Processing of Semiconducting Materials
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Lecture - 13
Bulk Crystal Growth – II

In our last class, we have seen that the bulk crystal growth takes place using one technique which is known as czochralski technique. And we have discussed in detail that in czochralski technique, what happens the silicon is kept in a crucible, the crucible is made of generally quartz; that means, silica and high temperature is required because the melting point of silicon is very, very high.

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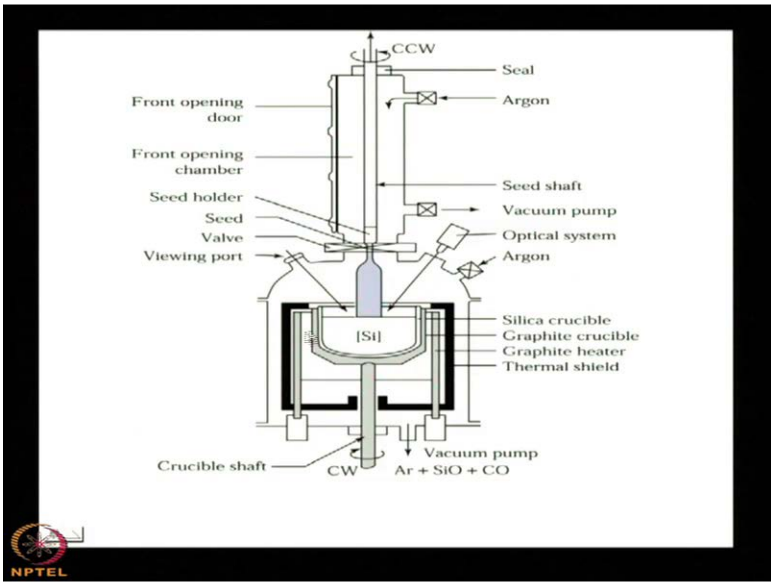

So, the effect of the growth is that in some cases, you will find that there will be contamination; if you see these duigraphy you will see that this is the crucible this is the silica crucible and it is in touch with the crucible valve. So, what you find that particularly the oxygen or different kinds of contaminations will be there in the melt of silicon, because silicon is in the liquid state; it is almost the melt, melting state. And there is another technique in which we can avoid this kind of contamination from the crucible; contamination from the crucible.

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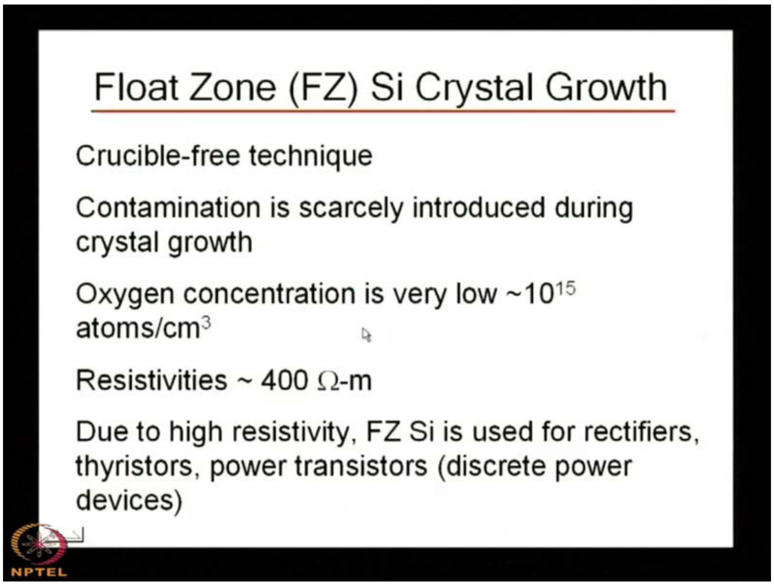

Float Zone (FZ) Si Crystal Growth

Crucible-free technique

Contamination is scarcely introduced during crystal growth

Oxygen concentration is very low ~10^{15} atoms/cm^3

Resistivities ~ 400 Ω-m

Due to high resistivity, FZ Si is used for rectifiers, thyristors, power transistors (discrete power devices)

And that is known as the float Zone silicon crystal growth that is known as the float zone silicon crystal growth. These float Zone silicon crystal growth is a technique in which we do not use crucible. So, you see that it is a crucible free technique. We do not use crucible. So, contamination is scarcely introduced during crystal growth basically there is no contamination during crystal growth and oxygen concentration is also very low, it is approximately 10 to the power 15 atoms per centimeter cube; and so the resistivity is very high; it is 400 ohm meter remember not centimeter ohm meter is very high.

And due to this high resistivity float zone silicon is used for rectifiers, thyristors, power transistors; that means, which are known as the discrete power devices. So, what we find that due to crucible free, there is no crucible in this technique, I shall show you the diagram for this kind of crystal growth; and if you compare this crystal growth with the previous one; that means, czochralski technique.

You will find that there is a crucible associated with this type of a technique. There are other kind of differences, apart from these use of crucible is that the seed crystal is placed at the molten state, at the surface of the molten silicon, and then pulled, then pulled. And in this case we shall show you that the seed crystal is placed on the bottom not on the top. Then because of there is no contamination, you will find that the resistivity is very high, you know that if there is a iota of impurity if there is a iota of impurity, the resistivity decreases, because you know that if a semiconducting sample is not doped at all; that means, it is known as the intrinsic, it is known as the intrinsic.

So, if the semiconductor sample is intrinsic in nature, the resistivity is very high; that means, intentionally or unintentionally you have not doped the sample with any kind of impurity. So, that is the difference between the intrinsic and extrinsic nature of the material. So, in czochralski technique you will find that from the crucible itself there will be impurity apart from silicon, oxygen there may be carbon or other kind of impurity carbon is another of impurity which is readily available during crystal growth why the what is the source of carbon the source of carbon is you know that there is highness then there is heater then pgraphite acceptor. So, from those kind of material always there will be carbon emission in the form of carbon monoxide or carbon dioxide and they will be absorbed in the silicon melt.

So, that; that means, during czochralski technique growth you will find that there is many ways through which the impurity can be associated in the melt giving rise to some increase in conductivity; that means, decrease in resistivity, but there are some application particularly you will find that the application in discrete power devices discrete power devices; that means, a devices are known as rectifiers thyristors power transistors etcetera very high resistive sample is required material is required so; that means, this material must be free from any kind of impurity. That is why no contamination is allowed in this case and you will find that due to the contamination the resistivity decreases. So, if there is no contamination the resistivity increases and you find the value is 400 ohm meter is quite high value.

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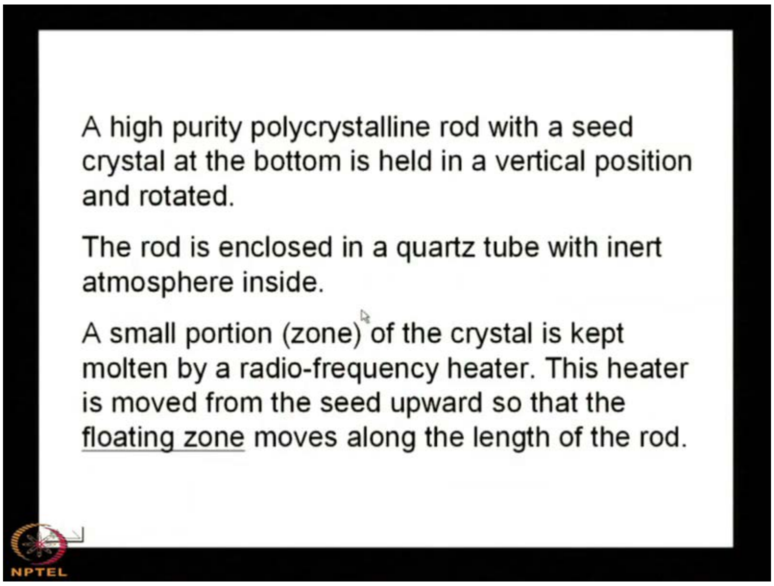

A high purity polycrystalline rod with a seed crystal at the bottom is held in a vertical position and rotated.

The rod is enclosed in a quartz tube with inert atmosphere inside.

A small portion (zone) of the crystal is kept molten by a radio-frequency heater. This heater is moved from the seed upward so that the floating zone moves along the length of the rod.

And in this float zone technique generally a high purity polycrystalline rod with a seed crystal at the bottom is held in a vertical position and rotated here also you find that the starting material is polycrystalline silicon and in our last C Lass we have discussed about the synthesis of high purity polycrystalline can you remember we have synthesis the high very high crystalline high purity polycrystalline of the order of 10 and on 11 and purity. So, in almost all the cases be a czochralski technique or float zone technique the starting material is high purity polycrystalline silicon and here also a high purity polycrystalline rod with a seed crystal now what is the necessity of seed crystal?

Why we use a seed crystal for the growth of any crystal why it is required at all? Yes basically we know we want a particular orientation of the crystal 1 0 0 1 1 1 1 0 1 any particular orientation. So, there is a melt and it crystallizes using the technique of solidification and during solidification.

If you introduce one seed crystal, so the crystallization takes place in a better way with a particular orientation. So, that is the reason that you will find in all most all crystal growth technique beed bulk or epitaxy there is a seed crystal in epitaxi the seed crystal is basically the substrate on which the growth takes place basically the substrate on which the growth takes place. So, in the direction of the surface of the substrate the epitaxial growth takes place. So, in this case you find that we start from a polycrystalline very pure silicon rod and the seed crystal.

At the bottom held in a vertical position you see that this is the silicon high purity silicon rod this is and there is a seed crystal at the bottom which is placed in a vertical direction right. So, the now if you find the difference between these thing and the czochralski what you find here you see that there is no crucible there is no crucible and in czochralski you find that there is a crucible in czochralski pole is taken from the upward direction here it is in the bottom direction you will find that the crystal growth takes place. Now the rod is enC Losed in a quartz tube with inert atmosphere inside it as as usual there also you find the in czochralski technique there is a quartz atmosphere it is it is covered with a quartz tube and the argon is passed through the quartz tube.

why the argon was necessary for the crystal growth yes to replace basically oxygen etcetera and to control the oxygen which comes from the crucible another thing is that the graphite acceptor is used and oxygen is very detrimental at high temperature it will be oxidized and it will be damaged. So, that is why inert atmosphere is maintained inside the quartz tube within which the total growth system is housed here also you see that the rod is enclosed in a quartz tube with inert atmosphere inside; that means, this is your rod and it is fully covered with a quartz tube it is fully covered with a quartz tube and inside there is a inert atmosphere.

A small portion of the crystal the small portion is known as the zone z o n e. So, the name of this technique is float zone technique zone comes from this concept that a small portion of the crystal is kept molten by an RF heater radio-frequency heater. This heater is moved from the seed upward. So, that the floating zone moves along the length of the rod. So, the float zone comes from these concepts that the zone moves.

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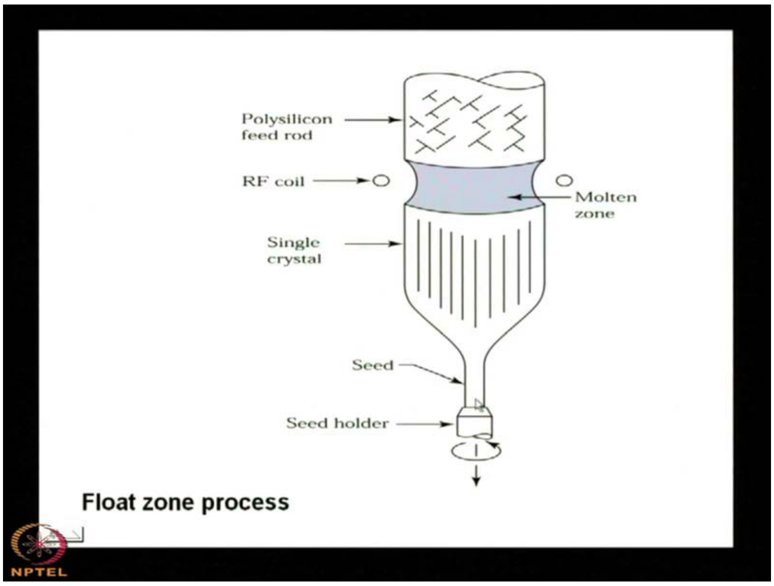

Float zone process

That means you see that the heater is moved from the seed upward you see this is your RF coil so; that means, the RF coil imparts heat to this rod. So, it is in a molten state and this RF coil is moved upward direction so; that means, this zone is not fixed here the zone was earlier here near the seed then the zone moves upward and since there is a seed and it is pulled in this direction downwards.

So, due to the temperature gradient of the molten state and between the solid-liquid interface there is a temperature gradient it solidifies; that means, freezing effect is there and the single crystal grows in this manner. So, at the end what will happen the whole rod will become single crystal because of this movement of the heating source; that means, the molten zone is moved. So, that is why it is known as the floating zone it is floating basically.

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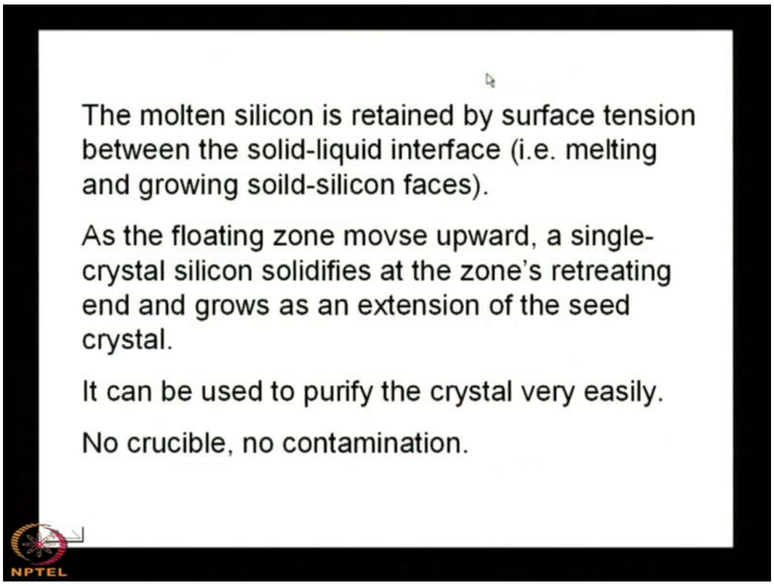

The molten silicon is retained by surface tension between the solid-liquid interface (i.e. melting and growing soild-silicon faces).

As the floating zone movse upward, a single-crystal silicon solidifies at the zone's retreating end and grows as an extension of the seed crystal.

It can be used to purify the crystal very easily.

No crucible, no contamination.

And it moves along the length of the rod and you see that these molten silicon is retained by surface tension between the solid-liquid interface that is the melting and growing solid-silicon faces There are two faces one is the growing; that means, where the it solidifies and another is the molten; that means, where the RF coil is there so because of this surface tension between these two interface it is held there it does not detach from its position as the floating zone moves upward see the spelling mistake floating zone moves upward a single crystal silicon solidifies at the zone retreating end and grows an extension of the seed crystal retreating end means? This end this is the retreating end.

So, as it moves crystal increases the single crystal increases at is moves upward. It can be used to purify the crystal very easily no crucible and no contamination that is the most important advantage of the float zone technique that because of no crucible no contamination takes place and so, it can be purified very easily. Why this term purification we use? We use this purification term because you see that when the crystal lies in takes place generally all bulk crystal is made using the melt growth process; that means, fast the material is melted and then it is pulled using a seed crystal.

So, when the crystallization takes place always you will find that the impurity distribution in the crystal; that means, in the bulk is less compared to the molten state; that means, see if x is the impurity concentration in the melt the solid will not have x it will be less than x concentration why? Because, why it happens? Because of the solidification the temperature is maintained in such a way that the solidification takes place of the silicon material itself right? If there is an impurity then what will happen? Solidification temperature will be different 1 degree; 2 degree; 4 degree may be different but, here the temperature is maintained in such a manner that even plus minus 1 degree centigrade is not allowed. So, most of the impurity is rejected in the melt and as the crystal grows gradually melt becomes impurity reach earlier it was x right? Then the quantity decreases melt quantity decreases, but the rejection takes place many fold.

So, the crystal the melt will be increasingly impurity reach. Let us take on concrete example suppose we want to dope silicon with phosphorus. So, what will happen? We generally mix phosphorus in the silicon melt that is calculation I shall show you how the calculation is done. If you take 10 k g; 40 k g; 50 k g; 100 k g of silicon then what should be the quantity of arsenic or phosphorus or boron if you want to dope it by 10 to the power 16 or 10 to the power 17 per c c impurity. So, you put some phosphorus in the silicon melt right. Suppose you have given 10 to the power 18 silica phosphorus in the melt, but after the growth you will find that it will be 10 to power 16 in the solid it will be 10 to the power 16 not 10 to the power 18, but as the silicon, because the melt is silicon plus phosphorus, so as the more of the more and more silicon is consumed.

So, what will be there the phosphorus quantity percentage will increase inside the melt so the melt will be reach in phosphorus. So, eventually what will happen the whole crystal will grow at the end it will full of impurity. So, generally the tail is sliced out from the main crystal because the impurity is very, very high in the tail region and also the neck; that means, the seed region it is also chopped out because if you see a crystal from the seed you can imagine that there will be a solder due to the seed and there will be a tail at the end so the tail and the solder are both chopped out from the crystal. So, as to avoid the so, as to avoid the impurity inside the material.

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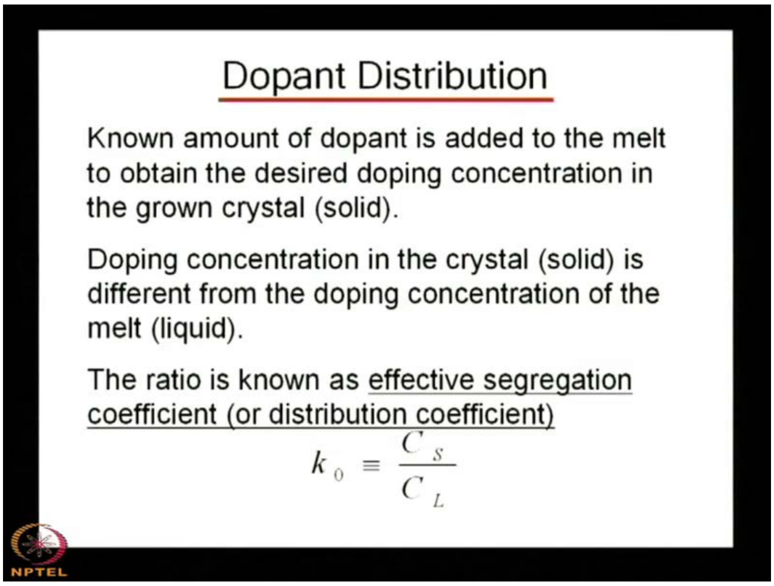

Dopant Distribution

Known amount of dopant is added to the melt to obtain the desired doping concentration in the grown crystal (solid).

Doping concentration in the crystal (solid) is different from the doping concentration of the melt (liquid).

The ratio is known as effective segregation coefficient (or distribution coefficient)

$$k_0 \equiv \frac{C_S}{C_L}$$

Now what so be the dopant distribution you see that a known amount of dopant is added to the melt known amount means? It may be gram or milli gram of phosphorus or arsenic or antimony or boron is added to the melt to obtain the desired doping concentration in the grown crystal when we say crystal; that means, it is the solid when you say the melt it is basically the liquid; that means, in it is In a molten state doping concentration in the crystal.

That means, in the solid is different from the doping concentration of the melt; that means, liquid the ratio is known as segregation coefficient or distribution coefficient what is this ratio? This ratio is the doping concentration in the solid you see that it is C Suffix S, S stands for solid and it is C Suffix L, L stands for liquid people have taken the experimental data to obtain this C SC S and C LC L and they found that in all most all the cases it is less than 1. So, if this ratio C S by C L is less than 1 what it implies? It implies that the impurity is rejected to the melt ideal is 1 ideal is 1; that means, all most all the impurity is taken up by the crystal.

As per your calculation, but if it is less than 1, you will find that it it means that the it is there is a rejection of the impurity in the melt itself. So, the K 0 or K d in some books you will find that it is written as K d or simply K it is the segregation coefficient or the distribution coefficient of the impurity in the crystal.

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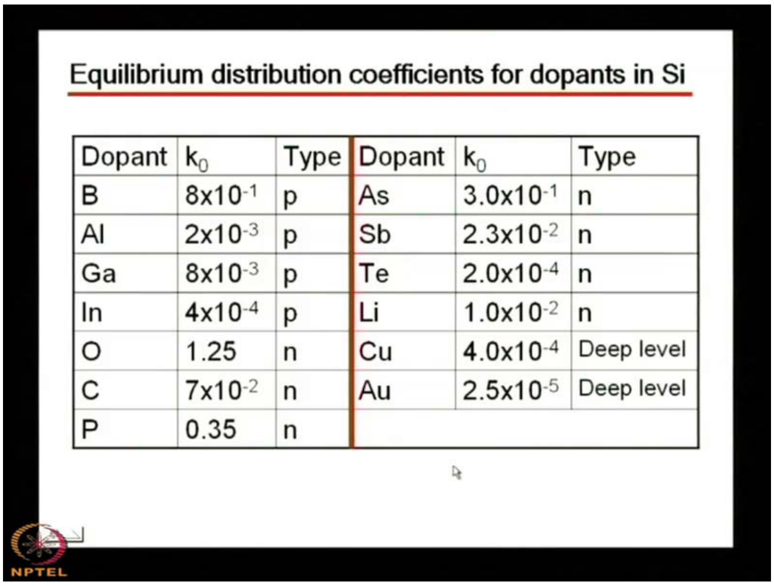

Equilibrium distribution coefficients for dopants in Si

Dopant	k_0	Type	Dopant	k_0	Type
B	8×10^{-1}	p	As	3.0×10^{-1}	n
Al	2×10^{-3}	p	Sb	2.3×10^{-2}	n
Ga	8×10^{-3}	p	Te	2.0×10^{-4}	n
In	4×10^{-4}	p	Li	1.0×10^{-2}	n
O	1.25	n	Cu	4.0×10^{-4}	Deep level
C	7×10^{-2}	n	Au	2.5×10^{-5}	Deep level
P	0.35	n			

And you can see that the values of the distribution coefficient for different kinds of dopants in silicon you see that the dopant is boron, aluminum, gallium, indium all those four dopant give rise to p type doping and the type is given and the segregation coefficient you see 0.8 for boron it is 0.8; for aluminum it is 2 into 10 to the power minus 3 very very less, gallium 8 into the power minus 3, indium 4 into 10 to the power 4.

So likewise, you see that except oxygen it is very high 1.25 for all most all other cases you will find that it is less than 1 so; that means, a K 0 is less than 1. So, C S must be less than C L, C S must be less than C L because K 0 is nothing but the ratio of C S to C L and there are other two dopant you see that copper and gold you can dope silicon with copper and gold, but you will find that they will give rise to deep level what is deep level? Can you say what is deep level? You see that when impurity doping takes place.

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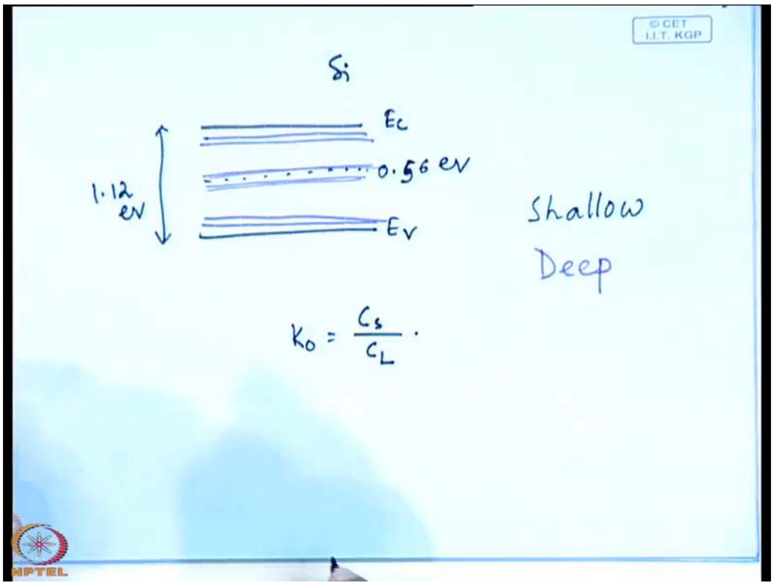

So, let us draw the silicon it is the conduction bandage it is the balance bandage and the value is how much? 1.12 electron volt this is silicon this is Fermi level intrinsic Fermi level it is at the mid gap; that means, 0.66 56 0.56 electron volt now when we talk about doping basically those are shallow in nature shallow s h a l l o w those are shallow in nature; that means, for donors they will occupy the position just below the conduction bandage and for accepted type of thing they will occupy the position just above the balance.

Balance bandage. So, that is why they are shallow in nature; that means, these levels these are the shallow levels very near to the conduction bandage or balance bandage that is why they are shallow and another thing is the deep level as the name implies they will occupy the position deep inside the band gap; that means, these positions. So, they will not contribute to the conduction mechanism they will not contribute to the conduction mechanism.

Why they will not contribute to the conduction mechanism? Why they will not contribute to the conduction mechanism? It is because the ionization energy will very, very high and who will supply that ionization energy the semiconductor is popular because at room temperature is conducting in nature because from the normal thermal temp value thermal energy k t all most all the donors are the acceptors are ionized because the value is of the order of the some milli volt milli electron volt, but if there is a deep level the ionization energy is so high that at normal room temperature or operation temperature the impurity will not be ionized. So, if they are not ionized they will not give you the electron or whole for the conduction mechanism say see this is a shallow level and these shallow level the difference is some milli electron volt what is the room temperature thermal energy it is 26 milli electron volt it is 25.9 milli electron volt. So, with that temperature all most all of the donors will be ionized.

So, if the donors are ionized for each donor atom one electron it will donate to the conduction band. So, at the conduction band you will find many numbers of electrons coming out from the donor atoms and the donor atoms will be ionized the donor atoms will be ionized in mobile ions will be there. Similarly for acceptors the wholes will be given; that means, you will act as acceptor there are many states which can accept the electrons. So, that is the conduction mechanism in semiconductor but the deep levels will not contribute to either electrons or wholes because of the position they are occupying is very, very deep. So, far as the conduction bandage or balance bandage is concern and consequently such huge amount of energy they will not be provided

Say, if it is near the mid gap so what is the value? The value is 0.56 electron volt almost 0.5 electron volt. So, 0.5 electron volt is very high value for semiconductor 0.5 electron volt is very high value for semiconductor and if you consider 0.56 electron volt what should be the thermal energy? What should be the temperature which will give rise to 0.56 electron volt; that means, k b t is equal to 0.56. So, t equals to 0.56 divided by 1.38 of 10 to the power minus 23. So, it is very, very high value very, very high value at that high value the silicon will not remain as silicon and also huge power will be consumed

So, the spirit of semiconductor technology will be lost because semiconductor needs very, very small power and miniaturization. So, that will be lost. So, you see that for silicon the copper and gold they will give rise to deep level they will not form either n type or p type conductivity in silicon now this K 0 equals to C S by C L that is known as the segregation coefficient.

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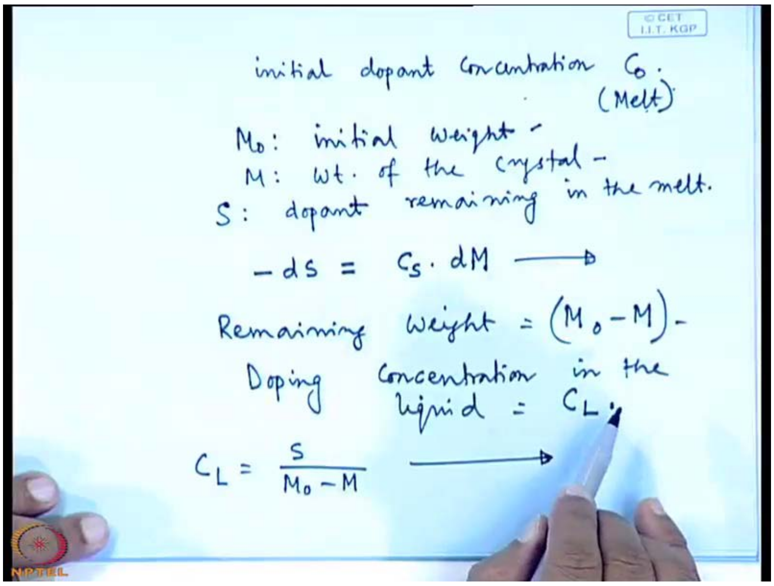

initial dopant concentration C_0.
(Melt)

M_0: initial weight -
M: wt. of the crystal -
S: dopant remaining in the melt.

$$-dS = C_S \cdot dM \longrightarrow$$

Remaining weight $= (M_0 - M)$ -
Doping concentration in the liquid $= C_L$.

$$C_L = \frac{S}{M_0 - M} \longrightarrow$$

Now let us make some small mathematics very small type of mathematics you see that suppose there is a crystal the initial concentration dopant concentration the initial dopant concentration is say C 0 in the melt it is in the melt and M 0 is the initial weight M 0 is the initial weight then as the crystal growth takes place at is as it approaches then what will happen? Some of the crystal will be solidified say M 0 is the initial weight. So, you see that there will be M 0 and there is as M 0, progresses. So, S is the dopant remaining in the melt, remaining in the melt.

So, minus d S will be equals to C S into d M what is d M? d M is the amount of crystal which is being produced very small amount of crystal say d M, M is the total weight. So, d M is the impersonally small weight and you know that S is the dopant remaining in the melt. So, why it is minus? Because it is rejected, it is rejected. So, we can write minus d S equals to C S into d M what is C S? C S is the concentration of the dopant in the solid state; that means, in the crystal it is in the solid after solidification right? Another expression we shall write that So, remaining weight equals to M 0 minus M M 0 minus M is the remaining weight of the crystal and doping concentration in the liquid equal to C L. So, we write that C L equals to S by M 0 minus M.

Let me explain again let the initial dopant concentration in the melt is C 0 dopant and initial weight is M 0, M at certain instant of time say after time t M amount of crystal is grown M amount of crystal is grown. So and S is the dopant remaining in the melt. So, we can write that minus d S equals to C S into d M why it is minus? Because it is decreasing it is rejected to the melt. So, it is that is why it is minus d S equals to C S into d M, M at instant of time the weight of the crystal; that means, in the solidifying state now what is the remaining weight? The remaining weight is M 0 minus M then the doping concentration in the liquid if I consider that C L. So, C L will be S by M 0 minus M, M 0 minus M is the remaining weight of the crystal because initial weight was M 0. And at instant of time t M is the weight of the crystal. So, M 0 minus M is the remaining and S is the dopant remaining in the melt. So, dopant remaining in the melt minus the weight of the crystal will give you the doping concentration in the liquid which is C L

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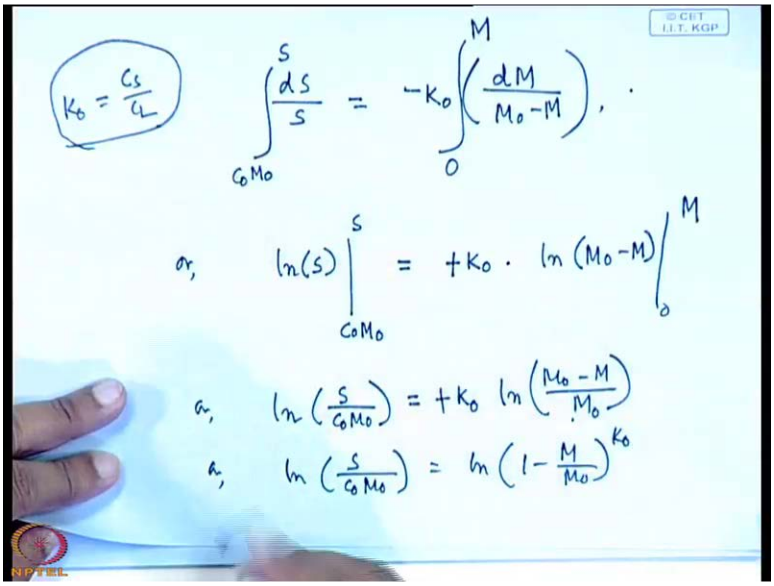

$K_0 = \frac{C_s}{C_L}$

$$\int_{C_0M_0}^{S} \frac{dS}{S} = -K_0 \int_{0}^{M} \left(\frac{dM}{M_0 - M} \right) .$$

$$\text{or, } \quad \ln(S) \Big|_{C_0M_0}^{S} = +K_0 \cdot \ln(M_0 - M) \Big|_{0}^{M}$$

$$\text{or, } \quad \ln\left(\frac{S}{C_0M_0}\right) = +K_0 \ln\left(\frac{M_0 - M}{M_0}\right)$$

$$\text{or, } \quad \ln\left(\frac{S}{C_0M_0}\right) = \ln\left(1 - \frac{M}{M_0}\right)^{K_0}$$

Now if you put these two if you join this two equation you will find that d S by S it is equals to minus K 0 d M by M 0 minus M you see that first equation was these thing minus d S equals to C S into d M and second equation was C L equals to S by M 0 minus M using these two equation I can write d S by S equals to minus K 0 d M by M 0 minus M why? Because you know that K 0 is equals to how much C S by C L. So, if you put C S by C L. equals to K 0 you can arrive that this expression now I want to integrate these things that what is the limit? Limit is that here for S you see that it must be S. The final and C 0 M 0 is the initial because when the weight was M 0 the concentration was C 0. So, C 0 M 0 was the initial limit and S is the final limit because we have already assumed that S is the dopant remaining in the melt.

Student: (( )) Weight of the crystal is remaining…

Weight of the crystal no weight of the melt will be decreasing.

Student: In generating M naught.

M 0, yes and if M crystal is grown so; that means, M amount is consumed if M weight ofthe crystal is grown; that means, M melt is consumed. So, the remaining will be M 0 minus M your melt was M 0; that means, total crystal will be M 0 right? And M amount of crystal has grown M by weight; obviously, so; that means, from the melt M 0 amount is consumed.

So, remaining is M 0 minus M and in this case you will find that minus K 0 d M by M 0 minus M it must be from 0 to M because the crystal is grown up to the weight M at any instant of time then if you solve this equation what you will get? If you solve this equation what you will get or what will be there? l n S C 0 M 0 S it is equals to minus K 0 into l n M 0 minus M 0 to M or l n S by C 0 M 0 whether it is which one? This one (( )) which one? C naught M naught is the initial doping concentration and S you see that the dopant remaining in the melt is S we have assumed and initial doping concentration was C 0. So, C 0 by weight; that means, 1 gram of the crystal C 0 is the doping concentration. So, for M 0 it is C 0 into M 0

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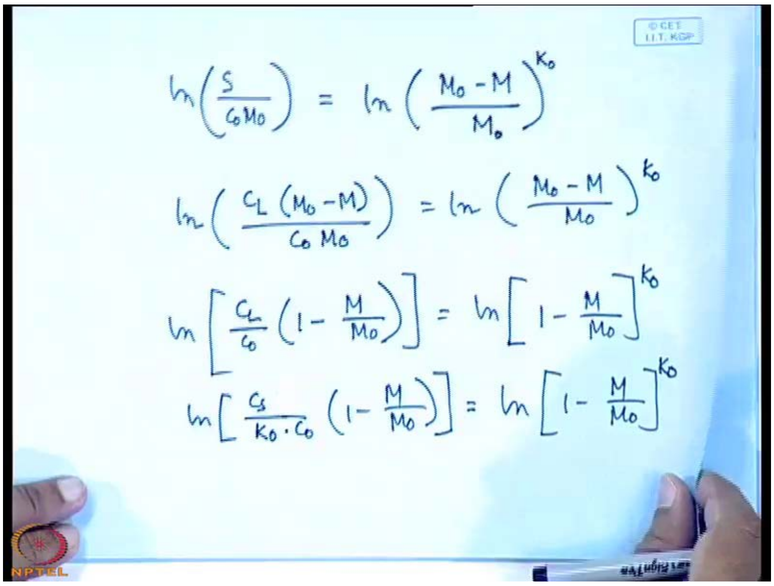

$$\ln\left(\frac{S}{C_0 M_0}\right) = \ln\left(\frac{M_0 - M}{M_0}\right)^{K_0}$$

$$\ln\left(\frac{C_L (M_0 - M)}{C_0 M_0}\right) = \ln\left(\frac{M_0 - M}{M_0}\right)^{K_0}$$

$$\ln\left[\frac{C_L}{C_0}\left(1 - \frac{M}{M_0}\right)\right] = \ln\left[1 - \frac{M}{M_0}\right]^{K_0}$$

$$\ln\left[\frac{C_S}{K_0 \cdot C_0}\left(1 - \frac{M}{M_0}\right)\right] = \ln\left[1 - \frac{M}{M_0}\right]^{K_0}$$

Then you see that from this expression we can write l n S by C 0 M 0 which one?

Student: The integration (( )).

Which one? It will be M 0 yes it will be M 0 to the power K 0 right. Now you put the value of S what was the value of S? These was the value of S this was the value of S C L into M 0 minus M. So, you put the value of these thing or then you put these equation; that means, C S by C L equals to K 0 this thing in place of C L you can write C S by K 0 here you see in place of C L you write C S by K 0 in place of C L it is C S by K 0 into C 0 1 minus M by M 0 it is l n one minus M by M 0 to the power K 0 right.

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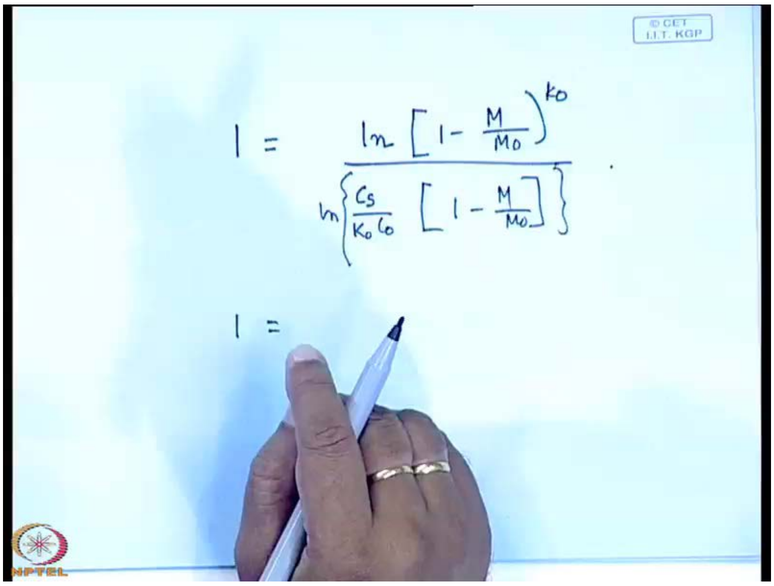

$$1 = \frac{\ln\left[1 - \frac{M}{M_0}\right)^{K_0}}{\ln\left\{\frac{C_S}{K_0 C_0}\left[1 - \frac{M}{M_0}\right]\right\}} .$$

$$1 =$$

Next is you can write 1 equals to l n 1 minus M by M 0 to the power of K 0 by C S by K 0 C 0 1 minus M by M 0 it is then what will happen? It is l n a by l n b l n a minus b. So, you put here what will happen? 1 equals to you can calculate why? (( )) let me see the calculation again you up to this it is…

Student: Sir next page.

Up to this it is no no you do one thing or yes l n S by C 0 M 0 it is equal to l n 1 minus M by M naught to the power K 0 then it remove the log then you remove the log then you remove the log.

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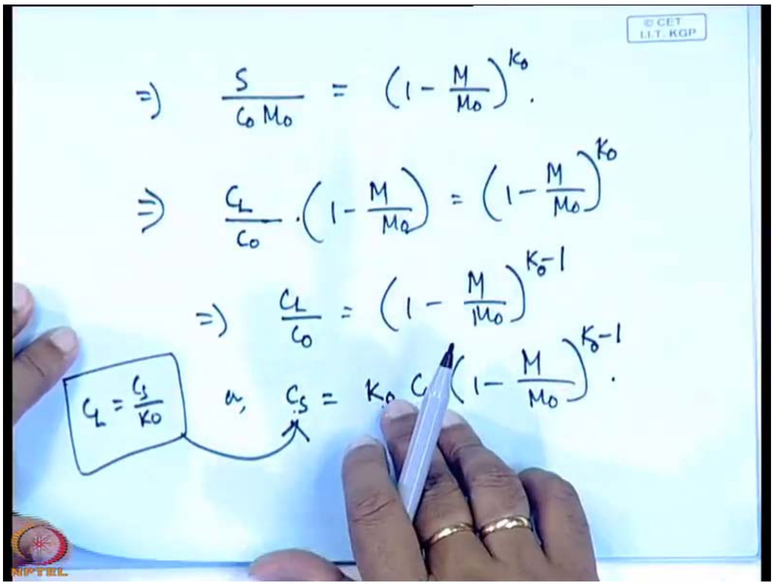

$$\Rightarrow \frac{S}{C_0 M_0} = \left(1 - \frac{M}{M_0}\right)^{K_0}.$$

$$\Rightarrow \frac{C_L}{C_0} \cdot \left(1 - \frac{M}{M_0}\right) = \left(1 - \frac{M}{M_0}\right)^{K_0}$$

$$\Rightarrow \frac{C_L}{C_0} = \left(1 - \frac{M}{M_0}\right)^{K_0 - 1}$$

$$\boxed{C_L = \frac{C_S}{K_0}} \qquad \text{or,} \quad C_S = K_0 C_0 \left(1 - \frac{M}{M_0}\right)^{K_0 - 1}.$$

Then what will happen or S by C 0 M 0 it is equal to 1 minus M by M 0 to the power K 0 now replaces fine now replaces S is equals to how much C L C L upon C naught 1 minus it is equals to 1 minus M by M 0 K 0 or C L by C 0 it is 1 minus M by M 0 to the power K minus 1 right or C S equals to K 0 C 0 1 minus M by M 0 K to the power minus 1 K minus 1.

That means, here you see that I have replaced C L with C L equals to C S by K 0 (( )) right. So, this is the expression for the dopant distribution in a float zone technique and this distribution is applicable for any kind of crystal growth where the doping is takes place when the doping takes place right; that means, C S is equal to K 0 C 0 into 1 minus M by M 0 K 0 minus 1 where C S is the dopant concentration in the solid; K 0 is the segregation or distribution coefficient’ C 0 is the initial doping concentration; M 0 is the initial weight of the crystal and M is the weight of the crystal after time t say right. So, this is the expression C S is equal to K 0 into C 0 1 minus M by M 0 into to the power K 0 minus 1. So, this is the dopant distribution in a crystal in terms of the segregation coefficient.

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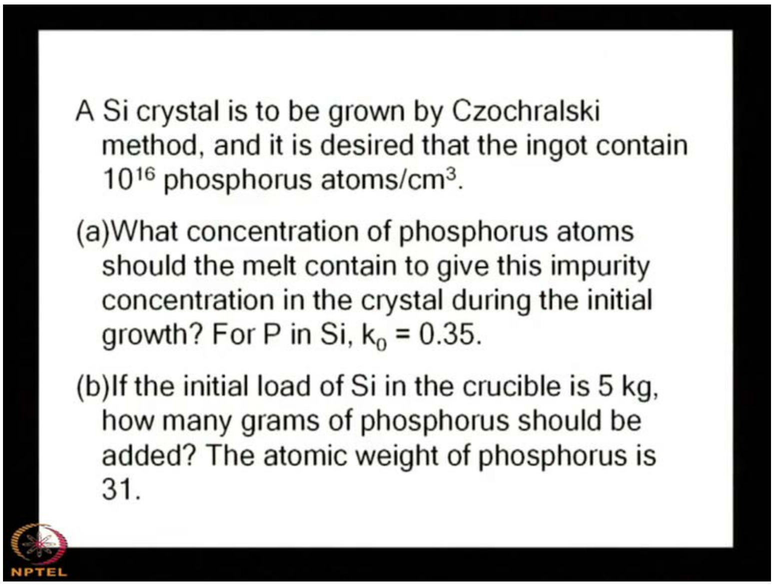

A Si crystal is to be grown by Czochralski method, and it is desired that the ingot contain 10^{16} phosphorus atoms/cm^3.

(a)What concentration of phosphorus atoms should the melt contain to give this impurity concentration in the crystal during the initial growth? For P in Si, $k_0 = 0.35$.

(b)If the initial load of Si in the crucible is 5 kg, how many grams of phosphorus should be added? The atomic weight of phosphorus is 31.

Now let us take one example these example we shall we can take say these thing a silicon crystal is to be grown by czochralski method, and it is desired that the ingot content 10 to the power 16 phosphorus atoms per centimeter cube what concentration of phosphorus atoms should the melt content to keep this impurity concentration in the crystal during the initial growth? For phosphorus in silicon k 0 is given as 0.35. If the initial load of silicon in the crucible is 5 k g, how many grams of phosphorus should be added?

The atomic weight of phosphorus is given it is 31. So, there are two parts one part is that what concentration of phosphorus atoms should the melt contain to keep this impurity concentration what is impurity concentration? 10 to the power 16 phosphorus atoms per centimeter cube another thing is that how many grams of phosphorus should be added? So, here for this problem first you have to calculate C S.

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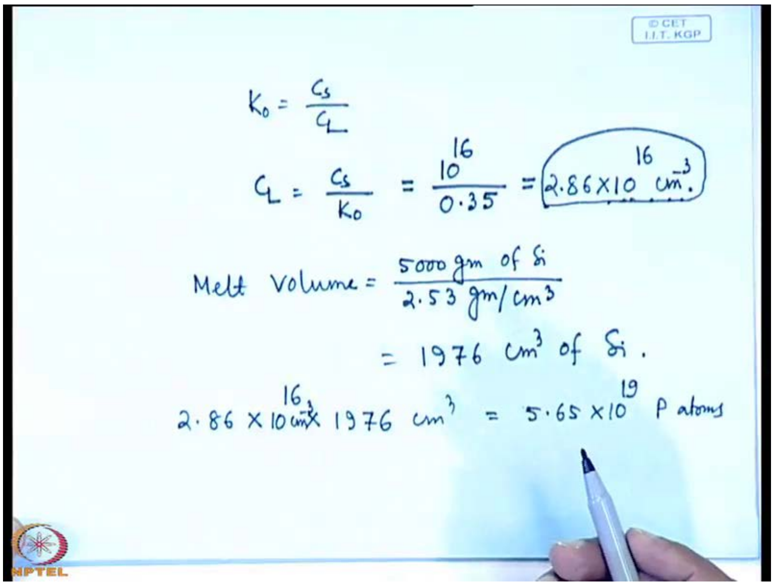

$$K_0 = \frac{C_s}{C_L}$$

$$C_L = \frac{C_s}{K_0} = \frac{10^{16}}{0.35} = \boxed{2.86 \times 10^{16}\ \text{cm}^{-3}.}$$

$$\text{Melt Volume} = \frac{5000\ \text{gm of Si}}{2.53\ \text{gm/cm}^3}$$

$$= 1976\ \text{cm}^3\ \text{of Si}.$$

$$2.86 \times 10^{16}\ \text{cm}^{-3} \times 1976\ \text{cm}^3 = 5.65 \times 10^{19}\ \text{P atoms}$$

So, you calculate C S you calculate C S C S equals to…

Student: 3.5 meter per cube.

How much it is? (( )) C S K 0 equal to C S by C L or C L equals to C S by K 0 C S is given how much? 10 to the power 16 by K 0 is 0.35. So, how much it comes out to be 2.86 into 10 to the power 16 centimeter cube inverse yes S is given yes question is what concentration of phosphorus atoms should the melt contain? Melt melt in it is given that 10 to the power 16 phosphorus atoms in the solid; obviously, ingot contain means; that means, solid ingot means the raw crystal ingot means the raw crystal as grown crystal you have not sliced it into vapors. So, that crystal is known as ingot that is basically the raw crystal it is 10 to the power 16. So, what concentration of phosphors atoms should the melt contain? To give these impurity concentration in the crystal.

So, melt must be 2.86 into 10 to the power 16 centimeter cube inverse right. So, you see that the melt contains more phosphorus than the ingot the melt contains 2.86 into 10 to the power 16 the ingot contains 10 to the power 16; that means, one-third almost; that means, almost one-third. So, two-third of the phosphorus is rejected in the melt itself. Now these amount of phosphorus we have to converted into weight right. How you can do? See this phosphorus per centimeter cube of the melt now what is the volume of the melt?

Melt volume is how much melt was there? 5 k g so; that means, 5000 gram of silicon divided by density of silicon density of silicon is how much? 2.33, but the molten silicon has higher density than the solid silicon and it is 2.53 gram per centimeter cube yes 2.53 and normal silicon is 2.33 as per the data obtained in the literature. So, if you calculate these thing. So, what you will find that it is 1976 centimeter cube of silicon here one thing I must clear that only I have consider the melt is melt consist of silicon only yes what is there in the melt? Silicon plus phosphorus, but the amount of phosphorus is very, very less I shall show you that is why in solving such problem always you take the volume of the melt as the volume of the silicon or gallium arsenic; that means, the constituent host the host crystal basically 1976 centimeter cube of silicon

And you see that C L is these per centimeter cube phosphorus. So, amount of phosphorus is how much? 2.86 multiplied by 10 to the power 16 into 1976 centimeter cube it is equals to it is centimeter cube inverse. So, you will find 5.65 into 10 to the power 19 phosphorus atoms 5.65 into 10 to the power 19 phosphorus atoms.

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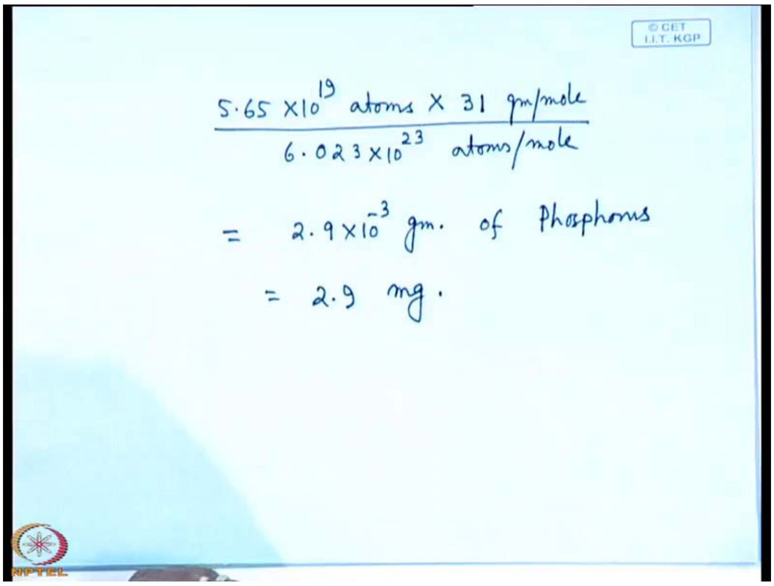

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$$\frac{5.65\times10^{19}\text{ atoms}\times 31\text{ gm/mole}}{6.023\times10^{23}\text{ atoms/mole}}$$

$$= 2.9\times10^{-3}\text{ gm. of Phosphorus}$$

$$= 2.9\text{ mg.}$$

Now you use the Avogadro number, how you can use? You see that 5.65 multiplied by 10 to the power 19 atoms into atomic weight of phosphorus is 31 it is this gram per mole divided by 6.023 into 10 to the power 23 atoms per mole. So, that is equals to 2.9 into 10 to the power minus 3 gram of phosphorus; that means, how much? It is almost 3 milligram 2.9 into 10 to the power minus 3 gram means almost 3 milligram. So, what you find? That for 5 k g of silicon to obtain 10 to the power 16 per centimeter cube carrier concentration 10 to the power 16 concentration means 10 to the power 16 electrons you need only 3 milligram of phosphorus atom. Problem.

You come to this problem yes 10 to the power 16 phosphorus atoms were there and first thing is that what concentration of phosphorus atoms should the melt contain? We have seen that it is 2.86 into 10 to the power 16 and finally, we see that only 2.9 milligram of phosphorus is to be added. So, that is the beauty of the doping in semiconductor. 5 k g of silicon is doped by only 2.9 milligram of phosphorus. To get a concentration of 10 to the power 16 if you want 10 to the power 16 to be 10 to the power 17 or 18 then 2.9 will be increased, but not in the value of kilogram or gram it will it may be several milligrams right?

And where this phosphorus goes? Where this phosphorus goes? They occupy either the vacancy position or the interstitial position. There can be another kind of example say this is another example you can practice it. A silicon ingot which should contain 10 to the power 16 boron atoms per centimeter cube is to be grown by czochralski technique what concentration of boron atoms should be in the melt to give the required concentration in the ingot same problem. If the initial load of silicon in the crucible is 60 k g how many grams of boron with atomic weight 10.8 should be added the density of molten silicon is given 2.53 gram per c c and also k 0 the segregation

Coefficient it is given it is 0.8 same type of problem and here the result I can give you you you please write down the result. So, that you can practice and you can compare it is 5.31 milligram. It is just 5.31 milligram; that means, for 60 k g of silicon if you dope with boron to obtain 10 to the power 16 concentration only 5.3 milligram of boron is required very, very less amount for 60 k g. So, what we see that the doping concentration can be calculated once you know the segregation coefficient using the same expression which we have deduced.