Processing of Semiconducting Materials
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Lecture - 15
Defeets is Crystals – I

In the last class, we have discussed about the horizontal Bridgman technique. So, what are the different techniques we have discussed one is the czochralski technique growth, czochralski crystal growth technique number two is...

Student: Float zone.

Float zone number three is.

Student: Neutron.

No neutron is a transmutation is not the crystal growth technique; it is basically a technique for the doping. So, one is czochralski technique of crystal growth; number two is the float zone technique; number three is the horizontal Bridgman. And during our horizontal Bridgman, we have introduced one thing it is the horizontal gradient freeze horizontal gradient freeze technique. In horizontal Bridgman, what we have done basically we have pulled the heater, we have pulled the heater from the left to right, but that was the in that case it was the involvement of the mechanical movement which we want to avoid.

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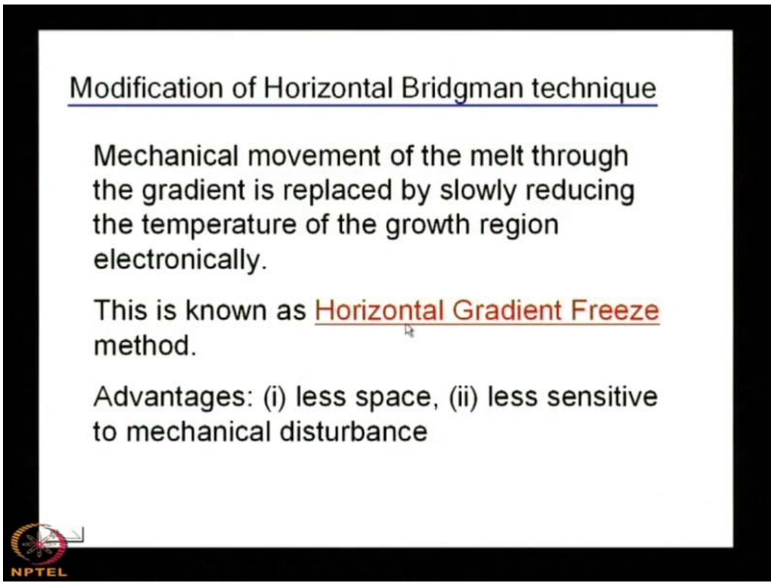

Modification of Horizontal Bridgman technique

Mechanical movement of the melt through the gradient is replaced by slowly reducing the temperature of the growth region electronically.

This is known as Horizontal Gradient Freeze method.

Advantages: (i) less space, (ii) less sensitive to mechanical disturbance

So, that is the reason we introduced one new technique which was known as the gradient freeze, horizontal gradient freeze technique. And you can see that in the horizontal gradient freeze technique slowly reduction of temperature of the growth region electronically, slowly reducing the temperature of the growth region electronically, it is horizontal gradient freeze. It is almost similar to horizontal Bridgman technique except that there will be no mechanical movement only at the gradient temperature will be reduced electronically and slowly; that means, by the help of a computer program. And there was advantage of horizontal gradient freeze gradient freeze it is the less space less sensitive to mechanical disturbance.

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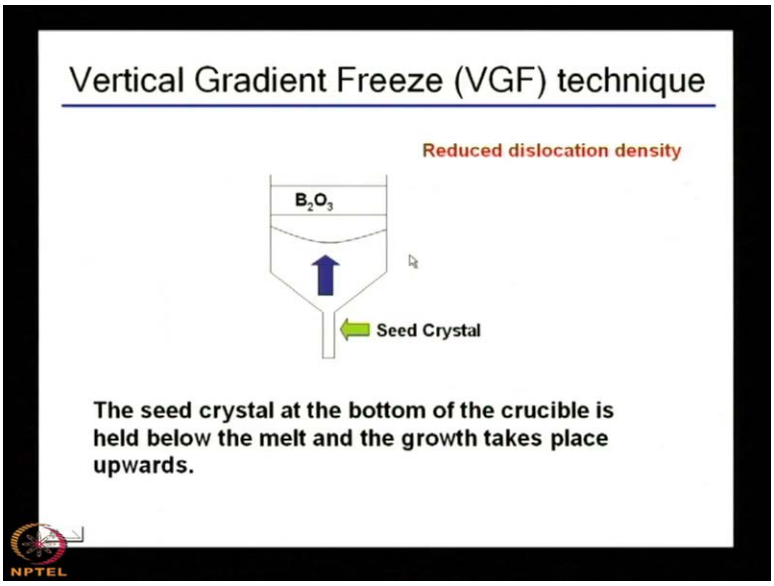

Vertical Gradient Freeze (VGF) technique

Reduced dislocation density

The seed crystal at the bottom of the crucible is held below the melt and the growth takes place upwards.

Similarly, there is another technique which is known as the vertical gradient freeze, there is another technique which is known as the vertical gradient freeze; that means, in horizontal gradient freeze, the direction of the crystal growth was horizontal. Here it will be in the vertical direction, you see this is the crucible and is seed crystal is there at the bottom, this is the seed crystal. And the freezing is done dynamically from bottom towards up upwards freezing is done electronically and slowly. Obviously, there will be a B 2 O 3 encapsulation because we have discussed that in gallium arsenide growth or indium phosphate growth, there will be dissociation of arsenic or phosphorous from the surface of the material.

So, you need B 2 O 3 encapsulation over the molten surface of gallium arsenide or indium phosphate. Now, why those techniques are so important? Why we devote our much time and attention on different types of crystal growth? It is because of the defect inside the crystal; when we grow a crystal, we measure the defects states inside the crystal by various techniques say one defect is known as the dislocation density. We shall discuss that thing detail today itself. What is dislocation? Then dislocation free crystal is very important and you will that in vertical gradient freeze technique the dislocation will be less compare to horizontal gradient freeze or horizontal Bridgman technique. So, people have evaluated various techniques they have tested various techniques. And they have come across the techniques which will give you less less number of defect density or dislocation density in the crystal itself.

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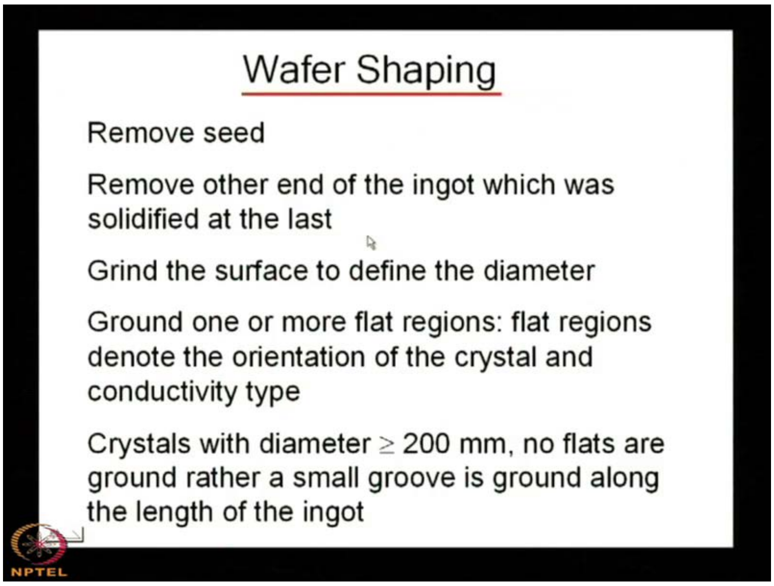

Wafer Shaping

Remove seed

Remove other end of the ingot which was solidified at the last

Grind the surface to define the diameter

Ground one or more flat regions: flat regions denote the orientation of the crystal and conductivity type

Crystals with diameter ≥ 200 mm, no flats are ground rather a small groove is ground along the length of the ingot

Now what are the next processes in crystal growth we grow bulk crystal which is known as the ingot which is known as the ingot it is basically the freezing of the whole melt. So, it can be one feet’ it can be two feet; it can be more than that with different kinds of diameters it can have one 100 millimetre; 200 millimetre; 300 millimetre different types of diameter it can have then from that ingot wafer shaping is done. What are the steps for wafer shaping? You see that first remove the seed because in all the crystals we started from seed. So, you remove the seed remove other end of the ingot which was solidified at the last why this is required? Remove other end of the ingot which was solidified at the last.

Student: Because of the impurity.

Yes because of the higher concentration of impurity in that tail region you can say that that is the tail region. So, concentration of impurity will be higher as you grow from the seed region to the tail region successively. So, that you you must remove that thing also. Then grind the surface to define the diameter. Grind the surface to define the diameter that that is if it is say 100 millimetre plus minus. So, you stick to 100 millimetre. So, that the diameter can be given a particular value of that material it can be 200, it can be 300 millimetre, but the there may be some 100 plus minus. So, if say it is 100 minus something 1 millimetre 2 millimetre better make it 95 millimetre. So, you grind the surface to define the diameter then ground one or more flat regions. Flat regions denote the orientation of the crystal and conductivity type that is very important.

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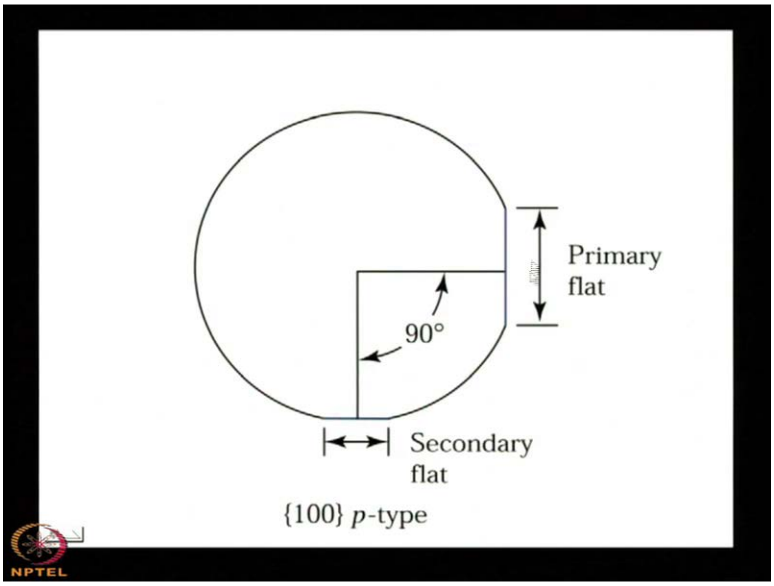

Flat region I can show you what are the fact regions you see that this is the flat region that is one flat this is known as the primary flat; this is secondary flat; that is another flat. So, depending on the flat regions you can say whether this is a p-type crystal or an n-type crystal whether it is 1 0 0 or 1 1 1 or what else. So, that is the reason that mechanically by seeing the wafer itself when you go to the laboratory you will find that a whole crystal has that kind of a flat at least two flats are there one is known as the primary another is secondary and viewing that flat you can tell that sir it is p-type, sir it is n type, sir it is 1 0 0, sir it is 1 1 1 you can take.

So, that is why one or more flat regions are ground on the crystal and crystals with diameter greater than equals to 200 millimetre no flats are there only one groove is inserted one groove is inserted means say this is your crystal and one groove is inserted; that means, one tunnel type of thing is inserted right? And depending on the value of those groove you can assume whether it is p-type or n-type or it is 1 0 0 or 1 1 1 etcetera.

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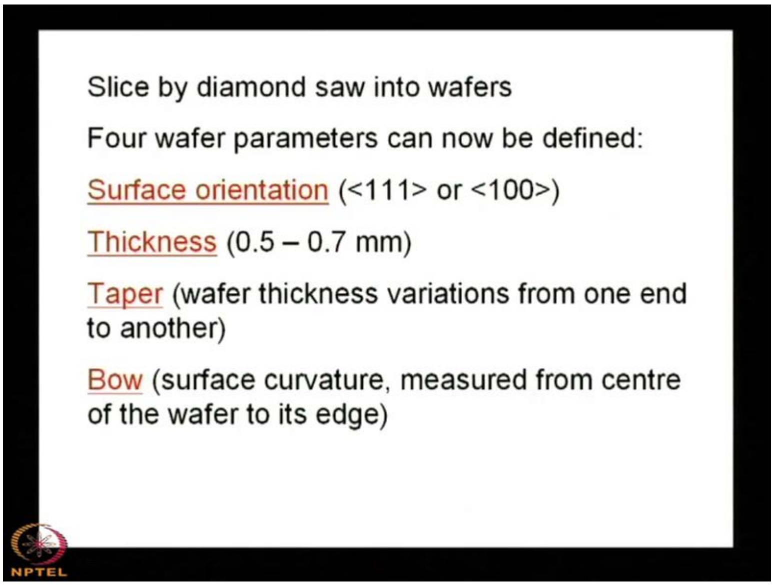

Slice by diamond saw into wafers

Four wafer parameters can now be defined:

Surface orientation (<111> or <100>)

Thickness (0.5 – 0.7 mm)

Taper (wafer thickness variations from one end to another)

Bow (surface curvature, measured from centre of the wafer to its edge)

Then what to do? Upper grounding the flat etcetera slice by diamond saw into wafers slice by diamond saw into wafers and when you slice then it becomes wafer. So, you have started with a high purity material then from the melt you have grown the ingot by using a seed, then from the ingot you have first confirm the diameter then you have made some flat primary or secondary then you sliced by diamond saw into wafers. That wafer is basically act as the sub sub straight for the device fabrication or successive operations using the wafer then there are four wafer parameters.

If I give you a slice of wafer then there can be four types of parameters which you can have from the wafer one is the surface orientation that orientation is will give you whether it is 1 0 0 or 1 1 1 or anything else it can be different types of orientation; that means, the crystal orientation then the thickness, the thickness can be 0.5 to 0.7 millimetre. If the diameter is large thickness will also be large if diameter is small thickness can be small because there must be a proportion of the diameter to the thickness otherwise mechanical strength will not be there.

Then another parameter is known as the taper. What is taper? Taper is known as the wafer thickness variations from one end to another if you take that thickness variations from one end to another it can be 1 micron; it can be 2 micron there may be some difference because though you use some computer control machines even then within that thickness say it is some millimetres 0.2 millimetre; 0.5 millimetre; 0.7 millimetre there can be a thickness variation if you go from one end to the other end it may be micron level of thing one micron, two micron, but there may be some taper.

And another is bow b o w it is the surface curvature, measured from centre of the wafer to its edge whether there is any curvature from the centre of the wafer to the edge whether it is completely plat parallel to the ground or there is any small type of curvature it can be 1 degree; 2 degree; 3 degree. So, if you find the crystal there are such kinds of specifications will be there say 500 micron plus minus 2 micron and 2 degree of 1 0 0 2 degree of so; that means, there is a curvature variation of say 2 degree as you go from the centre to the edge of the crystal. So, these are the basic parameters of the wafer.

And if you procure parameter from the market sometimes say when you will work of your own you have to purchase the wafer from the market generally in India no wafer is produced. All the wafers are basically imported. So, then the manufacturer or the vendor will ask you the specification the diameter carrier concentration whether the doping will be if with a s arsenic or phosphorous or boron or aluminium for p-type then what is the thickness? What is the orientation of the crystal? Whether 2 degree of will surf your purpose? Whether the taper can be plus minus say 2 micron or 20 micron what is the resistivity? So, they will ask you.

And for a particular application you must give all those specifications and parameters to the vendors. So, that he can give you the right kind of wafer that is available so you must know what are the parameters that you have to give the value to the vendors or the manufactures then.

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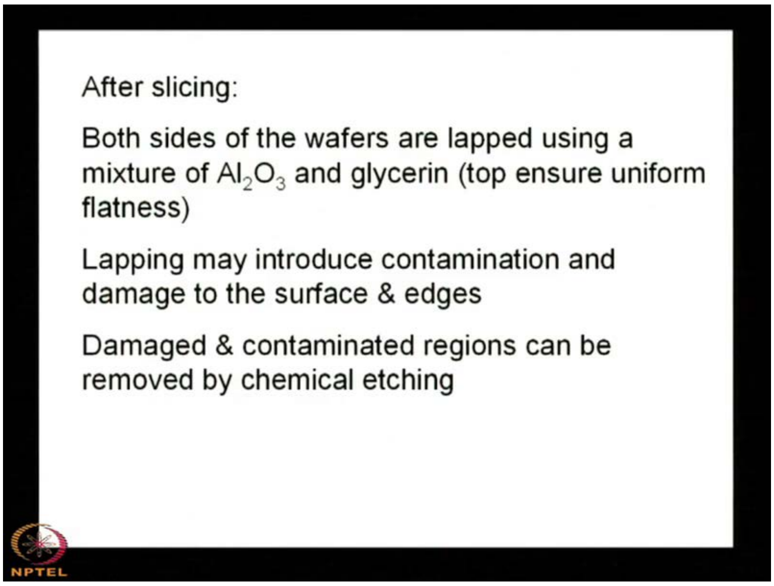

After slicing:

Both sides of the wafers are lapped using a mixture of Al_2O_3 and glycerin (top ensure uniform flatness)

Lapping may introduce contamination and damage to the surface & edges

Damaged & contaminated regions can be removed by chemical etching

After slicing what is done both sides of the wafers are lapped using a mixture of Al 2 O 3 and glycerine that ensure uniform flatness basically lapping is rubbing there is a pat growth pat on which you take some alumina Al 2 O 3 and glycerine then lap it, it is done now by the help of some crystal lapping and polishing machine you can see in my lab there is a crystal polisher and lapper machine.

So; that means, it ensure uniformity of the surface then during lapping there may be damage or contamination there may be damage or contemn contamination means? In the surface some carbon or aluminium or dust particles can be there on the surface and contamination as well as damage to the surface there may be some small crack type of thing can happen then you have to remove those contamination or the damage and that is done by the chemical etching that is done by the chemical etching damaged.

And contaminated regions can be removed by chemical etching and for chemical etching there are several types of etchants several types of combinations of chemicals using which you can etch the surface of a semiconductor wafer and the etchants are different for different materials for silicon there is type a etchant, but you cannot use type a etchant for gallium-arsenide wafer, for gallium-arsenide wafer you need type b etchant. So, depending on the situation you have to use what kind of etchant you will apply for removing the contamination and damage of the lapped wafer.

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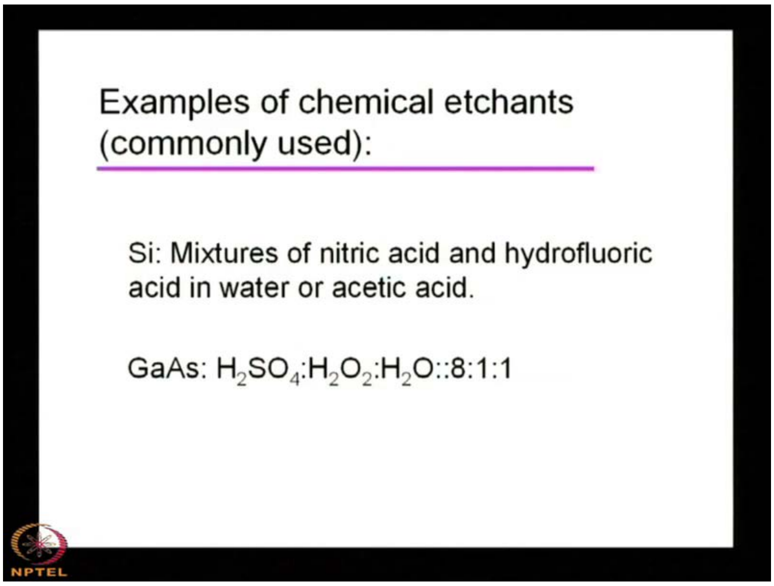

Examples of chemical etchants (commonly used):

Si: Mixtures of nitric acid and hydrofluoric acid in water or acetic acid.

GaAs: $H_2SO_4:H_2O_2:H_2O::8:1:1$

So, I can give you one example of chemical etchant commonly used for silicon and gallium arsenide, in silicon you find that mixtures of nitric acid and hydrofluoric acid in water or acetic acid a mixture of nitric acid and hydrofluoric acid in water or acetic acid that is commonly used as etchant there are several etchants from the literature you will find that there are 100s types of etchants used for the etching of silicon.

And you must know that etching means what is etching? Removing some micron thickness material from the surface that and for and every etchant has its own rate of etching say with this silicon etchant; that means, nitric acid and hydrofluoric acid in water or acetic acid the rate of etching is almost 0.6 to 0.8 micron per hour. So, if you put that material in that etchant solution, the etching rate is 0.6 to 0.8 per hour very slow etching is required otherwise what will happen? Almost all the material will be removed because you know that hydrofluoric acid is very reactive in nature corrosive in nature.(( )).

Right? So, what will happen say 300 micron substrate is there and it takes away 100 or 200 micron from different parts of the surface. So, your device fabrication will be at jeopardise now this mixture of acetic acid and nitric acid and hydrofluoric acid you see how it acts?

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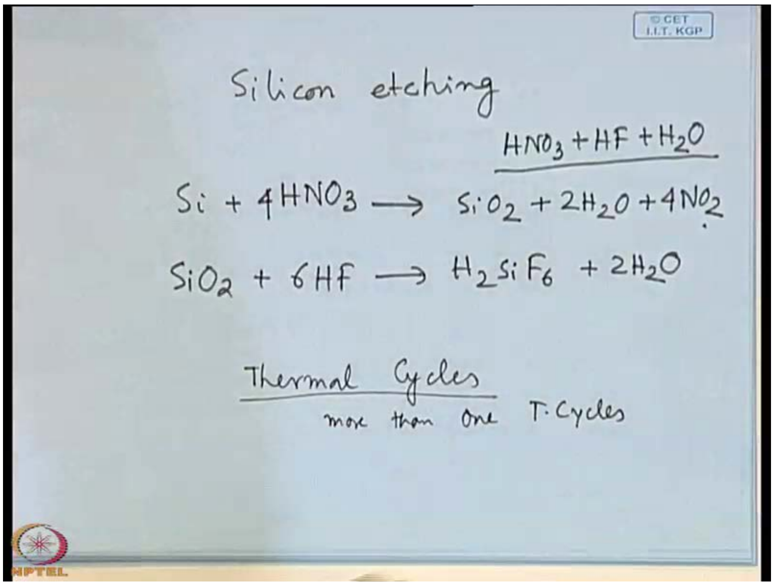

Silicon etching

$HNO_3 + HF + H_2O$

$$Si + 4HNO_3 \longrightarrow SiO_2 + 2H_2O + 4NO_2$$

$$SiO_2 + 6HF \longrightarrow H_2SiF_6 + 2H_2O$$

Thermal Cycles

more than one T·Cycles

Let me give one example for silicon etching you take silicon then h n o 3 nitric acid you use a solution of nitric acid, hydrofluoric acid plus water or acetic acid whatever be that is let us take the water. So, first what happens that nitric acid oxidise a silicon. So, what is the reaction? You see the reaction is Si O 2 plus twice H 2 O plus 4 NO 2. So, silicon oxidise sorry nitric acid oxidises silicon into Si O 2 water and NO 2, NO 2 is a gas. So, you will find that bubbles will come out from the solution you will find if you take a glass beaker generally glass beaker is not used because of hydrofluoric acid because that is very corrosive. Teflon is used generally. So, using a Teflon beaker you take H N O 3 H F and H 2 O and you put a piece of silicon that you have to do in advance practical lab you will that some bubbles are coming out from the solution because that is n o 2 and water will be mixed with the beaker solution.

So, s i o 2 will be formed on the surface of the silicon then s i o 2 is removed by hydrofluoric acid so if you take the solution of h n o 3 h f and h 2 o, basically h 2 o is for dilution or acitic acid is for dilution but first the nitric acid oxidises silicon into s i o 2 then s i o 2 reacts with hydrofluoric acid and you will find that this type of a reaction. So, this silicon etch etched this silicon is etched as soon as you etch it the surface will be very very clear clean and specular finished it is like a mirror, mirror finished surface you will get, but it depends on the quality of your etchants quality of your etchants and the time for how long you will dip the material in the etchant solution.

So, there is data now in these days you will find the data in the data sheet or in the hand book. So, absolutely you need not to worry you can use for different kinds of solutions for different kinds of etchants for time the graph is available how long you will have etch the silicon? For what what is the rate of the etchant? Etching rate etcetera everything is available then for gallium arsenide there is a problem what is the problem? Problem is that gallium and arsenic those are two different materials though the material is gallium arsenide, but as soon as you dip gallium arsenide in an etchant the etching rate of gallium is different that of the Arsenic.

So, that is why very smooth mirror finish surface for gallium arsenide is not very easy compared to silicon in silicon only one type of material is inbounded silicon atom there are two types of atoms gallium and arsenic and there direction can be different, etching can be different in different orientation 1 0 0 can have etching faster than 1 1 1 why? Because in 1 1 1 the bonding are very strong. Since the bondings are strong. So, etching will be less compared to 1 0 0. So, those factors are there, but for gallium arsenide you can use H 2 SO 4; that means, sulphuric acid then H 2 O 2 hydrogen peroxide and H 2 O water with the ratio 8 is to 1 is to 1 that mean in a beaker you take 8 c c of sulphuric acid, 1 c c of hydrogen peroxide and 1 c c of water and you will find that it is acting as a very good etchant for gallium arsenide.

And these etchant can be taken in a glass beaker because those are not corrosive like high H F H 2 O 2 is hydrogen peroxide it is stored in refrigeration temperature normal room temperature is regimental to h 2 o 2 then h 2 o 2 will be decomposed. So, generally h 2 o 2 kept inside a refrigerator you take the deionised water and; obviously, another point is that in all such processing you have to use deionised water be it silicon or sulphur or gallium arsenide or indium phosphate it must be deionised water why deionised water is used? Otherwise the ions inside the water will contaminate your wafer or substrate then the very spirit of removing the contamination will be lost.

If some of the chemicals contaminates your sample then the spirit of removing the contamination will be lost. So, that is why very high purity chemical you must use at the same time you use deionised water what is the resistivity of deionised water?

Student: 18.6.

18.6 megon 18.6 megon its very, very high.

Student: 18.6.

18.6 present day in my lab you will get 18.6 first 18.3 is formed and then it is again deionised to 18.6 megon it is available now in my laboratory it is there so; that means, you can use 18.6 megon deionised water and that is; that means, almost all ions are removed from water if there is an iota of ion in the water then what will happen? The resistivity will be less, conductivity will more. So, that is why you must remove all types of ions and it is known as the deionised water.

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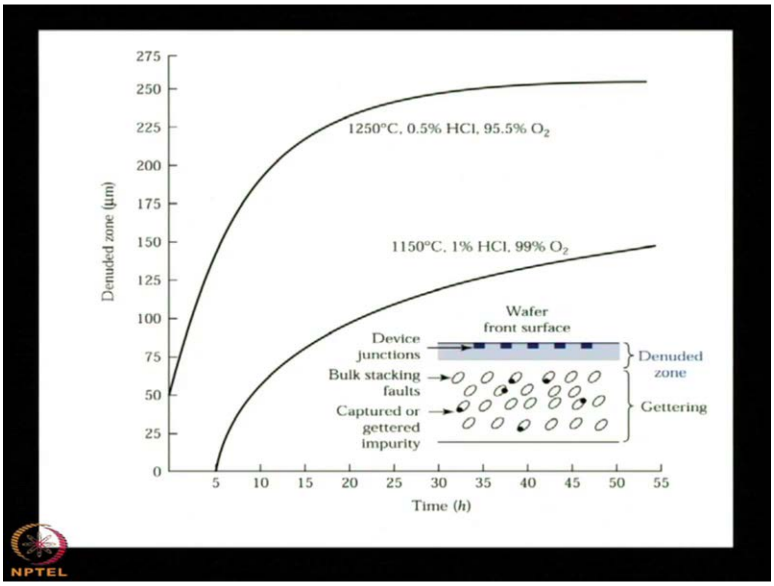

Another important thing is that during processing of those materials this thermal cycles are thermal cycles. The wafer is passed into a large number of thermal cycles, thermal cycles means it is annealed it is heated and in different kinds of ambiance or environment. I have shown you two examples one is you see that 1150 degree centigrade and another is 1250 degree centigrade; that means, the difference is 100 degree centigrade it is 95.5 percent oxygen ambiance it is 99 percent oxygen ambience.

Then what you find you find that in the x axis it is time hour; that means, if you take a ten hour. So, after ten hour this is your thickness of denuded zone which is almost 50 micron see for 1150 centigrade it is almost 50 micron this point is 50 micron, but if you take 1250 degree centigrade thermal cycle then you will find that is almost more than 175 micron and please remember the denuded zone are that zone on which the device is fabricated.

That means, it is free from impurity dislocation etcetera. So, if your thickness of the material is say 500 micron or 400 micron. So, at least 5 to 7 micron or 100 micron denuded zone is required on which all the device is made; and at the bottom of the denuded zone, it is useless basically. So, at the bottom you can form some precipitation of the impurities etcetera, but at the top layers at least for some micron the wafer must be free from any impurity; that means, using some thermal cycles you can entries the thickness of denuded zone from 50 micron to 175 micron or 200 micron just by changing the temperature of 100 degree centigrade and here I have seen that is the vectorial diagram of the denuded zone you see that this is the denuded zone this region.

And bottom of the denuded zone you find that there is the gettering the gettering we have introduced where the impurity are there actually the oxygen precipitation takes place and at those precipitation there will be some thermal stress and the stress will be relieved by making some what?

Student: Dislocation lines.

Yes dislocation lines where the impurities will be trapped. So, those are the gettering process and the devices junctions or all the devices are made on the denuded zone at the wafer front surface. So, thermal cycles are important in the sense that you can have more than one thermal cycles more than one thermal cycles several thermal cycles are resorted to are if are subjected to the wafer can be subjected to several types of thermal cycles. So, that the gettering or the denuded zone improves that is possible.

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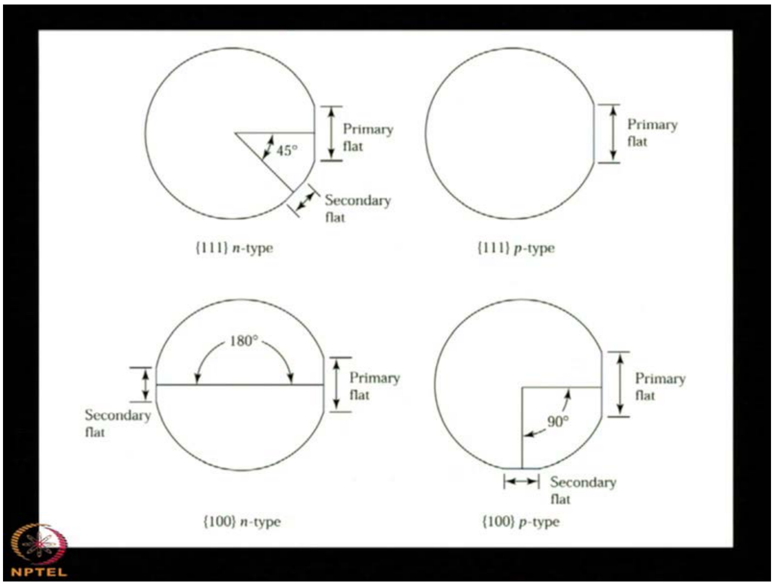

Now come to this primary flat and that type of thing you will see that this primary flat and secondary flat there are two flats ground on the wafer one is primary flat if there is only one primary flat it is known as the p-type with 1 1 1 direction only one primary flat. However if there is two flats one is primary another is secondary and the angle between the primary flat and the secondary flat is 90 degree then the material is not only p-type, but the orientation is 1 0 0. So, if you have if you are given one wafer having one primary flat you can say confidently that it is p-type 1 1 1 and if you are given one wafer having two flats the mutual angle of which is can be if if you find that is 90 degree then you can say it is p-type with 1 0 0 orientation of the crystal.

Student: Zero.

Similarly, if the angle between the primary flat and the secondary flat is 180 degree centigrade; that means, vertically opposite you will find that it is n-type with 1 0 0 and if the angle between the primary flat and the secondary flat is 45 degree it will be n-type with 1 1 1 direction. So, generally in our labs in micro electronics or in some device fabrication we shall come across four types of crystals it can be either p-type or n-type, it can be 1 0 0 or 1 1 1 generally there may be other types of crystals this is obviously, for silicon I am talking about or gallium arsenide. Because if you take other types of crystals which are not cubic in nature say zinc oxide then it will have four crystal directions not three we shall discuss those things also in later.

So, there can be four types of crystals and depending on the flat position you can say that whether it is n-type or p-type whether it is 1 0 0 or 1 1 1 type you need not take help from anybody yes.

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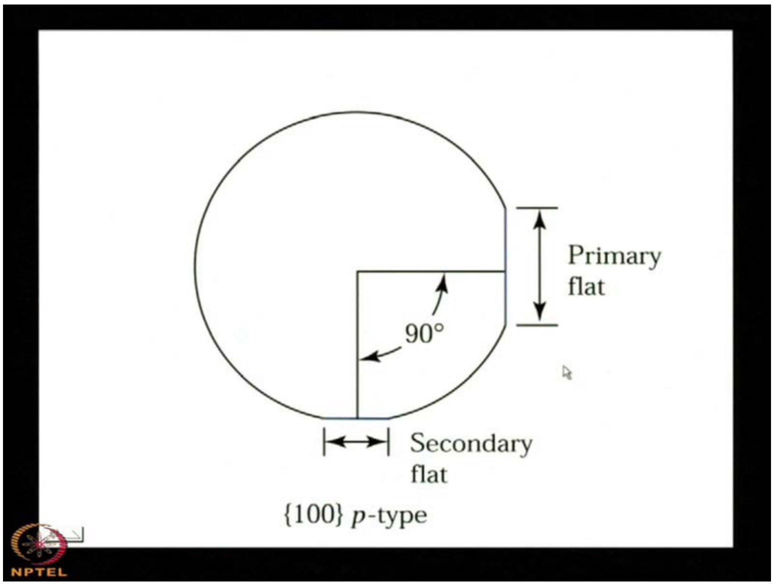

This is the magnified diagram of the primary flat and the secondary flat you find that the angle is 90 degree and it is p-type 1 0 0.

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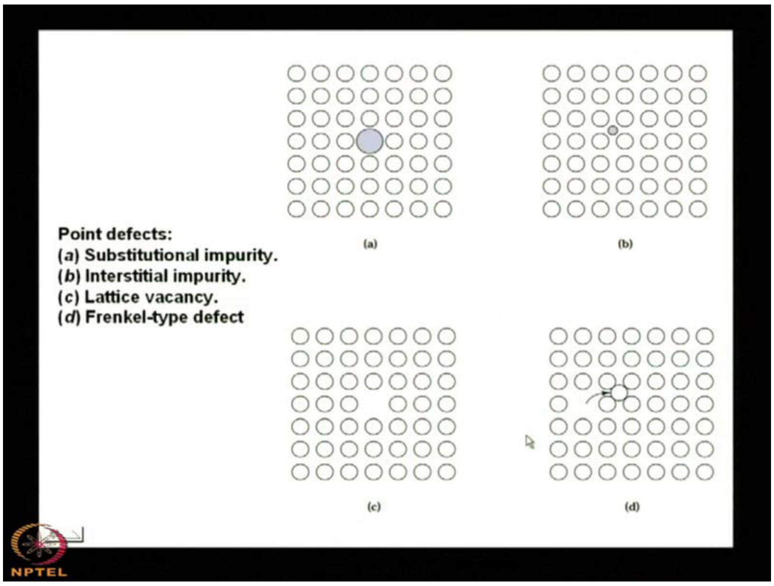
Point defects:
(*a*) Substitutional impurity.
(*b*) Interstitial impurity.
(*c*) Lattice vacancy.
(*d*) Frenkel-type defect

So, now, you have a wafer from the ingot to the wafer there is a large number of processing’s involved and now you have a full pledge wafer then your next technique will be to evaluate the defects in the crystal. Now what is the origin of defect in the crystal? Why there is defect in a crystal? It is because of the thermodynamic requirement. Thermodynamic It is because of the thermodynamic requirement. Suppose you are growing silicon crystals and one silicon atom is missing in the crystal lattice then that is known as...Vacancy.

Vacancy type of defect that is known as vacancy type of defect and you see that in these diagram there is one vacancy type of defect then this is the substitutional impurity; that means, there is an impurity which has taken that place.

That place of vacancy or say this is silicon which was substituted by arsenic or boron. So, this blue ball or these gray ball is basically substituted atom it has substituted silicon it has substituted silicon or it can assume the position of the interstitial place. Interstitial place means? The point between the crystal lattice there is no missing atom you see there here there is a full pledge missing atom, but here there is no missing atom it is in the interstitial position there is one impurity and; obviously, you must admit that impurity having very less diameter or low diameter; that mean, lower size compare to the host they can be accommodated in the interstitial position.

Otherwise in the interstitial the though I have seen though I have shown that it is very big such big place is not there inside the crystal it is all always nanometre dimension and if one thing is that if the host atom that occupies the position of the interstitial region if it occupies the interstitial position then it is known as the frenkel-type defect. So, all those are the known as the point defect these are all point defect now what is the energy requirement for formation of a vacancy?

Student: (( ))

What is the energy requirement? It is basically.

Student: (( ))

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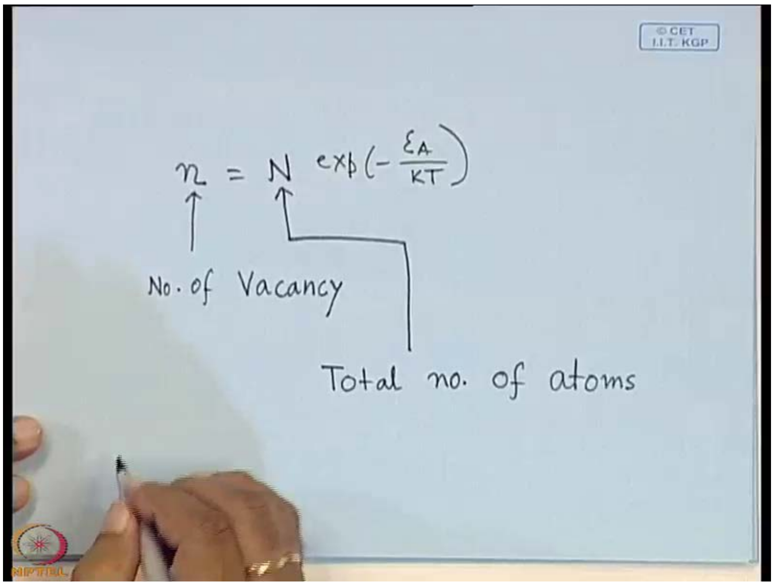

No there is no work function here it is exponential minus.

Student: E a.

E a by.

Student: K T.

K T right that much energy is required. So, number of vacancy will be n equals to N is the total number of atom in the material multiplied by exponential minus E a by K T. So, E a is the energy which is required to...Vacancy.

Create a vacancy. So, number of vacancy you can calculate from this empirical relation it is basically the Boltzmann factor exponential minus E a by K T. So, small n is the number of defects number of vacancy and this N is total number of atoms E a is the energy for creation of a vacancy.

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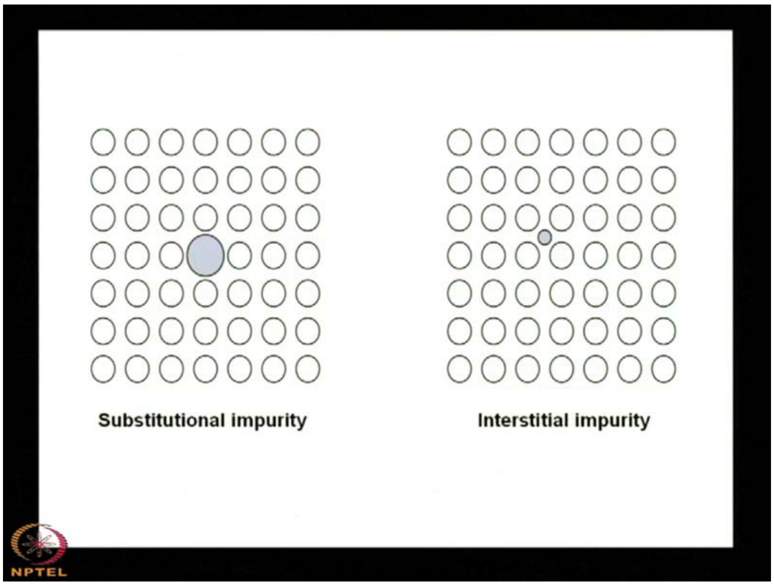

So, you can estimate the vacancy in a material provided, you know those parameters in this diagram the magnified picture of the substitutional impurity and interstitial impurity is shown.

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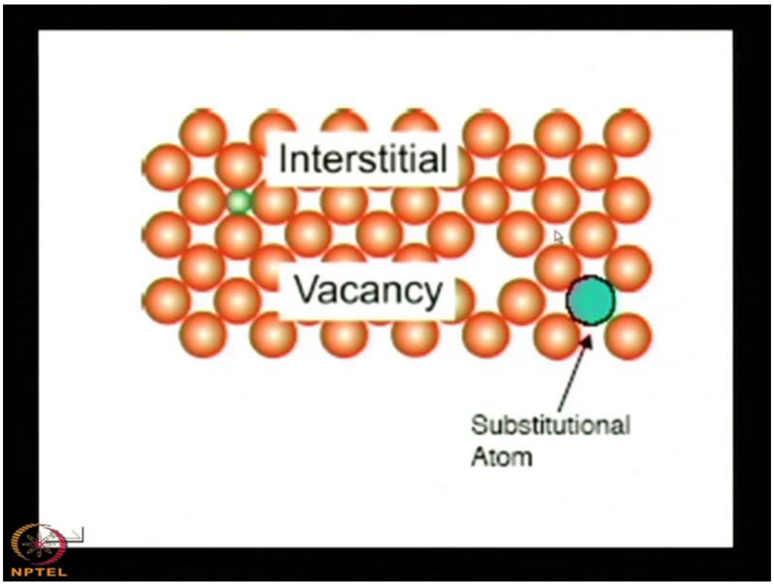

You see that in this crystal lattice there is one interstitial the green inside the red balls it occupied the interstitial position. Then there is any one vacancy position you see there that is the white region this is vacancy and there is one vacancy.

Green ball which replaced one red boll; that means, it is the substitutional atom. So, in a crystal lattice many things can happen not that it will have only vacancy type of defect not necessary not necessary it can have different kinds of vacancy at a time now how the vacancy can be estimated these these are the open volume defects theses are known as the open volume defects and how this vacancy type of defects are estimated can you name one technique using which the vacancy can be estimated it is known as that is a nuclear technique that is nuclear technique.

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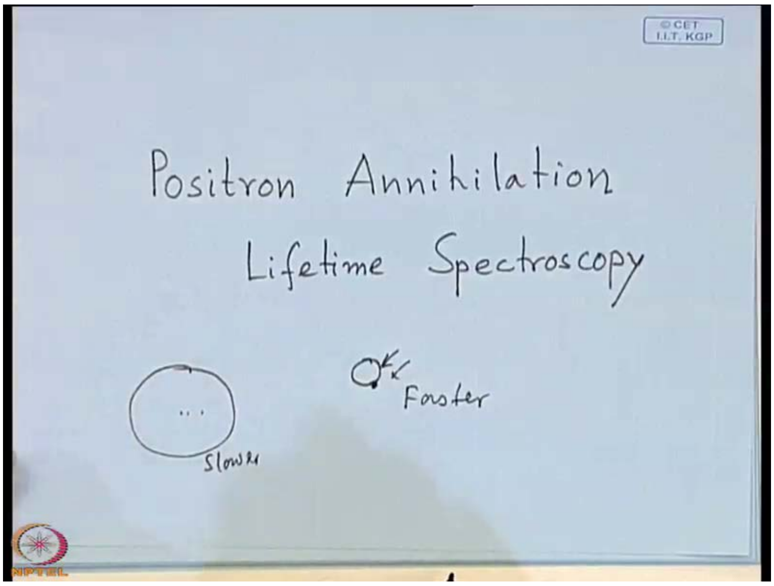

Positron Annihilation
Lifetime Spectroscopy

It is known as positron annihilation lifetime spectroscopy positron annihilation lifetime spectroscopy this is the very good nuclear technique using which you can estimate the defect in a crystal. How it is done you know that positron is a positive charged particle right? When it goes inside the crystal matrix positron annihilates with the electrons and during annihilation gamma ray is.

Student: Emitted.

Emitted right and when the positron goes inside the material from say a sodium chloride material radioactive material then what happens? One gamma ray is also emitted when a positron leaves the source so, one gamma ray leaves the material when the when the positron is emitted from the radioactive source to the material and inside the material it is annihilated with the electron with another gamma ray. So, there will be two gamma rays one during the emission of positron and one during the annihilation of positron.

But the annihilation of positron will depend on the number of electrons inside the crystal matrix if there is less number of electrons; that means, positron will take more time for its annihilation because less number of electrons are there if there is more number of electrons positron will annihilate first compare to the previous case. Suppose this is one vacancy and this is small vacancy. So, what you will find that here the deficiency of electron is more compared to this place this is the microscopy taught then what will happen? The positron annihilation will be faster in this case it will be faster annihilation.

Faster compared to where? Compared to this thing. So, if we compare this two cases here it will be slower, it will be faster so; that means, from the positron annihilation life time spectroscopy you can determine the crystal lattice vacancy in the material vacancy type of defect can be easily estimated from this technique. Then you have to measure the difference in time; that means, when the gamma is emitted first during the emission of the positron

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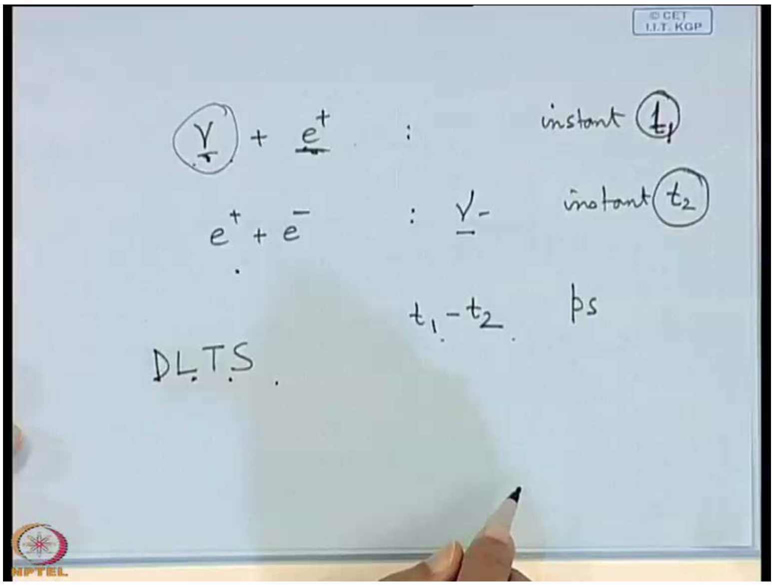

One gamma will be there during the emission gamma plus positron this is say instant one instant say t 1 it is t 1 and when there will be annihilation then also one gamma will be emitted this is say instant 2 or t 2. So, difference between t 1 and t 2 difference between t 1 and t 2 is the time for the annihilation of positron inside the vacancy that is the time and this time order of magnitude is say is picosecond it is picosecond it may be 100 picosecond; 200 picosecond; 300 picosecond. Picosecond order of magnitude within that time it will annihilate inside the vacancy I repeat during the creation of the positron from the radioactive source one gamma is emitted.

These gamma say mow you start one stopwatch you start one stopwatch when these gamma is emitted how you will know? Whether the gamma is emitted or not there will be a gamma ray detector there will be a gamma ray detector how gamma ray is detected? How gamma is detected? There are many physics students here louder. So, many process there.

You can name one can you name one process? One is that high purity germanium detector is there h p g detector there is barium fluoride scintillators it ionises and then using some detector h p g detector you can detect the gamma. There are many techniques as well now one gamma is emitted during the emission of one positron and you start your stopwatch, then another gamma will be emitted during annihilation. You stop your stopwatch. So, the difference in time means during that time the annihilation of the positron was made inside the crystal lattice that time is the t 2 minus t 1 it is denoted by the picosecond.

So, basically it is the coincidence count it is the coincidence count one gamma will there and it will coincide coincidence count will be there when there will be another gamma right. Then that is converted into time that amplitude is converted into time at time to amplitude converted is there t a c those are basically nuclear instrumentation. So, these positron annihilation is a technique using which you can detect the vacancy type defect inside the material, but you cannot detect dislocation or that type of thing only when there is a definite electron deficiency defect means there is electron deficiency then only this type is possible.

Otherwise there is another technique which is known as the deep level transient spectroscopy d l t s deep level transient spectroscopy. So, using d l t s also you can estimate the defects in a material there are several techniques here the capacitance is measured voltage is given and capacitance is measured in d l t s yes.

One point is these difference in time which we.

Student: Annihilation and creation.

Yes. Annihilation and creation.

Student: This is different for different crystal.

Yes there is different for different crystal it depends basically not on the crystal, but on the density of electron inside the material.

There is one thing that if I want to measured these difference I equate a crystal. So, that first thing take a difference time then I can compare with the other crystal.

That is for the estimation of the defect that is if you know the nature of the defect whether there is mono-vacancy or di-vacancy or tri-vacancy or there is a vacancy complex if you want to mathematically determine those thing then you need one perfect crystal for comparison for comparison; obviously, otherwise you can roughly estimate the defect concentration inside the material using these technique.

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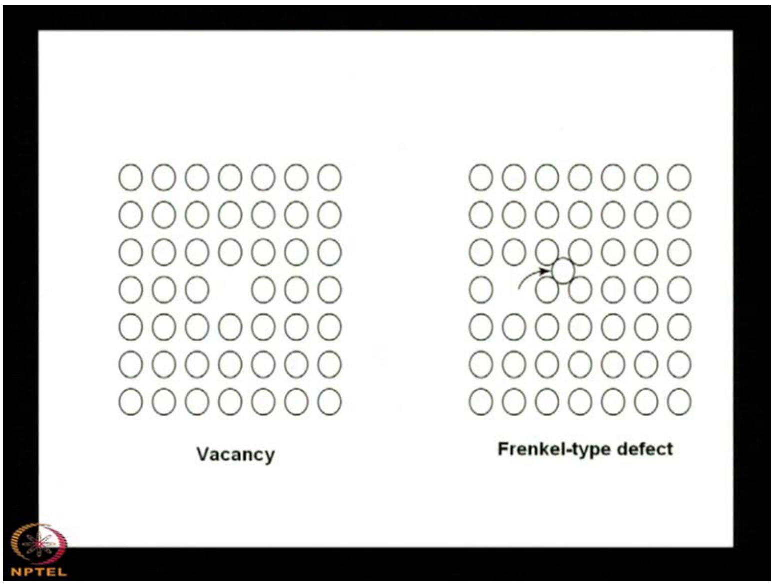

This is vacancy and frenkel type defective you have seen. And you know that in frenkel type defect basically the host atom has taken the position of the interstitial.

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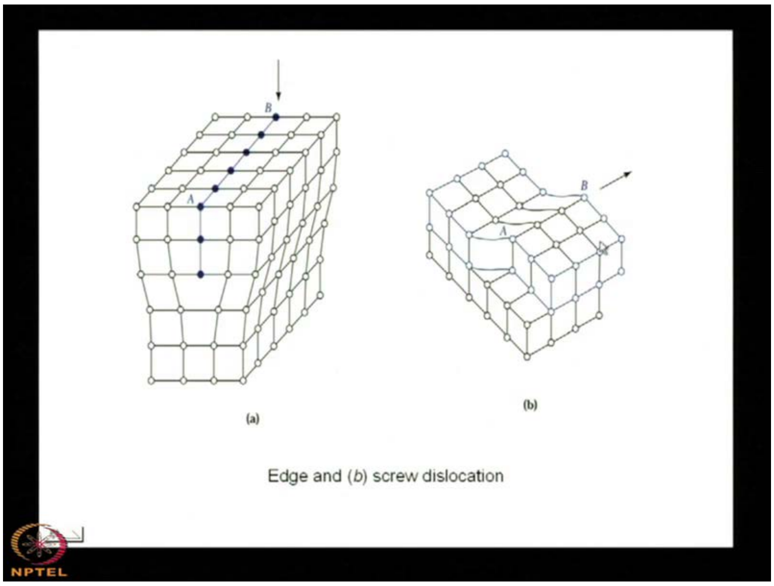

Edge and (*b*) screw dislocation

Then the most important part is the dislocation there are two types of dislocation one is known as the edge dislocation another is known as the screw dislocation. Edge dislocation and screw dislocation those two types of dislocations are there remember that for point defect where we have discussed about the vacancy or the impure interstitial or substitution whatever be the case that was due to thermodynamic equilibrium, but for dislocation type of defect it is not thermodynamics in nature.

It happens due to thermal or mechanical stress during crystal growth it happens during thermal or...

Mechanical.

Mechanical stress during crystal growth. So, when growing a crystal if there is a mismatch of stress or if you intentionally give some stress then these dislocation or edge or screw type of dislocation is happened here for edge dislocation what happens one crystal plane is inserted in the perfectly oriented crystal lattice. So, suppose this is a perfectly oriented crystal lattice and one plane you insert here that type of thing. So, if you insert one crystal plane inside the perfectly crystal lattice.

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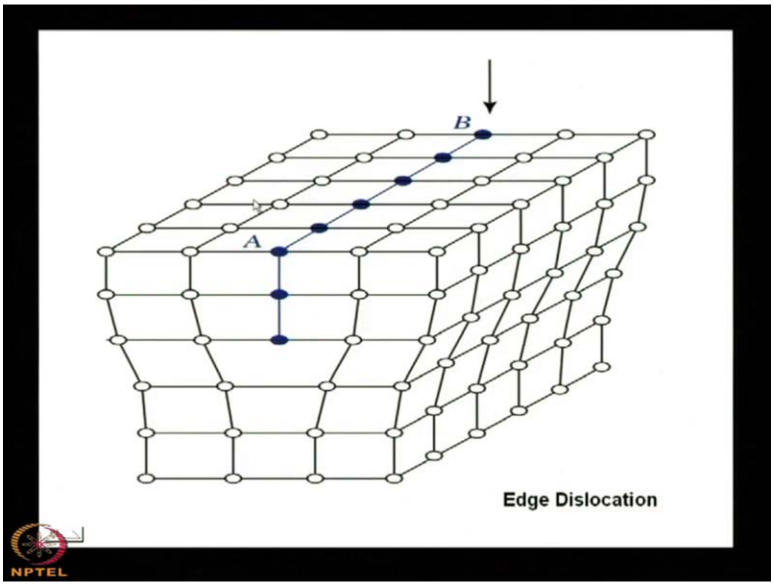

Then it will assume this type of a shape and this shape can be magnified in this way that you see that this A B is a crystal plane which is forcefully inserted in the normal crystal lattice then what happens? You see that there is a distortion you see you look at the bottom or the side parts in that top part it is ok, but, so far as the bottom or the side parts are the concerned there is a distortion in the crystal lattice yes.

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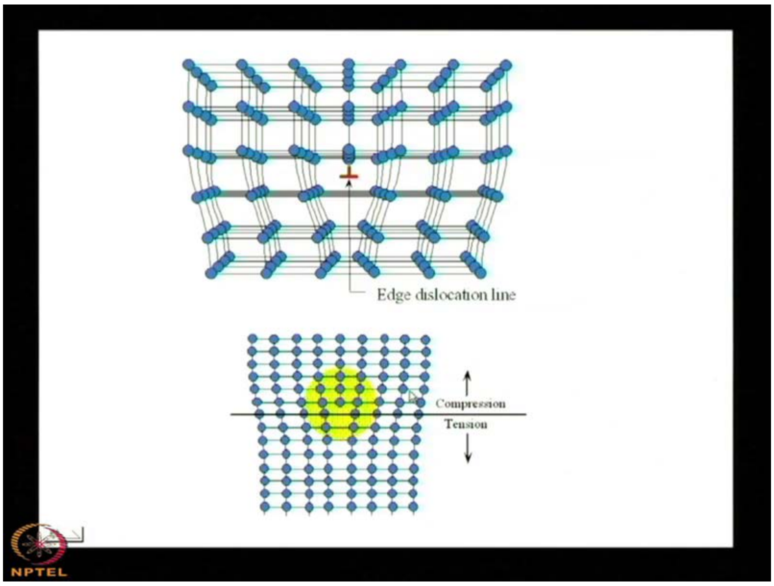

This is edge dislocation and you see that this part practically below this invert red t there is a red t I do not know whether you see or not this t inverse t is there and below this inverse t region you see that there is a distortion in the crystal lattice. So, there will be compression and tensile strain there will be strain in this distortion region.

Why because. So, far as the bottom portion is concerned it will be pulled the atoms will be forcefully as if you have pulled the atom and. So, far as the top portion is concerned you have forcefully pushed the atom. So, that mans when there will be a push or pull. So, it will give rise to some compression or tensile strain in the atomic planes and a strain will developed. So, the effect of the dislocation is that a strain is developed and there will be a dislocation line the problem with the dislocation line is that it can percolate suppose it is formed at the top say within one micron or two micron it can percolate deep inside the material with thermal cycling.

Suppose during crystal growth there is dislocation. So, during oxidation or during diffusion there will be percolation of that defect inside deep inside the material at different directions and those defect lines or dislocation lines what will happen the impurity will be trapped in those defect lines and if the impurity is there then the life of the device will be reduced because ultimately you have to send the current and every time because of this potential inside the impurity trapped sides there will be there will be heat developed and since the heat is developed in very smaller region it will not be able to dissipated throughout the crystal lattice instantly then after 2,3,10 days 5 days 100 days 2 months there will be damage inside those areas. So, the device will be damaged or in some cases it will burn.

So, that is the disadvantage of the dislocation that crystal dislocation is basically a line of order nanometre how many lines are there? Say 5 lines per millimetre square or per nanometre square there will be 7 lines so; that means, the dislocation density is measured per centimetre square per centimetre square area say you if you take 1 nanometre square; that means, 1 nanometre by 1 nanometre and the dislocation is say 5; that means, 5 dislocation lines per 1 nanometre square area here because of this dislocation different types of as I have started that different types of crystal growth has invented say vertical gradient freeze the dislocation is very, very small.

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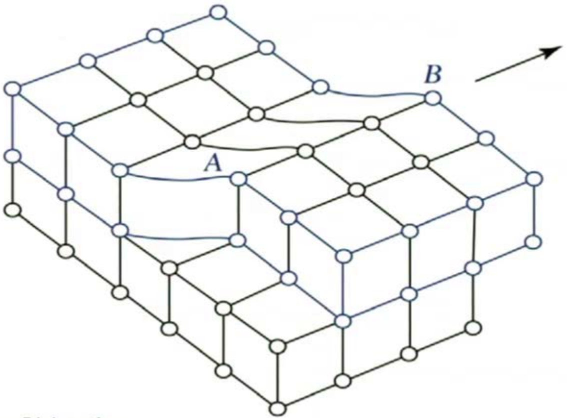

Screw Dislocation

Another dislocation is the screw dislocation it is basically the sharing type of thing; that means, you cut one part then that part is over lapped on the other part. So, there is say this is this part is originally it was there then you have cut here and you have sent it to the other part

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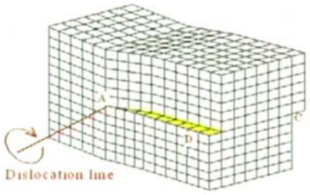
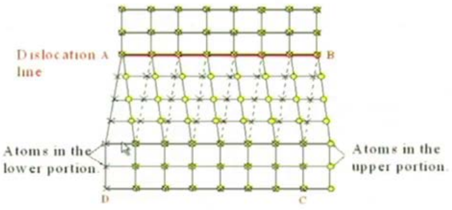


(a) A screw dislocation in a crystal



(b) The screw dislocation in (a) as viewed from above

This is screw dislocation and if you see that this looks like a screw basically, this yellow part you can find, you can take this material from me today. So, that you can find that this A B, b is not seen here that A B C D; there is a displaced you see that this A B C D is displaced from the original position there was displacement of one atomic layer.

Then this A D portion you see that there is a screw type of appearance which is the dislocation and if you find that is A b is the dislocation line then this part is the atoms in the upper portion, this part is the atoms in the lower portion, you see that there is a mismatch, there is a orientational problem; here in this line you see that the yellow dot and yellow cross are over lapped; can you see? This yellow dot and this yellow cross are over lapped up to B it is over lapped, up to B it is over lapped then you see that dot and cross are detached; that means, one plane is detached from the other. Here dot and cross are the same means dot plane and cross plane was perfectly aligned then there was an misalignment detachment. So, that is known as the screw dislocation, because it looks like a screw, and the effect is same.

And in many case you will find that it is a mixed type of thing; that means, in the same crystal lattice, there may be screw dislocation as well as the edge dislocation. And dislocation is very bad type of defect, and it is line defect not a point defect; vacancy defect is a point defect it is a line defect. And in such defects the major problem is that the impurity will trap inside the dislocation line, thereby reducing the life of the device; or in some cases if it is in the denuded zone, then the device even can be spoiled at the very beginning itself right. So, these are the difficulties with the dislocation. So, there will be more two types of defects that we shall discuss in our next class; one is the area type of defect that is grain boundary to in etcetera and another is the precipitates, which is the volume type of defect; and then we shall conclude our discussion on the defects.

Thank you.