Processing of Semiconducting Materials

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Lecture - 12
Bulk Crystal Growth I

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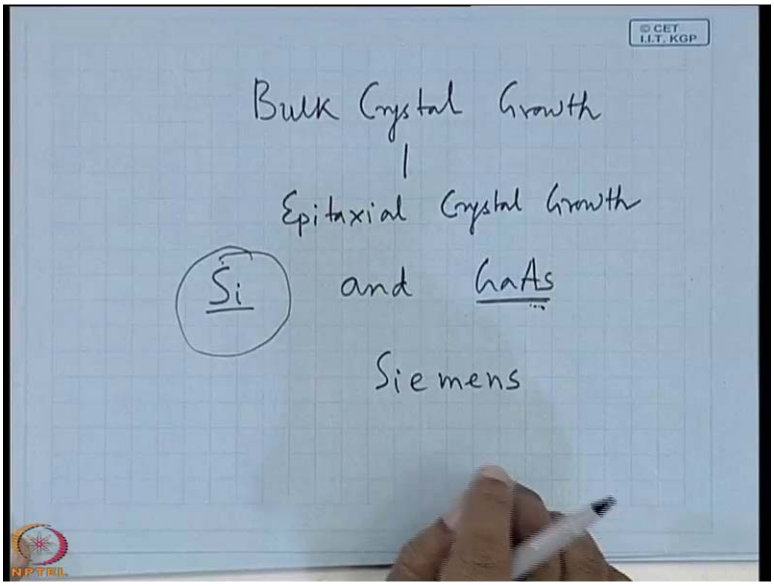

From today onwards we shall start discussing bulk crystal growth and you know that So, for as the bulk crystal growth is the concerned, there are other type of crystal growth which is known as the epitaxial crystal growth, bulk crystal growth another is the epitaxial growth. There are 2 types of crystal growth that we shall discuss in this class. Now in bulk crystal growth mainly we shall concentrate our discussion on silicon and gallium arsenide, in bulk cystal growth we shall concentrate our discussion on silicon and gallium arsenide.

Why? Because these are the 2 most important semiconductors which are used for the fabrication of semi conductor devices and you know that the silicon is the most important material, we have discussed this thing in our earlier class. Now, so far as the whole electronic material is concerned, particularly the I C technology silicon is the only material, but if you go for the up to electronic materials or the high speed material for application in high speed or high mobility area then only this 3 files semiconductor or gallium arsenide is used.

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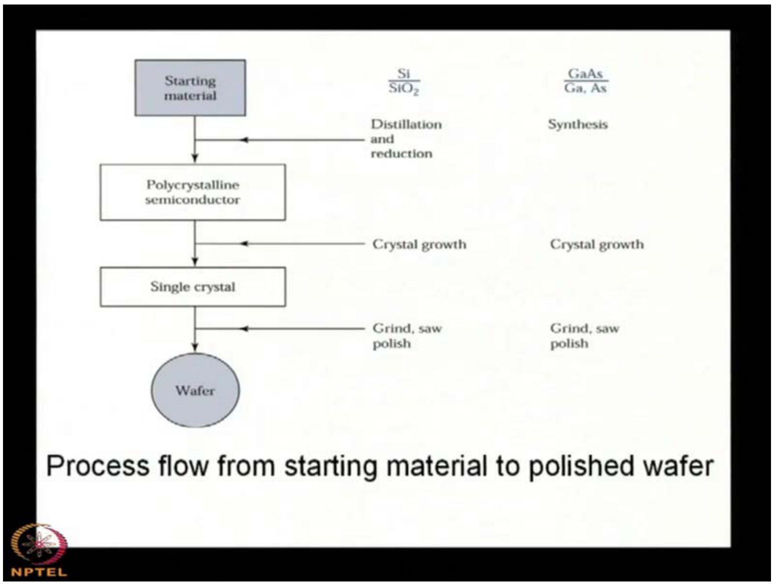

So, today we shall concentrate discussion on the silicon crystal growth. Now if you see this blue graph you will see that first we start from a material which is a starting material and then polycrystalline semiconductor will be grown. And finally, to the single crystal then the single crystal will be cut into pieces to form the wafer on which the whole technology is based on and for silicon you see that we start from SiO2 , and then we shall make some distillation and reduction to obtain the metallurgical silicon and finally, to semiconductor grade or electronic grade silicon.

And then there will be crystal growth, then the crystal will be grinded saw, polished et cetera to obtain the wafer. For gallium arsenide what we shall do? We shall use gallium and arsenic, then we synthesis gallium arsenide, finally the crystal growth will be done and the same process will be followed to obtain the wafer

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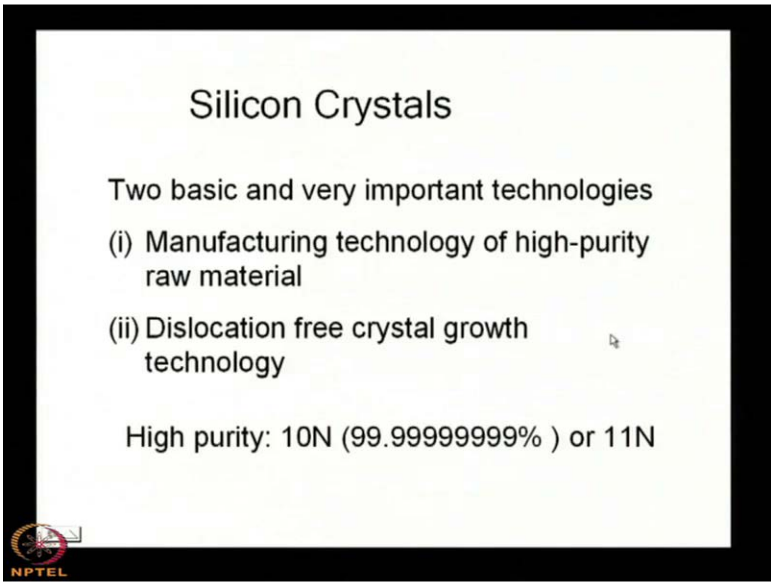

Now for silicon crystal growth you see that are there are 2 basic and 2 very important technologies involved in the silicon crystal growth, one is the manufacturing technology of high purity raw material that is very important you see that this high impurity raw material, first is the this is the pre condition that you cannot grow silicon using just SiO2 or sand taking from the earth crust, that is not possible.

So first you have to take the SiO2 that is silica or quartzite, SiO2 then you have to make some kind of processing to obtain the very high purity grade out silicon material. And so if you consider that first that the manufacturing technology of high purity raw material will be taken care of, and then the second part is the dislocation free crystal growth technology, remember that dislocation free crystal growth technology right. So, there are two steps we shall discuss in details both the steps, one is the high purity raw material another is the dislocation free crystal growth and when we talk about this high purity raw material; obviously, for silicon crystal growth the high purity raw material, raw what is the raw material for silicon crystal growth? For Silicon crystal growth.

Same but, but for finally, your raw material is silicon, finally the raw material is silicon and high purity means you see that there are 10 nines; that means, 99.99999999 percentage which is known as the 10 n, such kinds kind of purification is required; Very high purity material is required. Better if you can use 11 impurity; that means, 99 and then after decimal 9 nine’s. So such kind of purification is required and that is possible only for silicon only, there is one technology which is known as the Siemens purification method Siemens Siemens purification method.

And you using this Siemens purification method we shall show you that very high quality and high purity silicon can be obtain from silica or quartzite. Then another question comes that are about the diameter of the crystal, diameter of the crystal is very important. If you see the present day technology of I C fabrication; that means, chip fabrication then what is the length of the technology? What is the gate length? What is the channel length? Do you know? It is 7 nanometre; by 2018 it will be 7 nanometre.

What is 7 nanometre? let us take one example that almost all the I C chip you know that is based on the transistor or MOS technology; so that means, you have to grow a innumerable numbers of MOS transistor, innumerable number. How many of MOS transistors are there? How many transistors there in I C chip? Millions, so if you see that the chip is of say 1 centimetre by 1 centimetre or even less than or larger than that, then the how many transistors are there inside millions of transistor are there. So that means, the physical dimension of one of the transistor must be very very small.

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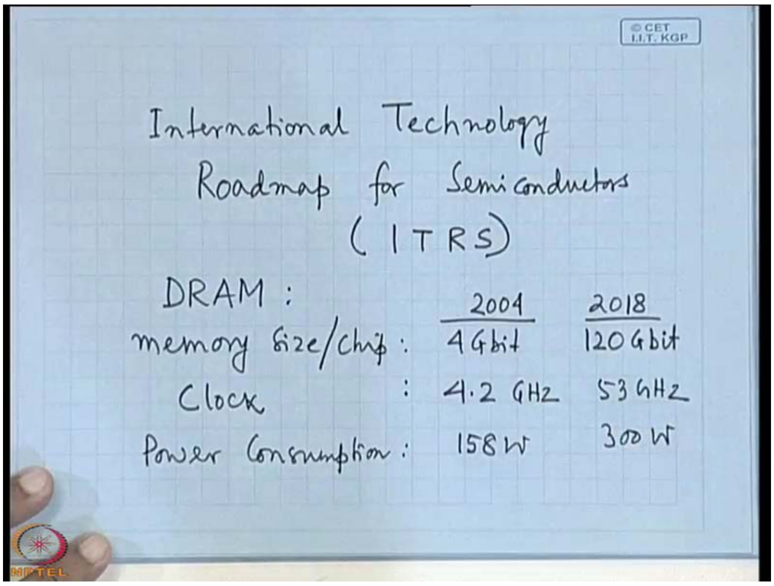

So, in that sense present, the technology uses 7 nanometre particularly that is the there is one organization which is known as International Technology Road Map for Semiconductors, which is known as International Technology Road Map for Semiconductors, I T R S that is an organization and according to the prediction made by this International Technology Road Map for Semiconductors. So, far as say let us take on example of DRAM, you know what is DRAM?

DRAM means Dynamic Random Access Memory. So, memory is very important thing in the I C chip. So, this DRAM. So, far as the DRAM is concern you will find that memory size per chip it is 4 GIGA bit in 2004 and in 2018 it will be 120. So, there is a transition from 4 GIGA bit to 120 GIGA bit, it is the memory size per chip. Then if you consider the other specifications say that clock, what is the clock speed of this this computer?

Student: 2.8.

2.8.

So, now actually it is 4.2 gigahertz which was predicted for 2004, it will be 53 gigahertz right. I am giving you the prediction which was for 2018 and then power consumption; it is from 158 watt to 300 watt. So, if you consider this prediction for 2018 which was done by the International Technology Road Map for Semiconductors; you will find that the memory size per chip will be increased by manifold, then the clock speed will be increased by manifold, power consumption will increase by manifold, but the size of the chip will not be reduced, that is not possible, why it is not possible? Because if you increase the memory size per chip, so the physical dimension of the transistors or the moores you cannot reduce by very much. Only some scaling is possible and that scaling is known probably the physics students know, that is the channel length. Channel length means the channel length of the moores.

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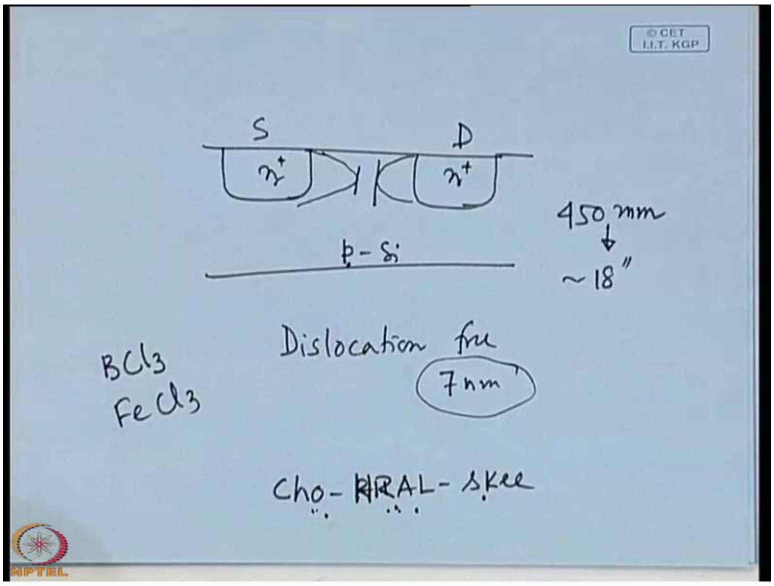

When we talk about the channel length, what is channel length? You see that say this is one material this is say p type silicon or say n type silicon, p type silicon one example I have taken p type silicon, then 2 source and drains are fabricated; this is n this is n, n plus or n plus heavily (( )) right then what is the channel length? Channel length is the length between the source and the drain.

But the actual length is smaller than this physical dimension. Why? Because the length is determined by the region between the 2 depletion regions. We shall come into the detail description of depletion region you know that this is n type and this is p type. So there will be a depletion region.

Similarly this is n type this is p type. So, there will be some deletion region and in fact there may be the final region may be this type of thin or that part of the channel.

Channel

That is predicted to be 7 nanometre that is predicted to be 7 nanometre. So, under such circumstance we have no other option but to increase the diameter of the wafer. So that many more transistors or the MOS devices you can accommodate

Accommodate.

And the prediction is 450 millimetre diameter, now what is that what is its dimension inch? Its almost 18 inch, its almost 18 inch. So, 18 inch diameter silicon will be used as per the prediction of the I T R S for 2018 I C technology fabrication. So that means, if you want to reduce the cost or if you want to make the yield to be the same then you have no other option, but to increase the diameter of the silicon crystal remember that the whole I C technology depends on the silicon O F R. If the material scientists are unable to provide very good quality, very good diameter silicon O F R for fabrication process the whole fabrication process will be stalled.

So, it entirely depends on the diameter of the silicon O F R that is to be provided to the I C manufacturer and here the important question comes, that this very high diameter silicon O F R 18 inch almost, present day we use 12 inch, 13inch 300 millimetres, 350 millimetres that the present day we use. So, this kind of silicon O F R is required for 2018 fabrication as per the prediction. So, the silicon crystal growth is becoming a very hot subject for the future generation I C manufacturing technology also.

Because unless you can provide very good type of material. In this case not only the purification, another thing is that the diameter not only it will be large at the same time it will be dislocation free. This is another term which is very important dislocation free.

What is a dislocation? That is a kind of defect, when we shall discuss about various kinds of defects we shall discuss in length what is dislocation, how it looks likes et cetera, but our presently discussion dislocation means it’s kind of defect that you have to avoid. So, if the diameter becomes large, so there is a possibility that there will be dislocation because you can care for small thing, but the things become larger you cannot expect that the same care can be taken on the whole material. So, that is the reason that not only you need very high diameter material very high purity 10 n or 11 n purity, at the same time you need the dislocation free material.

Another important factor so far is the dislocation free is concerned is there now it is 7 nanometre, which one the gate length, earlier it was greater than 7 nanometre say almost micron type of thing, and what is the dimension of the defect? Dimension of the defect is also of the order of nanometre.

So; that means, unless you make the dislocation free this 7 nanometre will be jeopardised.

Sir.

Yes.

If they form some dislocation you cannot remove it.

No you cannot remove it. There is, there are some process using which you can avoid that place only; there are some place there is the process using which you can avoid say this is your silicon O F R and there is a dislocation here. So, thus that can be predicted that can be determined. So, you cannot at those at the most you cannot use that place only. So, that the other part can be used, because ultimately you have to make a large number of pieces because using a whole O F R say of 400 millimetre dimension how many chips will be there?

There will be hundreds of chip; obviously. So, that is not a single chip. So, chips which are being made as those parts which are dislocation are concerned you can reject so; that means, if this is your whole material. So, this is 1 chip, 2 chip, 3 chips, 100 chips can be processed and if you find that there is dislocation or defects in some regions. So, those chips which are made on that region can be rejected can be removed at the in process.

But since suppose there are some dislocations here throughout the material then what will happen? Then almost all the chips you have to throw out, that is not possible because you have to make the cost also viable. So, that is why the dislocation free must be done.

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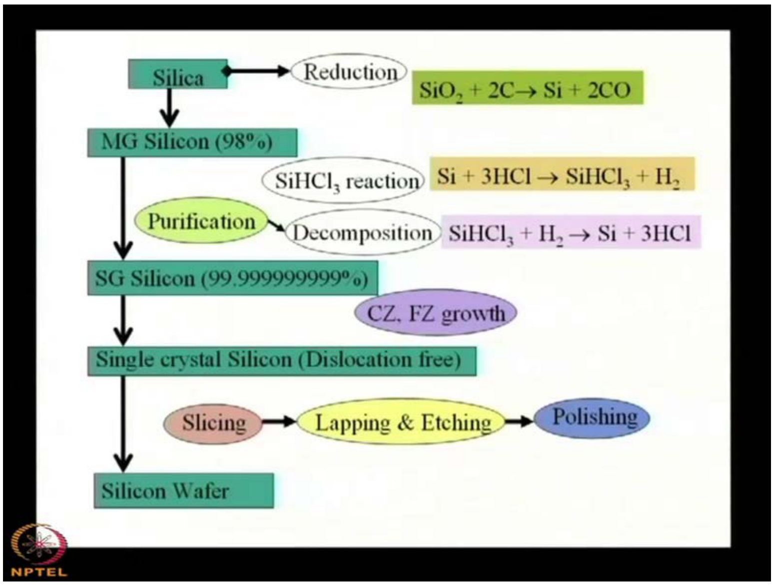

So, if you now consider silicon crystal growth you see that first you have to use silica, this silica is nothing but SiO2 which is also known as quartzite which is also known as quartzite, this is available in Brazil and China, very good quality silica mineral they produce.

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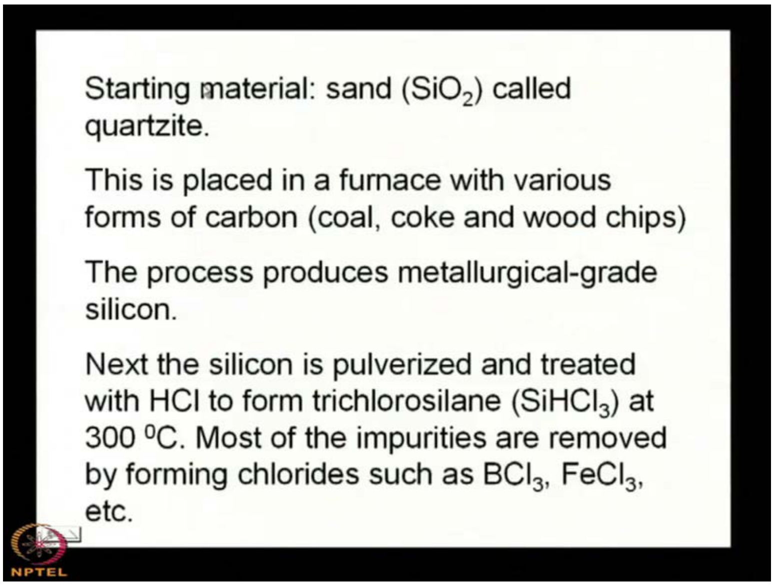

So almost all of the silica materials; which are used as the starting material for silicon crystal growth come from the Brazil or China. Then this silica is placed in a furnace, starting material is sand called quartzite, this is placed in a furnace with various forms of carbon; that means, it can be coal it, can be wood chip, it can be coke et cetera. Right then there is a reduction reaction, reduction reaction means SiO_2 is there.

Gives us to (( )).

O you have to remove so; that means, some reduction reaction must be performed and you see that this is the reduction reaction. So, at the end of this reaction Si is obtained.

I want to change a built.

Here the temperature required is almost 1200 1300 degree centigrade very high temperature is required, or even the higher than that in some books you will find that 1700 and 1800 degree centigrade. Right, normally processing silicon is very difficult also though the technology is very matured and it is available in the market, why? because the melting point of the silicon is very high.

What is the melting point of the silicon? 1410 degree centigrade very high temperature. So, anything which you want using silicon particularly the processing technology you need very high temperature. So, the silicon is first reduced, silica is first reduced into silicon. This silicon is known as the metallurgical grade silicon M G metallurgical grade silicon; that means; it is 98 percent pure, it is 98 percent pure which is known as the metallurgical grade silicon. Now from metallurgical grade silicon to semiconductor grade silicon S G silicon, S G silicon is generally known as the semiconductor grade or electronic grade E G in some book you will find that it is known as E G electronic gate silicon.

So, what is the difference in purity from 98 percent to 10 n or 11n purity? This step is very, very important metallurgical grade silicon to semi conductor grade silicon using this purification process which is known as the Siemens purification. I have mentioned just now Siemens purification, because they have obtained the patent in 1960. You know there is a company name Siemens and they have this patent of purification. So, they earn huge amount of revenue from the silicon processing also, though they have other communication system technology et cetera in Siemens, but there are very useful in purification of silicon as well.

Then what happens for this metallurgical grade silicon you see that this metallurgical grade silicon is pulverized. What is pulverization? What do you mean by pulverization?

Grinding.

Yes pulverization means grinding, crossing, it is means crossing or grinding the material into almost powder right that is known as pulverization. Next the silicon is pulverized and treated with hydrogen chloride to form trichlorosilane at 300 degree centigrade. So, if you see this reaction you see that silicon then react with hydrogen chloride to obtain trichlorosilane, this trichlorosilane is very important product in the since that its melting point just 31.8 degree centigrade; that means, it is almost liquid.

And the advantage of a using a liquid is that you can distil it, you can distil it. So, by fractional distillation trichlorosilane you can remove almost all impurity. So, that is the reason that trichlorosilane is made. That is very important step, the importance of trichlorosilane is twofold, one is that using theses chlorine other impurity say BCL 3 say boron is there, say iron is there where these boron iron is there in the metallurgical grade silicon. It is 98 percent means there are 2 percent impurity in it, more than 2 percent impurity in it. So, you have to now concentrate on the removal of that 2 percent impurity from metallurgical grade silicon to obtain the semiconductor or electronic grade silicon. So, this trichlorosilane as I informed you this reaction occurs at 300 degree centigrade not very high temperature is required, but this trichlorosilane is liquid at room temperature because its melting point is 31.8 degree centigrade.

And this trichlorosilane can be successive with distil. By fractional distillation of this liquid you can purify that is why purification step is there, that you can purify the trichlorosilane into very high purity trichlorosilane and other types of impurity which are there that I mention say that can be removed as a chloride compound. Because you are making the reaction using hydrogen chlorine HCL then this trichlorosilane is decomposed using hydrogen to obtain silicon and HCL. So, this silicon is the semi conductor grade or the electronic grade silicon having 10n or 11n purity.

So, most of the cost is involved in the purification of silicon; that means, from silica to semi conductor grade silicon yes.

Student: Sir what type of (( )) materials removed during purification.

Whatever kind of impurity is there, there are many kinds element because it is mineral type of thing. So, almost all kinds of element can be there, iron can be there, cobol can be there, nickel can be there, boron can be there, aluminium can be there, many kinds of impurities are there and that is the reason know because you see that from 98 percent to 10 n or 11 n such process are involve; that means, 2 percent impurity reduction is necessary is also in our case. Whatever be the impurity that is not our look out because you need ultimately 10n 10n or 11n purity.

So, we cannot bother about any kind of impurity. Be it aluminium, be it iron, it's almost same to us we have to remove it, then the decomposition of this trichlorosilane using hydrogen you get silicon.

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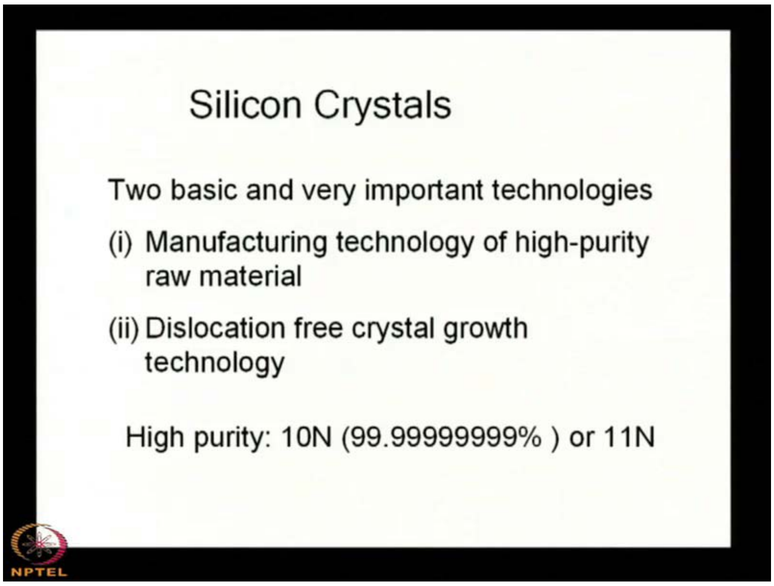

So, the first part is over. What was the first part? First part was you see that manufacturing technology of high purity of raw material. Now we are in a position to get the high purity raw material, then these high purity raw material will be used for single crystal growth of silicon. There are 2 processes; one is known as one is known as the Czochralski technique.

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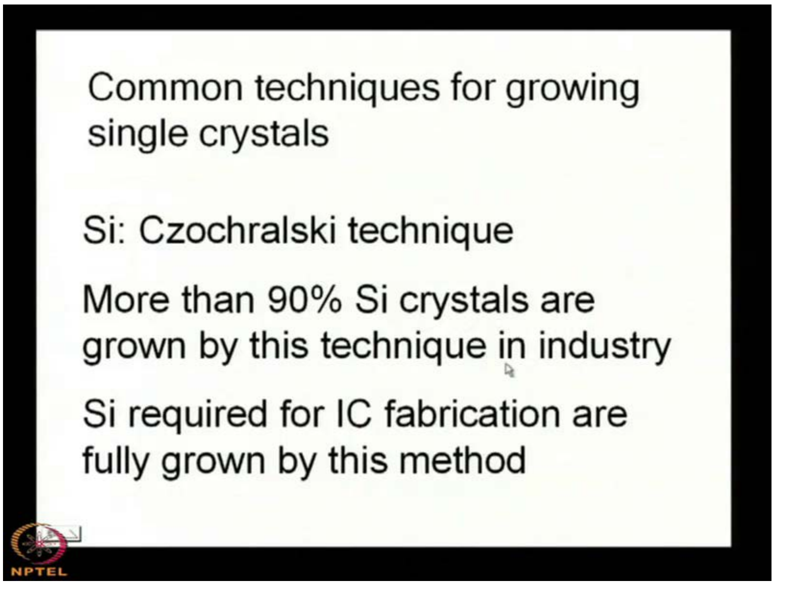

What is the pronunciation, the pronunciation is the CHO-HRAL-skee; that means, this the pronunciation of this is Czochralski cho ral skee, C H O H R A L hral s k ee. So, basically he is a scientist from poland who at the age of only 31, 32 discovered this technique for the bulk crystal growth, single crystal growth of a material. He was doing something using metal melt, he was melting some metal and an unfortunately his pen dipped inside that melt. So, when he took his pen out from this melt he saw that some string type of crystal has been grown. So, that is, that was his final inspiration to get into this Czochralski technique.

I shall discuss that thing in detail and you see that these 90 percent silicon crystals are grown by this technique in industry. Silicon remember, almost 90 percent of silicon single crystals are grown by this technique and silicon required for I C fabrication because of other type of silicon is also required for detector material et cetera. So, that is a different story, but for I C fabrication the whole lot of silicon is grown out of Czochralski technique. Remember that technique is for the growth of single crystal. Why single crystal is required? We have discussed, that it must be defect free dislocation free and mobility will be high.

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So, those are the reasons that single crystals material are grown. There are other techniques also for crystal growth, one is say Float-zone technique another is say the Bridgman technique. The Bridgman technique can be Horizontal Bridgman, it can be Vertical Bridgman and we shall see that for gallium arsenide fabrication this Bridgman technique is used and Czochralski and Float-zone techniques are used for silicon technology.

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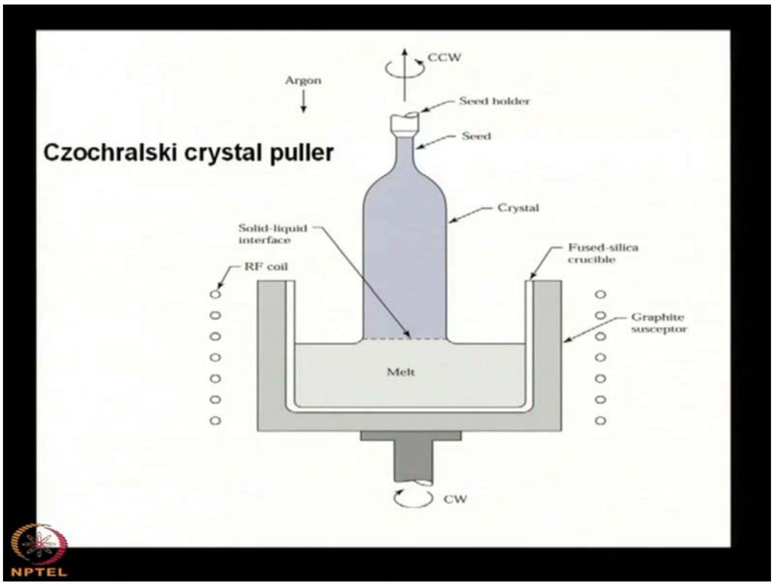

Now if you see the Czochralski crystal puller that is the Czochralski crystal puller you see that it has many parts, it has many parts, one part is that it is there is an graphite susceptor, this is a graphite susceptor.

And inside which there is a crucible silica crucible and the polycrystalline silicon is kept inside this silica crucible. It is heated that is why the melt is there. So, the inside the silica crucible there will be a melt of polycrystalline silicon. So, apart from this graphite susceptor which house the crucible, you see that there is there must be a heating arrangement. These dotted are the RF coil, these small circles RF coil; that means, using some RF heat source, radio frequency heat source you can heat this material. Remember that how much temperature is required.

Student: (( )).

It is obviously greater than 10 degree centigrade. Because the melting point of silicon is 1410 degree centigrade. So, if you want to get a melt of silicon; that means, it must be greater than 1410 degree centigrade. So, almost 1420degree centigrade is required and that is very high temperature that is why you need a radio frequency type of source using which it can be heated and this melt; that means, this is the melt of polycrystalline silicon.

So, when material is melted; that means, it is no more in crystalline state it is basically liquid it is basically liquid then one seed crystal is dipped at the surface of the melt one seed crystal. What is the seed crystal? A seed crystal is the seed crystal of the single crystal silicon so; that means, this is your crucible on which there is a melt, you dip one seed crystal at the surface of the melt then you pull it, then you pull it. So, as you pull it what you will find? At that boundary between the solid and the liquid at that boundary between the solid and the liquid the temperature difference will be there, because the melt temperature is 1410 or 20 that is the melt temperature, but just above the surface when you put a seed on the melt, the temperature will be somehow less than 1410 or 20. So it will crystallise, because of the temperature gradient it will crystallise.

Then you very slowly pull the seed crystal. So, if you very slowly pull the seed crystal then the whole single crystal silicon will be gradually grown and at the same time what will happen, the melt will be the quantity of the melt will be reduced. Because that is being solidified obtain the crystal. So, basically this Czochralski crystal puller, that is why the name puller is there you are pulling the crystal first the seed was see this is neck the neck is seed and there is a seed holder which holds the seed and it is gradually pulled.

First where is the seed? The seed was at the surface of the melt. Then with time it goes up and this whole crystal is formed. First the melt was say up to this region this point, the melt gradually reduces, crystal gradually grows and this is the diameter of the crystal. It will depend on the pull rate of pulling and the temperature at the solid liquid interface the temperature at the solid liquid interface. So, remember that this is very important consideration and you can vary those parameters using a computer control system. Say you want pull to be 1 millimetre per hour, 1 millimetre per hour or even less than that. So only a computer can control the pull rate using which you will get only 1 millimetre per hour or 5 millimetres per day because very slowly you have to pull otherwise what will happen?

There will be defect.

There will be defect. Otherwise there will be defect. Very very smooth must be there. So, that is known as the Czochralski crystal puller. You are pulling the crystal from the melt. So, it is a melt growth process, growing the crystal out of the melt. First you take the electronic grade or semiconductor grade material, you melt it where it will melt on the crucible. Crucible.

The crucible is made of Silica.

Silica and on which it will be placed?

On a graphite susceptor.

On graphite susceptor on a graphite susceptor crucible is and you have to heat. Where is the heating element it is.

Behind the susceptor, it is behind the graphite susceptor. Now the question comes why you is Argon, you see that Argon is there and arrow is given why there will be Argon.

Produce land mark so.

No.

So, it cannot oxidise yes why, what is the problem with oxidisation?

Because silicon is formed.

Because.

(( )).

No not only that here you have to drive oxygen arrow from this whole environment, it is because graphite when heated in presence of oxygen it will be damaged.

Sure.

Yes graphite, you can graphite can be heated, but that heat must be not in presence of oxygen the yes graphite is also and can with stand very high temperature, but not in presence of oxygen it will be damaged. Another thing is that unless you control the oxygen in the atmosphere, unless you control the oxygen atmosphere you must control otherwise what will happen? The material will be oxidised as well. SiO_2 will formed as you told. So, that is why Argon will be passed through the material environment; that means, this Argon will replace oxygen there is oxygen. So, it will replace oxygen and here there must be an exhaust, here at the bottom there will be an exhaust through which that Argon and SiO gas will be removed.

SiO gas will be form and argon will be there. So, there will be continuous flow of Argon. So that the pressure must be controlled in such a way inside the apparatus, that the Argon pressure remains constant. Because it is continuously removing the SiO gas also. So, basically SiO gas is coming out from the surface of the melt, from the crucible surface SiO gas is evolving and Argon is taking those SiO gas to removing through the exhaust at the bottom. That is why the pressure and the quantity of Argon must be control very precisely and that can be done using computer.

There is no computer here, you see that there is no control system, but the whole thing is being control by a computer. Process parameters like temperature, then temperature gradient, pull rate, Argon pressure, everything will be determine by the computer. So, there will be computer control system. I have shown you a very simple diagram of crystal puller and apart from computer control, there must be an optical window to see the diameter of the crystal. You can see the diameter of the crystal using some say optical window means there must be CCD Charge Coupled Device, CCD camera must be there using which you can see how much it has grown, what is the diameter? Is it 100, If say you need 150 and you see that it is 152 or 149 then what we have to do? We have to adjust; you have to adjust some of the process parameters. So, using a computer control, using a computer control system you can adjust those parameter there is a loop. So, you can adjust the parameter. So as to get the exact diameter of the single crystal. So, it is not as simple as it looks like. There will be optical device, there will be computer control system and argon pressure will be there everything.

And another thing I have to mention that there is one magnetic field also which is used. There is a one magnetic field which is also used here at the crucible. And why the magnetic field is used? What is the advantage of using a magnetic field for crystal growth? It is because of 3 factors, one is that oxygen concentration control; to control the oxygen concentration in the crystal growth process. One thing is to reduce impurity contamination and number 3 is that here you see at the surface of the melt there will be movement, there will be vibration because at 1420 degree centigrade there is a liquid having some density. So, what would be the surface? Surface will be vibrating. To reduce that vibration magnetic field is applied.

Why? Because unless you reduce the vibration, it will give raise to defects and dislocation, it will give raise to defects and dislocation.

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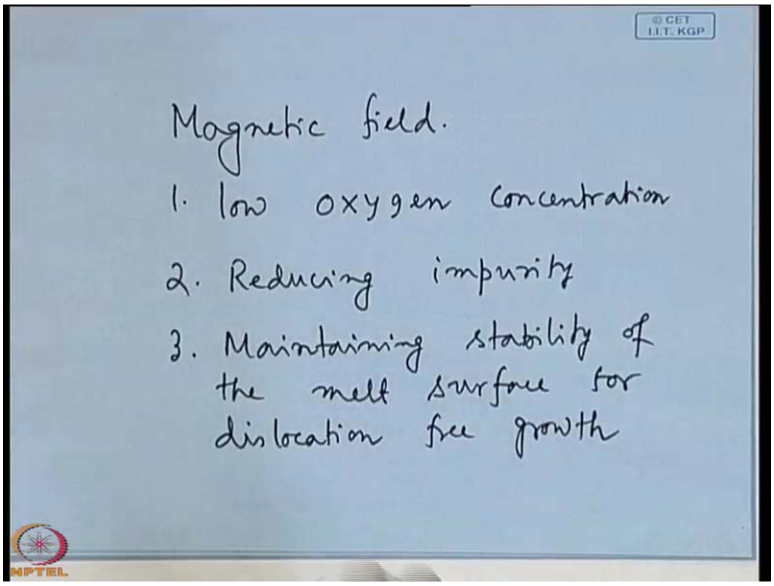

So, you see that the magnetic field is very important. It is one is low oxygen concentration, to maintain low oxygen concentration. Number two is reducing impurity and number three is maintaining stability of the melt surface for dislocation free growth for dislocation free growth. So, these are the three points for which we use a magnetic field. One point is maintaining low oxygen concentration. Ok.

Now, you can ask me Sir why it is required? It is required because at this high temperature oxygen will be coming out from silica, oxygen will be coming out from silica because there is no aerial oxygen, you have used argon to remove the oxygen from the system. Then what is the source of oxygen? The source of oxygen will be silica because the crucible is silica. So, from the silica crucible oxygen is automatically be mixed inside the melt, that you have to control. Otherwise the material will be oxygen rich. Then the problem will be that the melting point of pure silicon is 1410, but if there is sufficient quantity of oxygen in it. So, then the temperature will be different.

Even plus minus 0.5 degree centigrade temperature also can jeopardise your growth. The temperature to be maintained is very precise manner; otherwise you cannot control the growth. Such diameter, such dislocation free material you cannot grow.

So the temperature is very important factor, because it will be crystallised at the solid liquid interface at the solid liquid interface and the interface temperature control is very important. So, that is why oxygen controlling is very important aspect in bulk crystal growth so far as the Czochralski technique is concerned. So, magnetic fields in one way control that oxygen concentration. Number two is the impurity concentration, there are many impurities particularly that impurity which can be attracted by magnetic field, iron Cobol, nickel et cetera those are there in the material.

And third one is the stability of the melt surface for dislocation free growth. Stability maintaining stability of the melt surface, as I told you that the melt surface will be (( )) vibrate. So, that is why magnetic field will be there. Another important aspect of oxygen is that…

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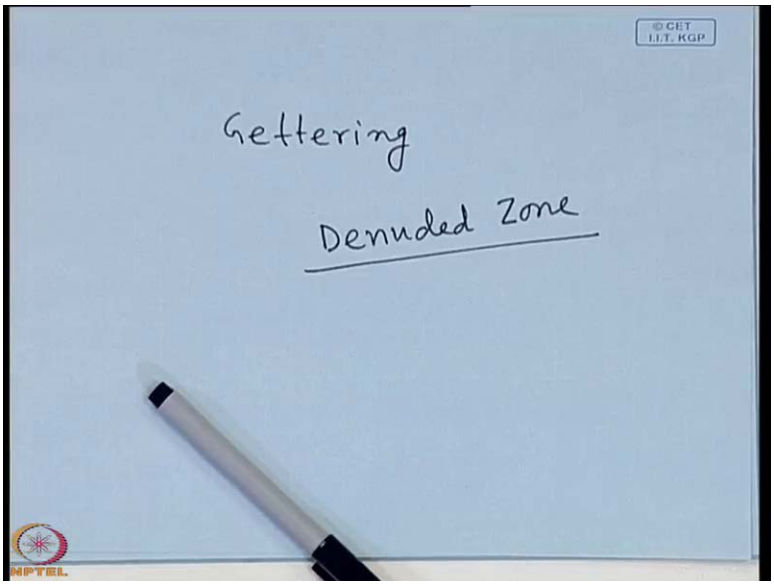

There is one term in crystal growth which is known as Gettering, which is known as Gettering. Gettering is a process which removes the unwanted impurity from the surface to the bulk from the surface to the bulk, that is known as Gettering.

Say this is a crystal this is a crystal, this is its surface this is a surface. So, Gettering actually drives the unwanted impurity from the surface to the bulk or the back side.

Bulk or the back side.

How much thickness is required for the device fabrications? How much? Some 1 micron, 2 micro, 5 micron. So, if can make clean of the whole surface say 5 microns or 10 microns, 100 micron then your purpose will be solved. Let the impurities be settled at the bottom or at the back side, because how the there is an impurity where it will go. So, people have been trying to drive the impurity away from the bulk surface region, because the whole processing technology will be on the surface. The growth will be on the surface and only some micron from surface to the bulk we use, the other thing we do not use other thing is removed basically it is.

So, that is the reason that impurity is driven away from the surface region to the bulk or the back side of the sub straight or the wafer. That is done by Gettering that is done by Gettering and oxygen plays an important role a gettering the impurity. Why say there is oxygen and that oxygen it is coming from SiO2, if a control manner you can put some oxygen in the material, you can control then there will be and super saturated oxygen at the say surface of the material or at the bulk of the material. Somewhere in the material there will be a super saturated oxygen region, that oxygen will grow that oxygen will grow.

When it will grow. So, at some time what will happen? Some stress it will provide. So, the stress will be relieved only if some dislocation or defects are formed in the material. Those defects and dislocation trap the impurity; those dislocation defects trap the impurity. When we talk about the gettering of impurity where the impurity will go? The impurity will be trap or will be taken away by the defect or dislocation in the material, but not at the surface away from the surface.

But how the dislocation is provided at that point? That is done by oxygen. To relieve the strain of the oxygen dislocation is formed and that dislocation will trap the impurity material at that point so that they cannot move. They are trapped at some point away from the surface or the device region. So, basically the devices are made at denuded zone. Denuded zone, the denuded zone means the zone on which the device is made. The zone on which the devices are made. Ok.

And this is very important zone for us. It is very important zone for us and you see that this gettering is done away from the denuded zone, and that is done by oxygen or you can use other type of gettering like implantation of phosphorus at the back there are other types of thing, but it is very intrinsic process. You are using the oxygen taking from the silicon crucible controlled by the magnetic field, to grow at some point where they relieve the stress by forming some dislocation inside the material and that dislocation lines will trap the impurity away from the denuded zone. That is gettering and that is very important factor.

Student: Sir (( )).

Yes this is your material and inside it is it is growing basically bulk crystal growth. So, you control the oxygen in such manner not very high oxygen is required, if you control the oxygen is such manner that it becomes super saturated at some point. So it will grow basically, the growth oxygen bubble say will be there. So, after some point because of thermo dynamic consideration it will give raise to stress. So, the stress will be relieved by forming the dislocation inside the material. At that point that dislocation line will trap the impurity, so the impurities are trapped in the very small region away from the surface or away from the denuded zone. This is very simple thing and you can proceed if you see the crystal growth process or that type of manufacturing plant when you after some time, when you can see in some foreign laboratory or elsewhere.

You will see that it is common practice, standard practice gettering of impurity. Since no foreign body is involved because during crystal growth it is being done. So, that is why it is known as the intrinsic gettering. Extrinsic gettering means after crystal growth if you getter something after crystal growth then that is known as the extrinsic gettering, but since it is the part of the bulk crystal growth so that is known as the intrinsic gettering and remember that this impurity will be very very much small how much 1 PPB what is PPB?

Parts per.

PPB is parts per billion; that means, 1 in 10 to the power 9,1 in 10 to the power 9 parts per billion, that is means it is practically one second in 32 years, 1 second in 32 years its parts per billion, or say 1 drop in 1 drop in 250 chemical drums, you have seen the chemicals drums. So, 1 drop of water drop in 250 chemical drums, the dilution is known as PPB level of dilution. Very minute, very small, 1 in 10 to the power 9. If you have 10 to the power 9, say marbles of red colour and 1 marble is there in green colour show what is the impurity, it is P P B level. It is the impurity is in that case we shall say that it is P P B level and what is P P M parts per million. It is 10 1 in 10 to the power 6, it is 1 in 10 to the power 6; that means, it is almost 1 second in 11 and half hours. Suppose we have a clock it is going fast or slow by 1 second in 11 and half hours then you can say that it is going slow or fast by P P M level. It is it is basically 1 drop of water in 50 litter tank, physical if you can consider.

So, today we have discussed about some aspects of bulk crystal growth particularly the Czochralski technique and next day we shall start the Float-zone technique.

Thank you.