it kind of evaporates and so we need to certain that it comes back in its safe zone. So, after we have independently poured this, we had mix these two chemicals together in this beaker and what I am going to do is to now turn on the fume hood essentially because this is a very exothermic reaction.

And essentially, we have to also pull down the cover just about to a level where you can just put your hands inside and do the operations. So, essentially now you will be pouring the hydrogen peroxide into the sulfuric acid this is very critical part because this may actually explode. So, as you see when you pour the material there is immediate reaction which takes place and there is a lot of fumes which are generated as you can see, and this fume has to be done in a very very close environment. And we have to wait for some time till this fume actually disintegrates or disappears totally and piranha is made in that process. So, as you can see the fumes are slowly settling down because essentially it is a very very highly exothermic reaction.

So, what you do now is to actually use a glass rod and stir the solution very well. So, that the mixing between the hydrogen peroxide and sulfuric acid takes place and then once this is ready and mind you this is a very hot chemical. Essentially you have to be careful while even pouring it into the separate petri dish as I will just illustrate in the next step. This is a glass rod you cannot really use any other metal rod for doing this because the acid immediately produces the salts from the metal, and it also deposits the metal and takes it off and you know in the process gets contaminated. So, you have to always use a glass rod or a glass container for doing this piranha-making process.

Once this is made you rinse off the excess piranha on the glass rod and keep this rod back into the container for H2O2 and this would later on be cleaned before we can reuse this again. So, what we now do is essentially take this piranha what we have prepared and then pour it over our silicon wafer which will be keeping in this particular petri dish separately. So, what we do is essentially we take our wafer silicon wafer and open this and clean in order to clean this wafer we put this wafer back over the petri dish here. As you can see here, we are putting the wafer in this petri dish and once we pour the piranha, we can no longer use this metal tweezer for handling this wafer. So, we will have another separate Teflon tweezer for doing this wafer handling once it is out of the piranha for washing and rinsing.

So, now we slowly pour this chemical the piranha over this wafer and you know it is extremely hot as you can see and essentially it also fumes as you pour it and immediately if you can see there are the organic contaminations over the silicon surface has been immediately removed and we store all this container later on for cleaning and using it for different applications. So, now we keep this close and wait for about 10 to 15 minutes. So, these as you see are now Teflon coated. These tweezers have tips which are coated with Teflon, or they can be complete Teflon tweezers which we can use. So, what we are going to do is to provide a normal rinsing using distilled water as you can see here which is resting in the flask of this particular piranha clean wafer sample and then this would be followed by another wash of DI deionized water.

So, that it gives a super clean surface on the wafer. So, what we do is we basically pull it out very carefully because essentially this is all acid coated now and one has to be very careful and then hold this over this edge and rinse it inside this with water and rinse it on both sides as you can see. All the water should typically go and rinse all the acid of the surface of the silicon wafer and essentially once this is clean the in the next stage what we do is we take this DI water and slowly rinse it on the surface of this particular wafer. As you can see here this is actually a squirt bottle which is squirting away the DI water on the top of the silicon wafer. So, essentially after completely rinsing it you basically try to just change its holding location to a different area.

So, that you can rinse off the acid in the particular area where it was held before and this way you can clean the whole sample and essentially you can see now that the sample is more or less thoroughly cleaned, thoroughly washed and there is a super clean nature on the surface. So, once this is totally clean, we need to now use the compressed air to dry this particular wafer, but before doing that we need to take care that the acid etcetera which is actually kept in open needs to be kept away. So, that there is no squirting of the acid in general. So, now you take it. So, this is basically an air nozzle it actually sense in compressed air and what we are going to do is to actually slowly use this nozzle to clean off the surface water as you can see here slowly from the surface.

So, essentially you have to move this thin film of water in the clean hood away from the side. So, that you are actually left with a clean surface of the wafer, a clean shiny surface of the wafer and there should not be any water drop in this manner on the surface typically all the water film should go away from the surface. Similar cleaning has to be done for the reverse side and I am going to do that as you see here seeded from the compressed nozzle side towards the other side and it is then rinsed off the surface by squirts of compressed air as you can see. So, this now really is a super clean surface for lithography to take place.

So, we put this sample this clean sample. Back into the wafer box as you can see and then we will actually do a heat treatment of this particular wafer. So, that it can get rid of all the water from the surface, and that way we have a completely dehydrated surface. We need to cover it at this stage because the moment we move it out of this clean area it can again become dusted, and the contamination of the surface may happen. So, this is how the piranha cleaning process of the wafer is done. So, basically what we do now is to take this wafer that we just made super clean using piranha process and take it to an oven.

The oven basically that we are using here is a gravity-fed convection oven which actually is based on the principle of free convection. There are set of heated coils at the bottom and there is a current of air heated air which actually makes the temperature uniform. There is a PID-based controller using thermocouple which is somewhere at the floor of this particular heater. This right here is that oven. So, what I am going to do is to illustrate a little bit about this oven and then basically use this oven to heat dry the wafer surface.

So, basically, if you look at this oven really it is a shelved oven as you can see. There is a fan which actually does forced convection along this whole area and essentially the wafers are kept at various levels. The thermocouple is somewhere at the bottom that is one disadvantage of this particular type of oven because it sometimes is not a very good indicator of the temperature that happens. This right here is a controller. It is based on proportional integral differential controller.

So, as you see here there are two different readings. There is a set point and then there is a variable point where the temperature goes up and down based on what the set point is. In order to control this basically if you can see here right here there is a set option. So, you press the set option and then take this up arrow or down arrow, and as you are seeing the figure here which is the SV or the set value is varying 89.3, 0.4, 0.5, 0.6 so on so forth. So, we take this all the way to about 100 degrees which is important for proper hydration of the wafer surface and once you reach 100 you basically leave the set key, and this is now set at 100 degrees. So, this temperature which is also the proportional integral differential temperature actually slowly equalizes the set value after a while and basically there is some kind of a flickering around the set value. It does that flickering and slowly attains the set value point. So, basically now as you are seeing here the variable value is have has almost reached 100 degrees and this is time enough for our wafer to get loaded inside and get dehydrated. So, what we basically do is essentially take the wafer box which we pulled out of the fume hood after the piranha clean, and then basically put an aluminum foil on the top of one of these shelves and then slowly load our wafer sample.

So, that we can get it heated and remove any water if present on the surface of this wafer and the whole idea is to have a perfectly dehydrated surface of this particular wafer. So, that it can be good for adhering to the photoresist that we essentially spin coat on the top of it before doing photolithography. So, we keep the wafer in the oven for dehydration for about 10 to 15 minutes at about 99 to 100 degree Celsius. The next step is to unload the wafer and start doing what we call spin coating of the photoresist. So, what I am going to do is to just unload it and carry it back again.

Please note that we are using the same wafer box for carrying the wafer again from the for the constraint that it should not get contaminated while going between operating stations. So, we slowly use the tweezer which was again used for the other processes. This is again a clean tweezer, and we slowly pick up this wafer from the oven, transported into the box here, and then convert this or cover this with the lid. So, basically, now we have a clean wafer which would take to the next station which is actually the spin coater where we will be doing the resist coating. So, the next stage basically is spin coating the photoresist and for spin coating, the first thing that one needs to take care about is the grade of resist that one is using.

There are many manufacturers of resist in the world. We will be doing negative tone photoresist here which basically means that wherever light UV light is used for exposure of the photoresist film, there would be a general cross bonding among the molecules and the resist stays back and the portions which are unexposed can be developed off. So, really what you would have is basically small features translated from the masking mask design onto the resist surface and wherever light has fallen through the mask window onto the resist, the features remain. The other portions of the features go away after developing. So, the first thing that is important here is to download the specifications of the particular grade of resist that you plan to use and what we normally do is we use a resist from Microchem which is actually a resist maker and essentially we are using a grade of resist called 2025 SU8 which has a certain viscosity and what the resist manufacturer really does, he really puts together an experimental curves for this particular viscosity. And so, basically what he determines is what is the rpm at which we should spin the resist so that a particular thickness can be achieved and thickness defined by the rpm is really thickness of the feature that we are looking at.

What it also does is it actually mentions about the temperature steps that you need to include in order to process the resist once it has been spin-coated and also after the exposure. It also mentions specifically about what is the exposure dosage which is needed and what is the time for which the resist needs to be exposed so that it can have enough cross-linking and cross-bonding. Just at the outset, I said this process of photolithography is about developing cross bonds between different molecules and that is essentially driven by reaction chemistry and has a certain rate. So, it is very critical for us to be able to determine how much temperature is needed, what is the time point or what is the time of holding for that particular temperature step. Also, we also need to ascertain what would be a typical exposure dosage for all the molecules within that small window to get exposed so that they get cross-linked very well.

So, essentially, I would like to go ahead and make features which are about 20 to 20 microns thick. And for doing that if you will see at this resist grade sheet, you basically get these curves here where it talks about what is the rpm on the x-axis here and what is the corresponding film thickness that you will be getting. So, when we are using a certain grade here which is mentioned in this table here as you see. So, SU8 2025 which is the lowest grade here is really corresponding to a curve which is the least this curve essentially here. And so corresponding to about 20 to 25 microns what we find out is the rpm that we would need for this is about close to 3500 rpm.

So, I am going to in just about in a minute set up the spin coder that we have here and tell you about more about how to program this machine so that you can have the particular spin speed at a particular rpm. And you can also be able to hold it at that spin speed for a certain amount of time. This right here is what we call the spin coder. So, essentially if you look into this machine closely you have a spin stage which is represented here, which is here in this area. Essentially the principle is you use vacuum for holding the wafer onto the spin table.

And if you look closely into this particular area, you have these grooves here which are actually crisscross, and they are placed over the whole periphery of the spin stage. And the purpose of these grooves are that there is a vacuum track immediately below this which is connected to a vacuum pump underneath this whole system. And essentially the vacuum propagates all the way up through this small center hole here and then also propagates along these grooves and kind of holds together the wafer on the top of the surface. What is also important for me to tell you is that there is a control which is here for which we can actually use for flexibly controlling the spin speed. So, the amount of time for which we can hold at a certain speed and also what is very critical for different grades of resist is the acceleration at which you can rotate in order to achieve a certain speed.

So, here in this particular example what I will be demonstrating as per the resist manufacturer specifications the spin speed that we are using is about 3500 rpm. And also, you know the spin speed has to be attained with an acceleration of about 300 rpm per second. And what it also mentions is that you have to hold at a certain spin speed for about close to 90 seconds for the spin coating to be uniform. I would also like to illustrate here that the resist being a thick material needs a little bit of time for uniform coverage over the whole surface. When we are talking about a circular wafer what is very important for us to understand is that the first of all the resist that you are putting should be sufficiently covering the wafer.

So, that you know once the so what is also very important for me to illustrate here is that really what we are doing is to spin the resist on the top of this circular wafer which is about 4 inches or so. And we need to be able to certain what is also very important for me here to illustrate is that you know the particular spinning operation should be able to adequately cover the whole wafer surface. This is a circular wafer of about 4 inches diameter and the goal here is really that the resist should not have any gaps or any islands on the surface as you are spin coating it. So, you have to certain how much area you need to initially pour or cover so that you have enough resist.

So, that essentially spinning process is nothing but centrifugation. There is a slow coverage of the surface of the resist which has been poured somewhere in the center by centrifugal forces. And so, the whole idea is that you cover adequately and give adequate resist so that when it goes radially in all the directions it should be able to have uniform coverage on the surface. So, for doing this what we would need to find out first is how to set up the controls in the particular spin coating and how to control the rpm time, the rpm per second rates etcetera. So, let us look at that in our next step. And corresponding to this program number what all steps are there in the program are illustrated just in this particular region.

So, as you are seeing here in this in the run mode the step 1 of the program illustrates that there would be an rpm of 3500 rpm which is attained at an acceleration of 300 rpm per second. And the time of hold for this is about 180 seconds and this is with an option of vacuum operated. So, that the wafer is pulled down while the spinning happens and then finally, you have to somehow change this program to suit to your requirements. So, what we essentially do is to first use the program mode here as you can see to go to the number of the program. Once we want to make a new program here, so we find out the or we give a new number here let us say we want to make program 7.

And then we try to see or try to illustrate what is there in program 7. So, we go to the mode option here. So, basically what we now do is after we have entered program number 7, we enter this program and then go to the mode option. So, that we can get a detail of what all steps are involved in this program. So, here really the program is about step 1 and only it is a 1-step program and followed by the end of the program.

So, it is 1 end. Now, what we do is basically move to the next option here and we get this rpm which is actually 2000 this particular case as you can see. So, what I am going to do is to change this to 3500 which is our requirement, and we can actually hit enter here for the system to take this. The time for which we need to hold this rpm is about 90 seconds. So, we do 90 here and then enter the data and the next step is what all revolutions per minute per second we need this speed to be. So, we put the value for the acceleration 300 and essentially enter this value and for our condition, we need the vacuum to be on while the spinning is happening.

So, we just take whatever is the default and that completes pretty much the program. So, all we need to do is to now actually put the wafer back to the spinning stage after which we will be doing the run operation. So, what I am going to do now is to actually simply load the wafer onto the spin table and then we have to also see whether the wafer is actually centered which I will do a little bit later. And what I do is I just turn on the vacuum you can see this light the green light appearing here which means that the wafer is now firmly held to the surface, and it cannot come out and it is basically clamped pretty firmly onto the spin table. So, now it is almost ready to rotate and spin and essentially coat whatever is there on the surface of the material.

So, we would like to also have a look as whether this wafer has been centered and the best way to do that is to close the lid and see from this transparent section on the top whether this wafer is really at the center of the spin table. In case it is not then you can switch off the vacuum and again and again change the position in a manner. So, that the wafer can come pretty much at the center of the spin table and the thing which we are ensuring here is that there should not be any wobble really of the wafer and it should actually rotate at its own axis and so it should rotate at its own axis and that can ensure that there is no underutilization of the resist which is at the very center of the particular wafer. So, basically, we have now placed the wafer and essentially what we need to now do is just turn on the vacuum here the light would come on as you can see here this is in the on mode.

So, basically, the vacuum pulls the wafer. So, that it can sit on to the spin table and then we have to also see whether the wafer is centered and the way to do it is basically close the lid of the spin coder and turn this RPM on. So, that the system actually starts rotating and see from this top transparent area where there is any wobbling in the particular wafer. Now, as I can see here from the top the wafer is more or less centered and there is very less wobble. So, I really did not do anything about position of the particular wafer. So, I am going to switch this on you see the wafer is moving inside spinning and essentially there is very less wobble, and we can do with it with this kind of a wobble.

So, I am going to now spin cote the photoresist on the top of this wafer by pouring the resist and then doing all this execution of the RPM cycle. The moment the resist is spin coated we also need to take this now for the twin-step heating process which I am going to describe in little bit. So, the resist as I told you needs to be heated and one of the purposes why heating needs to be done is that there is a solvent which is really a carrier solvent for resist. It has really an epoxy resin which is dissolved in a carrier solvent which is actually cyclopentanone and essentially the purpose is really to transport the epoxy uniformly over the surface of the wafer in the spin coating process that we saw last in the last step. And then we need to get rid of this solvent because essentially that would ensure that the resist film is stable, it is hard enough, it is kind of equibonded and before doing exposure it is very critical because the mask would sit on the top of the resist.

And so therefore, if there is some undried portion or uncured portion the resist is going to get damaged and that is something that we do not want because that would mean that our surface of the micro-features that we would result I mean that it would result in damage will also be damaged because of that process. So, we need to ascertain that the resist is fully cured before taking it to the next exposure step. Now, I would like to illustrate one fundamental factor here: we all know that because of heat addition there is a thermal expansion, and this is the thin film we are talking about, the resist is really a thin film. And so there may be a rapid due to rapid heating or rapid cooling there may be a tendency of the resist film to warp over the surface and create undulations. And that is something that we want to avoid too because we need to be as much planner as possible for the surface or for the structures integrity to be maintained.

And so it is really a good idea to heat the resist in a stepped manner, heat it at a lower temperature may be about 65 degrees or so and then heat it to a higher temperature so that it is adjusted enough and there is no undulation or warping of the film as such. So, therefore, we use hot plates for this purpose here as you see in this particular illustration there are two hot plates I have, they have been preset to the temperatures of 65 and 95 degree Celsius. And each of these steps would have a certain time associated with it. So, the spun-coated resist on the wafer would basically brought in and these plates would be used for heating these so that we can get a cured film of the resist on the surface. Close this and just start the spin coating process and let the film that we have set kind of spread over the whole surface and create a thin film which is about 20 to 25 microns of this resist on the surface of the wafer.

So, now we have to be now the resist is actually spun-coated now. And we have to be very careful about removing the wafer, we have to hold it from a thin corner at the sides because that is typically the area where there should not be any designs and structures. We will just use a little bit of tweezers space for holding it and be extremely careful about handling because mind you at this stage the resist is actually a kind of liquid in nature we have not cured. And before the curing the film is like tacky and then if you have any stresses or any impact on the film it is going to create a huge difference and make the film not behave properly. Also, we need to certain of one basic fact that the table that we are using for keeping or aligning our hot plate should be perfectly parallel to the ground because otherwise there may be a possibility of the resist running to one side thus creating a thicker film at one end which is highly undesirable because we want a uniformity in the film thickness which also determines the sizes and nature of our structures and features. So essentially now the program has stopped, and I am going to slowly pull and as you can see here there is a thin film of resist on the top of the surface.

I am going to actually take the wafer box here and then slowly use a small amount of space. So, in first thing we need to do is to close the vacuum. So that we can decouple the wafer from the spin table. We take a very close very small portion and bite along with this tweezer on that portion and then slowly transfer the resist-coated surface onto this wafer holding box and then once we have done it we actually cover it with this cover here not press it very tightly and then slowly move towards our next step which is the hot plate and keep it on the 65 degree set hot plate and wait there for about 3 minutes or so. So, I am going to put this wafer now on the top of this particular hot plate which has been set at 65 degrees.

So, for doing that we have to be again very careful about pulling this resist-coated wafer out. We use the exact same area as we had used before for holding just in a small edge or a small corner and then keep it on the hot plate. We have a stopwatch with us here at this particular stage we would like to operate on the stopwatch by setting it at 3 minutes and then starting to operate this and basically the idea is that this will give an alarm at the end of 3 minutes. We need a 3-minute heating time for this particular process step of 65 degrees and then we will go to the next step which is another 3 to 4 minutes on the 95 degrees.

So, this watch is now reading about 19 seconds or so. Now, this is actually an alarm system it would tell you in advance as the time is over you will have a beeping sound from which you can actually figure out what is the exact time for which the resist has been heated. The thing about microfabrication is that you have to be very careful about the exact hole temperatures. This right here is an illustration that the time is over. So, what we will do is we will go ahead and pull out the resists now, the resist-coated wafer now.

Again the same precautions need to be followed. You need to hold the resist from a very you know small corner here and then slowly put it over the surface that we want to mean, want to put it. So, I am going to now transfer this resist-coated wafer onto this particular surface. It is almost, it is always a good idea to actually coat the heated surface, or it hold the heated surface at room temperature and let it come back to the particular ambient room temperature for you know the film to have least possible undulations and warping is possible. We will just cover it in case there is any dust accumulation on the surface. Another thing I want to point out is that the environment in this in which this coating process is carried out is a very clean environment.

We estimate, we plan to actually do these things typically in clean rooms where the particle contamination may be as low as about close to 1000 ppm or 100 ppm depending on what kind of feature sizes you are using. So, essentially, we will hold this for some 5, 6 minutes till it equilibrates back to the room temperature and then we will actually use the second heating step of 95 degrees and put this resist back again for about 5 to 6 minutes for the full curing action to take place after which we will do the UV exposure of the resist using the mask. So, after the, from its location and put it over this plate which has been set to a temperature of 95 degree Celsius. We start on the stopwatch and set it to about 6 minutes time. So, the idea is that you know after 6 minutes as we here the second alarm we should be able to pick this up and then again let it equilibrate back to the room temperature before the exposure process.

So, we are nearing the end of the time that it takes and there is an alarm bell now again. So, what we have to do is the same thing we will pull back the wafer from the surface here and then put it back again on the you know use just a small area here to keep the wafer or hold the wafer through the tweezer and then put it back again on its resting place where we will use a little bit of time for equilibrating it back to the room temperature. So, we are now ready after this temperature is close to the room temperature to do lithography on this particular wafer. So, essentially this is called the photolithography equipment, and this is used for exposure of the resist to very characteristic frequency of light mostly in the UV area. Essentially here what you do is to use something called a hard mask which you can see here right here. This is actually a glass chrome mask where you can see very closely if you look at some of these features really are at the micron scale and these have been made using laser etching in a film of chrome that you have heard and that this side this particular side which has the coding really sits with the wafer being aligned with the wafer because otherwise if you have the other side sitting in proximity to the wafer there are diffraction effects.

If you see the thickness of the mask this is made in a glass plate which is about close to 900 microns or so thick. And so therefore, it is very good idea to have the metalized surface in proximity to the coated wafer 0.9 mm or 900 microns is good enough for a beam of light to get hugely diffracted. And so therefore, if suppose we were to do the other way round with this side the glass side sitting on the top of the wafer the features that we typically looking at would be much more in size because of diffraction effects. So, what I am going to do now is to tell you how to use the lithography setup to actually do alignment and exposure.

So, here we have something called a mask holder which is actually this region here. The mask is really sitting on the top of on the bottom side of the surface of this particular holder and it is actually facing the wafer which would be placing somewhere here this is the wafer stage and the idea is to be able to precisely align the hard mask over the wafer surface. So, in order to do that what we do is to kind of loose these particular points here there are four such screws and then slowly pull out this part from the machine, and essentially as you see this really is the surface which holds this particular hard mask. And there is a stand for this application or this mask loading you have to put it right in that particular spot it is like a jig, and it ensures that there is no unnecessary toppling or falling down of the mask holder. So, take the hard mask and this has to be pre-cleaned this, of course, is a pre-cleaned sample. So, what you should normally do is to put liquid compressed nitrogen or compressed air and blow dry it thoroughly.

So, that there are no marks suppose there is some finger mark or something which comes on the top. So, you could use a small amount of acetone and wet a Kim wipe and then slowly rub over it and then wash it in ethanol and then clean it using dry air-dry nitrogen, or compressed air. So, what I am going to do is to actually align this mask in its place here and slowly. So, there are two slots really for that purpose and I am going to actually make it face down. So, therefore, the chromium side has to be facing the wafer surface.

So, which is actually given by this dark brown region of the mask. So, I slowly put it inside the mask holder, and then basically this is only a passive gripping we need to make it active by using vacuum which can be operated by using this controller turning on the controller and the controller power on and then actually use the wafer holder and the mask for the vacuum to be operated on to the mask. Now, if you see the mask really is held very firmly. So, now we have it actually mounted and well connected with vacuum from the system. So, what we do is we take this wafer holder out and it is pretty much firmly gripping to the mask now and there is no possibility of the mask falling as you can see.

So, we go back into its position here and then try to mount it in a manner. So, that you can actually bolt this mask holder on to the top of the wafer surface. So, there are 4 bolts for that purpose you actually try to align them with the bolt heads which are there on the top of the mask holder and essentially you can actually now use the locking mechanism to ensure that they firmly get locked over the wafer surface. So, what we do is now actually after mounting this properly we need to actually bolt it firmly. So, we are going to actually use these set of screw heads to ensure that there is a good contact between the holder, and it grips really good on the surface. So, we are going to just ensure proper gripping of the holder, of the mask holder on to the surface of the stage.

The stage is by the by going to move along with this whole mask holder to the exposure zone which is underneath the scope as I will be showing you just in a little bit. And it has to be having a tight grip for the purpose of proper alignment with the wafer on the surface. So, what we are going to now do is to actually move this exposure stage, the scope actually from its current location to near this over the mask holder. So, that I can have this zone here for wafer loading and unloading free. And essentially now I take out the wafer and load it on the surface of the chuck which is just here in this particular region.

So, essentially now what we are going to do is to take the wafer from its box and actually put it in this particular zone here which is meant to do wafer holding. Then we would like to use vacuum as a means of locking this wafer, this spun coated wafer, resist coated wafer onto the wafer, the exposure stage. And this switch right here which says wafer vacuum actually ensures that the vacuum is used to pull and lock the wafer. I want to just check in whether the vacuum is working well, and I found out that it does not move anymore, the wafer is jammed with respect to the stage.

And then next step is actually exposure to UV. So, in the next step what we do is we actually now align the mask with the wafer by pulling this stage all the way up to its position here, location here. And then try to actually manually bolted, bolt the holder in this place so that it does not move back. And also, what we would need to do here is to actually go ahead and move this microscope stage back for the correct focus. So, the idea is that the wafer has to be z-displaced so that it can come in contact with the mask surface.

And for doing that we also use this scope, this microscope. There is a small IR beam which is actually, there is a small red-light beam which is actually used for the purpose of seeing whether the wafer is really touching on to the mask surface. And so what we do is in the first stage we move this particular microscope or the scope stage all the way to its position here above the mask. And then there is a small lock here which we use for locking. There is also a control here where we can actually turn on the red light which actually is now focused on to the mask and the wafer.

And the idea is we should be able to move the various, the wafer stage. And we do it by moving, this is the x displacement and really this is the y displacement for the scope. So, the scope can position on a particular area and the wafer stage can be moved by the controls which are there at the bottom here in this particular zone. And we can actually move the z displacement and see whether the feature on to the mask is really in focus. If it is in focus that is an indication that the wafer has touched the mask surface and that is really the spot at which we should do the exposure. It is so fine aligned that if you just go above that focus point or below that focus point, it indicates either you are pressing the wafer hard to the mask which means at the cost of damaging the resist or you are going away that means creating a gap between the wafer and the mask surface.

Either event is not good for us. We have to just be able to make just a close contact without much pressure on to the resist-coated surface. One of the reasons why this kind of alignment systems are also called contact aligners. So, essentially, we I would just like to see through this microscope stage and try to find out if the features etcetera are close. I see that there is a little bit of displacement which is needed to be done on the z-axis so that the line the images can be correctly focused.

Now, I think we have really pretty good adjustment and we can do, or we are all set to do the exposure. So, this right here is also a controller for the exposure time. If you look at the resist manufacturer sheet, it gives the exposure dosage for certain thickness of the resist film. So, what we need to do is to calculate from there using lamp power how much time of exposure is needed for the particular thickness that we are operating. So, because our thicknesses of the resist are about 20 to 25 microns, we can get the correct exposure at the dosage rate that this particular lamp offers in a time of about 20 to 22 seconds.

We use this timer setting for achieving that. So, you have these different values here in minutes and you can see right now the setting is about 22 seconds here which means that the exposure would be for 22 seconds. So, now what we have to do is after all this exposure time setting etcetera has been done, we need to take care of this microscope stage by moving it back because now we also need to do exposure. So, essentially, I am going to unbolt this whole stage from here and then shift it slightly towards the right and dock it in its position. And essentially that is going to give me a through pass for the light, the UV light to go through the mask and fall onto the wafer surface.

So, this is now taken care of. The mask is there in contact with the wafer and in order to protect the operator, there is a UV shield which has to be installed here before doing the exposure and we are all set to do the exposure. So, I am going to now actually turn on the exposure light and as you see here the moment, I turn it on, the timer clock has started and the light, the UV light is now falling sharply onto the wafer. And essentially this is the time reading here says that is rapidly reaching 22 second mark that we had set before. The moment that is done, this light will go off, the exposure light will go off and our exposure process of the photoresist is complete.

As a matter of fact, it is just complete now. Now we have to actually just unload the wafer and the mask, separate them together, and then we need to go for a post-exposure bake step that I will be explaining in the next step. So, now I am actually going to go ahead and turn off the exposure system because it has been working for very long time. And now we need to step by step do the processing in a manner that we need to separate the wafer from the mask. So, a good way of doing that is to actually go anti-clockwise so that the masking stage can go down and I can now take the wafer all the way by leaving contact with the mask surface. The next step would be to move or push back the particular mask holder all the way back to its resting zone which is close to this end and turn off the wafer vacuum so that I can pull out the wafer.

And this is actually the exposed wafer which we are pulling out. We will again load it back into its resting place, which is this container here, right here and we will do something called post-exposure bake after this particular step. So, slowly you have to pull out the wafer from its stage. Now it has been released vacuum is no longer holding it and you actually slowly take it and put it back into its wafer box, cover it so that there is not much dust contamination on the surface, close it and set up the microscope back to its place here. We also need to just reverse the sequence to pull out the mask. We need to just switch off the wafer holder as well as the mask vacuum and essentially need to just pull back the mask in the pretty much similar manner as we had loaded it before.

So, these bolts need to be tight, untied so that they lose grip on the top of this wafer holder. Slowly move the holder back in its place. And keep it back here and essentially move off the mask as we had done before and store the mask in its place, in its box right here. And we can also put this holder back in its place so that the machine is ready for the next run. So, the system is turned off, the next stage is basically to take this wafer and do post-exposure bake.

And one of the reasons why that needs to be done is that this really is a heat-catalyzed process. If I put the exposed wafer in room temperature conditions and keep it for longer time, there would be a slow protonation in the exposed areas which would create really the opening of the epoxy chains and cross bonding in the areas which are exposed. However, I would like to fasten this process so that the overall time duration for which the lithography is completed is lower. And for that we need heat-based catalysis of the process. And so doing this what we really need to do is to actually take this wafer back to our heating station. And then there are again manufacturer specifications of the resist which talks about how many minutes we need to post-exposure heat or bake this using the hot plate at the two temperature conditions that we had done before.

So, I am going to now actually pull out this exposed wafer coated with photoresist as we did in the last step. And slowly pour it on the top of this essentially this hot plate. And the time here that we give for allow it to be heated for at the 65 degrees step is about 1 minute. We turn on the stop clock and essentially wait for the lamp bell to go in so that we know that we have heated for the time cycle that was supposed to be. Again, we have to equilibrate it to a room temperature condition and then put it back into the 95-degree step.

So, that we can have undulated properly exposed, and cured for the resist film. So, time is up really now and so we should whatever we are wanting to actually take it back again put it back into its resting place again. And then wait up till this equilibrates to the room temperature and go back do a 6-minute heating step in the next temperature step that is 95 degree Celsius. Actually, now we actually put it back on to this wafer surface on to this hot plate surface which is set at 95 degree Celsius. And essentially, we heat this for about 6 minutes or so. And one thing very good about this process is that if you look at closely you could really see the features coming up on the surface as you are heating using this 94 degrees.

Essentially the points which are slightly misc contrasted you can see the different contrast there in the zone which is exposed. When you develop it using a developer solution those are typically the zones which remain back and the remaining portions which were unexposed would go away. And that is essentially what a negative tone resist is supposed to do on the wafer surface. So, we are going to now pick up this wafer from this particular place and you know we have now completed more or less the whole exposure and post-exposure baking steps. And essentially, we are now ready for the next step in the process which is developing.

And this developing is important because essentially this actually leads to the features really getting generated within the surface. So, I am going to just take this wafer to the fume hood and there is already a developer solution which is actually already placed in the fume hood. There is a certain time for development which the resistor manufacturer specifies, and this again is a function of thickness of the particular resist. As we our thicknesses are in the range of 20 to 25 microns. So, the resist maker specifies the developing time for this particular thickness which is about 4 to 5 minutes in our case.

So, let us actually try to develop it. Another important point that I would like to mention is that the resist which is actually left over onto the surface while this developing is taking place, and it is unexposed kind of turns white or cloudy as you spray isopropanol. So, development process is really after the whole-time duration is over it is an iterative process where you kind of spray the isopropanol on the top of this surface again and again and see if there is a cloudy or milkiness associated with the surface. Any resist which is left over which is unexposed would definitely turn milky and cloudy. So, you have to see when by pouring isopropanol you do not get this cloudiness anymore which also means that your development process is complete and that gives you the best resolution of the features that you are looking at on the surface.

So, one thing we have to also take care of in this case is that you cannot just simply drop the wafer on into the developer. You have to keep on stirring the developer solution from time to time. So, that there is no accumulation of the resist which is coming off unexposed resist which is coming off at one particular place. So, the idea is to keep on dissolving it by swirling the fluid which is over it in a particular manner. So, I am going to do that and then after 4 seconds, I am going to also spray isopropanol to see whether this resist that we have done is actually totally developed or not and essentially start the time now this set to about 4 seconds and then we keep on giving some swirls to this developing action and essentially you have to ensure that this happens.

So, that you get good features on to the surface. So, as you can see here in this particular case after the developing is happening immediately after you put it into the developer the features kind of nicely and beautifully get generated. We need to do a proper microscopic analysis later on, but this really is the success of the process. That whatever you have exposed is essentially keeping there the resistors all cross bonded and the remaining portion has been removed and essentially again you have to keep circulating this and spraying isopropanol from time to time to see whether you know everything is remaining on the surface. So, I am going to put this for the first time and see this is another beaker that we have put here for spraying isopropanol to see.

Let us pull this out and this bottle right here is really the isopropanol. So, I am going to see this I see that there is some clouding action which has happened which means that resistors still present undeveloped resistors still present. I put it back into the solution and again try to just give it a few turns and see. So, this process keeps on going on for the stipulated time and at the end of the process, you will have really sharp distinguished features which come out the process. So, basically, we had in an earlier experiment developed this wafer this piece of wafer and essentially now whatever was there on this mask has been transferred onto this wafer using the process of photolithography. And since in essentially, this is not the end of the process because we really need to measure and calibrate and be able to see the microscopic features that have been imprinted on the top of the resist which will be using later for our purposes.

And for doing that we need something which can create high magnification object. So, in our laboratory here we have this microscope it is actually a inverted fluorescence microscope, but it does have an option of being able to image using the bright field, dark field imaging regime. And essentially this microscope is from Nikon there are certain manufacturers of these optical devices they are precise. This needs to be rested on vibration free table as you can see, and I would like to describe at the very outset little bit about this microscope and how we do the imaging modality. So, here in this particular zone, these are also known as the objectives.

So, essentially, they are nothing, but lenses and they all have the capability of magnifying in different capacities. So, we do have objectives varying from 4x which means that the image which is actually seen through the microscope is 4 times the actual size of the object all the way to about 150x. So, essentially there are about 6 objectives here. The way that this microscope operates is pretty simple you have an illumination source which is at the background which is actually a UV source. It passes through a set of ND filters, neutral density filters which would cut off the UV light into different intensities.

And then finally, the cut off light at a much lower intensity reaches this portion of the microscope which has what you know as filter cubes. So, I like to explain what these filter cubes really do. Essentially if you look at the way that the filter cubes are assembled, these cubes have you know two basically they are cubes which have two filters essentially. What are filters? Filters are essentially pieces of glasses which are designed to cut off certain frequencies and let certain frequencies of light go past it. So, in this particular filter cube as you see there is an emission filter which is situated at the top, there is an excitation filter which is actually situated here.

And then we have something called a dichroic mirror which is just placed in between this cube in a 45-degree angle. The purpose of this filter is essentially to take off the unnecessary frequencies from the UV. As I told you this microscope also has a capability of doing fluorescence measurements. It is almost always important to be able to excite a certain dye with a certain wavelength of light. Let us say we have a dye which is excitable in the range of 390 nanometers wavelength. So, I should have something some cut off mechanism where all the different components of the UV which are coming from illumination source to this filter should get cut off except the 390 plus minus may be about 20 nanometers.

So, which is also known as a dichroic mirror which is placed inside this filter cube probably it is not visible from outside, but the way that that mirror operates is also based on this cut off principle. So, there may be a cut off wavelength beyond which the filter the dichroic mirror may be able to refract the light and below which it should be able to reflect the light. So, that is how these mirrors are typically designed. Now, with this combination in mind let us look at what is the optics. So, this particular filter as you are seeing here is going to face the UV light and it is going to take off the particular portion which is unimportant and send or transmit the portion which is necessary for the particular fluorophore.

Now, each of these fluorophores are designed for a certain frequency and essentially, they have an emission frequency range and an excitation frequency range. So, whatever cut-off we use should correspond to the excitation frequency of the fluorophore. Now, once this particular portion of light comes in the filter it is reflected of the dichroic mirror which is now placed at a 45-degree angle and actually goes down this filter cube to the objective. So, you have light beam coming from this end cutting a portion of it through the filter, and then the cut off portion which is necessary portion goes and falls onto the 45 degrees mirror which is placed in the center of the cube, and it goes reflected through the mirror because that is the property of the dichroic. So, let us say we are trying to cut off 390 plus minus 10 nanometers wavelength band.

So, essentially, we use a filter so that the particular package or the part of the package of light which comes out of the filter is from 380 to about 400 nanometers. And let us say we have a dichroic mirror which cuts off at 590 which means that anything below 590 is reflected of the mirror and anything above 590 is refracted of the mirror and it goes past the mirror. So, now just because the reflected beam goes down it actually passes through this lower end of the filter cube and reaches through the objective onto the sample. This right here is the sample stage it is an XYZ precisely moving stage which is capable of positioning the sample with respect to the objective and we can actually maneuver over the sample and see the portion of the zone which we want to focus and image. So, essentially when the light goes and strikes the sample surface and there is a fluorophore there is an emanation of a certain frequency which is the emission frequency of the particular fluorophore.

Now this frequency actually would come back from the objective and come through this hit the mirror and here as you see the dichroic does its job again. In this case because of the stoke shift the wavelength that is generated by the fluorescence is actually higher on the higher side. And so, suppose we have a fluorophore which generates an emission frequency in the range of 620 nanometers, which is above the 590 cut-off that is provided by the dichroic. So, what the light beam which is going to come from the fluorophore through the objective is going to do is to go past the mirror in the refraction mode. And essentially you can pick it up using this other filter here which can further streamline it to the band that we are looking at. So, anything above 590 is sent out and then we are trying to identify let us say a 620 plus minus 10 nanometers which is about 610 to 630 nanometers region or band of the wavelength which actually comes out and comes through the objective onto the eyepiece and that is how you get the image.

Now, in a bright field dark field option particularly for lithography the problem that we faces that we cannot image these silicon wafers which are trans which are actually opaque using an inverted mechanism of light in glass samples, glass holders, or transparent or translucent samples that is still possible. There is a light source here in the microscope which is actually white light as you can see which can go past the sample surface if the sample is kept at this particular state. However, in our case if I put the silicon and the silicon is opaque the light will not be able to go past.

So, this is really not the imaging modality we are looking at. So, what we use is this principle of filter cubes and essentially, we just remove the filters from both ends. So, therefore, it is just plain light which we are actually looking at for exciting and whatever is reflected off is captured and essentially, we can actually design the dichroic mirror in a manner that it actually gives only in the visible region of the spectrum. And so typically we can see a mixed coloration from the white light which is reflected off the surface of this wafer and which comes out and gives a good feeling about what the images on the particular sample. Now, what the objective would also do is to try to blow up the image and make it well magnified and this is very essential for micro features. We are looking at let us say a 26 microns feature or let us say a 50 microns feature as we probably know you know all of you probably by now know that the human hair itself is about 100 microns.

So, we are talking about half of that size, or we are talking sometimes about one-tenth of that size. So, it is not very easy to visualize until you really magnify to a certain extent, and this is the tool which is used to do that. So, with this background in mind let us go ahead and try to do some imaging on the resist that we had actually processed that day. And so essentially, I would like to close this filter cube and I would like to tell you now about how the image processing can actually be done using this particular imaging system. So, I am also going to show you now how we acquire these images digitally of course, through the eyepiece.

This is also known as the eyepiece through which the image can be seen because it is closer to the human eye that is why we call it eyepiece. And essentially what I am now going to describe is the way that we can digitally acquire these images and electronically sent it so that we can have digital photographs. So, one of the options that is available to us in this particular scope is this unit right here which is also a charge couple device a CCD camera. And essentially again this is probably the finest form of miniaturization that can happen using microelectronic processing technology. So, essentially whatever light intensity is allowed past the dichroics and the filters actually goes past this tube here.

And there is a small Peltier cooled CCD chip which has thousands of this or millions of this pixels which are independent devices. So, the idea is as the intensity falls on these devices the intensity of the light there is a transduction process, there is a generation of electrons from the photon. And that gives you a signal that gives you an aspect about what is the intensity, what are the different textural profiles from which the light has been reflected. And that can be reconstructed simply to make what you call the real image. Of course, the magnification is done at the outset here by the objective of the particular object. So, the light goes past into the CCD here, the charge couple device here and electronically transfers the data electronically transfers through this data cable as you seen to a computer which is placed right over.

So, the data which is collected here electronically goes past this data cable all the way up to this computer here that you can see. And essentially in this computer we do have a reader software which actually also is able to acquire the data from the charge couple device on the microscope. And read it on this frame digitally using this particular software. So, we have a licensed version of the software called Image Pro which is used to identify the signal responses from the CCD camera. And essentially, I am just in about few minutes going to demonstrate how we can read out using the eyepiece and how we can see here. Now, the advantage that the software also offers is that we do have a scaling mechanism here where by feeding the particular scale factor the magnification factor we are able to generate a cursor which can give you dimensions as you join different points on a same image.

So, essentially I am going to describe this whole operation by starting with our sample which is the spun coated exposed and developed from the microscope stage. This right here is the XYZ stage. So, I am going to actually go ahead and just simply place this wafer on this stage and kind of approximately center it. This being a bigger wafer we do not have a clamping mechanism here. But essentially now what I am going to do is to actually take this filter set to number 4 option which is actually the bright field option here.

And I already described what bright field would mean essentially. And then I am going to actually turn on the shutter so that the light starts falling on the wafer surface here through the 4x objective. My goal now is to look into the eyepiece and see how this image is being visualized on the top of this wafer. And yes, I can actually now see the images very cleanly which have come from the resist. And I am going to actually transmit this data onto the CCD screen for your advantage so that you can see it.

And I am going to now also position the wafer in an area where we can really have a good grasp and we can also have a scaling etc. So, this right here I have now a very well-focused object. I just change the focus a little bit and see if I can go any better. And I think it is probably now very well focused on to the area. The way that you focus these things is by lifting the stage up and down and going in the z-direction. You have a lever here and corresponding knob on the other side here which you can rotate clock or anti-clockwise for the z displacement to happen in the positive or the negative direction.

And you what you need here is actually to look into the scope into the eyepiece and see that corresponding to what z distance is the image contrast the maximum, the image resolution the maximum. You will see that above a critical distance if you go any further the image becomes blurry. Similarly, below that distance, if the image you know becomes it becomes blurry again. So therefore, we need to really ascertain the right z level for the correct focus to happen in this particular case.

Now, I am going to actually transmit and use the CCD camera to acquire what is there for your benefit. So, that you can see what you did or what we did in our last experimental photolithography. So, for that what we need is basically try to use this lever to open the shutter for this particular camera. Now, there are three options in this particular lever as you can find out. This lever can actually come out and go back in.

So, essentially when the lever is actually in its inward position it only exposes the eyepiece and you can only see the image, but you cannot really see through the CCD camera. But if you are actually able to push it all the way to the most outward position for this lever in that particular position you can only expose the CCD camera and cut off the eyepiece. So, you cannot see anything anymore by this eyepiece. So, I am going to now transmit. So, now this the lever being in this position whatever is reflected off the surface of the wafer is getting transmitted through this CCD camera into the computer.

And I am now going to actually look at this image using the software. So, that you can also have a grasp on that. So, we had earlier opened the Image Pro software. So, what I am going to do here is to go to this acquire menu and there are different options here in this particular software. The first option mentions video slash digital capture. So, we actually are able to. So, our purpose here is to get a digital image although the capabilities of the systems are also to get real movies, particularly in real-time cases where you may be capturing particles or you may be doing a reaction etcetera within a small architecture.

So, the capabilities of this particular microscope are enormous. So, what I am going to do is to actually ask this microscope to digitally capture. And so, there is a menu which has been opened here it is called the Q imaging menu. And you have different options in this menu including the exposure preview, the exposure acquisition and essentially you can also have auto calculating option for the intensity. So, that you can get a good grasp of the image.

So, I would actually be able to first see the preview here from this option. And if I click on it as you see this is really the image that I was wanting you guys to see. This is something that we have developed using photolithography on to the surface of the wafer. Now, I will be doing the dimensioning part just about in a little bit, but what we need to do is to actually suppose there is out of focus or in focus you can actually change the focusing stage on the microscope as I told you and be able to get a very good focus on these images. Now, this is probably one of the best for size that one can get using this images because I have already calibrated it using the eye piece. Now, I am going to actually store this image.

So, I go to the snap option here and automatically a photograph is generated here as you can see which actually gives you a digital image of what has been captured from the CCD camera. Now, regarding the scaling option this actually a very easy way out to do scaling. So, what I am going to do is to actually see what magnification we are using for this particular image and as you may recall the magnification that we had used was 4 x. So, this image is 4 times the actual size of the image that is there on the feature. So, I am going to actually go ahead and use the calibration tool.

So, you go to this option called measure there is a calibration option and then I also want to somehow ask the software to identify that scale at which the image is being processed. So, the magnification value has to be put in the software for it to tell what really would be the actual image size. So, whatever sizes it is getting in terms of pixels on this digital image would be converted by dividing by a factor of 4. So, that the actual sizes can be obtained.

So, I am going to actually go ahead and ask the system or give the system the magnification. So, it is providing a standard magnification of 10 x which has been the set value, but ours is 4 x. So, we go to this drop-down menu and actually go ahead and see or input the reference calibration and make it 4 x and let the system understand that is 4 x. And then we have an option here of scale which is actually having a text box that says measure lengths and distances in the particular image. So, I click on this option and a scale comes up and then I am actually going to use the cursor and connect two points from end to end to see what distances it would be talking about.

So, let us say if I click on this edge of the image here, right here and go and click on this image edge here in this particular area, this distance is corresponding to about 127.9 microns. So, 0.9 is actually relevant. So, let us say it is about 128 microns. So, this way we can actually get a very good feel of what the actual you know distances would be.

So, let us say we want to just connect this two points here on the small you know this small this piece here. So, this is corresponding to about 37 microns. So, essentially you can actually measure say from here to here in this particular figure this corresponds to about 187 microns. So, you can actually very accurately and precisely measure the size of what has been generated. Mind you this 37 microns is only one-third the human hair dimension. So, it is a real small entity to be seen with normalize, but this powerful imaging system or modality that we have enables us to actually see and measure what we have done.

So, essentially, I would like to actually go ahead and look at other areas and let us actually save this image. So, we save changes to untitled. So, we actually save by going to this snap option. So, we take this as a snap because you know we have done the measurements here. So, even this needs to be snapped for saving properly. So, we snap it and then go to file and save this as a certain let us say experimental experiment photolithography 1 and use the save option here. So, this has been saved in the desktop we can go access it by just looking at this particular image here it has been saved and you can see that this image exactly is the same as we had done before saved before.

So, we can save these images digitally and use them at your advantage. So, what I am going to now do is to actually use a different area on the wafer and would like to show that how or what all features are there on the wafer surface. So, I again basically go to the acquire mode and use the video digital capture and now I am going to go and essentially do the preview mode you can see this is what we had done before, and I am going to move off and let this shift to different places and you can see what all has been written in this particular you know domain. So, let us actually go to a different area of the wafer let us say we are talking about these channel-like regions here.

So, these are essentially the circular channel-like regions let us I am interested to find out what is the width of one of these.

So, these are actually trenches as you can see in the resist and let us see what the width of one of this particular feature would be. So, we again snap the image based on this put it somewhere down here and then again do the calibration by selecting spatial scale and calibrating it to 4x mind you the system actually gets back to the default 10x every time we take a new image. So, we have to actually be careful of feeding the exact magnification factor that we are using we have not changed.

So, we are using the 4x. So, we make it calibrated again we go to the scale option and let us look at the size of one of these channels. So, this size really is about 125 microns. So, essentially let us also look at one of these edges how these edges would look like. So, they are again close to about that same 133. So, 125 or 133 microns. So, around 125 to 130 microns domain.

So, there are some other areas on the wafer let us actually do the same option again to save it we go to the snap tool and essentially save this file and make it experiment photolithography to option. So, we make 2 here and save this image close this particular image here and then let us go to a different area on the wafer and look at some other options. So, if you look at something is written here on the resist and let us look at different spot where it may be a little visible in a little better sense, we have to probably do some focusing in order to see what is actually written here. And let us actually focus this is going out of focus back to focus here. So, it is something like the inverted image of what was there on the mask is probably I can see this is the inverted C this is the inverted E inverted I S, and in this particular domain let us actually shift the wafer a little bit.

So, that we can exactly see what is on this. So, we actually move this wafer just about a little bit. You can develop a thin film of metal onto such a resist and then remove the areas where the resist was cross bonded or remade or unbonded or remaining. So, therefore, when that resist comes off it takes off the metal also and the places of the vias or trenches or capillaries which you have opened in between where the silicon was exposed the metal stays back and you can use these technique for developing thin interconnects on chips, especially in microelectronic chips. You can communicate electronically between two such islands or posts by having several 20 microns or 25 microns wires running in between, and this gives you a tremendous advantage which can be used for sensing diagnostics signal transduction so on and so forth. So, basically, photolithography can be considered to be one of the fundamental processes associated the first steps processes associated in realizing something at the micron scale. Thank you.