Chemical Engineering Principle of C V D Processes
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Lecture No 05
Introduction to CVD Films

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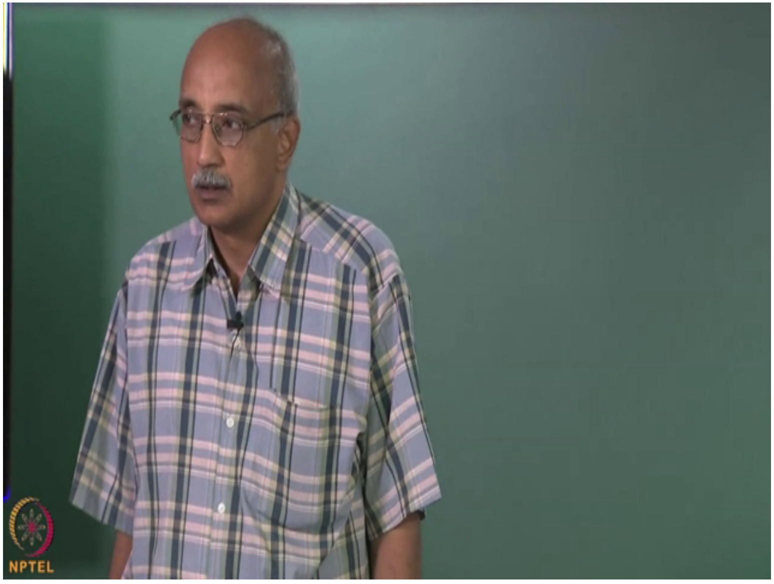

Good afternoon. So let us continue with our discussion of C V D processes. In the last couple of lectures we had talked about the thermodynamic and transport aspects of C V D film formation and so we will now discuss in some detail, aspects about the structure of C V D films and their properties, probably in the next couple of lectures and then we will talk about methods of measurements that are used to characterize these properties of C V D films.

Before we do that, one quick correction. I think in the last lecture I was talking about the formula for the boundary layer thickness. I do not know if you caught it or not, but I think I made a mistake. The boundary layer thickness is 5 times square root of, it should be nu times x divided by nu infinity where nu is the kinematic viscosity and

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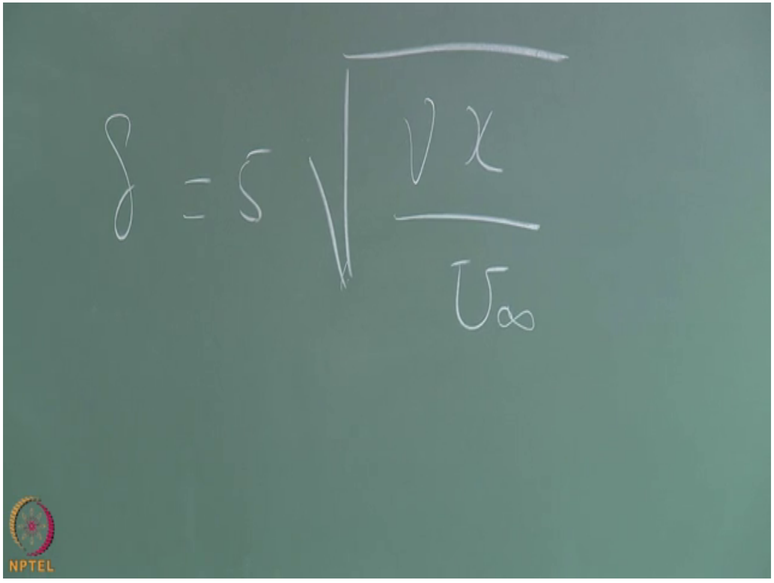

$$\delta = 5\sqrt{\frac{\nu x}{U_\infty}}$$

x is the downstream distance and u infinity is the approach velocity.

I believe I had not written it correctly, so just make this correction. Dimensionally it checks out and also the thing that bothered me even the other day at the back of my mind is that, as the velocity increases the boundary layer thickness should decrease. So this formula has the right qualitative dependence and so just make this correction in your notes.

Ok, so talking about C V D films and structures, again there are two ways in which we can classify C V D films. The first is based on their functionality and second is based on their actual structure. Now based on functionality, C V D films can be simply classified as semiconductors, conductors and insulators or dielectrics. All three kinds of films can be formed on surfaces and the substrate itself can be conducting or insulating or semiconducting.

Now in terms of structure as we have briefly stated earlier, the three types of C V D film structures that you can achieve are the amorphous structure, the polycrystalline structure and the crystalline or the single crystal structure. Basically as you go from amorphous to polycrystalline to single crystal, the order of the structure keeps increasing and you get a very precise crystalline structure when you talk of single crystal films where as an amorphous film can have a very little structure essentially. And there are ways in which you can control the C V D process to achieve these films and we will talk about that a little bit.

The other aspects of C V D films that we need to be aware of is the actual sequence in which they form. When you deposit a C V D film on the surface, it does not immediately form as a smooth, continuous, uniform film.

There are actually four stages in the formation of a C V D film and these are, first you have a nucleation step.

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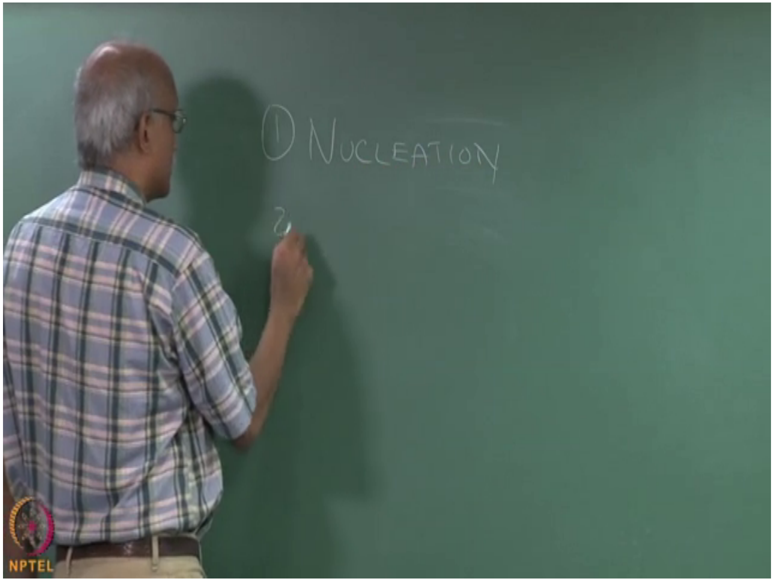

The second stage is called nucleary growth.

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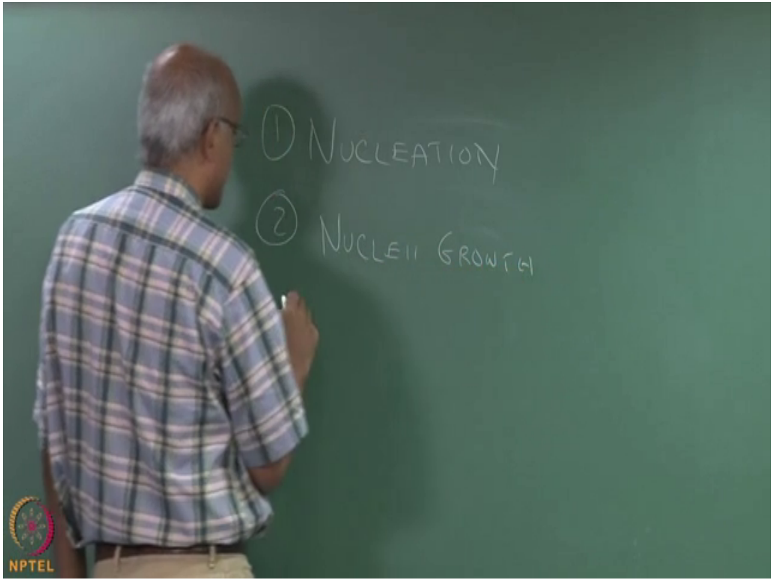

The third stage is called island coalescence

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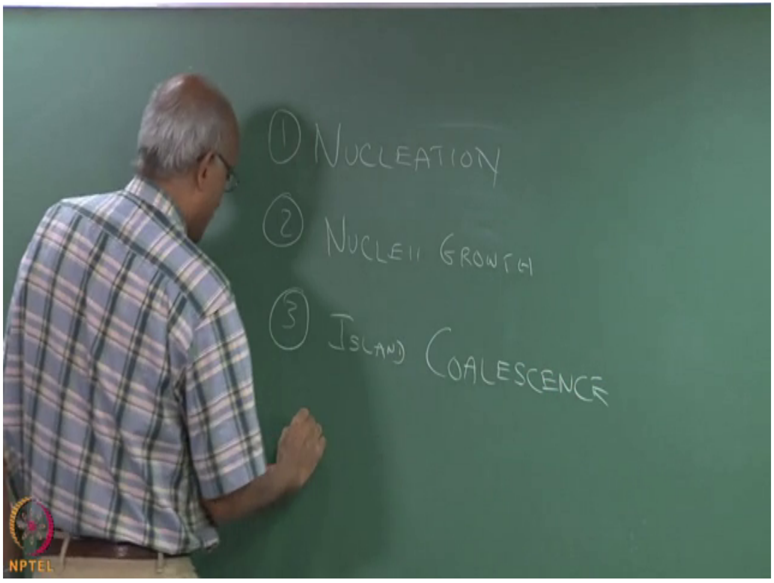

and fourth and final stage is where bulk film forms.

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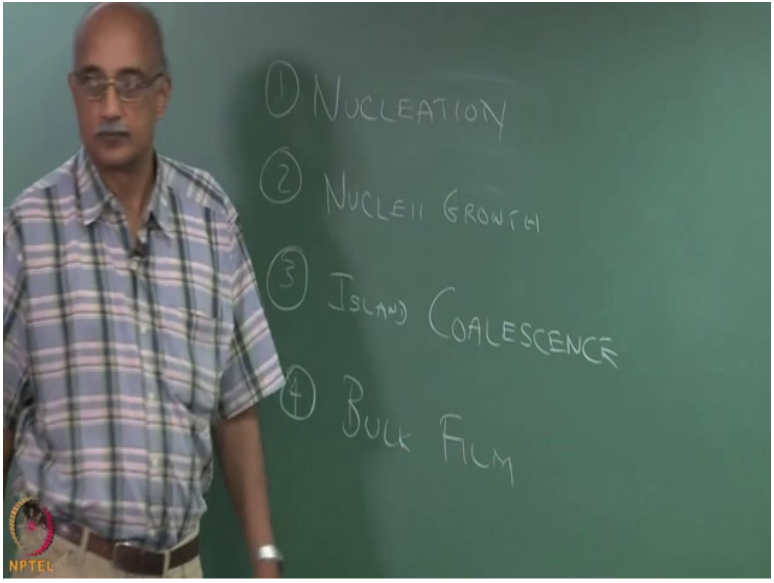

As the name suggests, initially what you form are these isolated nuclei on the substrate which happens essentially

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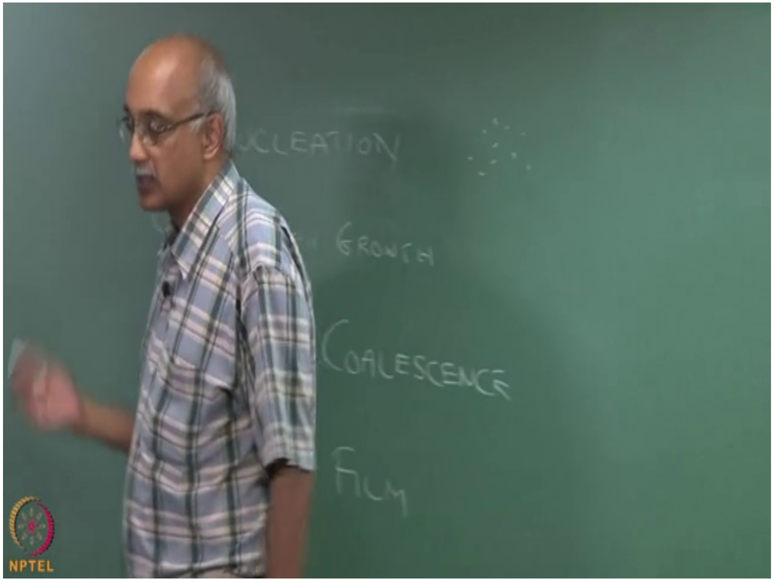

because of heterogeneous nucleation as the vapor phase comes in contact with the energized solid substrate. These nuclei are likely to be the order of a few Angstroms or tens of Angstroms. As more deposition happens, eventually these nuclei start to become larger

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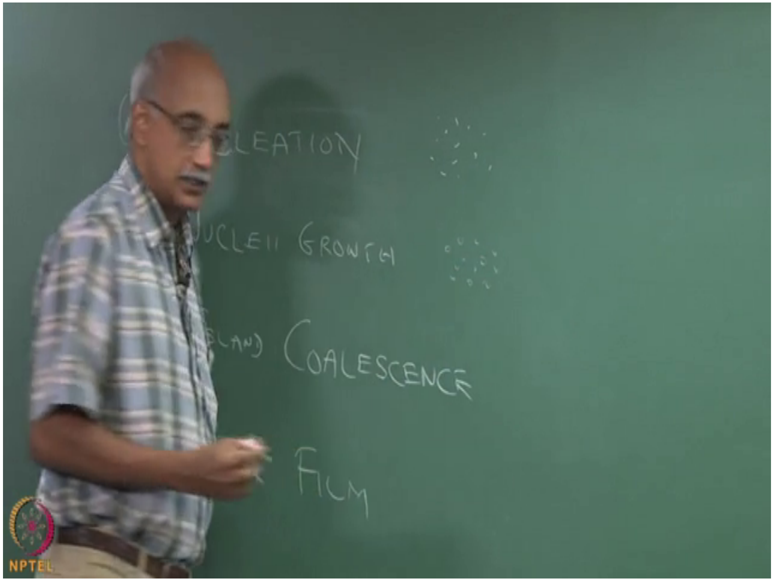

as they absorb more vapors that are depositing on to the surface.

So that is the second stage. It is a transition stage where you have not still really formed the film. These are still isolated locations where the condensate exists. The third stage, island coalescence is where a few of these start finding each other as they grow large enough and forming these islands

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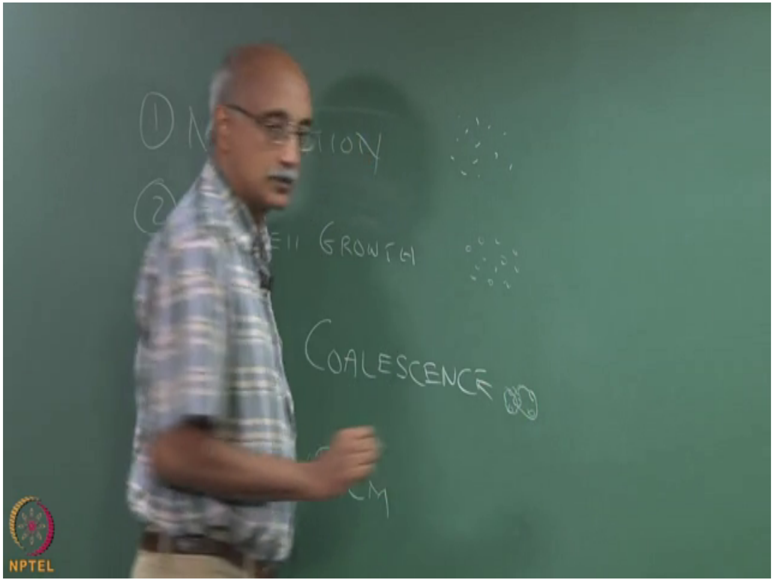

which is still not a continuous film but now you are starting to form clusters of molecules attaching together to form these isolated and very, very short films. Finally the bulk film stage is where these islands start to

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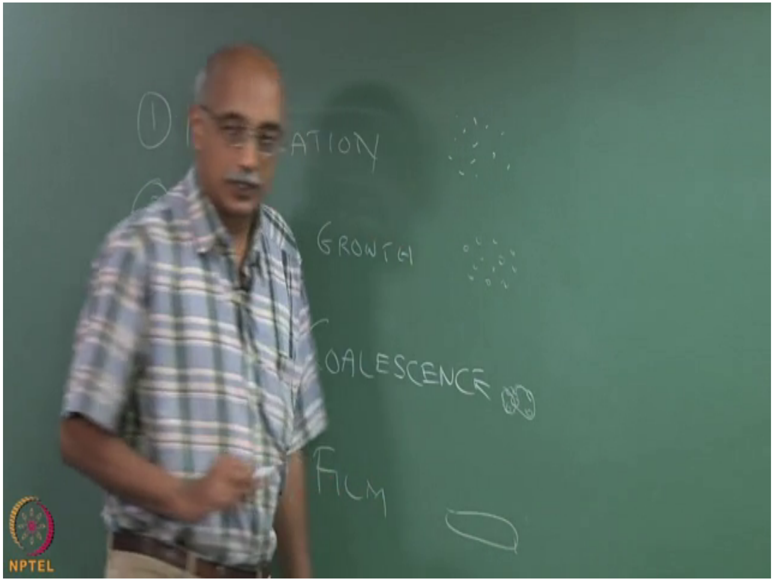

coalesce together and they eventually bind up with the nice, continuous, contiguous film.

Now if you look at what is happening at each of these stages, and what are the barriers, the first stage nucleation is actually pretty much controlled by the vapor phase processes, the transport processes that bring the molecule to the surface as well as the heterogeneous equilibrium at the solid surface.

Does this surface promote the formation of these initial nuclei? So that very much depends upon whether the surface is sufficiently energized to promote the formation of the nuclei. If the surface energy conditions are such that the formation of these nuclei is thermodynamically and kinetically favored then these first droplets will start appearing on the surface.

But at that stage it is not a stable film. These nuclei are just as capable of reversing and re-evaporating. The second stage of nuclei growth happens when there is sustained arrival of vapors on to the substrate. So you need to have a vapor deposition rate that is sufficient and sustained so that the droplets do not re-evaporate and enter the vapor phase but rather more and more material accumulates on the surfaces of the nucleated droplets and the droplets start growing.

The third stage actually requires that these droplets kind of find them, find each other. So they have to be sufficiently mobile on the surface so that they can find the nearest neighbor, get attracted to the nearest neighbor and form these so-called islands or clusters. What that requires is that surface diffusion processes must also be promoted by the prevailing conditions of the substrate.

Again it is primarily an energy issue. If the molecules are sufficiently energized when they strike the surface, they will have a tendency to migrate on the surface. And eventually they will find each other and form a continuous film.

On the other hand, if as the molecules arrive on the surface they are not at a sufficiently high energy state to be able to move around on the surface, they may never find the nearest neighbor. So the isolated nuclei may stay as isolated nuclei.

So at the third stage, the propensity of the surface to allow migration becomes important. And finally the fourth stage is actually what you see as a product, the continuous film. Some of the other properties of the substrate that play a role in this are, for example surface energy, hydrophobicity, hydrophilicity.

Does the surface accommodate the arriving material and allow it to form droplets? For example if you have a very low surface energy surface it will actually repel arriving molecules. Nothing will stick. You know, you remember the sticking coefficient we talked about. The sticking coefficient is the direct, has the direct dependency on surface energy.

The higher the surface energy, the greater will be the sticking coefficient. If you have an extremely low energy surface, for example if you try to do C V D on Teflon, very difficult to make it happen unless you pre-energize the Teflon by bombarding it with plasma or ions or laser or something.

But as it is, Teflon is an example of very low surface energy surface which will not easily accommodate arriving vapor molecules. So surface energy, wettability of the surface, how easy is it to form a continuous film on the surface or is it going to keep breaking up. So even if you get passed stage 3 and you are trying to get to stage 4,

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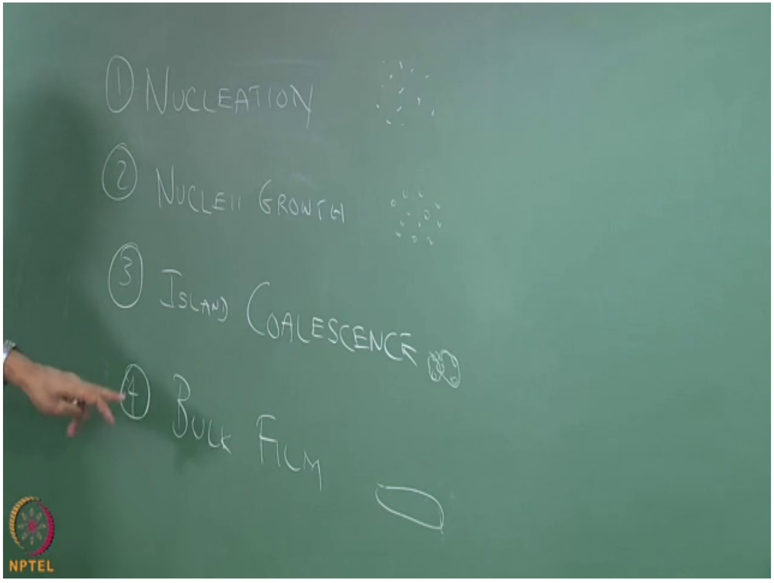

is this transition again thermodynamically favored?

So there are lot of issues that affect each of these steps in the process and you really have to, in order to get a nice smooth, continuous C V D film on the surface what this points out is there are several aspects of not only the gas phase but also the solid substrate that also must be controlled and optimized in order to, in order to make this happen.

But suppose we have succeeded in making a C V D film on the surface then we have to start looking at the properties of the C V D film and whether they satisfy our specifications, our requirements. So when we talk about C V D film properties we can actually classify them

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into two categories. One is functional and the other is physico-chemical.

Of course the

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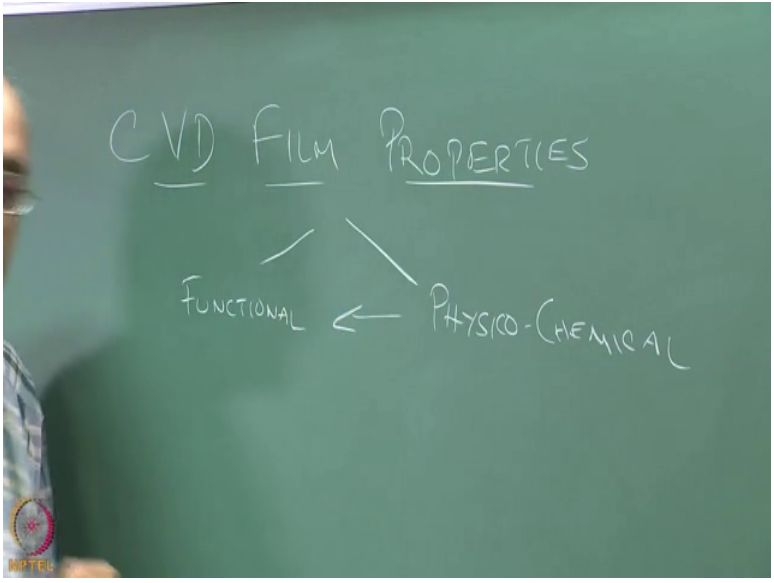

physico-chemical properties of the film actually deliver its functional properties. So there is a linkage between the two but when you deposit a film as a product what we are really interested in is the functional properties. Does it do the job it is supposed to do?

If you have deposited the C V D film in order to achieve a certain conductivity, let us say, have you achieved that conductivity? Or if you have deposited the film to achieve a certain hardness on a surface, you know, if it is a coating for example, have you achieved that hardness? So the functional properties vary depending on the application.

For every application that you have there is a specific property or more of the C V D film that is appropriate. So from a producer viewpoint and from a consumer viewpoint these functional measurements are the most relevant. Because they basically decide the quality of the film that you are receiving.

However in order to achieve that quality, in order to achieve that functional value what we do is we try to control these in order that, that happens. So

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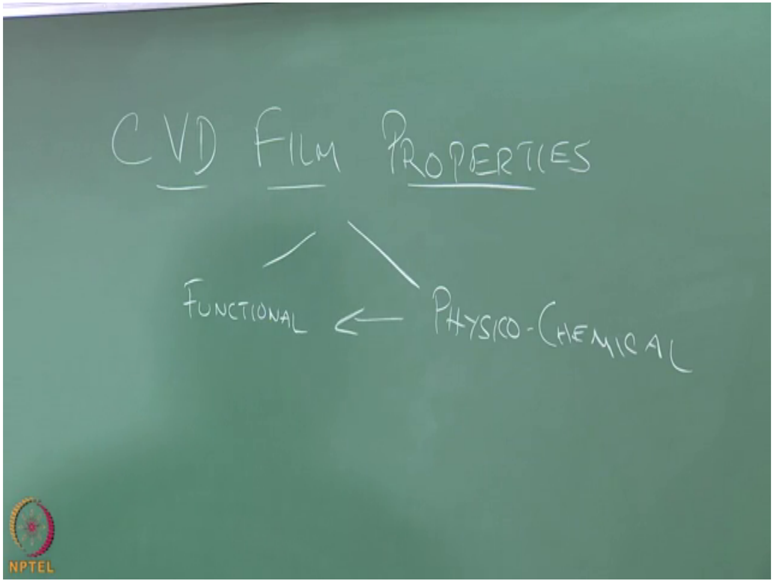

our direct controls are on these properties whereas our direct effect is based on the functional properties of the film that, that we are achieving. So what are some of the physical, chemical properties of the film that are important?

Obviously the thickness

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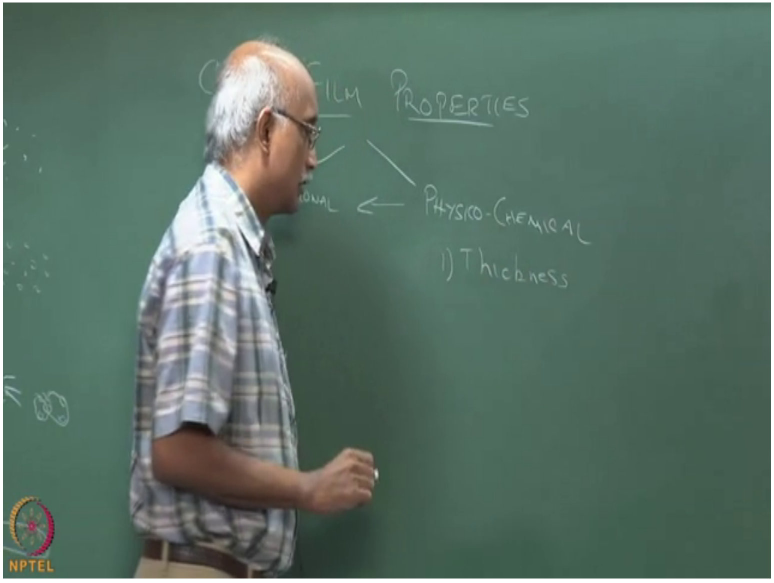

and related to that the deposition rate,

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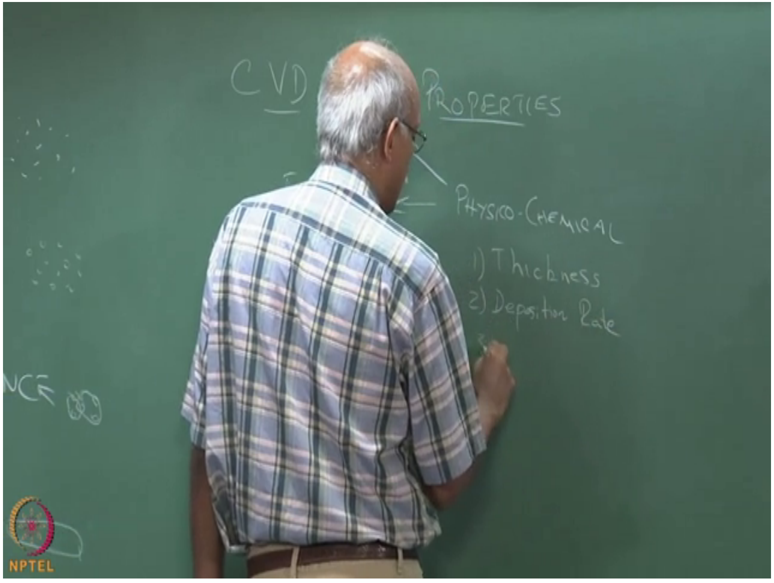

uniformity,

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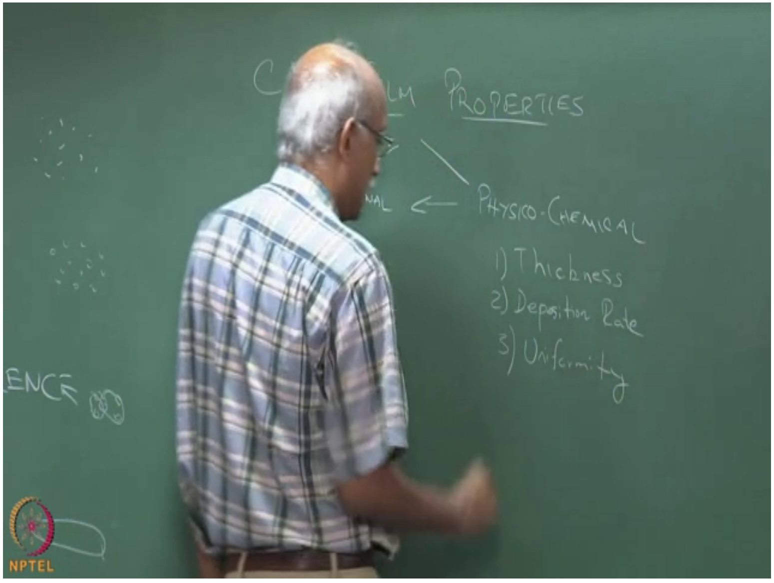

and composition. These are what

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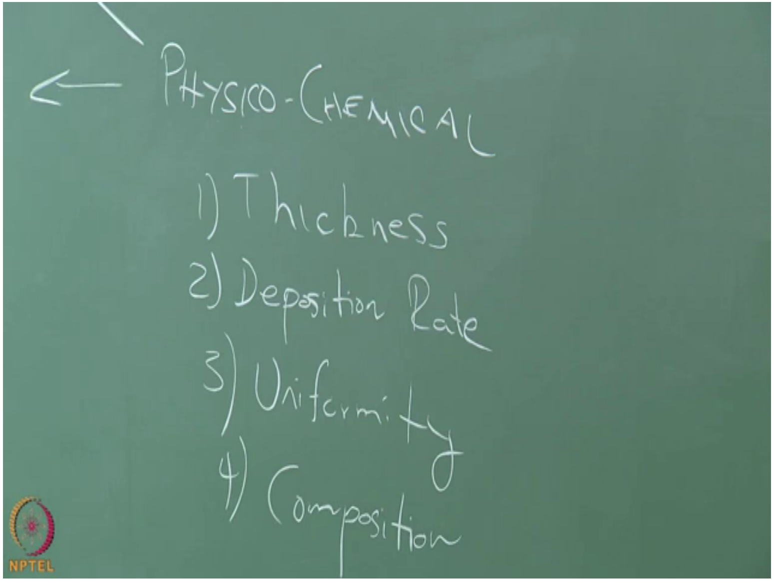

I would call first order effects. When you are designing a C V D process these are the parameters that you focus on right away and try to set some specifications, what is the thickness range you want to have, what is the rate at which you want the film to be forming, what is your specification on the uniformity, do you need plus or minus 1 nanometer variation or do you need plus or minus 1 micrometer variation over the surface. And the composition, what exactly should be the chemical state of the film that you are depositing on the surface.

Now if you look at these, we will talk in the next few classes about how to measure these things but thickness of the film is obviously related to the deposition rate. Essentially higher the deposition rate, the greater is going to be the thickness.

Uniformity on the other hand is not necessarily dependent on the deposition rate. You can have a very high deposition rate but the uniformity may not be very good unless you have tight controls over how the substrate itself is prepared and presented to the C V D process.

For example, if your substrate is, has a lot of impurities on it, contaminants on it; that can affect the uniformity of your deposition process. So depending on the local level of contamination on the surface you may get a completely different type of film, different thickness, different deposition rate and also it may depend on the features on your substrate.

If you have a very flat and plain surface, the uniformity may be very good but if you have a rough surface or one that has lot of contours, the uniformity may be more difficult to achieve. So uniformity actually provides a connect between the process of deposition and the process of film formation on the surface.

So related to the uniformity is what we call the step coverage. If your substrate has certain features on it, particularly steps how well is the C V D film able to follow this step structure and provide uniform coating thickness everywhere. So this step coverage is another important parameter when we are trying to characterize a C V D process.

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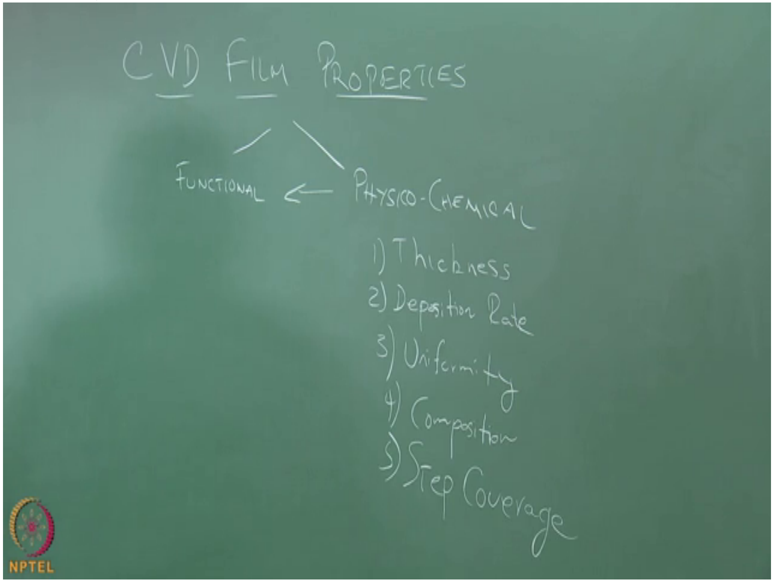

CVD FILM PROPERTIES

FUNCTIONAL ← PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage

What are some of the other parameters that, that could be important? And by the way, when we talk about composition the reason it is important is obviously because the composition decides the functionality. If you are trying to deposit a semiconductor, you want to see a semiconductor, silicon. You don't want to see silicon oxide, right which is a dielectric. So controlling the composition is very important but the composition is very sensitive to the process of C V D.

For example, if you are trying to deposit silicon from silane and if you are using hydrogen as a carrier gas, if an excess of hydrogen actually gets absorbed on the silicon, then you don't get the crystalline structure of silicon. You start getting amorphous silicon or polycrystalline silicon.

Or in other cases for example, if you have some impurity that enters your C V D reactor, for example oxygen is frequently an impurity in C V D systems, because unless your C V D reactor is hermetically sealed, it is very difficult to prevent air from seeping in which is mainly O 2 and N 2. N 2 is relatively inert so usually does not bother us. But oxygen, if it seeps in, can certainly affect the composition of your deposit.

Another one is water. Very, very difficult to get, keep moisture out of C V D chambers. So oxygen and H 2 O are frequently contaminants that will enter your C V D system.

Now so what can happen in that case is instead of silicon semiconductor films, you may start forming silicon oxide, right, or in case where the nitrogen gets adsorbed you can even form silicon nitride type of films which are clearly what you don't want.

So the composition is a very important parameter to monitor and maintain records of, because it is an indicator of whether your system is performing as it is designed or you are having impurities and contaminants enter the system. And even in cases where you are trying to make an oxide film, suppose your C V D film could be S i O 2, even then the amount of gases can play a big role.

For example you want a stoichometric S i O 2 but if you have an excess of O 2 in your system you may form some S i x O y where the ratio of oxygen to silicon is higher than stoichometric ratio. In which case the film which you deposit will not have the properties that you are looking for. So the composition of the film has to be monitored because it will give you a very sensitive indication of the functionality of the film.

So composition is one that we need to keep our eye on. So what are some of the other properties? Grain size. Particularly when the durability or integrity of the film is very strict requirement, the grain size plays a huge role.

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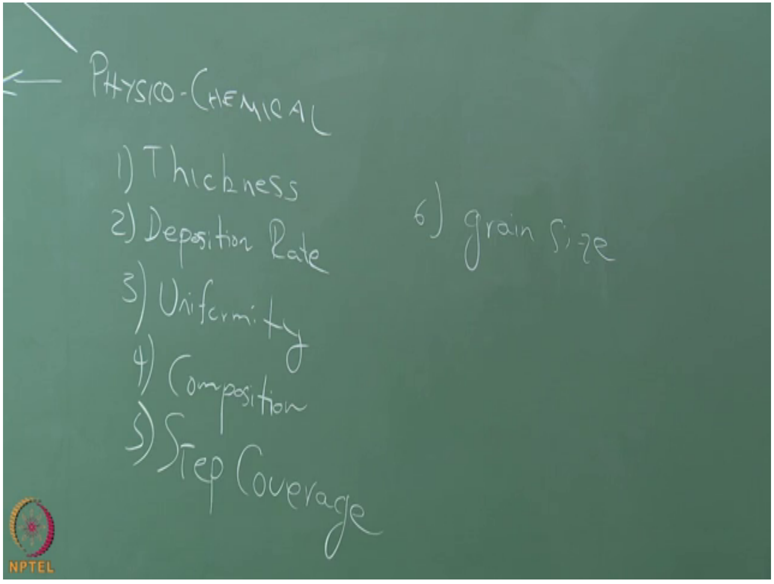

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size

You want to, in C V D process achieve as finer grain size as possible, mostly. So you have to have some control over the grain size that you are achieving.

Now grain size is also related to the stress level on the film.

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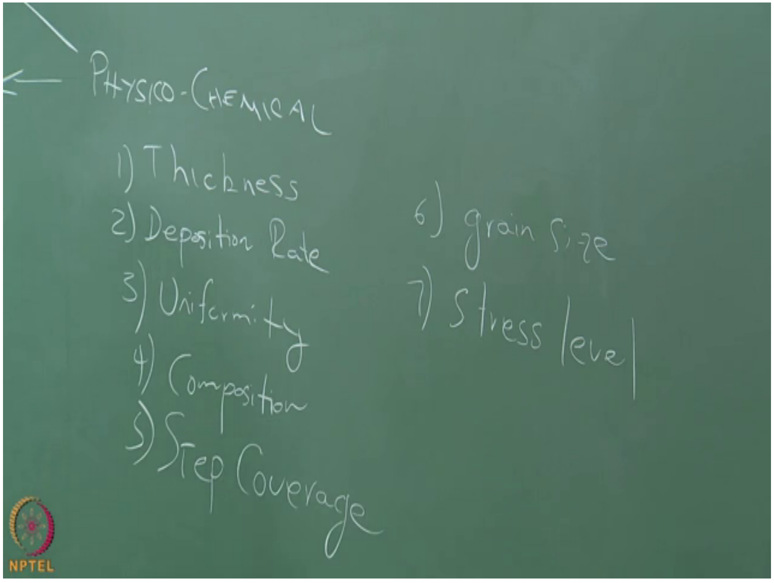

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level

When a film is subject to compressive or tensile stress, it can crack. So the susceptibility of a film to cracking or other types of stress-related disorders is very important to characterize as well.

Now what controls the stress level again is the grain size. The coarser the grain, the more likely it is that the film will be affected by various stresses that are present on the surface. A fine grained structure enables a much more robust film to be realized on the surface.

Other things that may be of importance are smoothness or roughness of the film. When you do a morphology

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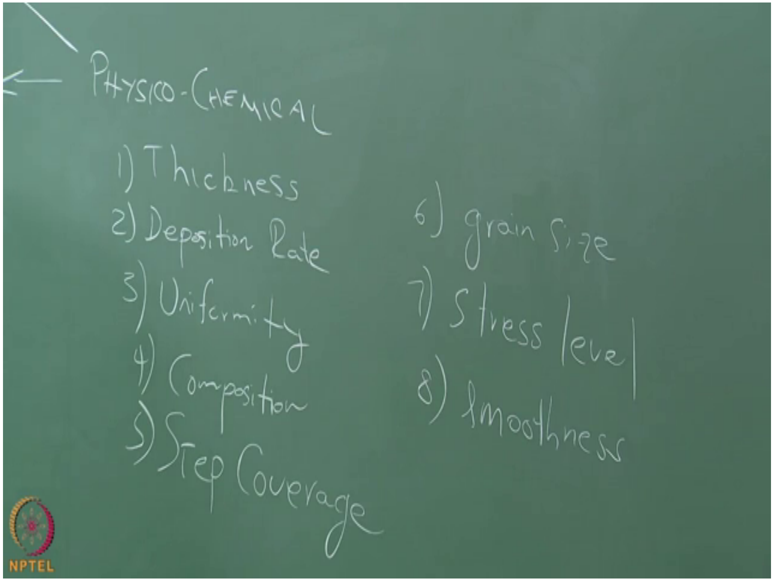

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level
8) Smoothness

characterization in 3 dimensions your requirement may be that the third dimension which is the surface roughness profile cannot exceed a certain value.

You may have a fairly tight standards on how smooth the film should be, in which case we have to use a technique like A F M to understand not only the two dimensional structure but the three dimensional structure of the film and ensure that the film roughness is below the specifications that, that we need for, for that particular product.

What else? I mean obviously things like hardness, density. Actually another parameter that

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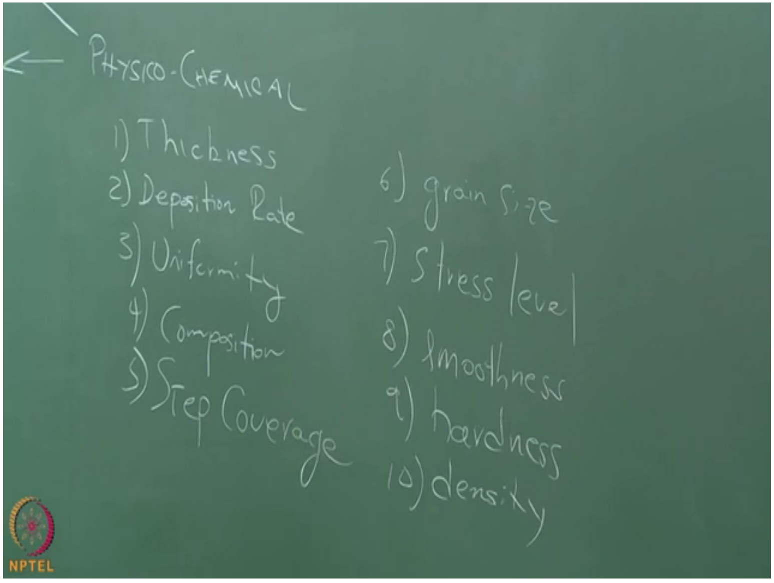

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level
8) smoothness
9) hardness
10) density

is frequently measured on C V D films is called the etch rate. So what is done here is, is

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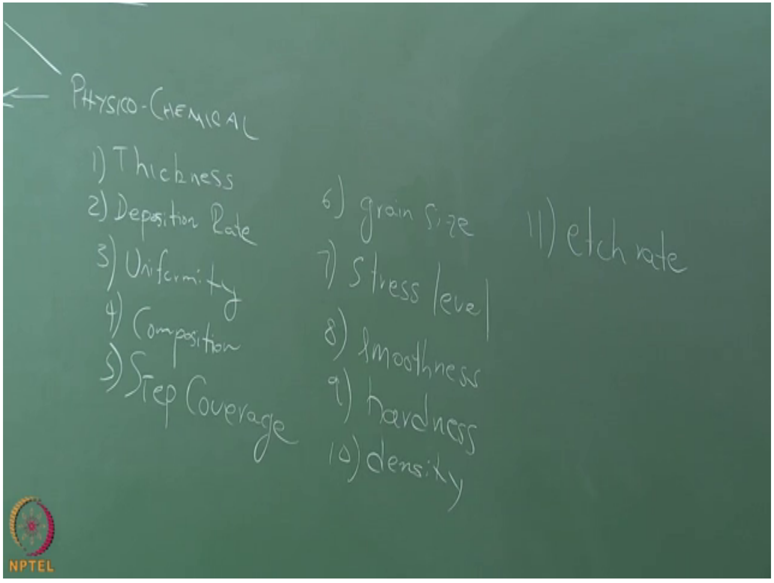

PHYSICO-CHEMICAL
1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level
8) smoothness
9) hardness
10) density
11) etch rate

take the film and expose it to hydrofluoric acid. And you measure the rate at which the film is being etched by hydrofluoric acid of certain concentration.

The rate of etch of the film is a very good indicator of how well integrated the film is on the surface. So essentially, higher the etch rate, the less strongly adhered the film is to the surface. So typically for any C V D film, depending on the application there will be a specification on the allowable etch rate. So the conditions will be specified, what acid to use, what concentration to be used it at, how much time to be allowed for the etching and then there will be a value given as to what is the maximum allowable etch rate. So that is another very sensitive parameter of that, that reflects the quality of the C V D film particularly in terms of surface integrity and so on.

And in fact another parameter that we need to look at is purity and integrity. Purity is essentially the level or

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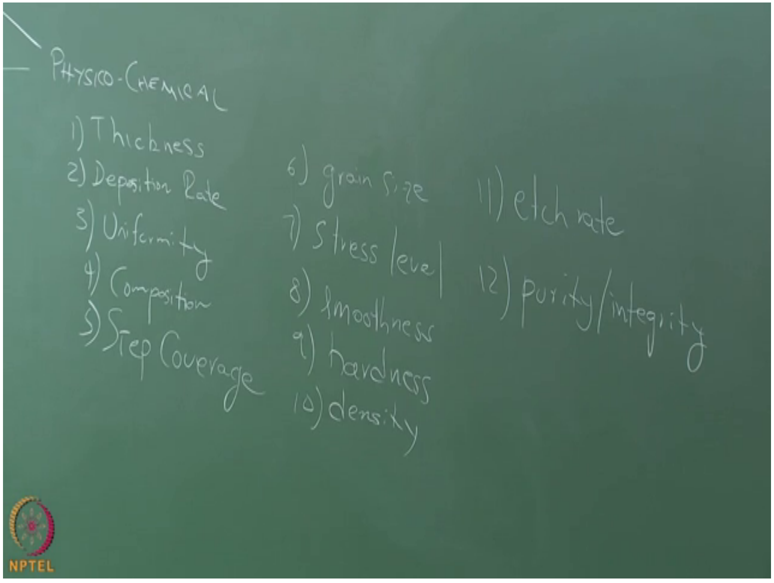

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level
8) smoothness
9) hardness
10) density
11) etch rate
12) purity/integrity

the concentrations of impurities in the film. Integrity refers to how that purity changes as a function of the depth of the film.

So in other words, if you slice the film and you looked at the impurity levels at each cross-section, the purity typically refers to the outermost layer. Integrity is the reflection of how well the impurities are contained throughout the thickness of the film.

That is in terms of compositional or chemical integrity. Similarly you can also talk about physical integrity where some of the parameters that we are talking about like hardness and

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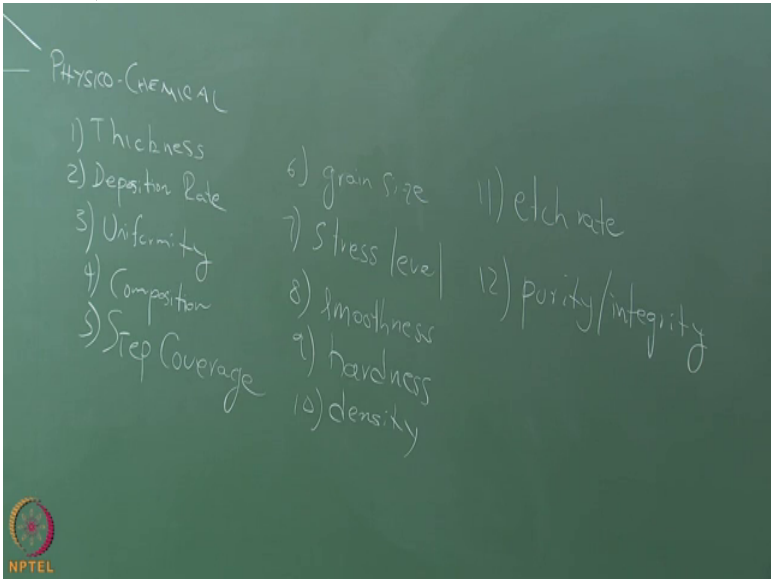

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level
8) smoothness
9) hardness
10) density
11) etch rate
12) purity/integrity

density and so on, you can similarly slice the film and ensure that these values are maintained not only at the outermost layer of the surface but throughout the bulk film, Ok.

So these are just the examples. There are many, many parameters you can measure. There is refractive index and in fact the thickness of a C V D film is measured using its refractive properties and, so the refractive index is another one that is fairly high on the list of parameters that are measured.

And of course there are many other properties

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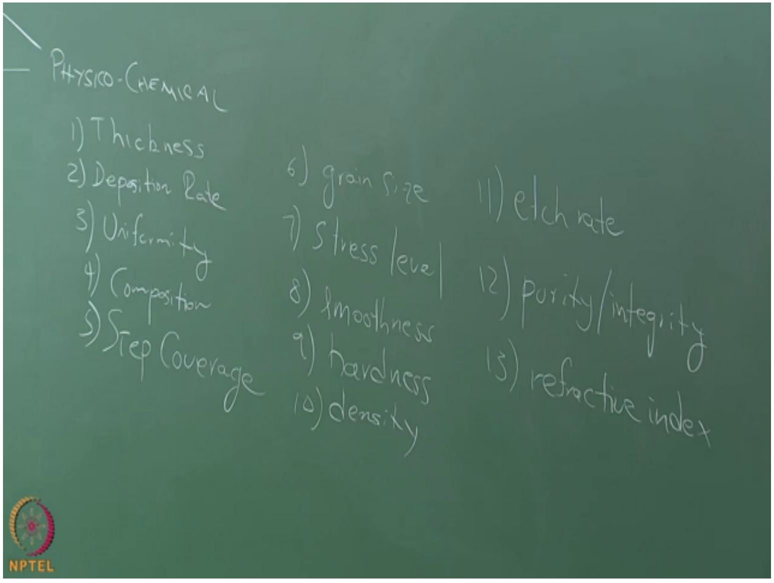

PHYSICO-CHEMICAL

1) Thickness
2) Deposition Rate
3) Uniformity
4) Composition
5) Step Coverage
6) grain size
7) Stress level
8) smoothness
9) hardness
10) density
11) etch rate
12) purity/integrity
13) refractive index

such as depth and width profiling of the film, its ability to follow corners. So the number of measurements you can do to characterize the film in terms of physical, chemical properties is very large.

Now the reason that you want to do that, I mean when we talk about functional properties as well as mentioning these could be simply, electrical, mechanical and so on. These measurements are

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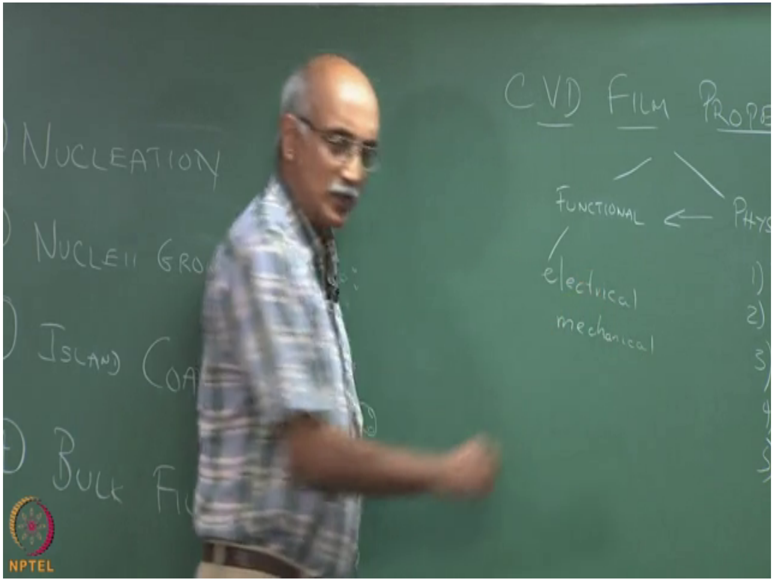

actually much easier, usually. I mean all you need to do to measure the conductivity of film is to use the conductivity meter and measure its conductivity, right?

And similarly mechanical properties. If you want to measure its, for example its coating strength or whatever you expose the surface with the film to high temperature, high humidity environments and see if corrosion happens. If it does not, then your coating is good.

So the functional measurements are actually easier to do. But the property measurements, the physico- chemical property measurements are important when you are first designing the process. When you are first setting up the process, you have to do the whole battery of tests in order to ensure that the process is set up the way it should be.

But once the process is stable and running, you do not need to do all these tests on a daily basis. What you would typically do for day-to-day quality control is do a functional test and then some subset of this, for example thickness is measured on a daily basis.

But deposition rate is not. Composition is not because once you have set up a system, you do not expect composition to change on a daily basis. You will probably do a check, say on a monthly basis just to make sure that some impurity has not entered into your system but typically if the composition has changed, it will show up in your electrical or mechanical measurements. So you do not worry about it too much.

So of all these tests, the one that would be done most frequently would be the thickness and the etch rate test and uniformity will, of course, be looked at as a part of the thickness measurements. So essentially when you do the thickness measurement, you do not do it at just one place, you randomly select several locations on your substrate and measure the film thickness and that gives you an idea about how uniform the film is, Ok.

So we have taken a brief look at some of the properties of C V D films and as I said in couple of lectures down the road, we will talk in more detail about how to measure these properties. Let us switch gears now and again talk about the different types of films, particularly the single crystal films versus the polycrystalline versus amorphous.

We want to really focus on what are the different characteristics of these films, how do they differ and what is common between them.

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So single crystal films are also known as,

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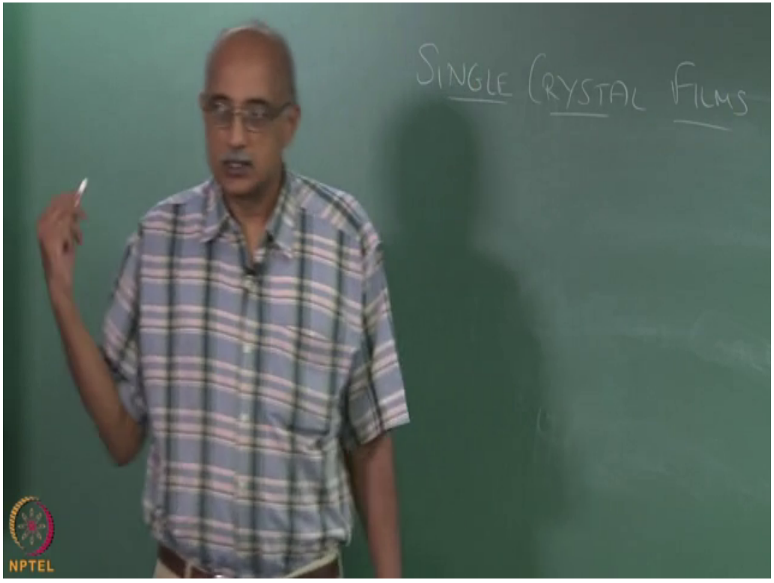

does anybody know the other name for single crystal films, that is actually a Greek name; they are also called epitaxial films.

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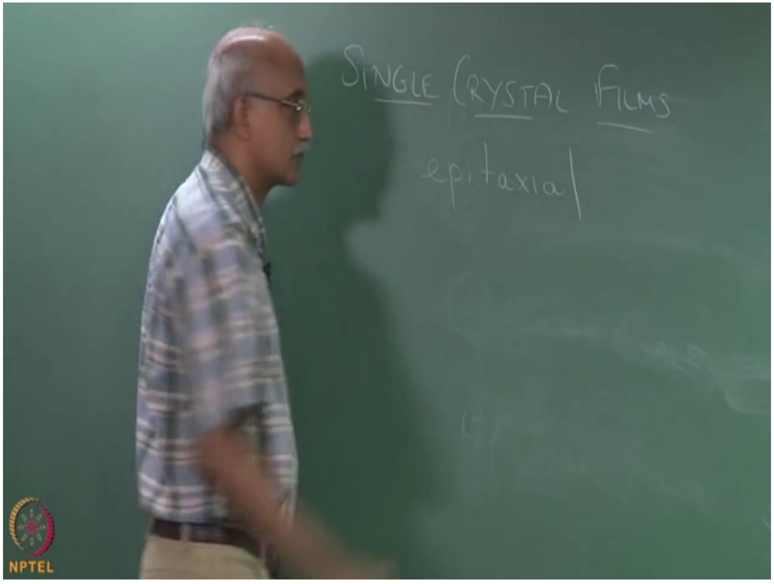

Epitaxial in Greek literally means arranged upon. So basically that is what it is. In an epitaxial film, you are taking the arriving material and arranging it on the substrate in such a way that you have a very precise, crystalline structure at the end of the process.

The most commonly realized film using epitaxial C V D is silicon,

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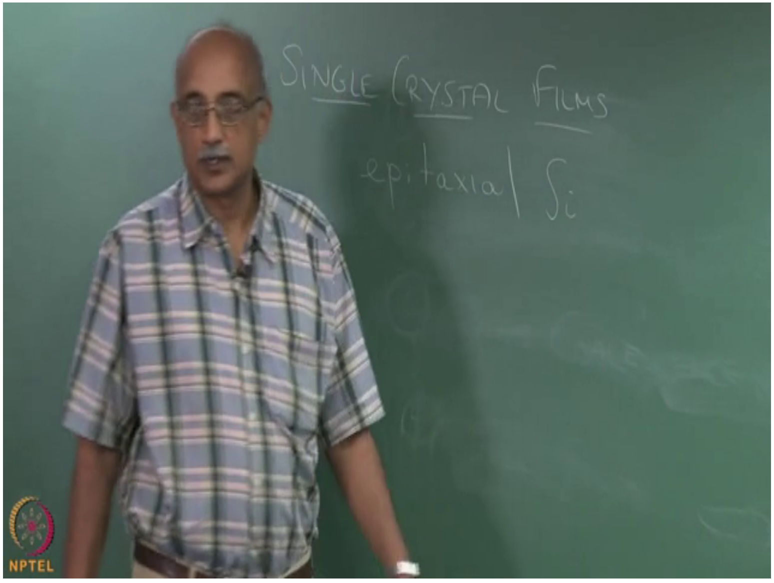

epitaxial silicon but others are also used, germanium, even compounds like silicon germanium, and so on.

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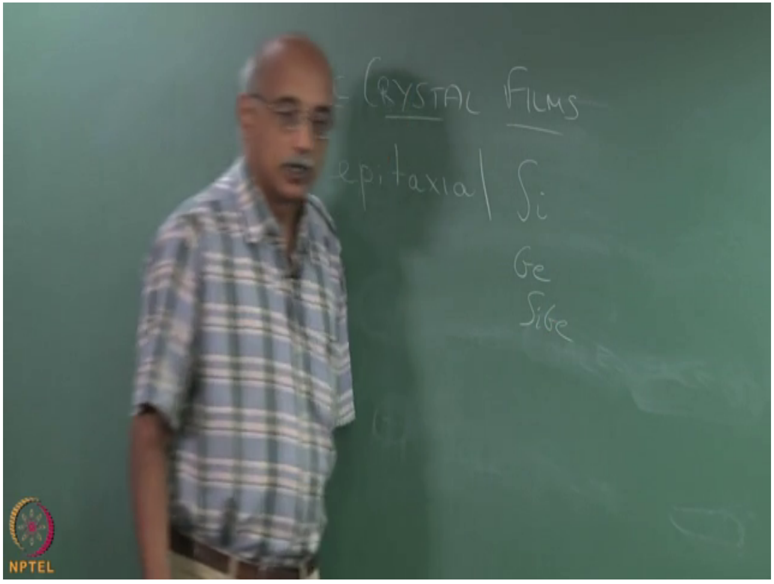

The substrate itself can also be of the same material or it can be of a different material.

So for example when you put silicon on silicon, it is called homo-epitaxial process where the substrate and the film material are the same.

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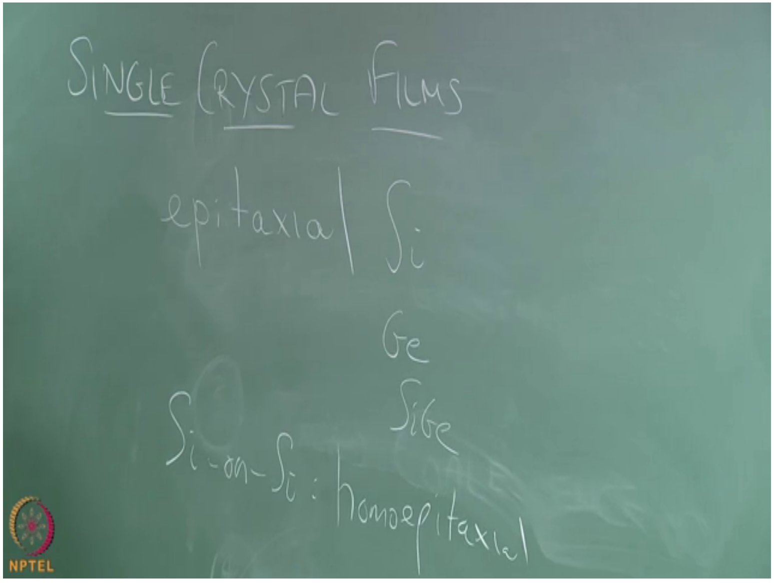

SINGLE CRYSTAL FILMS

epitaxial | Si

Ge

SiGe

Si-on-Si : homoepitaxial

Why would you want to do that? I mean why would you want to put a silicon film on a silicon substrate? What do you gain? The reason you want to do that is bulk silicon that you can get in large quantities has properties that are very difficult to control, highly widely varying in every possible way.

The composition could be varying; the crystalline structures could be varying. So you cannot guarantee that the surface of a bulk silicon ingot has certain properties but by depositing a very thin film on top of this silicon, you can now have a top layer that has a very precisely controlled crystalline structure that is sitting on top of this epitaxial, I mean on this silicon. So essentially you are depositing epitaxial silicon on top of bulk silicon.

Now when we, when we put silicon on silicon, if you deliver the silicon molecules to the silicon substrate with sufficient energy such that they move around on the surface and orient themselves according to the crystal structure of the substrate, that is when an epitaxial film happens.

So for example if you have bulk silicon that has a 1-1-1 structure and you deliver these vapor molecules to the surface and as they impinge on the substrate they immediately orient themselves also in the same 1-1-1 crystalline configuration, then you start building a structure on the substrate

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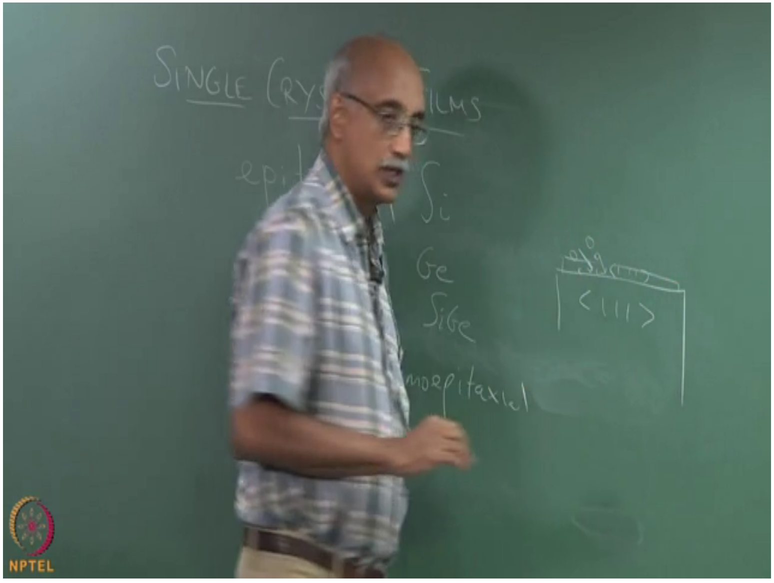

which exactly matches the crystalline structure of the substrate. That is how you get an epitaxial film, right?

But what happens, if you have, for example, if the silicon itself is not pure silicon but it has been oxidized. So you have a very thin oxide film on the surface. Then the arriving molecules are not going to see a crystalline silicon structure to attach themselves to, right? So instead they will be now trying to replicate the silicon oxide structure that they see on the surface.

So if there is oxygen contamination on the surface which leads to the formation of S i O 2 on top of the silicon

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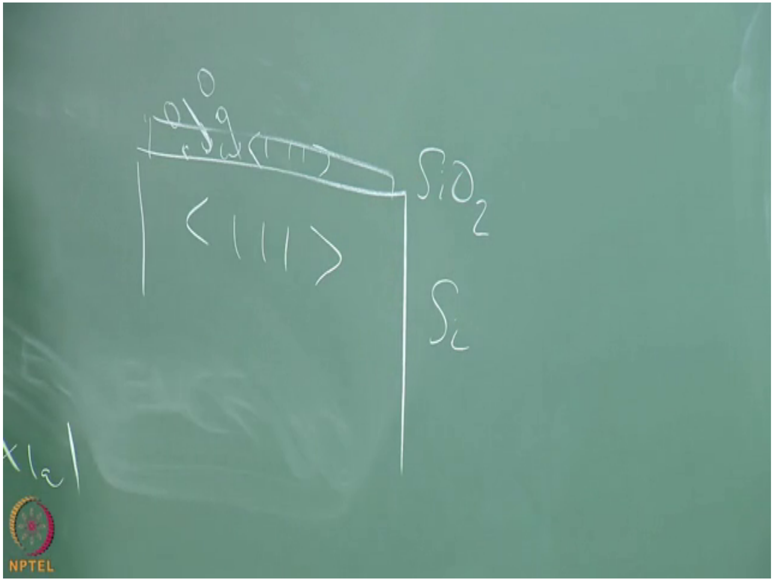

layer then the film that results is going to be amorphous in nature

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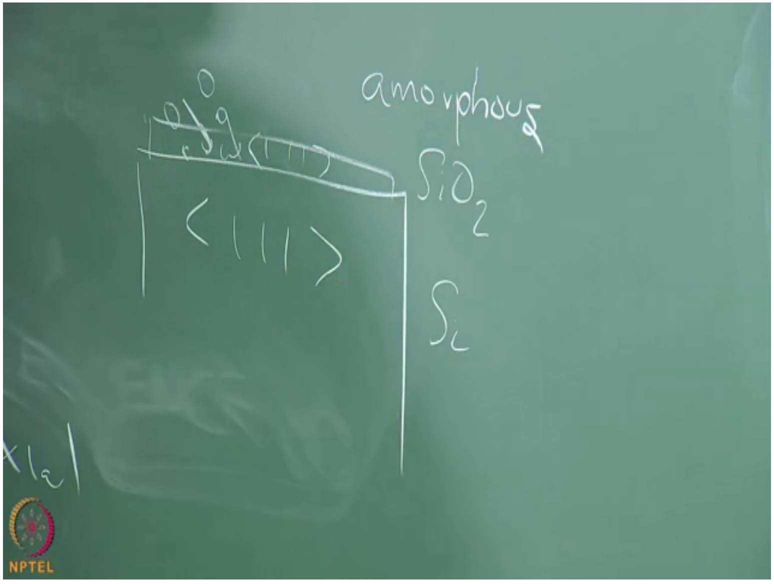

because it matches the surface that it is seeing.

Or the other reason why this could happen is, if you have again impurities or contaminants on the surface. Here again the vapor molecules that arrive at the substrate is not going to see crystalline silicon, it is going to see whatever contaminant is sitting on the surface.

So the molecules are going to orient themselves in accordance with the contaminants rather than in accordance with the basic underlying substrate material. So the point is we are trying to make single crystal films, very important to have oxide-free surface. It is very important to have impurity-free pristine surface. That is the only way that you can make a crystalline film happen.

On the other hand if you are trying to make a polycrystalline film or an amorphous film, then you can actually do it by allowing selective oxidation of the surface to happen or by changing the composition of the surface in such a way that the arriving molecule will orient itself in an amorphous fashion or a polycrystalline fashion. Now in an epitaxial silicon layer, one of the advantages of using C V D to do, to form these films is that you can very easily dope the layer with other materials.

For example elements like phosphorus or boron are frequently used to lend additional properties to the C V D film. In a C V D system, it is very easy to incorporate these external elements into the film simply by introducing them as an additional reactant into the film, into the reactor.

So by just changing the inlet composition or the feed stream entering the reactor, you can achieve either a pure film, whether it is silicon or silica or whatever or you can achieve a film which is, which has certain dopants incorporated in it. So C V D reactor can essentially become a doping rector in a sense.

To make epitaxial silicon, the favored precursor is S i C l 4 which is typically reacted with H 2 to give S i solid plus H C l. The reason that silicon chloride is preferred is because it can be used in a high temperature reactor, which essentially means that you can have a high deposition rate and you can get a crystalline structure.

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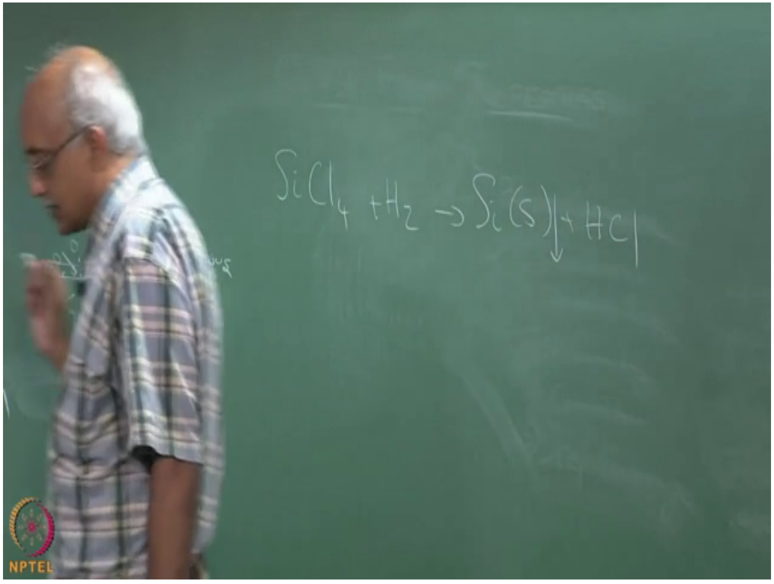

Essentially the higher the temperature, the more crystalline will be the structure of the film that you make. If on the other hand you use S i H 4 and do the pyrolysis reaction. This reaction

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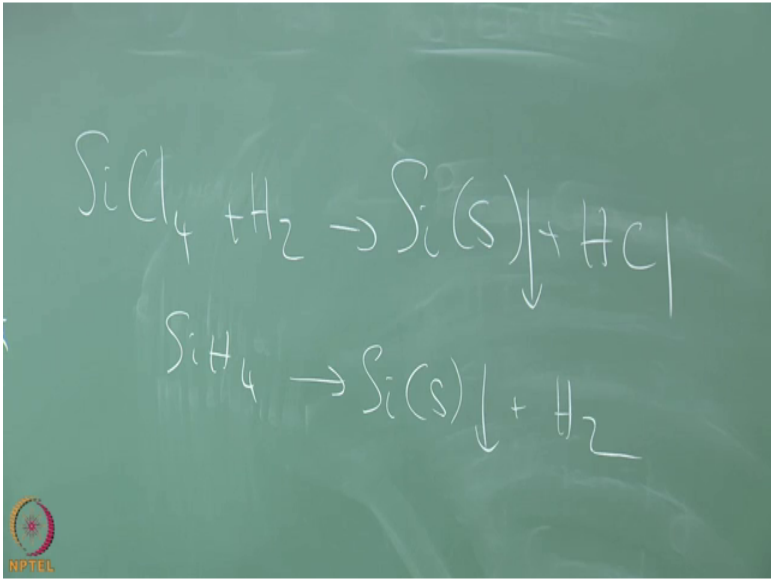

$SiCl_4 + H_2 \rightarrow Si(s)\downarrow + HCl$

$SiH_4 \rightarrow Si(s)\downarrow + H_2$

does not require the temperature that is as high as what you need to use for the S i C l 4 reactor. This reaction will actually run at temperatures that are about 200 degrees lower than what you require than what you require for the S i C l 4 reaction. Another possible way of making this is S i H 2 C l 2 which again will go to S i s plus 2 H C l. The S i H 2 C l 2

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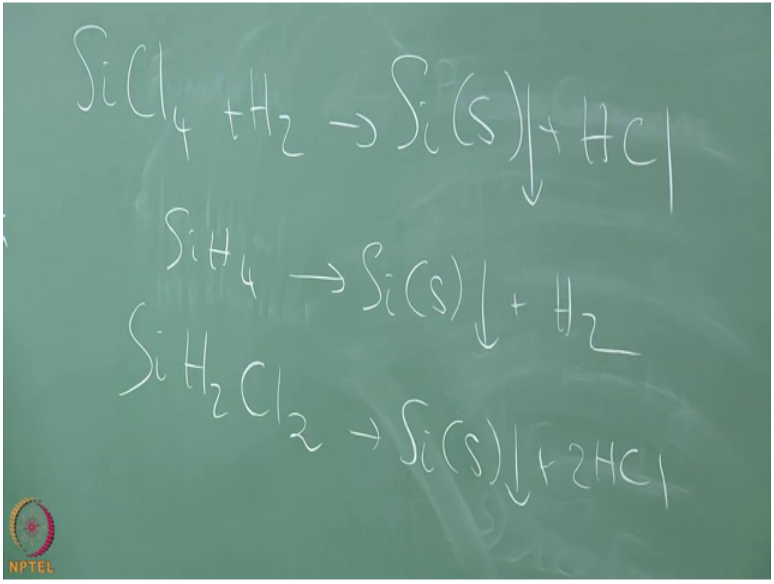

$SiCl_4 + H_2 \rightarrow Si(s)\downarrow + HCl$

$SiH_4 \rightarrow Si(s)\downarrow + H_2$

$SiH_2Cl_2 \rightarrow Si(s)\downarrow + 2HCl$

process to break down into silicon also can be run at a lower temperature.

So this reaction is more suited for epitaxial silicon production where as these reactions lend themselves more to polycrystalline and amorphous structures.

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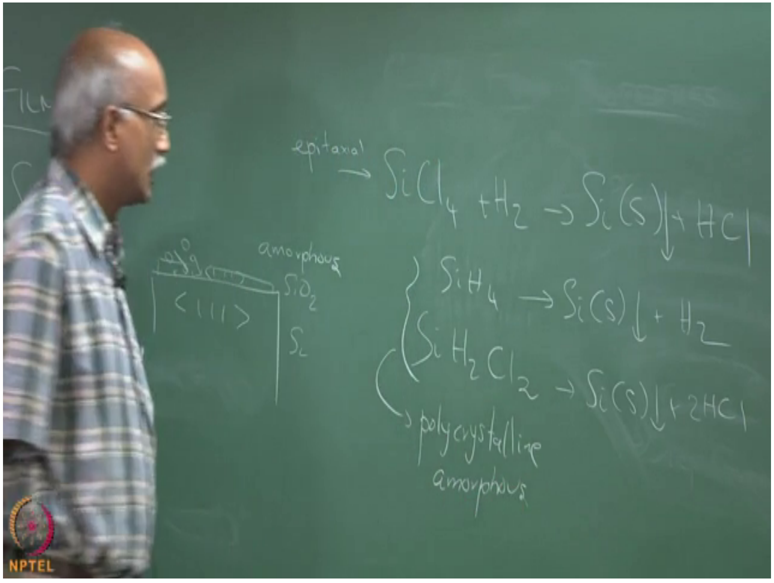

The S i C l 4 reaction sequence actually has another benefit. In that you can actually control the rate of formation of the film through both deposition and etching.

It turns out that if you keep on increasing the concentration of S i C l 4, eventually the deposition process will stop and the silicon tetra chloride will actually start etching the film that is already on the surface. That is interesting because it gives you a way of controlling the thickness now using 2 mechanisms.

Instead of trying to control it only using the deposition mechanism, you can also now control it by using the etching mechanism. In fact if you plot the film growth rate which is typically in micrometers per minute against the numbers of S i C l 4 molecules as a function of, as a fraction of total gas molecules you can actually have

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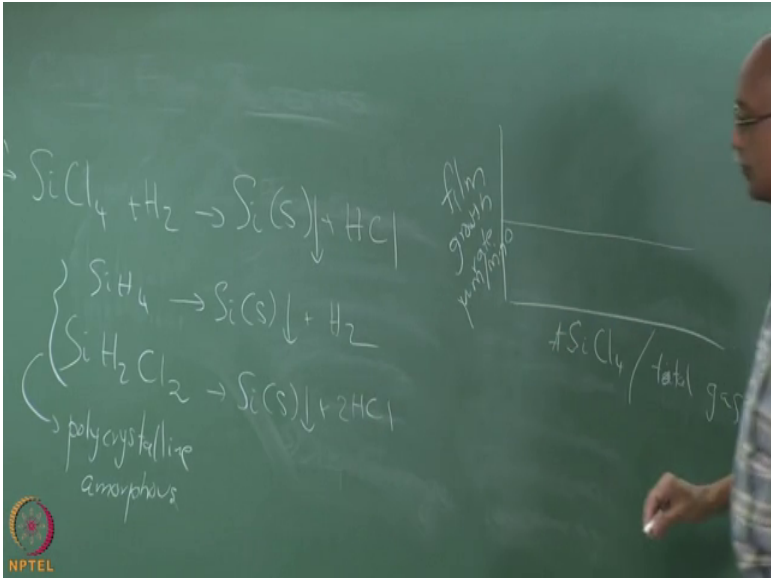

a behavior where the deposition rate goes from positive to negative.

In fact the typical behavior looks like this. So this is minus 1, minus 2, 1, 2, 3. This is somewhere around point 3.

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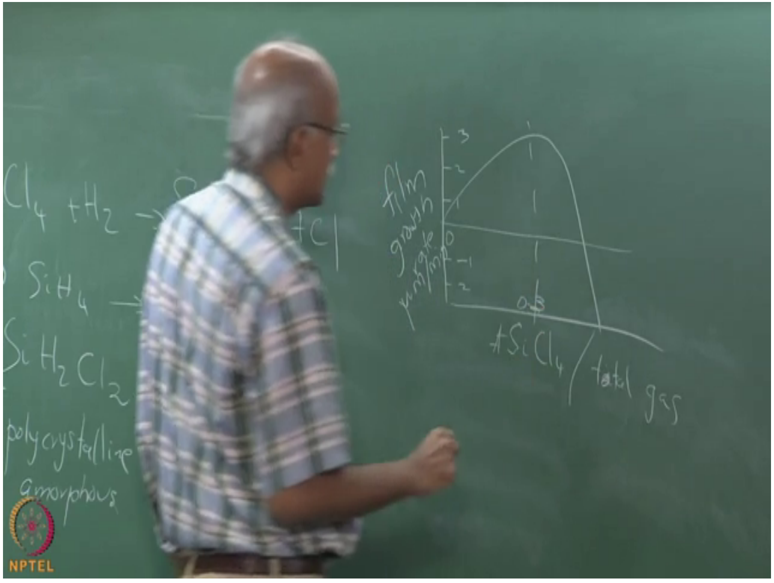

So what this is saying is as you keep increasing the amount of S i C l 4 in your system, you can actually start etching a pre-existing film on the surface.

And then as you keep lowering the amount of S i C l 4, the deposition rate will turn positive

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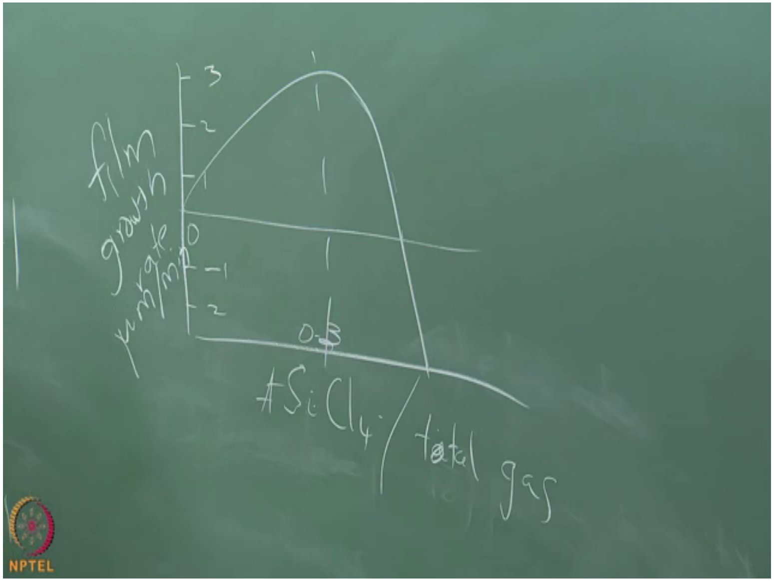

and you will reach a certain maximum growth rate for a certain value of the S i C l 4 concentration and then again it will turn negative and finally as the S i C l 4 concentration goes to zero, the film growth rate will also go to zero.

So this process, if you are trying to home in on a certain growth rate, we can do it lot more sensitively using this system simply by treating the concentration of S i C l 4 as a tunable parameter until you get exactly the growth value that you are looking for. That type of precision control is very difficult to achieve with the S i H 4 and S i H 2 C l 2 systems.

So when you are growing crystalline film, obviously the most critical deliverable for the process is the crystalline structure of the film. So you constantly have to be on the watch out for defects in the crystalline structure. So what are the typical types of defects you can get when you are trying to grow crystalline C V D films? Again contamination, both particulate contamination as well as organic contamination are defects to look out for.

Organic contamination is also known as haze. Basically if you look at a C V D film and if it is heavily contaminated with organic materials, it will have a hazy appearance, you know. You won't see a very sharp image. It is usually an indicator that you have organic vapor species that have been incorporated into the film as impurities and you have to get rid of them.

But in terms of the structure, the major types of defects to look out for;

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the first is what is known as spikes.

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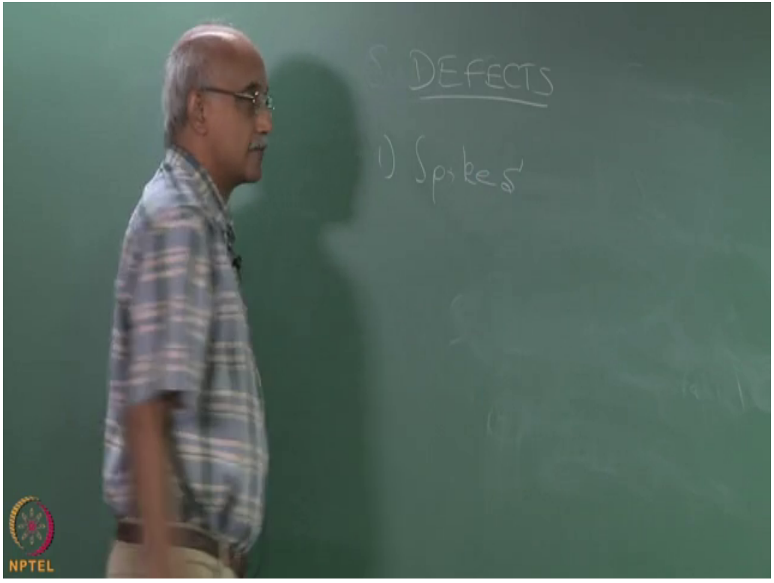

When you are trying to grow a film, obviously you want an equal growth rate everywhere on the substrate. But what can happen is, if we have certain types of impurities present at certain locations on the substrate, the growth rate at those locations would be much greater than at other locations.

So instead of seeing a nice uniform, you know, a film like this, essentially you will see something that looks like that.

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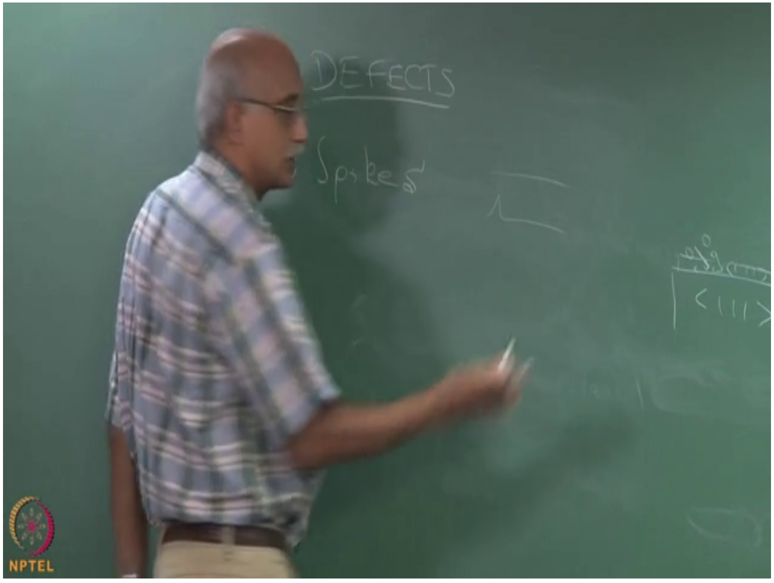

You will see a sudden jump in the thickness of the film at some location. So the structure may still be crystalline but the uniformity of the film will be affected. So that is the type of defect known as a spike.

The second type of defect is known as pattern shift. A pattern shift happens when the crystallinity

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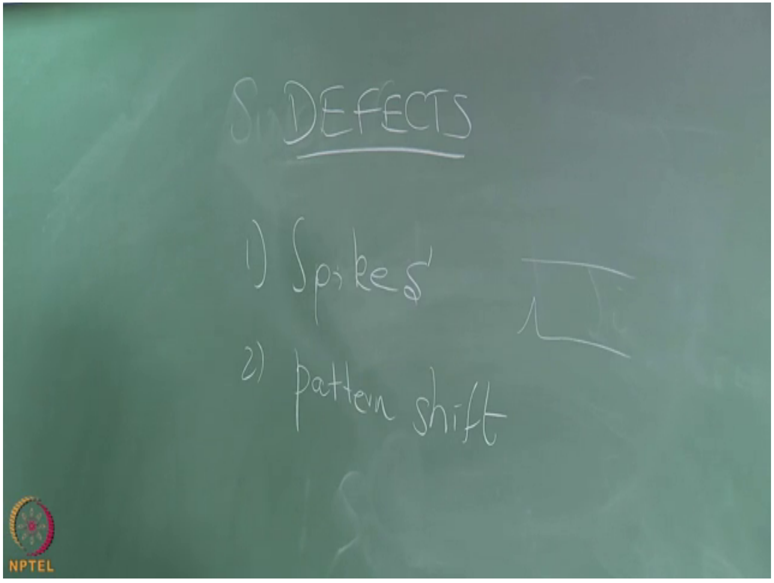

itself is affected. For example if your growth rate is too high, if your deposition rate is too large, then instead of growing in a single plane like it is supposed to, you may start growing a plane at a different angle just to accommodate the extra material that is coming in. Or you might actually add another plane to your film which is not supposed to be there.

So these types of defects essentially lead to a change in the crystalline pattern of the film itself. So these patterns can sometimes result in dislocations, they can result in the formation of an extra layer or extra plane of material and so on.

They also have the habit of starting close to the substrate but then propagating their way through the film. So it is once, this type of defect starts it becomes irreversible. So eventually the defect will show up even at the outer surface of the film even though the initial part of the defect formation was close to the substrate.

Another type of defect that we see is slip.

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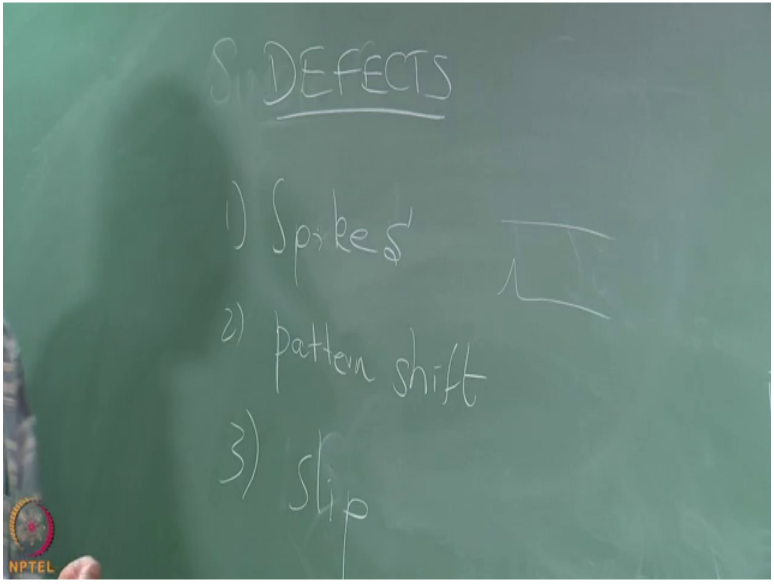

Slippage can occur between successive layers of the film, because when the C V D process happens you are essentially putting down the C V D film one layer at a time, one molecular layer at a time; that is a few Angstroms at a time. You are assuming that when the second layer deposits on top of first layer, it is going to, you know, just settle down and stay, right? But that is not always the case.

There may actually be slippage between successive sections of the C V D film so that the crystals are laterally shifted from one another. So that the uniformity of the structure may be Ok in the horizontal direction along the direction along the film but in the vertical direction, across the thickness of the film, you start seeing discontinuities in the crystalline structure. So that is the other type of defect that we see which we call slip defects.

All of these defects, obviously some of them can be fixed and some of them cannot. For example something like a spike. If you see it, you can certainly take steps to address it by, you know, essentially taking the substrate out, cleaning it, putting it back in. Usually that will take care of it.

Something like a pattern shift or a slip is more difficult to control because that has to do more with the, the molecular behavior of the film itself and the only way to address issues like this may be to, either change your reactive conditions, change the species that you are using for the C V D process or in some cases, by, essentially by introducing a post C V D step which can take care of these defects.

For example if you have a condition where the structure is not well-aligned, you can actually do what is known as a post-annealing step which is essentially high temperature baking. But what this does is it will provide sufficient energy to the molecules comprising the film that they will be imparted certain mobility and essentially they will find the proper structure. You know, they will, kind of move around until the film settles down into its optimum form.

So annealing is a process which is frequently resorted to in order to improve the crystallinity of the C V D film. You can take amorphous film or a polycrystalline film and by doing a high temperature annealing process you can turn it into crystalline film. But in addition you can also take a crystalline film and improve its crystallinity and reduce its defects by doing thermal annealing.

So in any C V D process, you know, supplying thermal energy to the substrate is always a good thing to do unless the surface itself is prone to oxidation or other types of failure modes when it is exposed to high temperatures. That is why if you look at C V D processes particularly for achieving crystalline structures, they try to employ as higher temperature as possible because it yields very high deposition rates, film thicknesses can be achieved in a much shorter time.

But in addition to all that, you can also have better quality of the film. The impurities can be reduced. Some of the defects that we see can be eliminated. And in fact, if we have a surface in which some gases have been accidentally absorbed as impurity, H 2 gas or O 2 gas, again a high temperature process will enable you to desorb these gases and get them out of the C V D film quite effectively.

So wherever possible, if you are trying to achieve an epitaxial film on a substrate, try to use a, as few chemicals as possible and b, as higher temperature as possible so that you get a good structure and you minimize the potential for any impurities to get incorporated into the system.

Now in order to minimize impurities, essentially what that means is you want a system that is not open to the atmosphere. And in fact, most C V D systems that are used to get epitaxial materials are closed chambers with a very tightly controlled environment, quite expensive and the production rates are typically small but the product that is being made from these processes is also a high value product. And so people are willing to make the investment.

On the other hand amorphous and polycrystalline films which we will talk in more detail in the next class are more likely to be laid down using atmospheric pressure and even open environment type of processes. Because in those cases, the impurities and the crystallinity in the film is not such a big factor and mostly what you are looking at is maximizing the number of films that you can make per day and also the cost per film, that you are trying to minimize.

So we will see that in the design considerations for making polycrystalline and amorphous films are very different from the design considerations that we talked about today for making epitaxial films. Ok, so let us stop at this point. Do you have any questions?

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(Professor – student conversation starts)

Student: Sir, the 0:47:10.8 shelf-life of the material, the property we have discussed...

Professor: Yes

Student: The shelf-life also changes for different types of...

Professor: True

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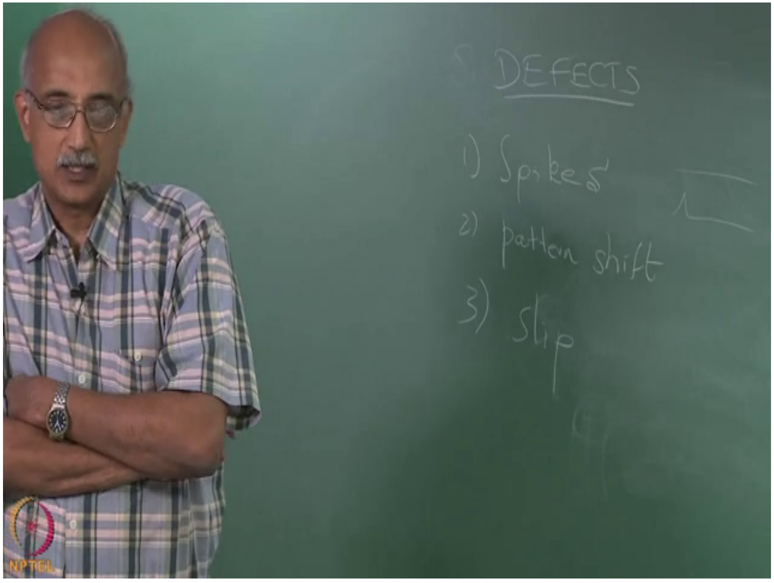

but see, once you make the C V D film on the surface it will typically get used in the next step of the process within a few hours usually, or at the most within a few days. I mean you are not going to make a C V D film and put it on the shelf for months or years at a time. Typically these are used for high production processes.

(Professor – student conversation ends)

Now there are certain products like C V D coatings which have to have the lifetime of the order of years, so for those films shelf life should not be an issue. But for semi-conductor films, particularly those that are used in microelectronics it can be an issue but essentially as long as you are following first in first out principles and using the C V D surface as soon as possible, it should be Ok.

But that is where the measurements come in, you know, you have to, if you have made a C V D film and you are storing it for subsequent use then you have to periodically go in and re-inspect it for its physical as well as chemical properties to make sure that they stay intact. So, see you on Friday.