Processing of Semiconducting Materials

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Lecture - 6
Importance of Doping

Good morning, let us start the importance of doping, and you know that in the last discussion, I have shown you that the doping basically increases the conductivity of a material.

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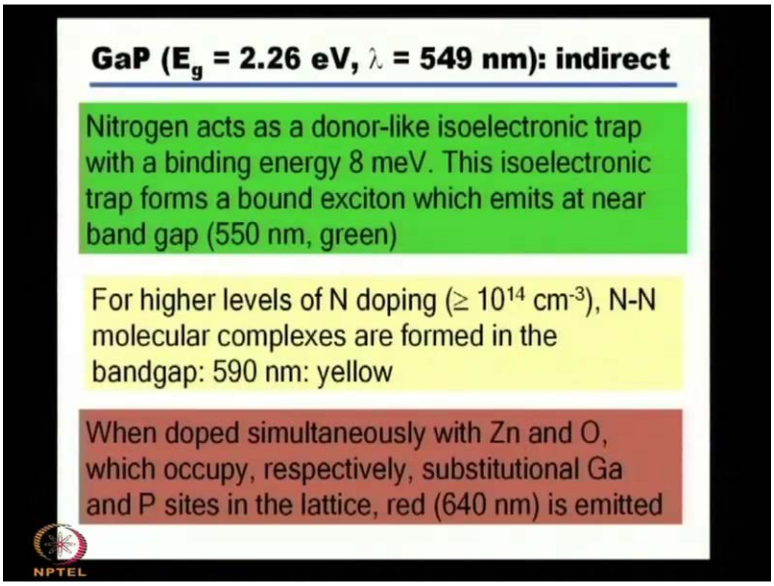

GaP (E_g = 2.26 eV, λ = 549 nm): indirect

Nitrogen acts as a donor-like isoelectronic trap with a binding energy 8 meV. This isoelectronic trap forms a bound exciton which emits at near band gap (550 nm, green)

For higher levels of N doping ($\geq 10^{14}$ cm^{-3}), N-N molecular complexes are formed in the bandgap: 590 nm: yellow

When doped simultaneously with Zn and O, which occupy, respectively, substitutional Ga and P sites in the lattice, red (640 nm) is emitted

And, we have given you an example that if we add a minute quantity of doping or dopant atom in material, then the conductivity increases by several times; and to get a minimum voltage of say 50 milli volt, we have seen that only required if you get a current of 1 micro amp from the sample. Whereas, if it is an intrinsic sample, then how much voltage was required? Some more than 1000 volt is required. Now another important aspect of the doping is that if you see this presentation, you will find that gallium phosphide – GaP, it is an indirect band gap semiconductor, see it is an indirect band gap semiconductor, whose band gap is 2.26 electron volt.

So, if you compare with silicon, this 2.26 electron volt is obviously higher, and it is a wide band gap material gallium phosphide. And if you use the relation E equals to h nu and nu equals to C by lambda, you will find that lambda will be 549 nanometer. That means the emission from gallium phosphide will be in the wave length of 549 nanometer.

But problem is that, it is an indirect band gap semiconductor. So, if it is an indirect band gap semiconductor, so you know that material is not used for sources, for the fabrication of optical sources, because of the indirect nature of its band gap. So, what to do? Because gallium phosphide can be easily made, it is comparatively cheaper not cheaper than silicon but compared to other materials it is cheaper.

So, then how to use gallium phosphide for optical source fabrication? And, you will be glad to know that almost all light emitting diodes, you have seen the light emitting diodes in various applications, and almost all light emitting diodes are fabricated out of gallium phosphide. So, if it is an indeed band gap semiconductor then how it was how it could possible to fabricate a light emitting diode using gallium phosphide it is because of the doping in gallium phosphide. Not only that it increases the conductivity of a material, at the same time its give some valuable property to the material coienet enters into the host matrix of the semiconducting material.

You see that, nitrogen acts as a donor like isoelectronic trap with a binding energy 8 milli electron volt. Now, there are some new volt 1 is isoelectronic you know what is trap? We have discussed trap; trap basically a defect level mainly which can trap electrons in the material. And what is isoelectronic? Isoelectronic means phosphorous and nitrogen belongs to the same group of the periodic table that is why, their electronic structure is same and it is known as the isoelectronic. So, nitrogen when moves inside gallium phosphide its act like a donor like trap with a binding energy 8 milli electron volt.

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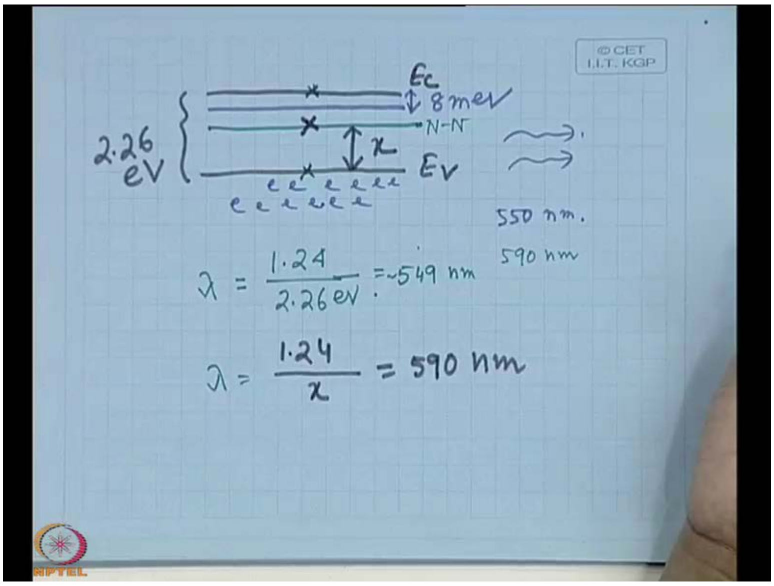

Now, this meaning of this 8 milli electron volt you see that, this is the conduction band and this is the valence band for gallium phosphide it is 2.26 electron volt, it is 2.26 electron volt. And, if you dope gallium phosphide with nitrogen then nitrogen will act as an isoelectronic trap with a binding energy of 8 milli electron volt. That means, this level it is 8 milli electron volt; very near to the bottom of the conduction band 8 milli electron volt to can imagine that if you compare that this gap is 2.26 electron volt, then 8 milli electron volt is very near to the bottom of the conduction band and since it is the donor level, so it will be nearer to the conduction bandage.

If it was an acceptor level then, it could lie just above the valence bandage or near to the valence bandage. So, if you put nitrogen in gallium phosphide then it will give an isoelectronic trap of 8 milli electronic volt and this isoelectronic trap forms a bound electron a bound exciton. What is an exciton?

It is a pair of electron and hole before recombination. Normally, electrons and holes recombine but, in there are some cases some electronic environment, some temperature and purity in a material depending on which electrons and holes do not recombine immediately rather they form a pair of electron and holes which is known as the exciton. And that exciton is takes the nitrogen that exciton takes the nitrogen and they formed a bound exciton. When an exciton is bound to some impurity here the impurity is nitrogen, which is just 8 milli electron volt below the conduction bandage. So, that nitrogen when bound with the exciton a bound exciton is formed and when that bound exciton recombines finally, it will recombine so, the emission will be there that means you will get the electromagnetic wave in the form of light and what should be the value of the emission wave length.

You see that the band gap is 2.26 minus 8 milli electron volt divided by 1.24 and it will be 550 nano meter. This 550 nanometer is the wave length of green emission so, we can conclude that if gallium phosphide is doped with nitrogen in a controlled manner the emission from gallium phosphide will be in the green region. And almost all green LED's which we find in these days are made in this manner that doping nitrogen in gallium phosphide. You cannot use the simple gallium phosphide without doping because of indirect nature but, here the trap you introduce why this trap is required? It is for the conservation of momentum, we have discussed a little bit earlier.

Now, let us take a second example, you see in the presentation for higher levels of nitrogen doping; higher levels means when the concentration of nitrogen is high increased, when the concentration of nitrogen is increased then nitrogen molecular complexes are formed in the band gap. When the nitrogen concentration is greater than or equals to 10 to the power 14, when it is greater than or equals to 10 to the power 14 nitrogen nitrogen complex will be formed and they will give rise to an energy level in the band gap of gallium phosphide. That means, suppose this is your band diagram then nitrogen nitrogen complex where it will be say, here it will be these lines say this green line green line is due to nitrogen nitrogen complex right this green line will be there.

And, the emission wave length will be 590 nanometer, this 590 nanometer corresponds to yellow; whether it will be green or yellow or red it will be depend on the level. The level inside the band gap if it is band to band transition then it will be governed by the value of the band gap. Here, the value of the band gap is 2.26, so without any doping etcetera the band to band transition that means transition from the valence band to the conduction band or from the conduction band to again the valence band.

The energy required is 2.26 electron volt and if you divide 1.24 by 2.26 electron volt you will get green emission right. But, for yellow you find that 590 nanometer so, you make a back calculation, you make a back calculation 1.24 by 0.59 then what should be the energy; then obviously the energy will be less than 2.26. Because it is within the band gap so, it will be less than 2.26 I repeat, if the transition was from say this point to the conduction bandage between these two points the value of lambda will be 1.24 by this gap and this gap is say 2.26 electron volt, this value will be some 550 or 548, 49 around 549 nanometer.

Now, if this is reduced to here this nitrogen hydrogen complex gives rise to a band here so, obviously it will be 1.24 by this gap so this gap is say x so, it is x that will be 590 nanometer because it will give rise to the yellow band. So, from where you can calculate the value of x so, if you dope something inside the material it will depend on the thermodynamic and chemical conditions of the material, where it will stay inside the band gap and the transition will be band to band or from band to impurity band etcetera and that will give rise to some radiation.

The mechanism we have discussed again I repeat that in ideal situation the electrons will be in the valence band. When you supply some energy these electrons will move to the conduction bandage or some impurity band if there are some impurities; if there are some impurities some impurity band will be there if there are some impurity band it will go to the impurity band. So, that means here these electrons will move to this green line say for nitrogen nitrogen complex it will move to this green line not to the conduction band not required also.

Then again, what will happen they are excited electrons in that level they are excited and what will they do they will fast come to the very fast they will try to come to the ground state. So, they will come back to the valence band where they will recombine with the holes created due to the movement of electron from the valence band to the conduction band or to the impurity level when an electron moves from this point to say here 1 hole is created.

So, when this electron again jumps back to the valence band it will recombine with the holes and there by the energy will be released in the form of electromagnetic wave or electromagnetic radiation and depending on the value you will get different colors of light. Next example, you see that when doped simultaneously with zinc and oxygen simultaneously means (( )) yes, it at 1 go zinc and oxygen are doped inside gallium phosphate.

In the first case, we have doped the gallium phosphate with nitrogen whose value was less than 10 to the power of 14 per cc. Then in the second case, for yellow emission we introduced nitrogen nitrogen comply the more and more nitrogen 10 to the power 14 greater than 10 to the power 14 per centimeter cube. Here not nitrogen but, we used zinc and oxygen; if you simultaneously use zinc and oxygen to dope gallium phosphide, then you will get red emission the value is 640 nanometer.

You see that from 549 to 550 and then from 550 to 590 and from 590 to 640 basically the energy decreases why because, the wave length increases. So, if the if the wave length increases energy must decrease energy of the levels inside the band. Now what the zinc and oxygen will do, they will occupy the substitutional gallium and phosphorus sites in the lattice. What is substitutional?

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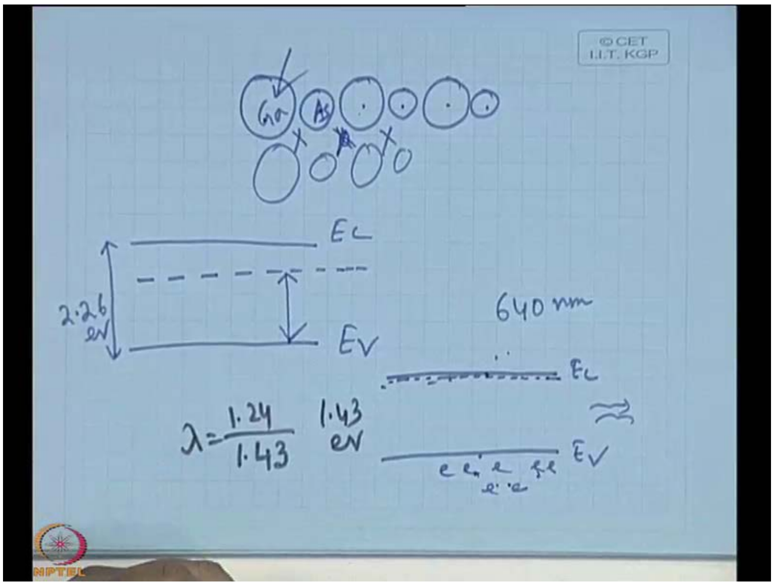

Suppose, there is a crystal structure like this, this is say gallium, arsenic, gallium, arsenic, gallium, arsenic then gallium, arsenic, gallium, arsenic and so on and so forth. If this be the case a crystal lattice in two dimension then say this is gallium this is arsenic so, zinc will substitute gallium that means there must be a vacancy at the gallium site and the zinc will occupy that vacancy site inside the crystal lattice.

Remember that, there are 2 positions only in the crystal lattice, where the impurity atom can reside can occupy 1 is the substitutional site another is the interstial site interstial means between these atoms yes between these atoms these places between these atoms these places. So, either they can be substituted or they can be they can move to interstitial position I can show you there is a view graph and so that the discussion will be simpler; here you see that in this case the diffusion can be of two types diffusion means the diffusion of the impurity. Impurity can be diffused inside the material, the doping can be done by either diffusion or by ion implantation we shall discuss those things in detail.

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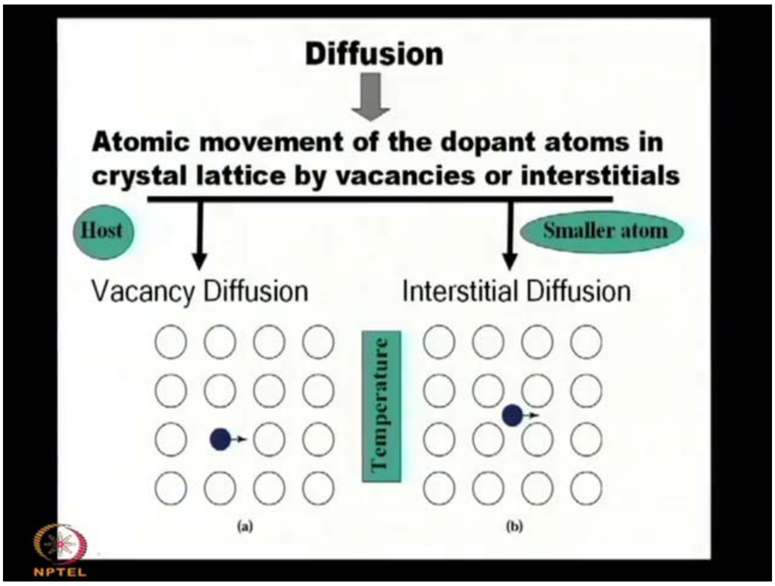

Diffusion

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

Vacancy Diffusion

Interstitial Diffusion

But, for diffusion if you can dope a material by the technique of diffusion then what they will do either they will occupy the vacancy position or they will occupy the interstitial position. You see here the 1 atom is missing say silicon is missing or gallium is missing or arsenic is missing. So, if there is a missing atom the impurity atom can occupy that position or it can occupy the interstitial position.

But one thing is that, for interstitial position the molecular dimension of the impurity must be small so, that it can occupy the interstitial position. Because vacancy site is larger interstitial site is smaller so, suppose there is a silicon atomic crystal and if you find that there is an interstitial impurity that means that impurity must have dimension less than silicon if it is comparable to silicon then it cannot occupy the interstitial position, it must occupy the vacancy position.

So, for doping either it must go to the interstitial or it must go to the vacancy site. Now, let us come to our own discussion original discussion here that so the zinc will substitute gallium and oxygen will substitute phosphorous. If this is the case then we shall get red emission that means if I draw the diagram say this is conduction bandage, this is valence bandage here it is 2.26 electron volt and say this level corresponds to that zinc oxygen doping. So, that the emission wave length in this region will be red or 640 nanometer. So, that means we find that the emission from a semiconductor is perfectly depending on the doping. So, not only that the doping gives rise to the enhanced electrical conductivity of a material at the same time it leads to very good light emitting diode.

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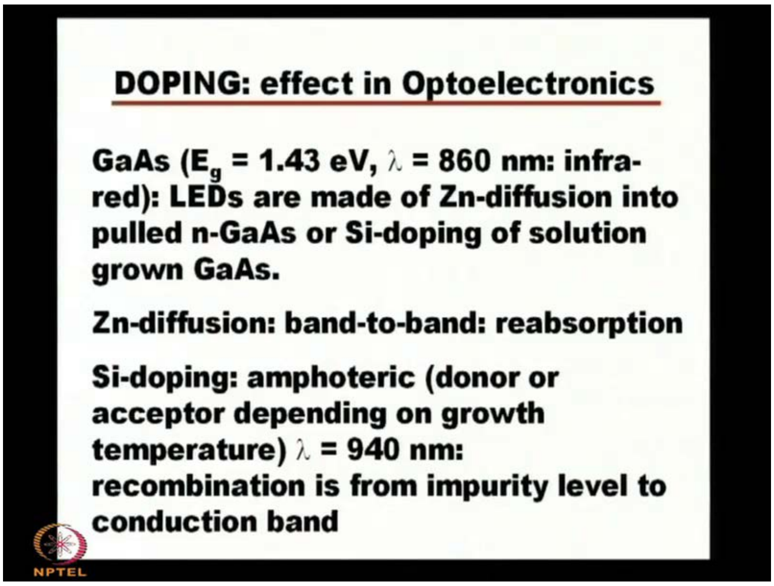

DOPING: effect in Optoelectronics

GaAs (E_g = 1.43 eV, λ = 860 nm: infra-red): LEDs are made of Zn-diffusion into pulled n-GaAs or Si-doping of solution grown GaAs.

Zn-diffusion: band-to-band: reabsorption

Si-doping: amphoteric (donor or acceptor depending on growth temperature) λ = 940 nm: recombination is from impurity level to conduction band

Let us take another example, say gallium arsenide here you see that there I we are talking about gallium arsenide here you see that the band gap is 1.43 electron volt and if you use that formula this formula if you use 1.24 by E g you will find that lambda will be 860 nanometer. It is basically comes from E equals to H nu, nu equals to c by lambda c is the velocity of light and h is the Planck’s constant from where you can get 1.24 by E g and the infrared radiation will come from the gallium arsenide.

Now, LED’S are made of zinc diffusion into pulled N gallium arsenide or silicon doping of solution grown gallium arsenide there are 2 new terms for you 1 is pulled another is solution grown. Basically, we are talking about the crystal growth when we discuss about the crystal growth we will find that the bulk crystal is formed by different techniques 1 is known as the pulled technique.

You take gallium arsenide material very high purity in a crucible you heat it so, it will melt then from the melt you put 1 seat crystal and then you very slowly pull it so, if you very slowly pull it the crystallization will be made and you will get a bulk crystal so, that is pulling. So pulled N gallium arsenide means during pulling when you melt gallium arsenide in a crucible you add some amount of zinc you add some amount of zinc or you add some amount of silicon if you grow gallium arsenide from a solution. Various kinds of crystal growth techniques it can be from solution, it can be from pull there are epitaxial techniques also liquid phase epitaxy molecular epitaxy etcetera we shall discuss in this class all those things in detail.

So, if you put zinc then what will happen, zinc diffuse inside the gallium arsenide crystal lattice and you will find that you will get infrared radiation in the in 860 nanometer. But problem of zinc diffusion is that zinc gives you band to band transition, that means zinc will be staying very near to the bottom of the conduction band it is almost you can say that it is the conduction bandage. The zinc will stay that means the give zinc will give rise to an electronic level which is very, very near to the bottom of the conduction band. So, if zinc gives rise to the band here say this is gallium arsenide it is E c it is E v and it is 1.43 here, it is 1.43 electron volt, so zinc will be very near to the bottom of the conduction band very near to the bottom of the conduction band. So, the emission will be from almost band to band, band to band means from conduction band to valence band band to band transition and this band to band transition will give rise to an emission of lambda equals to 1.24 by 1.43.

If you calculate, you will get around 860 nanometer which is infrared. But problem of zinc diffusion is that, since it is very near to the bottom of the conduction band there will be reabsorption you can say sir what is reabsorption? Reabsorption means when there will be transition from the conduction band to the valence band emission will be there but, that emission will be absorbed by the material itself, so that the electrons in the valence band will again be excited to the conduction band.

That is the problem of band to band transition in all cases, almost all the cases could you get my point. Suppose, here the emission wavelength is 860 nanometer, so that 860 nanometer light what will happen it will again we use to excite the electrons in the valence band to the conduction band. What amount of energy is required for excitation of the electrons from the valence band to the conduction band in this case band gap 860 nanometer.

So, that 860 nanometer light which is coming out from the material from the transition that light will again be absorbed in the material itself. If it was less than this so, it will not be absorbed it will not be absorbed, because minimum amount is required from is the band gap, it will be either greater than or equals to the band gap for absorption. But in this case since it is equals to band gap so, the electrons will absorb that light and that electrons will move from valence band to the conduction band.

So, a reabsorption will be there but, reabsorption means from the material the output will be very very low; if 50 percent 60 percent is reabsorbed then what should be the output 40 percent 30 percent will be the output. So, that means zinc in gallium arsenide is not a very good choice so, silicon is doped in gallium arsenide and if silicon is doped the nature of silicon in gallium arsenide is amphoteric in nature. You see, it is amphoteric in nature it is amphoteric, what is amphoteric? That means silicon inside gallium arsenide can be a donor or an acceptor; arsenic in silicon donor acceptor arsenic in silicon donor boron in silicon acceptor nitrogen in gallium phosphide donor.

But, silicon in gallium arsenide it is it can be donor, it can be acceptor depending on the growth temperature. At which temperature the gallium arsenide is being made, the gallium arsenide is being synthesized depending on that temperature it can replace gallium or it can replace remember that gallium group 3 in the periodic, table gallium group 3 in the periodic table, silicon group 4 in the periodic table so, if silicon replaces gallium what will happen? If silicon replaces gallium what will happen, extra electron will be there like arsenic in silicon you will get free electron. So, in that case if silicon replaces gallium it will act as donor if silicon replaces arsenic silicon 4 arsenic 5 acceptor.

Because arsenic has 5 electrons silicon has 4 electrons so, in that case it will act as an acceptor. So, depending on the position it is occupying, is it replacing gallium or it is replacing arsenic it will act as donor or acceptor. That is why it is known as amphoteric in nature, the meaning of the amphoteric is that it can be donor it can be acceptor. Not only silicon any material if acts in that manner that it can act as donor it can act as acceptor depending on the temperature or other thermodynamic consideration then it is known as the amphoteric impurity. Now, if silicon if you put silicon here then the emission wave length will be 940 nanometer, 940 nano meter and this 940 nanometer obviously not band to band because band to band was 860 nanometer. So, it will be inside the band gap there will be level due to silicon and it will give rise to 940 nanometer emission that means it was say silicon this line zinc silicon can be here.

So, that the transition will be in the 940 nanometer and if it is in the 940 nanometer then it is also infrared, 860 is also infrared 940 is also infrared. But here, there will be no absorption why, because it is less than band gap it is less than the band gap of the material.

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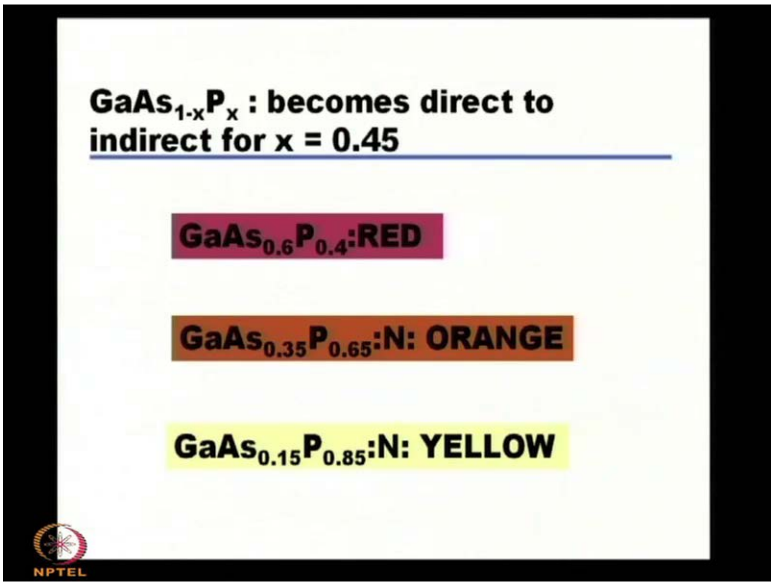

$GaAs_{1-x}P_x$: becomes direct to indirect for x = 0.45

$GaAs_{0.6}P_{0.4}$:RED

$GaAs_{0.35}P_{0.65}$:N: ORANGE

$GaAs_{0.15}P_{0.85}$:N: YELLOW

Then, there is third example of the importance of doping is, gallium arsenide phosphide it is gallium arsenide phosphide. You see that, gallium arsenide phosphide is a ternary material; why it is ternary because gallium arsenic and phosphorous are involved. Because gallium arsenide phosphide is made of 3 elements from the periodic table 1 is gallium another is arsenic and third one is phosphorous. So, since 3 elements are involved that is why it is known as ternary, gallium arsenide it is binary, indium phosphide binary, gallium nitrite binary, silicon carbide binary these are all binary compound silicon, germanium these are all elemental semiconductor. This is known as the elemental semiconductor silicon germanium then binary ternary is gallium arsenide phosphide.

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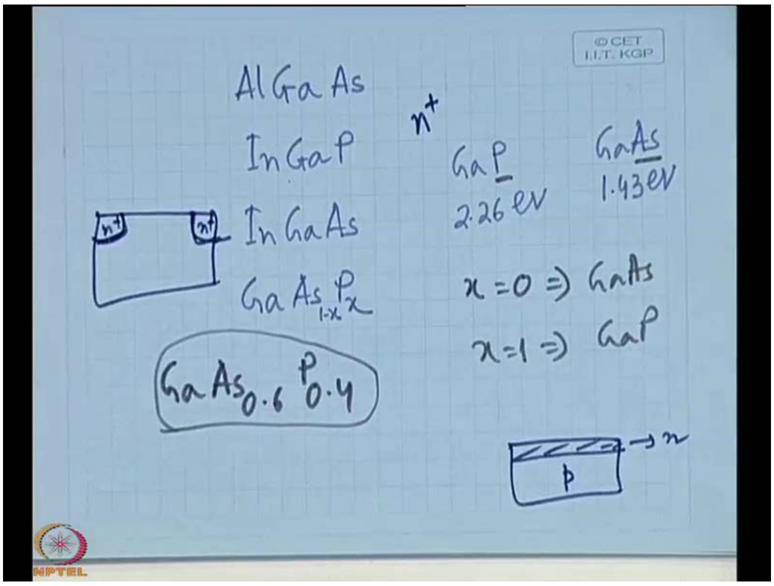

There are other ternary material as well like say aluminum gallium arsenide algaas this is known as algaas, aluminum gallium arsenide this is ternary. Then, indium gallium phosphide this is ternary, indium gallium arsenide it is ternary, these are all ternary say it is also ternary, gallium arsenide phosphide is also ternary gallium arsenide phosphate. So, what is this? This p suffix x and A x A s suffix 1 minus x. What is this, see this is this 1 this gallium arsenide phosphide you see that 1 minus x suffix is there with arsenic and x is there with phosphorous what is that?

Basically, there are 2 material 1 is gallium phosphide another is gallium arsenide, 1 is gallium phosphide whose band gap is 2.26 electron volt another is gallium arsenide whose band gap is 1.43 electron volt. So, that means just by changing the composition of arsenic and phosphorous, you can change the band gap from 1.43 to 2.26. When x equals to 0 what is the material gallium arsenide, when x is one what is the material gallium phosphide.

So, that means just by varying A x you can change from gallium phosphide to gallium arsenic or vice versa that is known as band gap engineering. We can change the band gap of the material by changing the composition; how those things happen we shall discuss in some later stage in details. But let us take that example of gallium arsenide phosphide the changing the concentration of phosphorous or arsenic you can change the band gap of the material.

So, if you change the band gap of the material then emission wave length from it will be different, because emission exclusively is a property of the band gap the at least the color depends on the band gap. So, gallium arsenide phosphide it becomes direct to indirect for x equals to 0.45 that means, if you take 45 percent phosphorous then what should be the value of arsenic 55 percent. So, if you change gallium arsenide if you change x above 0.45, then this material becomes indirect band gap semiconductor this material becomes indirect band gap semiconductor.

Remember, value of x you can change when x equals to 1, it will be gallium phosphide when x equals to 0, it will be gallium arsenide so, value of x you can change x can be 1, 2, 1.5 x can be 1, 0.9, 0.8, 0.4, 0.2, 0.27, 0.43 any any volume it can assume it value it can assume. So, if x is 0.45 then it becomes indirect that means 0.45 0.46 0.47 up to 1 it will be indirect you see that when x equals to one basically it is gallium phosphide. Gallium phosphide is indirect band gap semiconductor and when x equals to 0 it is gallium arsenide it is it is direct band gap semiconductor, so there is a changeover from indirect to direct or direct to indirect by changing the value of x. Now, if you take x equals to 0.4 in this example, x equals to 0.4 if you take x equals to 0.4 whether it is direct or indirect. Direct because 0.45 and above it is indirect so, 0.4 is direct so, this is a direct band gap semiconductor and it will give red emission.

That means band gap with this composition band gap with this compositions that means arsenic 0.6 and phosphorous 0.4 with this composition it is a direct band gap semiconductor and the value of the emission wave length is in the red color. The color is will be red that mean is the value is correspond the value corresponds to the red emission, the band gap value corresponds to red emission. Now, if you take x equals to 0.65 x equals to 0.65 it is indirect, for indirect you need some doping here which doping we have used nitrogen; same thing you have seen that for gallium phosphate we have used what, nitrogen. So, here the nitrogen we have used and the emission wave length will be orange just by changing the composition and adding some nitrogen it gives rise to orange.

Another example is, when x equals to 0.85, means it is going nearer to gallium phosphide what is the meaning of 0.85? Phosphorous is 85 percent that means it is going towards gallium phosphide. So, arsenic is only 15 percent, here also you see that nitrogen is used and the emission wave length is yellow. So, we can conclude that in ternary compound also, where there is a change over from direct to indirect band gap or from indirect to direct band gap there also we can use controlled amount of doping to obtain the light emission from it. So, one thing is the increase in conductivity another thing is the light emission property. So, those can be achieved by the doping of material inside the semiconductor and we shall find during our crystal growth discussion that this nitrogen or we are talking about arsenic in silicon or zinc in gallium arsenide or silicon in gallium arsenide the quantity is very small.

I shall show you that if you take say 40 k g 50 kg of silicon only a few milligram is required for doping that means, if you take a charge of say 60 kg of silicon you want to grow a crystal of 60 kg whose weight will be 60 kg. If that be the case then to dope it with N type or p type either you will use boron or a you will use arsenic but, the quantity of boron or arsenic will be around 5 milligram, 3 milligram. For 40 kg I could remember that the boron will be 3.5 milligram, for a particular carrier concentration say 10 to the power 15 10 to the power 14 type of thing very minute amount of thing.

So, doping is an unique property in semiconducting material it is pentavalent then oxygen is also there there are more electrons but, two things you must keep into mind, one thing is the processing technology whether the processing technology is available. Second thing is that, if you use arsenic or phosphorous you can I shall show you that generally liquid dopant is used, generally liquid dopant is used with very high purity so that kind of purity and state of the material you must have.

There are several materials but, whether the processing technology is mature enough to use nitrogen in silicon that we have to see. Generally, the silicon technology is matured with these materials boron, aluminum, gallium, arsenic, phosphorous, antimony. People have tried with oxygen or nitrogen but, they could not succeed because you know that that is a chemical nature it is not a physical type of thing and there is thermodynamics.

So, within the material there must be some state of affairs where it can accommodate oxygen or nitrogen very cordially otherwise we will not get the effect it is like implantation in the body. Suppose, your kidney will be implanted not that you can take kidney from all the sources ideally you can so, there are some considerations using which we use this arsenic, antimony or boron, aluminum, gallium etcetera.

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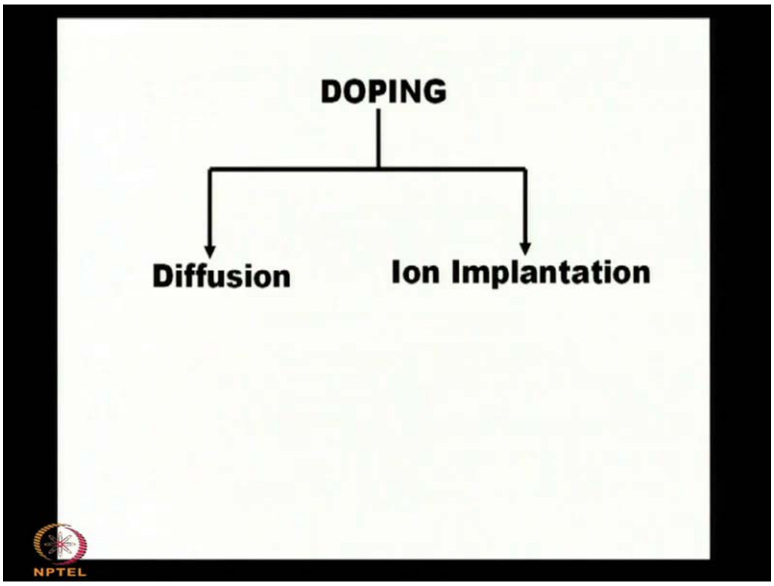

DOPING

Diffusion

Ion Implantation

So, now one thing we can start from today is the doping mechanism. Till now, we have discussed the importance of doping and with related to doping we can say that doping can be done during crystal growth time, during crystal growth. So, a few amount of the material impurity you can add with silicon or gallium arsenide etcetera that I we shall show you. But at the same time, you can use two techniques one is diffusion another is ion implantation one is diffusion another is ion implantation for doping a material.

Suppose, you want to make a p n junction, so you have p type material, you have p type material or you have n type material then how you will form the junction; you can form the junction by impurity and that is done by either diffusion or ion implantation. Suppose there is a more structure metal oxide semiconductor and in those cases you know there is a source there is a drain so, how the source drain etcetera are made. Say, if the material is p type then the source and drain will be what type n type.

So, you have to deposit 2 n at 2 corners suppose this is the structure so, here you have to make 2 n type of material deposited n plus, plus means heavily doped. When we use this plus as a suffix say this is n plus that means it is heavily doped not lightly doped so, to in 2 areas you have to make use of impurity diffusion or say the you have a material of p you want to form.

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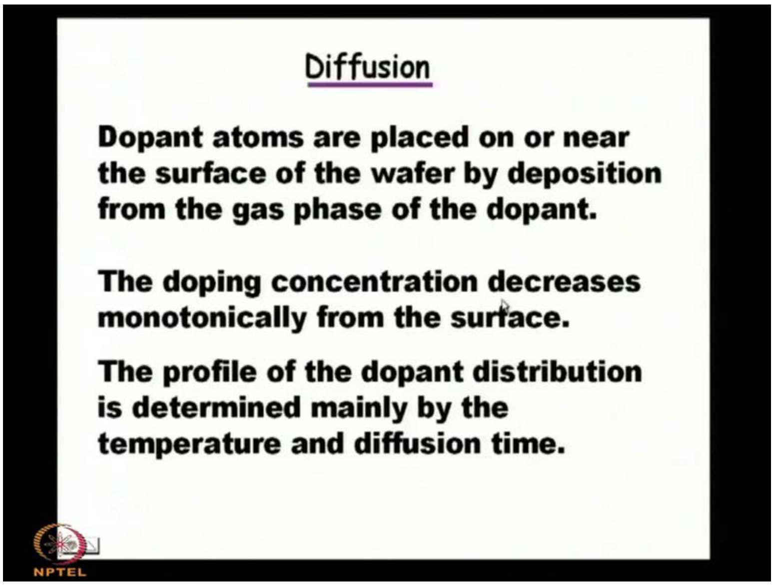

Diffusion

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.

A junction n this is n to make a p n junction so how you will do? You will do using either diffusion or by ion implantation. Now, for diffusion dopant atoms are placed on or near the surface of wafer by deposition from the gas phase of the dopant. It is placed on or near the surface of the wafer what is wafer? (( )) No it is not a layer.

Actually, wafer is used as substrate but what is a wafer? Wafer you have heard during the advertisement of potato chips wafer thin you have heard that term wafer thin. Wafer thin means very thin wafer is a very thin layer but, the material itself can stand so, that something can be grown over it. It is a very, very thin single crystal layer of a material. Say this is a wafer it is very, very thin and it has some mechanical strength so, that on which you can grow some semiconducting structure over it. So, when you grow a bulk crystal generally a bulk crystal is grown, where it has say dimension of the type say 4 inch diameter or 6 inch diameter a cylindrical type of structure say this is some inches with a diameter. Then if you cut into a number of pieces very thin, how thin it is? 400 micron, 500 micron, 300 micron.

So, 1 piece of wafer means it is around say 400 micron thickness and the diameter it can be 2 inch, 3 inch, 4 inch, 6 inch or even higher. Basically it will be like it will look like a disc cd, it will look like a cd. But, thickness of cd is very, very high compared to 300 micron so, the thickness will be even lesser so, generally 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. What is doping profile? Doping profile means when some impurity is doped on the material, how it will move inside the material, what is the trajectory of its motion inside the material that is doping profile.

So, first you take the wafer, put some impurity on the surface, raise the temperature it will diffuse inside the material, it will diffuse inside the material provided you raise the temperature of the wafer. Wafer means the material which you would like to dope, I shall in my next class I shall show you the wafer. So, you take a wafer put it in a furnace because from where the temperature will come, temperature will come from the furnace.

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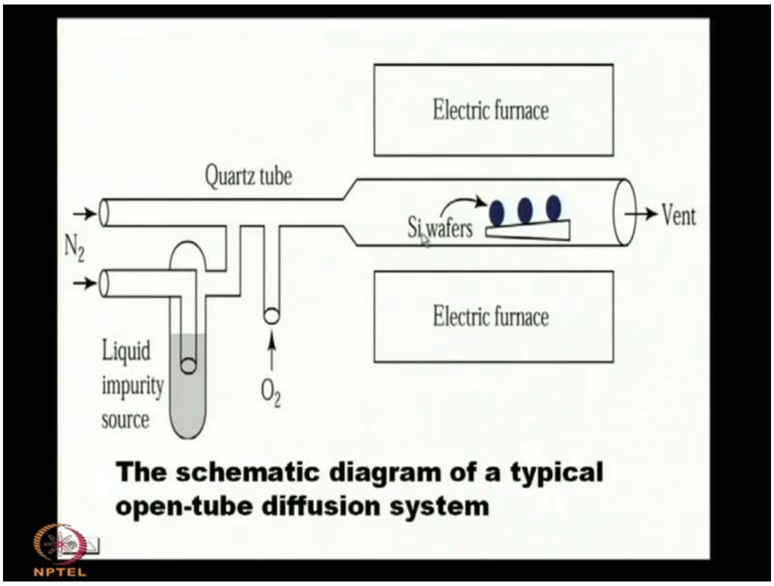

The schematic diagram of a typical open-tube diffusion system

This is you see, the diagram of the diffusion process this is known as the open tube diffusion process. Open tube means it is open both the sides are open and you see that the wafers are placed here and this is electric furnace that means the temperature of this furnace of this quartz tube, this is the basically made of quartz the whole thing is made of quartz. Why quartz is used I we shall discuss all those things so the silicon wafers are put inside the furnace and here there is a liquid impurity source liquid impurity source say boron so, boron has some chemical compound in the form of liquid. It can act as it can it is available as solid, it is available as gases, it is available as liquid.

So, all three states it is available and when this nitrogen, the nitrogen is the carrier gas it carries the impurity wafer to the wafer site. So, say this is a liquid containing boron then nitrogen wafer will pass through this source, it will carry the wafer to this position where there is the temperature either temperature can be from 600 to 1000 degree centigrade very high temperature is required, very high temperature is required. So, if there is the temperature here so, it will diffuse inside the material and the vent means the other gases because there will be some chemical reactions obviously so, for that chemical reaction I shall show you that say chlorine will be emitted. So, where the chlorine will go it will pass out from the vent it will pass out from the vent.

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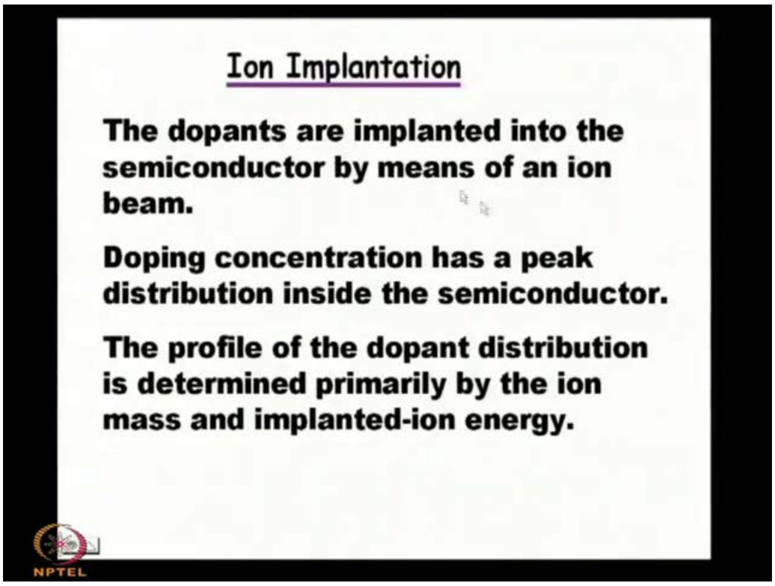

Ion Implantation

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.

Another is thing is the ion implantation. Ion implantation is the dopants are implanted into the semiconductor by means of an ion beam and 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. One thing is that suppose you want to dope arsenic in silicon so you need a arsenic ion beam first arsenic will be converted into an ion beam that can be done using a cyclotron, that can be done you have to using a cyclotron. And very nearby we have 2 cyclotron 1 is in variable energy cyclotron center in Calcutta VECC another in Indian institute of physics in institute of physics Bhuvaneshwar IOP Bhuavaneshwar. They have a one cyclotron that is meant for material science research but it is meant for nuclear science research in VECC.

So, the ion mass and implanted ion energy it will the profile will depend on these two things.

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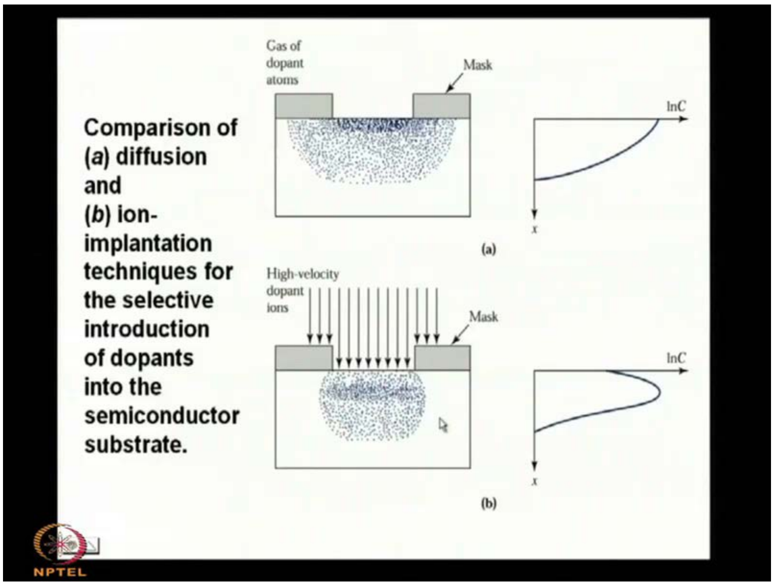

Comparison of (*a*) diffusion and (*b*) ion-implantation techniques for the selective introduction of dopants into the semiconductor substrate.

This is very important curve and you see that in the first case we have diffusion, in the second case, the ion implantation. In the first case, it is diffusion, it is ion implantation. What is this? These two are the mask; mask is like forming a window. That means we do not want to dope in the mask areas, just below the mask, we want to dope we do not want to we do not want to dope below the mask, we want to dope in the open region, where there is no masking. Here you see that due to diffusion the there is a diversion of the profile, the profile has reached below the mask region also you see you could not control during the mask region and this is basically, the lateral diffusion so during diffusion there will be a lateral diffusion as well.

But in case of ion implantation you see that it is almost confined to the window region; below the mask it has not expanded like the diffusion case. Just if you compare these two pictures it is confined to this region, but here there is an extended region. So the profile of the concentration in this axis it is lnC, C is the concentration of the dopant and it is x is the distance from the surface, it is surface, it is x equals to 0 means, it is the surface; you see that the concentration is maximum near the surface, the concentration is maximum near the surface. And as it goes inside the material, it decreases, monotonically it decreases.

Similarly, in this case to see that there is the peak distribution at some x equals to something value. You see that in this case that it is dark just below the surface so the concentration is very high. Here the dark is at almost at the middle mid region. So, in my next classes, we shall go into details of this diffusion process the implantation process how it is done what is the energy consideration? And what is the advantage of ion implantation over the diffusion technique etcetera, we shall consider. And this is remember that this type of diffusion or ion implantation is made to form a mos structure cmos structure or a p-n junction.