Instability & Patterning of Thin Polymer Films

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Lecture No. 38

Template Guided Dewetting

Welcome back. We, in the last module or last few lectures, have discussed on dewetting and we have seen two aspects - one is a theoretical aspect of the understanding of under what condition a film spontaneously ruptures and dewetts but, the other thing that we have seen, and which is pretty interesting, that in this process of spontaneous dewetting of a thin film you are able to generate some mesoscale structures. So we have discussed that you just spin coated thin film you just heat it up beyond its glass transition temperature or expose to its solvent paper and and you see that first the holes appear if the system is unstable, then you see the formation of droplets and .

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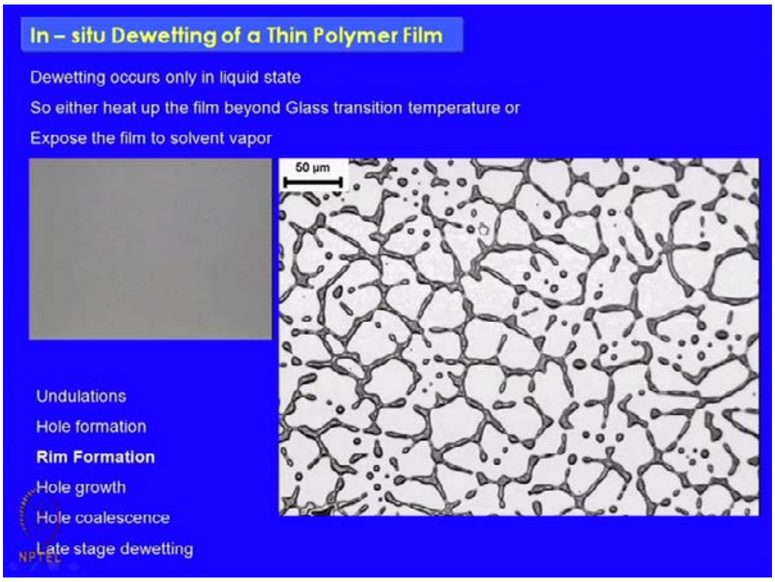

So, things like that we have already noticed. So, you just start off with a thin film and eventually, this is the next stage, we have seen this video again, you lead to formation of drops. So, this is now interesting, because we know that we have discussed a whole lot of things on how to figurally patterned or meso patterned surfaces have lot of industrial aplly or lot of application, and the whole science of soft lithography is essentially aimed at that. But here, you have a system; the other interesting thing that we had discussed in the previous class is that, the periodicity of the structures, the number density of the structures, the size of the structures they all scale with the film thickness.

So what it implies, I do not have a video or a view graph or micrograph here but, what is important is that if you vary the film thickness, let us say, from 20 nanometer to 40 nanometer. So generically, may be in 20 nanometer you get an array of droplets like this. In contrast, if you take, let us say, 40 nanometer thick film, you might get some droplets like this.

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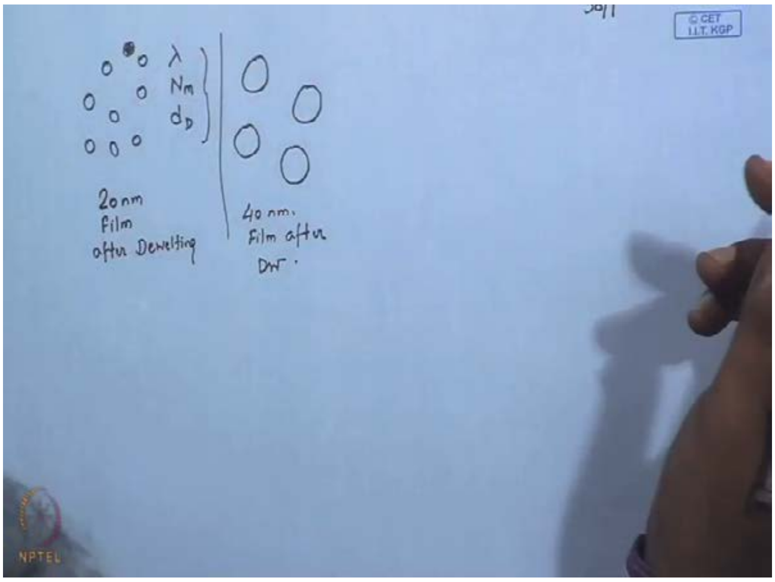

This is interesting, so few things vary, so lambda varies, number density varies and the diameter of the features, let us say, vary. So here, in if you now compare with soft lithography and you wanted to sort of create different structures, let us say. So the only way of doing that would have been to have different stamps with different features. But here, you see that you have additional handles or to sort of a Taylor the periodicity size number density of the structures. We also talk briefly, in the last class about the boiler dewetting where we talked about the reduced interfacial tension. So that also affects the number density as well as the feature size. Right?

So, in a way, this spontaneous instability or instability mediated techniques sort of give you an additional handle or tuning parameters based on which you can create different structures without any hardware requirements. So the key advantage would be that, you have these smaller droplets first is the larger droplets, you do not need any additional hardware like a stamp or whatever you just vary the film thickness and you get to that.

The second major advantage is that if you look at this evolution evolution sequence, this evolution sequence continues till the very end because you have kept the temperature beyond the glass transition temperature; it is elevated that glass transition temperature. But, let us say I decide that I do not want my film to dewett completely and I, let us say, want a holey template.

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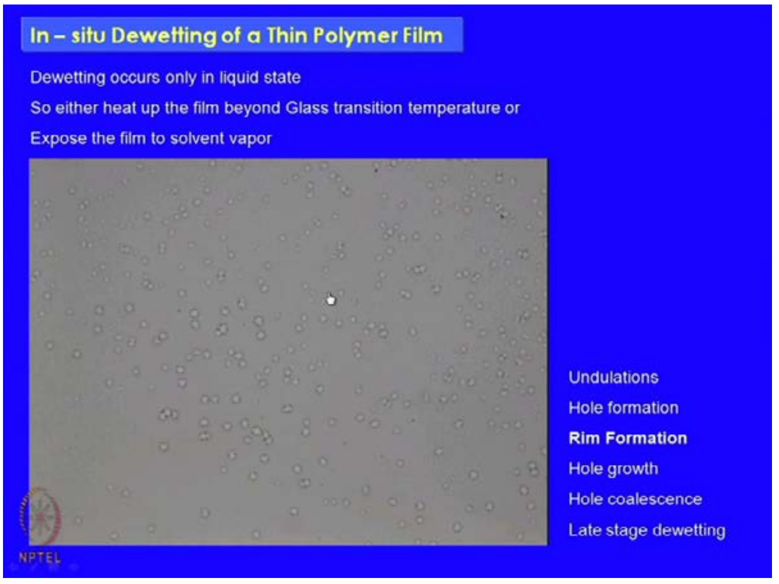

So I want a film which has some holes, what I would like to want to grow something, let us say. I have the advantage of stopping this process right here. And how does one do that? By simply quenching it.

Or in other words, I heat up the film based on its thermodynamics it is now evolving and now I reduce the temperature at an intermediate stage. I do not go all the way up to complete dewetting. So I have the advantage of stopping the process at any juncture and thereby, create difference structures. So, let us say, from the same thin film now of, let us say, 40 nanometer or 30 nanometer thickness, we can have holes, we can have ribbons, we can have a droplets and all these things are possible. So that way the film dewetting or to spontaneous dewetting which is extremely unwanted, we also discussed this particular aspect, which is unwanted from the stand point of a coating application can really find interesting or can really be used in an innovative way to generate surface patterns with meso and nanoscale lateral dimension and resolution. What is the real problem? The real problem is that these structures, whatever structures, the instability mediated structures or patterns that what we get, they are highly random; they are isotropic structures.

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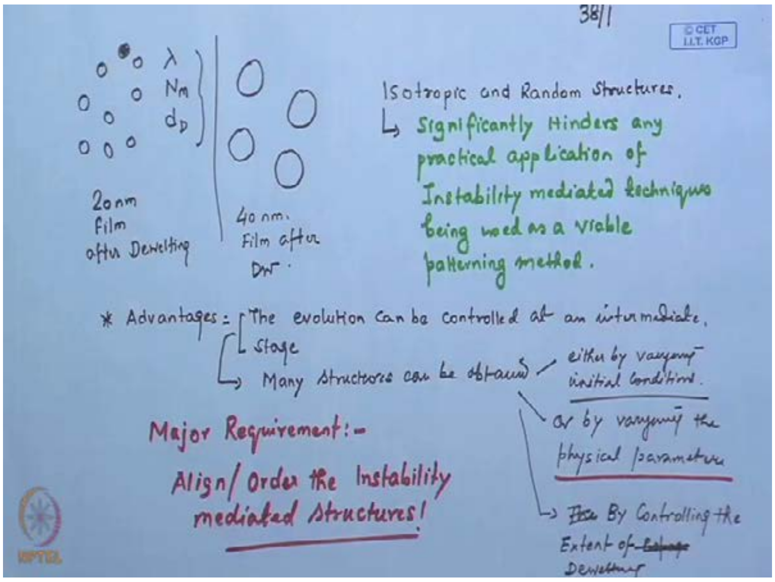

So this is a severe hindrance and significantly hinders any major practical application of instability mediated techniques being used as a viable patterning method. That is a real problem. What are the advantages? Advantages are the evolution controlled at an intermediate stage. So, many structures can be obtained either by varying the initial condition or by initial conditions or by varying the physical parameters. I like give an example of that, that will make it clear or the extent by controlling the extent of this proposition or a progress extent of dewetting.

So, initial condition you understand whether I take a 20 nanometer film or a 40 nanometer film that is by controlling the initial condition. By varying physical parameters well you can till at the surface tension by, sort of, submerging the film under another liquid layer or a another polymer. Or you can even do things like, you can tailor the surface energy of the substrate because yesterday we told, to we talked about the fact that if you if your holes are growing and the surface is extremely non wettable there is a chance that there might be re mean stabilities which are occurring. In contrast if the wettability is not that low, the the one would typically get nice neat attraction, so that itself sort of even from from the same system you can have you can lead to the ribbon like stage we say we say completely random array of droplets. However, still the major disadvantage that remains is that these structures are random. So what we so in order to sort of use them as with any viable application, the most important requirement, major requirement would be to align these structures. This is the key requirement.

And therefore, in recent past significant focus is on or the significant research is going in these directions to workout strategies which can be used to align these structures, both with simple polymers like polystyrene, poly methyl, methacrylate which are good model systems, as well as for functional polymers. So we will discuss some of these approaches and pickup some examples to give you idea how it works.

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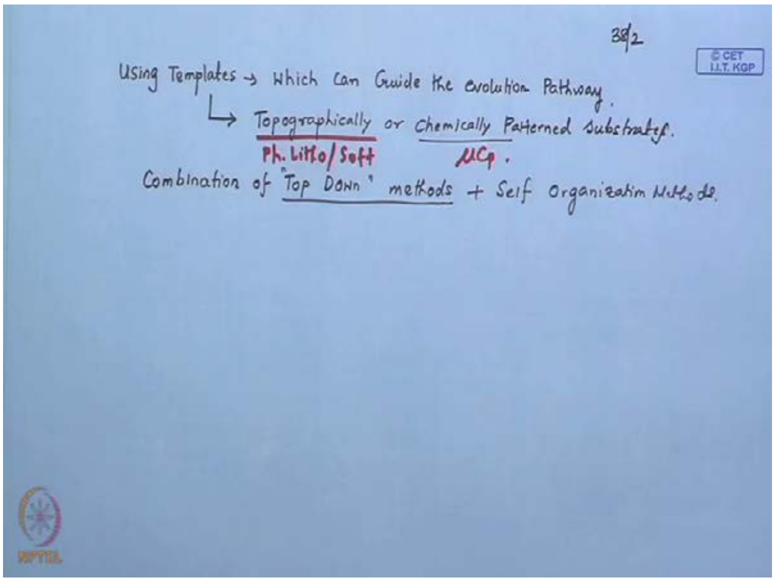

So the easiest way to sort of achieve it is based on using some templates or which can guide the evolution pathway. And the templates that are most commonly used are nothing but, topographically or chemically patterned substrates.

We will give you some examples from that. But, if you remember in one of our very initial slides we talked about three paradigms of mesoscale fabrication, right? One of them was self assembly based techniques, one of them was the top down techniques like the lithography's and the third one we talked about another form of a bottom of approach is a self-organization. So, these majority of the instability mediated patterning methods we have argued that they are essentially self-organization. Now, whenever you are using a template it is essentially a combination of the top down methods and the self-organization methods. Okay.

So why top down, because you have to make your topographically your chemically patterned substrate by some lithography. So if you were talking about a chemical patterning, you are going to use let us say a technique like micro contact printing, which is typically used. If you were talking about topographically pattern surface, you can use photolithography or some other soft lithography methods. Okay. So we will see how it works but, interestingly that the there is a possibility of aligning these dewetted structures was a first shown by Jones, famous scientist from UK in around 2000. The paper was published in nature where the simply took a glass slide and before coating it with a polystyrene or a p m m a film all the deed was to rub the glass slide in one particular direction with some emery paper.

So this result at, this rubbing essentially resulted in some scratches micro scratches on the surface of the glass slide and eventually when a film was cast on on this particular surface and the film was allowed to dewett, that the the the strong isotropy resulting from this rubbing or scratching a particular direction made the structures which were completely align.

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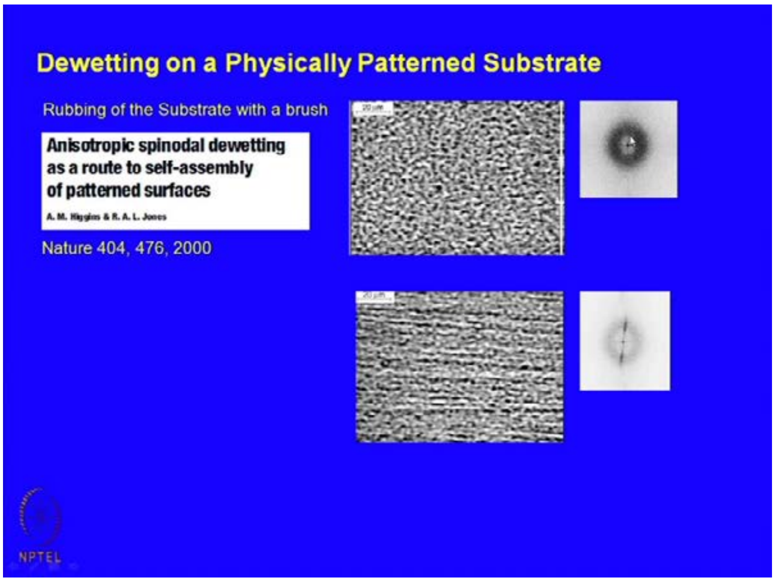

So that was the first time which you can see. Here that the structures, so this is the typical structures we would get from a dewetting of a spinodal dewetting the all the stages of spinodal dewetting on a flat surface but, instead of using a flat substrate the same substrate if you just take a micro scratched or a rubbed surface in a particular direction you can see that the structures are highly aligned and you can also verify the isotropy of the surfaces here from the the these FFT’s - Fast Fourier Transform diagrams, okay.

So this was a conceptual approach to show that yes indeed it becomes possible to align this structures. But, you have to understand that by you using a technique like rubbing for example, it is not going to work for for an industrial application or of if for producing something in a reproducible manner.

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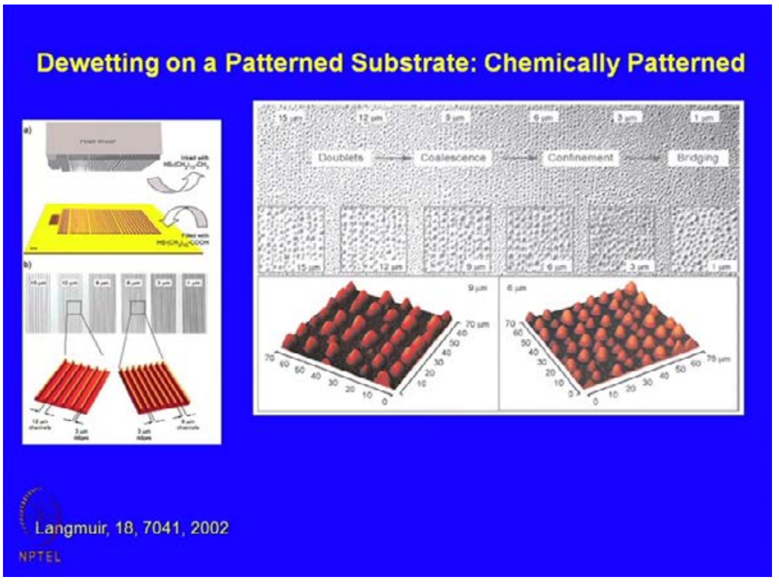

So what has been a major approach is essentially to dewett on a topographically or a chemically patterned surface.

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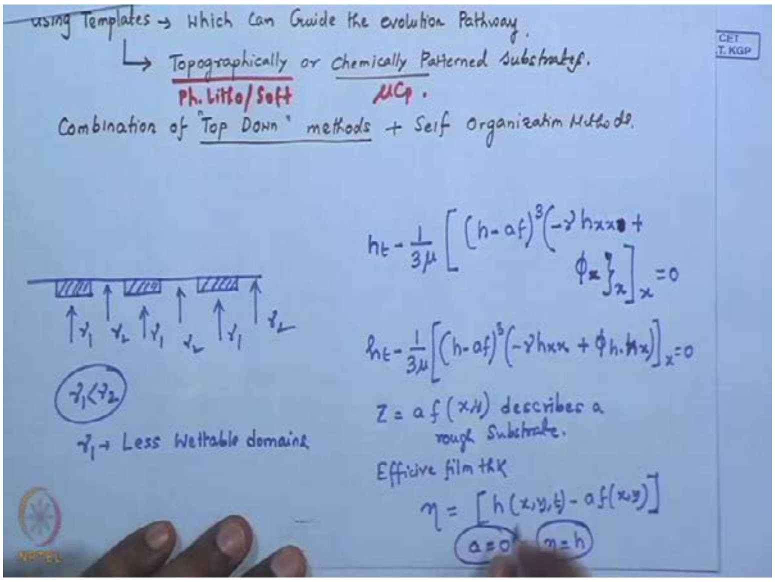

So let us first talk about a chemically patterned surface. You all understand what is a chemically patterned surface, so it is something like this. So let us say these are domains with gamma 1 and these are domains with gamma 2 and gamma 1 is less than gamma 2. So, gamma 1, these are less wettable domains.

So, what happens is when you are talking about dewetting on a chemically or a topographically pattern surface your equation, which the thin film equation, if you remember from our 35th lecture which which has this form, gets a slightly modified as ((No audio from 15:33 to 16:20)) okay. I will write it like this. I will I will rewrite it. So if you compare this with this form of the equation, you first see that h has been replaced with h minus a f, where a f is a or z equal to a f. x y describes a rough substrate and the effective thickness film now becomes. So, for a smooth surface you can write that a is equal to 0 for a smooth surface. Or 5 is equal to eta is equal to h for a smooth surface.

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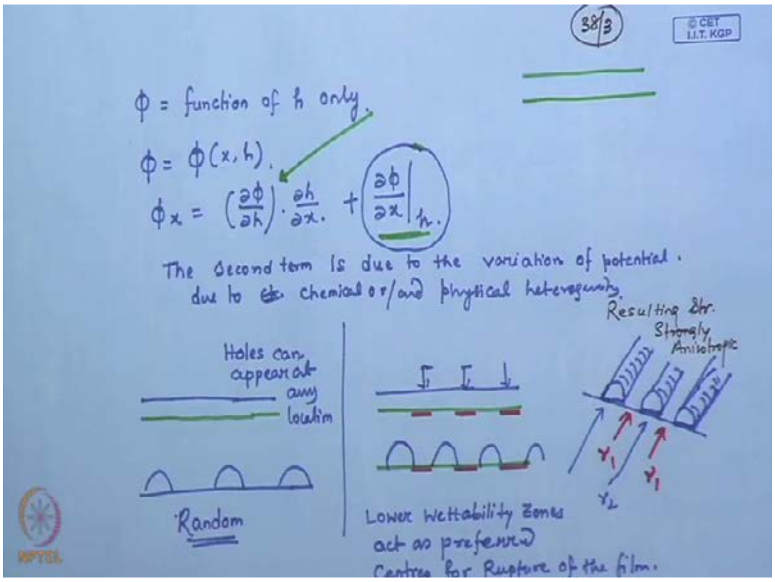

So this is a modification. e that comes in. So firstly these parameter sort of takes care of any topographic roughness that is present in the system but, more importantly what happens is phi now becomes, earlier phi we had taken to be a function of h only, okay. But, in this case what happens is phi becomes a function of x and h. Therefore, this term, phi x now becomes which was this we had while doing the linear stability analysis we have used phi x as del phi del h into del h del x but, now there is an additional term present in this which is del phi del x evaluated and at any specific h. Or in other words this particular term represents the second term is the force due to or is a array is due to the variation in potential the in plain variation of potential due to chemical or and physical heterogenic.

So, in other words, under the action of this particular force the fluid sort of moves from the less wettable area. So this is sort of an in-plain potential radiant. So earlier what we have seen that for a flat film on a on a homogeneous surface or a smooth surface, it was the sign of this term, which essentially if you considered the 100 volts force you you can write this in terms of the Hammett constant and then we talked about this term in terms of the sign of the Hammett constant. But, here additionally even if the Hammett constant is positive or negative or even if Hammett constant sort of is giving you a stability, this additional force field arises due to the in-plain gradient in the potential so what happens is due to the in-plain potential radiant in the potential now if you have a thin film on a chemically patterned surface, let us say, what is going to happen? So these are domains which are non wettable.

So, the film will preferentially rupture over these areas. So in simple terms what will happen is that, suppose if you have a flat surfaces we say we say chemically patterned surface and you have a film over here and you have a film over here, same thickness let us say, here the evolution or the dynamics is completely random. In contrast what is going to happen, the lightly scenario, is that the film is going to rupture only over these locations. And the remaining part of the polymer will retract to the areas having gamma 2. So you will be the first the morphological evaluation, instead of being a completely random evaluation, you will get isolated strips of polymer like this or in other words these are zones with gamma 1 let us say where the film has ruptured and the polymer has the many cases retracted back over the areas with thickness a where where with surfaces energy gamma 2, okay.

So, this way, instead of a completely random path way. Or in other words what it means that here on the surface the nucleus the holes can appear at any random location. So, in contrast, over here, you are since you have these zones which have lower wettability, so the lower wettability zones act as preferred centers for rupture of the film and therefore, the final resulting structures becomes strongly an isentropic. Okay. So this is how it goes on a chemically patterned surface and you can use a chemically patterned surface to align the structures. Of course, what is important that other parameters also coming to play.

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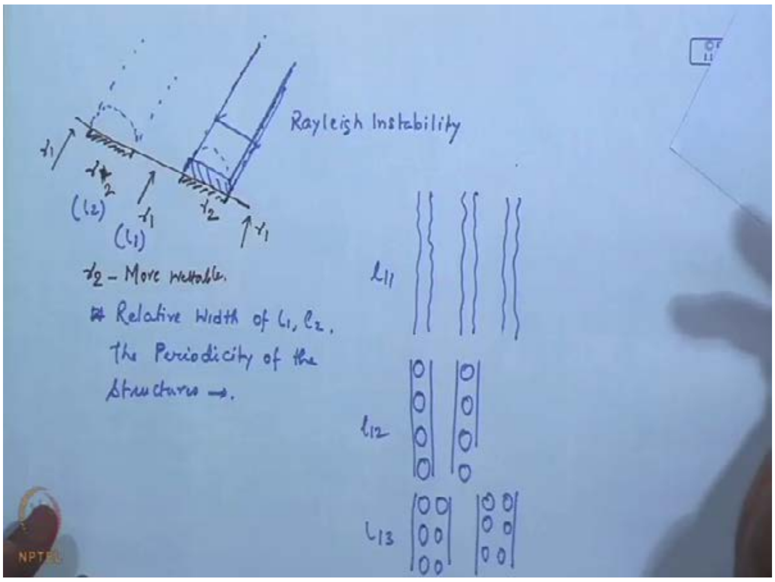

So suppose this is a chemically patterned surface, let us say I put the markers here, so gamma 2 let us say is less wettable, or gamma 2 is a more wettable, I am sorry. That is how we have a drawn the picture gamma 1 is less wettable. So these are the domains with gamma 1 let us say. Film has ruptured. Film has ruptured and it as now got accumulated over these zones, okay. Now other parameters will also coming to play, let us say the width of these zones so let us say these zones have width of l 1; these zones have a width of l 2. So the width of l 1, the relative width l 1, l 2, the periodicity of the structures, everything becomes important. Because what you have to understand after they have dewetted, they now form actually very long polymer threads, so there is always a tendency of Rayleigh instability being exhibited.

So, this was shown in a 2002 paper by Allergen Karim's groups, that depending on the width of the less wettable and the more wettable zones you can get a whole lot of structures. So, let us say, for every thin thread and if there these zones are about a micron wide your structure will comprise isolated polymer ribbons, okay. But, in contrast if you have wide reams, let us say few microns, then you might have aligned droplets arrays like this. For even wider, so let us say, this is l 1 1, this is l 1 2, for l 1 3 even wider zones you might have a double periodic array of a droplets. So, once you now confine the entire polymer film to one of these zones, okay, now again it is a question of it is now a localized isolated thin strip of a film; thin strip of a thin film.

So, now again it can show its it can rupture following its spinodal mechanism or it can exhibit in plain Rayleigh instability or whatever. But, you can see that as compared to for example, if you look at this particular figure you can see that you again have droplets which are common in dewetting but, these droplets are no longer completely random but, they are pretty well aligned. So this can be easily accomplished with micro contact printed surfaces one can also, sort of tailor the extent of wettability contrast. So that is another very interesting work that was published by the same group but, few years back. So you have a micro contact printed surfaces, so we all know this is what did what is a micro contact printed surface.

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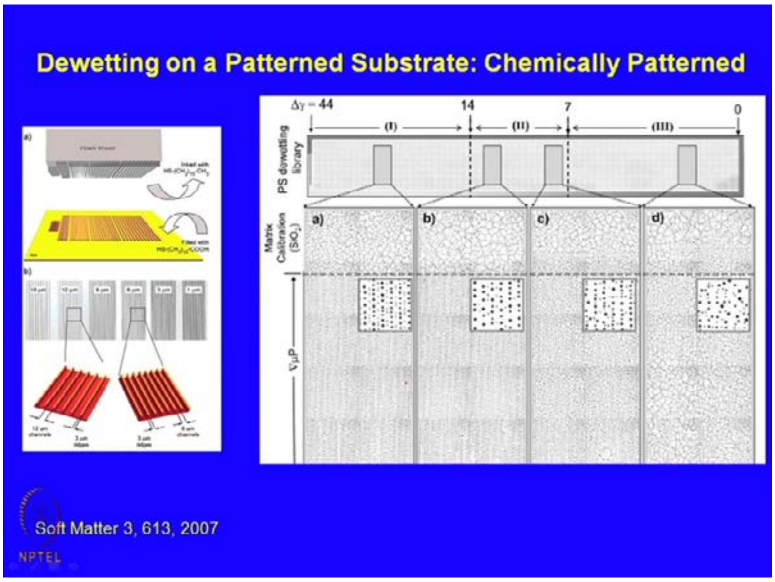

So, let us say this is gamma 1 and gamma 2. So they also showed that depending on the difference of or the extent of ordering is a strong function of this difference. Because, how does it manifest in the equation? Because the strength of this particular term the strength of this particular term depends, actually depends on the relative difference. So if you take surfaces different micro corporate surfaces, well let us say, the gamma 1 minus gamma 2 is varied and this can be easily done by from your soft lithography understanding you can immediately say that if you, sort of take silence which have different surface energies or it take a base surface which has different surface energy this can be accomplished.

So lower is the difference between gamma 1 and gamma 2 what is going to happen is that the strength of this term is going to become weaker and the anisotropy of the structure sort of reduced reduce. Or in other words the the extent of alignment sort of gradually reduces and the structure tend to become more random. In fact, they could show that they are exist ascetical value of delta gamma, that is the in plain wettability gradient the, below which the the ordering is completely lost. So again these are very advanced areas in which research is still active, lot of new findings coming every year but. So from completely random structures to this type of align structures.

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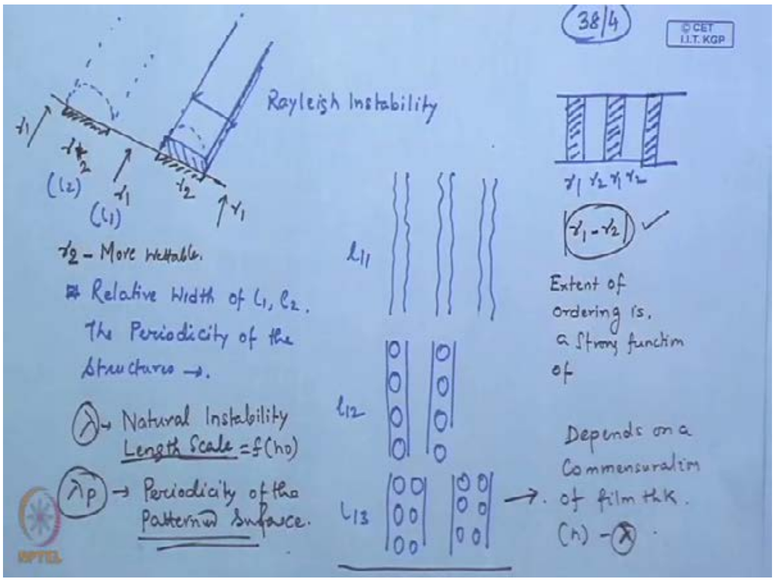

So this is exciting now because, again here, you have the potential to stop the evolution at any intermediate location and also what we find that the final morphology depends on a commensuration of a whole lot of parameters. So film thickness film thickness brings in the natural length scale of instability. So lambda is the natural instability length scale, which corresponds to, let me remain that if you do the the analysis for a particular thickness on a flat surface do the linear stability analysis what you get from the fosters brewing mood so that gives you lambda, so this is the natural instability length scale which is a function of the film thickness, the 8 0.

And here you have another parameter that is the lambda p, which is the periodicity of the patterns. So, the final structure, final morphology of the structure is a strong function of the commensuration between lambda and lambda p, okay. So, of course, apart from lambda p issues like l p, delta gamma.

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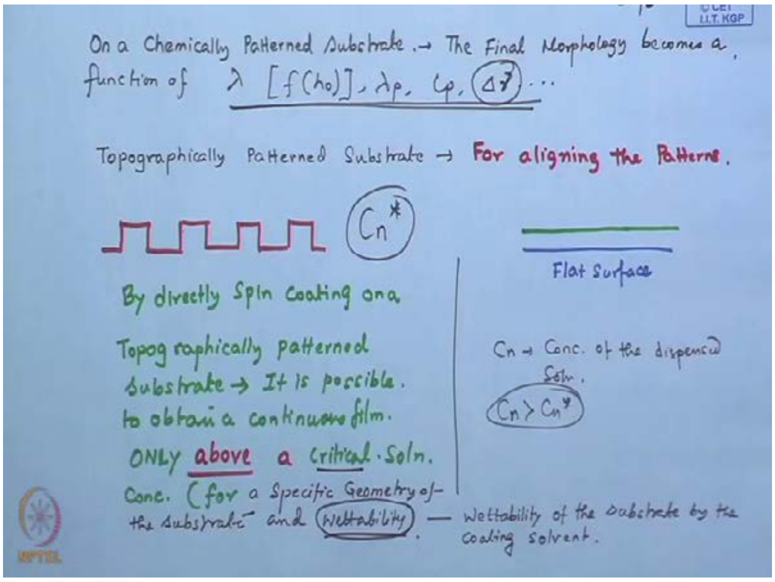

So, let us write it down neatly. So on a chemically patterned substrate the final morphology becomes a function of lambda, which is a function of the film thickness, lambda p, l p, delta gamma etcetera. And therefore, again you have whole lot of handle by simply using the same template or same pattern substrate but, the films of different thicknesses you can get to different structures. You can so, you can use same pattern substrate but, with different delta gamma you can get to different structures.

So these are the advantages. Unlike top down soft lithography where every time you want to create a new structure you have to have a different stamp, so you you can really rule that out a work with tailor or play with around with the parameters and you can get to a whole lot of things. But, the critical thing is that these dependence is often non-linear, it is a multi parameter dependence and it is often non-linear, so if you want to sort of do experiments blindly you might not lead anywhere because, every new combination will give you a completely new set of results, because the initial conditions are extremely important. So, in that case, it is very difficult to draw some cohesive ah understanding only based on experiments and other the unless the experiments are sort of very well planned.

So what typically is found is necessary is to have a very strong and robust simulation tools. There is been lot of work from addict and pure group and another groups also in the world on simulation of these type of system, which really sort of become very, very handy in understanding the or predicting the likely morphology. So if you have robust simulation tool then you can sort of identify the structure you want to obtain and do experiments based on picking up appropriate initial condition. That reduces your experimental efforts to a large extent. So similar to using a chemically patterned surface one can also use a topographically patterned surface for aligning the structures.

So we all understand what is a topographically patterned substrate, so it something like this. So, in principle what will happen the moment you use a topographically patterned substrate, it is this particular term that becomes very important. Now the film thickness sort of varies, theoretically the film thickness varies along the length. So h itself or eta becomes a strong function of x. But, in practice say these more critical because, how do you really get a film on that, on this type of a surface? Because, on a flat surface what you do, if this is your flat surface and you you simply spin coat you get a film. How do you get a film on this type of a surface?

Because if you spin coat we have talked about it very briefly, and here you can see again that by directly spin coating on a on a topographically patterned substrate, it is possible a continuous film only above a critical solution concentration for a, of course you have to understand that this concentration is nothing like a universal gas constant or something like that this critical concentration, for a specific geometry of the substrate and wettability. So, how wettable your substrate is? And this wettability is not the water contact angular whatever this wettability is governed by the wettability of the substrate by the coating solvent.

So this is very, very important. Immediately you can understand if you have a more wettable surface the critical solution concentration will be low, if you if the surface is non wettable it will be high. So here you can see a whole lot of things.

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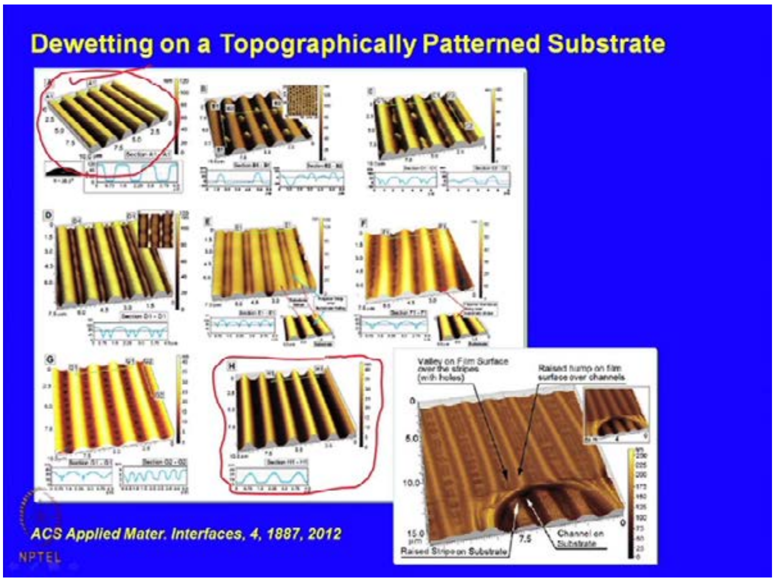

So this is that the this particular experiment was done in our lab. So this is the topographically patterned substrate, it is a grating patterned substrate that was taken which have was lithographically fabricated. Now if you try to spin coat only above critical concentration let us know point in coating the number because that varies from case to case let us say C n star, we could get a continuous film. So let us say C n is the concentration of the dispense solution. So only for C n greater than C n star we could get a continuous film.

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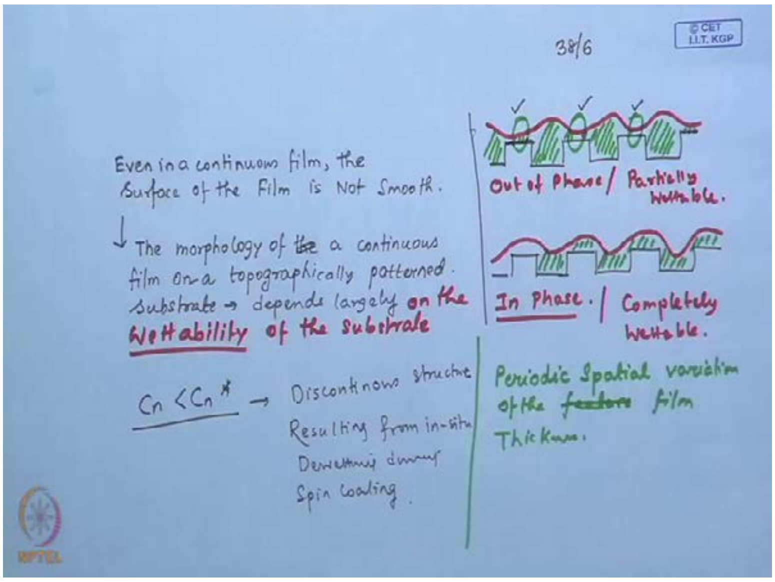

And the other important thing is that, though you get a continuous film, even in a continuous film the surface of the film is not smooth, okay. And in fact, what we get the morphology, this we have very briefly talked, the morphology of the of a continuous film on a topographically pattern substrate depends largely on the wettability of the substrate. So we have talked and we have shown recently in this paper that the structures will look like this.

So you will have film with an undulating top surface. And the undulations will be in face with the substrate patterns only when it is completely wettable, the substrate is completely wettable. In contrast, the structures or the undulations will be out of face in if the substrate is partially wettable. So this is a very decent and exciting finding. So, for a system like this what will happen even if you have a continuous film, you can immediately understand that at. There is a periodic special variation of the feature height, of the film height or film thickness. So if they are out of phase you can immediately see that these of the locations. Above the stamp, above the substrate protrusions the film thickness is much lower. So they the the surface undulation.

So again irrespective of this morphology the surface fluctuations we have talked about the surface present. So here, the chances of the surface fluctuations growing and touching the base of the substrate which is here, is much higher. So one would expect a preferential dewetting to be rupturing on top of the substrate pillars in this type of a case, which is very, very common and immediately add sort of a directionality to the dewetted structures. But, more interesting is even for C n less than C n star, you would not get a continuous film so because there is not adequate polymer or there is, what happens is, there is actually an in situ dewetting during the spin coating process itself.

And under certain specific conditions you might get some random structures, so let us say this is a random structure, I am not going into the detail mechanism if anyone is interested you can contact me or these are random structures. But here you see some structures like these are isolated droplets already, what you would be you might be expecting to get by dewetting, or these are thin strips of polymer within these groups of the substrate, okay. So these are pretty regular structures and you can also see that this thin strip already exhibits a Rayleigh instability, which is seen in this insay. So what you do not get is for C n less than C n star, you already get some structures which are resulting from an in situ dewetting so the discontinuous structures resulting from dewetting during spin coating, from in situ dewetting during spin coating and this is what is known as spin dewetting.

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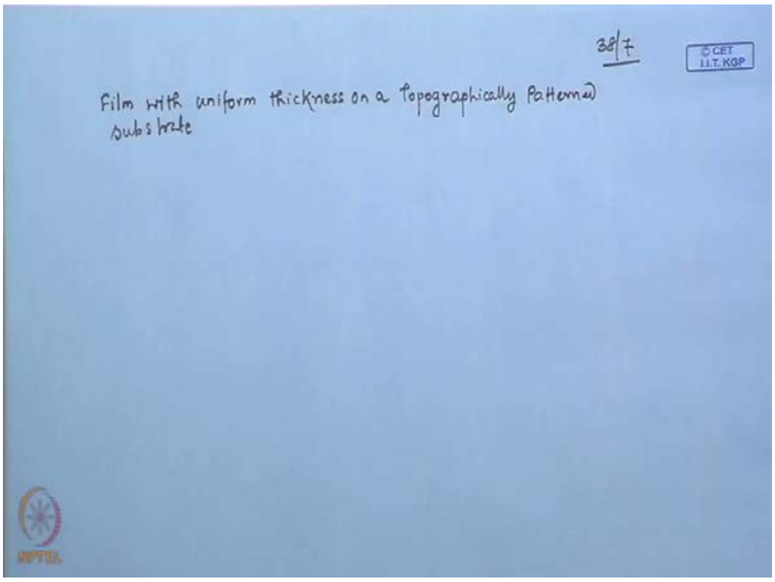

So one critical question is that, how does one really look at a film which has a uniform film thickness on a topographically patterned surface? Is it possible to do that? Film with uniform thickness on a topographically pattern substrate. Because, if you spin coat directly it is obvious that you will get a film with an undulating top surface.

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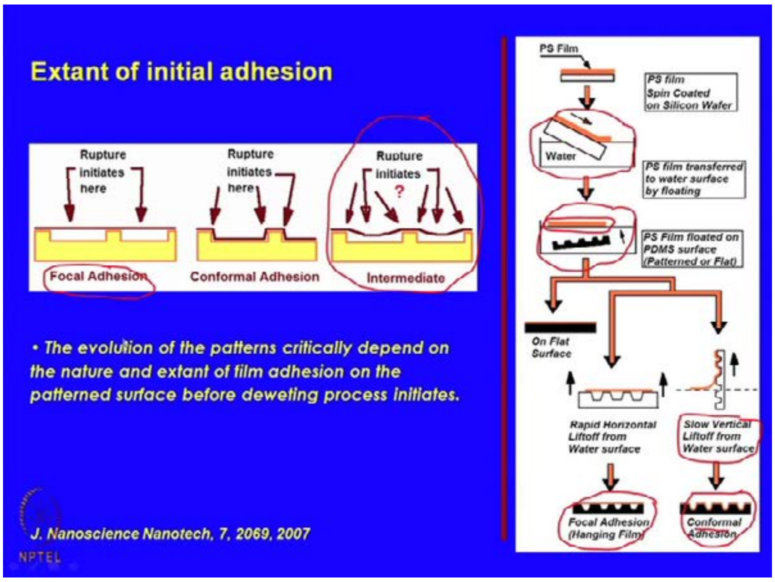

And this was a pretty challenging problem but, what is typically done in this case a very complicated. Rather complicated but, pretty well known experimental protocol is used which is based on floating of a thin film on a on a liquid surface, let us say, and need not liquid surface like water. So what is done a polystyrene or any polymer film is first spin coated on a flat surface, and then it is peeled off peeled off from the from that surface by floating on water.

So this very complex, not a very complex but, it is very tricky experimental protocol where you sort of hold through the edge and the film sort of detaches completely from the substrate in which you have coated it. So, you now have a freely floating a film on the surface of this liquid and which you have to recapture now with a topographically patterned substrate. So this is difficult but, it can be done and while doing this following this protocol, so this has been done for a lot of systems even before but, while we were capturing this a with a topographically patterned substrate it was also realized that depending on how this this capturing step or this step is implemented you can have different morphologies.

So, for example, if you have rapid horizontal lift-off from water surface you get to a morphology like this, where it similar to this, where a film is like a stretch sheet on the topographically patterned substrate which which is touching only the top of the substrate protrusions of the substrate top of the strips, if it is a grating. In contrast, if you have a slow vertical lift off from the water surface, then you would have this this type of a conformation which we term has conformal addition where the film is conformably adhering to the substrate. Depending on, if you have pulled it out at an angle or something like that you can have an intermediate configuration. So, now, this type of a system, how it is unique and distinct from this type of a system?

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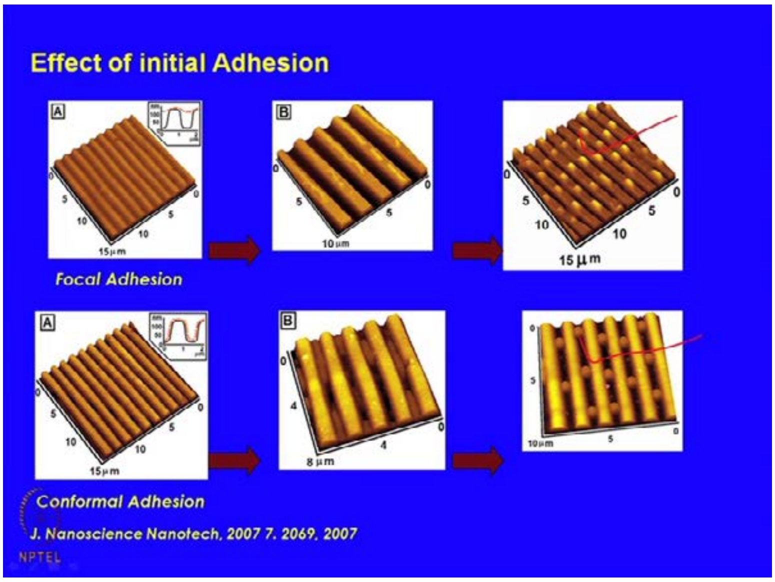

Here, the film thickness was a function of x but, here you have the potential of having a film with uniform thickness on a topographically patterned substrate. And what was important to realize that this initial adhesion, whether you have a focal adhesion or conformal adhesion. So the pre because of the presence of this the substrate or the template the structures anyway get aligned: what you can see from this picture or this picture, that the structures are aligned. But what is most interesting to notice is that if you have initial focal adhesion, the structures go and rest on the top of the stripe, informal. If you, in contrast, if you have conformal adhesion, the structures go and sit within the valleys. So here now you have an additional handle on tailoring or controlling the positioning of the droplets.

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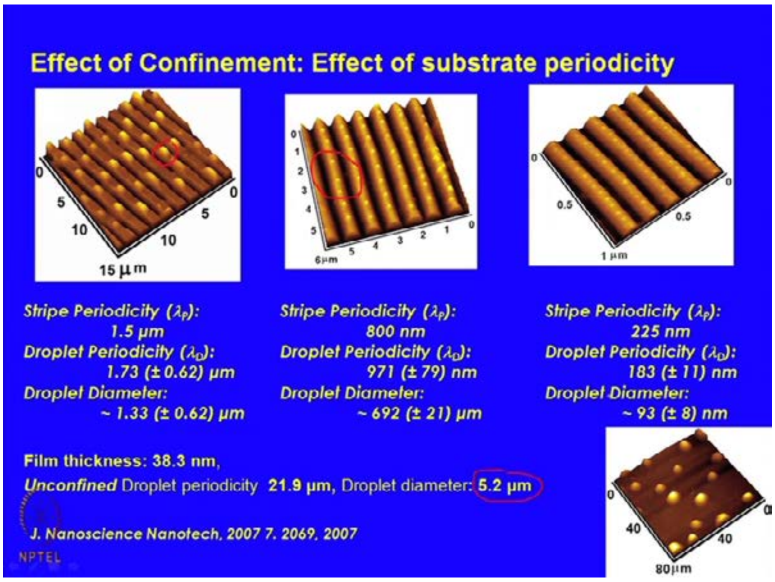

If you go on taking a narrow stripes or gratings with low reduced periodicity, you can show that the periodicity of the structures can also be controlled; you can get smaller droplets, they can get aligned; you can sort of reduce the periodicity in comparison to the natural periodicity by at least one or two orders.

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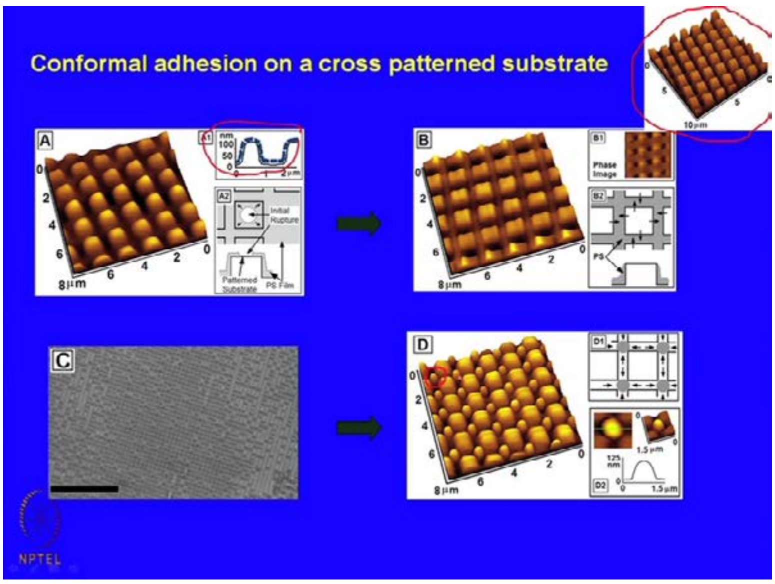

If you take a more complex template like this with a top 2D ordered array of square pillars and make a sample exactly following the same root have with the conformal adhesion you can have some very nicely arranged dewetted droplets. You see so this is the original template, and you see by the by dewetting of this film what has happen is that, at each of the interstitial location between the channel.

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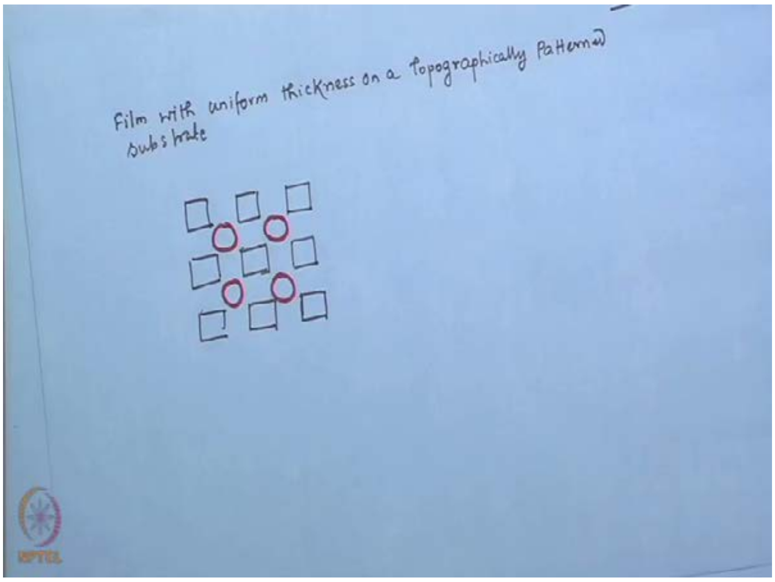

So here was the structure, this is an array of square pillars onto which you have floated your film and then allowed it dewett, so what you see that at every interstitial location gets filled up with one dewett droplet, okay. So the periodicity of the droplets here is completely governed by the periodicity of the template, right. So you can take templates with different periodicities and you can now tailor the periodicity the size of the droplets; the size of the droplet also is a function of the size available within.

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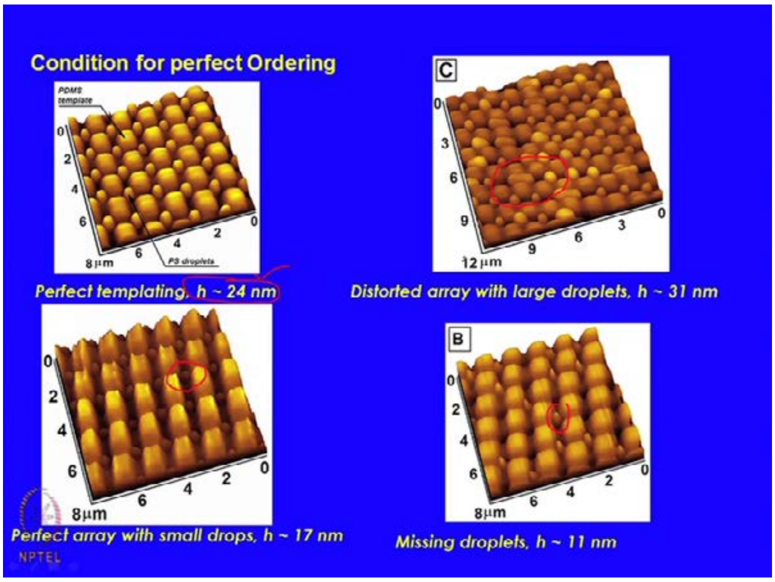

So, scientifically it is intriguing because with a 2D order template, perfect templating, where every locations gets filled up by a droplet of equal size or the maximum possible size that can be accommodated is possible for a specific thickness, which again is not a very critical very important number. But, one needs to understand that there is critical thickness for a specific template design. These can be resolved with simulations and people have been doing at about these sorts of things.

So, for larger or smaller or lower or higher film thickness the ordering sort of gets to tends to gets distorted. As you can see you have some droplets which are missing here, you have droplets which are smaller, or here you have some droplets which are interconnected.

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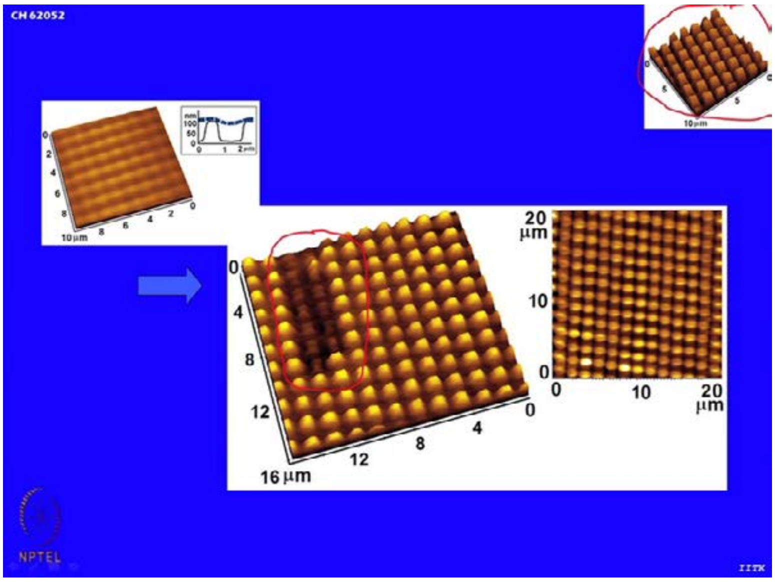

In contrast, even on this type, this template with this 2D order or this array of square pillars if you now have focal adhesion where the film is just touching only the top of the asperities or the top of the protrusions, you can again see that the droplets now go and align themselves from top of the pillars. So this is an image, which is a nice image, it is I like this image a lot because it had a zone where it had some defect. So here you can see through this defect through this zone the bottom of the so you can see clearly the substrates structures and this brighter spots which appear or essentially because that dewetted droplets now have gone and settled on top of the each of the pillars.

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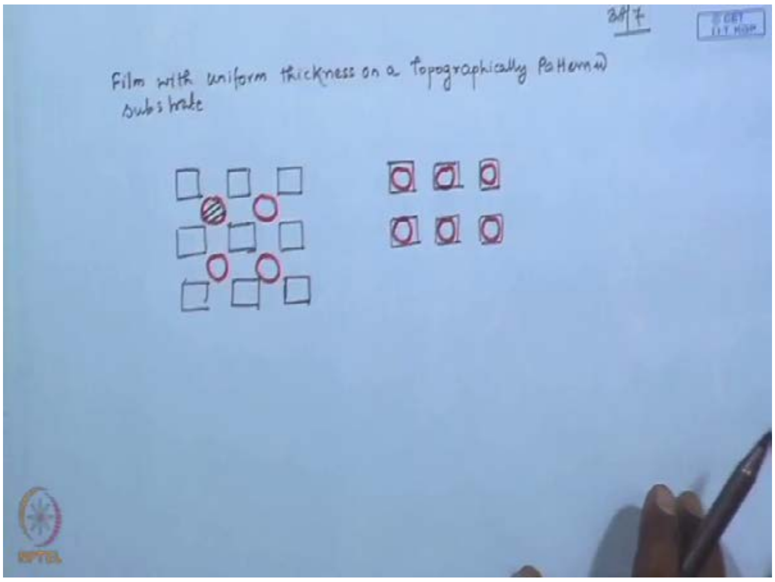

So, this way, by controlling the extent of initial adhesion it becomes possible to finally control or further control the positioning of the droplets.

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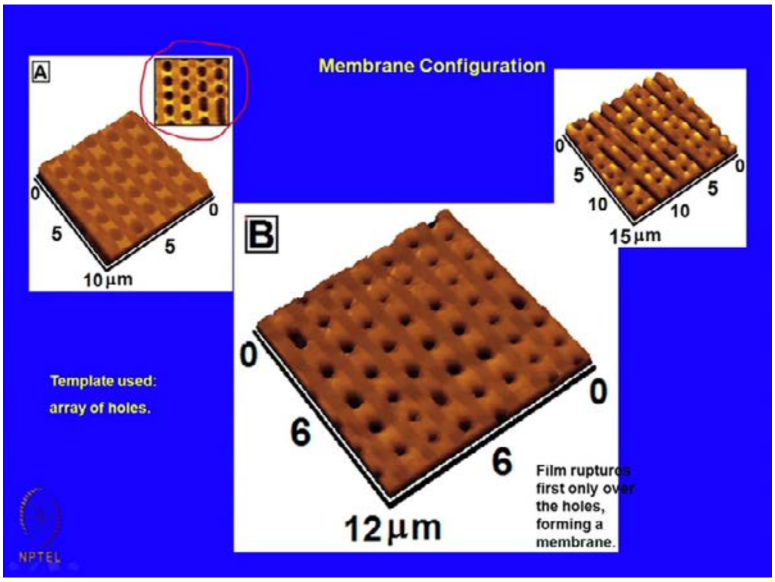

So this is a nice case study. This is another interesting case study, and I will show you a video which will excite you more. So, you had a template like this a holey template. So, you had a surface with holes. And a film was floated on that. So you can see through this AFM image, this is a film, intake film, which is floated on this particular templatted zone. If you now allow the film to dewett it is more like a focal adhesion.

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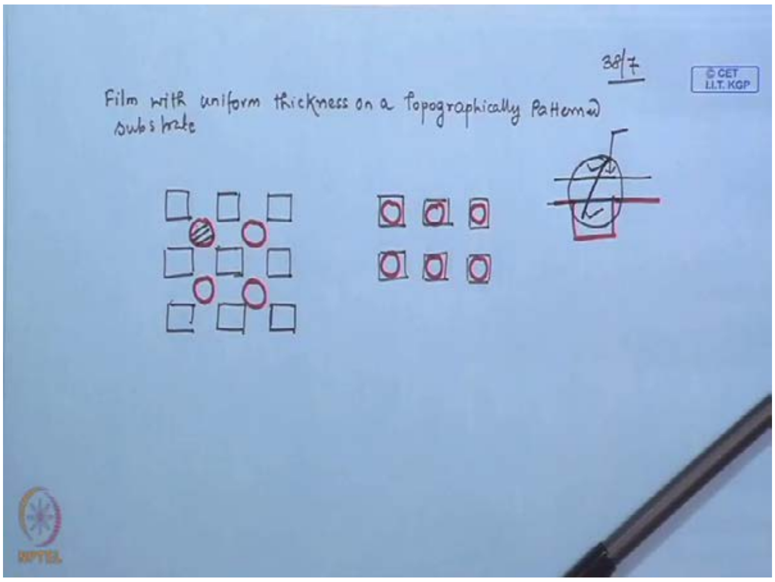

So what happen is, in focal adhesion, this is the film, so over these zones the energy penalty of sustaining two separate film may are interfaces is higher as compared to these zones and therefore, they it sort of a free standing a film over these zones and they rupture rather explosively.

So this has been what what is the theory says but, and therefore, you expect that the film will rupture over these zones in this particular case and look at this particular video.

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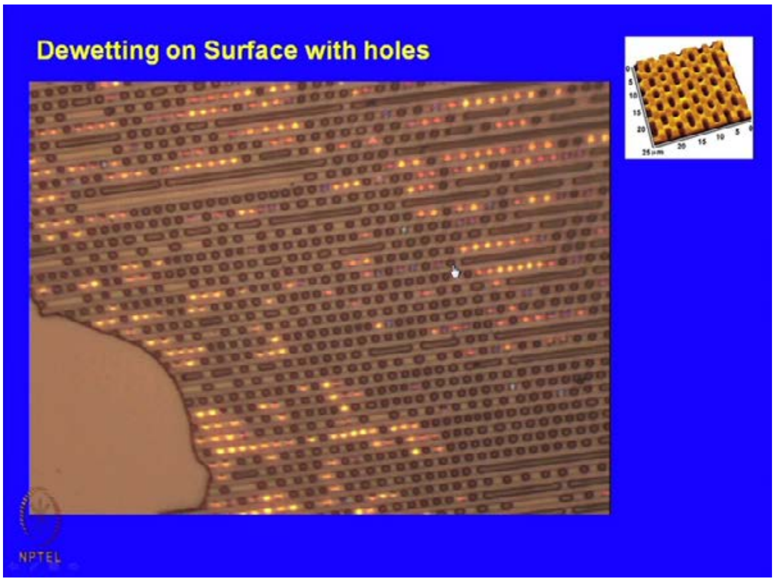

So this is what you see, a film has been floated on this type of a surface and if you now look at the video you see that some flash bulbs are going off somewhere, okay. So let me just tell you once more so so here you see some bright holes on which the film is still intact, which as not ruptured. And these brown colored holes are the zones over the film already ruptured. So if I allow running this video again, you see that at some of these brighter holes or sort of getting darker. So that is what is happening is that the film is sort of rather explosively rupturing over these zones.

So, you can clearly see that the film is a dewetting, is rupturing over those zones, and finally, once it rupture, so this is the intermediate morphology, so you have a possibility of stopping the evolution sequence right here, without allowing any further progress. So you can get film which is also whole and then you can transfer that film or use that as a membrane or whatever. But, if you allow the film to dewett further it forms again droplets which correspond to the lowest energy configuration or something like that. So here is the video if you want to see, have a look at it again. So you see that some of the films are films the intact portions of the films over the free which are freely hanging over the holes; they are sort of rupturing and opening up, forming a morphology like this.

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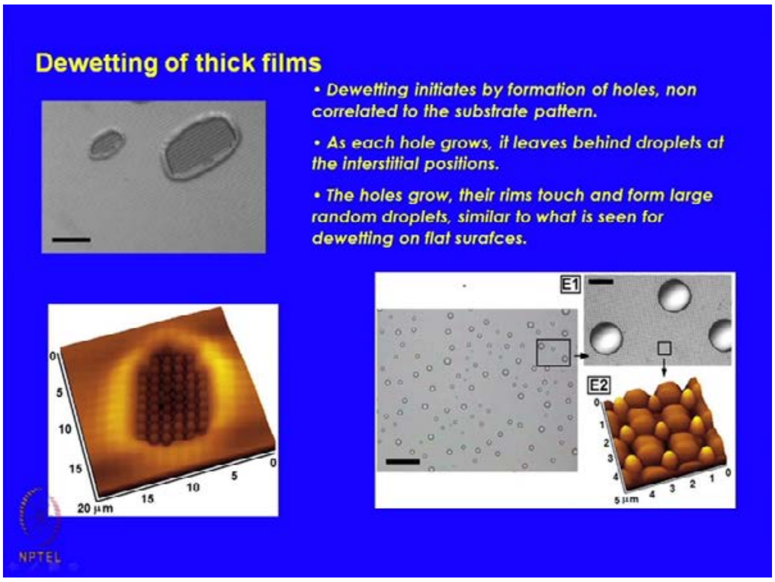

So another interesting thing is that, if you have a film which is in conformal contact but, which is much thicker, okay. So it something like this the film is much thicker as compared to substrate there might be some mild undulations. This is a floated films so there is that is no question of a film thickness varying. So, what happens is that, in this particular case, oh sorry, in this particular case the film does not rupture at the length scale of each of the pattern feature. So, what happen, what we showed in the case of this movie for example, is that the films ruptures at the length scale at or at the level of each feature.

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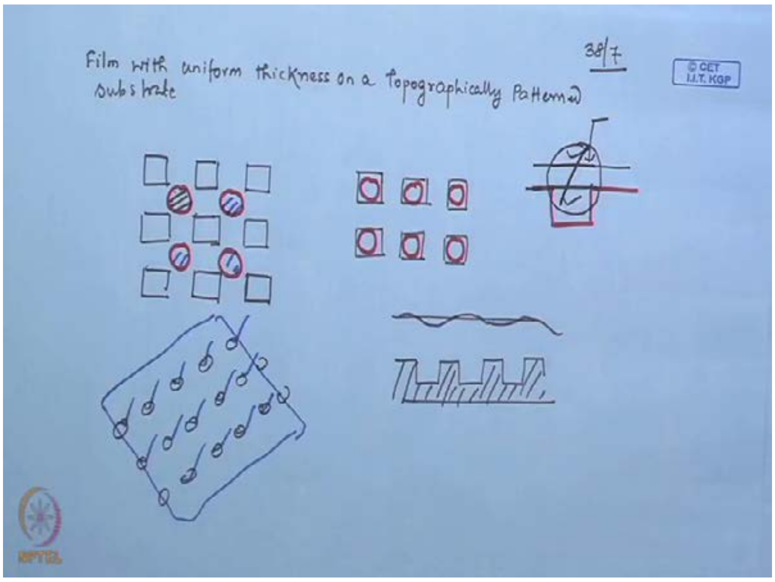

So you have an array of holes and you have a film which is floated on that, so the film ruptures over each of the features. And then, the subsequent morphological reorganization takes place.

And that is the same thing we have noticed here. We have argued here that the film ruptures over each of the each of these zones over here, or even of a chemically patterns are the same argument that we place that over each non wettable zone the film ruptures. But, for slightly thicker film, it is more interesting in the sense that, the film does not rupture at each of these at the at the level of each feature. In contrast, it sort of ruptures with the formation of holes which are non-correlated to the substrate of the template, like you see the formation of random holes on a topographic on a on a featureless flat surface.

So you see these holes under optical microscope, pretty high resolution optical microscope. And you see, so this is on a surface compressing this square pillars or whatever, you see that you can see the bare substrate also. But, if you examinate, so this is what you see under an optical microscope, so the hole has opened up; you can also very clearly see the formation of a rim. But, if you examinate under an atomic force microscope, you see that the as the rim retracts, so this the hole as opened, this is the direction of the retraction of the rim. As the rim has opened up, it sort of, while retracting back it will leaves behind a droplet at each of this interstitial location. So your finally, morphology if you allow complete dewetting, has structures at two length scales.

So if you see a low magnification image, you see some random droplets, which sort of resembles very you the dewetting on a on a flat surface. if you examine with higher magnification image, what you can see that well these droplets are not resting on a flat surface but, they are actually resting on a topographically pattern surface, and if you investigate each of these zones you again see a structure where you have tiny droplets which are occupying each interstitial location like this. So, for a thicker film you actually are able to generate a multi-length scale structure by dewetting on this type of a surface.

There are many, many more case studies which are available, I just picked up one case study to impress upon you that, well, in combination with suitable templating strategies which in this case is use of a topographically patterned or a chemically patterned surface, it becomes possible to align the dewetted structures. And there, let me tell you there has been significant work in this area to use a these type of a structures for a commercial application.

For example, these type of a structure with a functional material each one can sort of be used as a pixel for display or sample or some other application like that. So they find they had been using it been used in various type of application like microelectronics, plastic organic electronic, even in biotechnology and things like that. so this class we I give you a glimpse of how a template guided self-organization or a dewetting, let say to be more precise on a chemically or a pattern the topographical pattern surface can be used to align or impose some directionality or anisotropy to the otherwise random anisotropic dewetted structures. Thank you.