Processing of Semiconducting Materials
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Lecture - 20
Chemical Vapour Deposition – II

In the second part of our discussion on chemical vapour deposition, we shall take some examples of some materials, to grow those materials by CVD; we can we shall take the example of silicon, we shall take the example of gallium arsenide, we shall take the example of indium phosphate, because those are the important materials, which we take as example.

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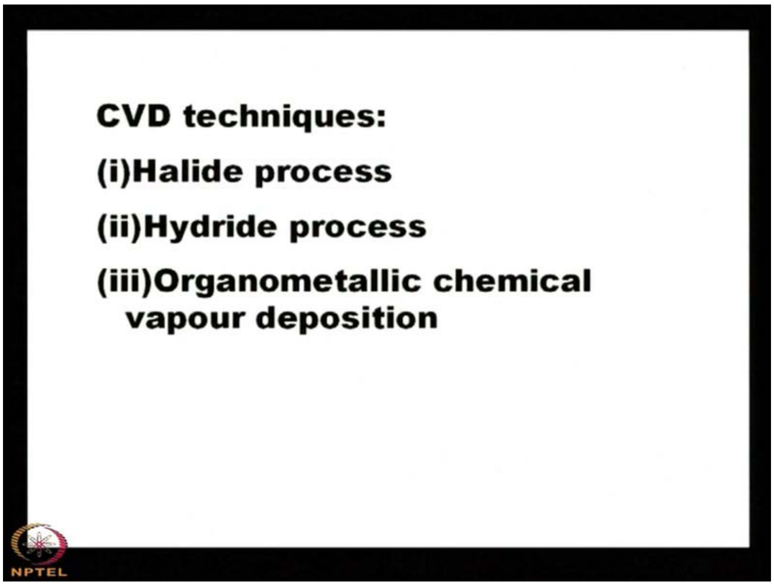

CVD techniques:

(i)Halide process

(ii)Hydride process

(iii)Organometallic chemical vapour deposition

And you see that, there are various CVD techniques apart from AP, LP, PE CVD, there may be halide process, there may be organometallic chemical vapour deposition process. As the name implies, the halide process means you start from the halide complex or compound of a material; halide compound means silicon chloride, chloride is a halide.

Student: Silicon

Hydride means, some compound containing hydrogen say arson. AsH_3 is the hydride, PH_3 is a hydride or organomatallic chemical vapour deposition that means chemical deposition from the organometallic sources. Organometallic sources means, the source containing some organometallic compounds. Organometallic means, it is a organic compound of some metal say gallium.

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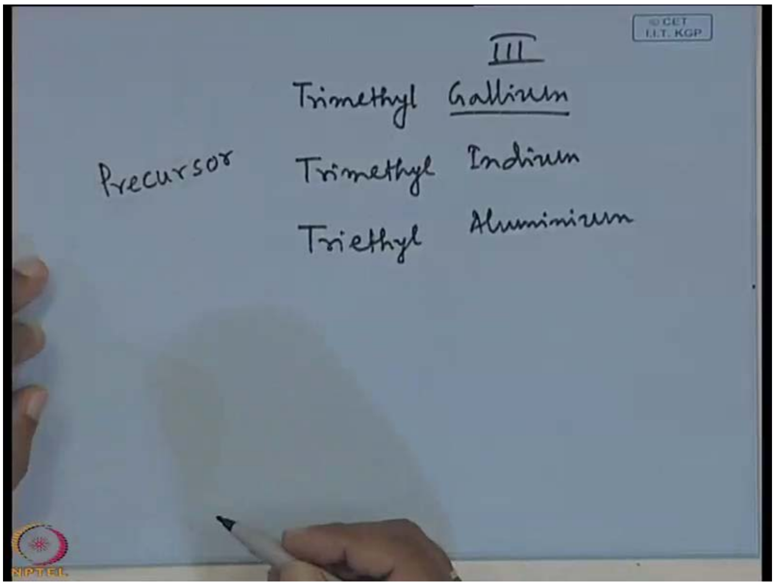

III

Trimethyl Gallium

Precursor Trimethyl Indium

Triethyl Aluminium

Like this say trimethyl gallium, trymethyl gallium. That means gallium is a metal in group three this is group three, of the periodic table. And trymethyl is the organic compound so, trymethyl gallium is a organometallic. Similarly trymethyl indium, that is also a organometallic of indium. Similarly tryethyl aluminium, tryethyl aluminium it is also an organometallics of aluminium. So, it can be trymethyl, it can be tryethyl.

Any organic organometallic source, so that is a different chemistry. There are some personal who work on organometallics, there are some advantage of organometallics sources, these are the basically known as the precursor P R E C U R S O R precursory, you have to start from a precursor. Your precursor can be halied, your precursor can be hydride, your precursor can be organometallic. So, these are the precursor to start with a reaction.

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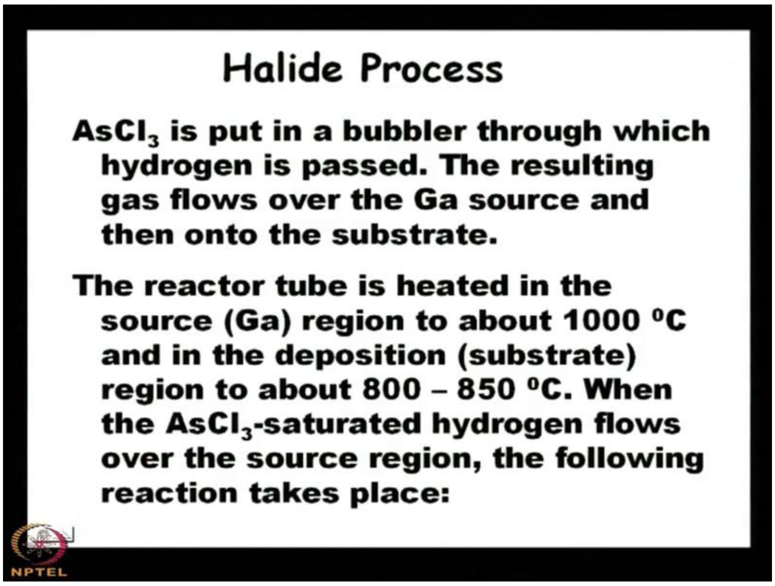

Halide Process

$AsCl_3$ is put in a bubbler through which hydrogen is passed. The resulting gas flows over the Ga source and then onto the substrate.

The reactor tube is heated in the source (Ga) region to about 1000 °C and in the deposition (substrate) region to about 800 – 850 °C. When the $AsCl_3$-saturated hydrogen flows over the source region, the following reaction takes place:

Now, if you see the halide process, you will find that in halide process, say for gallium arsenide for growth of gallium arsenide. As C l 3.

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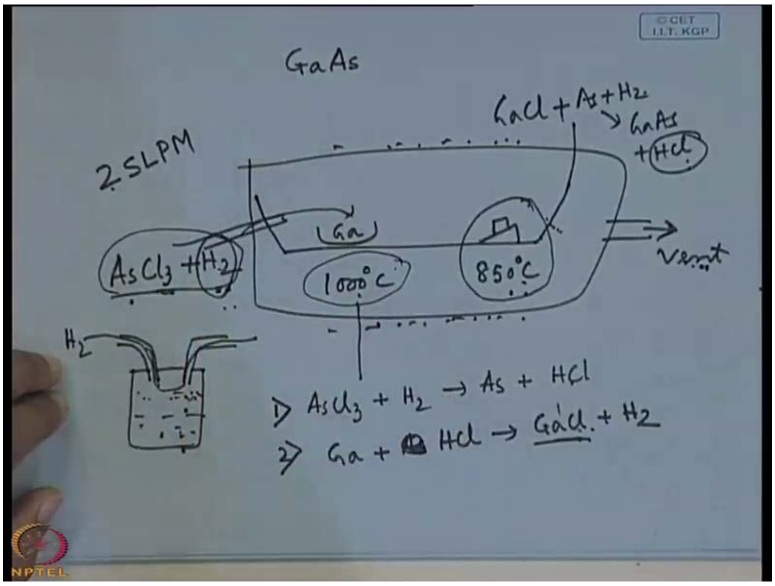

As C l 3 is put in a bubbler through which hydrogen is passed. What is AsCl3?

Student: Arsenic flouried.

Arsenic fluoride so it is a halied, halide of group five, because arsenic is the group five of the periodic table. And you can ask me sir why AsCl3, what is the speciality of AsCl3, that is more speciality except that it is liquid, high purity liquid. Similarly gallium is also a liquid at room temperature, you know that gallium is a liquid. The advantage of liquid is that, you can purify it by successive distillation method, you can purify a liquid by the method of successive distillation. Because in semiconductor the purity is very important. So, $AsCl_3$ being a liquid is put in a bubbler through which hydrogen is passed. The resulting gas flows over the gallium source and then on to the substrate. What is the substrate the substrate obviously will be gallium arsenide, because we would like to grow gallium arsenide.

The reactor tube is heated in the source region to about to about thousand degree centigrade, and in the deposition region to about 800 to 850 degree centigrade. So, that means you see that from this discussion it is evident, this is a two zone furnace, one zone is thousand degree containing gallium, another zone where the substrate is kept, it is 800 to 850 degree centigrade. So, that means, you can think like this is thousand degree centigrade, this is 850 degree centigrade here the substrate is kept, here in a boat molten gallium is there.

So, what happens $AsCl_3$ plus hydrogen, is passed to the reactor chamber this is inside a reactor chamber this is inside a reactor chamber. There is vent that means the by products will leave the reactor chamber, and obviously there will be heating elements, this is heating elements you can control, so that in this region the temperature is 1000 degree and this region 850 degree centigrade.

Now, we have talked about a bubbler, in a bubbler there are there is one inlet, and there is one outlet, and you can change the temperature, you put $AsCl_3$ in the bubbler, $AsCl_3$ there is one inlet, there is one outlet. Depending on the temperature of the bubbler, this space will be filled with the vapour of $AsCl_3$. Because it is all ah already a liquid, and the vapour pressure is a function of the temperature right, so at a particular temperature say 40 degree 50 degree 60 degree whatever be the temperature, there will be sufficient vapour pressure on the surface of the $AsCl_3$ inside the bubbler. So, when hydrogen will pass through the inlet, that hydrogen will carry not the liquid $AsCl_3$ remember, liquid cannot be carried, it will carry the vapour of $AsCl_3$ it will carry the vapour of $AsCl_3$ there. So, when I write this type of a thing that means it is the hydrogen gas high purity hydrogen gas, and the vapour of $AsCl_3$ coming out from the bubbler, with the help of hydrogen.

The reactor tube is heated in the source region to about thousand degree centigrade, and in the deposition region to about eight hundred degree centigrade. When the $AsCl_3$ saturated hydrogen flows over the source region, the following reaction takes place that means this $AsCl_3$ saturated H_2 vapour it will come to the source means the gallium region, first it will come to the gallium region. So, what reaction will take place this is the reaction that will take place.

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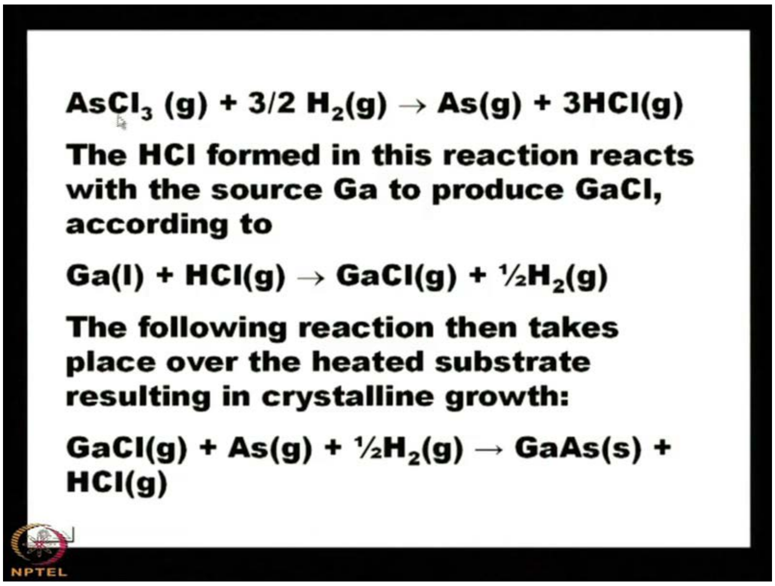

$AsCl_3(g) + 3/2\ H_2(g) \rightarrow As(g) + 3HCl(g)$

The HCl formed in this reaction reacts with the source Ga to produce GaCl, according to

$Ga(l) + HCl(g) \rightarrow GaCl(g) + \frac{1}{2}H_2(g)$

The following reaction then takes place over the heated substrate resulting in crystalline growth:

$GaCl(g) + As(g) + \frac{1}{2}H_2(g) \rightarrow GaAs(s) + HCl(g)$

That means see, AsCl3 gas g stands for gas, plus 3 by 2 H 2 which is also gas, it becomes arsenic gas and three HCL gas. So, this is the reaction which takes place, first this reaction will take place, So, what will happen HCL will be formed, HCL gas in the form of gas. Then the HCL formed in this reaction reacts with the source gallium, to produce G A C l according to this reaction. G A what is this is a l, liquid so, gallium liquid plus HCL gas, you will get gallium chloride it is a gas, plus H 2 it is also gas. In the next phase we shall see that, this G A C l, and hydrogen will react with this arsenic, to form gallium arsenide you see the following reaction then takes place over the heated substrate resulting in crystalline growth of gallium arsenide.

So, here at thousand degree centigrade, what happens first AsCl3 reacts with hydrogen, to form A s plus HCL, I am not balancing the reaction. As plus HCL then this is the first step step one, step two, then gallium is a liquid it reacts with this A s is reacts with this HCL, G a C l plus hydrogen will be evolved, this G a C l. Then the next reaction will take place in this region. Here the temperature is less compared to this, so there will be condensation there will be condensation because the temperature is less. You think of the bulk crystal growth, where the molten gallium arsenide, is kept in one boat and a seed is, what? pulled from the melt. So, what we find we find that at the inter phase, between the molten state and the seed there will be a temperature difference, where the crystallization takes place, the condensation will take place, because of the temperature gradient. Here also there is a temperature gradient from 1000 degree to 850 degree centigrade, so there will be crystallization of the gallium arsenide So, here the reaction will be like this G a C l, plus A s plus hydrogen you will get gallium arsenide, plus HCL gas. So, what is the by product what is the by product.

Student: H 2 A s c l.

H C l. H C l and H 2 HCL and H 2, these are the by product, and also, the un reacted AsCl3, because there is no guarantee. Completely.

(( )) it will completely it will be decomposed, so that is the by product. Now, we think of the process step 7 process step 6 and 7 in possessive 6 and 7 what we see.

Student: (( ))

The desorption of the by products, and diffusion on to the main gas stream, so these are the by product, this HCL is the by product, H 2 is that the by product, and a reactor at AsCl3 is a bi product, so these the by product which you find and this will be diffused on to the main gas stream and it will out through the vent line, I shall show you a one chamber of CVD in my laboratory. So, all those things it will be very easier for you to (( )) where is the gas line, where is the inlet, where is the outlet, where is the (( )) toot, where is the susceptor, how the susceptor is put inside the reactor chamber, how the substrate is kept on the susceptor. So, and how you can more important thing is how you can control the various kinds of gases, Because, until now we have not discussed about any controlling parameter.

Suppose you need some, 10 cubic centimetre of gas, 5 litre of hydrogen you need, per hour, or per minute, so those controlling parameters how it can be controlled because where is the control set up, it is totally, by the computer control or manually you can also, undertake the growth. Normally there are I am talking about this hydrogen, normally this hydrogen you know what is the favourite of this hydrogen, the favourite of of this hydrogen is typically, two s, l, p, m, what is s l p m?

Standard litre per.

Standard litre per minute per minute, per minute two litre of hydrogen, you have to flow through the bubbler, then only it will be possible for, then only it will be possible for the hydrogen, to carry this AsCL3 to the reaction place, Otherwise there will be no flow, we have to make the flow on so this is the two s l p m. In some cases I shall show you that it can be five six litre per minute.

So, that means huge quantity of gas is required per minute. So, if there is a growth of say 60 minute, so per minute if there is two litre, for 60 minute how many litres, hundred twenty litres per hour. So, you have to sustain the flow of hydrogen, through that rate, to support the growth. So, those can be controlled, how you how you can ensure that it must be two s l p m, not three or not four or not one, there is must flow controller there is must flow controller you can set the must flow controller, and the must flow controller will control in that manner, I shall show you that, set up.

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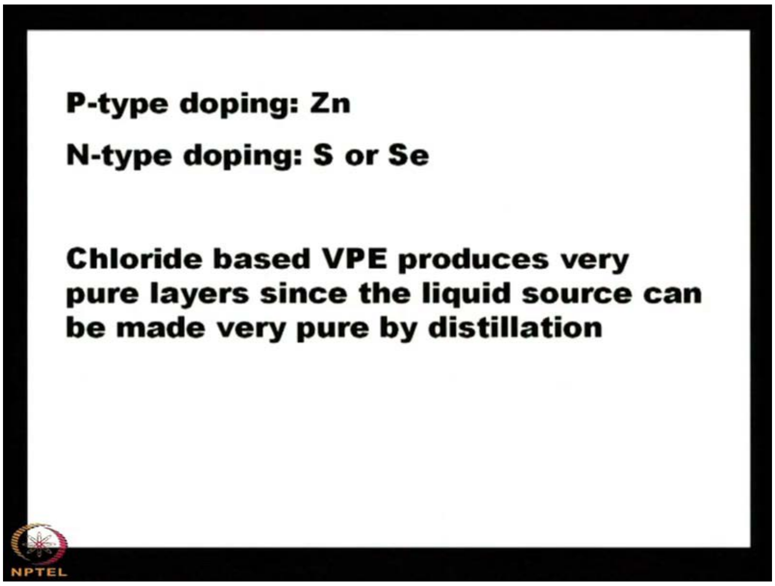

P-type doping: Zn

N-type doping: S or Se

Chloride based VPE produces very pure layers since the liquid source can be made very pure by distillation

So, this is the halide type of growth, and for P type doping, you see that zinc is used that we have discussed many times; and for n type doping sulphur or selenium, in the form of H 2 s, or HSe, H 2Se hydrogen selenide hydrogen sulphide, those are used for n type doping. One important aspect of this chloride based VPE, that it produces very pure layers, since the liquid source can be made very pure by distillation; that is the important aspect of this thing, but what is the problem with the chloride or halide, it is very corrosive. Chlorine is very corrosive, so special care must be taken, so that is also there. In all the processes you will find some advantages and disadvantages, is always there.

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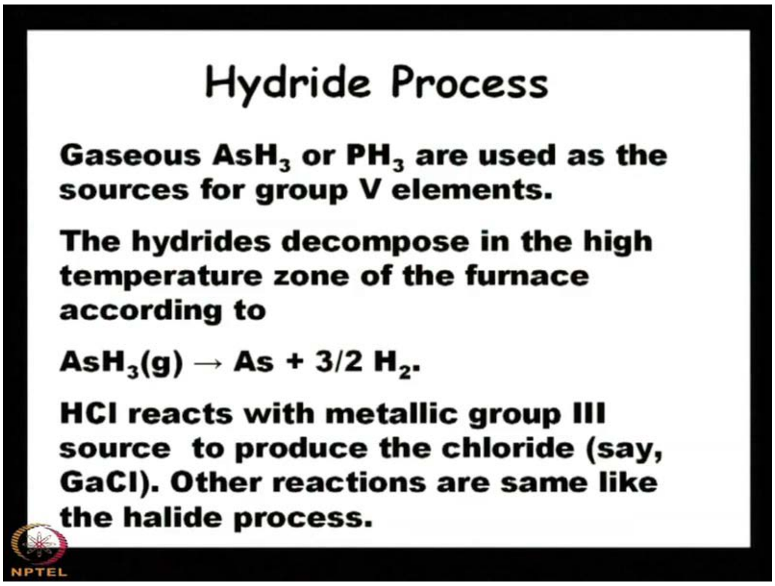

Hydride Process

Gaseous AsH_3 or PH_3 are used as the sources for group V elements.

The hydrides decompose in the high temperature zone of the furnace according to

$AsH_3(g) \rightarrow As + 3/2\ H_2$.

HCl reacts with metallic group III source to produce the chloride (say, GaCl). Other reactions are same like the halide process.

Now, if you take the example of hydride process, if you take the example of hydride process you see that in hydride process, gaseous ASH3 or PH3 are used as the sources for group five elements, that means you see that all the time we find, it is the game with the group 5 elements Chloride, in case of chloride we have used AsCl3, arsenic chloride. Here it is the arsenic hydride, that means arsine, or hydrides of phosphorous that mean phosphine, so all the time we are using the group five elements, either in the halide form or in the hydride form, the hydrides decompose in the high temperature zone of the furnace according to this. That means arsine is decomposed into arsenic and hydrogen, then this HCL, reacts with metallic group three source to produce the chloride say GaCl, that means you have inject HCL gas remember, we have to inject HCl gas. So, in zone one where there will be thousand degree centigrade, this HCL reacts with gallium, to form gallium chloride.

And the other reactions are same like the halide process, halide process means you see that this type of thing, so this reaction gallium plus HCL, here a c l three is converted into HCL, so there is a reaction between gallium and HCL, in the hydride process you find that there is no HCL, so we have to make input of HCL, that HCL gas will react with gallium to form GaCl, and these arsenic comes from AsH3 decomposition of AsH3 not C l 3, in halide it is C l 3, but in hydride.

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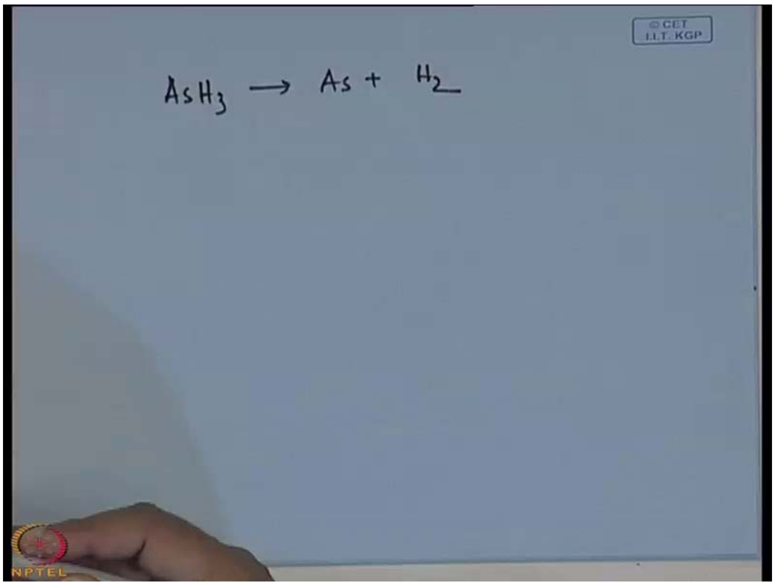

$AsH_3 \longrightarrow As + H_2$

This arsenic comes from the decomposition of AsH3, it decomposes into AS plus hydrogen, then the rest of the reactions are the same reactions.

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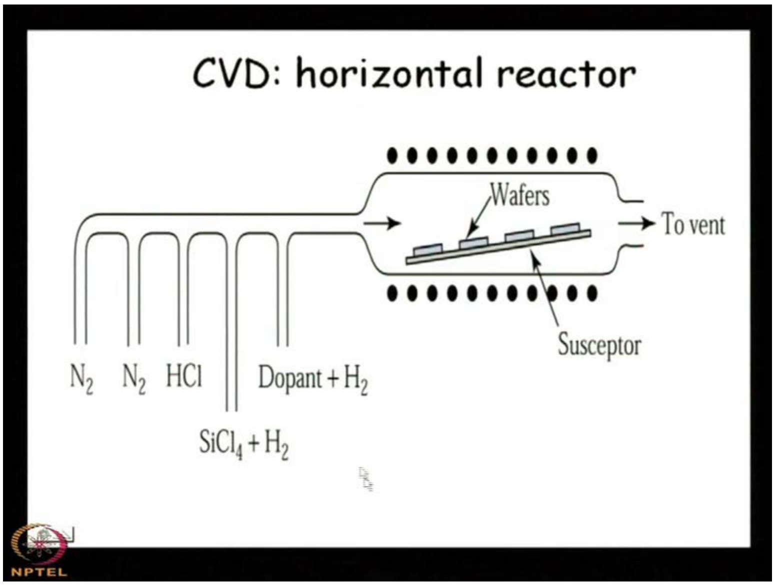

CVD: horizontal reactor

This is a CVD reactor of horizontal reactor, why it is horizontal, because the gas flow is in the (( )) parallel to the surface, parallel to the surface. Here you see that there are four wafers which are placed on the susceptor, the susceptor is graphite, and this is various kinds of gases which are sent to the reactor chamber this is for the silicon, not gallium arsenide because here we have used SiCl4 that we shall discuss also.

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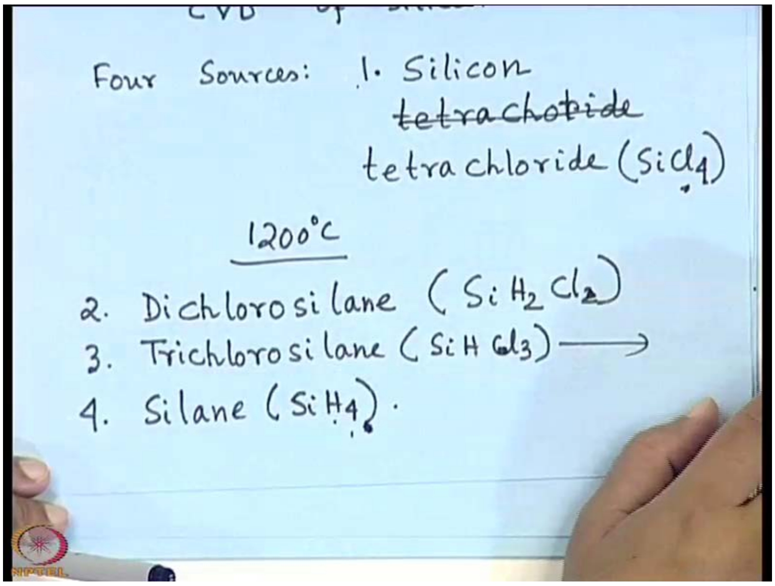

Four Sources: 1. Silicon ~~tetrachotide~~ tetrachloride ($SiCl_4$)

1200°C

2. Dichlorosilane (SiH_2Cl_2)
3. Trichlorosilane ($SiHCl_3$) →
4. Silane (SiH_4).

So, if we now discuss about the CVD of silicon you see that there are four sources, one is silicon tetrachloride, silicon tetrachloride, tetra chloride silicon tetrachloride it is SiCl4, this is the most important precursor which are used which is used for the silicon CVD, industrially this is used, but the temperature is quite high, twelve hundred degree centigrade its almost twelve hundred degree centigrade temperature is required.

Because, you have to decompose this SiCl4, you have to de compose this SiCl4, there are other sources because, as I mentioned that there are four sources one is silicon tetrachloride number two is dichlorosilane, that means SiH2 Cl2, number three is trichlorosilane, SiHCl3, and number four is silane so these are the four important sources, one is silicon tetrachloride, another is dichlorosilane, number three is trichlorosilane, and...

Student: Sir it is SiCl4 silane. (( )) Si c.

SiCl4 is the silicon tetrachloride. Now, what we see we see that, if we start from silane Si H 4 you see that in this case, one h is replaced by Cl, H is replaced by Cl or if we start from SiCl4, Cl is replaced by H, here you see that in this trichlorosilane, one chlorine is replaced by one hydrogen. If this is the case, then 50 degree temperature can be reduced to decompose that material. For one substitution, of chlorine by hydrogen, fifty degree centigrade temperature can be reduced to decompose, that means here it is the temperature is twelve hundred degree centigrade, here the temperature will be eleven hundred fifty degree centigrade.

similarly here 1100 degree centigrade, in this case thousand degree centigrade, because you see that here all the four chlorine atoms have been substituted by hydrogen atoms. For every substitution there will be a reduction of fifty degree centigrade. So, lower temperature growth is possible, but purity gas handling criteria those are there, so that is why only the silicon tetrachloride is the most effective precursor for silicon growth. So, we see that there are four sources, one is silicon tetrachloride, and dichlorosilane trichlorosilane and silane those can be used for the silicon CVD. Here you see that silicon tetrachloride, is sent to the horizontal reactor by the application of hydrogen, that means hydrogen has a carrier gas, right sometimes we have seen that in some cases HCl is required.

So, there must be some inlet of HCl. Then there must be some inlet of dopant, dopant means if you can grow p type or n type silicon then you have to use the dopant. So, different kinds of gas lines are there, you can use this gas lines for sending different gases to the reactor chamber.

(( )) it it it may be (( )) mistake, one will be dopant plus H 2 another will be another dopant plus H 2, it can be H 2 it can be N 2 also N 2 you can use, but problem is as we have discussed it is a purity, handling nitrogen is very easier than hydrogen, but problem is with the purity, we need 9 n or 10 n purity, and you cannot pure you cannot purify nitrogen to that level, hydrogen is very easy to purify because of the diffusion of hydrogen through the palladium cell at three hundred degree centigrade. So, at the input in a palladium cell, you send hydrogen, impure hydrogen, and if you heat the palladium cell at three hundred degree centigrade at the output you will get nine n 10 n pure hydrogen, say very easy to make. Even in the laboratory you can use the palladium cell, through which the hydrogen can be passed

If you come to my room I shall show you how a palladium cell looks like (( )) very easy fabrication were now...

Student: (( ))

No you cannot, first thing is that you know that it is very, very costly, second thing is that purification, not very easy like hydrogen, and availability, where is the helium availability, hydrogen and nitrogen is widely available.

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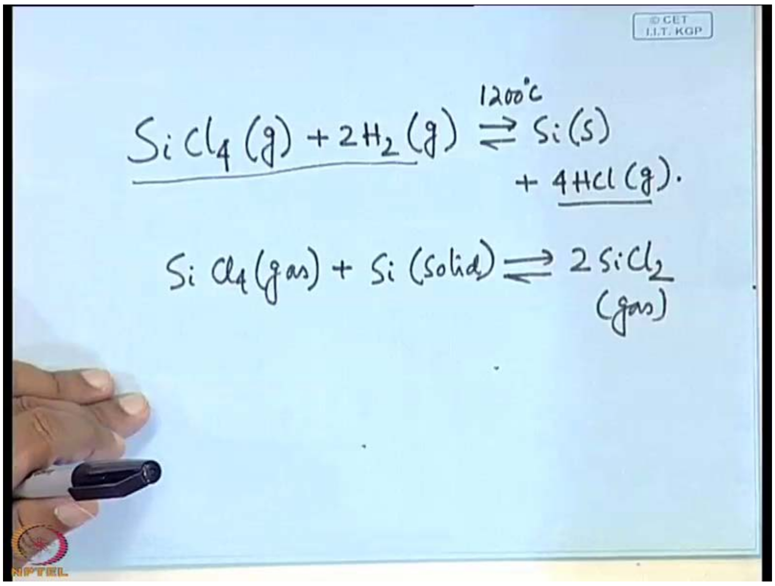

$$SiCl_4(g) + 2H_2(g) \xrightleftharpoons{1200^\circ C} Si(s) + 4HCl(g).$$

$$SiCl_4(gas) + Si(solid) \rightleftharpoons 2SiCl_2(gas)$$

Now, if you see the reaction it is SiCl4 silicon tetrachloride it is gas, it reacts with, hydrogen gas, to form Si solid plus 4 HCl gas, this is the overall reaction. Because your input was silicon tetrachloride, and that silicon tetrachloride with hydrogen reacts with hydrogen, in at that temperature at 1200 centigrade, it is 12000 degree centigrade, silicon solid plus HCl. So, what is the by product? The by product is...

It is HCl.

Obviously HCl is the by product; another is the unreacted this part, unreacted this part; that is also very important, that you have to sweep that gas throughout the through the reactor towards the vent. And another thing is that this SiCl4 gas, when reacts with silicon solid, 2 SiCl2 gas is formed. So, what we see from this reaction, you we see from this reaction that, this solid silicon which you have formed, it can react with silicon tetrachloride, to form SiCl2 gas that means, if the quantity of SiCl4 is large what will happen?

Student: (( ))

There will be, reversible reaction and so, instead of forming the film, the film can be etched, solid silicon means what, solid silicon means the film. So, the top of the film can react with silicon tetrachloride, to form SiCl2 that means, there will be etching, there will removal of the silicon film from the substrate. So this SiCl (( )) is a by product... Which on which one... Second one which is related to silicon... Yes but you do not want it...

Student: (( ))

You cannot avoid it, but it you want it because we have started to grow silicon. Why we shall loose silicon because this reaction, through this reaction we shall loose silicon.

Student: Sir Si Cl2 is a stable.

Sicl2 is the gas, so basically it will go out from the reactor. This will become is tetra (( )).

Student: (( ))

No I am not making the balance reaction, only thing is that SiCl2 will be formed as a gas and it will go out from the vent.

Student: (( ))

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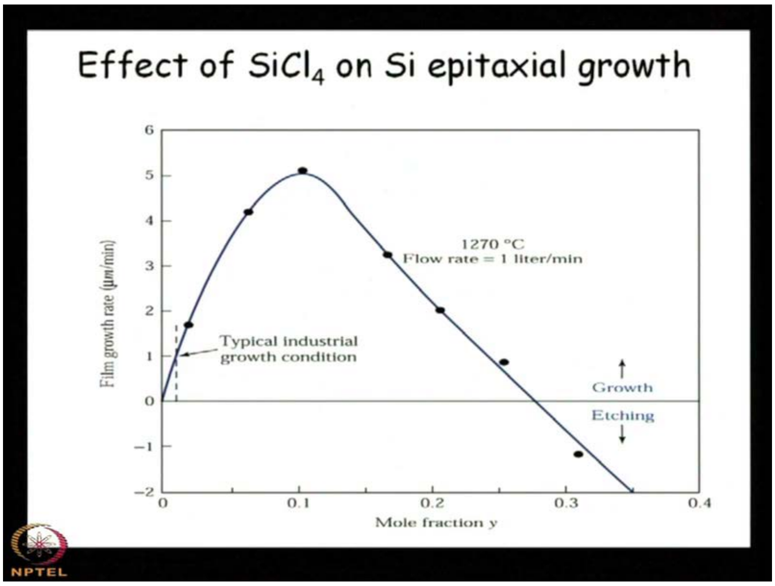

Effect of $SiCl_4$ on Si epitaxial growth

So, what people do you have to quantify this SiCl4, in a in this graph you will see that, this is the quantity of SiCl4. So, as the quantity of SiCl4 increases the growth rate increases, for a particular value it attends the peak, then as you increase the SiCl4 the growth rate decreases, Then if you further increase the SiCl4 then, there will etching because you see this is a 0 line. Above the 0 line it will be growth, below the 0 line it will be etching that will be etching. So, you have to choose very small amount of SiCl4; that means the growth must be kept in this region, only in this region.

In this region you will find that the growth rate is not so high like this portion, but you need not to worry about the etching of your material, and also it is a linear so, you can quantify the growth rate from the quantity of SiCl4. Very small amount of SiCl4, you have to take. So, that is not applicable for, silicon epitaxial growth this applicable for all materials. When you use a particular material in the vapour phase either in fluoride or in hydride, form you have to check whether there will be any reversible reaction which will degrade the performance of your growth process, whether there will be etching whether there will removal of your material from the surface.

If there is substantial removal from the material then, that will be not be cost effective, and this high purity material you have to lose that will go as worst product. we cannot use those thing so, that means the costing will be very high, because all the material what whatever you use, even if we use HCl or H2 gas or N2 gas or SiCl4 gas, it is very costly, because of its purity level. It is not industrial grade or normal laboratory reagent. So, you have to very careful about the quantity or the amount of SiCl4 for silicon epitaxial growth.

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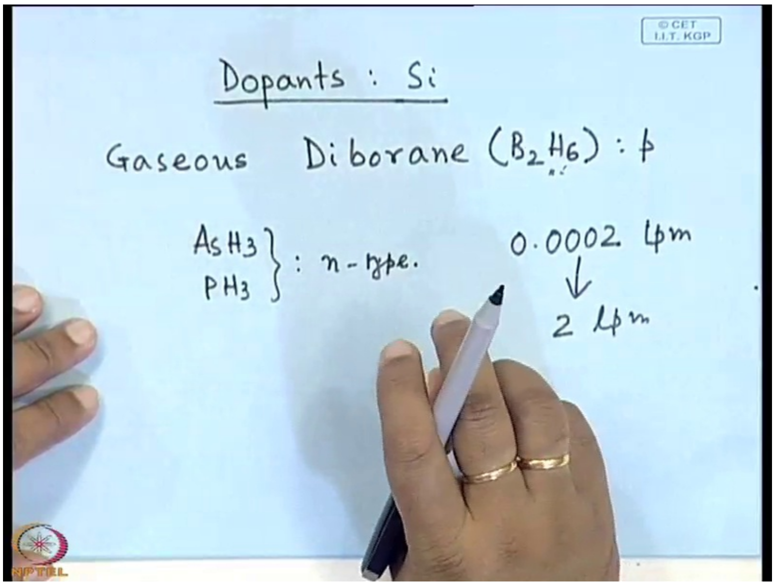
Dopants : Si

Gaseous Diborane (B_2H_6) : p

AsH_3
PH_3 } : n-type.

0.0002 μm
↓
2 μm

Now, what are the dopants, for silicon growth, gaseous diborane, it is p type and arsine phosphine n type. So, you can use two types of dopants one is the gaseous diboran, B2 H6 for p type and As H3 PH3 n type. But here one point you must remember that this is diluted what is dilution and how the dilution is made, and why dilution when I talk about this diborane or arson or phosphane, I am use the I have used the term dilute this material which material this B 2 H 6 or As H 3 or PH3 why?

Student: (( ))

Why dilution is required, dilution is required because of two reason one reason is that

Student: It is in toxic...

No not for toxic it is...

Student: (( ))

No it is to control, because we have seen in our bulk crystal growth that very minute amount of this material is required, can you remember one example, where I have used that for 50 k g fifty k g of silicon, only some three to five milligram of dopant was used, so how you'll control, for controlling you have to dilute how you will dilute, you have to dilute with hydrogen mix hydrogen more and more, so that it be diluted, and there is a calculation procedure you can use a computer simulation program. That what amount of hydrogen is required for the dilution of what amount of As h three or PH3, that you can calculate. Using some simulation program or using some chemical calculation, you can arrive at how much dilution is required. So, dilution means you have you can send the exact amount one point second point is that you can control also, very small amount is required so control becomes very difficult unless you make it very dilute.

Suppose without dilution say 0 point 0 0 0 2 litre per minute is required, without dilution 0.0002 controlling is very difficult to make. Even if you have a very good mass flow controller, because of the practical limitation of the mass flow controller, but if you can dilute it by 10 to that power 4 then it becomes 2 LPM, it if it becomes 2 LPM, then controlling of 2 LPM is very very easier to make by the mass flow controller. So, one thing is the control another thing is the amount very minute amount is required. So, theoretically you can have without dilution also, but how you will control it.

So, that is why hydrogen is mixed with this dopant gaseous sources, for its control and minute quantity interaction in the reactor chamber so, physics people will (( )). Now, one thing we shall discuss about this substrate the effect of substrate that is very important

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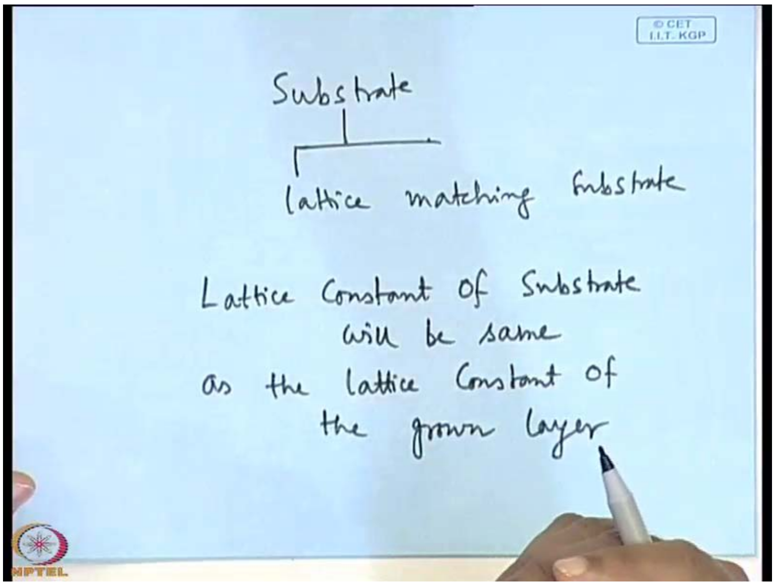

Substrate

lattice matching substrate

Lattice Constant of Substrate
will be same
as the lattice Constant of
the grown layer

You see that, effect of substrate is very important to make, that for epitay you have use lattice matching substrate, lattice matching substrate means, the lattice constant of the substrate will be same as the lattice constant of the film to be grown on the substrate. Lattice constant of substrate will be same as the lattice constant of the grown layer. Grown layer means what is grown layer grown layer means the thin film or the epitaxial layer you are growing basically

Now, if there is a mismatch between the lattice constants then what will happen?

Student: Dislocation.

Dislocation, but there is another important aspect that is, why I am again introducing this thing. That you have to use some temperature higher temperature during growth in almost all the CVD techniques you will find that it is 600 800 1000 degree centigrade's temperature is involved. If the substrate and the grown layer are of different material, suppose your substrate is silicon and you are growing gallium arsenide, then what is the problem apart from the lattice mismatch, the thermal expansion coefficient of the silicon is different from the thermal expansion coefficient of gallium arsenide.

So, there will be more stress, there will more stress so not only that it is a normal lattice mismatch, that is applicable for normal room temperature value if, your material and the substrate is of same constant then it is you are using silicon on silicon, you are using gallium arsenide on gallium arsenide its whatever be the temperature the thermal expansion coefficient will be the same for both cases, so there will be compensation right. But if you use different type of substrate then the thermal expansion coefficient is different, and because of the thermal expansion coefficient there will be thermal stress also, that will give you the dislocation. Then sometimes we find that suppose you want to grow gallium arsenide on silicon, then very small very thin gallium arsenide layer is can be grown without and defect very small why?

Because, there will be a stress but if the layer is very small then there will be no stress, that is known as the critical thickness. For all the material you will have a critical thickness, above the critical thickness there will be dislocation, up to the critical thickness there will be no dislocation, but if your critical thickness is say 6 angstrom 8 angstrom, can you grow with that precision no you cannot grow in that precision so, that is the problem.

If you can grow then it is possible to grow gallium arsenide on silicon, but you have to keep the critical thickness the thickness of the grown layer below the critical thickness, below the critical thickness it is possible to grow any kind of layer, but the critical thickness itself is very small it is the order of 8 angstrom 6 angstrom 10 angstrom, which normally you cannot grow even if you have very good epitaxial machine. Because if the growth rate, you say 8 angstrom per second, then how you will grow 6 angstrom layer per 8 angstrom layer, it will have more than less than one second, but less than one second control is very difficult to make. So, always you will find that you cannot grow below critical thickness it is always above critical thickness. If it is always above critical thickness then you will find that there will be dislocation.

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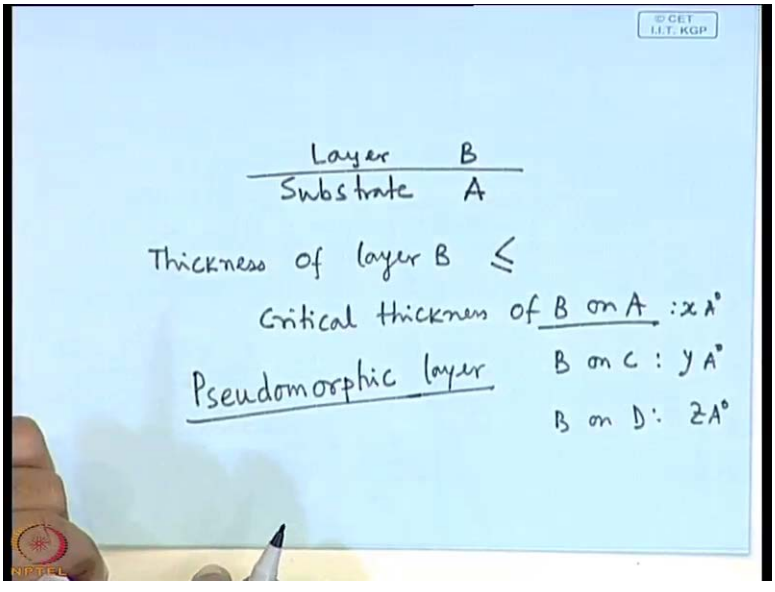

Layer B

Substrate A

Thickness of layer B ≤
Critical thickness of B on A : x A°
B on C : y A°
B on D : z A°

Pseudomorphic layer

We can summarize in this manner that substrate say substrate is a, layer is b, thickness of layer B most be less than equal to critical thickness, B on B remember that B on A. That means critical thickness will also change critical thickness will be different for different pair of materials, for b on a it can be x angstrom, for b on c it can be y angstrom, for B on D it can be z angstrom. So, it depends on a pair of material remember that a critical thickness is not a fixed dimension or fix thickness it depends on a pair of material. (( )) the thickness of layer b must be less that equals to the critical thickness of b on a, which is x angstrom right Now, this is very important and if this is possible that the thickness of the layer b is less equal to critical thickness of b on a, then this is known as the pseudomorphic layer that layer is known as the pseudomorphic layer. Remember that for pseudomorphic layer it will free from any kind of stress or strain.

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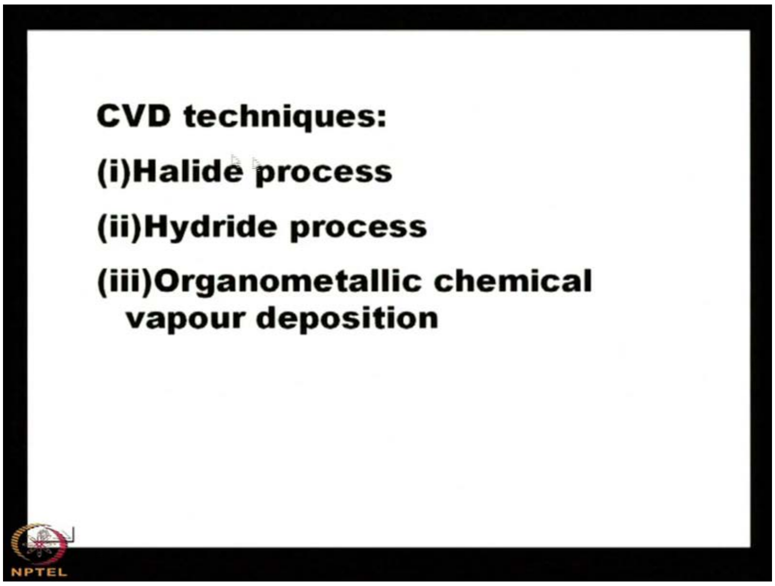

CVD techniques:

(i)Halide process

(ii)Hydride process

(iii)Organometallic chemical vapour deposition

Now, one important aspect of this thing you see that we have discussed that there are three CVD techniques one is the halide another is the hydride and third one is the organometallic chemical vapour deposition. So, we shall conclude today's discussion with that organometallic chemical vapour deposition some parts of the organic organometallic chemical vapour deposition. In organometallic cases it is known as the MOCVD or organometallic chemical vapour deposition same thing or metal organic vapour phase it is not coming.

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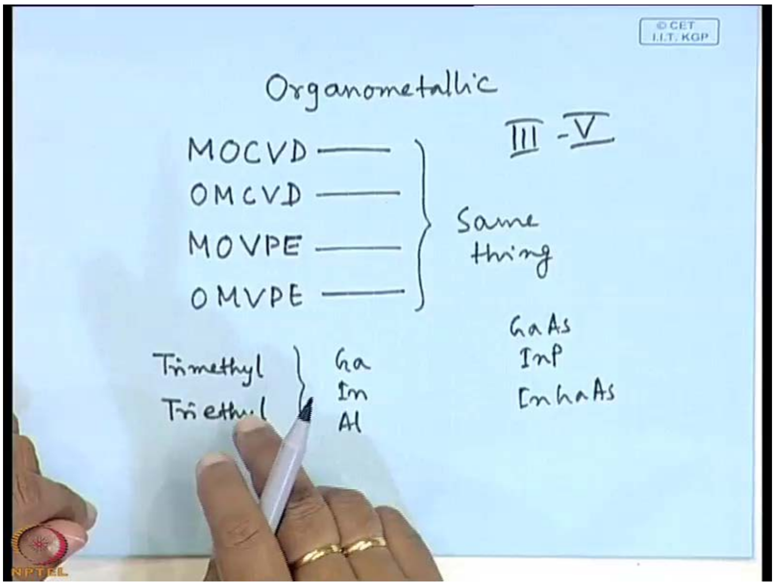

Metal organic vapour phase epitaxy. So, it can be MOCVD, it can be OMCVD, it can be MOVPE, it can be OMVPE, the same thing, same thing. The main aspect of this growth is that we are using a CVD technique and in all the CVD technique the process one to seven is fixed, so here also process 1 to 7 we shall apply. Only thing is that we shall not use any hallied sources or hydride sources, rather we shall use metal organic sources. For metal organic sources or organometallic the same thing, we shall use the trimethyl sources or triethly sources, not of group 5, not of arsine or phosphane that of the group 3, that means gallium or indium or aluminium, of gallium, or indium, or aluminium, if we talk about the 3 5 semiconductor growth. If you grow other type of material then you have to choose some efficient precursor for that material, organometallic efficient precursor.

Say silicon, if we if you have silicon organometallic precursor then you can grow silicon also, so you must have a organometallic precursor that is the precondition, material having organometallic precursor can be grown using MOCVD, material having no organometallic precursor you cannot by MOCVD technique you have to use different kinds of techniques, but this is very fruitful and very efficient and very popular technique for 3 5 semiconductor growth, 3 5 semiconductor means gallium, arsenide, indium phosphate, indium gallium arsenide, etcetera indium gallium phosphate, that means any combination of group 3 and group 5 elements of the periodic table.

In group 3 what are the materials gallium indium aluminium, in group 5 what are the elements, arsenic phosphorous antimony, So, those things you can use because very good organometallic precursors are available. In MOCVD the reaction temperature is less compared to the halide or hydride growth, that is one advantage of MOCVD advantage of MOCVD is that, it has a temperature lower than the halide or hydride it is the temperature lower than the halide or the hydride right

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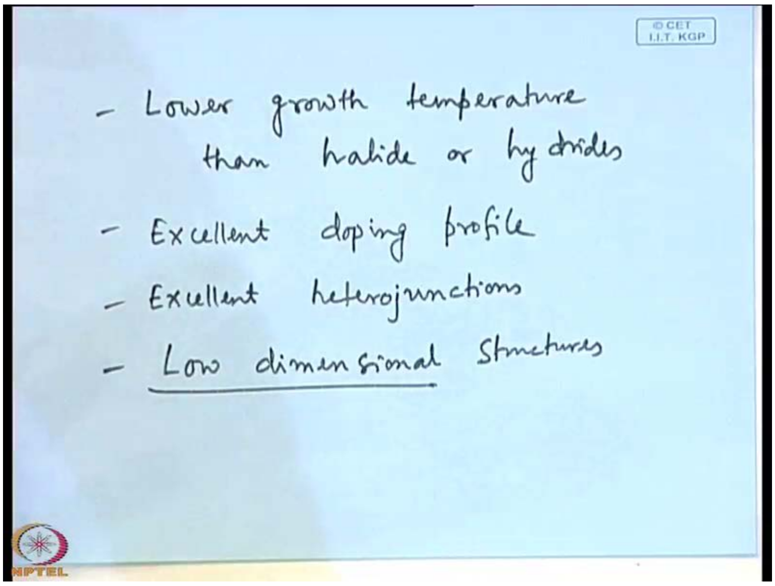

- Lower growth temperature than halide or hydrides
- Excellent doping profile
- Excellent heterojunctions
- Low dimensional Structures

Lower temperature than, lower growth temperature than halide or hydrides, that is very important thing. Number 2 - excellent doping profile, excellent hetero junctions. So, those are the advantages of MOCVD; and low dimensional structures, what is low dimensional structures? What is low dimensional structures? Low dimension structures means...

Student: (( ))

Not thickness it is quantum well, quantum dot, quantum wire, nanostructures, those are known as the low dimensional, low dimensional means it is less than three dimension. So, we have discussed that thing that.

Student: (( )) Splitting of the energy band.

Splitting of the energy bands yes I have given you the example of this room, that if suddenly the roof falls on you, so what you will happen what you will do that you will not be able stand, so you have to swing on the floor of this room, physically you have to lie down on the floor. So, that means you can move through the x and y direction, but on the z direction you will not be able to move through. Similarly if these two walls side walls come closer, then what will happen you will not be able to move on those two sides, only on the z direction you can move that means you can jump, but you cannot move on x and y direction, so that is the quantum wire, that is known as the quantum wire. That means your movement is restricted on 2 directions on x and y direction, your movement is restricted, only you can move on the z direction.

Similarly when the roof comes closer to the floor, you have no option but to lie down on the floor, so there also you can move on the x and y direction that means on the floor you can move, but on the z direction you cannot move. So, if you can move on the x y direction that means that is known as the quantum well. Two dimension in you are free to move, but your movement is restricted in one direction that is the z direction you cannot move. So, likewise if all the walls and the roofs are come closer very close to the floor...

Student: (( ))

Then your unable to move in any of the directions basically, so that is known as the quantum dot, or the nanoparticle. And under those conditions the energy level splits, because of the schrodinger wave equation, and Pauli's exclusion principle, if you can solve those thing under boundary conditions; you will find that there will be the splitting of the energy levels; and because of the splitting of the energy level many fundamental new properties are obtained or were found for those nanostructures or nano dimension. That is known as the low dimension, that is known as the low dimension; so where the dimension is now three dimensional, it is either 2 or 1 or 0 right. So, we shall discuss in our next class, how this low dimensional structures are made using CVD and also MBE.

Thank you.