Soft Nano Technology
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Lecture - 39
Elastic Contact Instability – 1

Welcome back. Penalty met lecture of the course, most of you should be happy that this course coming to an end. Happiness can be you are getting read of something happiness can also be that you have learned something please send your feedbacks to me I will be happy to receive constructive feedback. Do not really say that this course was rubbish and I did not understand, I am expecting for something like that I have tried my level best to make you learn a new thing in simple terms. So, please be constructive in your feedback that will really help and maybe myself to design the course in future in a different way or maybe (Refer time: 01:01) lecture in a slightly different way or to even change the Interaction platform, something like that.

Anyway, coming to topic the last topic I would like to take up is another form of instability, what is known as elastic contact instability. The word elastic should remind you of elastomer because you have already seen the use of an elastomer it film in the context of replica molding and yes the film that we use in these experiments are again those Sylgard 184 film which are elastic films, these are cross link.

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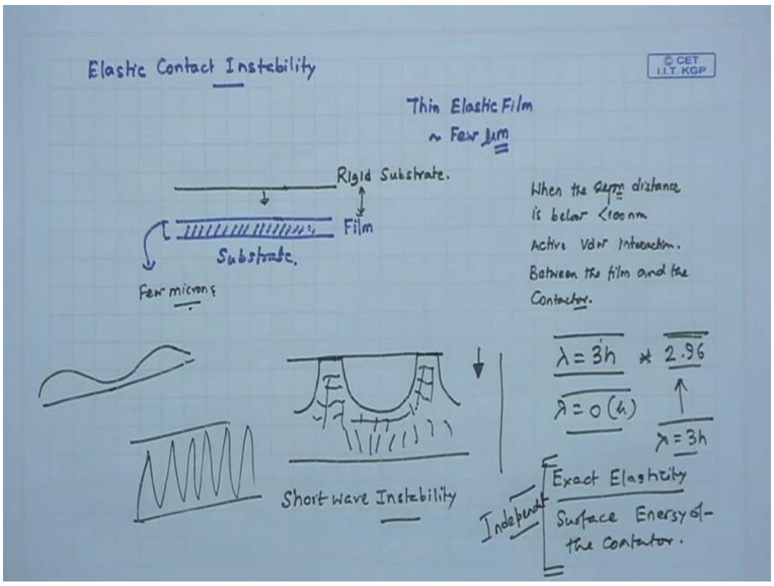

Films, so, only difference is you would like to take thin elastic films. And these films are not as thin as the films you required for deviating because as you will soon see the physics though it is triggered by the Van Der Waals forces is not due to the interfacial interactions across the two interfaces of the film. Therefore, the film thicknesses that of taken are in fact quite thin, if you compare them with the thickness of (Refer Time: 02:30) films. These are in the range of few microns. In fact, there is the problem if you go down below one micron there is in fact some problem which we will discuss.

So, what you typically do is you again take Sylgard 184, but you do not force Sylgard 184, the way you otherwise a code for let say something like we pick a molding, because that we lead to very thick films millimeter thick films. And I mentioned while I was talking about spin coating, that if you take a very viscous polymer or a material and then even if you rotate it at a very high rpm it often does not flatten out. So, spin coating even spin coating will not give you very uniform films.

So, what you typically do in order to create this films to take Sylgard 184, but you dilute it in regular solution regular solvent like an hexane or enheptane chloroform which are good solvent for Sylgard 184. Then do a spin coating of course, after you have spin coated the solvent has evaporated. In the Sylgard 184 mix is a created again by mix in part a and part b. So, write after spin coating in fact you do not have an elastic film, why? Because the part a and the part b of the cross linker has not really triggered the cross linking of the oligomer or part a.

So, this spin coded films are typically annealed in an oven let us what you typically do to cross link your film, it is an yield in an oven and then the films are ready for performing the experiments. So, look at the name it says is contact instability. So, contact with what? In fact this is the experiment of set of it is in fact you have this elastomeric film you take another rigid contactor and these two in fact, the instability manifest when the contactor comes in very close contact with the film.

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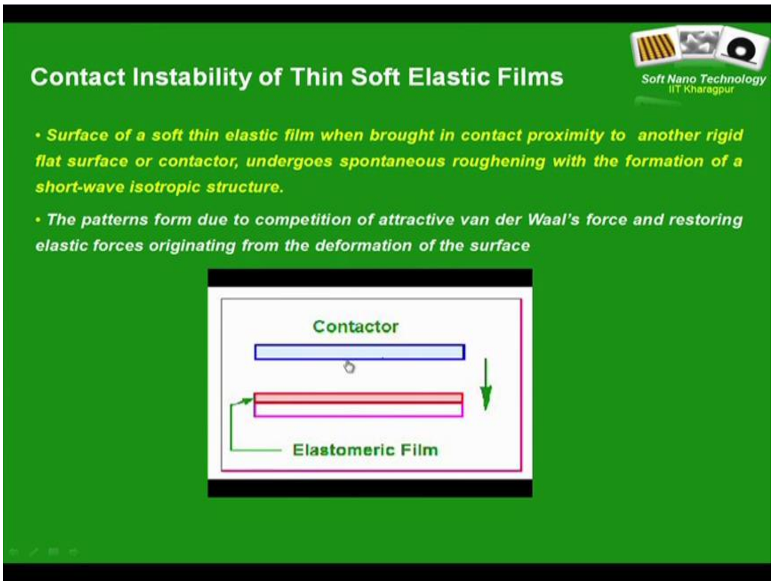

So, it is essentially a contact problem of a soft material and therefore, this instability class is very general and what happens is. So, what you have is a film which is suited on a substrate of course this film now. If you compare with what you have already learned in case of deviating there is 0 disjoining pressure or effective interface potential within the film is 0 simply because of the fact that the film is to think as I mentioned this is the film thickness is of the order of few microns.

And therefore, that is not the concerned, but issue is that you have another rigid substrate which is progressively coming in contact with to the film. I will sort of take help from use the AFM literature to use a word approach (Refer Time: 06:04).

An easiest way to describe the situation isnt it, a rigid surface is approaching a soft elastic film go to another surface. So, what is the final configuration final configuration is like if you have this film another surface is approaching it will simply touch which is fine, but please do not forget when the two come in conformal contact the separation distance is 0. Of course, in one of the settings you have where the even at contact their separation distance is not 0 it is d 0 and which is 0.158 nanometer. For all experimental purposes or all practical purposes it is quite logical to assume the separation distance to be 0.

Does it ring a bell, the question is that well indeed these two are coming in contact from a parts or a large separation distance and they come in contact, but before they come in contact the contactor and the film in fact, undergo through a separation distance where the separation distance is below 100 nanometer and does it trigger a bell and yes that is where the critical question is.

So, if you sort of a rapidly bring your contactor in contact with the film there is the possibility that you might miss out the evaluation physics, but suppose if the contactor is close enough to the film and you are bringing it very slowly then what happens is when the separation distance. Is below again the critical range of 100 nanometer; there is now active, vdw interaction Van Der Waals interaction between the film and the rigid contractor. Just the away in the context of an AFM, your tip was chosen to be a of a cantilever which soft enough to deform to Van Der Waals forces it turns out the these soft elastic films are also adequately soft and they deform subject to these Van Der Waals portions.

Now, what we are seeing, we are seeing the Van Der Waals interaction of two objects through year. There is nothing inside right and we all know that Van Der Waals interaction in air is always attractive. Therefore, the contactor in fact exerts attraction on the film surface therefore, the film surface tries to jump and go in contact with the contactor surface and analog of jump to contact. Up to this point there is no problem, but look into the material property of the film, it is not a liquid right heated beyond this class transaction temperature it is a cross link elastomer.

So, what happens is as part of the film I will just drawn an exaggerated few as path of the film jumps and comes in contact with the contactor, it leads to significant stretching of the cross link matrix and therefore, the cross link matrix on the other hand tries to pull it back. So, there is now a competition again in case of deviating we talked about a competition where the surface tension tries to try to stabilize the film and your joining pressure tried to destabilize the film. Here again this joining pressure was originating from Van Der Waals forces here again, the Van Der Waals forces are trying to destabilize the film here the only form of destabilization is destroying to come in contact quickly with the film.

However, because of the material property, because it is an elastomer, because it is a cross link film the physical cross links present within the matrix in fact tries to pull back and oppose this conformal contact or film surface moving towards the contactor, which is exerting attraction. More importantly as it sort of forms these type of contacts there is in fact significant amount of elastic stresses that remains stored within the matrix do not forget it is an elastomer and the easiest example do you remember about in elastomer is a rubber band. So, you stretch it remains stretched as long as your hands are active that means, that as long you are applying force from outside to perform this stretching it remains it stretch configuration. But the movement you withdraw the force it will restore back it is original configuration keep that in mind I will talk about that.

Of course, even after achieving this configuration if your contactor continues to come in close proximity what happens is the strength of the interaction between the substrate and the film sorry the strength of the interaction between the contactor and the film increases and therefore, you see more fraction of the film coming in contact with the contactor. I hope you have understood what I have tried to explain if not you see this cartoon once more.

So, you have a contactor which is coming in contact with flexible soft elastic film, and before they come in complete conformal contact there is a soul where the separation distance between this film and the contactor is again in the range of the hundred nanometer bracket therefore, there is active Van Der Waals interaction between the two and that leads to some sort of self organize instability structures on the film surface.

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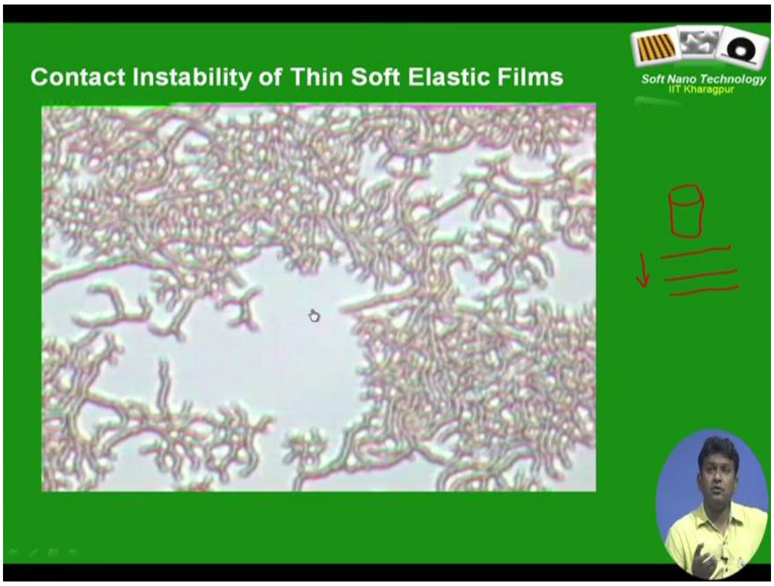

This is real time image taken under a microscope. So, what you have is again the situation we showed that here is the contactor this is coming in contact with the film and you are now observing from the top under with a microscope optical microscope. See what is there what happens. So, first what we see is that initial we had a plat film and the contactor was far away you see that some structures are appearing in the form of isolated columns and the contactor is still approaching and suddenly you see the whole area gets filled up with some structures.

And what is the nature of the structure is sort of a by continuous level in structures and I will come back to that. But if you even beyond this stage if you continue your approach, you now see that those labyrinths have transformed mostly into isolated holes. I will reap repeat this video again for your convenience see the initial stage of approach is a manifested with the formation of isolated pillars. Then this pillar transforms into bi continuous labyrinths.

See this is where the bi continuous labyrinths form and just like in deviating you did nothing, but to simply thermally anneal the film and everything was self organization here also you are doing nothing, but to bring in a rigid contactor. So, the rigid contactor in fact exerts external force to the system. So, the fundamental difference in this formal of instability with deviating type instability is in deviating the energy penalty for the system to evolve was available within the film itself in the form of excess free energy.

Here the films are takes; so therefore, there is no question of excess free energy therefore, in order to destabilize a film you need to supplies some energy from outside and that force is being exerted in the form of Van Der Waals force by the contact by the approaching contactor. Any way as the approach continuous you see a complete formation of these bi continuous labyrinths and even beyond this stage further approach in fact leads to formation of isolated holes. So, what are the things we observed?

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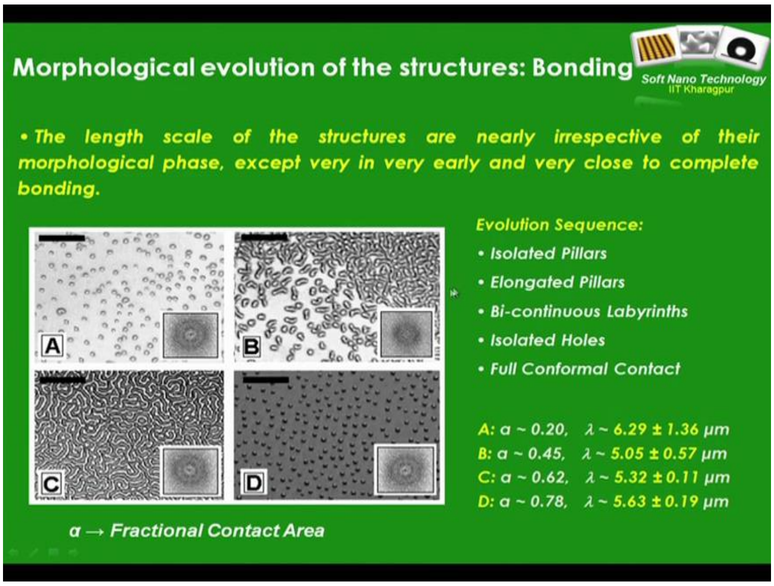

One important thing is what is related to the physical nature of the films what I mentioned that as some paths of the film in fact goes and touches the contactor the other paths sort of pull it back and that is why you saw some. So, such sort of a very closely fact patterns and that is because as some areas go in contact other areas pull down and that is related to the elastic nature of the film. And this in fact leads to undulations on the surfaces which are like this which is in clear contrast to deviating where the wave links were much higher. Therefore this form of instability is called the short wave instability.

Another important thing to realize this instability occurs entirely in the solid face there is no flow of liquid like what we saw in deviating. So, there is no flow of liquid and it is its purely solid state deformation of the completely cross linked elastic film, but there is something more to that what you see is the very fascinating aspect again from the stand point of patterning that simply by varying the inter surface separation distance you are now changing the morphology of the instability structures from pillars to some bi continuous labyrinths and eventually to some holes.

More interestingly, one observes that for a particular thickness. So, this transformation occurs as you vary the film thickness, and more interestingly one sees that within errors of course, as the film continued the substrate continues to approach the film the fractional areas goes up. More interestingly the periodicity of the structures what is periodicity here in fact the structures are random they are isotropic, but one can do an effetely and find out the periodicity of these structures from there.

The periodicities of the dominant wave length of instability of the structures are roughly the same.

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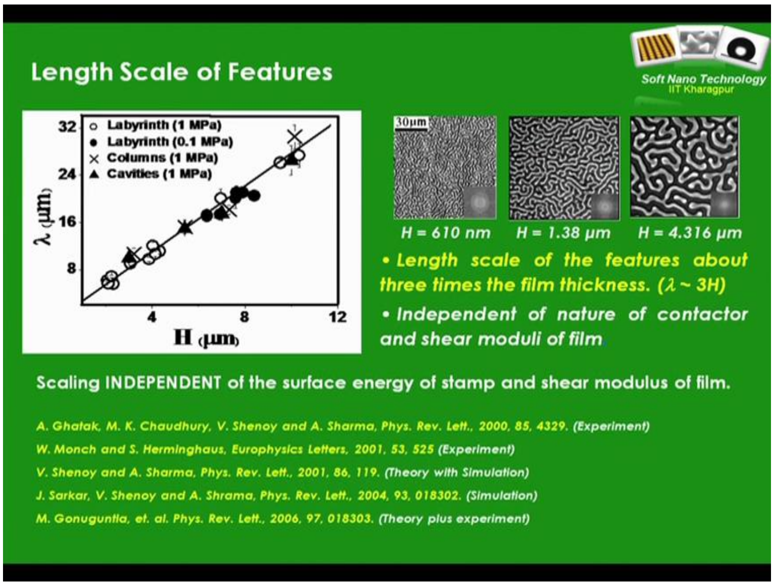

In fact, there has been significant amount of theoretical work also in this particular area and which shows for this type of instability the periodicity of the structure the dominant wave length of the structures scales as three times the film thickness, it is a shorter instability therefore, it is only. So, one can argue that lambda is of the order of film thickness and the free factor exact free factor is 2.96 which is theoretically found or it simply lambda equal to 3 h.

So, this is exactly what is shown in this particular plot. So, if you plot lambda versus h a linear scale you get a slope which corresponds two which is equal to 3. In fact, if you look into the symbols something very interesting is there and that is that this scaling relation is valid for all the morphologies. So, you have cavities columns labyrinths and more importantly it is independent of the exact elastic modulus of the film. So, you need to have a fully elastic film, but whether you have added 5 percent cross linker or 10 percent linker or 15 percent cross linker is scaling relations do not change. There is lot of very high and theoretical studies which has already taken place, but which I will not include for discussion here.

So, we will understand that if you have any elastic film which is coming in contact with a rigid surface you see morphological evaluation. That is one part of it and the evaluation is in the form of let us a pillar then bi continuous labyrinths and then eventually holes. More importantly not only it does not depend on the exact elasticity of the film, it also is independent of the surface energy of the contactor independent. So, these three pictures in fact tell you something interesting. So, you generate morphology remains the same you vary the initial film thickness you again see this labyrinths, but what you see the width and the periodicity of the labyrinths of simply gone up.

So, you can create bigger and smaller structures by simply varying the film thickness, but again the problem is these structures are random and therefore, from the stand point of patterning they have virtually no application. Where is in factor additional complexity, the complexity is when I gave you the example of a rubber band that is this after all an elastic film.

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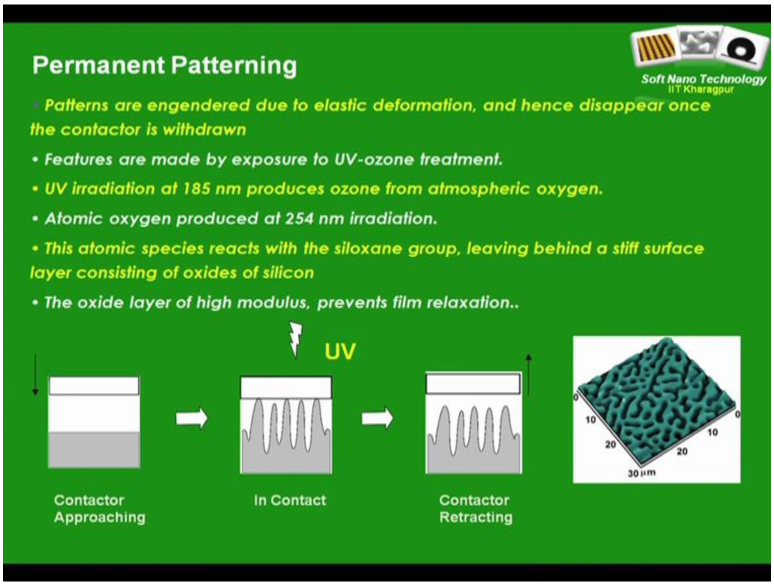

So, when it is in proximal continuity in contact proximity of the contactor of course, you see these structures right, but when the contactor is withdrawn because if you would like to use these patterns for some other application. Let say for fabrication of hydrochloric surfaces or something like that when the contactor is withdrawn it is in elastic film. So, the deformation that has been cost at the surface it is stored in the form of elastic deformation of the matrix.

So, simply as the contactor is withdrawn the film will revert back to it is Initial flat morphology and therefore, one must understand that the instability contact instability structures a transit. So, that is in fact one of the hindrance as for using this form of instability or making some permanent structures, but that also opens avenue for me to just mention briefly one more thing. So, here you see that these three sorts of cartoons or snapshots gives you an idea that the film the contactor is approaching the film it is in contact and you now know that depending on the separation distance which you may control. In fact, the morphology will be either pillars or bi continuous labyrinths or whatever.

You know that this approach sequence the morphology changes. So, very a pertinent question to ask at this point is, is there a morphology transition during the de bonding sequence also, like while we approached we saw initially the pillars came then the bi continuous labyrinths came then the wholes came then the eventually the two came incomplete conformal contact. Question to ask is during de bounding does it happened like that or something else happens or they simply detach and it turns out in de bonding one sees an exact opposite so, this an important observation. One observes exact opposite sequence during debonding.

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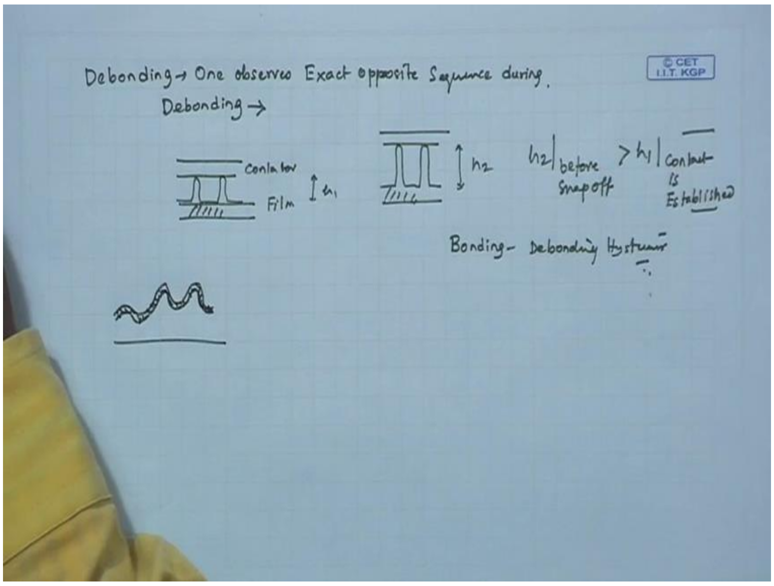

More importantly, since the wholes first then the labyrinths then the pillars, but most interestingly in fact there is hysteresis. So, the separation distance at which the two comes in contact if this is the separation distance. So, this is the contactor and this is the film where the first contact is established during debonding one observes that films are sort of stretched before they snap off. So, h 2 before snap off is greater than h 1 at which contact is established. So that is there, in fact this is what is referred to as the bonding debonding hysteresis.

Anyway, if one wants to use this technique as some sort of patterning technique the first necessary condition is to somehow feed the structures and there one can. In fact it helps of bit of chemistry because this is pdms polydide methyl syloxense. So, it contains the siosio backbone. So, it turns out that if UV light is shined on this particular film a thin layer of oxides of silicon. In fact, form over the film surface and that is steep enough that prevents the relaxation of the film and therefore, you can make the patterns permanent, and as you can make the pattern permanent and remove the contactor you can that is evident because now you can do an AFM stamp, because in presence of the contactor of course, you cannot do an AFM stamp.

So, one of the problems one of the limiting factors what sort of problem in utilizing. This technique as a viable patterning technique is eliminated that you can make the patterns permanent. What is a second problem? Second problem is obviously the structures are random, and therefore can something be done to make the structures alien. So, here the destabilizing field is in fact the contactor. So, it is very logical to assume that if one takes a pattern contactor.

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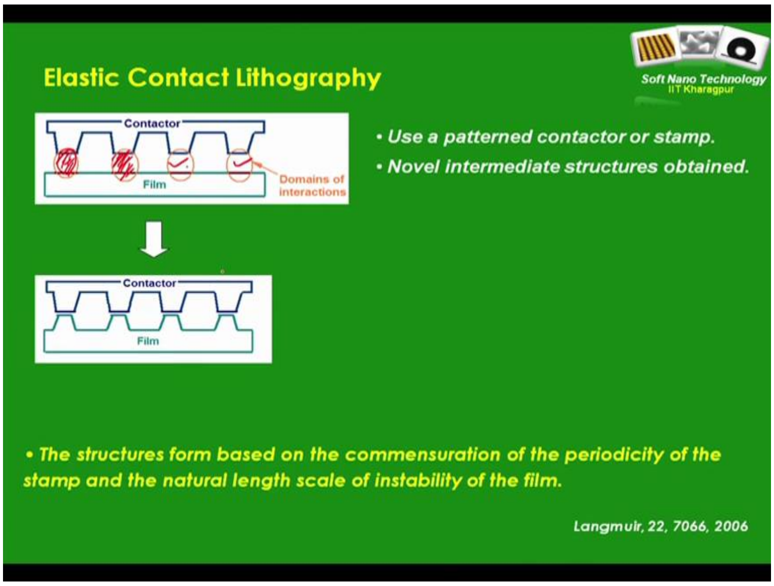

So, the pattern let say the contactor itself let say is in the form of aggregating, then one would typically expect that areas of the film. Below the stamp protrusions will exert so, there can be a separation distance where areas of the film below the stamp protrusion would exert some force or the Van Der Waals force over these areas will be active and in other area as the Van Der Waals force should not be active. And it is therefore, logical to sort of expect that one can in the process get a positive replica.

Well, it turns out that indeed the elastic instability patterns can be aligned in this approach, but one gets something much more novel and much more exhorting then a positive replica and that is what exactly what I will discuss in the last lecture of this course.

Thank you.