Processing of Semiconducting Materials
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Lecture - 7
Diffusion and Ion Implantation – 1

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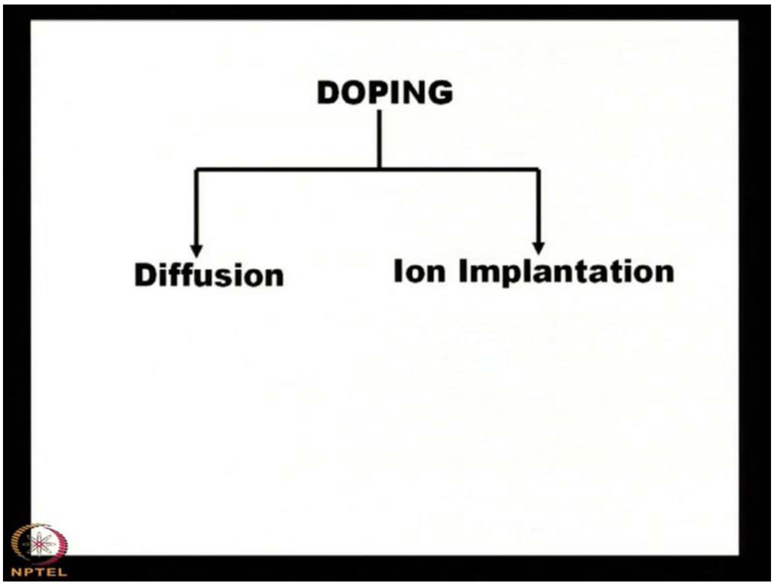

DOPING

Diffusion

Ion Implantation

We are discussing about the diffusion and ion implantation; and those two techniques; you see that they are used for the doping in a semi conducting material. So, it is related to the doping. Then, doping can be done by two ways; one is the diffusion, another is the ion implantation. And please note that, when we talk about the doping basically, when we talk about the doping basically, we have two things in mind.

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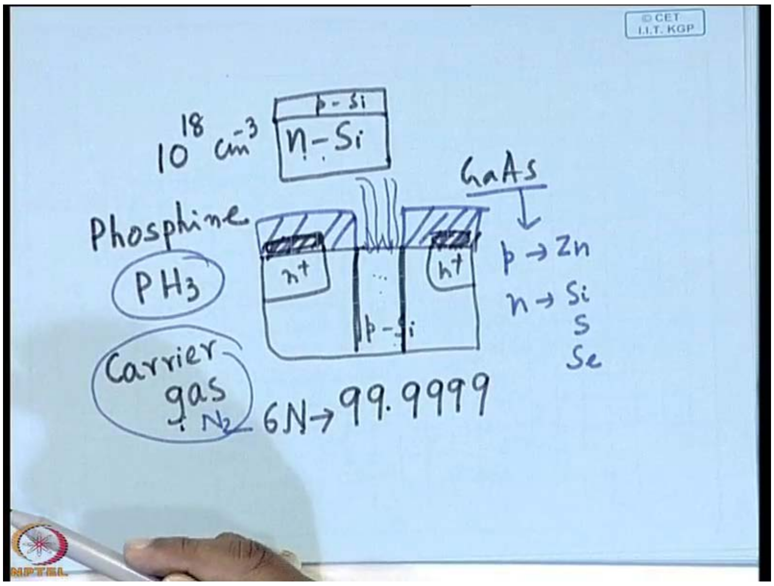

One is that you have already n type materials; say you have already a silicon material which is n type, it is already n type. And, then with that n type material, you form a junction with a p type. So, for formation of the p n junction or say you have a substrate like this, which is p silicon. That means, it is p type silicon and you want to dope it in two region to form it as a fet or mosfet; say this is n plus and this is n plus, source entering. So, during this process; right, when we want to dope and already doped material for formation of some junction or for some device fabrication, we need either diffusion or ion implantation, as the two processes using which doping can be done.

And, so far as this p silicon or n silicon is concerned, this type of doping is done during crystal growth which we shall start from next week. Suppose, I want to make n type silicon; so this is when we talk about n type silicon; that means it is the single crystal of silicon. And that single crystal is done using some crystal growth process; by the technique of bulk crystal growth which grow silicon crystal or any other crystals, say gallium arsenide or whatever be the crystals.

Now, during growth of the crystal, generally we dope the material either p type or n type. So, at the end of the crystal growth process, you will have either a p type semi conductor or an n type semi conductor. There are certain semi conductor during growth of it; even if you do not want to dope it as grown type, it becomes either n type or p type, because of the stoichiometry, say zinc oxide. If we want to grow zinc oxide, as grown zinc oxide is always n type, it is always n type. There are certain materials, because of its chemical nature due to thermo dynamics, it as grown type it becomes n type; you need not to dope it.

Now, you can control the doping by putting some other material or impurity to make it further n type or with some selected carrier concentration; say you need 10 to the power 18 and as grown is 10 to the power 15. So, you have to dope it again for n type. But generally silicon or gallium arsenide or indium phosphite, gallium phosphite; those are, those crystals can be grown either n type or p type. Then, using those crystal if you want to make some junction say p n junction or a in a c mos or in a mosfet, source drain etcetera regions. Then, we would like to resort to these two type of process; one is diffusion another is ion implantation, right.

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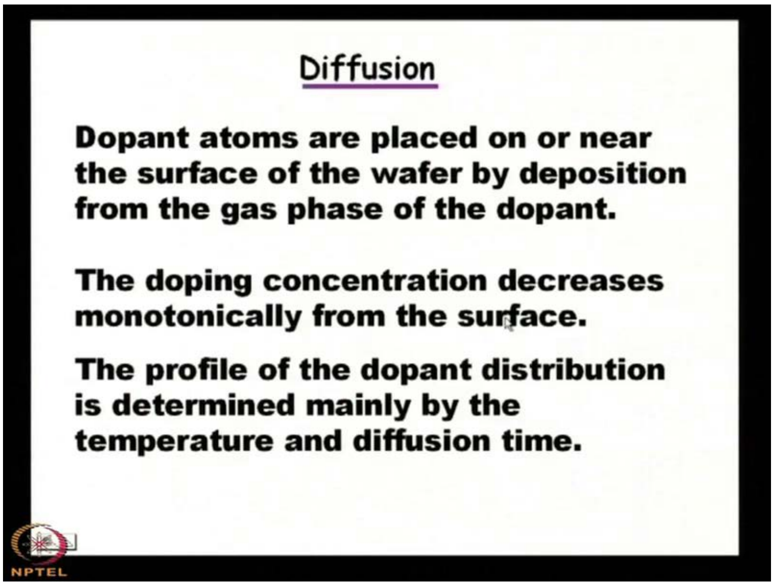

Diffusion

Dopant atoms are placed on or near the surface of the wafer by deposition from the gas phase of the dopant.

The doping concentration decreases monotonically from the surface.

The profile of the dopant distribution is determined mainly by the temperature and diffusion time.

Then, diffusion. First, we shall concentrate our discussion on diffusion. Dop ant atoms are placed on or near the surface of the wafer by deposition from the gas phase of the dopant. I have given you the example; that, suppose this is the wafer and what is wafer, we have discussed. What is wafer? Wafer is.

Student: (( ))

Yes, wafer is single crystal, thin layer. How thin it is? How thin it is?

Student: 300 micron.

300 micron, 400 micron, 500 micron of the order of 300 to 400 5500 micron. So, if I say that this is a wafer; that wafer means, it is a single crystal line material which is cut from a bulk crystal having thickness 300 to 500 micron. And, the diameter can be 2 inch to several inches; 2 inch, 4 inch, 6 inch, 8 inch. It can be several inches, the diameter. But the thickness is around 300 to 500 micron. So, the we start from the wafer. When we dope something; basically, we put the wafer inside the diffusion furnace or inside the ion implanter for its doping. Now, say this is the wafer and dopant atoms are placed on or near the surface of the wafer. Say this is the silicon; n type silicon. I would like to make a doping of p type. Then, I must put some boron on it, boron on it. And, then the deposition takes place because of diffusion; why there will be diffusion? Because of the concentration gradient, because of the concentration gradient.

You have boron here, the concentration of that material is high here compared to the bulk crystal compared to the other portion of the wafer. And, if you heat it; so, the atoms will be mobilized and they will diffuse through the material, right. The doping concentration decreases monotonically from the surface. And, the profile of the dopant distribution is determined mainly by the temperature and diffusion time. So, there are 2 parameters which must be optimized; one is the temperature, another is the diffusion time.

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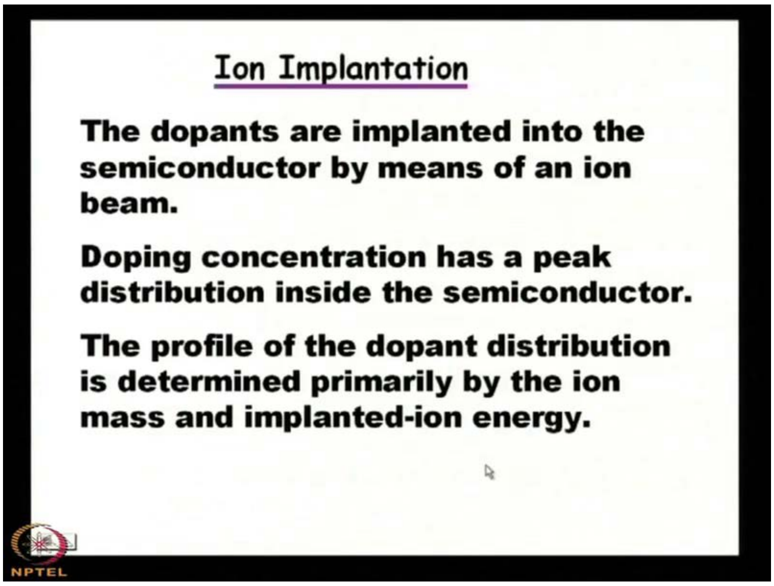

Ion Implantation

The dopants are implanted into the semiconductor by means of an ion beam.

Doping concentration has a peak distribution inside the semiconductor.

The profile of the dopant distribution is determined primarily by the ion mass and implanted-ion energy.

And, another process is the ion implantation. The Dopants are implanted into the semiconductor by means of an ion beam. Doping concentration has a peak distribution inside the semiconductor and the profile of the dopant distribution is determined primarily by the ion mass and implanted ion energy. So, what is the difference between these two techniques? One is the diffusion, another is the ion implantation. In diffusion, we put the dopant atom at the surface, here an ion beam is required, an ion beam is required.

Second thing is that, diffusion the doping concentration decreases monotonically from the surface. That means, at the surface it is the highest, at the surface it is the highest. Then, monotonically decreases as it goes inside the material. See in case of ion implantation, doping concentration has a peak distribution inside the semi conductor. So, there is a peak distribution inside the material not at the surface. When you talk about the peak, that means the highest concentration; the maximum concentration. For diffusion the maximum concentration is at the surface, but for the ion implantation it has a peak distribution.

And, another thing is that; for diffusion it is the, for diffusion it is the temperature and time which controls the profile of the dopant. What is profile? What do you mean by the profile of the dopant? Profile of the dopant is how it penetrates through the material. That means, the trajectory inside the material. The trajectory inside the material; how it moves from surface inside the material through the material, obviously inside the material. So, that is the profile and that profile obviously give you the thickness, that profile will obviously give you the thickness; how far it has reached inside the material. And, that is given for diffusion by the temperature and diffusion time. But for ion implantation, it is the ion mass and implanted ion energy. Temperature and time has no role in ion implantation doping profile.

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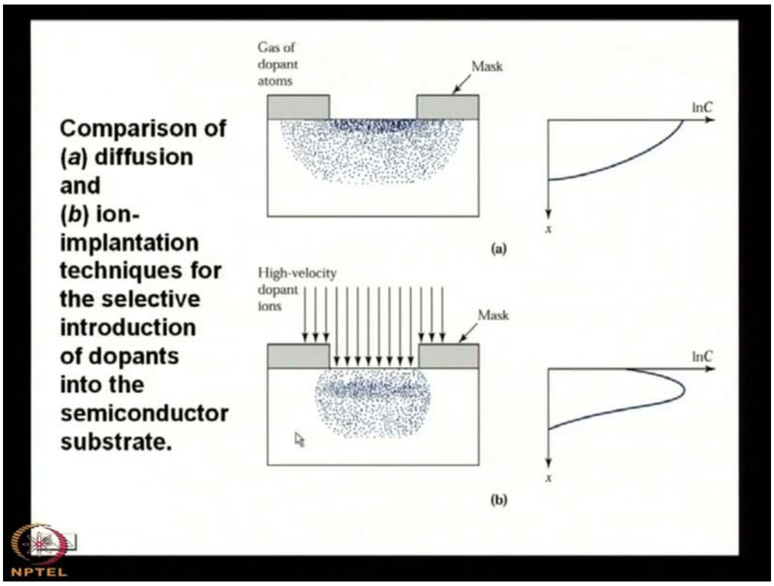

Comparison of (*a*) diffusion and (*b*) ion-implantation techniques for the selective introduction of dopants into the semiconductor substrate.

So, this is the example of a profile given by the diffusion as well as by the ion implantation. You see that this is the material and the material is doped with some material. So, this is diffusion; the first one this is the diffusion. And if you see the doping profile, you will find that the maximum concentration is here; l n c. Then, it decreases monotonically. So, what is the depth? Depth is from 0 to say this is x 1; so, depth is 0 to x 1, this is the depth. So, if this is the surface, then this is the depth and the highest concentration is at the surface of the wafer.

So, far as the ion implantation technique is concerned, you see that there is a peak distribution inside the material, not at the surface. From the surface, see if this is the surface; then, it increases. There is a peak inside the material and again it decreases. So, here this is the thickness but the doping concentration is highest in this region; say it is say x 1 to x 2. If this is say micron; so, take this point between x 1 and x 2, the peak is there and so the concentration is maximum.

Another important difference between this two process you see; that I want to dope this portion, the middle one; this portion. So, I have made a mask through to prevent, I have made a mask to prevent the doping at the two ends of this material. So, mask is generally a coating; a layer of the material which is made on the surface through which we do not want doping. Those portions we do not, in those portions we do not want doping. So, if I do not want doping here; say this portion and that portion, if I do not want doping, then made some masking here, made some masking here. Generally, s i o 2 for silicon s i o 2 is a good mask, silicon dioxide. You put a silicon dioxide layer or silicon nitride layer; so, they will act as mask through which the dopant will not penetrate through the material.

So, you can make any kind of arrangements. If you want to dope say this area, only this area; then, you dope, then you make a mask through this full area. You make a mask; so, what will happen? The dopant ion will, atom will move through this window only, this window only. But even if there is a window to define the diffusion area; see that actually the dopant atoms have move through beneath the mask area also. That is known as the lateral doping that is the disadvantage of diffusion; but that kind of lateral doping is not found in case of the ion implantation.

You see here though there is a small penetration beneath the mask or under the mask. Even then if you compare these two figures, you will find that here the spread is very less; here the spread is very less. You see that this is the non doping area, this is the non doping area, this is the non doping area, here it is the doped area. So, you find that the ion implantation technique will give you less lateral diffusion compare to the normal diffusion process. And here you see that the carrier concentration is maximum at the surface, because it is more dark; this region is more dark compared to the other regions, so, the concentration is high here.

Why it is so? Why it is maximum at the surface? I shall show you mathematically; I shall show you mathematically why at the surface the concentration is maximum. But here there is a peak distribution inside the material, you see that the dark area is not at the surface; but some distance away from the surface. So, these are two differences and mathematically we shall try to see why such a thing happen.

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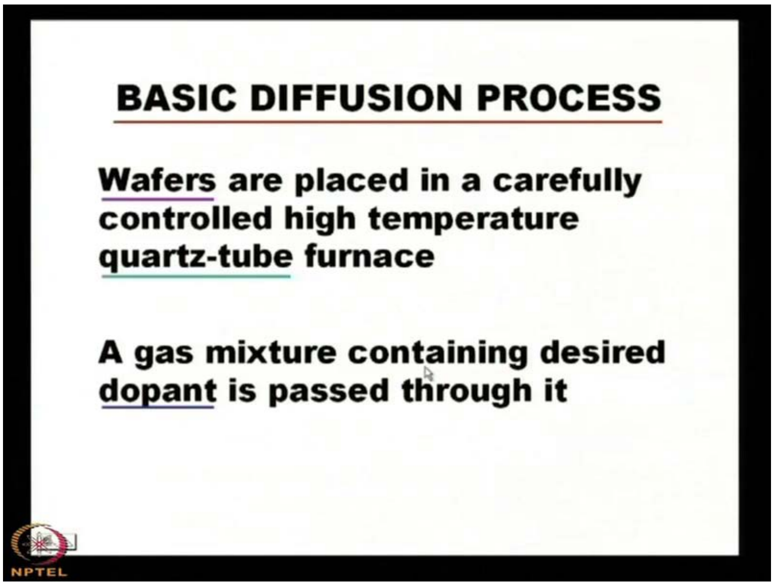

BASIC DIFFUSION PROCESS

Wafers are placed in a carefully controlled high temperature quartz-tube furnace

A gas mixture containing desired dopant is passed through it

Actually, ion implantation is better, but ion implantation is very costly also; because you need a ion beam and ion beam is very costly. Now, come to basic diffusion process, not ion implantation; this is the basic diffusion process. In this diffusion process, wafers are placed in a carefully controlled high temperature quartz tube furnace.

So, I have underlined two words; one is the wafer you see and another is the quartz tube furnace. So, that means you need a furnace which is made of quartz tube. Why I have made the underline? Why quartz tube is used? You can ask me, there are several materials on earth, but what is special about quartz tube; that we used for the for making the furnace for diffusion. And, wafer you know, we have already explained what is wafer. And, a gas mixture containing desired dopant is passed through it; through it means through the quartz tube furnace.

So, that means you need a gas mixture; gas mixture means if you want to dope with say phosphorous, generally we use phosphine as the dopant gas. Phosphine is available in the form of gas; arsine is available in the form of gas. For say gallium arsenide, what are the dopants used for n type and p type? We have discussed earlier; so, try to answer. For silicon, it is very well established and you all know that boron is used for p type and arsenic phosphate is used for n type. For gallium arsenide, that means for 3 5 compound semi conductor, gallium arsenide, indium phosphite, gallium phosphite; what are the materials used for doping as p type and as n type?

Student: (( ))

Louder.

Student: (( )).

No.

Yes, silicon is used. Silicon is used for n type doping and sulphur, selenium is used also for n type doping. That means, if you have some compound semi conductor say gallium arsenide, it is a compound semi conductor. So, for p type doping and n type doping; for n type you can use silicon, you can use sulphur you can use selenium. For p type zinc is used, for p type zinc is used, right. Now, these silicon and sulphur, those are available in the market as gas; silane gas. You have heard, you have heard s i h 4. H 2 s, hydrogen sulphide that you know, that hydrogen sulphide is available as gas. So, hydrogen sulphide or silane is used to dope gallium arsenide as n type. And, zinc is available for p type, but normal compound of zinc is not in gaseous form.

So, that means you can take diethyl zinc which is liquid. Then, if you heat it; vapour pressure will develop inside the bubbler, inside the container. So, you have some vapour pressure on the surface of the liquid, right. Then, you have to transport that gas either silane or h 2 s or zinc to the reaction chamber. Here the reaction chamber is nothing but the quartz tube furnace; here the reaction chamber is nothing but the quartz tube furnace.

So, through this quartz tube furnace, you have to send a gas mixture containing desired dopant. You want to dope the material with phosphorous; then, what is the gas mixture? Your gas mixture will be phosphine; P H 3, it is the phosphine and a carrier gas which will transport phosphine to the quartz tube furnace, a Carrier gas. Generally, the carrier gas is nitrogen in such cases; nitrogen or hydrogen, what is the advantage of hydrogen? The advantage of hydrogen over nitrogen as a carrier gas is, hydrogen is available in very pure form. If you can pass hydrogen through a palladium diffuser, then what happens?

Palladium absorbs and at the output of the diffuser you will get very high quality hydrogen gas. And, what is the quality? When you talk about the quality in semiconductor; generally it is 6 n 7 n 5 n purity. Then what about 6 n? 6 n means

99.9999 percent; total 6 9’s are there; you say you see. It is known as 6 N purity, 6 9’s are there. So, very, very high purity is maintained for semi conductor processing. Otherwise, if there is a few impurity atom or few impurity inside the material, then you will not get the normal device performance, from the device. The performance will be reduced. Let me give you one clear example. For gallium arsenide; it is almost 9000 is the mobility; 9000 centimetre square per volt second is the mobility. Now, this is for very pure gallium arsenide. But if there is an impure inside, if there is carbon inside gallium arsenide, few trace of carbon or few trace of iron or nickel; then, the mobility will be reduced from 9000 to even 2000, 3000.

So, if the mobility reduces for some reason, then that material cannot be used for very good electronic device, because the mobility is the basic criteria in such cases. Mobility is the basic criteria in such cases, right. Where gallium arsenide is used? The main use of gallium arsenide is in the, where? One is optical device, another is the microwave device; impatt diode. So, that is the microwave source; impatt diode is the source for microwave that is used for microwave generation.

And, since the mobility is very high, it is used there. And, if your mobility is reduced then you cannot use gallium arsenide for microwave device; silicon is not use for microwave device. So, one of the consideration is mobility and if there is a impurity inside the material, then it will jeopardize your application. So, basically 6 N purity, 7 N purity, 5 N purity that means very, very high pure materials are involved in such cases.

So, this carrier gas, this carrier gas also will have very high kind of purity. Nitrogen can be made pure, but not to that extent like hydrogen; because of the palladium cell. Through a palladium, you can send hydrogen, it will absorb the hydrogen and then when you heat it around 300 degree centigrade, at the output of the diffuser you will get very clean. It is not 6 N, sometimes we find it is 11 N; 11 n very, very high purity hydrogen gas is available. So, that is why hydrogen is mostly used, but handling hydrogen is very difficult.

It is impermeable not like nitrogen; so that is why people use nitrogen, it is also available, but not to such purity level. But 6 N, 7 N purity nitrogen is available or in some cases 11 n purity of nitrogen is also available; it is very costly. Normal industrial cylinder will cost say 2000 rupees, but say 9 N purity nitrogen will cost some 50,000 rupees. So, the difference is very, very high. So, a gas mixture containing the desired dopant is pass through it and the gas mixture is nothing but the dopant nothing but the dopant, phosphine in this case and carrier gas which is either hydrogen or nitrogen. Let us take in our case it is nitrogen.

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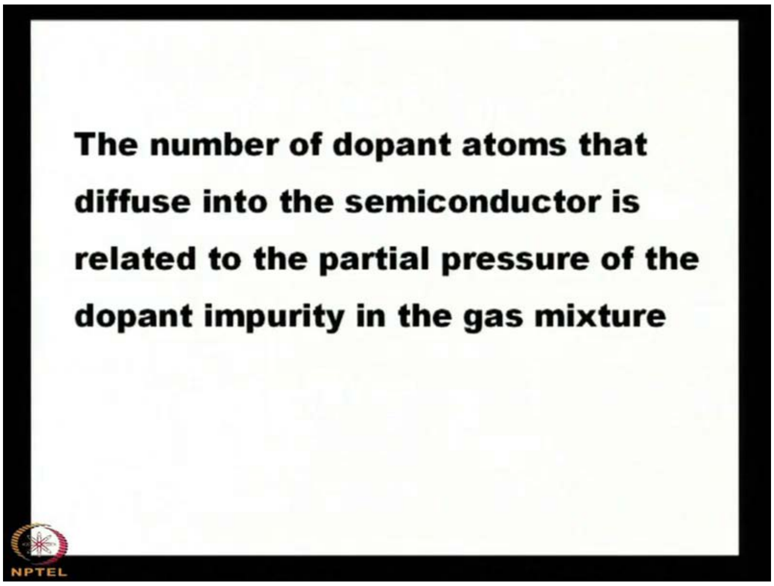

The number of dopant atoms that diffuse into the semiconductor is related to the partial pressure of the dopant impurity in the gas mixture

The number of dopant atoms that diffuse into the semi conductor is related to the partial pressure of the dopant impurity in the gas mixture is very very important. This is very very important. The number of dopant atoms that diffuse into the semi conductor; suppose you want to dope the semi conductor with say 10 to the power 18 centimetre cube inverse. That means, per centimetre cube volume there will be 10 to the power 18 dopant Atom. That means, you want to make the carrier concentration as 10 to the power 18. The carrier concentration, because carrier concentration is always represented per c c always, right.

This is the carrier concentration in say silicon; 10 to the power 14, 10 to the power 15 per c c; the unit of carrier concentration. That means, the if it is an n type material, the number of electron is 10 to the power 18 per cc of the material. So, this is the carrier concentration and for doping, we know that 1 dopant atom on ionization will give you 1 electron. Particularly, it is true for silicon and say phosphorous or arsenic. You know that because of silicon in group 4 and phosphorous or arsenic in group 5; so, each phosphorous atom on ionization will give you 1 electron.

So, if you dope the material with 10 to the power 18 per c c atom; then, considering that full ionization of the material, you will get 10 to the power 18 electron. So, the carrier concentration and dopant are all most synonymous; not same. It is synonymous, if all the dopant atoms are ionized. Now, the number of dopant atoms that diffuse into the semi conductor is related to the partial pressure of the dopant impurity in the gas mixture.

If you talk about this phosphine and carrier gas, if you talk about this phosphine and carrier gas; you will find that the mixture is phosphine and carrier gas is nitrogen. Now, what should be the amount of phosphine, which will diffuse through the silicon? Because it is the mixture; it is the mixture of phosphine and nitrogen. It will depend on the partial pressure; what is partial pressure? What do you mean by partial pressure?

Student: (( ))

Yes, exactly. Here there is a mixture of two gasses. So, pressure exerted by the, by a single gas, right. The partial pressure of phosphine is the pressure exerted by the phosphine, the partial pressure of nitrogen is the pressure exerted by the nitrogen. And, the individual pressure will be, when at the individual pressure when added will give you the total pressure of the system. What is the partial pressure of oxygen in air? What is the partial pressure of oxygen in air? You should tell.

Student: (( ))

No, no. You tell what is the normal atmospheric pressure?

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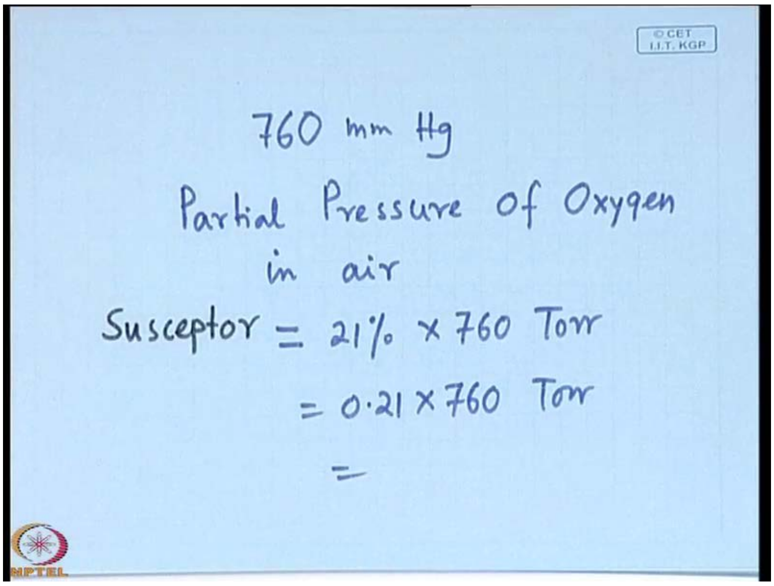

760 mm Hg

Partial Pressure of Oxygen in air

Susceptor $= 21\% \times 760$ Torr

$= 0.21 \times 760$ Torr

$=$

760 millimetre of h g; that means, 760 Torr. Millimetre of marker is nothing but Torr, it is 760 Torr. Now, what is the concentration of oxygen in air? 21 percent roughly. So, partial pressure of oxygen in air it is equals to 21 concentration multiplied by 760 Torr or millimetre of mercury. That means, 0.21 multiplied by 760 millimetre of mercury; what is the value? Whatever be the value 152, 153, 160; whatever will be the value, there is a value and you will get that oxygen partial pressure in air is this. So, similarly, the number of dopant atoms which will move through the material will depend on the partial pressure of the material and that is very important criteria.

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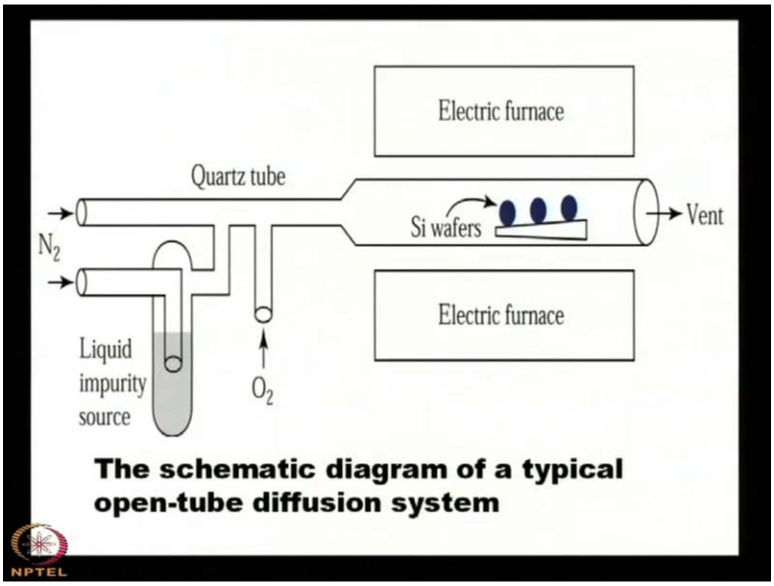

The schematic diagram of a typical open-tube diffusion system

This is the schematic diagram of a typical open tube diffusion system, open tube diffusion system. In this tube diffusion system, you see; why it is open tube? First tell. Both ends are open; very simple, both ends are open. Through this, they say this is the inlet and this is the outlet. So, through the inlet the gasses are passing, where? To the quartz tube furnace, where the silicon wafers are put. We have shown you 3 silicon wafers. Example and the silicon wafers are put on a susceptor. Susceptor is a material platform through which, on which the wafers are kept; the wafers are not kept at the floor of the quartz tube.

Generally, it is kept in a platform inside the quartz tube and that is made of either graphite or inconel or stainless steel; that means, which can withstand very high temperature. That susceptor can withstand very high temperature. You know that graphite can withstand very high temperature, inconel is a metal, which can withstand very high temperature, stainless steel can withstand very high temperature. So, depending on the material your susceptor; it is a platform on which the wafers are placed or kept.

So, the silicon wafers here are kept on the susceptor and you see that this is the liquid impurity source. And, nitrogen is passed through the liquid impurity source to carry the liquid wafer on to the silicon wafer. And, here you see that oxygen is also passed; why oxygen is also passed I shall show you, because the reaction is there where oxygen is required. And, this is the electric furnace; this electric furnace is due to heating of the element inside the reactor. So, this furnace will raise the temperature of the furnace; raise the temperature of the tube, the environment.

And, you can control the furnace temperature by some controller suppose you want to use 1000 degree centigrade for a particular doping. So, you can control 1000 degree centigrade; how long it will remain in 1000 degree? Say half an hour, 1 hour, 2 hour; that you can set. After 1 hour say, the temperature will drop to normal room temperature. So, there is a controller. That controller will control the temperature and time. Because you have to first calculate, how much temperature is required for the doping and how long you want the diffusion. And, say with some calculation you get 1000 degree centigrade for 1 hour. Then, you set the furnace parameter as 100 degree centigrade, a 1000 degree centigrade and 1 hour.

So, the temperature of the furnace will be 1000 degree centigrade for 1 hour and the diffusion will be there. That means, continuously this will flow through 1 hour and it will diffuse. And, the reactant gasses because there will be a chemical reaction and that chemical reaction will evolve some gas. That gas will pass through the vent; vent comes from ventilator. And, then that gas is driven out from the tube. So, this is a schematic diagram of a typical open tube diffusion system.

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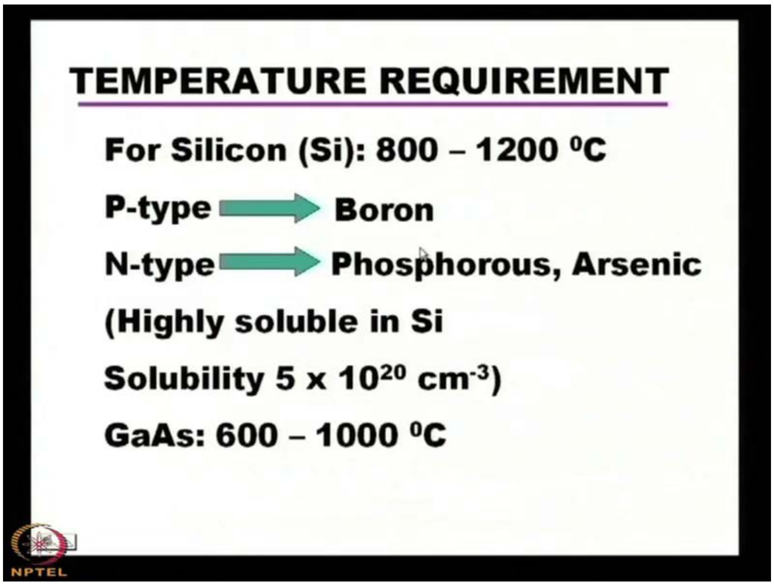

TEMPERATURE REQUIREMENT

For Silicon (Si): 800 – 1200 ^{0}C

P-type → Boron

N-type → Phosphorous, Arsenic

(Highly soluble in Si

Solubility 5 x 10^{20} cm^{-3})

GaAs: 600 – 1000 ^{0}C

What is the temperature requirement for silicon? For silicon that means if you want to dope silicon, the temperature requirement is 800 degree to 1200 degree centigrade; it is very high 800 degree centigrade to 1200 degree centigrade. And, generally for p type boron is used for n type phosphorous and arsenic is used, why? Because these materials; boron, phosphorous or arsenic it is highly soluble in silicon. It is highly soluble and its solubility is 5 into 10 to the power 10 power c c; very highly soluble. If it is not soluble then the diffusion will not take place properly. For gallium arsenide, you see that the temperature is lower than silicon; it is 600 to 1000 degree centigrade. So, for silicon high temperature is required if you compare with gallium arsenide. And, for silicon we choose this material because they are highly soluble. So, these are the condition.

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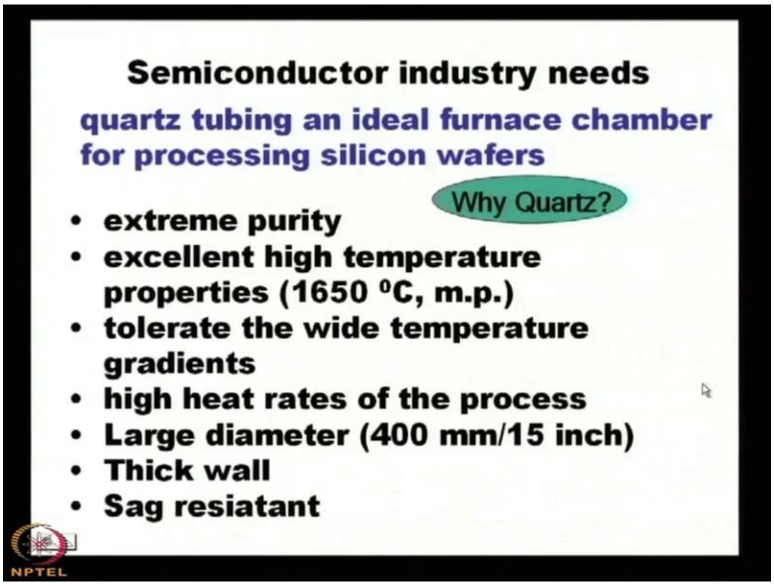

Semiconductor industry needs

quartz tubing an ideal furnace chamber for processing silicon wafers

Why Quartz?

- **extreme purity**
- **excellent high temperature properties (1650 ^{0}C, m.p.)**
- **tolerate the wide temperature gradients**
- **high heat rates of the process**
- **Large diameter (400 mm/15 inch)**
- **Thick wall**
- **Sag resiatant**

Then, the question comes; why we use a quartz tube? You can remember that we have made underline on quartz tube. Why we use quartz? Because semi conductor industry needs quartz tubing and ideal furnace chamber for processing silicon wafers, this is the standard thing. And, silicon furnace is always used for semi conductor processing, be it oxidation, be it doping; anything. We always need an quartz tube, why quartz? Because extreme purity; very high pure in very high purity form quartz is available. If you compare quartz with normal glass; so normal glass is not pure sodium, potassium those type of impurity are there. Excellent high temperature properties; excellent high temperature properties, you see that the melting point is almost 1650 degree centigrade. The melting point is almost 1650 degree centigrade and what is the temperature requirement? 1200 degree centigrade.

So, if your furnace does not withstand, unable to withstand the temperature; then what will happen? That will give rise to contamination; more and more impurity will penetrate through the material. So, since the temperature requirement is very high and you see that for silicon the temperature is always very high. The for silicon processing the temperature is very high. We shall see during the crystal growth of silicon that they are also very high temperature furnace is required.

So, excellent high temperature properties is 1650 degree centigrade; tolerate the wide temperature gradients. Sometimes, the gradients can be say 300 degree centigrade per second or 400 degree centigrade per second. High heat rates of the process, large diameter that means 400 millimetre. 400 millimetre is almost 15 inch, more than 15 inch; almost 16 inch. 400 millimetre thick wall and sag resistant. It will be resistant, what is sag resistant?

Student: (( ))

Yes, yes. Basically, with that temperature it should not be deformed; it should not be deformed in any portion. Sometimes, you find that where the furnace is there just above the furnace. The tubes sometimes bends, distorts or some deformation takes place. But if you use quartz, those things does not happen. So, because of this points it is mostly all are related to heat; all the points are mostly related to heat basically. That is why the quartz tube is always preferred over other kinds of furnace tube. Other kinds of furnace tubes also there; silicon carbide is there, aluminium is also there, stainless steel is also there. Those can be used, but quartz is used because of these advantages. And, the most important is the purity for which you cannot compromise for semi conductor processing. Because where there is 9 N, 7 N, 5 N, 6 N purity is required; you cannot compromise with the purity of the material.

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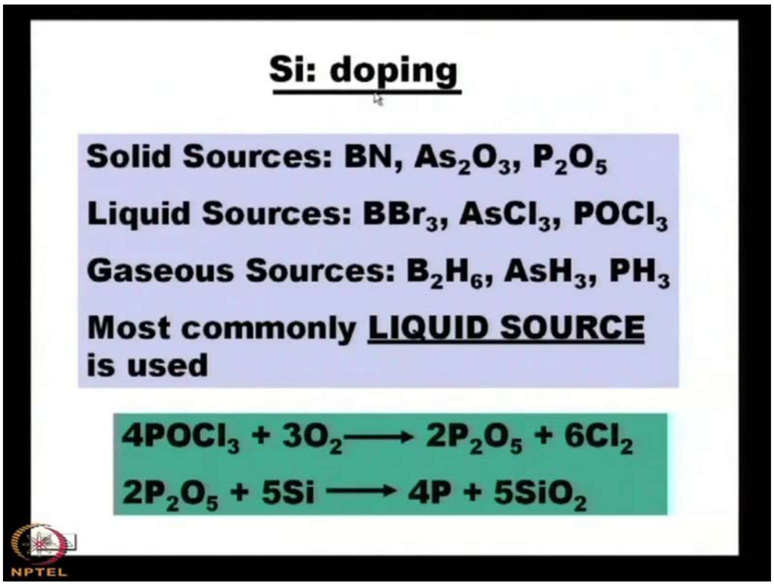

Si: doping

Solid Sources: BN, As_2O_3, P_2O_5

Liquid Sources: BBr_3, $AsCl_3$, $POCl_3$

Gaseous Sources: B_2H_6, AsH_3, PH_3

Most commonly LIQUID SOURCE is used

$4POCl_3 + 3O_2 \longrightarrow 2P_2O_5 + 6Cl_2$

$2P_2O_5 + 5Si \longrightarrow 4P + 5SiO_2$

Then, let us take one concrete example of silicon doping; one concrete example. You see that for silicon doping there are sources; sources means the dopant sources. It can be a solid source, it can be liquid source, it can be gaseous source. All type of sources can be used. And, for solid sources you see that B N, A s 2 O 3, P 2 O 5 those are used generally. That means, see B N is, what is B N? Boron Nitride. So, this B is the Boron which is used for silicon doping.

Then, A s 2 O 3, A s is the impurity. Then, P 2 O 5; P is the impurity; so, these are all available as solid source. And, liquid sources you see that B B R 3, A s C l 3, P O C l 3; so, those are liquid sources, bromide, chloride sources. And, gaseous sources are all hydride sources; arsine, phosphine, B 2 H 6 etcetera. So, what we find? We find that the hydride sources are gaseous and bromide chloride sources are liquid and this nitrogen oxygen sources are solid. But most commonly liquid source is used; you tell me why liquid source is used?

Student: (( ))

Yes, easy to handle; that is the main criteria. Solid, the problem of solid is you have to melt it for vapour pressure; you have to melt it. And, if it is very rigid solid, then the melting point will be high. So, additionally you have to supply power there to melt it and sufficient vapour pressure must be there; so that you can transport the vapour on to the surface of the silicon wafer. But for liquid it is very easy to handle, for gaseous it is also not very easy to handle. Control a gaseous environment ambient is very difficult. And, for liquid sources another advantage is apart from easy to handle; that this liquid at very small temperature, there is sufficient vapour pressure on the liquid surface, inside the bubbler. The inside the bubbler, the liquid is placed and the bubbler is some arrangement where there is heating element. You can control the temperature of the bubbler. So, where the vapour pressure is maximum, you use that temperature to vaporize it and the vapour will be transported through the nitrogen gas in this case.

So, now this reaction will give you the phosphorous doping in silicon. Then, liquid source; so, this is liquid P o c l 3, we used P o c l 3. And, you can remember that we have used oxygen; you remember that we have used oxygen, you see that there this is oxygen. So, now this P o c l 3; 4 P o c l 3 plus 3 O 2 will give you 2 P 2 O 5 plus 6 C l 2. This p 2 O 5 is, you see; what is the nature of P 2 O 5?

So, what will happen? After this reaction there will be a glassy surface on the silicon wafer; that glassy surface is due to P 2 o 5, because that is your solid thing, which reacts with silicon under that high temperature and environment will give you phosphorous and

S i O 2, the silicon dioxide. So, some portion will be silicon oxidized and another thing is that the vent. Through vent, what gas will pass? Chlorine gas will pass. So, these are the reactions which will happen during the diffusion of phosphorous on silicon wafer.

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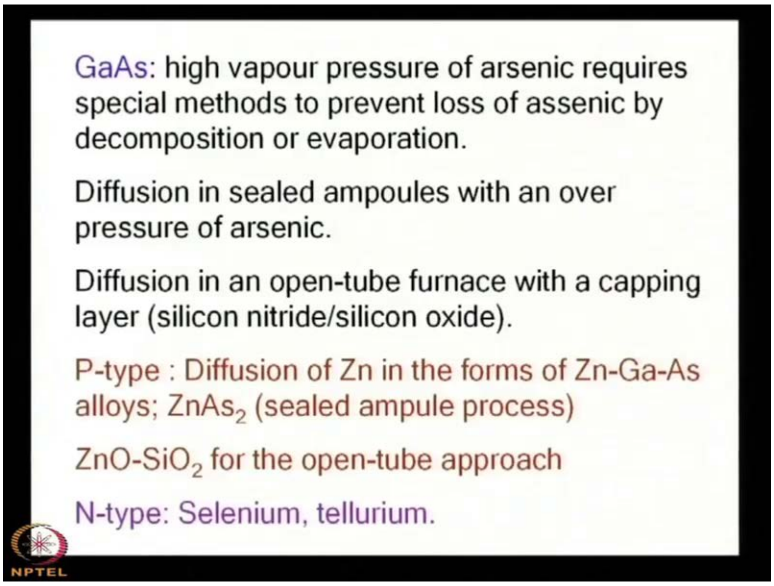

GaAs: high vapour pressure of arsenic requires special methods to prevent loss of assenic by decomposition or evaporation.

Diffusion in sealed ampoules with an over pressure of arsenic.

Diffusion in an open-tube furnace with a capping layer (silicon nitride/silicon oxide).

P-type : Diffusion of Zn in the forms of Zn-Ga-As alloys; $ZnAs_2$ (sealed ampule process)

$ZnO-SiO_2$ for the open-tube approach

N-type: Selenium, tellurium.

Now, if you consider gallium arsenide; if you consider gallium arsenide, one problem with gallium arsenide is that the arsenic has very high vapour pressure. That means, if this is your gallium arsenide say substrate; this is your gallium arsenide substrate at temperature, high temperature 300, 400 degree centigrade arsenic will evaporate from the surface of gallium arsenide wafer. So, if arsenic evaporates; then, what will happen?

Student: (( ))

Yes, stoichiometry; that will be non stoichiometry. That means, there will be deficiency of arsenic on the surface or in the material. The deficiency in technical term is known as the vacancy; there will be arsenic vacancy in gallium arsenide. That we do not want; because any change in the crystal lattice or structure will change the material parameters. So, if the mobility is say 9000 centimetre square per volt second; on evaporation of the arsenic from the surface it will be less than 9000 which we do not want. So, that is the problem with gallium arsenide that high vapour pressure of arsenic requires special methods to prevent loss of arsenic by decomposition or evaporation. So, that means you have to prevent loss of arsenic because without that high temperature diffusion is not possible.

So, for diffusion you need high temperature, but with that high temperature there will be evaporation or loss of arsenic from the material. So, you have to control that thing; so, what is the process? The process is you have to load the material; you have to load the material with some arsenic over pressure. That means, suppose this is a tube, you have load the gallium arsenide substrate. But you give some arsenic as well inside the tube and then seal it; so that if there is some evaporation, so it will be compensated, because it is in the arsenic over pressure.

So, that means diffusion in sealed ampoules with an over pressure of arsenic. So, that means that will not be an open tube furnace; that will not be an open tube furnace, because in open tube you cannot maintain the arsenic over pressure; that you cannot maintain. And if you use a open tube furnace, then what process you should take? You should take a capping layer on the gallium arsenide; you make a layer; so that arsenic evaporation will not be there. So, you kept it, you cover it and the capping layer; it is normal cases, it is silicon nitride or silicon oxide which are insulating in nature. So, these are used as capping layer.

For p type diffusion of zinc in the forms of zinc gallium arsenic alloy and or zinc Z n A s 2; obviously, o n there will be A s 2 it will be an sealed ampule process or in open tube approach you can use zinc oxide S i o 2. For n type selenium, tellurium is used; sulphur is also used. So, for p type generally zinc or zinc is used or silicon is used right. For p type, for n type sulphur, selenium etcetera are used.

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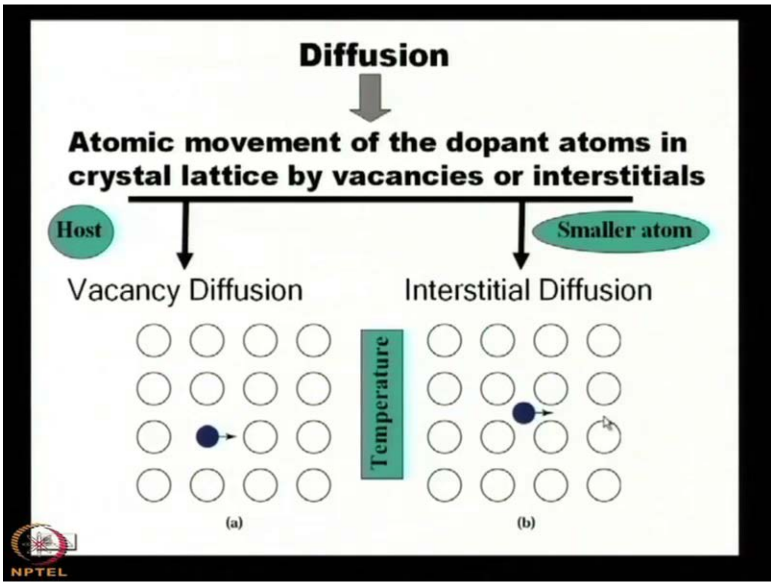

Diffusion

Atomic movement of the dopant atoms in crystal lattice by vacancies or interstitials

Vacancy Diffusion

Interstitial Diffusion

Now, what is the physical diffusion process? How we can look at the diffusion physically? You see that atomic movement of the dopant atoms in crystal lattice generally is governed by the vacancies or interstitials; generally by vacancy or interstitials. You see that there is a vacancy of atom here, say this is silicon lattice and if you heat it, then what will happen? That this silicon atom will be displaced and in its place phosphorous or arsenic or boron atom will be, will be placed or it will occupy; the dopant atoms will occupy that positions.

So, that means you see that it is a host; which one is host? Host is the silicon matrix or the gallium arsenide that is the host. And, there is another position which is known as the interstitial position; that means placed in between the normal atomic positions. You see that this is interstitial position, this is vacancy position. Here the host atom is missing; here the host atom is not missing. But between 4 host atoms, there is a place which is known as the interstitial place and in that interstitial position, that atom can be placed.

So, there must be some dimension criteria. If that interstitial place is sufficiently large to occupy that diffusion that dopant material or not say Boron. Boron is small compared to silicon the atomic radius of boron is less compared to silicon. So, boron can occupy the interstitial position, but for say phosphorous the atomic radius of phosphorous is larger than silicon. So, phosphorous atom cannot occupy the interstitial position rather it will occupy the vacancy position; it will occupy the vacancy position.

Another thing is the temperature criteria, you see one is the dimension criteria whether it is a small atom or a larger atom; smaller or larger than what? Smaller or larger than the host; smaller or larger than the host. Then another criteria is the temperature. Why the temperature is required? You see that this place, how the place is created? How the place is created? Normally, if you heat a material what happens? Its molecules or atoms vibrates in its mean position; vibrates along its mean position through its mean position. Then, on further temperature or further heat, what happens it will gain sufficient energy and will be detest from the atom; from the lattice, right. So, when it will be detest from the lattice, then at its place what will be there; vacancy will be created.

So, unless there is vacancy, there will be no diffusion. But where the atom will go? Either it will occupy the interstitial position or it will be occupy the vacancy position. And, we shall in the next class, we shall consider the energy; how much energy is required for vacancy diffusion or interstitial diffusion?

We shall see that for vacancy diffusion, the temperature will be more; why because first you will have to create the vacancy. Here for interstitial diffusion, you need not to create the place; the place is already there in the lattice side, but for vacancy, you have to create the place first. So, creating a vacancy and then diffusion; so 2 energy criteria is there. That means, the energy will dissipate first by creating the vacancy and next by diffusion; next for the diffusion. So, that is why the temperature required for vacancy diffusion is larger than the temperature required for the interstitial diffusion.

Thank you.