Processing of Semiconducting Materials
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Lecture - 21
MOCVD

Today, we shall discuss about one special type of chemical property position is which is known as the metal organic chemical property position, in my last class we have seen that there are different types of CVD.

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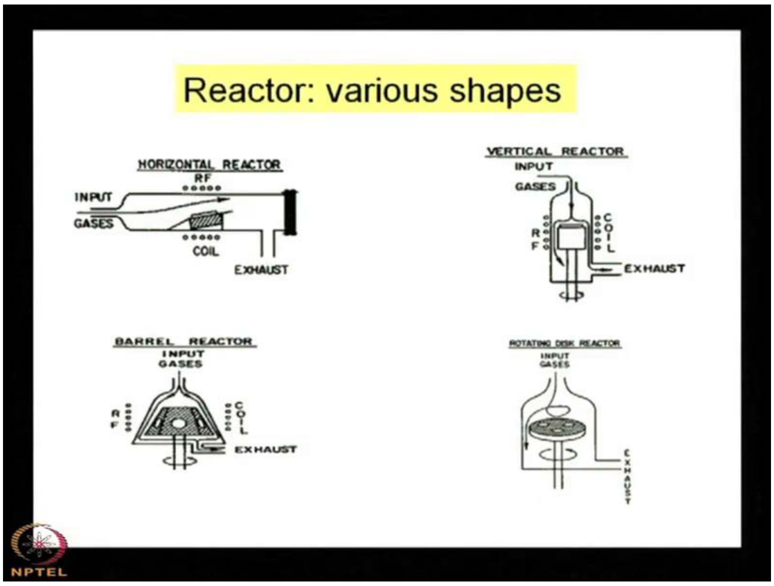

There can be say, it can be atmospheric pressure CVD, it can be low pressure CVD, it can be p type CVD, plasma enhanced CVD. There is one type of CVD which is known as the metal organic chemical vapour deposition, as the name implies there we use the metal organic as the precursors. Now, what is the advantage of metal organic precursors the advantage of metal-organic precursor is that it can be volatile.

So, if it is volatile, then to remove the volatile species from the reactor is very easy because to remove liquid is very difficult, to remove solid is very difficult, but to remove volatile species of a reacting agents or of reactor are very easy. So, I shall show you one special type of CVD reactor which is the MOCVD reactor, this is a typical MOCVD reactor and we shall discuss about this reactor. Before that, let us see how many different shapes of reactor can have, it can be horizontal reactor that means when the gas flow is parallel to the horizontal surface of the substrate

It can be vertical reactor, which means when the gas flow is perpendicular to the surface of the substrate, it can be barrel type of reactor, it can be a rotating disk reactor. Different groups throughout the world have proposed different kinds of shapes of for the reactors and they have the own advantages as well. If people have proposed that you use vertical reactor, see these are the advantages some group have told that if you use horizontal type of reactor you have different kinds of advantages.

So, in this reactor, you see that this is quartz, this is made of quartz and this is the inlet through which the gas flows through the reactor, this is the inlet, you see that there is a inlet aperture and that is the outlet. Through this outlet, basically the by products and the un reacted gases passes from the reactor to the atmosphere, but care must be taken that before releasing to the atmosphere. If there is any toxic substance, you have to remove that toxicity from the gases or from the by products.

So, that is the reason that the by products or the un reacted gases are passed through a scrabber, what is a scrabber? A scrabber is basically a heated chamber where charcoal bed is there, so there is basically there is a bed of heated charcoal, so when the gas or the un reacted gases or the by products come in contact with that hot or the heated charcoal bed. It burns then the toxicity, it loses its toxicity, then it can be released to the atmosphere, it is basically connected to the scrabber. If you see the construction of this type of reactor, you see that this is the susceptor, this is a graphite block, this is basically a susceptor.

This susceptor is placed inside the reactor on the susceptor, the substrate is kept on the susceptor, this is a susceptor and you see the shape of the susceptor on that susceptor you have placed the substrate, now what is the dimension of this susceptor?

The dimension of this susceptor is basically 2 centimetres by 2 centimetres, so that means using these reactor at the most you can use 2 centimetres by 2 centimetre substrate not more than that you cannot use your four inch 2 inch, 6 inch vapour growth. Using this reactor, that is not possible because that is the laboratorial reactor; this is for research purpose that is not for the production of any industrial application.

So, this is the graphite susceptor on which the substrate is placed, you keep it here and this is basically placed in a heated chamber or in other way I should say that the susceptor is heated. There is some arrangement in our laboratory, it is the lamp heating, lamp is heated and the temperature increases, it can be RF type of heating coil, it can be inductive type of heating coil, and it can be laser kind of heating coil. Different kinds of heating arrangements can be done, you can use any kind of heating provided we can control it, why you can control it because the temperature of growth is different for different materials

If you use gallium arsenide, the temperature of growth is say 625 degree or 600 degree centigrade for indium phosphide it is say 650 degree centigrade for indium arsenide say it is 500 degree centigrade. So, for zinc oxide it is 400 degree centigrade or even less than that, so from 300 350 to 700 degree centigrade to use and it must be very precise why because the heating must be limited or confined to his place only through the other parts of the reactor.

So, in that sense you can say that the susceptor is heated and the walls must be cold the wall must be cold that means very confined type of heating must be done. So, that is the reason there are two apertures, you see it is for the circulation of water there are two leads through which water circulates. Cold water circulates to keep the other parts of the reactor cold, but it is not cold if the temperature at this place is say 600 degree centigrade. On the other parts, it will be 400, 500 degree not cold compared to this portion, it is cold.

So, those things you must ensure and this is another quartz tube and this quartz tube is placed. You see that there is a groove inside the susceptor and it is placed like this, why it is placed like this, to measure the temperature of the susceptor because the thermocouple is inserted through this tube.

How to control the temperature, how you will see the temperature? You cannot measure the temperature by some thermometer; we have to use some thermocouple. So, this is basically for the typical emissivity type of reactor, it is placed inside like this type of thing and obviously there will be another tube through which the by product or the un reacted gas will pass through the centre. It is made of quartz, one thing you have to keep in mind that if you use oxygen for any purpose inside the reactor chamber. You should not use graphite because at that temperature the chemistry people should know at that temperature will be burnt carbon dioxide will be formed.

So, it will spoil your growth, so I mentioned earlier that we have to use inconel or stainless steel or that type of a substrate through which you can grow good type of thing because it must not be reactive. If you use aluminium say at that temperature, it can melt, care must be taken that it can withstand that high temperature without any damage or distortion.

So, that is why inconel, stainless steel are good thing, another thing is it must be thermally conductive. Otherwise, you cannot measure the temperature, it must be thermally conductive because you see that it is not in directly contact with the heat it is placed inside some heating arrangement. So, it must be heated if it is not thermally conducting, then what will happen, there will be no heat increase, there will be no increase in temperature of the substrate or the susceptor.

So, that is a stainless steel, you know that it is not a very good conductor of heat, so generally what happen, you have to wait for a long time. We have used stainless steel susceptor as well and we have seen that 30, 40 minutes are required to stabilise the temperature. Suppose, you need 550 degree temperature, so you have to wait for 30 minutes, 40 minutes for graphite, it takes just 5 minutes to attain that temperature and to stabilise it.

Yes you, if you have any question.

Student: Just tackles the susceptor.

Yes. When expansion is low. Thus step up the susceptor. Chamber temperature is low, so the decompose product is the chances of decompose product will be adhere to the surface. I know actually what happens you see that when gas passes through this chamber, a gas mixture passes through this chamber. So, you see there is a volume inside and the susceptor is made in such a way that it is a slanting type of thing that means as you go away from left to right that is from inlet to outlet the volume decreases.

Basically, the height above the susceptor decreases, you see that the temperature of the upper layer gas is less compared to the lower layer. So, that is the reason I shall show you that designing a reactor is very important, how to design the reactor. You have raised very pertinent question that what will happen, what should be the sticking, what should be the decomposition of the gas?

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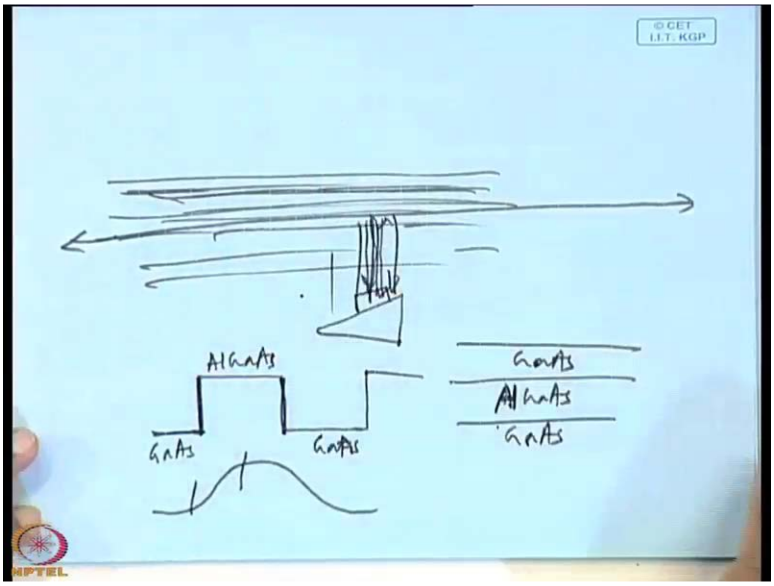

The idea is that it will diffuse, say this is your susceptor that black block on which your substrate is kept, gas is flowing through this chamber, gas is flowing. This gas you can say that this is a boundary layer, boundary layer means below this layer there will be diffusion of the different chemicals onto the substrate and there is temperature variation. So, our idea is that it must diffuse because unless it is diffused from main gas stream, there will be no reaction because adsorption must be there, then will be decomposition, then some nucleation will be will be formed and then the layer will be grown.

So, now there are some conditions, what should be the diameter of the reactor, what should be the volume of the reactor, what must be the density of the flow gas inside the reactor? So, there are different kinds of consideration and we shall today concentrate our attention on that on those things also.

It also depends on the direction of flow direction of flow is constant, here you see that there must be one inlet and one outlet, you cannot change the direction what you can do. I think that you are asking that type of a question that whether there can be other inlets also say for zinc oxide. We have encountered one important problem, what is that problem that zinc oxide you know that it is very reactive in nature, if you put zinc and oxygen even if you put zinc in atmosphere zinc oxide is formed. For that, you need not do any kind of chemistry or any kind of CVD etcetera not required, also it is very easily zinc oxide is formed is very highly active.

So, what happens from this inlet if you put zinc and oxygen simultaneously together, then what will happen? All this parts zinc oxide is formed, here also it will be formed, here also it will be formed, but on the other parts of the reacting reactors. There will be formation of zinc oxide that is known as the gas phase reaction or parasitic reaction because that is unwanted you want that the zinc oxide or any type of material must be formed on the substrate only.

So, if it is formed elsewhere on the walls of the reactor tube that means it is gas phase reaction that means your material is costlier. So, cost will increase so far as the industrial applications or the industrial production is concerned, so what people do that let the zinc vapour passes through this inlet. There must be another inlet say very near to the substrate surface where through which the oxygen will pass, so there will be two inlets here there is one inlet this is designed for three pipe semiconductor.

In three pipe semiconductor that means gallium arsenide, indium phosphate type of material where that parasitic reaction is not very easily readily available or encountered this is not very easily found why because arsine and phosphine. The tracking efficiency is very high, the sticking coefficient is problem is there and so only at the hot zone they react. They do not react on the other parts of the reactor, but for zinc oxide or there may be other type of material because we have not tried all the material, the gas phase or the cold zone reaction or parasitic reaction is a problem.

So, there may be another type of reactor where one this is one inlet, there must be another two second inlet or third inlet must be there. Through different inlets, you are sending different chemicals so that on the hot zone only the reaction takes place because you are not sending the oxygen here. So, there is no chance of reaction, here only you are sending the oxygen through this portion.

So, there will be reaction on this portion, so that is also important thing that direction is not the important is that you have to minimise the parasitic reaction or the reaction in the gas phase.

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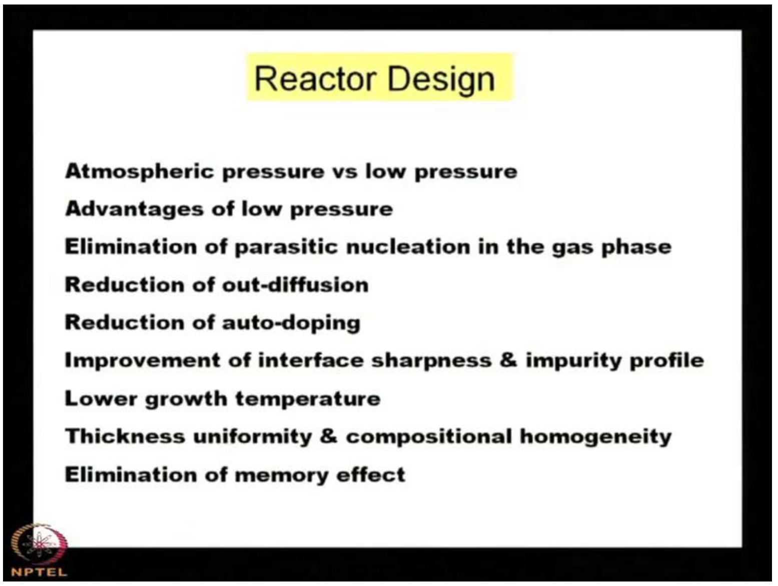

Now, this thing we have considered that how to react design the reactor, there are some consideration, one thing is that you see that it may be atmospheric pressure or low pressure. Advantages of low pressure are that elimination of parasitic nucleation in the gas phase that we are discussing.

That means if you use a low pressure reactor then that gas phase reaction can be minimised reduction of out diffusion. I have discussed that thing also what is out diffusion, out diffusion means of the surface, diffusion from the substrate from the surface of the substrate or from one layer to another layer. That means suppose you are growing aluminium gallium arsenide on gallium arsenide, so what you are doing, you are first making a gallium arsenide layer. Then, one aluminium gallium arsenide layer say this is your gallium arsenide layer, then this is aluminium gallium arsenide layer the again gallium arsenide layer because in hetero junction many layers are grown.

That is the advantage of this type of CVD which is not there for bulk crystal growth, in bulk crystal growth you cannot grow layered structure, layered structures means which is known as the hetero junction that is known as hetero junction. In technical terms, it is basically hetero junction, junction between two dissimilar semiconductors, now out diffusion means here aluminium from second layer can diffuse to the above layer or the layer below it.

So, that is out diffusion or from the substrate some impurity can diffuse to the layers that are the auto doping when there will be impurity diffusion from the substrate to the layers. Then, it is doping, auto doping you are not doping through any chemical, it is automatic from the diffusion of the impurities which are there in your layers or which are there in your substrate. If I am not cleaning this thing very effectively because cleaning is also important, if you how it is cleaned, it is cleaned through aqua regia, you have to put this thing in aqua regia for 24 hours overnight.

Then, you have to boil it in water, and then through deionised water, finally it is put in a vacuum to dry it because you are using nine and ten impurity chemicals that is very pure. Now, if your reactors or the susceptors or the substrate is not clean to that level then what is the use of using 9 and 10 impurity chemicals, no use. So, out diffusion or auto doping may be possible, it is it is quite possible during the growth, so these can be avoided if you use the low pressure system. Then, improvement of interface sharpness and impurity profile interface sharpness means this say, this is the interface here the interface is between gallium arsenide and aluminium gallium arsenide.

Here, another interface between aluminium gallium arsenide and gallium arsenide say if the interface must be like this very sharp interface that means change over from gallium arsenide to aluminium gallium arsenide is very sharp. Similarly, from aluminium gallium arsenide to again gallium arsenide is very sharp it is very sharp that is step profile.

Normally, if this care is not taken how it will look like it will look like smeared what is this smeared out that means there will be diffusion of aluminium on both the sides from this side that side. So, those things will be there and there will be smearing of the interface it will not be a step profile like picture. Lower growth temperature can be lowered thickness uniformity and compositional homogeneity elimination of memory effect he has asked me that he could not understand memory effect.

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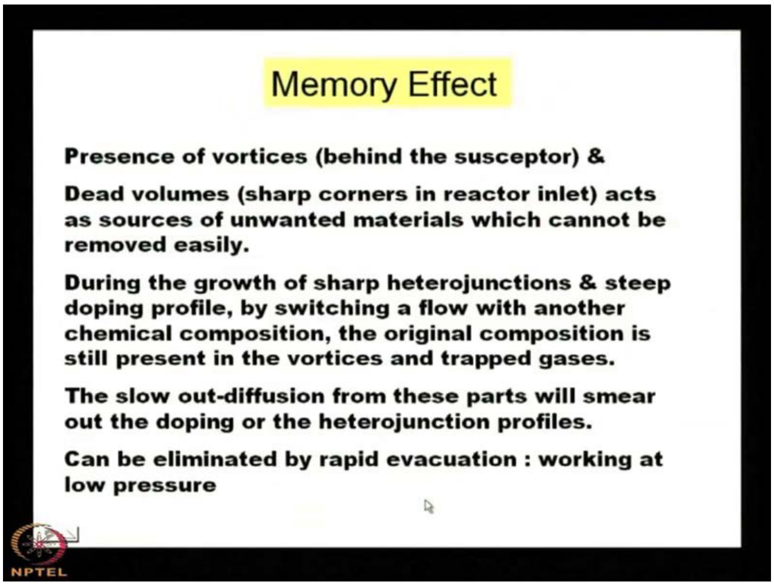

Now, what is memory effect, memory effect that is behind the susceptor and sharp corner in the reactor inlet. There may be unwanted materials yes you see that when it is placed when it is placed there is dead volume behind this susceptor because gas is coming out from here. So, gas is filling the whole volume of the reactor reaction taking place on the front side where there is a temperature hot zone.

So, at the end at the back end of the susceptor, the gases are not going to react, they are not going to react. Similarly, there are many sharp edges in the reactor, you can see there are many sharp edges from the reactor, so on those sharp edge, there may be trace amount of material say aluminium may be there.

So, when you undertake this growth, that means from aluminium gallium arsenide to gallium arsenide, what will happen? This trace amount of aluminium will be there inside the reactor chamber because intermediately you cannot clean the reactor unless the whole growth is finished. When the whole growth is finished using aqua regia, you can clean this thing so that there will be no aluminium, no gallium, no arsenic.

When you are comparing the layers, so during the inter, during the growth you cannot clean this reactor, so there may be some trace amount of aluminium or other here, we are taking the example of aluminium. It can be different types of materials also, those can be trace amount of those materials can be there in the behind the susceptor and the sharp corners in the reactor inlet which cannot be removed easily.

So, how you it can be removed, it can be removed by no by low pressure because at atmospheric pressure it can be forced to be removed from this reactor to the scrabber. If it is a low pressure type of thing, then continuously it is evacuating it is sucking from what are their inside the reactor. So, the memory effect can be reduced using low pressure reactor, not atmospheric pressure reactor because there are some chemicals which are additive in nature like aluminium. Removing aluminium is very nasty job even on the emissivity reactors for the different gas lines if you pass aluminium through those gas lines the whole line will be blocked by the aluminium scales.

That is the problem with the zinc oxide also, that is basically the memory effect memory effect means you see that this aluminium can be moved to the second layer though it is your gallium arsenide layer. Some amount of aluminium may be incorporated in the second layer or third layer or the successive layer, so that is the memory effect during the growth of sharp hetero junction and steep doping profile by switching a flow with another chemical composition. In the original composition still present memory in the vertices and trapped gases the slow out diffusion from these parts will smear out the doping of the hetero junction profiles can be eliminated by rapid evacuation that means working at low pressure.

So, memory effect is one important thing which can be considered for this type of reactor, so you can design a reactor where the memory effect can be less. So, people have arrived at this reactor after many R and d why the shape is like this because of the those considerations only people have tried with different kinds of steps.

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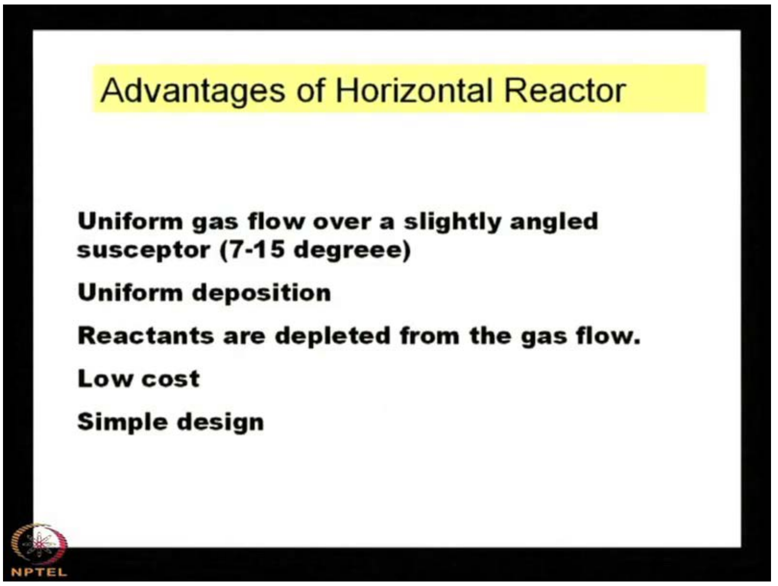

It is a horizontal reactor what are the advantages of horizontal reactor the advantages of horizontal reactor is that uniform gas flow over a slightly angled acceptor this is 7 to 15 degree because it has been proofed that the gas flow will be uniform. If there is a certain slanting of the susceptor because of the velocity problem that we shall come uniform deposition reactants are depleted from the gas flow low cost simple design.

What is the meaning of this term reactants are depleted from the gas flow? This is the gas flow and the reactants are depleted means they are diffusing to the substrate or to the susceptor surface. So, that is the meaning of this term reactants are depleted from the gas flow low cost simple design etcetera.

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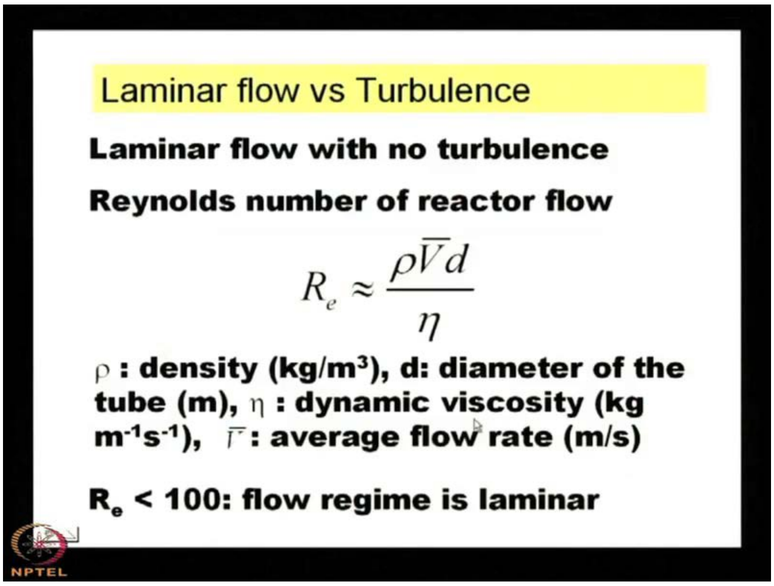

Now, very important aspect is that for very good CVD reactor we have to consider two important aspect one is that the gas flow must be laminar flow not turbulent the opposite of laminar is turbulent you know what is turbulence that is random.

The flowing of water in the field basically during flood, the flow of water in the river during flood it is because of turbulence or you will find that turbulence in the big rivers also in Ganges. In big river also there are always some turbulence, but we need laminar flow, laminar flow means the flow will be in a particular direction free from any distortion. It will start from one point and it will take the same path and will reach the same point which will take the same path the gas molecules, in our case we are talking about the gas molecules in gas molecules all the chemicals are embedded

So, we are concerned about the flow of the gas inside the reactor, now for laminar flow we have to take the help of Reynolds number what is Reynolds number Reynolds number is given by rho V bar d by eta what is rho, rho is the density. I have given the unit also k g per meter cube, it is the density of the gas in this case, it is basically a mixture of gases that is not a single gas. Suppose, if you use one single gas say silane, then it is the density of silane if you use say diethyl zinc and oxygen, then it is a mixture of the vapour of diethyl zinc.

The oxygen gas and the carrier gas which are carrying those vapours into the reactor chambers because the vapour pressure must be having obviously, but at the same time vapour pressure cannot go of its own on reactor side. You have to carry those vapours by some carrier gas, it may be nitrogen, it may be hydrogen, we have discussed those things in detail when we shall use nitrogen, when we shall use hydrogen, why hydrogen is preferred. For zinc oxide, we cannot use hydrogen because it can be what is the problem with hydrogen? In zinc oxide growth because oxygen is there, so it be it may be because oxygen is there and if you put hydrogen, so there may be in pressure

So, you see that it is the density rho V bar is the average flow rate of the gases d is the diameter of the tube eta is the dynamic viscosity and if you make a reactor you are making a reactor for silicon growth. Let us take an example for silicon growth, you can calculate the rho of the gas mixer what will what would be the gas mixer gas mixer will be silane and hydrogen. So, take silane and hydrogen and calculate the density it is available in the litre then viscosity is also available in the litre H R V bar is the average flow rate and d is the diameter.

So, you have to work out with V bar and d we have to work out with v bar and d to obtain R E which will be less than hundred because if R E is less than 100 that is a thumb rule. It can be 97, it can be 120, but normally if it is less than 100 the flow regime will be laminar, it will not be turbulence if R E is greater than 100, then it will be turbulence. So, that means your diameter of the reactor that means your diameter of the reactor this is the diameter of the reactor and your gas flow rate what should be the flow rate? It is 6 litres per minute, 5 litres per minute 100 cc per minute.

So, those things we have to work out so that the Reynolds number becomes less than 100 and the flow regime is laminar. So, there are two considerations, one is a Reynolds number to make the flow laminar free from turbulence and another we shall introduce the Rayleigh number which will give you the diffusion not the convection. The flow must be laminar and also inside the reactor it will be diffusion not the convection.

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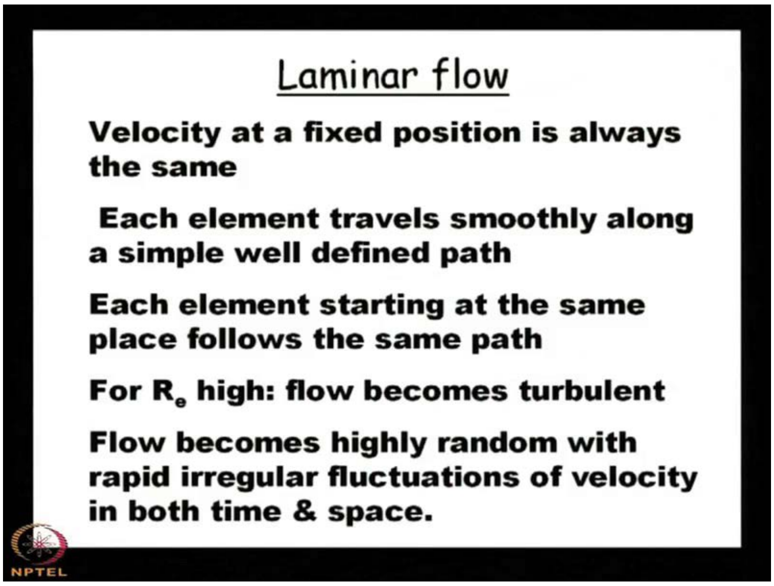

So, what are the characteristics of laminar flow? The characteristics of laminar flow is that velocity at a fixed position is always the same velocity at a fixed position is always the same means say velocity at x equals to t or x equals to x dash inside the reactor it is always same throughout the growth. If you grow for 1 hour or if you grow for say 20 minutes or if you grow for 10 second, the velocity at a particular point is always same each element travels smoothly along a simple well defined path.

Each element travels smoothly along a simple well defined path, each element of gas molecules that means in the gas molecules what should be the molecules, one type can be say for 3, 5 semiconductor growth. It can be the molecule of the trimethylindium says you are growing indium phosphate, says you are growing indium phosphate.

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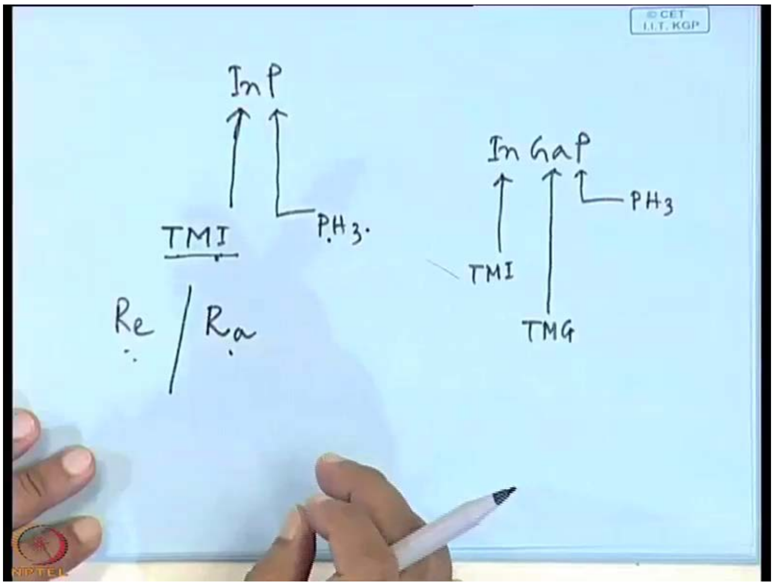

So, for indium what is the precursor trimethylindium, that is why it is organometallics trimethyl means it is a organometallic trimethyl indium and for phosphine. So, wafer of trimethyl indium plus wafer of phosphine is in the gas state, so there is no question of forming vapour plus hydrogen is carrying those things. If you dope it, say n type then additional it will be hydrogen sulphide or saline, so trimethylindium phosphine hydrogen sulphide and hydrogen for indium phosphate n type of growth if it becomes indium gallium phosphine.

Then, trimethylindium for indium for gallium, it is trimethylgallium and phosphine phosphine, then it will be hydrogen as well and if you dope it p type or n type dopant molecules will also be there. So, each element means considering all those things travels smoothly along a simple well defined path each element starting at the same place follows the same path for R e high.

That means if the Reynolds number is high, flow becomes turbulent, flow becomes highly random with rapid irregular fluctuations of velocity in both time and space because as the time elapses it will be there will be fluctuations. Also at different points of the reactor chamber it will be different, so there will be turbulence, so care must be taken that means you must design your reactor in such a manner that there will be no turbulence of flow will be laminar flow it is clear.

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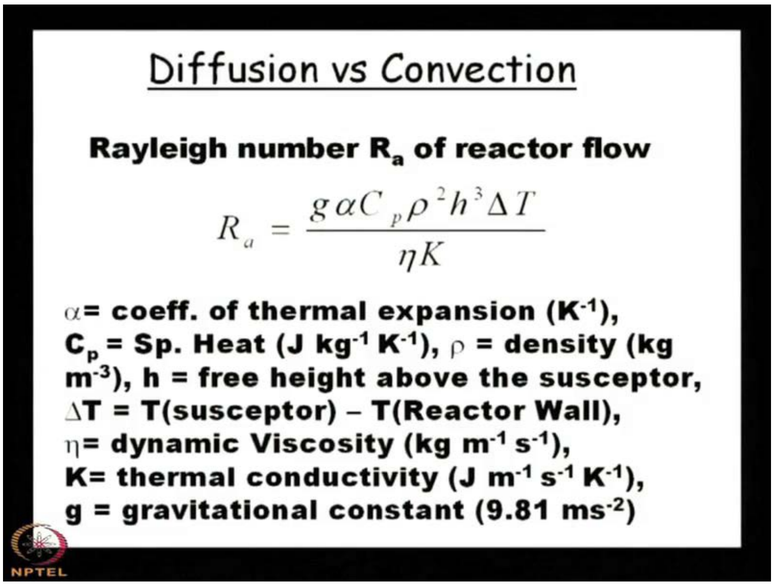

Another important aspect is the diffusion and convection because you see that if you see this view graph this is the average gas flow inside the reactor and it must diffuse. There will be cohesion or convection, the cohesion or convection is that the density of the gases inside the reactor is different as you mentioned because of the temperature gradient in the reactor chamber the density is deferent.

So, if the density is different then what happens convection happens like the storm how storm originates when the air from earth surface. It becomes hot and it moves upward then to fill that gap cold air from the surrounding regions come to fill that gap so there will be a convection type of thing. So, here there is a chance since the temperature variation is there at the at very near to the susceptor, very near to the susceptor you see that there will be more heat than the top layers. So, the difference of density will be there and there may be some convection obviously there may be some convection.

So, to avoid that convection we have to calculate the Rayleigh number Rayleigh number of reactor flow. It is given by g which is known as the acceleration due to gravity or gravitational constant alpha is the coefficient of thermal expansion. C p is the specific heat rho is the density h is the free height above the susceptor and delta t is the temperature difference between the susceptor and the reactor wall.

There will be a difference of temperature between the susceptor and the reactor wall and it is in the numerator in the denominator there will be the viscosity eta and the thermal conductivity. So, this is the equation for the Rayleigh number that means you can calculate the Rayleigh number using this parameters and for any gas for gas mixture you can calculate the parameters or the parameters are available in the litre itself.

If you put the values, you can calculate what should be the value of R a what should be the value of R a here you see that R a proportional to rho square here if the other things are constant then R e is proportional to rho square. In the earlier slide it is R e proportional to rho R e proportional to rho for that means the Reynolds number is proportional to density and Rayleigh number proportional to density square.

So, most important consideration for the reactor design is the variation in density because you know that the variation in density will be there because of the temperature gradient. So, that is the most important factor you have to play around that thing only then only it is possible to design a very good reactor it is it is not it is not true for only the m o CVD. It is basically for any kind of CVD reactor because in almost all the CVD's you are sending some vapour or the gas or the chemicals in the gas phase so there diffused onto the substrate and adsorption is taking place followed by the reaction.

So, for any CVD you have to ply with the reactant because the gas is not very important gas is there in these days you can procure any kind of gas any kind of chemicals with very high purity. That is not the problem is with the good reactor if you have a good reactor then only it is possible to grow very good materials. Otherwise, you cannot do and here you see that there is another important term which is the delta t this delta t is the difference in temperature between the susceptor and the reactor wall.

So, that is also important because to keep the Rayleigh number as a particular value delta t must also be optimal now see what should be the Rayleigh number to obtain a diffusion because we do not want convection. Remember, we do not want convection because in convection you do not have any control you do not have any control you have to make diffusion because if it is if the chemicals from the main gas stream diffuse very efficiently.

Then, the growth will be uniform the growth rate will be high, otherwise what will happen if the diffusion does not take place properly the growth rate will also be very less more diffusion will take place more and more thickness of the layer will be grown.

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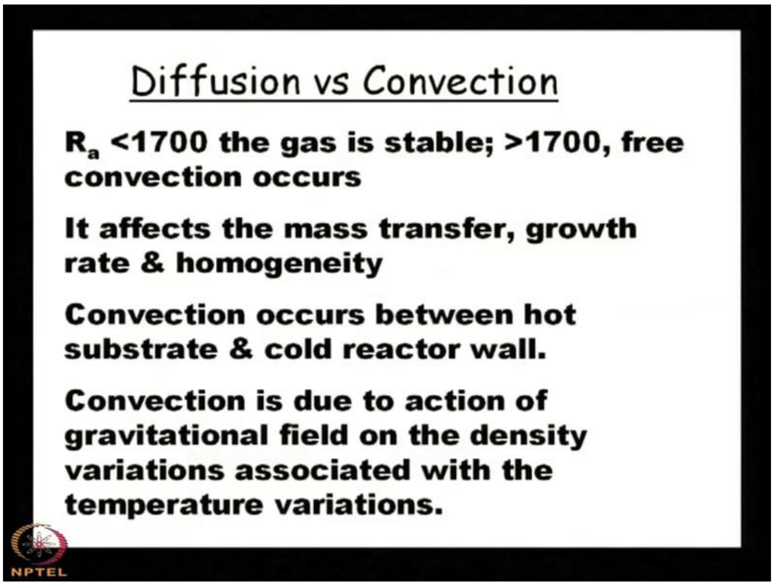

So, now the Rayleigh number will be less than 1700, the gas is stable and greater than 1700 free convection occurs you do not have any controls the convection will be there. It affects the mass transfer growth rate and homogeneity, so mass what is mass transfer mass transfer is the diffusion of the chemical species from main gas stream to the substrate. It must be the mass transfer will be a whole mass transfer that means all reactants, suppose if you consider that this indium phosphide will be grown. So, trimethyl indium and phosphine both molecules must transfer to the substarte side not that only t m i diffusion will be sufficient no because unless the same quantity of phosphine is there there will be no reaction.

So, one thing is the mass transfer and a growth rate as we have discussed that if the diffusion takes place in a improper manner then the growth rate will be very less. The homogeneity will not be there homogeneity means it is uniform layer there will be no deficiency of indium or phosphorous. It is a homogeneous film of indium and phosphorous indiumphosphide, sorry now convection the origin of convection.

We have discussed it occurs between hot substrate and cold reactor wall only then there will be convection if there is a temperature gradient. In the mass flow in the gas flow convection is due to action of gravitational field on the density variations associated with the temperature variation that is the textbook thing that you all know that since there will be a variation of the temperature.

So, the density will be different in some places, it will be rare in some places it will be denser and when it when the gravitational force is there. So, it will move like convection, so what we think what we see that Rayleigh's number and Reynolds's number it is Rayleigh and it is this two thing we have to consider. So, suppose if you now try to develop a reactor for a CVD for any material for a new material say for a nitrites that it remains scope for nitrites there is immense scope for ceramic thin films.

Suppose, you want to make with some CVD reactor then we have to consider the design of the reactor in this manner first you have to calculate or you must know the different parameters of the gas flow. Then, we have to calculate the Reynolds number or the Rayleigh's number and then you have to analyse what should be the diameter of your reactor what should be the angle what should be the flow rate so those things we have to optimise.

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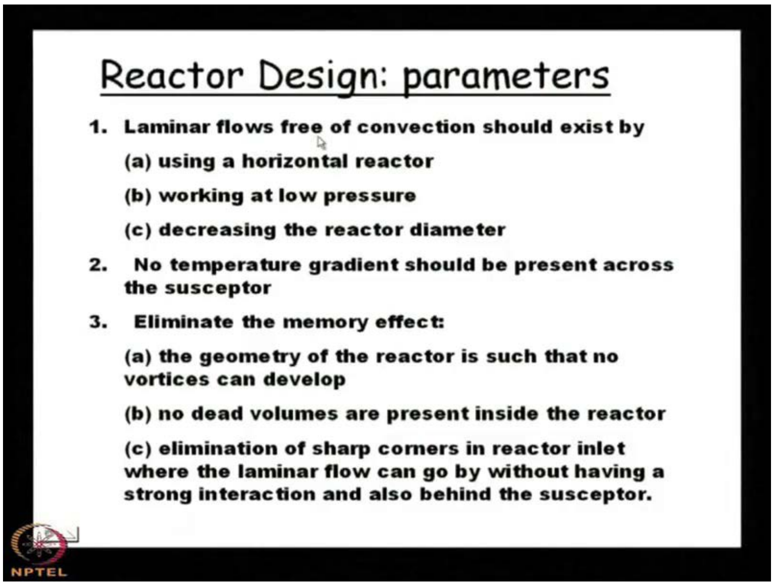

So, in a sense we can say that laminar flows free of convection should exist by using a horizontal reactor working at low pressure and decreasing the reactor diameter. So, a decreasing the reactor diameter how you decrease the reactor diameter the reactor diameter can be decreased if you make the susceptor inclined to make the susceptor inclined then what effectively the diameter reduces it is like this.

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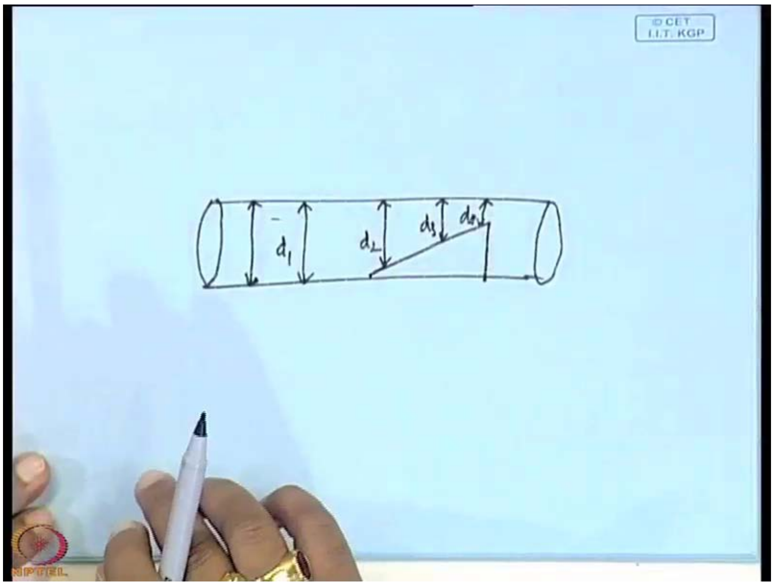

This is the uniform tube or reactor you want to make the diameter less the effective diameter becomes less effective diameter becomes less because here the diameter is say d 1 here, it is d 2 here, it is d 3 here, it is d 4. So, the design principle is based on those facts that you use a horizontal reactor you use low pressure and decrease the reactor diameter. Then, you can ensure laminar flows free of convection sir which diameter we will take in that case which diameter in the in the reactor.

In this reactor also if you see where the diameter is gradually decreasing, so inside the reactor where the actual growth takes place on the on the surface no. Here, you see that in this in this pictorial diagram the diameter of this whole thing this is the diameter actual diameter now putting this acceptor in a inclined manner means you are reducing the diameter. So, diameter basically inside the tube inside the tube do not think that the diameter of this thing, it is it is basically the cover of the thermoelectric wires, this is basically the casing of the thermoelectric wires this has nothing to do with the growth or the reactor.

It is basically a cover of the thermoelectric wires to measure the temperature because we are speaking we are we are telling that the temperature is 800 degree centigrade, how to measure that temperature how to table the temperature.

Now, no temperature gradient should be present across the susceptor eliminate the memory effect how by the geometry of the reactor is such that no vertices can develop vertices means the dead space behind the susceptor no dead volumes are present inside. The reactor means different edges different edges here also you can see if you minutely check this reactor. You will find that there are many edges inside and elimination of sharp corners in reactor inlet where laminar flow can go by without having a strong interaction and also behind the susceptor.

The flow must be smooth if there is any edge or some uneven surface so that means the flow will be obstructed so there will be some obstruction if obstruction takes place then there will be turbulence any obstruction will be turbulence.

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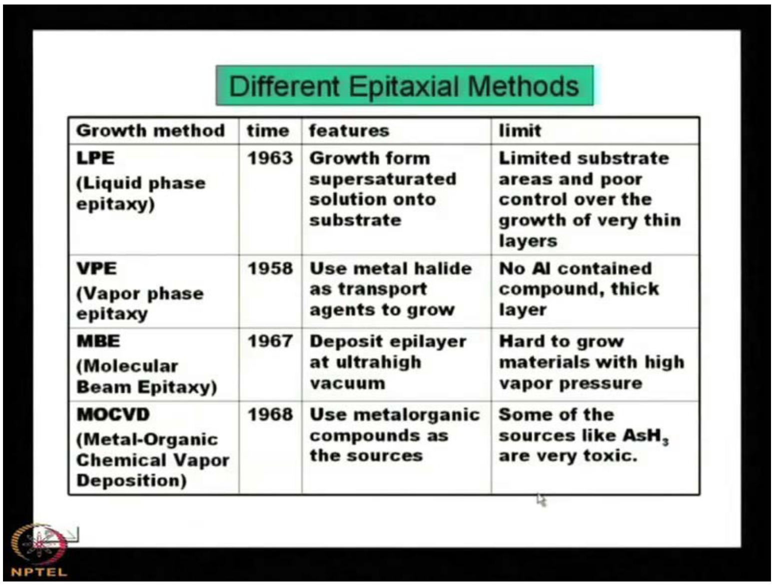

Different Epitaxial Methods

Growth method	time	features	limit
LPE (Liquid phase epitaxy)	1963	Growth form supersaturated solution onto substrate	Limited substrate areas and poor control over the growth of very thin layers
VPE (Vapor phase epitaxy	1958	Use metal halide as transport agents to grow	No Al contained compound, thick layer
MBE (Molecular Beam Epitaxy)	1967	Deposit epilayer at ultrahigh vacuum	Hard to grow materials with high vapor pressure
MOCVD (Metal-Organic Chemical Vapor Deposition)	1968	Use metalorganic compounds as the sources	Some of the sources like AsH_3 are very toxic.

So, this is a different epitaxial method we have discussed earlier also that is LPE VPE MBE MOCVD in our next class we shall discuss about this MBE.

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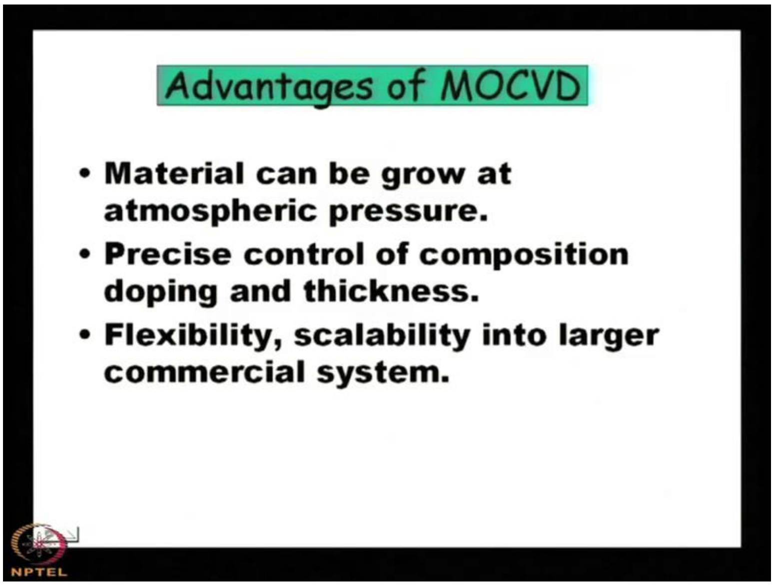

Now, what are the advantages of m o CVD growth it is that means advantages over the other CVD. Here, the material can grow at atmospheric pressure one advantage second advantage is that the precise control of composition doping and thickness one is composition second is doping and third is thickness. You can very precisely control precisely control means plus minus 1 angstrom plus minus 1 angstrom thickness.

You can control for doping it can be it can be 2 into 10 to the power 17 or 2.5 into 10 to the power 17 or 3 into 10 to the power seventeen you can precisely control. If you want it should be 1.8 into 10 to the power 17 it is possible using MOCVD very precise control in some device applications. In our later part of this class we shall show of this course we shall show that in some cases you need the doping very precise and flexibility scalability into larger commercial system.

That is possible if you can grow with say one centimetre by one centimetre substrate it can be grow by one four inch substrate as well because it is basically you are playing with the gas. If it is liquid or it if it is solid or it is a physical type of thing then it was not possible to cover the whole surface since you are using the gas so the whole surface can be covered.

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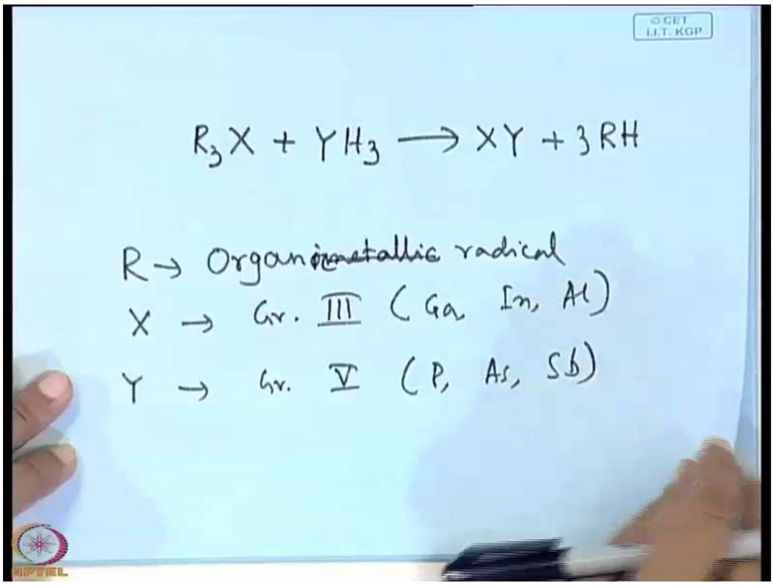

Now, in emissivity what is the reaction the reaction is that this R 3 x plus y h 3 what is R is an organometallic compound what is x is group three element that means gallium indium aluminium etcetera metallic. Also, help yes actually organic radical basically R x is organometallic R three is an organometallic, so you can say that it is a organo radical or organo, organo organic radical. It is known as organic radical methyl ethyl butyl, so these are the organic radical so R 3 x is the organometallic and y what is y y us group five element that means phosphorous arsenic antimony etcetera. So, if this is the case here you here you see that it is the reaction will give you x y plus 3 R h 3 R h right 3 R H, so that is the organometallic.

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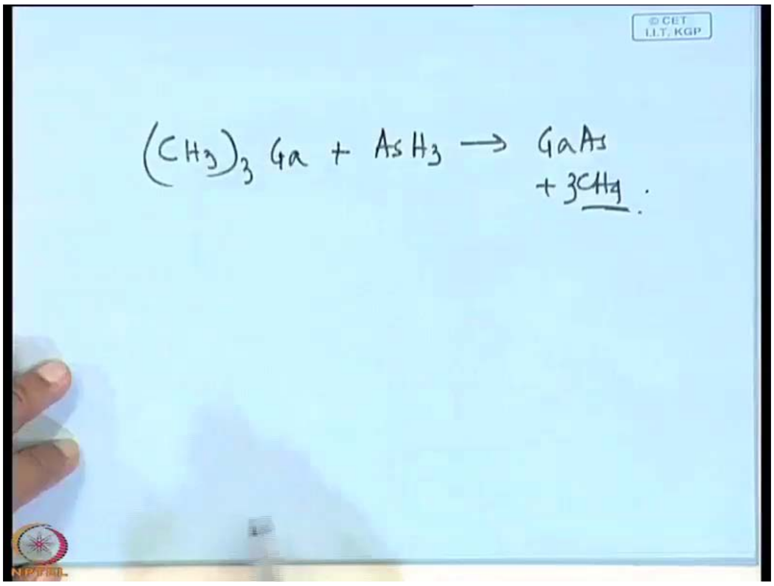

If you take one example you see that trimethyl gallium C H 3 gallium plus ASH 3 arsenic you will get gallium arsenic plus C H 4 that means methane. So, methane is the by product that is the problem with the MOCVD that is the problem means it is very toxic it is informable arsine phosphine is involved. So, care must be taken in a nutshell we can say that there are some advantages of MOCVD, but the problem is with the design of the reactor and the toxicity of the chemical associated with the MOCVD growth.

Thank you.