Processing of Semiconducting Materials
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Lecture - 18
Band gap Engineering II

We are discussing about the band gap engineering basically as we have discussed earlier that if you want to tune the band gap of a material for a particular application or for a application which is suitable for some device etcetera. Then we have no other option but to go for the band gap engineering, because you know that nature does not support any kind of material having any kind of band gap. So, there are certain materials or elements or compounds which have certain band gaps. But those will not be useful for all the applications.

So, that is the reason that a band gap engineering are resorted to; and in that band gap engineering basically we use some epitaxial machines. Epitaxy means single crystal thin film, and thin means it is really thin, it is very thin and the order of some Angstrom, and for which you need a suitable substrate having a lattice constant equal to the lattice constant of the grown layer. Say as discussed earlier that there are different techniques for epitaxial growth.

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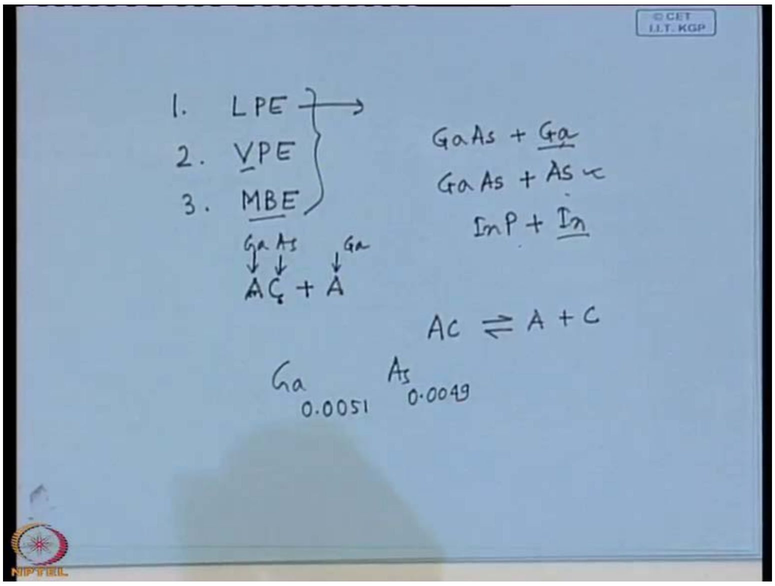

One is say liquid phase epitaxy which is known as the LPE, another is say vapour phase epitaxial number three is MBE molecular beam epitaxy. Now, apart from this all epitaxial techniques there are other epitaxial techniques as well, and today we shall discuss about the liquid phase epitaxy. Then if you see in slide that liquid phase epitaxy basically, an epitaxy which is known as the growth from the melt or solution; remember that it is a growth from the melt or solution, unlike other epitaxial techniques, where we will find that no melt or solution is used either vapour is used or molecule beam is used, but only LPE is the only technique, where we will use the melt or solution.

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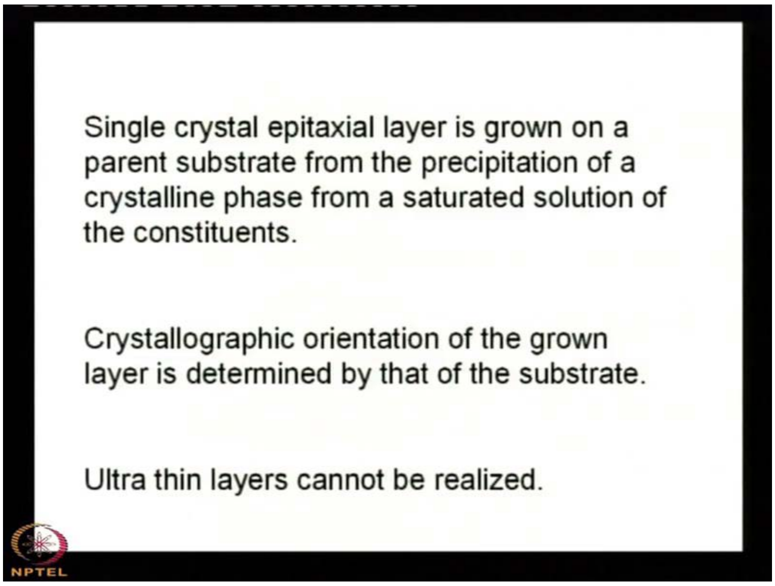

Single crystal epitaxial layer is grown on a parent substrate from the precipitation of a crystalline phase from a saturated solution of the constituents.

Crystallographic orientation of the grown layer is determined by that of the substrate.

Ultra thin layers cannot be realized.

And, in this epitaxial technique you see that single crystal epitaxial layer is grown on a parent substrate from the precipitation of a crystalline phase from a saturated solution of the constituents; that is very important thing this term that the saturated solution of the constituents.

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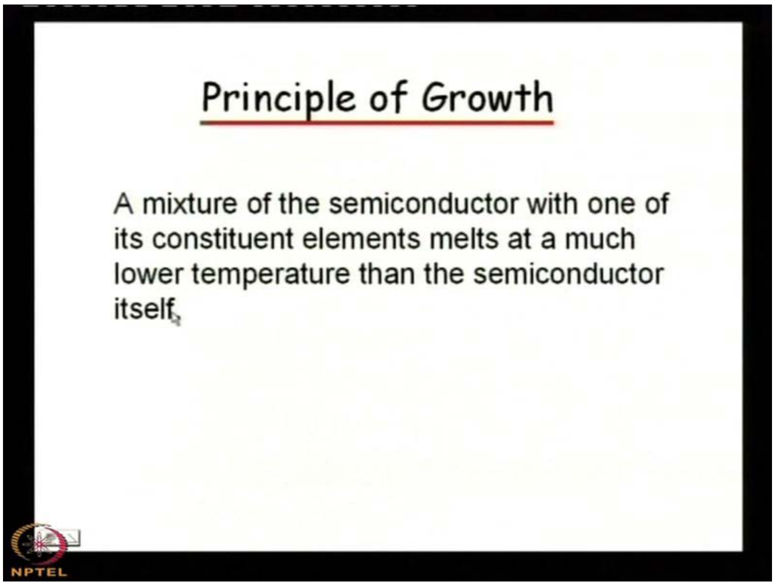

Principle of Growth

A mixture of the semiconductor with one of its constituent elements melts at a much lower temperature than the semiconductor itself.

Now, what is saturated solution basically the principle of growth of LPE is that a mixture of the semi conductor with one of its constituent elements melts at a much lower temperature than the semi conductor itself. This is the principle that means if you take the example of gallium arsenide its melting point is how much? 1240 degree centigrade say exclusively it is precisely twelve hundred thirty seven degree centigrade. Now, if you want to melt gallium arsenide how much temperature is required? 1240 degree centigrade. But, if you add certain amount of gallium or indium with gallium arsenide then the melting point will come down to 800 or 900 degree centigrade.

So, that is the principle of growth for this LPE technique. A mixture of the semi conductor with one of its constituent elements melts at a much lower temperature than the semi conductor itself. Much lower temperature means it is say 800 or 900 or 700 degree centigrade. So, that is the principle of growth for LPE. Then as usual that you need a substrate on which the crystalline phase will be precipitated and the crystallographic orientation of the grown layer is determined by that of the substrate.

Obviously, here you know that in epitaxial technique the substrate plays the role of the seed crystal in bulk crystal growth. In bulk crystal growth what we found? You need a seed; the seed is placed on the melt and then slowly pulled. That was the bulk crystal growth technique. That seed basically gives you the orientation of the grown crystal from the melt.

That means the crystal from the melt will assume the orientation of the seed crystal. If the seed crystal is 100 then the whole crystal will be 100.

Similarly, in epitaxial growth technique, remember that we don’t use any seed crystal. Here the seed crystal; basically the substrate; substrate place the role of the seed. So, if the substrate is 100 then the epitaxial layer will be 100. If the substrate is 111 the epitaxial crystal will also be 111. So, substrate is equivalent to seed in epitaxial growth technique. Another thing is that we have seen that for bulk crystal growth using seed, the melt is kept in a crucible; the melt is kept in a crucible. Here the melt will be placed not in a crucible, but some other container is there as we shall show you. And one of the problem of LPE is that the ultra thin layers cannot be realized. That is the problem of the LPE crystal growth. So we shall discuss this thing in detail.

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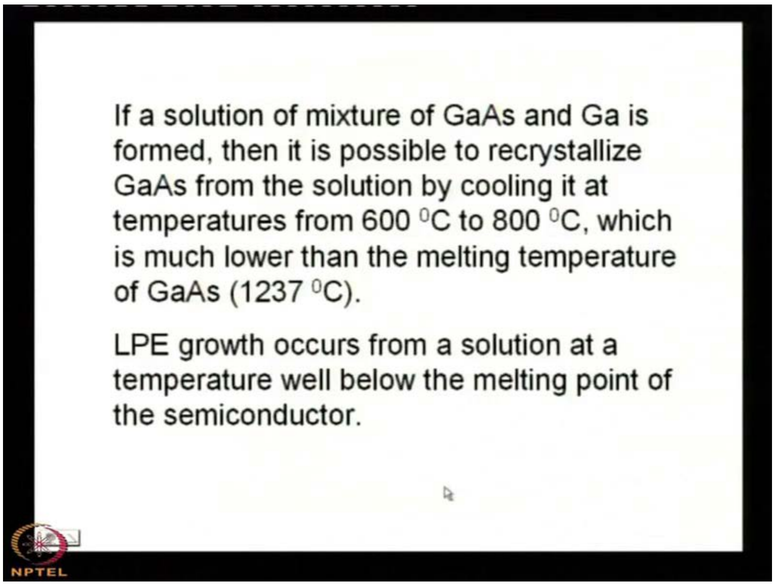

If a solution of mixture of GaAs and Ga is formed, then it is possible to recrystallize GaAs from the solution by cooling it at temperatures from 600 ^{0}C to 800 ^{0}C, which is much lower than the melting temperature of GaAs (1237 ^{0}C).

LPE growth occurs from a solution at a temperature well below the melting point of the semiconductor.

As, mentioned earlier if a solution of mixture of gallium arsenide and gallium is formed. Remember that we would like to make a solution. Solution of what? Solution of gallium arsenide and gallium. Now, what is the melting point of gallium?

Student: 30 20 or 30.

No, it is almost 38. Exactly, because it is liquid at room temperature almost. So, its melting point is very low. So, if you put gallium and gallium arsenide, then it is it will be a solution and then it is possible to recrystallize gallium arsenide from the solution by cooling it at temperature from 600 degree centigrade to 800 degree centigrade. That means the growth temperature will be between 6 to 800 degree centigrade. What was the temperature required for the Czochralski or Bridgeman technique for gallium arsenide? It is the melting point of gallium arsenide.1240 degree centigrade. Here, you see the reduce almost half. 600 to 800 degree centigrade, depending on the growth operators, growth machine etcetera.

You need temperature from 600 to 800 degree centigrade, which is much lower than the melting temperature of gallium arsenide, which is 1237 degree centigrade. And, LPE growth occurs from a solution at a temperature well below the melting point of the semi conductor as it is discussed. And, that is why it is known as the growth from the melt or solution. Unlike in other epitaxial techniques where we find that either the vapour or the molecular state of the matter will be used for the deposition of the epitaxial layer on the substrate.

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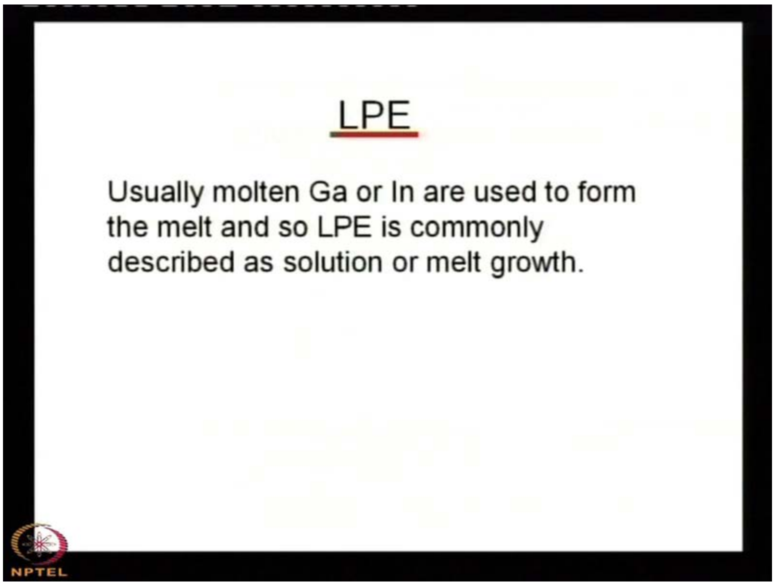

LPE

Usually molten Ga or In are used to form the melt and so LPE is commonly described as solution or melt growth.

So, usually molten gallium or indium. You can use indium as well. We have given you the example of gallium plus gallium arsenide, but you can use indium plus gallium arsenide as well. Then also the temperature will be low, but not as low as what we find for gallium plus gallium arsenide, because the melting point of the gallium is too low, because it is almost liquid at room temperature. Usually, molten gallium or indium are used to form the melt and so LPE is commonly described as solution or melt growth. So, the whole idea is that you take gallium arsenide semi conductor and you mix gallium with it. Make a saturated solution of gallium arsenide and gallium. Or gallium arsenide plus arsenic. You can, for indium phosphate plus indium right? So, generally gallium arsenide or indium phosphate are grown from by the epitaxial technique, so either we use gallium or indium.

Because, if you use you can ask me sir why arsenic is not used? Arsenic can be used theoretically, but the problem is again the vapour pressure of arsenic. Problem is again the vapour pressure of arsenic. Say if you choose the region of 800 to 600 degree centigrade, from 600 to 800 degree centigrade. Then there will be loss arsenic as well. Because, you have seen that for Bridgman growth what we edit, basically we put some arsenic at one end of the boat right? so that any loss due to the decomposition from the surface can be compensated by the arsenic which was placed in the reserve. Basically, you can think that there was an arsenic reserve or in case of Czochralski technique we used B 2 O 3 encapsulated. We have covered the molten surface by B 2 O 3. So that is why generally arsenic or phosphorus are not used, they are not favourable. Generally gallium or indium is used.

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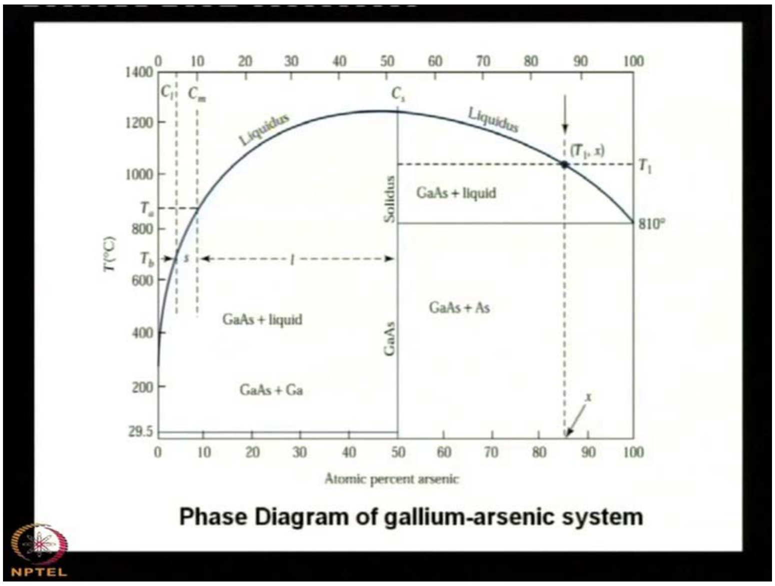

Phase Diagram of gallium-arsenic system

But, this growth actually is a thermo dynamic equilibrium growth. So you have to use the phase diagram. This is the phase diagram of gallium and arsenic. Basically, it is applicable for any binary compounds. Three five binary compounds right? So, suppose you have semi conductor AC, say a is gallium, c is arsenic or a is indium c is phosphorous. So when you put gallium with AC with gallium arsenide or say you put a with AC, basically a is say gallium. AC is gallium arsenide. So, if you mix a with AC, generally the liquid will contain molecules of gallium arsenide as well as gallium and arsenic as atom. Right? Because, for equilibrium it is very much necessary that AC must be A plus C.

So that means the liquid will contain the molecule of AC as well as the atoms of a and c. So, that when you mix with a, it will be a liquid containing both AC and A and C, as soon as it will get a substrate for re crystallization when the temperature is lowered, A and C atoms will be absorbed by the substrate surface and AC film will be grown. So, that is why it is known as the thermo dynamic equilibrium growth.

And, all such thermo dynamic equilibrium growth will be governed by the phase diagram. Now, if you consider this phase diagram, what you see? You see that there is a cut line which is known as the liquidus. What is liquidus? That means above this line it is liquid. above this line it is liquid. So, that means you see what we have plotted in the phase diagram we have plotted the temperature. Here in the y axis you see that the temperature is from 29.5 to 1400 degrees centigrade, and in the x axis the atomic percent of arsenic. Atomic percent of arsenic means? When I come to this point at 0 that means there is no arsenic at all. It is fully gallium.

Similarly, when you come to this point at 100 arsenic concentration, that means there is no gallium. And at 50 you see that gallium arsenide with stoichiometry will be grown. With stoichiometry, you can grow here also. Then that will be non stoichiometry. That means if you growth here you find that it is less than 50, arsenic that means it will be gallium reach. So, you take gallium reach here you see that, I have mentioned gallium arsenide plus gallium. Because, this is the gallium reach. And on the right hand side of this 50 percent atomic percent arsenic means, it is gallium arsenide plus arsenic. Plus in this region, there will be more arsenic. In this region there will be more gallium. Right? So, you find that at 50 percent atomic concentration of arsenic here it is solidus. That means it will be a solid, so if you melt gallium arsenide and if you go for the bulk crystal, bulk crystallization you find that, say let us taken an example of say x. What is x? X is 85 percent arsenic.

So, this point means T 1 the temperature and x is 85 percent arsenic. So under such a circumstance if you reduce the temperature from say T 1 to this line, that means what will happen? These liquid will be solidified, as the temperature is reduced. Right? Similarly you see that in LPE, that is for the bulk crystal growth. But for LPE we need liquid. So, liquid means you see that the left portion of this phase diagram can be used. Say, this is temperature T A. You see this point is temperature T a and what is the state of gallium arsenide in this region? It is obviously liquid. Because, this is the liquid s curve. So all such portions will be liquid. So, as you low the temperature from T A to T B, T A say 850 and T B say 650 or say from 800 to 600. Any two temperature. If you reduce temperature from T A to T B it will solidify.

So, the temperature, how you will choose the temperature? How you will choose the composition? That will be fully governed by the phase diagram. For any crystal growth you need a phase diagram. And phase diagram is available in the literature, because people have been growing gallium arsenide for many years. So, there is no dark of data in the data bank. Right? You have many data on gallium arsenide in m phosphate, so you can take this phase diagram and depending on your system whether you want to make the bulk crystal growth or the liquid crystal growth, whatever be the case you choose the temperature or that region. But, what will happen? In this region you will see that since it is reach in gallium, so what will happen? There may be some non stoichiometry. But, the composition will be like this, say gallium 0.0051 and arsenic say 0.0049 type of thing. Right?

So, that means for all practical purpose, that is a stoichiometry growth for all practical purpose. Minutely, if you make the chemical analysis of the growth, if you take shell layer you will find that there may be some deficiency of arsenic or that. But, that is in practical, it is as good as the stoichiometric layer. Because, you see that in this case it comes at the fourth place of decimal. It comes at the fourth place of decimal. So, you see that the phase diagram is an important thing, and it is a growth from the melt or solution that means the left part of the phase diagram we shall use, here I have shown that gallium and gallium arsenide is mixed so it's becomes liquid, liquid gallium arsenide that means in the liquid there will be gallium arsenide as well as the atoms of gallium and arsenic and if you reduce the temperature from this part to that part that means it will solidify and then you can say that it is the epitaxial growth of the gallium arsenide. Yes if you have any question in this...

Student: Liquidus cardinal zonal it stretches four degree centigrade.

Yes.

So, at this point means if you go four hundred to 600 800 means liquid portion is as well is mixed maintain on gallium arsenide its starts at four hundred degree centigrade.

Not melting, basically as you mixed gallium so it becomes a solution. Problem is not 400 or 600 degree centigrade. Why? the it will the lower limit of the temperature will be determined by the fact that... constant. There will...

Student: Constant in nature.

No, there will be surface absorption. There will be surface absorption. So what is the substrate? Substrate is gallium arsenide. What is the deposition? Gallium arsenide. So, that means on the substrate surface there will be absorption of gallium and arsenic atoms. For that one minimum temperature is required. So, you cannot go beyond that temperature. May be that have 400 that is not possible. Some more temperature is required. Absorption is possible at 600 degree centigrade. So, even if the temperature is 400 degree centigrade you cannot use that temperature. For a particular material, it has a surface absorption temperature. Below which thus it will not be absorbed on the surface and so the growth will not take place.

So, you have to come from say T A to T B that is arbitrary. Say from 800 to 600 then you have to cool below 600 below because in 600 also as you told it will be in the molten state. On 600 it will be on the molten state. So that it will be system will be cool down only then it will be solid epitaxial layer.

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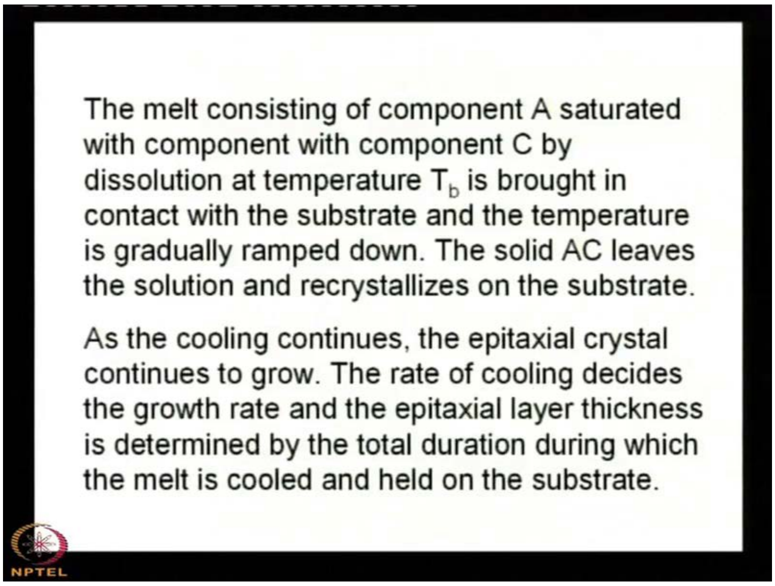

The melt consisting of component A saturated with component with component C by dissolution at temperature T_b is brought in contact with the substrate and the temperature is gradually ramped down. The solid AC leaves the solution and recrystallizes on the substrate.

As the cooling continues, the epitaxial crystal continues to grow. The rate of cooling decides the growth rate and the epitaxial layer thickness is determined by the total duration during which the melt is cooled and held on the substrate.

What we have discussed I have written here. The melt consisting of component A saturated with component C by dissolution at temperature T B is brought in contact with the substrate and the temperature is gradually ramped down. The solid AC leaves the solution and re crystallizes on the substrate. As the cooling continues, the epitaxial crystal continues to grow. The rate of cooling decides the growth rate and the epitaxial layer thickness is determined by the total duration during which the melt is cooled and held on the substrate. So cooling rate is basically the growth rate. The growth rate will be determined by the cooling rate. Cooling rate means say in this case.

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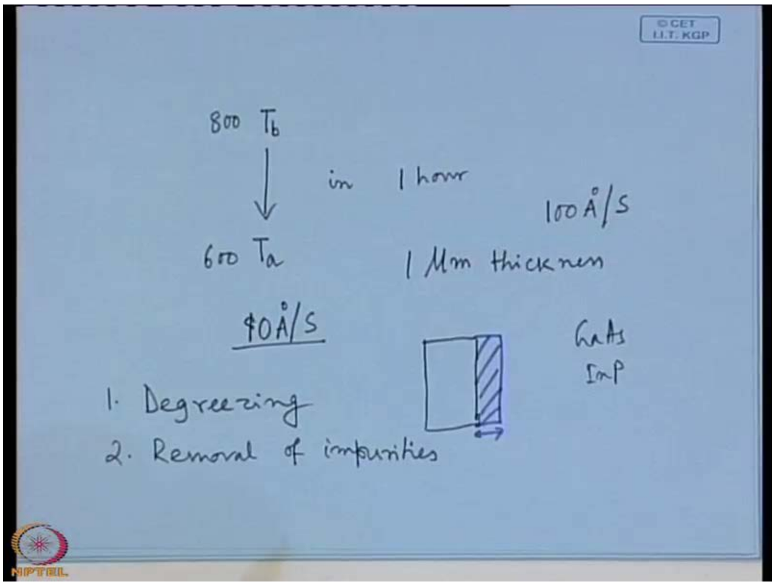

800 T_b

in 1 hour

600 T_a

100 Å/S

1 μm thickness

40 Å/S

GaAs

InP

1. Degreezing

2. Removal of impurities

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If you say that the temperature is lowered from T B to T A in say one hour. So what is the rate of cooling? T B minus T A degree centigrade per hour. E P T is 800. E P T is 600. That cooling rate is 200 degree centigrade per hour. So you can change that cooling rate by means of a computer control system. All such crystal growth systems have computer interface. Very good control can be made using some computer or micro controller system. So, you can make some programming. What cooling rate you want? if you want that the cooling rate will be one degree centigrade per hour. That can be made. So the temperature controller will have to be programmed in such a fashion that the cooling rate will be one degree centigrade per hour. So, depending on your cooling rate or the growth rate. Suppose, you want a growth rate of say 100 angstrom per second. That means 10 nanometre per second. Or say 100 angstrom per minute or 100 angstrom per hour.

So, depending on your growth rate you have to fix your cooling rate, and if your growth rate is say 100 angstrom per second that means if you grow for 60 second what should be the thickness? 6000 angstrom. If you go for the 100 second what should be the thickness? 10 thousand angstrom. So, depending on your growth rate you can calculate how much time is required for the growth to complete for a particular thickness. Suppose, for a particular application you need one micron thickness, and the growth rate is say 10 angstrom per second so what should be the time? If one micron thickness is required for a particular application and if the growth rate is 10 angstrom per second then what should be the time? Time is one micron divided by 10 angstrom, one micron divided by 10 angstrom. That much second if you divided by 60 that much minute again further 60 you will get hour.

So, you can fix the temperature of growth. For how long you will make the growth depending on the thickness. Now, how the thickness is measured? How you can calculate the growth rate? How you can calculate the growth rate experimentally? I would like to know the experimental technique using which you can know the growth rate of a particular technique.

Student: S I D O.

S I D O.

No, can X R D measure the thickness? There are many techniques one important technique that you all know, it can be done by transmission electron microscopy .Why? Because substrate and thickness they are different. Substrate and thickness they are different. So, using a transmission electron microscopy you can view the growth actually. That means if it is your substrate and say it is your epitaxial growth layer using a high resolution T M H R T M, you can see this picture. And you can measure this thickness using the scale. Another thing is that there is a stylus measurement S T Y L U S. Stylus basically it is related to the reflective index. So variation of the reflective index, you can measure the growth rate.

Suppose, you want to make the note the growth rate of gallium arsenide then what you have to do? You have to take a say sapphire silicon substrates and you grow gallium arsenide. Reflective index of gallium arsenide is different from that of silicon. So, from the reflective index variation the thickness can be calculated. That is very simple thing. Stylus, thickness measurement unit right? So, you can measure the thickness of the grown layer and suppose you have grown for one hour and you find the thickness is one micron.

Then what is the growth rate? One micron per hour. So you can convert it into second or minute. So, you will be knowing what is the growth rate for your particular system. And remember that growth rate of gallium arsenide is not same as the growth rate of indium phosphate or the growth rate of the silicon. It is completely different, because the thermo dynamic is different. One example I can give you that is for gallium arsenide and indium phosphate. The growth rate is low in gallium arsenide.

Why? Because the cracking efficiency of arsenic is less than that of phosphorous, the cracking efficiency of arsenic is less than that of phosphorous. So, if you grow gallium arsenide the growth rate will be lower than indium phosphate. Because, unless it cracks it will not be absorbed on the surface and so the growth will not take place. So, that is the reason that not necessarily that all growth will be of the same type of rate.

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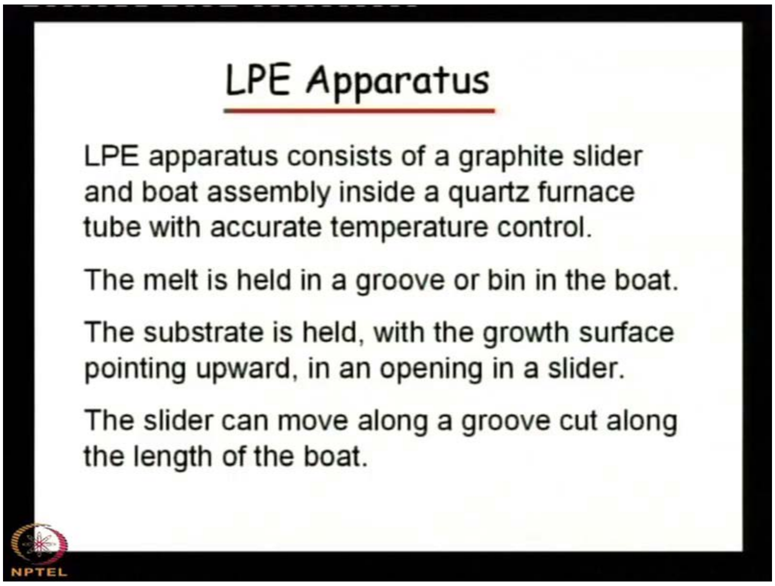

LPE Apparatus

LPE apparatus consists of a graphite slider and boat assembly inside a quartz furnace tube with accurate temperature control.

The melt is held in a groove or bin in the boat.

The substrate is held, with the growth surface pointing upward, in an opening in a slider.

The slider can move along a groove cut along the length of the boat.

LPE So, far as the LPE apparatus is concerned it is very simple that is the beauty of LPE. if you compare LPE with other system say wafer pressure epitaxy or M B E or M O C B D M O M O B P whatever be the other techniques all other techniques are very, so far as the apparatus is concerned it is very complex type of system. It is very complex type of system. Here an LPE apparatus see that it consists of a graphite slider and boat assembly, inside a quartz furnace tube with accurate temperature control. That means you have to make a quartz furnace tube. On that quartz furnace tube you must have a graphite slider and slider boat slider means.

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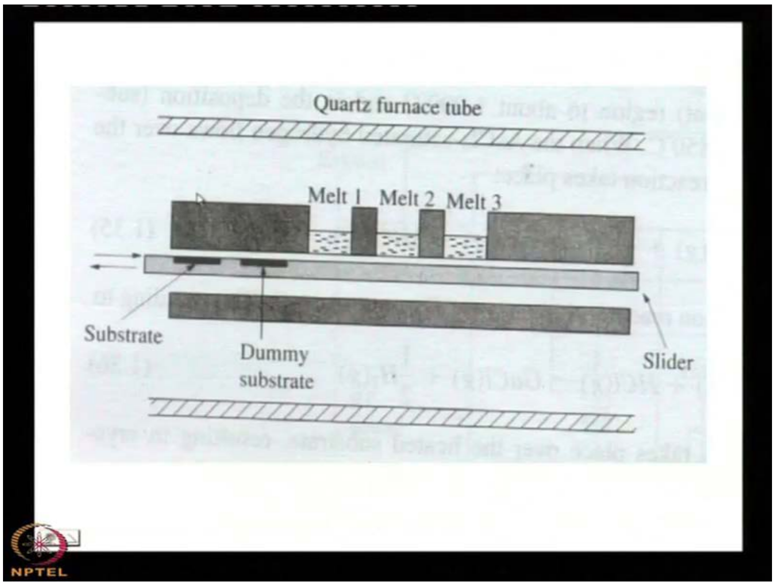

This is slider it you can slide basically you can slide it is like drawer side and this is the boat and on their boat there are groups or beam. Say here I have shown you melt one melt two melt three. Forget about melt 2 melt 3. Let us take a concede example that melt one is there. What is melt one? In melt one there will be gallium arsenide plus gallium. At a particular temperature. Say 800 degree centigrade.

Then you put a substrate with its say clean surface on the top, because you have to grow the epitaxial layer on the substrate. So our aim is to put the substrate just below the melt which can be done by the slider. So, first if you pull a slider what will happen? The substrate will come in touch with melt one. Then you reduce the temperature, and say you have calculated. Half an hour is required for one micron growth. You need one micron growth. So you stay here for half an hour then you pull it remove it they you totally cool down the system.

So that means it consist of a graphite slider and boat assembly inside a quartz furnace tube with accurate temperature control. The melt is held in a groove or bin in the boat. That means groove or bin means this is groove or bin where the melt is kept. So, here we don’t use crucible type of thing. The substrate is held with the growth surface pointing upward in an opening slider. In an opening in a slider, with the growth surface pointing upward, that means suppose this is your substrate and you know that on the substrate there are two phases.

Generally, on one phase the growth is made. Why? Because, on the both the sides you cannot make the growth you have to put the substrate on some platform. So, that is why you will find that on one side where there is a rough side not the two sides are polished. One side will be polished surface and another will be unpolished surface. Because, when from the bulk crystal the substrate is made that means it is cut into pieces one side is generally polished, because polishing also needs cost. So, if you want both sides polish that is also available in the market then the cost will be simply double. If one piece of gallium arsenide with one side polished cost rupees 20,000 two inch I am talking about two inch substrate. Two inch gallium arsenide substrate. One side polished it cost more than 20,000 rupees in Indian market. If you want that both sides are polished then it will be 35,40,000 rupees.

So, one side polished the polish on the surface you have to make the growth. And as usual that the polish surface have to clean because there may be some oxide formation and because of you are handling that the finger prints can be on the substrate surface that means you need degreezing. One point is degreezing and number two is the removal of impurities or contaminations. Degreasing mean grease means oily substance. Grease means oily substance. You have to move the oily substance. How the oily substance are removed? Can you tell? What is the technique using which the oily substances are removed? You all know.

Here you cannot use. So basically you have to use some organic solvent. Yes, generally for 3 5 semi conductors substrates the gallium arsenide or indium phosphate first it is boiled in trichloroethylene. T C E. First you boil in trichloroethylene.

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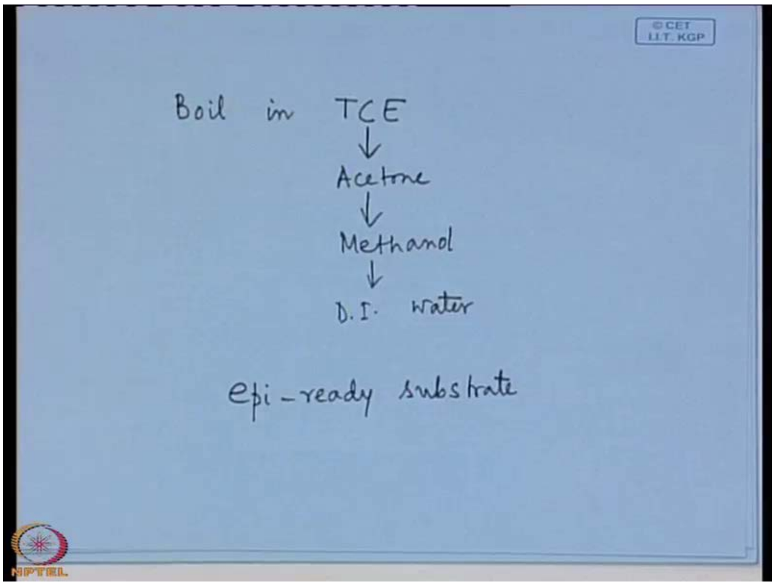

Boil in TCE
↓
Acetone
↓
Methanol
↓
D.I. water

epi-ready substrate

You take a beaker you put some trichloroethylene say 5 C C 10 C C put your substrate generally on in our laboratory level growth the substrate is one centimetre by one centimetre. We don't use the whole 2 2 inch vapour. For lab scale you use two one centimetre by one centimetre or one inch by one inch substrate. That means we have to cut a piece from that two inch diameter substrate. Then you take a beaker put some T C E put the substrate on T C E inside the beaker and place it in a heater. For five minutes you boil it. So what will happen? Yes, actually substances will be dissolved by T C E. But, T C E means it has carbon. So, now if you put your substrate in the growth apparatus then what will happen? Carbon contamination will be happen will be there because on the surface there will be curve once. Then you have to remove T C E. How to remove TCE?

No, T C E is removed by acid only. There is a step. Then you remove T C E from the beaker and you put acetone. You range with acetone. So the job of the acetone is to remove trichloroethylene. Acetone has also carbon component. Acetone has also carbon component. Then what will happen? You have to remove acetone by methanol. Then, you have to remove methanol because methanol has also carbon.

Student: Deionised water.

Yes, then you arrange by your substrate by D I water deionised water D I water.

Student: Sir I have to boil in after some time?

No, you have to boil it. So these are the steps normally we use for degreasing a substrate. It is always done.

Student: Sir acetones can dissolve oil?

Yes, acetone can dissolve oil but T C E can dissolve oil in better in much better way. So, people have basically the standardise such kind of cleaning process. These are basically invented in the well lab. Because they are the main what I should say that all such discover is or invention were from the well labs. So far as these electronic materials and the micro electronics is concerned. So they have standardised this method. And we followed their standard methods only. May be there are other substance. Not that these are the only process. There are several process as well. But, people have taken as standard thing because the well lab used it. Probably they are what you told that as acetone if you boil the substrate with acetone, the same result can be there. I admit. But since we follow that process so we have taken as a standard. First boil in T C E then you remove T C E by acetone. Then you remove acetone by methanol and methanol can easily by removed by D I water.

But you cannot remove T C E or acetone by D O I water. There will be carbon signature in it. And another thing is that in some cases that you have opened the packet we have open the packet in which the vapour was kept. First the vapour when it is imported it is put inside air tight cover packet. So you cut the packet remove the vapour. As soon as you remove it it come in the contact with atmosphere. It immediately gets oxidised particularly the silicon. Gallium arsenide indium phosphate also oxidised but not a easily like silicon.

Then what you have made 1 piece say 2 inch by 2 inch or one inch by one inch. Then so what about the other pieces? Though will be fully oxidised, so on second day when you want to make some growth using another piece you have to remove the oxide layer from the substrate. For oxide layer removal there are several techniques. Generally a H 2 S O 4 H 2 O 2 and water is used. Etching in my previous lecture I have given you the composition. Generally H 2 S O four or H N O 3 along with hydrogen peroxide h two o two and water is used. And sometimes you find that H F is used to remove the oxide particularly from silicon, H F is used.

So, those are the techniques which one should follow religiously. One should follow religiously. Otherwise what will happen between the substrate and the epitaxial layer? There will be a oxide layer. That oxide layer not only we'll reduce the efficiency of your device but at the same time there will be lattice miss match. If you take cell layer gallium arsenide is lattice match to substrates gallium arsenide. Not with gallium arsenide. Because, the lattice constant of gallium oxide is different from that of the, another thing is that gallium oxide or silicon dioxide whatever be the oxide they are basically insulator in nature.

So, when you put current what will happen? they will the electrons movement will be restricted or it will be scattered. Because, that is insulation so from the substrates to the epitaxial layer there will be no current path. So, that is why you have to remove oxide. All the time you use either EPI ready substrate. One thing is that there is EPI ready substrates. EPI ready means? the substrate is ready for epitaxial growth. The substrate is ready for epitaxial growth that is known as the EPI ready. That means when you would like to grow on two inch three inch or five inch diameter whole crystal whole vapour then you just cut the packet take the vapour and put inside the epitaxial machine. You need not to make any treatment. When the whole vapour is used as a substrate in generally for micro electrons fabrication or I C E fabrication the whole vapour is used.

But, in lab scale it is one centimetre by one centimetre or one inch by one inch type of thing. So far lab scale religiously we have to follow the oxide removed as well as the degreasing steps. But, if you can use EPI ready substrate then you need not to follow that thing. So, here we were that the substrate is held with the growth surface pointing upward. Growth surface means the polish surface. Growth surface means the polish surface on which the growth takes place. In an opening in a slider the slider can move along a groove cut along the length of the boat. So, this is you substrate the polished phase placing upward and you can make the movement by moving the slider to and fro. So, that is the total set up here you y there is quartz furnace tube inside the furnace tube the whole thing is placed.

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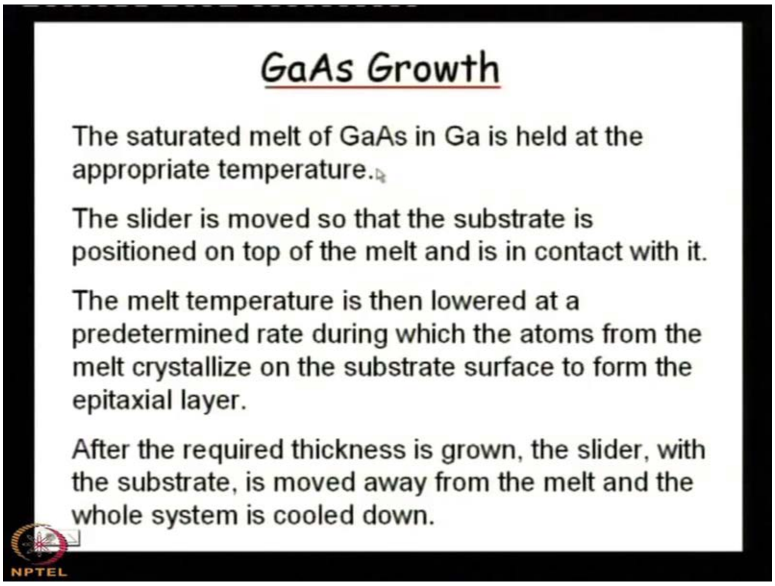

GaAs Growth

The saturated melt of GaAs in Ga is held at the appropriate temperature.

The slider is moved so that the substrate is positioned on top of the melt and is in contact with it.

The melt temperature is then lowered at a predetermined rate during which the atoms from the melt crystallize on the substrate surface to form the epitaxial layer.

After the required thickness is grown, the slider, with the substrate, is moved away from the melt and the whole system is cooled down.

If you now particularly take the example of gallium arsenide growth, you see that the saturated melt on of gallium arsenide in gallium is held at the appropriate temperature. That means in one of the beams say in melt one, you take gallium with gallium arsenide. The slider is moved so that the substrate is positioned on top of the melt and is in contact with it. So between the melt and the substrate, there should not be anything. The substrate must touch the melt. So, that means the slider movement or the arrangement must be there. So, that you can easily touch so that the substrate can easily touch the melt with its polish surface upward.

The melt temperature is then lowered at a predetermined rate during which the atoms from the melt crystallize on the substrate surface to from the epitaxial layers. After the required thickness is grown, the slider with the substrate is moved away from the melt and the whole system is cooled down, because say the temperature was from 800 degree centigrade to 600 degree centigrade. But, at 600 centigrade it is typically horned. So, you have to cool down. Remember that when you cooled down it must be in an inner atmosphere. Otherwise, at 600 degree centigrade in presence of oxygen some oxygen will react with gallium arsenide surface and gallium oxide or arsenic oxide can be formed. So all thing all such cooled down etcetera must be in an inner atmosphere.

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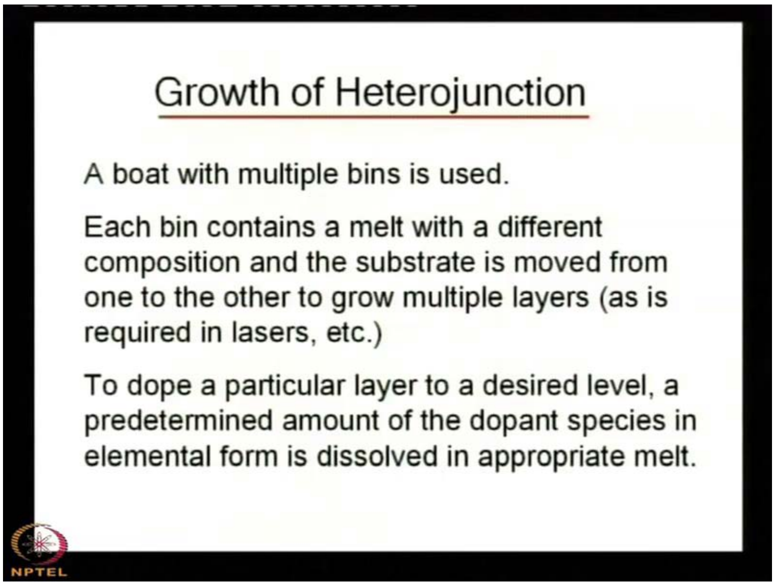

Growth of Heterojunction

A boat with multiple bins is used.

Each bin contains a melt with a different composition and the substrate is moved from one to the other to grow multiple layers (as is required in lasers, etc.)

To dope a particular layer to a desired level, a predetermined amount of the dopant species in elemental form is dissolved in appropriate melt.

Now, if we take the example of growth of hetero junction. Now, what is hetero junction? What you mean by hetero junction? Because still now we were in the epitaxial growth of a particular layer. So, it can be gallium arsenide, it can be silicon, it can be indium phosphate. But, what is hetero junction? Right. Hetero junction means a junction is found at two dissimilar semi conductors.

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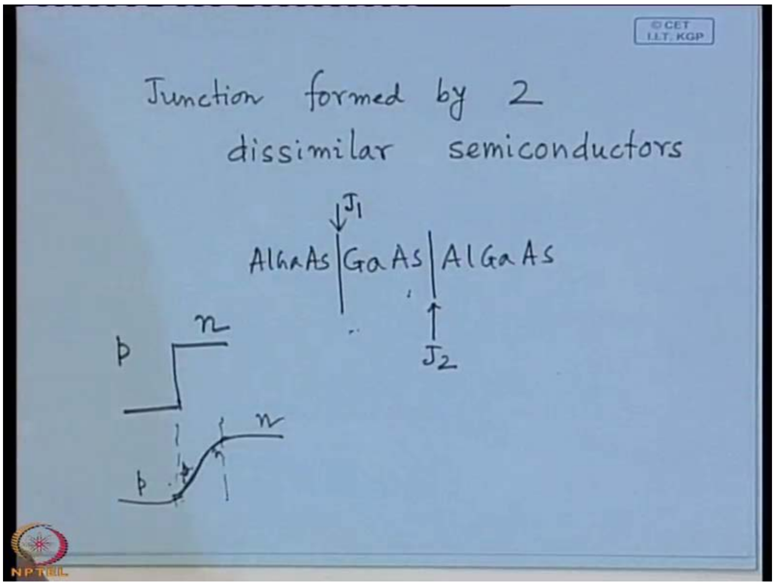

Junction formed by 2 dissimilar semiconductors

Junction formed by 2 dissimilar semi conductor. Dissimilar means band gap is different to different material. Silicon p n junction. It is not a hetero junction. It is basically a homo junction. Why? You have used silicon material. One side of it can be doped with p and then in. That means you take silicon. First you make it a p type by putting boron in it and then you dope with arsenic so that p n junction silicon is made. That is not hetero junction hetero junction means it is completely two different entity. Say this is gallium arsenide material. Aluminium gallium arsenide.

So, it is a hetero junction of gallium arsenide and aluminium gallium arsenide. Remember that, that is a hetero junction. Why? This is junction J 1 say and this is junction j two say .That is why it is known as the double hetero junction. When we shall discuss about the laser and LED, you will find this kind of structure is required. Here I have written that as is required in lasers so double hetero junction structure or say you want to make a quantum o l. A quantum O L means the same structure where gallium arsenide is the O L.

Gallium arsenide is the O L and the barium arsenide aluminium gallium arsenide. But, the difference between hetero junction and quantum o l is there. In hetero junction you can take any thickness. There is no thickness restriction That means gallium arsenide can be x angstrom, can be y angstrom, can be z angstrom anything. Similarly, aluminium gallium arsenide can be a angstrom, b angstrom, c angstrom anything. But, here in quantum O L the

O L and barrier thickness must be calculated very precisely. Otherwise, you will not get the quantum effect.

So, generally in quantum O L is gallium arsenide aluminium gallium arsenide will be very small. Say, gallium arsenide is say 40 angstrom, 80 angstrom that level. Very small. So, if you want to make the hetero junction growth then you see that multiple bins are used. Why multiple bins? In one bin you have to make you have to keep gallium arsenide plus gallium. In second bin you have to place aluminium gallium arsenide melt. If you, if you, if you see this structure say bin one is aluminium gallium arsenide, bin two is gallium arsenide, bin three is again aluminium gallium arsenide.

So, that using successive bins first melt one is say aluminium gallium arsenide. So, the substrates comes where the aluminium gallium arsenide is deposited. Then melt two it is say gallium arsenide obviously. Generally, aluminium gallium arsenide in gallium arsenide plus gallium melt is there along with, there will be aluminium. And also remember that those will be governed by the phase diagram .You cannot take any amount, you cannot use any temperature. It must be governed by the phase diagram of aluminium gallium arsenide.

So, melt one is say aluminium gallium arsenide, melt two say gallium arsenide and melt three is again aluminium gallium arsenide. So, hetero junction can be melt. And to dope a particular layer to a desired level a predetermined amount of the doping species in elemental form is dissolved in appropriate melt. Say, you want to met p type then you use zinc elemental zinc with high purity. 10 n 11 n purity you can use. Or for n type you can use sting s n elemental form because you have seen that the elemental form is required. No compound.

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Advantages:

- •Simplicity of equipment
- •General safety
- •Expe4nsive vacuum equipment: not required
- •High deposition rate
- •Good crystal quality
- •High degree of reproducibility
- •Thickness and composition control: possible due to computer-controlled equipment

Then what are the advantages of LPE? The advantages of LPE is that simplicity of equipment very simple. General safety is there no gas or that type of thing. Expensive vacuum equipment not required. This is expensive not four. Expensive vacuum equipment not required. As I shall show you that for M B E very expensive equipment is required. And so for as the safety is concerned vapour phase epitaxy or the metal organic vapour phase epitaxy is not safe. High deposition rate good crystal quality high degree of reproducibility. And, thickness and composition is control possible due to computer controlled equipment. You want to makes a one point two micron, one point three micron, 0.75 micron. So, that is possible. These are the advantages. These advantages make the LPE growth very attractive. But, it has some advantages as well.

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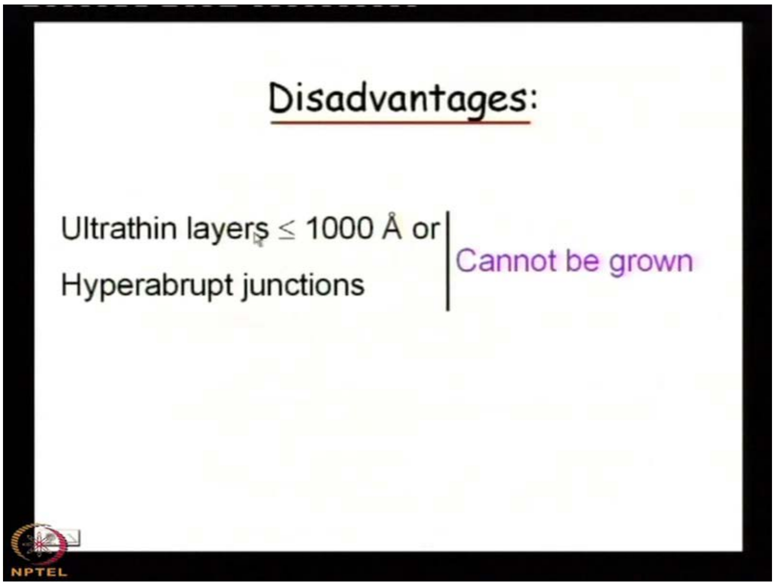

Disadvantages:

Ultrathin layers ≤ 1000 Å or
Hyperabrupt junctions

Cannot be grown

So, what are the disadvantages? The disadvantages are Ultra thin layers. Ultra thin means less than thousand angstrom. That means 100 nanometre. What is ultra thin? It is less than thousand angstrom or hyper abrupt junctions cannot be grown using LPE. But, modern device needs ultra thin layer as well as hyper abrupt junctions. What do you mean by hyper abrupt junctions? Hyper abrupt junction means the junctions will be like this. That means suppose this is p type and this is n type.

So, change about from p type to n type will be very serve. Not like this. Is it serve? Here you see that the junction is not serve, because the junction has taken that type of thickness. The width of the junction is very high. For p n junction hyper abrupt junction is required. So, that is very important that using LPE you cannot make hyper abrupt junction. There will be a smearing. There will an extended type of junction on both sides. That means P will be here also n will be here. Also smearing of p and n region right and ultra thin means you cannot grow quantum O L or quantum dot using LPE. Ultra thin means yes that thing that you cannot grow quantum O L quantum dot quantum o r using LPE. So, these are the drawbacks for the LPE. However, it has very many advantages and so it is very attractive for normal junction or normal material growth.