Fundamentals of Materials Processing-2
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Module – 02
Thin Film Deposition
Lecture - 19
Thin Film Morphology-Zone Structure Model

Welcome to Lecture 19 of Fundamentals of Material Processing, and we are in Module 2 discussing Thin Film Deposition Techniques. In the previous lectures we had discussed how thin film starts to grow and what are the parameters which controlled what kind of morphology, we will get in our thin film. In this lecture also we will continue our discussion on thin film morphology, and in this we will discuss model which is called Zone Structure Model.

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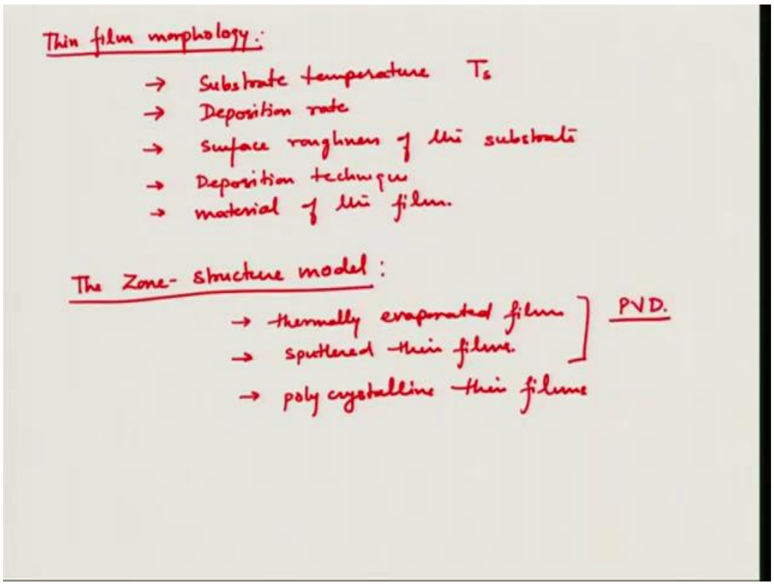

So, before we start we should discuss, what are the different parameters which influence the morphology? So, we are discussing thin film morphology, and this is the morphology means what is the structure of the of the grains in the thin films are they if course grained of verified grain, how many grains, what is their growth direction, are they any voids or anti species defects in the film. So, we are discussing all these aspects.

The main process parameter which influence thin film morphology, we had discussed this that is substrate temperature which we can call Ts. We had also discussed deposition rate. There are some other parameters; we had discussed these two parameters. There are some other parameters like surface roughness of the substrate. This also influences how your thin film micro structure will look like; deposition technique and also material of the film. So, these are certain aspects which influence the morphology of the thin film.

So, now we come to the zone structure model. This model was first proposed for thermally evaporated films, and later on also this model was evolved to incorporate sputtered thin films as well, and this model mainly for the poly crystalline material, crystalline thin films. If you recall from the previous lecture we had discussed that at the extreme ends of the two range of processed parameters we will get either epitaxial thin films which are single crystal on a substrate or we will get a morphed thin films.

The range in between these two extremes was for poly crystalline thin films. So, these zone structure models described how these poly crystalline thin films will evolve, and how their morphology will depend on various parameters. So, these zone structure model is we will discusses in little bit of detail; keep line that though these have been described for either thermally evaporated films or sputtered thin films. So, these two techniques which we call physical vapour deposition, but these can be again on case to case can further be enhanced to incorporate chemical vapour deposition as well.

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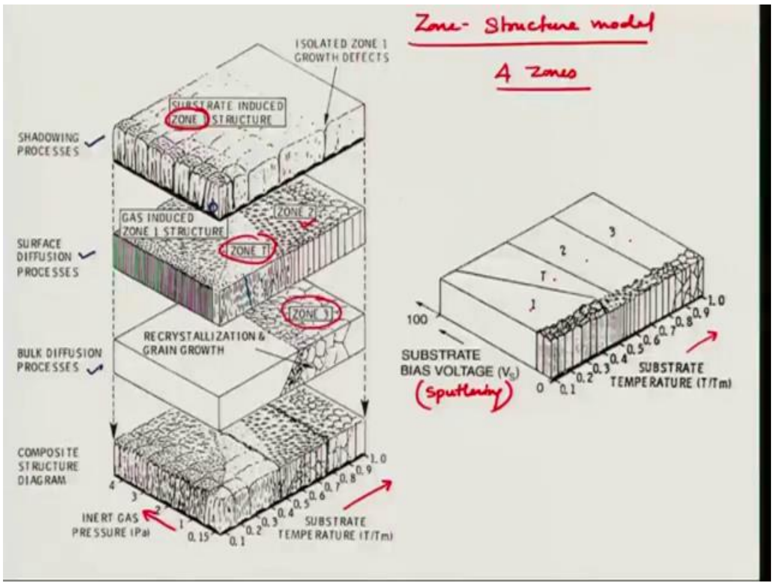

Now, let us have a look at this complicated diagram which describes the zone structure model. Now if you see in the bottom most part of this figure there are two axis: one is substrate temperature and another is the inner gas pressure. And this is the substrate temperature and this is the pressure of during a chemical deposition process. Now this process is have different zones, if you see that this is called zone 1, zone 2, zone T and zone 3. So, these all zones, this structure can be divided into four zones. And this is in a simplified diagram it is shown here zone 1, zone T, zone 2, and 3.

And here this is substrate temperature and this is the substrate bias voltage and this is for sputtering specifically for sputtering, because in the sputtering you have a plasma and you have charged species and you can apply certain bias voltage to your substrate which will change the morphology also; because it will change at which rate the ions or of or the material ions are approaching your substrate.

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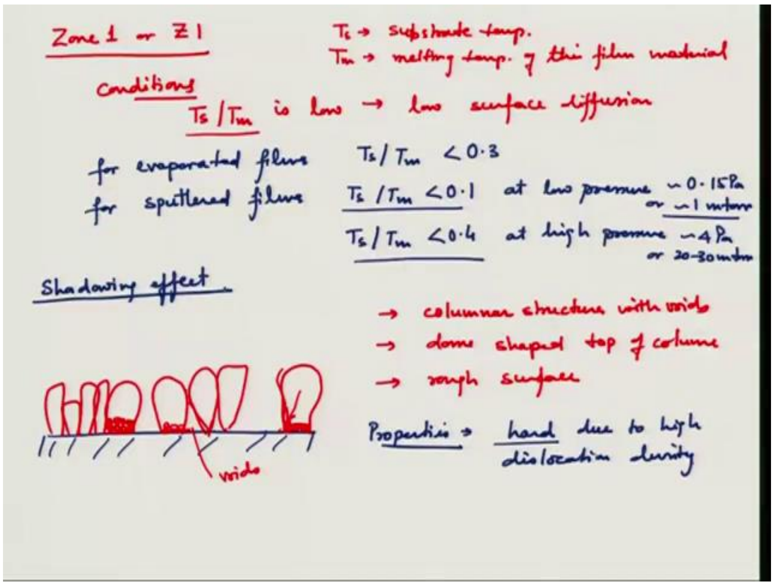

So, we will discuss these zones individually in the next few slides and discusses how different process parameters affect these. First discuss we discussed zone 1 or we can call it Z 1. Now zone 1 morphology exists under the conditions which are: that, Ts over Tm is low which describes low surface diffusion. So Ts is the substrate temperature, Tm is the melting temperature of thin film material. So, if the surface temperature is very high then and very close to the melting temperature then you would approach that we have very high surface diffusion, but when the surface temperature is low related to the melting temperature then we have very low surface diffusion and we are in zone 1.

Now, this for two different kinds of films, for evaporated films is Ts over Tm is less than 0.3. So, if your surface temperature is less than 0.3 of melting temperature for thermally evaporated films you will get zone 1 structure. For sputtered films if Ts over Tm is less than 0.1 at low pressure; if you recall that in the previous slide the pressure was also a variable at around 0.15 Pascal or around 1 milliliter. Then if you are in these conditions then we will get zone 1 or if you are at higher pressure then you will get zone 1 up to very high temperature around 4 Pascal or 20 to 30 milliliter.

So, these are the condition which give you zone model structure. Now what is zone model structures, we will discuss this in slightly more detail. So, this is my substrate on which I am depositing my thin film. And in this zone structure model it is governed by shadowing effect, because surface temperature is low enough so there is no very low surface diffusion, so once an atom or molecule gets to the surface of the substrate it just sits there, it does not move on the substrate. So what happens, that you start with small crystals and you keep on depositing on that like this and slowly you will have this kind of grins and this enhancing this and you can have like this kind of grain structure.

Now, we call as soon as you have a certain layer, suppose I shown it here right and you a directional input for a thermal evaporation on sputtering this area which is very next to this growing thin film is not receiving because of shadowing effect, because any molecule which is coming will get absorbed here rather than go where it is shadow lies; it will grow like this. And when it grows like this then it will create more and more shadows and sometime it will leave voids in the thin film; voids and lot of grain boundaries because it will start with this. And so the thin film zone or the zone which that the structure which describe this zone is say that columnar structure with voids, dome shaped top of columns, and very rough surface. So, it will be like this. So, it will be columnar grow with the dome shaped tops and lot of voids.

Now, because of these you will get semi different properties of this material. So, the properties of these thin films would be very hard which would be very hard due to high dislocation density. And we know that these locations are the stress points in the thin films where when the two dislocations get interlocked they does not allow the material to yield and the material comes very hard. So, this is zone 1 structure and it is mainly governed by shadowing effect.

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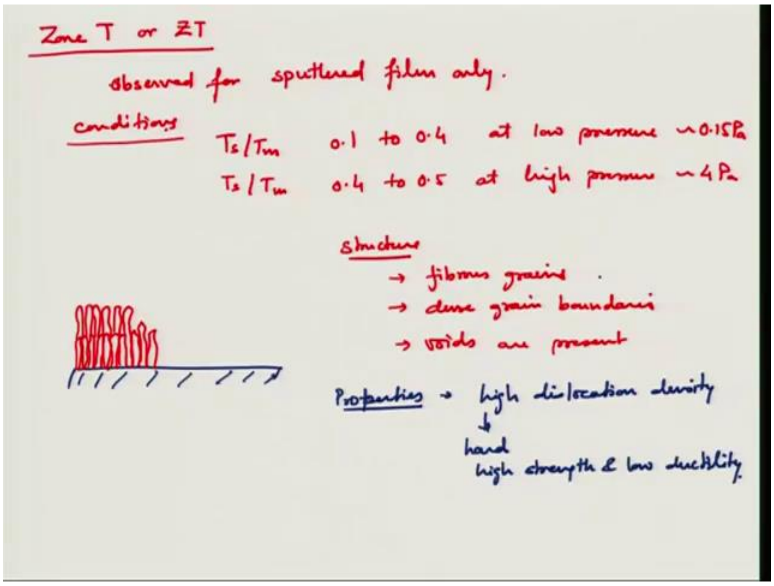

Now, we will come to zone 2; before we go to zone 2 the zone which is called zone T or Z T. And this is observed for sputtered films only. So, the morphology of this zone is usually not present in thermally evaporated thin films. The condition for this zone is Ts over Tm between 0.1 to 0.4 at low pressure around 0.15 Pascal, and Ts over Tm between 0.4 to 0.5 at high pressure around 4 to 5 Pascal. So, this is the conditions for zone Ts morphology to be observed, and it can be in between. So, you need to have an idea about which kind of zone you will have if your conditions are somewhere in between.

Now, this structure is described as; so this is my substrate and my structure of thin films is very fine columnar growth like this. So, the structure of films is fibrous grains which means grains are elongated in the direction of growth and they have thin, they are small in diameter. Dense grain boundaries; and voids are still present though it is very dense, but they are still some voids present in this and due to this properties of the thin film; so this as high dislocation density which gives it hard, it as high strength and low ductility. So, these are the properties of the thin film which you observed in zone T kind of macrostructure which is long and fibrous grains.

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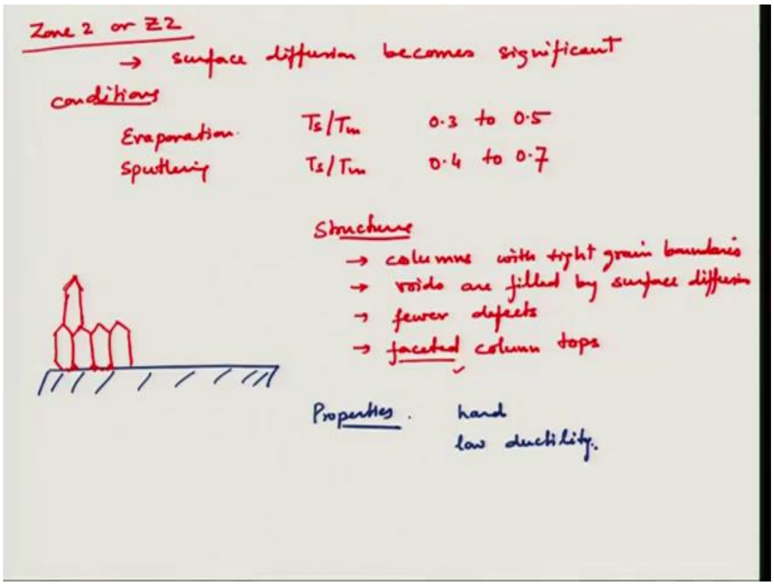

The next zone is zone 3, sorry zone 2 this is the next zone. And in this condition the surface diffusion becomes significant. Now the condition for this are: since surface diffusion is higher you can expect that the surface temperature or the surface temperature is high for these two conditions. And at these conditions now pressure does not play as bigger role, so pressure is not very important. So, for thermal evaporation these Ts over Tm relative temperature of the substrate is between 0.3 to 0.5, and for sputtering this Ts over Tm is between 0.4 to 0.7.

Now, let us discuss the structure of this film. This is again my substrate, and in this you observe the structure; again it is columnar structure with very tight grain boundaries. And these voids are filled by surface diffusion. So, this will be your structure of the thin film in this case; so let me structure is a column. Again, it is because of during the deposition there is still shadowing effect. So, the thin film grows in columns, but since the surface temperature is high enough then some of the atoms start to defuse on the surface and fill the voids. So, this is column with tight grain boundaries, voids are filled by surface diffusion, and it has fewer defects. Because, now some of the defects which are present when the thin film is growing because of higher temperature they get annealed out. And it has faceted column tops. So, the column tops are no longer rounded, because you know any material will try to adapt to certain kind of grain structure.

Now in any structure any polystyrene material certain directions of any crystal would be low energy planes. So, the material will try to have that low energy planes exposed not the high energy planes. So, that is why it will try to adopt such that those low energy planes are exposed not the high energy planes, and that is why it gets more faceted column tops. In the zone 1 we had discussed that we have round tops, because that is how the material gets deposited. And if it has not enough energy to find the low energy planes or facets it will just sit there like dome tops, but once the atoms and molecules which are getting positive higher energy to defuse they will find that low energy planes. And then we will give rise to faceted column tops.

The properties of these types of films; so these are hard and have low ductility, because of high number of grain boundaries they have low ductility.

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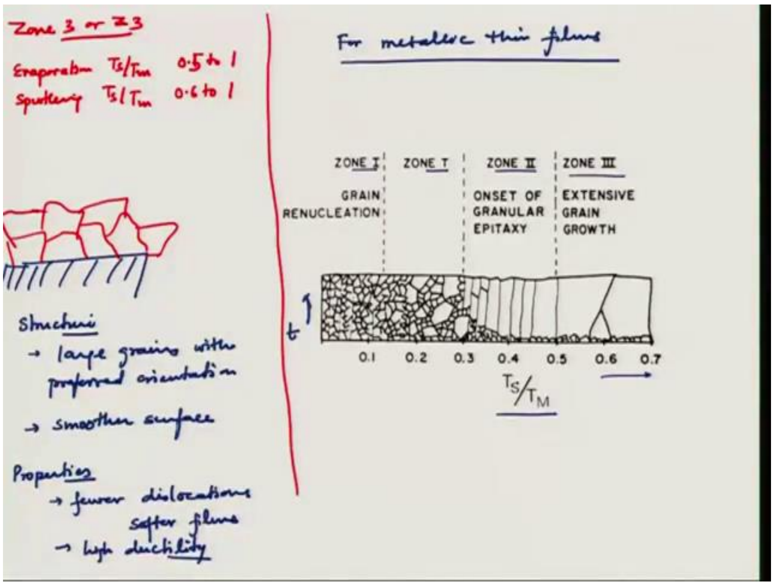

Now, we will come to the last of the zones. Let us discuss it here zone 3 or Z 3, let me separate this out we can discuss this part here. Now in zone 3, it is the conditions for evaporation are Ts over Tm 0.1 to sorry 0.5 to 1. So, very close to melting temperatures and sputtering also it is Ts over Tm 0.6 to 1. So, very close to melting temperature, a very high surface diffusion; we are not melting it just closed. Now the structure of these films will look like which we expect in any polycrystalline bulk material if you crystallize it or from melt it will have the structure with big grains, with very few grain boundaries; so the grain start to grow.

Grain with the preferential crystal orientation will like to grow more. So, the structure of these films would be large grains, and these are no longer column type because as soon as the material curve phase surface it as high enough energy because of high surfaced or substrate temperature it will start to find the grains which will minimize it is energy right, so it will start to diffuse on the surface it will not wait till it starts to form a column and then starts to surface diffuse, because it as an energy enough to find to help the large grains with preferred orientation to grow.

So, large grains with preferred orientation, a much smother surface because now we have surface diffusion the material will try to diffuse and the grains will start to (Refer Time: 24:32) as we had discussed in the previous lecture and they will try to form neck and then due to sintering effect also the material will try to go and into the neck region and we will start to give you on much smoother surface. The properties of these are fewer dislocations, and so these are softer films with high ductility. Ductility is the term which will we often use for metals. So, this is the grain structure of zone 3.

So, let us go back and just look at this complicated film structure also. So, if you see this structure which is zone 1 with lot of voids here and the large big columns with dome shaped. Zone T, which is shown here it is very long and thin grains with voids and these are called fibrous grains. In zone 2, you can see that these are faceted column tops with almost no gaps between the grains or these columns so these voids are field. If you go further to zone 3 you can see at higher temperatures these have large grains of no preferred orientations.

So, these are no longer like columns; so these different zones in a very complicated process. And zone 1 is governed by shadowing process, zone T by surface diffusion; zone T and zone 2 both, zone 3 is by bulk diffusion. Now come to this; this is especially for metallic thin films. This is the same principle; sometimes you do not get large senses towards thickness. And different zones: zone 1, zone T, zone 2, and zone 3. In this sometime you do not get columns, but get very fine grains which are equiaxed. And towards high temperature you get extensive grain growth and you get very large grains with very few grain boundaries.

So, this zone structured model gives you a guild line to adjust your substrate temperature related to the melting temperature of the material that you are depositing, and also to change the pressure to see what kind of microstructure you will prefer in your films. As I had said on the first line that this is largely for physical vapour deposition methods, because of the reason that substrate temperatures for chemical vapour deposition are usually very high. But this model can also be adopted for low temperature CVD processes to describe the grain structure of those thin films.

With this we will stop with our morphology and other thin films, in the next lecture we will discuss how to characterize these thin films.

Thank you.