Instability and Pattering of Thin Polymer Films

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Lecture No # 17

Soft Lithography- II

Welcome back to this course on instability and pattering. We were discussing we just started in the previous class discussion on the Soft lithography and next couple of lectures at least we will continue discussing the same.

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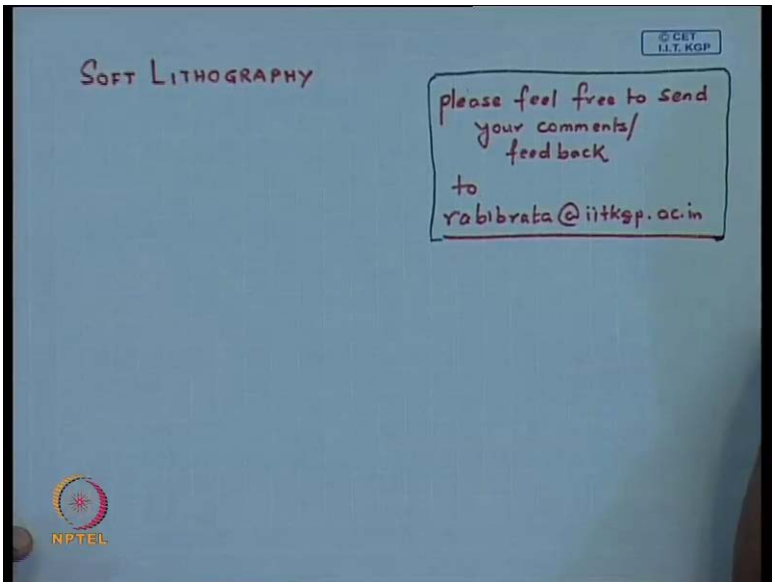

But before that, I would like to sort of formally make an announcement for the course that we are almost approaching the half way stage. And every day, the beginning of the class I show a slide, which contains my mail id. So, I would like to sort of repeat which I have said in the very first lecture itself that if you have any feedback, comments or question, feel free to send me an email at my mail id, which is also I typically give on the first slide of every class.

So, feel absolutely free to sort of send any of your suggestion or any question comments you have. I will try to sort of get back to you as fast as possible. And try to help you

resolve any doubts you have. The reason, why I said is because I must be honest that for a chemical engineering for a student doing under graduation in chemical engineering.

This is pretty new area. Though of course, I will not regard that the concepts are very, very tuff or I mean some basic understanding of twelfth standard science is probably, all you need to follow this course which is not heavy on mathematics or anything like that. But if you still have any doubt feel absolutely free to get back to me at my designated email id. So now, coming back to the subject we started discussing about Soft lithography and in the finishing hours we talked about the or introduced you to the concept of a material called Sylgard or a cross linked Poly dimethyl Siloxane.

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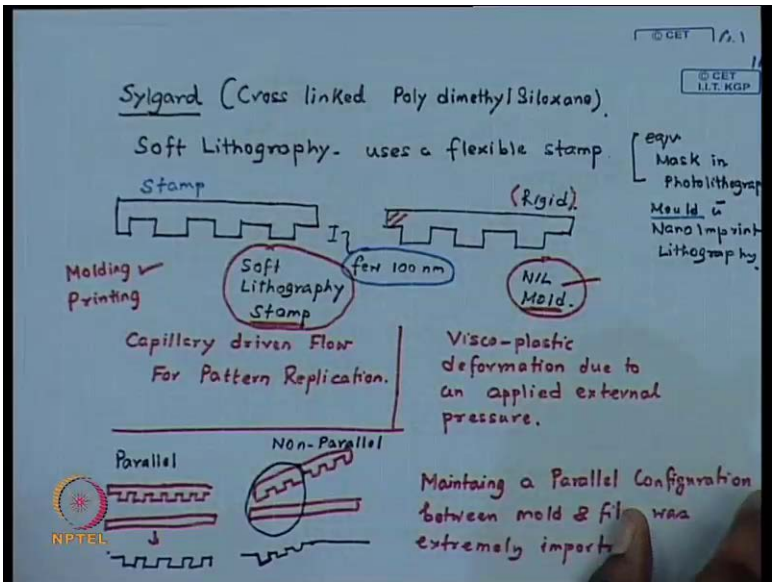

We just talk about how Sylgard is more of a brand name. It is a product, it is a internationally famous product everyone who is even, doing some bit of work on Soft lithography or Microfluidics pretty routinely uses this and this is product from very very well renowned product from dou called in U S A.

There are other companies who sort of make other elastomeric products. So, please do not feel that Sylgard is sort of the only material or I am in no way through this course certifying this to be the best material, but it is if you look at Soft lithography literature or papers published in the area of Microfluidics you will find extensive use of this particular material.

Now, so one of the things is what we talked in Soft lithography is that, it uses a flexible stamp for patterning. So, this is equivalent to the mask in Photolithography and the mold in Nano Imprint lithography. So, I would regard that a Soft lithography stamp is nearly identical to that of a N I L mold both having a relief structure. One of the key difference is being this is in a soft elastomeric material, in contrast this is rigid.

So, this is the rigidity of an N I L mold is necessary, because of the way the technique is implemented, because you will be, sort of pressing it hard with the application of an external pressure on the film. So, that your stamp or your mold can withstand that external pressure and can replicate the patterns on the film surface or can cost the viscoplastic deformation, which you want on your film surface to result you need the structural rigidity of the mold and that is why N I L typically relies on a rigid mold.

In contrast in Soft lithography, you typically do not apply an external pressure we will see today what are the mechanisms? Or how exactly, the pattern replication mechanism differs from that in Nano Imprint lithography. And you rely on stuff like capillary driven flow primarily, I would say you would we rely on capillary driven flow for pattern replication. There are, various different forms in which it can be implemented we will talk about some of them, in contrast to a viscoplastic deformation due to an applied external pressure.

Now, saying that of course we will discuss in details about the pattern replication mechanism. But what I can also tell you at this point of time, the use of a flexible stamp in contrast to a rigid mold as it is used in case of Nano Imprint lithography has one major advantage or couple of very significant advantages. I mean you will realize as and when we processed in our discuss in soft lithography, but at this point of time may be it will not be bad idea to highlight some of those advantages.

The first advantage is that, if you remember in one of the slides of Nano Imprint lithography, while we were talking Nano Imprint lithography. We did mention that, maintaining a parallel configuration between mold and film was extremely important. Because, if you do not maintain a parallel configuration, what is going to happen is that, this is your stamp this is perfectly parallel let us say, in contrast if you have a arrangement like this you can pretty well imagine here.

You would be sort of getting pretty decent pattern replication spanning of a large areas. But here what you will get? You will get the pattern getting transferred only over a limited area number one and. Secondly, there will be a variation in the pattern morphology along the films surface, because of its non parallel configuration.

So, this we understand is very very important in Nano Imprint lithography. But if you also philosophically look I mean the reason why the research paradigm gradually shifted to Soft lithography and imprint based techniques, rather than remaining stuck with Photolithography is to explore areas in bulk nano technology. Where, you essentially need the structure or topographically pattern surfaces for also non microelectronic application and various low cost applications.

So one of the selling points of this imprinting as well as the Soft lithography techniques has been, where you can implement them at the lab scale at any lab scale may be at a high school laboratory scale, without elaborate infrastructural arrangement like, what you need in Photolithography. Like you may not have a clean room or you do not need a really room for example. But you may not also have a clean room, where you are sort of proceeding with your Soft lithography experiment. So, in that case, if you think from a practical stand point, there is every possibility that your sample or the film surface or the film you want to pattern might have some dust particles here and there.

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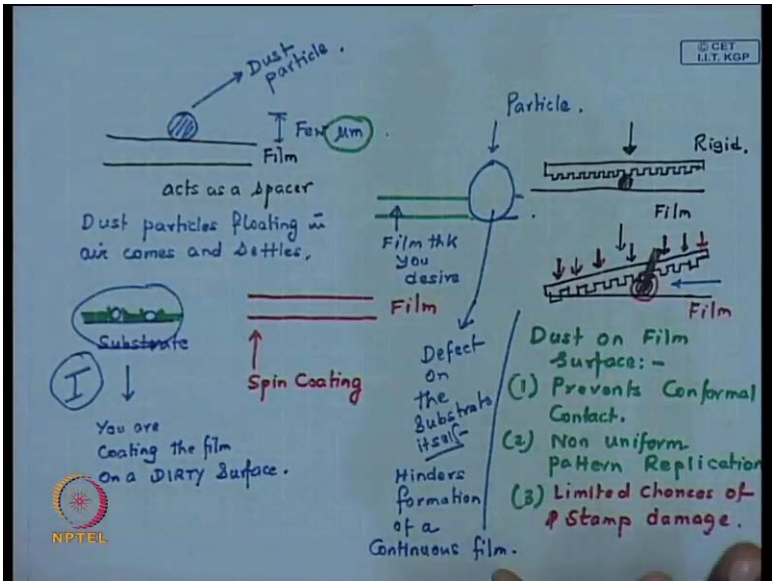

So, what will that mean that you have the film. You have coated the film and in one of the previous lectures I remembered that, we mention that, a typical dimension of a dust particle can be few tens of microns. For example, human hair depends on the texture varies from person to person is roughly 50 to 100 microns.

So a typical dust particle will be anywhere between 20 microns to let us say, 100 microns. Now, you are talking by way of pattering dimensions at dimensions which literally let us say, few 100 nanometer down to let us, say 10 nanometer. That is what we said and we talked that since, pattern replication in neither Nano Imprint lithography or Soft lithography is diffraction limited. And therefore, you can go down to as low as 10 nanometer. So, feature height also can be let us say, something like few 100 nanometer.

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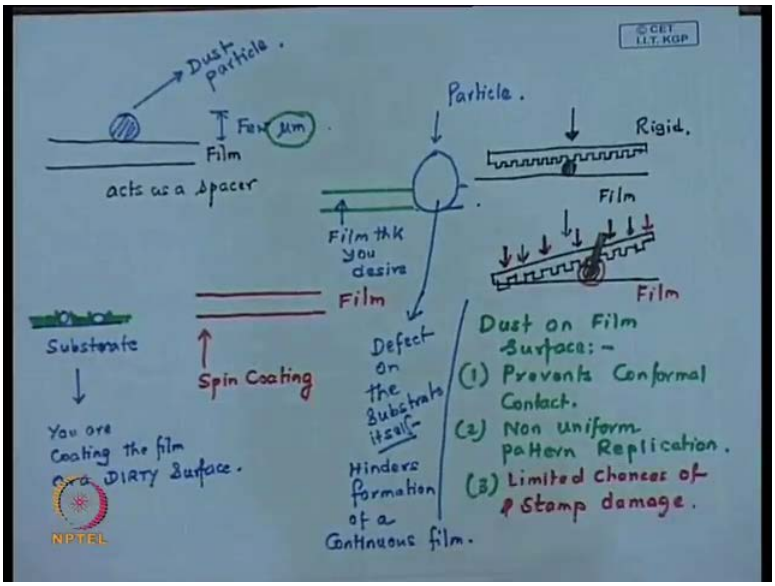

So, now you can imagine that, in case you have a film and you have a dust particle which has a height of even if it is few micron, what that means? It means, when you want to bring your stamp into contact or your mold into contact, this particle will act as a spacer.

So, in case you have a rigid stamp it is definitely. So, you now let us say I redraw the things so you have a film, you have a dust particular over here and you have rigid stamp. So, this particle might lead to several things. Firstly, it will not allow the full stamp. It will prevent the complete stamp to come into conformal contact with the film. Second thing is, you are sort of approaching this stamp towards the film and then, what you would be doing? You would be applying the external pressure.

So, the moment you apply the external pressure, this because the stamp is or the mold is not uniformly touching with the film. So what can be a likely configuration? A likely configuration can be like over some areas, the stamp comes in contact. So essentially, this replicates a configuration like this it is a nonparallel configuration.

The other thing is now if you look from the stand point of the implementation of the Nano Imprint lithography, you might be applying high pressure, high uniform pressure. So, that uniform pressure will try to bring the stamp again in conformal contact with the film surface. So, the pressure applies all over the stamp surface and that sort of tries to force the stamp or the mold to come in contact with the film. And this particle might get deform partially, but what might also happen, that this might in the worst case lead to a stamp breakage from here.

So, that is disastrous. So, not only you get a bad pattern replication, but you might also eventually land up with a stamp damage. So, there can be if you have some particles or dust on film surface, that would imply that prevents conformal contact, non uniformity in pattern replication as well as, in the worst case not a very common scenario, but there can be limited chance I would say of stamp damage.

So therefore, though we proclaim that imprinting group of techniques are rather simple to execute and probably, they do not extensively require infrastructure and instrument support. Reality is that if you are really serious about implementing your Nano Imprint lithography group of methods carefully. You would like to ensure that, your film surface is at least dust free.

And in order to ensure that, how can you ensure? I mean all you are doing is that, you can use a syringe filter of something like that to ensure that, during the coating the spin coating process no dust goes in or no contamination goes in to the film surface from the solution. Or in other words, I mean if you look at the practical setting again, if you are looking at a film, this film has been created let us say, by spin coating. This is a very normal procedure and I remember that, while talking about Photolithography we have discussed about spin coating in greater detail.

So, the question is that, what are the likely settings or likely causes to bring in something like a particle sitting on the film surface. So, one of the possible thing is: you must think practically. What from where this particle can come? So, you can have a dirty

surrounding or your lab environment is not that clean. So, there are lot of dust particles which are roaming around within the dust, lot of particles which are in the dust, I mean in the air, in the surrounding air, if it is not a clean room.

So, one possibility is that you take the substrate for coating. So, from air some particle can come and sit on the substrate itself, before the film is coated. So, essentially what might happen, that you are coating the film on a dirty surface. So, what is dirty here? It contains some dust particles and I think we talked in terms of while we were discussing spin coating, the importance of cleaning the substrate. So, this is one of the key things. So, if you now try to coat the film on such a surface by spin coating itself, you are going to get enormous thickness variation around the particles.

And then again think, we told that this is a few micron in size or in diameter and then by spin coating you are probably, looking at creating a film which is like a few 100 nanometer at best may be you are looking at a film which is 40 or 50 or 20 nanometers. So, compared to the film thickness this particle so, this is your film thickness you are aiming, and the reality is this particle is like Mount Everest sitting on the surface.

So, this is an exaggerated few of the particle and this is the film thickness you desire. So this actually, acts as a defect on the substrate itself and hinders formation of a continuous film. So, this you must understand. So, one of the possible ways of (( )) the dust or possible means from where a possible defect I mean possible reason for having dust on the film surface is that, the dust might have been present on the substrate even before the film was coated.

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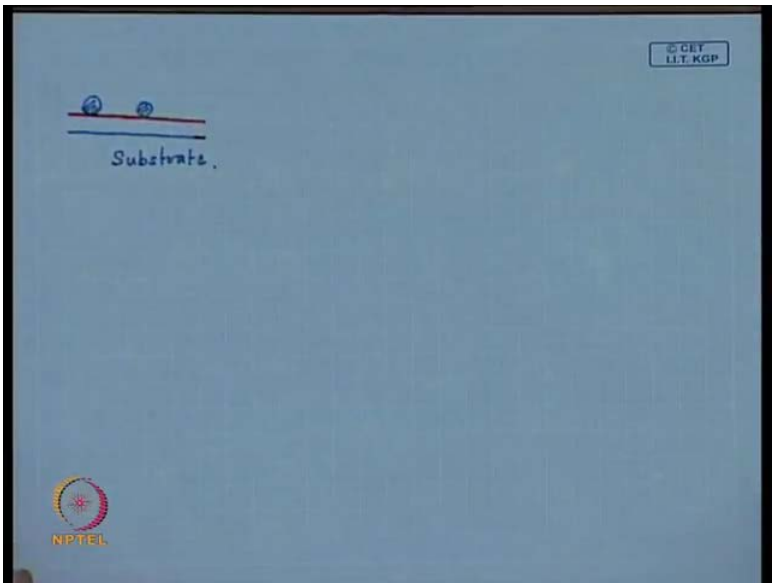

The same thing even if you sort of take good care of cleaning your substrate and then coat your film by let us say spin coating. So the substrate you sort of ensure was dust free. You now have coated and while you are try to waiting to do the experiments or while you are processing the film for subsequent downstream processing that is embossing or imprinting or whatever. Some dust particles from a dirty environment can come and now settle down again on the surface of the film.

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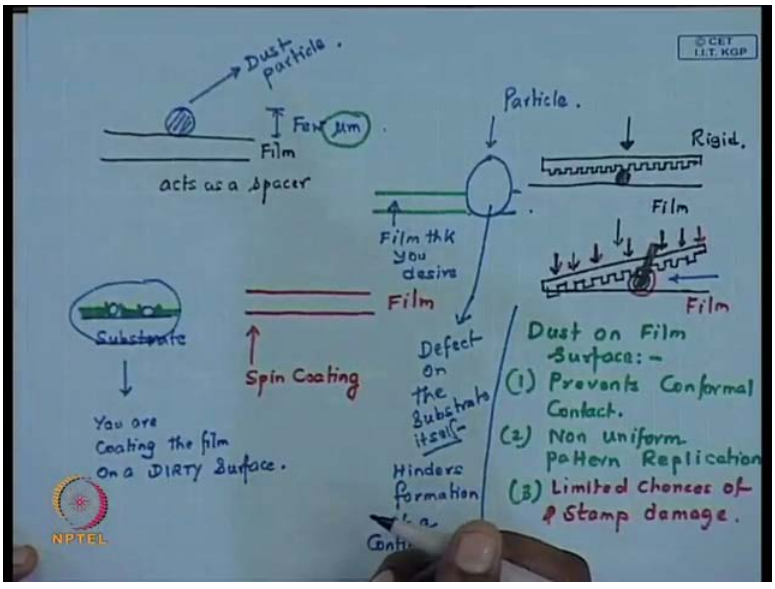

So, that is precisely the scenario we talked over here. So, some dust particles sort of gathered from the surface of from somewhere may be from air and settle on the surface of the film. So, here there is slight difference between the previous case. If you have the dust present on the substrate before the film is coated then, what you will eventually result is that you will have a film which contains defect.

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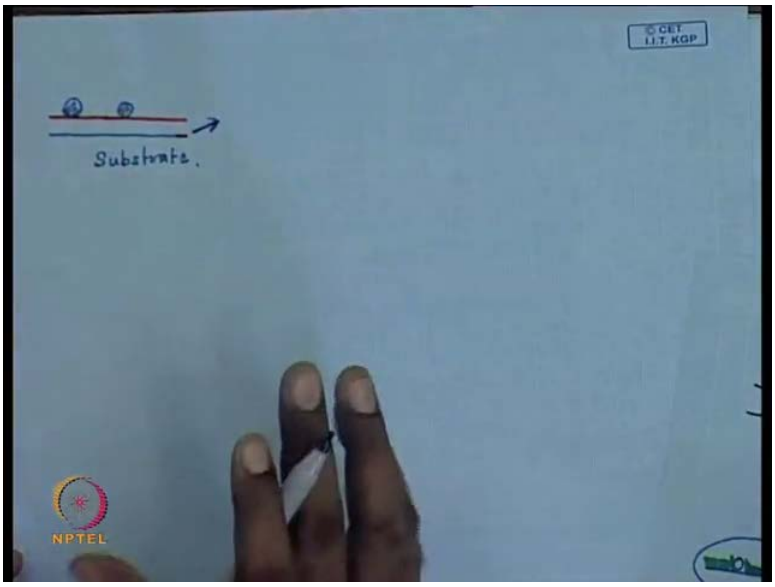

But this is a scenario, which is slightly different you might have a nice continuous integrated film or nice continuous film and on which, so the dust particles can come and settle. So, while the film is good here. But the consequences during the imprinting will be pretty disastrous in this case also. So, that is not at all desirable.

But the third possibility also remains. So, in these two cases both the cases we sort of assume or we sort of feel, that the dust particles which was present floating in air comes and settles either on the substrate or on the coated film. But there can be a third possibility that, you bring in some contaminants or particles along with the solution you are dispensing.

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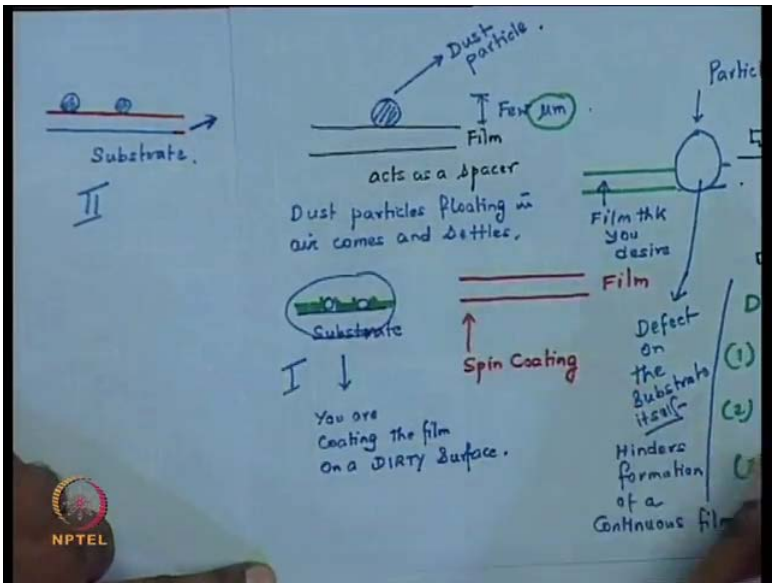

So, here it is you let us say you a take a clean. So, I would regard that this is the second likely setting, this is the first likely setting of incorporating a defect, this is the second setting.

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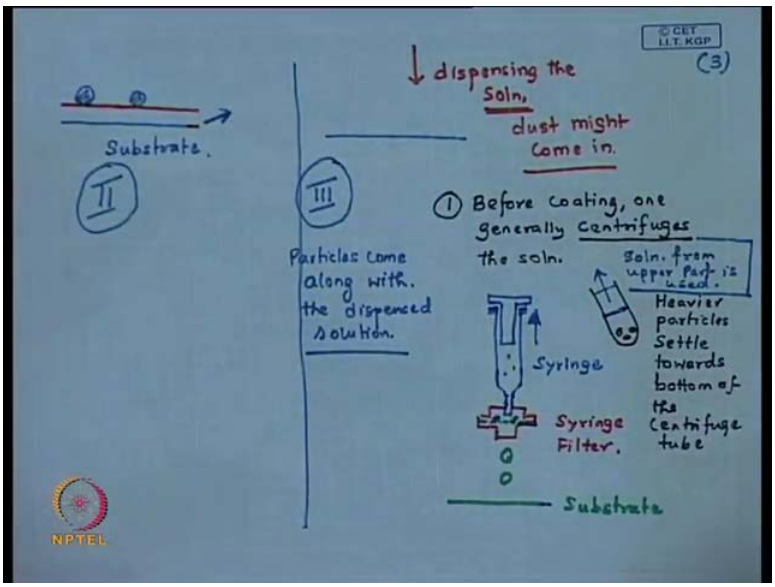

But, you can thing of a third setting also this is again from a I am giving you or telling you in a fashion which is very, very practical you really, if you are interested in implementing any of this lithography techniques or want to work in thin film polymer, thin film experiments, you sort of have to be very careful about that. That can be that

when you are dispensing the solution, you might along with the dispense solution or dispense drop some dust might come in.

So, you have to be careful about this aspect also. So, typically two experimental protocols are followed in order to prevent this occurrence. One of them is: before coating one generally centrifuges, you all know what a centrifuge I guess is. Centrifuge is the solution. So, if you sort of centrifuge the basic idea is that, as compared to the polymer solution, the dust particles which might be heavier, would sort of settle towards the bottom of the centrifuge tube.

So, even if you have some particles it will sort of settle at the bottom of the centrifuge tube. So, naturally what you would be like interested to do, is to take the solution from the upper part of the centrifuge tube for coating. So, solution from upper part is used and this is very common. I mean lot of people who do coating with thin films even in the industrially Photolithography wherever you do spin coating this is a practice that is generally followed.

And how do you take out this solution, you typically you would use some sort of a syringe and a needle, typically a syringe. And, so the second precaution typically you would take so, if this is your syringe from which you would it can be a micro syringe or whatever, from which you would like to. So, here first you suck out the solution from this upper part of the centrifuge tube and once you are happy or once you have adequate amount of solution for dispensing

Then, before instead of dispensing directly so what you will be doing, you will be bringing the syringe may be with automatic, if you have an automatic attachment. Many spin coaters come with an automatic dispensing mechanism, so that is also possible. But the other thing is, that you can just bring it, carry it manually and dispense it I mean even then spin coating works.

So, a typically second precaution that is taken is that instead of dispensing it directly from the dispensing nozzle of the syringe, you would put on something called a syringe filter. So, all it has a sort of cap like thing which has a filter paper or something attached. So, this further sort of does not allowed, there can be different cut off sizes. So, the final drop that is getting dispensed on the substrate is through this syringe filter.

So, even if there are some particulate impurities in the solution which you have taken after centrifuging, those particles the idea is that those particulate objects are sort of trapped here at the syringe filter and you get a drop which is as clean as possible. So, a very briefly this is what excitedly related to Soft lithography or Nano Imprint lithography or Photolithography. Specifically, but this is an important aspect and it is a good discussion.

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I thing we had that, you need to have very clean film particularly free from particles to sort of execute any of the pattering techniques you would like to do. And so typically, dust particles can sort of come in or sort of contaminate your system in three likely ways. The first possibility is, that the particles stick to substrate, the second possibility is that you get a clean film but the still the particles because you might be working in a dirty environment or something like that. So, the particles come and sit on the film surface and the third possibility is that the particles come along with the dispensed solution.

So, third one we sort of routinely take care so that, it does not affect your film quality. But I am afraid for the first two, the only possible way is that if you are working in a clean room that is probability the most desired thing. Irrespective of the lithography type of lithography you are doing, but even if you are not working in a clean room so, try to work in a laboratory space which is quite clean it is not very dirty or very dusty.

So, if not a clean room may be a cleaner room or a cleaner portion of the lab where these type of activities sort of can be taken care of. And in context of I would say it is a very practical problem particularly if you are a non expert in the lithography and feel that this technique is pretty simply and let us do some homemade Soft lithography or Nano Imprint lithography and I can tell you that unlike Photolithography which really requires extensive hardware and things like that and therefore, it is only the dictated groups and many of the industries which actually implement it.

Soft lithography and embossing and imprinting lithography, many of the research groups all over the globe who are non experts in lithography, but want to have pattern surfaces for some other application like let us say, structural color or super hydrophobicity or whatever, they do it. So, that way this is actually these techniques are very easy to implement and they are pretty flexible. So, it is done pretty routinely.

So, in spite of understanding all the possible problems and taking care of some of them in a scientific fashion; for example, you can almost certainly prevent any dust contamination coming in with the dispense drop. I mean, there is very sort of well established protocol now that the dispensed that dropped to be dispensed, or the solution to be dispensed for coating typically is centrifuged and then, you use a syringe filter. But I am afraid the settling of dust on a film surface or on a substrate is rather difficult to control.

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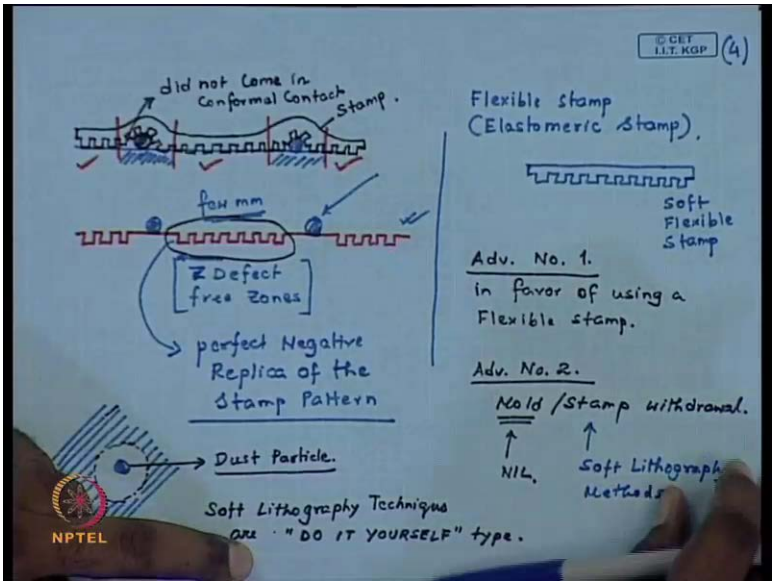

So, assuming or agreeing to the fact or if we sort of accept the fact that you can have some random dust particles coming here and there

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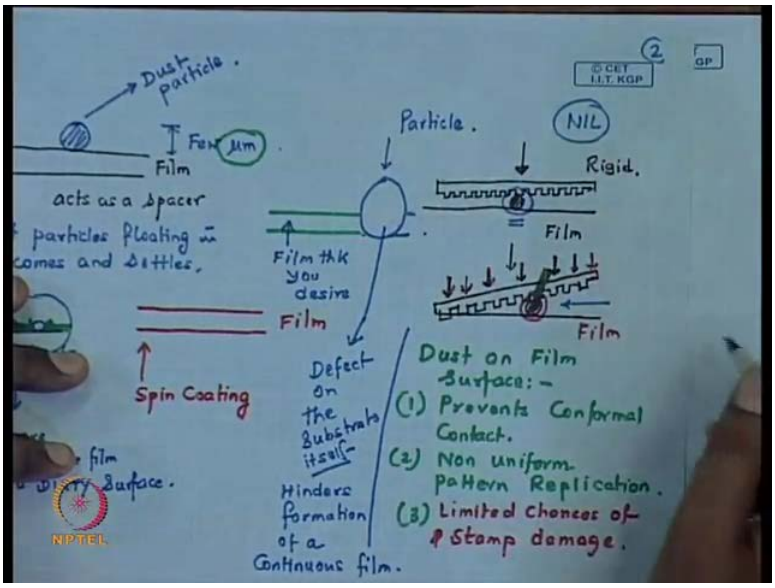

We have now seen that this almost even the presence of a single dust particle, sort of makes implementation of Nano Imprint lithography perfectly almost impossible. So, this is a major problem. Because you are using rigid stamp and here we just noted down or we noted down what are the likely problems because of the presence of this dust particle. May be even once single dust particle over the area in which you want to implement your patterning.

In contrast, now if you are using a flexible stamp let us say, an elastomeric stamp of cross linked Poly dimethyl siloxane, so that is flexible now. So, this is the stamp. Let us say and we had a pretty similar setting in case of Nano Imprint lithography only thing is this was a rigid mold, here this is a soft flexible stamp.

So, can you guess, what is the difference? That is going to come up (Refer Slide Time: 19:40) in these two settings. So, here the dust particle sort of did not allow the stamp a major part of the stamp to come in conformal contact. So, may be only a small area came in contact and that to, it was does not a conformal contact there is a continuous variation in the depth of the structures, because of the presence of maybe even a single dust particle.

But, look at or try to guess what happens here. Here, the stamp is flexible. So, it is sort of comes in conformal contact sorry for the drawing here, the thicknesses should not have been more with the film and particle. So, what it means that over a significant portion of

the film in spite of it contains some dust particles on the surface, it is in very good conformal contact.

So, now if you implement one of the Soft lithography techniques which we are going to discuss subsequently, you can see that though there were some dust particles, your final pattern of the film may not be, may contain some defects around the particles, around the places where you have particles. But there are significant zones which for many of your application can be adequate or good enough for you to use this substrate for experimentation.

So, that is a huge advantage. So, if you are looking at creating a pattern substrate for carrying out some experimentation on let us, say any of the phenomena you want to study. Let us say it can be on structural colored, it can be on super hydrophobicity or it can be waiting deviating studies this type of any areas.

So, let us say this is a few millimeter you get which is defect free where there is no defect, where the pattern you have created is a perfect negative replica of the stamp pattern. Well you are through. You actually have a reasonably good area in which the in spite of the presence of the dust particles which is the very very practical problem you would be encountering or you can encounter you can still get zones which are pretty defect free and nice. So now, compare and think of yourself about the advantage.

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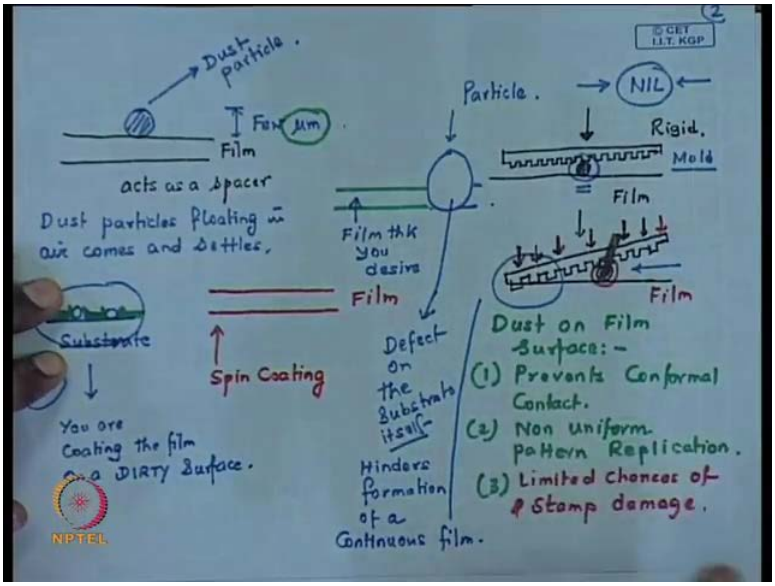

In Nano Imprint lithography or classical imprinting based techniques which rely on the use of a rigid stamp. Even the presence of one single dust particle can sort of not only distorts your pattern, but it can eventually lead to as something as catastrophic as damage of stamp.

However, in contrast to that you see yourself now or you realize that the presence of the use of a flexible stamp makes it really sort of flexible; that technique itself is now pretty user friendly. So, you might have patches of areas and you can actually see it under the microscope, that there might be one dust particle and surrounding. So, let us say this you are now seeing from the top under the microscope.

So, you have a pattern surface like this and all of a sudden you will see that there is an area like this. Where, there are no structures. And these structures have not come in because of the fact that, over this area because of the dust particle, the stamp was unable or rather did not come in conformal contact. So, that is prevented.

So, this is sort of that area, where the stamp has not come in conformal contacts. So, this can be one dust particle. And I will try to show you one of such images in the next within the next one classes or something from my own research group. We have we do get lots of these type of images where, you see that one dust particle there is one area which is so that is an area, adjoining area it is surrounding area where there are no structures or the patterns are missing. But there are other parts of the sample you have huge or large areas where, pretty uniform structures have formed.

So, this is one of the very, very big advantages of using a flexible stamp or the concept that was introduced by way of soft lithography, which sort of has really brought in your non photolithographic patterning techniques to sort of at a scale where it can be implemented with really bare minimum facilities. And in laboratories which are not specifically designated for patterning research. So, you can be working on some other aspect but you can still get or do it at your with the minimal facilities you have by using your hands and not much instrumentation.

So, in other way the Soft lithography techniques are quite do it yourself type. And that is really the key advantage or key reason, why these techniques are extremely popular. The second so, this is one of the major advantages if I am allowed to note down. So,

advantage number 1 in favor of using a flexible stamp I guess, there is no further point for me to sort of summarize it again and again.

That even if you have a sample which is not free from defects. So, there can be dust or there can be scratches other contaminants on the film surface, you can still get reasonably large areas where the pattern dimensions are literarily or physically the pattern are not at all distorted. And which might sort of serve your purpose for various applications it may not serve purpose for microelectronics, but there are host of applications where if you get a reasonably wide zone like this it is perfectly fine.

Now, apart from this one there is a second significant advantage and that is associated with the mold or stamp withdrawal. So, this mold withdrawal is essentially, for N I L and stamp withdrawal is for the Soft lithography methods. What is that advantage?

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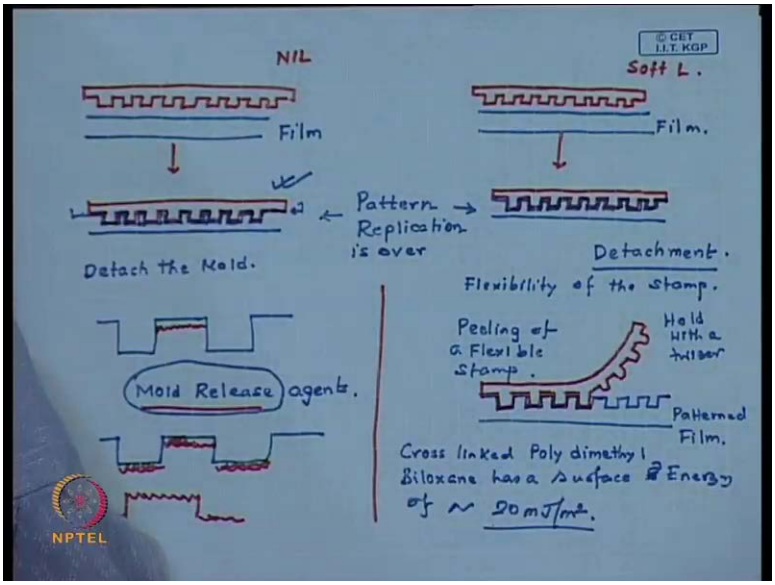

So, let us say that you somehow have a dust free environment, you have ensured, you have coated nice films. And one side you are implementing NIL, on the other side you are implementing soft lithography. So, here you have a nice rigid NIL mold, on this side. You have a nice flexible Soft lithography stamp. You here you imprint or emboss the film. Here also you do the pattern replication. We are yet to sort of discuss in detail about mechanism which we propose to take up shortly. So, things are in conformal contact in both the cases. So, the pattern has been transferred on to the film surface. So, the thermal cycling is over in NIL and we will talk what needs to be done.

So now at this stage we are good at, pattern replication is over. So, once pattern replication is over, you now understand what is the subsequent stage? The subsequent stage is in case of NIL for example, you would be lowering the temperature. So, the thermal cycling will be over. You will be doing the cooling. And once it is cooled what you are going to do? You are going to withdraw the stamp or detach the mold not the stamp, detach the mold. And we had a detail discussion pretty detailed discussing on this topic in NIL.

So, what needs to be done, the entire mold has to be sort of dislodged all at once. So you have to grip it from the sides or something and then you have to dislodge all at once. And we had discussed in detail that if you do not use mold release agents, there is a significant possibility that there might be a cohesive failure within the structures.

So, you may not get a clean detachment of the mold so, you might have random layers of polymers sticking to the mold surface, leading to two stage damage. The mold becomes sort of non usable or secondary processing or cleaning has to be done of the mold and the structures are non uniform on the film surface.

So, we talked about that, we need to you use mold release agent and things like that. In contrast so, the other thing is apart from using a mold release agent of course, you need to have a griping mechanism. So, that sort of holds the entire stamp and detaches just like that. So, depending on how small it is at a lab scale it can be a tweezer, where you sort of push it from one side and detach. It can be a pretty good robot arm if you are talking in terms of huge automatic NIL setup.

But this step also becomes pretty important; pretty important in the sense that you should assure that by way of detachment not only you use the mold release agent, and things like that. You really do not do something that or mechanical force you apply for the detachment should not be so high or something like that, that damages the stamp. That is of utmost importance, because if the stamp gets damage then you cannot use it again.

So, this is a real important critical and often a tricky stage of Nano Imprint lithography. So, in another words that even if you have a defect free film, you have a nice film, you have a nice stamp, you do everything perfectly, you do the pattern replication, you do the thermal cycling, you know that the viscoplastic deformation and the force was adequate, the mold filling has occurred nicely even then, there is a possibility of the stamp to sort

of I mean the structures as well as the stamp might get damaged during the detachment phase.

In contrast here, same thing has happened. Pattern replication has taken place. But when it comes to the question of detachment, you have a huge advantage. And what is that advantage? That advantage is imparted or given to you because of the flexibility of the stamp.

So, what does it mean? It means that unlike in a setting like Nano Imprint lithography where you were using or you had to use a rigid stamp. So, you have to design of something like a holding mechanism for the whole stamp to sort of come up all at once. Here what you can do? Is you can use simply something like at a tweezer to hold the stamp from one of the sides and you can merely ,you can understand what I am going to say I am sure now.

You can merely peel it off from one side, because this is flexible so this possible. You just peel it, hold it with a tweezer or something like that and simply peel it. You all understand what is peeling removal of the I mean you can just hold it and pull it out. So, what will happen is that the stamp can be nicely withdrawn from the pattern film exposing the patterns once it is fully peeled off.

Other advantage is that, since Sylgard is a pretty low surface energy material in itself, I think we discussed in the previous class the cross liked surface energy or of approximately 20 milli joule per meter square. So, anyway this is low surface energy. So, it really does not adhere too well to any of the polymer, or any of the film that you have imprinted using that.

So, detachment is pretty clean. So, a low surface energy essentially implies that it sort of act or performs the same functionality what a mold release agent is supposed do in case of Nano Imprint lithography. Because, a mold release agent is also nothing but a layer or a coating on your stamp with a low surface energy material, which sort of reduces the addition between the stamp martial and the film of the polymer film material which you have imprinted during this stage.

So, that way they are comparable I really will not comment that, this surface energy or PDMS or cross linked PDMS is really greatly advantageous from the stand point of it is

does not attach or the interaction is different. But the real advantage lies in the fact that you can peel off a flexible stamp; so peeling of a flexible stamp. This is hugely advantageous thing and you can imagine that if you are performing your Nano Imprint lithography with a small stamp at a small area probably, you can somehow manually dislodge the stamp without sort of damaging it.

But, if you are really keen on implementing your NIL or performing your NIL over a large area let us say, a few centimeter square area let us say, over an area of 2 centimeter by 2 centimeter which will be roughly something like this. Even then it is difficult. In contrast even a full 6 inch wafer scale if you have the appropriate type of stamp, you can sort of peel it off nicely without any possible chances of pattern damage or something like that.

So, I would like to sort of summarize quickly the discussion we had so far in this class. And we talked about the distinctions in a way or sort of the similarities I would say of a mold in Nano Imprint lithography with a stamp in Soft lithography.

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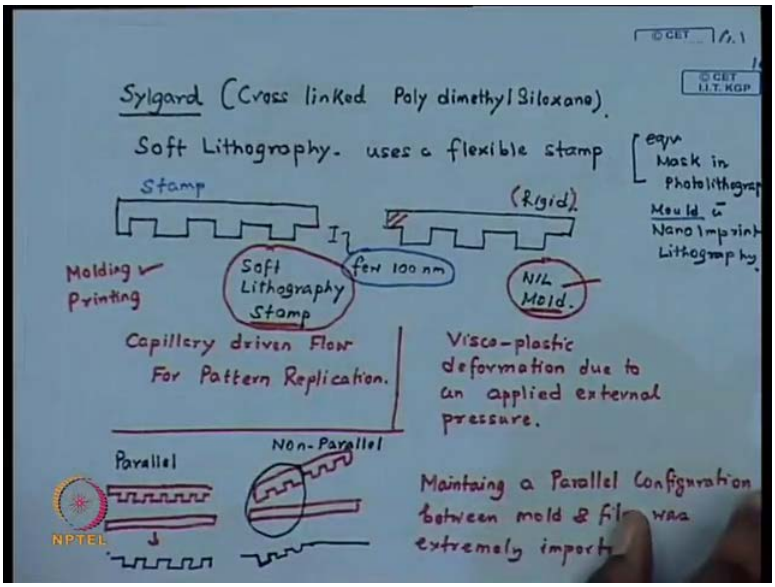

So, a Nano Imprint lithography mold is pretty equivalent to Soft lithography stamp, because if you are performing Soft lithography in the molding mode because you might remember that, we had talked about two different modes one is the molding mode one is the printing mode and molding mode is essentially what we are so far limiting our discussion of course in subsequent classes we will be talking about the printing mode.

So, molding mode is something what you use for creating topographically patterned features and surfaces. In contrast in printing mode you will be using for making chemically pattern surfaces. Nano Imprint lithography also you make use for making topographically patterned surfaces.

So, that way we would like to we sort of drew similarities between molding mode Soft lithography techniques we have not discuss the techniques we will shortly do so and the Nano Imprint lithography group of techniques .And we realize that the purpose of the mold here is exact equivalent to the stamp what a stamp does in Soft lithography (Refer Slide Time: 29:42) But we also contrasted from the practical setting as to what can be the advantages of using a flexible stamp as compared to a rigid stamp.

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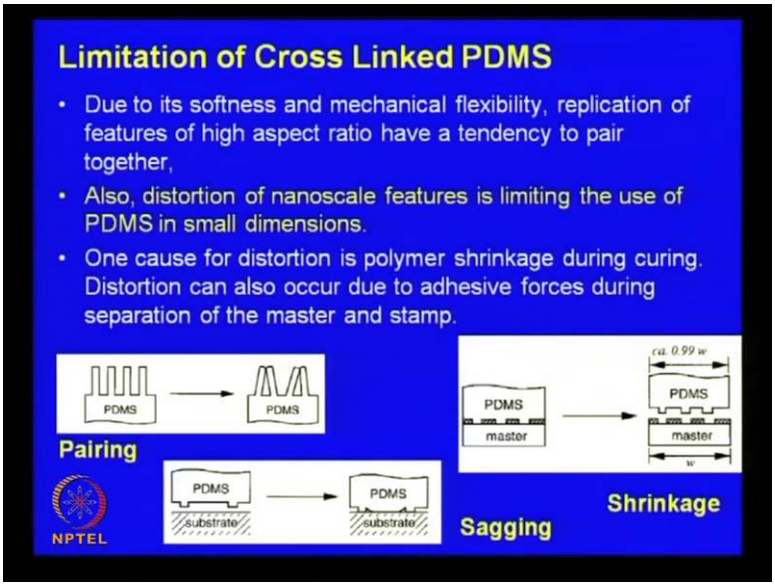

And we found that there are phenomenal advantages number one is that the use of a flexible stamp can sort of handle defects present within the on the film. So even if your film which you want to pattern or the zone you want to pattern is not completely defect free. Then again, you can sort of you can still work with Soft lithography flexible stamp. And the second thing is you have a huge advantage when it comes to the question of a stamp release, or mold release in case of Nano Imprint lithography as compared to stamp release in Soft lithography where you can simply do a peeling to achieve that.

Having said that, we must also acknowledge that there are some limitations of using a flexible cross link PDMS as a stamp. Due to its softness primarily and the mechanical flexibility often, it becomes difficult to replicate structures with high aspect ratio.

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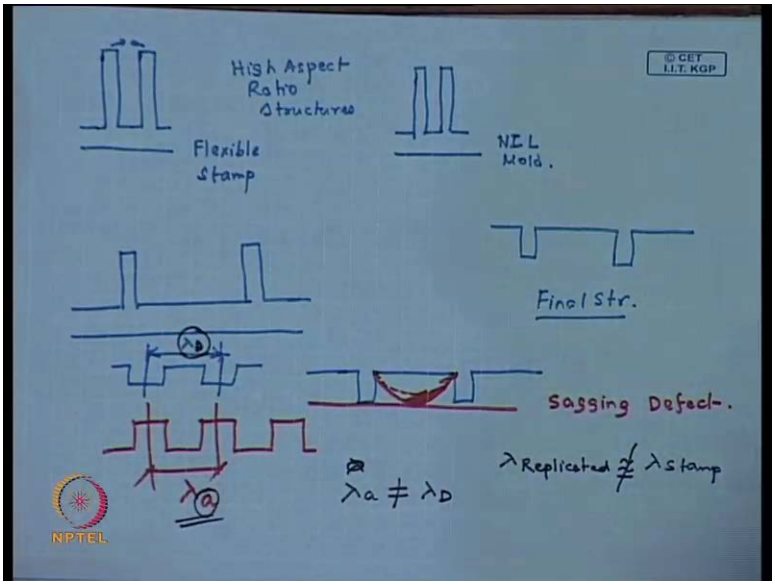

So, if you want to have structures with high aspect ratio that is if you want you create tall structures like this and if the sort of pattern density is very, very high so, you have low periodicity but very high aspect ratio structures like this, on a soft flexible stamp. This can be a major issue.

On a rigid NIL mold the fabrication can be costly, but there is no associated problem. What is the problem here? There might be a possibility that these two structures adjacent structures sort of get attach to each other like this. So, you will not be getting the desired replica and this phenomena or this particular occurrence is known as the pairing defect.

You can also there can also be additional problems; if you try to make a very low duty ratio square structure. So, your final structure will look something like this. This duty ratio is very, very low. So, in order to a chive a low duty ratio structure you would like to use a very high duty ratio stamp.

So, you have a large gap between two adjacent protrusions let us say and when you try to sort of imprint such a stamp, imprint with such a stamp because of the mechanical

flexibility, this particular portion might sag and can actually come in contact with the film you are trying to pattern.

So, this is what is known as the sagging defect. And also there can be some sort of literal shrinkage in the pattern replication during the pattern replication procedure. So, this might eventually result in some sort of a different in obtaining some structures, which have some specific lambda everything might look to be perfect.

So, this is we say that the lambda actual but you might have designed that, you would create structure at a periodicity of lambda d or which is let us say, the lambda desired or the lambda design. But there can be sort of a literal shrinkage which is not very, very high. I must say but since this is also a flexible polymer so, sometimes in presence of solvent and things like that, we will talk about it in somewhat detail. There might be a sort of shrinkage in the literal dimension.

So, in that case though you want let us say a periodicity of lambda D, you might actually get a periodicity of lambda a; everything looks pretty much the same. So, there is a mismatch between lambda a and lambda D or in other words typically your lambda replicated should be absolutely equal to the lambda of stamp.

So, which may not happen because of shrinkage; so I would like to conclude this class by saying that though we have in most cases this use of a flexible stamp in the context of Soft lithography is extremely advantageous and we have talked in details about some of the advantages.

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But still you have a few limitations in using a flexible stamp and which are typically taken care of so that they do not cause one of the very severe problems. But yeah I would say pairing remains a serious issue and therefore, with most of lithography techniques use a flexible stamp it becomes difficult to create very high aspect ratio structure.

But having said that you must realize that, the use of a flexible stamp in the form of cross linked elastomer is really, where most of the recent activities in Soft lithography is taking place. And that really makes the technique sort of gives the technique a flavor that you can implement it at your will, if and if you are a non expert in this field. In the

subsequent class, we will take up different techniques so the in detail about Soft lithography.