Instability & Pattering of Thin Polymer Films

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Module No # 01
Lecture No # 14
Nano Imprint Lithography

Welcome back. We in the previous class, we concluded our discussion and photolithography. And, now we move on to some of the recently development alternative lithography techniques which are much simpler, much easy to execute, which are offence specific to the polymer, polymers and other classes of materials. And, most importantly they are cheap, easy to implement, low cost and or not specific or not or beyond the scope of micro electronics industry.

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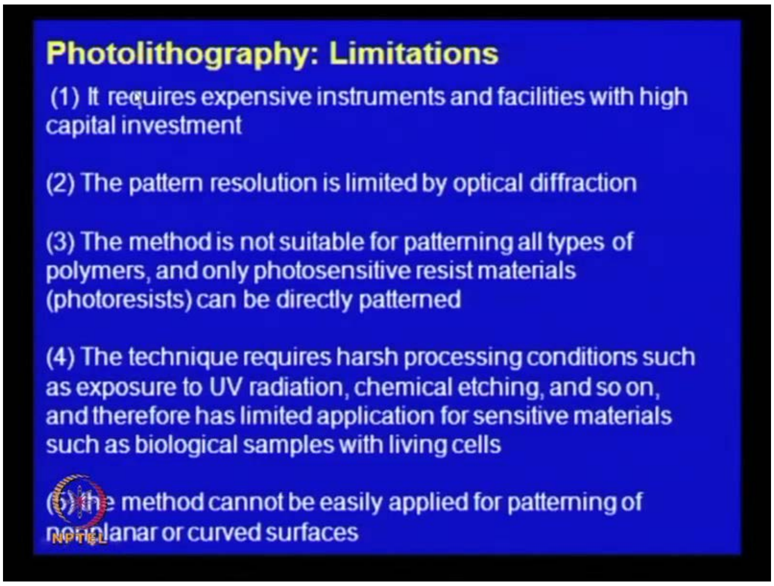

And, we start our discussion with one such method which is nano imprint lithography. Before that, we just one to have a quick look I mean, though we talk about photolithography it is very difficult to sort of find out any other technique, which as much potential as much important as photolithography in a particularly, in the micro electronics industry. There are several limitations of photolithography. For example, if it was extensive instrumentation and facilities with high capital investment. You can understand that based on the discussion we have had that really, if it was whole lot of infrastructure, mask liner, steeper, U V exposure fabrication of the mask, then whole lot of developments sequences, spin coating etcetera.

The pattern resolution, this we talked in one of our earlier lectures, the pattern resolution is limited by the optical diffraction. So, depending on the wave length of light you cannot really go below a certain thridical lateral resolution, irrespective of whatever is the feature size on your mask. The method is not suitable for pattering of all type of polymers. This I guess we understand by now, you need a photoresist or a photosensitive polymer to pattern by photolithography or in other words a photolithography can only directly pattern a photoresist film or a film or a layer of polymer which is photoactive. But there are whole lots of polymers which are, which do not have significant optical properties.

And therefore, photolithography cannot be use directly to pattern those types of polymers, which is a major which might be perfectly fine from the stand point of micro electronics industry. But as we have talked in one of our initial lectures, where we talked about a whole lot of application of pattern polymer surfaces you may want to create structures with other types of polymers, polymers other than photoresists. Because do not forget photoresists again is extremely expensive compare to other general polymers thermoplastics, elastor much let us say. So, photolithography directly you cannot apply for patterning other types of most other types of polymers.

The technique requires harsh processing conditions, such as the technique of photolithography requires harsh processing conditions such as exposure to U V radiation chemical etching etcetera. And therefore, as limitation limited application for sensitive materials, particularly if you are working with biological samples or living cells. Because now there has been lot of work which involves pattering of molecule, living cells, proteins etcetera. And so, since you have U V radiation and lot of dissolution in solvent and things like that, you just cannot use photolithography for those types of sensitive settings.

And, another major thing which we never talked when we were discussing photolithography is, that the method cannot be easily applied or the method cannot be adopted for pattering a film coated on a non planner are a curved surface. So, everything was sort of taken for granted that your film has to be on a flat surface, you place a mask which is parallel to that you do an exposure etcetera. But there are all settings, there are cases where you want to create or patterned surface or film which is not coated on planner surface.

So, these are some of the severe limitations, some of the limitations of photolithography. Still for the micro electronics industry photolithography is the best possible better research significantly on in that area. But in one of our previous lecture we also talked about Moore’s law and the projections that Moore’s law make there is severe doubt, that because of this diffraction limitation whether one can really achieve structures as smaller. I mean smaller than ten nano meter or at nano meter level by photolithography to where, here the micro electronics industry of the feature size of the transistor size of the line with this eventually positive head.

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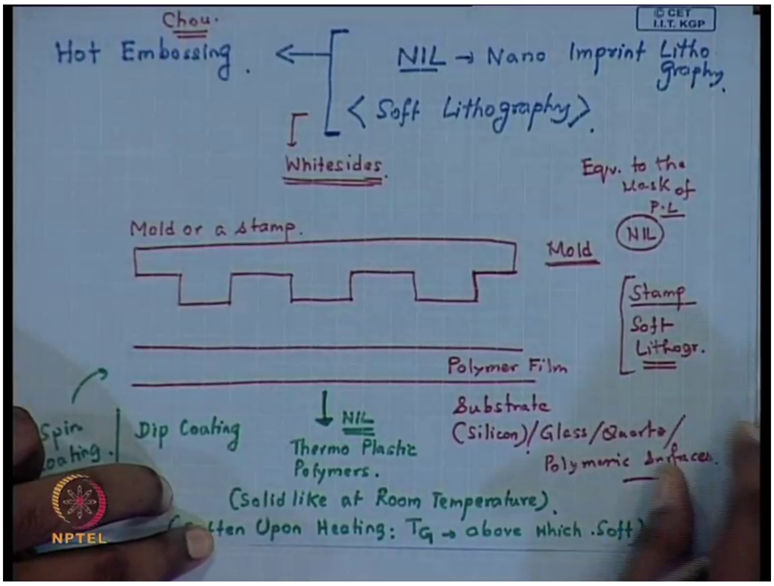

So, there is a significant search for other techniques which can sort of complement photolithography, even in micro electronics industry and some of these techniques which we are going to talk subsequently. One of them what we get started today is, what is known as the nano imprint lithography (No Audio From: 05:10 to 05:18). And a whole lot of soft lithography methods. What we discussed in one of the subsequent lectures are sort of potential candidates for even replacing photolithography in may not be that close near, but may be distant feature. Of course, the genesis of both of these setup techniques was not to compliment photolithography.

But to work out as a low cost, easy to implement alternative for pattering various classes of polymers and other types of materials also. So, both the imprint group of techniques, the nano imprint group of techniques which often also go by the name hot embossing as well as soft lithography. They are now capable pattering not only polymers, but other types of materials like in organic sol gel films are even metallic thin films under certain conditions. And, we will see in some of our subsequent lectures about some of these developments.

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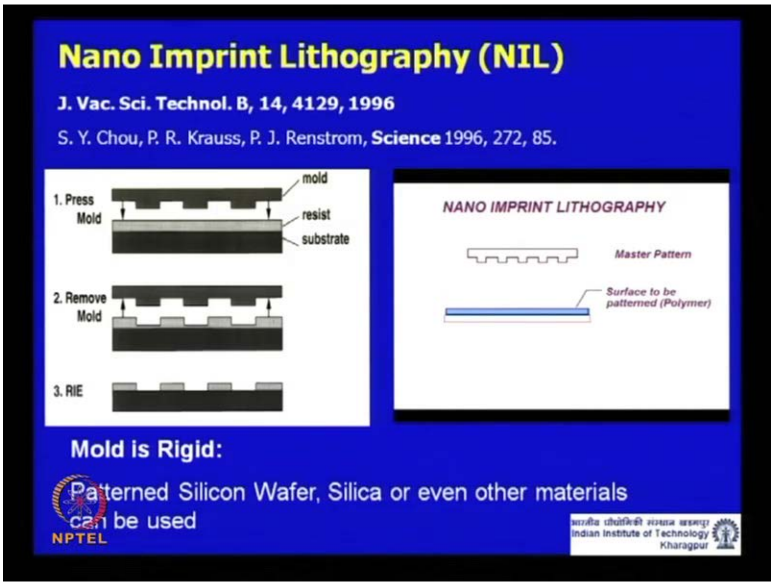

So, we get started with nano imprint lithography in this particular class, a technique that was developed in the middle of 1990s. So, these are pretty recent developments, I mean this entire area of nano imprint lithography and soft lithography is add based some fourteen to fifteen years old. Still a lot of research is going on and the potential was so high, I mean that the area is so significant that you have not less than at least twenty publications in the last fifteen years in top, in the tops scientific generals of nature and science on this particular themes.

These group of techniques where pioneered by two great scientists Stephen Chou at prinston, who pioneered the concept of nano imprint lithography and George whitesides at harward who came up with his amazing concept of soft lithography. In the next two or three classes we will be discussing in details about some of these techniques. And, I am sure as compare to photolithography once you listen to these methods; you will find that how amazingly simple these methods are. And even in a high school laboratory you can sort of implement some of these techniques with is. So, we will, I will try to give you some examples and some examples which all of you can actually try out to do.

So, the concept of nano imprint lithography is very very simple. This schematic gives you an idea all you take is a mold or a stamp. So, these like a rigid, it can be on silicon, it can be on silicon oxide, it can be a photoresist pattern, photo resist layer made by photolithography. You take a stamp of and refer to as mold in nano imprint lithography.

Stamp is more of inward which is more frequently used in soft lithography, soft lithography something we are going to take up in the next class. So, just keep it in mind. The mold is in some way equivalent to the mask of photolithography.

Now photolithographic mask of course, contains the more of a two d s structure of the desire pattern you want to make. In contrast to the at a nano imprint lithography mold or a stamp actually contains a physical relief structure. So, you have these structures this is the mold. What you do, you take a polymer film on a rigid substrate. This substrate can be silicon, but since many of the nano imprint lithography main structures might find the application in non microelectronic settings. So, there is absolute it is not at all mandatory that you have to work with silicon, it can be glass, it can be quartz or it can be other polymeric surfaces also (No Audio From: 10:00 to 10:06).

Of course, there are various similarities or various techniques which where sort of developed for photolithography also find application here. For example, when you want to make this polymer film, what is the best method? What is the best way by which you can make it? Well, spin coating still finds extensive application here. We have discussed in details about spin coating in the context of photolithography. But one can also (( )) with something like dip coating, job coasting and whatever method you want really use, really does not matter.

So, easiest examples are the classic NILs work with thermo plastic polymers (No Audio From: 10:57 to 11:03). Without going too much into the details of the chemistry of these materials, all you should know that these are polymers which are solid like at room temperature (No Audio From: 11:15 to 11:25). And they, if they are heated up the sort of soften and there is something I think we have talked in one of our previous lecture, call the glass transition temperature above which, they become significantly soft.

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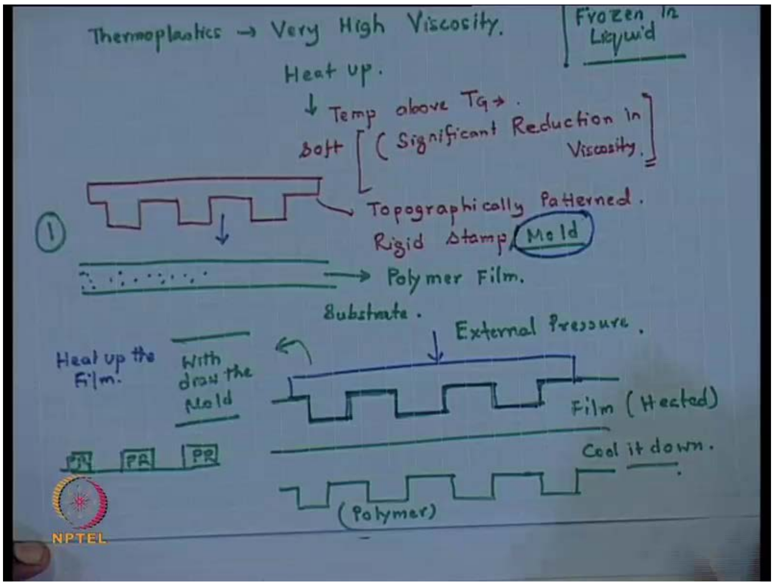

In other words, you might be knowing that polymer is an amour material. So, at room temperature most thermo plastics have very high viscosity to simply put it (No Audio From: 12:13 to 12:19). The viscosity is sort of so high, so it is more like a frozen in liquid. And the viscosity you might have learn from your fluid mechanic course is sort of, is an indicator of resistance of a liquid towards any sort of deformation or any externally applied force. So, higher is the viscosity slower will be the dynamic, subject it to the same force as compare to a liquid which as lower viscosity. So, for this type of a thermo plastic at room temperature, what happens is the viscosity is so high that it virtually behaves as solid.

Now, when you heat it up beyond to its class transition temperature or to temperatures above its glass transition temperature what happens is, it becomes soft. That is, see there is a significant reduction in viscosity. A complex true, there are lots of concepts, how it happens? How entanglement changes? Etcetera. I am skipping all the details, all you need to understand that you take a thermo plastic most of the plastic even this pen. For example, if you put it on a hot plate it will melt you know that. So, the body is made of a plastic its thermo plastic material. So, at room temperature this is behaving just like a solid and you sort of heat at up it sort of becomes soft.

So, this is very simple concept we need to know. If any one of you is interested you are free to search the internet for with key words like glass transaction temperature, thermo plastic, the you can look at the chemical compositionally details and things like that. But for the context of this particular course I will be skipping all those details which are, which I do not feel is that necessary. So, understanding this much that thermo plastic behaves like more like a solid film at room temperature.

And then, once you heat it up beyond its glass, transaction temperature soften of behaves like a lower viscosity liquid. You can probably now understand how nano imprint lithography works, it is very very simple. So, this is the hardware requirement, as I have already told that. You take a topographically patterned.

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Rigid stamp; you take a polymer film on a substrate. So, at room temperature this film is more like a solid, all you do is heat up the film. So, once it is heathen, heated up this sort of goes to a molten liquid state. Once it is in the liquid state you bringing the stamp and press it hard against the film. So, here is the stamp, here was the film. Now it is heated, you apply an external pressure. So, since this is no simple. So, since you are pressing a structured mold against liquid fair and molten film, the liquid will try to sort of follow the contuse of the patterned mold. And, all you do is in after reaching this stage, where a perfect negative replica of the stamp patterned has formed on the liquid film, you just cool it down.

So, as you cool it down what happens is that the liquid again goes back to its frozen in state with higher viscosity. But now, since the stamp is still there the frozen in liquid does not have a flat top surface. But it replicates a negative replica of the mold pattern on its surface. So, in the process you have created a pattern polymer film. So, after the cooling is done, all you have to do you have to with draw the mold. So, if you now compare it with their patterning of a photoresist layer or creating of a pattern photoresist layer which was in photolithography, which was again a polymer. You see how simply you have done it, there you required a mask, you required a U V exposure, and you required a breaking development etcetera.

But here what you do? You just take so step one, you take a polymer film, you take a rigid topographically structure stamp or a mold. I would be more carefully using the word mold which is more specific to the nano imprint lithography group of method.

Second stage you heat up the film, bring the mold in approximate to the film based hard film, press it hard against the mold, cool the whole assembly wild the mold is in place. So, that sort of makes it, makes the takes the liquid back to the frozen in state and then simply remove the photoresist layer, the mold. So, you have a structured polymer film. (No Audio From: 19:26 to 19:37).

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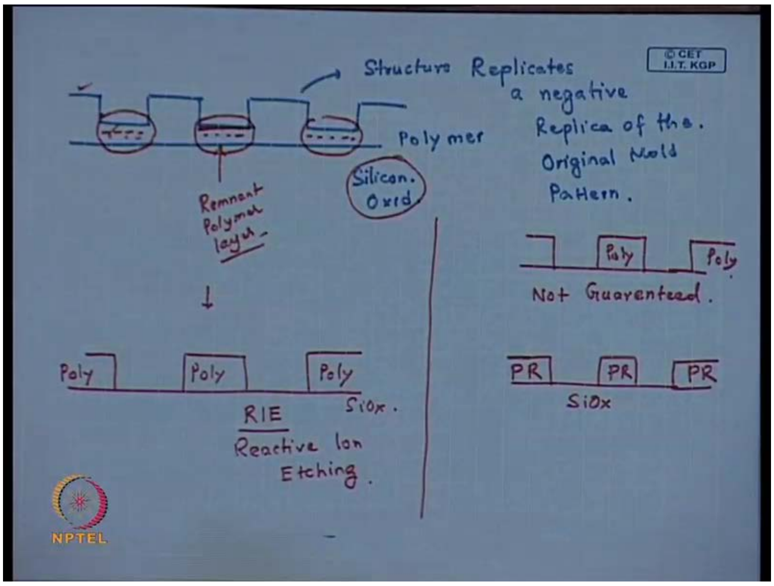

The structure replicates a negative replica of the original mold pattern. Of course, if you are talking about a microelectronic application and sort of let us say, this is again back to silicon or silicon oxide. So, you want to have an access to the substrate, because this way embossing does not guaranty that you are going to have a structure like this. This is not guaranteed. So, chances are that you will have even below the valleys on the structured film; you will have a remnant polymer layer. And if you really, if you want to sort of look at hydrophobicity of something like that want to do some experiments with structural color, you are perfectly happy with this type of a structure.

So, this actually is good in many settings because the upper part of the straight as well as the bottom part of the valley have the same material. But if you are sort of interested in having access to the substrate, of course you want to preferentially remove the polymer over these areas. And, by the method of what is known as RIE, Reactive Ion Etching. So you see, if you now compare with photolithography what we have? I am repeating and again comparing with lithography because that is something which you already know and you have discussed in somewhat detail. If you compare with photolithography, in conjugation with nano imprint lithography and Reactive Ion Etching, you can go to the same stage.

And, subsequently what follows is etching if you have, this is the oxide layer you can do the etching and you can have direct access to the silicon surface and follow it up. I mean then it becomes very similar to the later processing stages of photolithography itself. So, in principal nano imprint lithography group of techniques also has the potential to be used in the fabrication of microelectronic components. But its scope sort of extends much beyond that and for bulk nano application as well as rapid photo type nano imprints lithography is one of the easiest method to implement. I mean, I am sure we actually have already discussed the basic principal of nano imprint lithography.

So, you can imagine that understanding the different stages of photolithography to cause some four lectures. But here it takes roughly ten minutes to understand, it is so simple. So, in principal you take a rigid patterned stamp and or a mold and you just press it against a soften polymer layer. Freeze the structure right there, take out the stamp. I mean you have the negative replica of your of the desire pattern on the polymer film. Now, we Indians are all shock big time fans of sweets and if you walk into any sweet shop in my part of the country west Bengal or north India or in all other parts of the country, you find beautifully decorated sweets, Sandhesh become with nice designs.

So, what exactly are you doing? You have some sort of a mold to which you are pressing the chana and then you are just creating a nice looking sweet with desired structure. So, people might laugh, but that exactly what you are doing here, in nano imprint lithography it is so simple. Of course, there are some integrity issues which we will now discuss, but, conceptually this is what nano imprint lithography or hot embossing refers to. Why hot, because in the classical form or in most nano imprint lithography settings you actually start off with homo polymer film. And then, you gradually heat at up beyond its glass transaction temperature.

So, that it soften and then you do the imprinting at the stage which has its advantage because you are sort of embossing a soften layers. So, you need much less courses, but there are some associated disadvantage just also which we will discuss in the subsequent few minutes.

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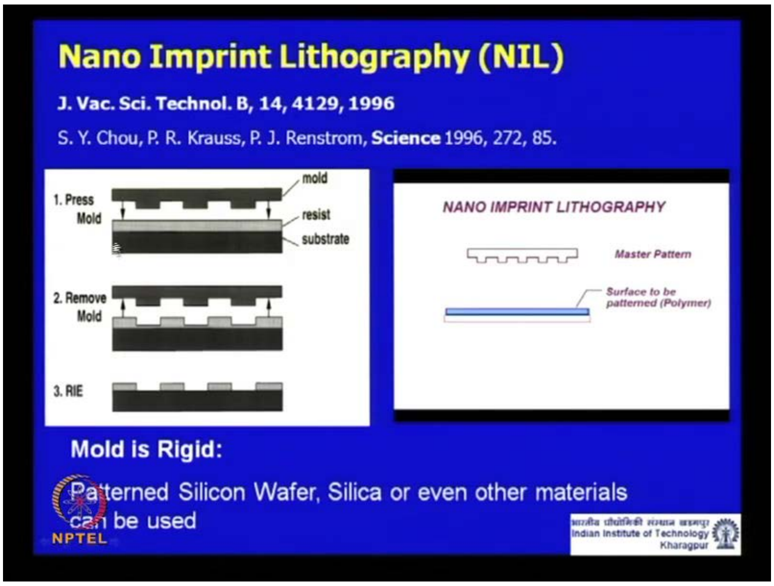

So, now I guess this picture makes perfections to use, you have a patterned mold, you have a resists or polymer layer, you have a substrate, you heat it up press it. Press the mold against it, you get the negative then cool it down, you get a negative replica of the pattern. And if you want to have the direct access to the substrate, you apply Reactive Ion Etching subsequent nano imprint lithography. With this sort of cartoon on the right hand side will also give you a clear idea. So, here of the starting hardware you have a master patterned or the mold which has the topography relief structures. You have a surface to be patterned a polymer film on a resist surface let us say. And so first you start off with by heating the film.

So that, film heating is typically it is heated to temperatures beyond the glass transaction temperature. So, once it is heated you sort of the polymer film become soft and then you bring in the mold of the stamp press it hot against the heated polymer film, with the application of external force. And then you cool it down, while the external forces is still being applied and the stamp or external force at the stamp is pressed against the polymer layer with the application of external force, cool it down. So, that the polymer goes back to its frozen in liquid state. And then, at this stage you would like to remove the stamp. So, pattern freezes and you remove the stamp and you get a negative replica of the stamp patterned on the film surface.

So, I will quickly go through the cartoon sequence again, see now you will understand every step. So, you have a mold or a patterned stamp, you have a polymer film, you first start of with heating up the film to a temperature beyond its glass transaction temperature. So, that the film becomes soft, now you bring in your stamp the mold press it hard by the application of an external force. Now, once the pattern transfer has occurred, cool it down the patterns, freeze and then you detach the original mold. So, this is in nut shell, the process of nano imprint lithography. It is very very simple rather easy to execute.

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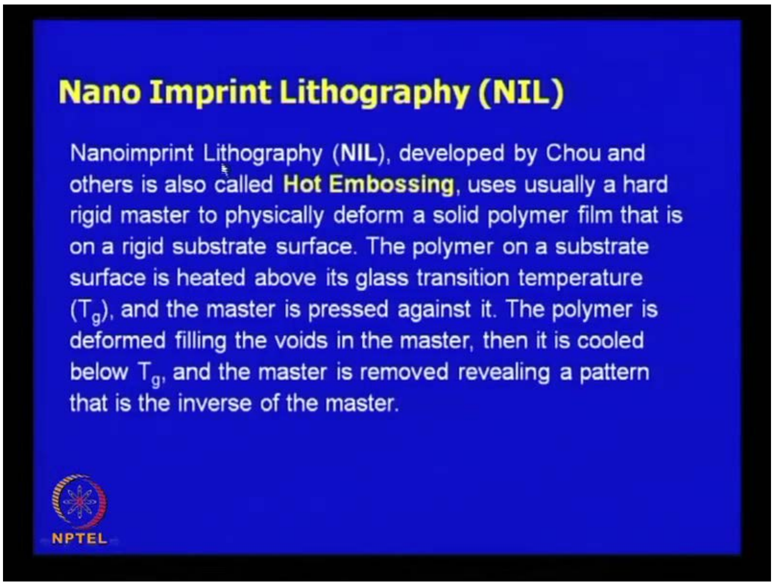

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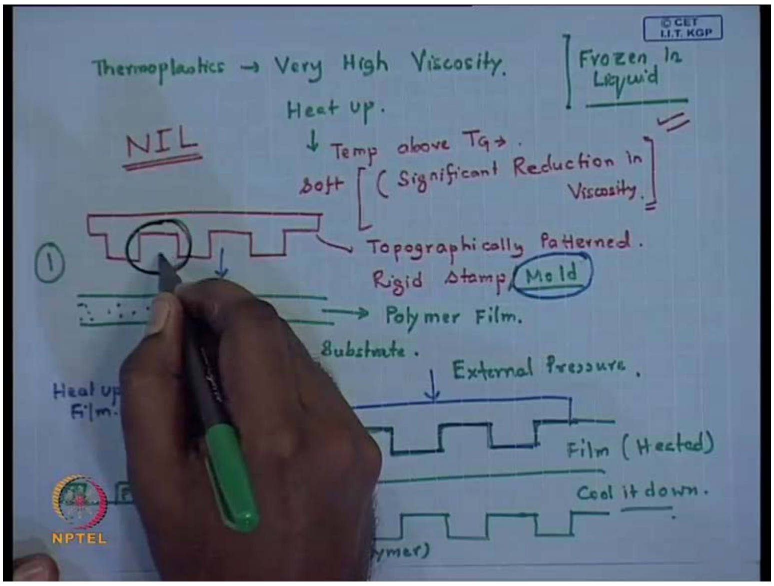

So, here is some sort of classical definition, nano imprint lithography which is commonly refer to as NIL. That is the standard acronym for nano imprint lithography in the lithography community, developed by Chou and others. As I told you with professor Chou is (( )) university of prinston is also called hot embossing. And usually, uses a hard rigid master or a mold to physically deform a solid polymer film that is on a rigid substrate. The polymer on the substrate is typically heated above its glass transition temperature and the master of the mold is pressed against it.

The polymer is deformed filling the voids in the master, so essentially these are the voids you can say in the master which the once you bring it in contact the polymer fills. So, the polymer deformed filling the voids in the master, then it is cooled to below T g and the master of the mold is removed revealing a pattern that is, inverse of the master or a perfect negative replica of the master. You read the sentences are whatever is here carefully and you can correlate it with the sequence of events that is shown here. You see that in the in the classical sequence of the definition of nano imprint lithography, there is no mention about Reactive Ion Etching.

Because of the fact that nano imprint lithography as a process does not require this RIE. Nano imprint lithography will lead you up to the stage two, on the figure shown in the left hand side. If you require access to the substrate, you additionally you would like to apply Reactive Ion Etching. So, in principal it is something very very simple, you take a thermo plastic layer, you heat at up beyond its glass transition temperature. So, that it becomes soft. You have a mold or a master which you bring in impress and the liquid polymer fills up. These are refer to as the voids or the valleys on the stamp of the mold surface and you get to a negative replica of the stamp pattern on the film surface.

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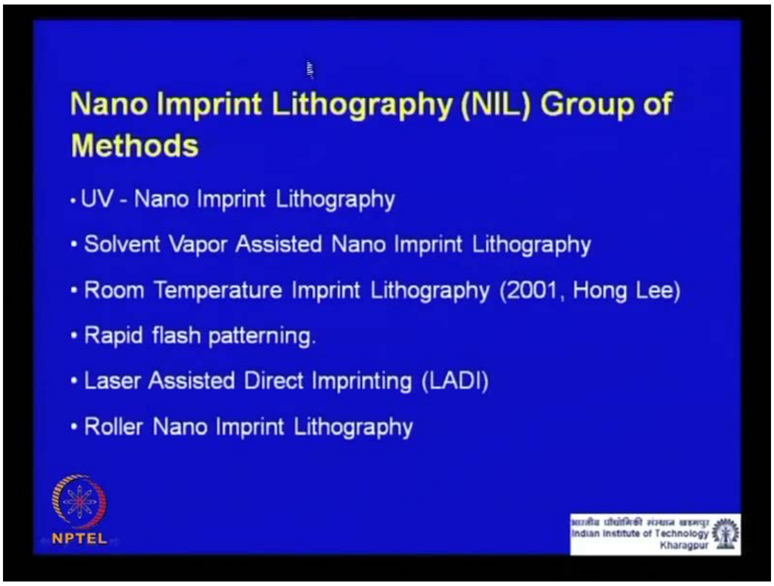

Now, this is in the nano imprint lithography in the most classical form. But there are quite a few techniques which have sort of been developed, derived from the classical nano imprint lithography after its invention by Stephen Chou in 1995, which sort of address some of the critical issues or problems of NIL in some form of the other. The major derivatives or major extension of nano imprint lithography is U V Nano Imprint Lithography or U V NIL, solvent vapor assisted nano imprint lithography, room temperature imprint lithography and this is a pioneer inward that was develop by Hong lees group in Korea and did not come from Stephen Chou’s lab.

Rapid flash pattering laser assisted direct imprinting LADI this is again 2002 work by stiffen chow group, where this technique NIL was extended to beyond polymers. And it was shown for the first time that nano imprint lithography can be used directly to pattern silicon. So, finally, you want your structures on silicon oxide or silicon, but LADI it is again a pioneering (( )) was one of the first technique square. It was shown that nano imprint lithography can be straight away used to pattern silicon. And then one of the later developments is the roller nano imprint lithography, which sort of tries to make this nano imprint lithography based techniques, sorry imprinting based techniques into the continuous mold.

Because if you look carefully the very concept of imprinting, you take a patterns of you take a film, you bring heat and of the stamp. You heat it up, you then press the stamp cool it down and then withdraw the stamp or the mold. And, you withdraw the film also is conceptually a batch process. Now, this roller nano imprint lithography sort of allows it or aims at making NIL groups of techniques into the continuous mold or a more of a roll to roll process. And this has, this is becoming an extremely popular as an in flexible electronic industry. So, we will discuss some of these techniques in somewhat detail.

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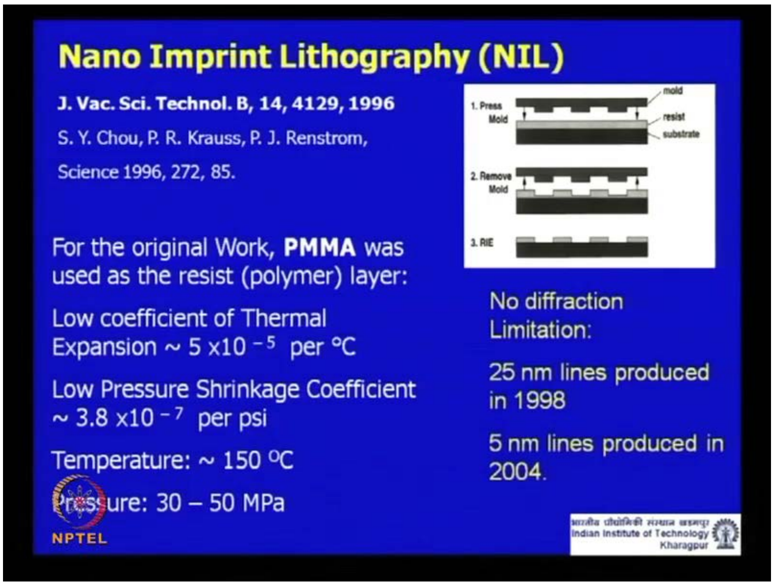

So, this is again a quick look at the classical nano imprint lithography, which was originally published in the in this form in 1996 exactly 15 years before. So, polymethyl methacrylate was the polymer that was used for that particular experiment. One of the critical thing of a proper NIL resist instead of photo resist, if you are allowed to use are refer to this polymer film as NIL resist layer, is one of the critical requirements. Since it involves a thermal cycling is that, it should posses a low coefficient of thermal expansion which is pretty low for PMMA.

The pressure shrinkage coefficient, another very critical parameter because ultimately you are going to apply even you are embossing, you are going to apply high external pressure. So, if there is a significant pressure shrinkage within the polymer due to voids present in the within the structure, with in the matrix, it is also detrimental for the whole process. So, you do not really want to have a very high pressure shrinkage. And, so, essentially PMMA was picked up for both these nice compatible properties to NIL, a very low coefficient of thermal expansion and low pressure shrinkage coefficient.

Typically temperatures vary from 150 degree to let us say 200 degree centigrade depending on the molecular way at the glass transition temperature of PMMA is around 120, 115 to 125 degree centigrade. Well, with back of the envelop, you may remember that you are talking about polymers. So, though, I mean so PMMA, simply stating PMMA is only part of the story the other important parameter is the molecular way. So, higher molecular weight an essentially would refer to longer chain molecules which any way will be more difficult to dislodge. And so, etching molecules or higher molecular weight polymers typically tend to have a higher viscosity which is reflected in terms of a higher class transition temperature.

But irrespective of the precious molecular weight that glass transition temperature, may vary by 15 20 degree centigrade. It can very more; I mean for very low molecular with thermo plastic seat can sort of be liquid even at room temperature. But if you are talking about some standard molecular whiteslides, like some thousand kilo (( )) above right up to above a million, it will sort of have a glass transition temperature somewhere around 115 to 125 degree centigrade for PMMA. So, this is the temperature that was used for embossing, pressure was kept at around 30 to 50 mill Pascal. Biggest advantage of embossing from the stand point of lateral resolution of feature is that you ultimately create a negative replica of your stamp pattern.

And, your diffraction, optical diffraction or the wave length of the light source you were using for your exposure as in case of photolithography, does not have any influence here or any roll here. So, what we talk in terms of as one of the major disadvantages of photolithography, is that the literal features size is diffraction limited is in no way responsible, in case of nano imprint lithography or embossing based techniques. So, if you have the right stamp, then it is possible that you can create as small a features size you want to create. It becomes a difficult; it becomes another question of course.

How does one create the original stamp? I mean that something I am going to talk may be in; I mean this is a common problem or a common question for both nano imprint lithography and embossing base techniques as well as soft lithography base techniques. That, though these techniques are very very easy to implement, you just heat up a polymer layer, you just press the stamp or the mold and you get a negative replica. One question you might think is, how does one originally create the stamp? And in many cases, the first stamp has to be created by either photolithography or by some higher and other next generation lithography techniques like electron beam lithography or focus Ion beam.

Lithography are something like that which makes the stamp a very costly and an expensive commodity. But one the advantage is that, once you have a stamp, you when use it several number of times to create (( )) on trading structures. So, even from the right of from the beginning it was realized, the beginning of the invention or beginning when the technique sort of came into existence, that there is no diffraction limitation. And the lateral the size, the lateral resolution of the feature size was entirely governed by the availability of the right type of the stamp.

So, way back in 1998 itself 25 nano meter lines where produced photo lithographically technology, it was stock at around 250 nano meters at that point of times. So, it was a huge quantum change in literal resolution of pattern features latest 2045 nano meter lines have been successfully produced by nano imprint lithography. But of course you need to realize that if you are creating 5 nano meter lines.

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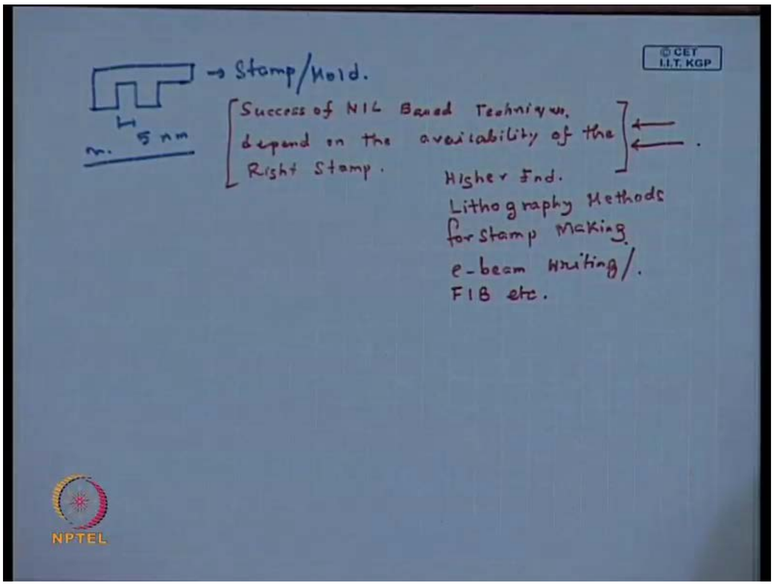

You actually need to have stamps or molds which itself as a very low literal dimension. So, this is really very very important as to get the or to a large extend the success of NIL based techniques (No Audio From: 38:50 to 39:03) depend on the availability of the right stamp. Well, we do not intend to really cover in greater detail about the higher end lithography methods for stamp making, maybe we will just quickly glands to some of the names like e beam writing or focused Ion beam etcetera. But we will, it is an important thing to remember that your feature size, the literal resolution of feature size as no limitation due to diffraction or any other optical property. And entirely depends on the availability of the right type of the stamp.

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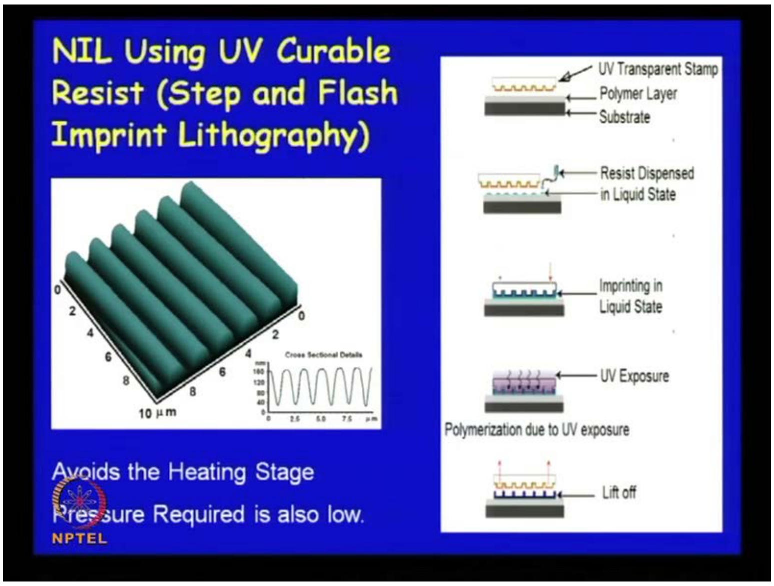

The one of the steps I mean if you look at the standard NIL one of the first things that you need to do is that you need to heat up your polymer. So, you have a thermal cycle associated with the step and for that you have to pick up a material which shows a low coefficient of thermal expansion. So, idea is that you take a polymer which is solid at room temperature you take it to the liquid phase where you want to embossing achieve your pattern transfer. But at that stage you sort of in order to achieve to that stage you need to heat up the polymer.

So, once you heat up the coefficient of thermal expansion becomes an issue. And therefore, it becomes difficult to handle polymers, which do not have a low coefficient of thermal expansion. So, one possible remedy of this was suggested, was the nano imprint lithography using U V curable resist which is often refer to as the step and flash imprint lithography. So, it is pretty similar to the conventional NIL but, the only difference is that you do not take a polymer layer. But you typically do not take a thermo plastic at room temperature, but you sort of use a U V curable resist which is liquid at room temperature.

And of course, your mask of the stamp or the mold has to be U V transparent. So, all you do that instead of coating a film which is solid at room temperature, you dispense a liquid in the liquid state at room temperature. So, it remains in the liquid state at the room temperature, but the only additional property you need to ensure that this liquid is

U V curable. So, again you are partly back to the regime of photolithography to some extent. That you are like a photo resist you are actually relying on a polymer or a material which is photosensitive. So, it is liquid at room temperature, but it is U V curable.

So, since it is liquid at room temperature what you do. uses bring in the stamp and emboss it against the liquid at room temperature. So, since you apply a pressure just the way you have done in case of the classical NIL, but your thermal cycling is not at all necessary here. So, your heating stage is gone. The advantage is that, the quite the chances of a thermal coefficient miss match and volume contraction or volume expansion due to the thermal cycling is also gone now. And, all you do instead of after the imprinting is over, the liquid has filled up the voids all this things happened, unlike cooling what you typically do in conventional NIL.

You just do a U V exposure and by U V exposure what happens is, there is chemical modification or chemical polymerization, that polymerization that goes in this polymer matter polymer with in this polymer. Or in other words if you do any U V exposure, there is physical cross linking within the polymer and the patterns become permanent and sort of it freezes. And, once the pattern freezes due to cross linking engendered by U V exposure, you simply leaf tuff the stamp.

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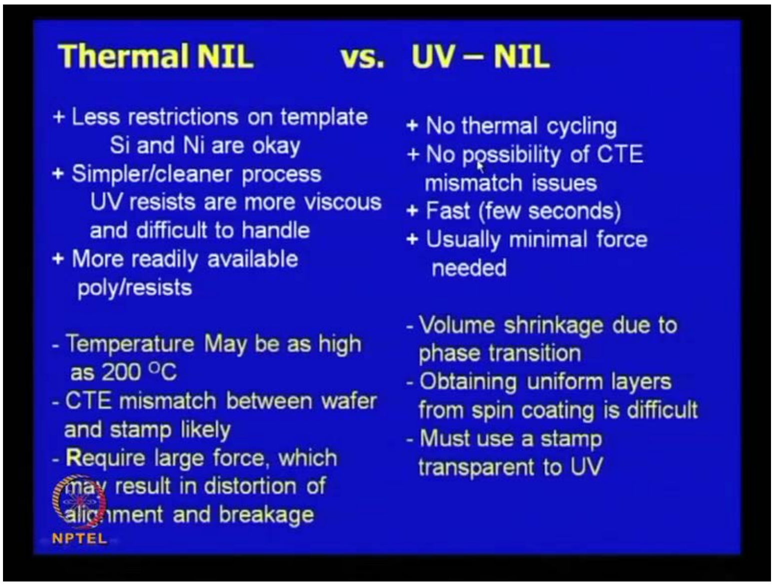

So, advantage here I mean. So, avoids the heating stage, the pressure required is also reasonable low, because typically it is a liquid state. So, it is at much more low viscosity as compare to a molten polymer. A quick look at the differences between the thermal NIL and U V NIL, of course U V NIL has it is shown advantages. But as it is shown, limitations also as you can see. Because the biggest advantage, one of the major advantage we talk about initially about nano imprint lithography is. That it is not material specific that advantage is lost in U V NIL. Because you are again talking about a material which is U V sensitive, I mean you cannot really work with any polymer.

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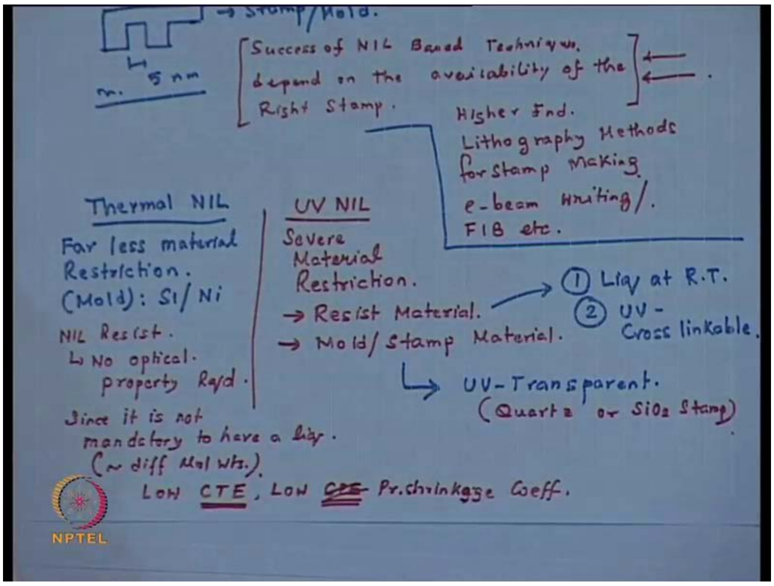

So, let us say up a quick look as what of the differences. So, thermal NIL it is, that is less restriction on the template or you can have any material, I mean pretty much all the conventional materials like silicon and nickel on the template at the mold at the stamp. In contrast in U V NIL, you have to have a mold or a stamp which is the stamp of the mold has to be transparent to U V. So, there is severe restriction of in U V NIL (No Audio From: 45:30 to 45:40) severe restriction from the stand point of materials not only. So, material here includes the resist as well as the mold of the stamp material. So, this is critical, the resist of the liquid has to be, it has to obey two properties.

It has to be a liquid at room temperature and secondly, it has to be U V cross linkable. In contrast the mold of the stamp has to obey property like it has to be U V transparent. In contrast in thermal nano imprint lithography, far less material restriction (No Audio

From: 46:56 to 47:05). You can have stamp or a mold of any material, it can be silicon, it can be nickel. Here, since it has to be U V transparent it almost automatically implies that, you need to have a quartz or silicon stamp, which is U V transparent also there, NIL resist no optical property required and since you do not need a liquid.

(No Audio From: 47:45 to 48:01)

So, you can have different molecular weights also. But in contrast it does require that you have a low C T E and low coefficient of pressure shrinkage (No Audio From: 48:30 to 48:50) material. Well, thermal NIL is in a way slightly simple as simpler or as some people mentions it to be cleaner process. U V resists, since they are liquid at room temperature have a tendency to be more viscous and often difficult to handle. So, if you really have a more viscous resist, one of the major problems is during the process of creating the film by spin coating itself. So, if you have a high viscosity liquid, there is chance that your initial film thickness will not be very smooth.

And of course exactly you, I remember you have talked about the existence of a yellow room in the context of photolithograph. So, the moment you are actually working with a U V curable resist. It also implies that it is necessary that you need to take all the precaution, because you do not really want to your rage liquid resists sort of start cross linking on hardening during the processing step itself. Of course, thermal NIL more readily available polymers or resists because you can word with pretty much any type of polymer, almost all thermo plastics can be handle by thermal NIL. Advantage of U V NIL, of course there is no thermal cycling.

So, you sort of save on the hardware, you save on the thridical issue of heating, controlling the temperature, then cooling it down and then detaching. So, it is far less step intensive I would say. Any possibility of thermal coefficient mismatch issue does not remain at all. So, there is no possibility of coefficient of thermal expansion mismatch, its much faster. It requires just a couple of seconds or few seconds because of the fact that you have a, you have the U V curable resist layer the U V curable polymer layer which itself is in the liquid state.

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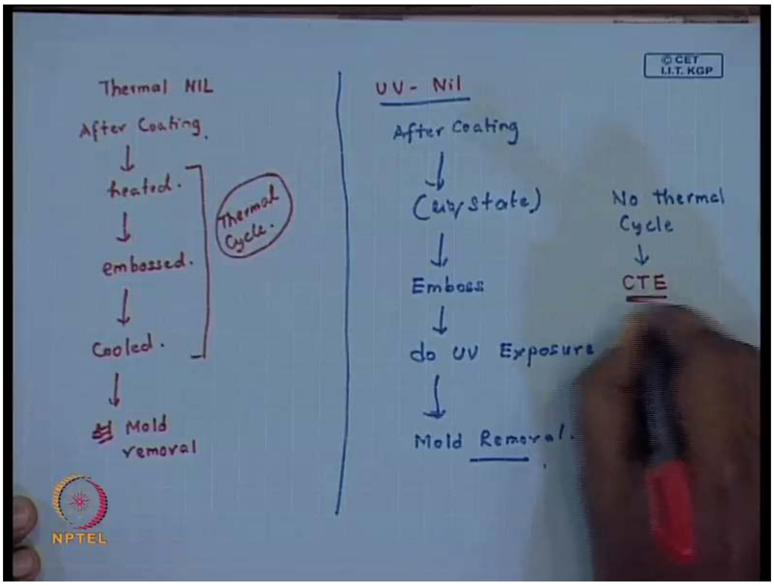

Here you after coating the film, so (No Audio From: 50:55 to 51:07) it has to be heated, then embossed, then cooled, then stamp or mold removed. So, it has quite a few. So, this is these are the substrate of the thermal cycle and it of course requires time. In contrast it is already in the liquid state, straight away emboss it. Do the U V exposure, your patterns have already formed, just removed the stamp. So, that way it is much faster, much faster. But it of course you have talked already it requires, as it is shown problems materials issue and thinks like that.

Since, you do not have the thermal cycle, so coefficient of thermal expansion and it mismatch between the polymer and if there is an expansion of the mold of the stamp material. This is what you are talking about the C T E mismatch that question does not arise. So, that is another major advantage of course if you have a polymer which might degrade, if it is heated to a higher temperature again. That is major problem in the conventional thermal NIL which can; I mean address by U V NIL. As far as working with living cells it is concerned, I would say just both the techniques are pretty much equally bad.

Because in one you are exposing your living cells to high temperature. In the other, you are exposing your living cells to half harsh processing condition in the form of U V exposure. So, it is not good for any one of them some of the soft lithography techniques which really does not have a thermal cycling as well as does not require an U V exposure are much better suited for biological applications. In thermal NIL coming back to the comparison, thermal NIL of course requires pretty high temperature and temperatures can be as high as 200 degree centigrade.

Well, there is a possibility of coefficient of thermal expansion mismatch between wafer and stamp and requires larger force as compare to much lower forces which are necessary in U V nano imprint lithography. And, much higher forces may result in distortion of the alignment and also possible breakage of the substrate as well as the stamp. That is real problem in nano imprint lithography and you understand by now, that a stamp is really costly piece of hardware. So, if there is breakage it is going to sort of pinch you hard, getting a replacement stamp and things like that.

In contrast of course, U V NIL has these advantages, but volume shrinkage there is significant volume shrinkage, this is important in U V NIL. There is significant volume shrinkage due to phase transition, this phase transition occurs when you are exposing the patterned resist layer after it has been imprinted or embossed with the stamp U V exposing it. So, there might be significant volume shrinkage, as we have already told because you are working with the high viscosity U V curable resist. It might be difficult to up to a uniform layers from spin coating and of course there are lot of material restriction on U V stamp.

So, this is we have talked in this class about some of the basics of nano imprint lithography and two of the most conventional form or most popular forms of nano imprint lithography, that is thermal NIL and U V NIL. In the next class, we will pick off the discussion from here and talk about the other variance or molds of nano imprint lithography.