High Speed Devices and Circuits

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Lecture - 31

Hetero Junctions and High Electron Mobility Translator (HEMT)

Last time we introduced the concept of hetero structure and hetero junction and today we will continue on that. I wanted to point out a few things related to hetero junction.

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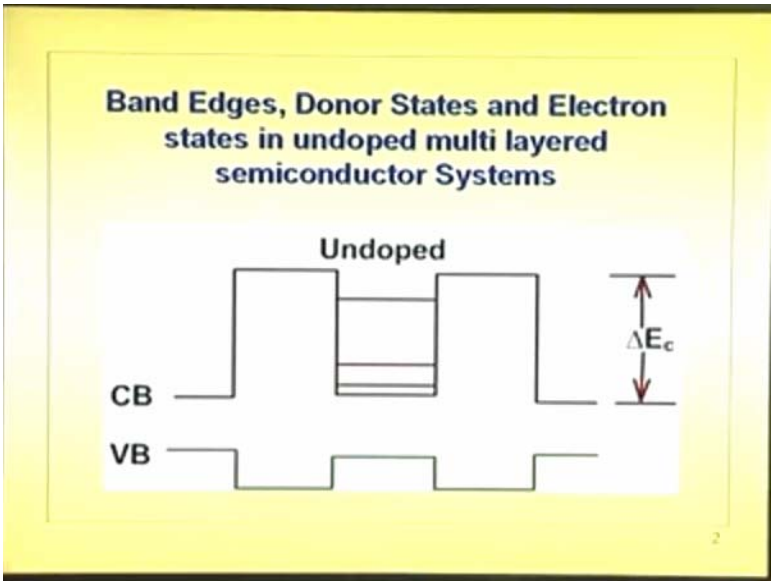

Here is a diagram which has a wide band gap material. This is the conduction band and this is the Valence band bottom. What we did is, showing a diagram, a hetero structure where both are undoped. Gallium Aluminum Arsenide probably, undoped.

Conduction band is there and valence band is there and how much is the band gap depends up on the elemeno content. It can vary from low value to high value. This one is the Gallium Arsenide or the narrower band gap material. Here we are not specific what is the material; so, this the conduction band and this is the valence band. You have actually got undoped layers.

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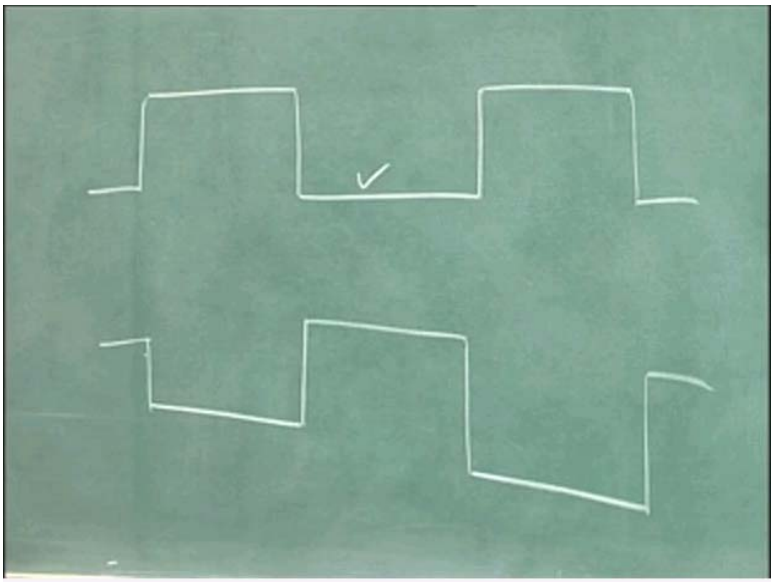

What you have got is layers going like this, joined with the conduction band and valence band, wide band gap, narrow band gap here. You can go on and you can build multilayer structures with hetero junctions. You can see here, I have shown there two wide band gap materials and of course here also, 1, 2, 3, 4 and you can go on until further. What you have got is a potential well where you can confine the electrons. And the entire energy band diagram takes a new term that I will discuss in my next lecture and will just point out today.

Usually when you draw a conduction band, what is the meaning? Energy levels are continuous. Now when you have a quantum well like this, a potential well and if this well is narrower than this well (Refer Slide Time: 03:38), then you will not have continuous energy levels, both in the conduction band and valence band. You will have those energy levels quantized. And this is what you call a quantum well. Energy levels are quantum levels just like the energy levels of an atom are discrete in nature.

If I put an electron there it will have discrete allowed energy levels. Today I am not going to discuss that. We will come back to that tomorrow because when you go to the next lecture, when we discuss in some detail. That is why some of the levels are shown there with level one, level two, level three; the gaps keep on increasing like in the energy

electron atoms. You we have discrete energy levels for an electron. How it comes up will driven so in our next presentation I hope you are familiar with the potential well problem the electron which is in a potential well will take discrete energy levels and this is a finite well okay that part we will discuss.

The main thing to notice there will be energy discrete energy levels and if there is more than one electron there than this discrete energy bands so you call this term as a sub band. What I am trying to point out here is 'undoped' right band, narrow band and there is no potential change okay all that we have been intrinsic level is going down like that coinciding the Fermi level and we have the delta here (Refer Slide Time: 05:36).

This is only for illustration I have put; nobody will be having fun in making hetero junction to undoped materials. Whenever you do you will have dope materials in that we have discussed that in the last presentation this I deliberately brought in that the discontinuity that we have is because of the differential band gap now this is the actually a situation (Refer Slide Time: 06:09) where a white band gap material conduction band, valence band of a wide band gap material….okay…this is what actually we had discussed last time. A n-type material gallium arsenide narrow band here, this is the bandage here, we are showing more than one so you have got multilayer semiconductor system like what we showed for undoped 1, 2, 3, 4, 5 layers are there gallium arsenide you will see, in fact it can have specific applications. You can specifically see if I have the structure like this you can confine your electron to this. We have discussed the last time this is the delta e in terms of and these circles which are shown here they are the donor impurities (Refer Slide Time: 07:05) okay. These are also donor impurities both N and M is not NP what discussed last time was NP M and N that is the different type of hetero structure iso type other one is anisotype. So you can still …..(7:33) even here you will have electron; this may be lightly doped; this is more heavily doped.

Electrons here can be transferred onto this, really confined in this well. now you notice here that is one level here when there are several electrons those electrons occupying in this particular level and from the uncertainty principles these electrons cannot occupy

same level all these exclusive principle says no two electrons can occupy the same place; but if they have same energy - one energy level permitted, then we can put a band.

This is the sub band (Refer Slide Time: 08:15). Similarly, we will have sub band here I have shown more than one here there may be one sub band here so in a such a situation what would happen would be, suppose I have electrons confined here and they are occupying here and if I have level here there are no electrons here the electrons here that is we showed one level then here.

The electrons are here; they can make a transition from there to there emitting light corresponding to this particular variants if we recall this gallium arsenide and showing the updoped situation which is holds good also this (Refer Slide Time: 09:00) is 1 point 4 electron volts the wave length corresponding to something like point 87 armstrong. 1 point 24 divided by 1 point 43 that is the wave length. In microns that is about point 87 microns now there is no electron here in this case when you confine them in a well like this so these electrons are above the bandage that is the allowed level. If you allow that to make a transition that is to recombine, it transfers from this level to that level and gap is more. If gap is more, what you have achieved is light emitted from here to here (Refer Slide Time: 09:45) actually has the wave length less than that corresponding to this wave length because if energy is more wave length is more.

You can get light of different wave length by making combinations of these things. In fact, this is one of the structures that you think of quantum lasers okay. Confine the electrons here (Refer Slide Time: 10:04) populate them as much you want allow them to combine; I hope I will have some occasion to discuss towards the end something about these things. You can have multiple multi quantum structure multilayer structures okay with it we can have an effective band here; not this, not this, for something in between that sort of things there.

In fact, one level and another level electrons are occupying at the lowest level like in the other case; so it is in the band. If you increase the concentration may be it goes to next level. These are some other tricks one can play with these types of structures - hetero junctions. You can see compound semi conductor gives you the specialty of not just

varying the structure by changing the material composition gallium arsenide GAs (Galgas) gas by changing x you can change the band gap plus multiple layers you put alternatively it gives another dimension all together. So for optoelectronic applications that is another thing. But here what we are talking of is the transistor you do not need multiple layers.

I just show one more diagram so this is N uniformly doped doping here is the same as here. Still there is transfer of electrons from here to here (Refer Slide Time: 11:33). Now you have another situation that is called Modulation doped. In fact, the transistor that is made out of this is called MODFET - Modulation Doped Field Effect Transistor. That is also called (it will come later) High Electron Mobility Transistor.

Now here, (Refer Slide Time: 12:00) this is the structure that I showed you; this is p-type but in the extreme it is undoped. But you never get undoped it will be lightly doped p when you have that, you have electrons here and we have got this diagram and electrons are confined here. Now if you remove those things instead of multilayer you go on to two layers; that is what we discussed last time (Refer Slide Time: 12:25).

I hope this is clear now; I showed undoped, all the layers uniformly doped, n-type and the next one - alternate layer doped, that is selectively doping this portion. These are layers arranged one over the other on the top. The bottom most will be that; you can go on to the top, okay (Refer Slide Time: 12:52).

The energy band diagram is drawn horizontally but layers are one over the other one. You go layer after layer; one layer you dope, then next layer, change over to the aluminum gallium arsenide, dope it, first layer do not dope it with gallium arsenide, dope this layer, do not dope it. It is very easy to do in technology may be that is, as you finish that gallium arsenide layer switch over to aluminum gallium arsenide that will give….

That is, if you are doing MOC in aluminum also you just switch over to aluminum gallium arsenide and you will not dope it. Add sulphur varying compound, sulphur monocholoride or hydrogen sulphide. You add on to them then you get that layer doped.

Now how thick the layer you want - that is decided by where you want the energy for a multilayer structure. But in this particular case where you have only two layers all that you are looking for is this notch (Refer Slide Time: 14:05) which is created by this. We have shown last time how to generate this energy band diagram for aluminum gallium arsenide. When you have multilayer structure, let me you go back once (Refer Slide Time: 14:15); same thing holds good. You can see there is a notch here from this side. From this side also there is a notch. The confinement takes the whole entire layer whereas here, the confinement is here only where there is a thick layer compared to this.

Now what we said last time is you have this notch delta Ec or discontinuity in the conduction band given by kai_2 minus kai_1 (Refer Slide Time: 14:45). We have derived that - that is called Anderson's model the first model to understand and delta v will be equal to whatever delta E_g there or delta E_v plus delta E_c equal delta E_g okay.

See I have the conduction band you do not have draw the vertical level now and then I left that up there discontinuity there I am not explaining how we went about that because quite bit of time (Refer Slide Time: 15:33); now you will have a Fermi level there.

Type goes intrinsic p-type Fermi level can be there; in fact, it will be there because below the Fermi level the electrons are occupied electrons will be there for Fermi level.What I am trying to point out is, this is delta E_c and this is delta E_v, sorry (Refer Slide Time: 16:15) any drawing it becomes.. .. and this is the valence bandage that is conduction bandage. That is, E_g 1 and this is E_g 2 so difference between two is sum of these two (Refer Slide Time: 16:37) and sum of these two is this delta v plus delta E_c that is the difference in the band here that utilize it because there are too many diagrams lies there.

For further discussion we do not need that; we can drop this and draw only conduction band; whatever is happening is happening here.

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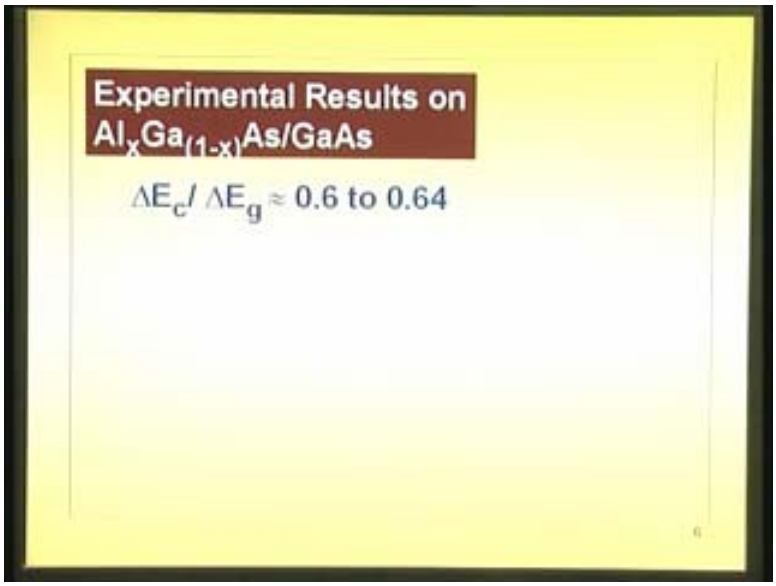

You will see to start with we have the three levels for their 0 level conduction band, valence band and here I had removed the top level electron; we will remove this because all whatever is happening is here (Refer Slide Time: 17:09). Delta E_c because E_v is the difference between the bands gaps; one of them if you know or two of them if you know, you know the other one.

Now in fact, they have measured some of these quantities and arrived at a conclusion that delta E_c by delta E_g is point 6 to point 64 okay and now few things I just want to bring out because we have drawn certain diagrams in certain way. Take a look at those diagrams and also see this here the delta Eg we are talking of as GaAs system.

Now delta Eg is the difference in the band gap now how much the delta Eg depends up on x – delta x. Let me go to the following diagram once and take a look at that diagram. I deliberately put this diagram (Refer Slide Time: 18:20) because we have been drawing all straight lines. That is idealistic tell you that it is almost linear; it is not linear, it is almost linear.

If you see this portion (noise) is highly linear but here it is not linear. I have shown three curves; now all through we have been drawing two curves (Refer Slide Time: 18:39). I

am putting it deliberately because you see this sort of diagrams; but whatever we have been telling earlier holds good in this case also.

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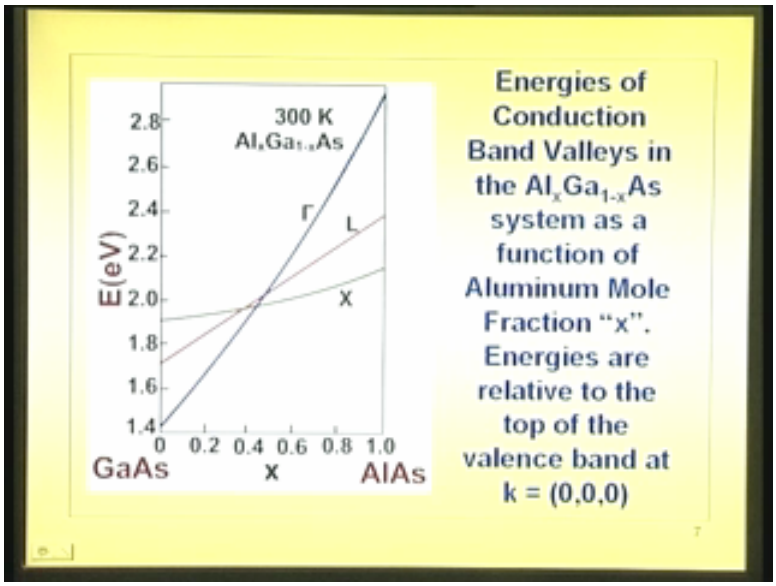

Now I just put those things we will go back to those explanations experimental result later take a look at this diagram okay what is happening is you have gallium arsenide and this diagram needs some attention that is why I am going to do that. This is the 0 level, k momentum versus energy; usually I used to draw only one diagram. I used to draw one diagram like this but actually it goes like this continuous and this particular quantity is point 35 (Refer Slide Time: 19:41).

Now this is actually (I will draw that diagram here), this is touching the 0 called as the X or the top. This is called by some notation to show that this is the direct band gap portion; we are not worrying much about that symbol that is direct band gap location. You can see the diagram that is 1 point 43 okay. This quantity here (Refer Slide Time: 20:25) is actually about 1 point 78; that quantity that is if you go to numbers which are point 35 point 31 that range, so it is around that.

Now you will have also one more level which actually goes bit higher than that, little bit higher than that; and that particular thing I have not shown; this is around 1 1 1 direction this is along 1 0 0 direction.

In the crystal if you move 1 1 1 direction this is along 1 0 0 direction, you get these values. If you recall, there are more than one values like that. I am just showing the two dimensions for just two values here.

This is just whatever borrowed from physics here just putting it across so this particular energy okay that is something like 1 point 9 or so, close to that. We were drawing some effective thing earlier - the linear thing; so now this is actually called the X (just one minute).

If you see the diagram here (Refer Slide Time: 21:55) this is the direct band here this is the 1 point 7 something. This about 1 point 9 or so; this particular X, this is X, and this is called L; this is actually X and this is L (Refer Slide Time: 22:00). Just show the boundary of this called brilliant zone actually we do not say that because boundary of that region where you are plotting this, that is L this is X, there are two values near the portion. If you take aluminum arsenide also you have similar structures. In aluminum arsenide corresponding to centre that is indirect … you can see the taut. I will now come back to this if you see here this is the taut corresponding to direct band here and there is a direct band gap corresponding to this level. Here one line going like that it is not really straight. In fact, it will try to be straight it latches on to that direct band gap and if you vary X that direct band gap keeps on varying from 1 point 43 to 3 point 02. It is about 3 point 02 that is what we have been telling earlier. We were plotting straight; strictly it is not so perfect straight line, just like curvature here.

Now there are other lines which are coming up that is this X line. X line is actually along that 1 0 direction. okay if you see the X line this is something like 1 point 9 or so, close to that okay this is where you will see the band gap. Sometime you will see one is point 35 other is point 5 or something else but, this one is close. Look at the transition from here to here (Refer Slide Time: 23:40) you worry about that. In this case aluminum arsenide also, you will have direct 3 point 2 and along 1 0 0 direction it varies x: this X, that is this X,

this X (Refer Slide Time: 24:00) it varies along 1 0 0 direction that band gap will vary from 1 point 9 to 1 point 17 near to point 17.

We were looking at actually 2 point 17 only and we were looking at somewhere here join them together so this band gap (Refer Slide Time: 24:20), let me go to this band gap ties along with we have the aluminum gallium arsenide, that is gallium arsenide.

Now here corresponding to that (so that I accommodate the whole thing) you will have that one is about 3 point 02 or so; slightly more than 3 electron volts so this will be the tau; if I vary x - this mole fraction, this will vary from 1 point 43 keep on varying to that.

That is the meaning of the line tau that we have drawn there. Similarly, you will have along this 1 1 1 direction that is, L direction, you will have a band gap which is actually equal to about 2 point 23, that is is also indirect. Something like that okay, that is actually L that is in 1 1 1 direction. So this will be tied on to that whatever I have marked L corresponding this gap (Refer Slide Time: 26:23) that will vary from 1 point 78, 2 point 23 as I increase x.

Earlier we used to plot as a straight line it is not really a straight line; it is slightly curved. There is one more along this 1 0 0 direction and this is 1 1 1 along this we have got one more which is actually even smaller than that; that is actually equal to 2 point 17. What we are telling is there are three things which we are tracking: one is this direct band here (Refer Slide Time: 27:03), 1 point 43 tracking with that 3 point 02 keeping on increasing almost linearly but not exactly linearly; other one is 1 point 78 tracking with that 2 point 23 close to the linearity not exactly linear; 1 point 9 tracking with that 2 point 17.

That is why x tracking with x, L tracking with that L, tau that is k equal to 0 tracking with k equal to 0, we were telling we can have as many number of semiconductors as you want with initially direct and finally becoming indirect of that as x varies from 0 to 1. We have done it earlier but with bit more rigor we are doing that. You will see these are the diagrams in literature but ultimately what was shown is whatever we have been telling but values might be slightly different.

You can see now that direct band gap portion 1 point 43 time with 3 point 02 all the way in this diagram tau and that x varying from 1 point 9 on left hand side there to 2 point (I am sorry) x varying from 1 point 92 to 2 point 17; that is that curve. Variation not much, that is also indirect band here then you have got the other one that is L varying from 1 point 78 to about 2 point 23 or so.

Now what is actually the band gap depends up on the minimum here 1 point 43 minimum here 2 point 17 is the minimum (Refer Slide Time: 29:03). So the effective band gap will be varying from this along this path the minimum of the all of three.

Now you can see up to this quantities direct band gap that is tau, the direct minimum is the tau and beyond that that is something slightly more beyond the 1 point 4 that is mole fraction about point 4, point 45 beyond that indirect band gap.

You can generate direct band gap material or indirect band gap material. Why I put this diagram to you is you get further clarity about this particular diagram also when you take point 4 that is there about point 4 you get 1 point 93 or so in that range somewhere here (Refer Slide Time: 30:10). From this diagram if you just draw straight line you will not get 1 point 93. In that I put earlier when I do straight line exactly, I put point 3 corresponding to that but it is very crude approximation, a real thing is that. In fact if you see the Indium gallium arsenide as x is varied it will not be really straight so the band gaps that you really get are slightly different okay. Where x equal to point 47 gallium concentration you get point 75 electron volts band gap because of the non-linearity.

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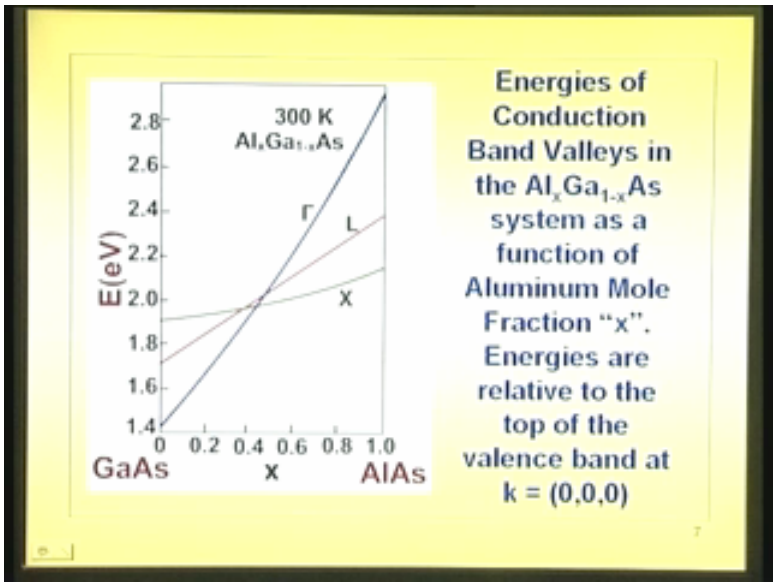

What we are telling is, when x equal to point 4; okay let us go back to that (remove all these now) understand these are the diagrams. This only represents the range - the directions along the crystal. What we are trying to tell is x equal to the mole fraction - Aluminum mole fraction; so x is equal to point 4 you get actually E_{g1} equal to 1 point 93 around that. This is Algas (Refer Slide Time: 32:05).

E_{g2} or gallium arsenide, calling it whichever way, is equal to 1 point 43. Delta Eg is point 5; E_{g1} minus $E_{g2;}$ we have to go back to that previous slide where that is put - delta Eg is point 5 electron volt; to get that I put that diagram for you. Because, if you just put straight from 1 point 82 in that diagram you will not get that. Now, what people have observed is this needs little bit of explanation. The qualitative understanding we will try to get; delta Ec is equal to point 64 times delta Eg that is for this particular Ec what you get here is point 32.

This is actually measured quantity you get from some optical measurement. There we have seen that the delta Ec the discontinuity in the conduction band is about point 32 for x equal to point 4 around that point 32 point 3. There also will be some errors in the measurement that is, the approximation is there.

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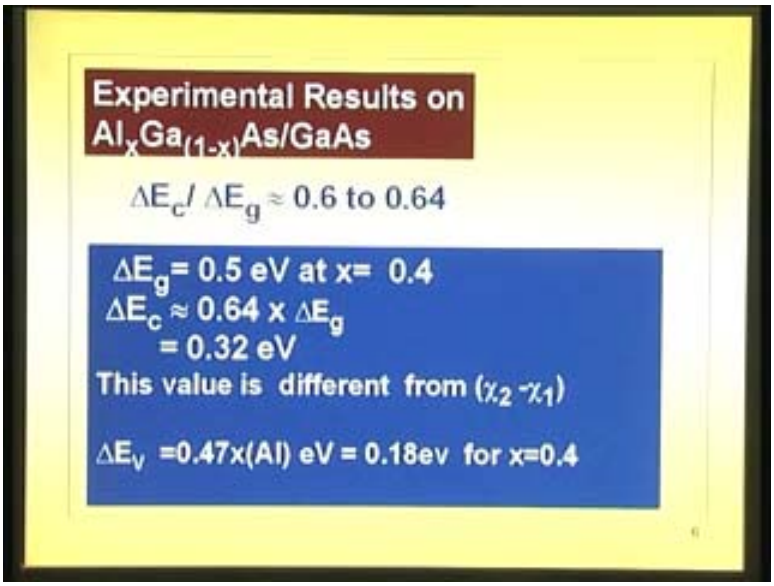

Because, people have put here point 6 to point 64 I am putting an argument now. To understand this we will see how. Watch me carefully; delta Ec is this; these values are different from kai_2 minus kai_1; kai_2 minus kai_1 is quite different from this. Also they have seen delta Ev is obeying the formula point 47 times x of aluminum.

So x is point 4 you get point 1 8; point 18 because point 32 point 18 plus point 32 point 5 with that. Now let us see what the trick here is. The whole thing is you actually use this equation; particularly it is valid for Algas … system. You cannot say point 6 times that is this formula point 64 times delta Eg holds good for all the system. It is like telling the neutral level in gallium arsenide is one third of E_g, in silicon it is one third E_g above valence band; but if it is gallium (helium) phosphate that is a different story all together. Neutral level is not at one third Eg above the valence band. So like that, this particular term will be different for different systems.

How does it come about what is it that is hidden in this? The discontinuity delta Ec and the band bending they are tied together. They take place finally so that the neutral levels are aligned like in the case of metal semiconductor short key barrier the Fermi level gets closer and closer neutral level here two materials are there with a neutral level aluminum gallium arsenide and gallium arsenide belonging to the same almost the same species.

Because after all aluminum can replace gallium very quietly to give aluminum gallium arsenide. The neutral level gallium arsenide is at one third E_g above the valence band. What this tell us is, this forces neutral levels E_0 on either side of the junction to align and lineup. Whatever I have put there let us see; I go through this explanation this is what you can see.

Let me draw first the energy band diagram. In fact, the conduction band is sufficient but since we are discussing the other aspect we will draw the valence band also, Fermi level there (Refer Slide Time: 37:11). What we are telling is this delta Ec and the band bending will of course have to do this Fermi level aligning; if that happens the exact delta Ec will be able to almost control all the things. Apart from the Fermi level aligning, the potential and the delta Ec together are such that, what we are telling is, the neutral particular level (Refer Slide Time: 37:44) E_0 - neutral level; just watch very carefully because I am just giving the theory which has been arrived at after number of applications.

The moment it was not matching everyone just plunged into saying that “here is my explanation”. Ultimately, what is now accepted is these discontinuities and the potential everything is such that this neutral level actually and neutral level of that tend to align; if they are exact that is the best.

They may not be exact but little bit close to each other. What happens if they are not exactly equal? Now the Fermi level is here (Refer Slide Time: 38:44); if they are exactly equal, this is actually interface common to both. This is outside the band gap of this gallium arsenide; it does not see that. It sees may be in terms of potential distributions so here all these levels are occupied (Refer Slide Time: 39:05). The Fermi level is above that all these levels are occupied all these levels are also occupied. I am taking a situation where the neutral levels are perfectly aligned. What is the situation if they are perfectly aligned? Charge on this aluminum gallium arsenide at the interface is given by, what is this gap? They are acceptors - D_{it} multiplied by that. All these acceptors are above the neutral level and they are below the Fermi level that is they are occupied. If they are occupied, they are negatively charged. They are all neutral; below the neutral level there are donors; they are occupied, they are neutral that is perfect I hope you are able to

understand, that the acceptor level is occupied is negative (I always have suspicion in…40:00). Donor level occupied is neutral, donor level unoccupied is positive, okay? Acceptor level unoccupied is neutral; that is the whole is present there that is plus; that is unoccupied by electrons. But when it is occupied by electrons the whole is gone to the valence band; that is negatively charged.

When you say occupied or unoccupied, you say occupied with electrons or not. Occupied electrons means the hole which was occupied that has left the place that is an electron has gone there; negatively charged. That is why an occupied acceptor level is negatively charged; all of them are negatively charged. There is perfect harmony between two layers in the sense that the charge is present here which belongs to both of them are common. Suppose there is a mismatch, what will you do? You do not need to worry about that is not coming onto this particular interface; the energy gap is outside the band gap.

It is not interfering this; so what is common here suppose the levels are slightly different; let me draw the diagram. Here it is perfectly neutral. Let me take a situation where the neutral levels are exactly aligned (Refer Slide Time: 42:00).

Charge on both sides in the interface is same; there is no charge transfer taking place there. There is no dipole layer formed whereas these are neutral levels which are exactly aligned here.

Let us take the situation where I am trying to draw another to show that I am deliberately drawing like this just to show the two levels and draw that and this one also slightly here corresponding to gallium arsenide. Neutral level of this one is here and the neutral level of that one is there (Refer Slide Time: 43:05). Let me magnify it so you can see it. I draw two lines here; this is a single line but it is not two distinct ways. This is here; this is the situation. More number of electrons here aluminum gallium arsenide less number of electrons here (Refer Slide Time: 43:25)

They have to be laid together; what happens is there is charge sharing takes place and this gets negative charge and this gets positive charge; a dipole layer is formed. In fact, the theory what is formulated says that it is not a condition for minimum energy. From the

energy considerations the dipole layer must be minimum. Even if you do not agree with that particular situation, ultimately charge transfer takes place and this become equal as close as possible.

This is not a favored situation where the neutral levels are same; this is the favored situation (Refer Slide Time: 44:09) because in this situation the charge transfer will take place further so that they are moving closer together. They may not move exactly but it will move close to each other like in the case of hake barrier forming level moves close and close to neutral level it is not exactly matching so that in the charge there is minimized charge that the interface is minimized it moves up to the point charge there is by the potential here of course other criteria is also comes into the picture so the charge in the interface that is the charge between this and that to be minimized that is all simple things we have to say so here the difference between two is 0 it may not be exactly 0 but it is close to that that is all what is said in the statement here.

The discontinuity and band bending take place such that the charge at the interface on either side is minimum in the sense charge difference is minimum or net charge on other side. If there is the charge difference one becomes plus 1 become minus that is minimized so aligned each other this what you are said here just as a statement ultimately what happens is each one of them force the level to align to each other the line up does not occur charge transfer takes place between the states on either side of the interface and this would create a dipole field from the energy consideration the system favors dipole minimization and therefore equalization of E_0 levels.

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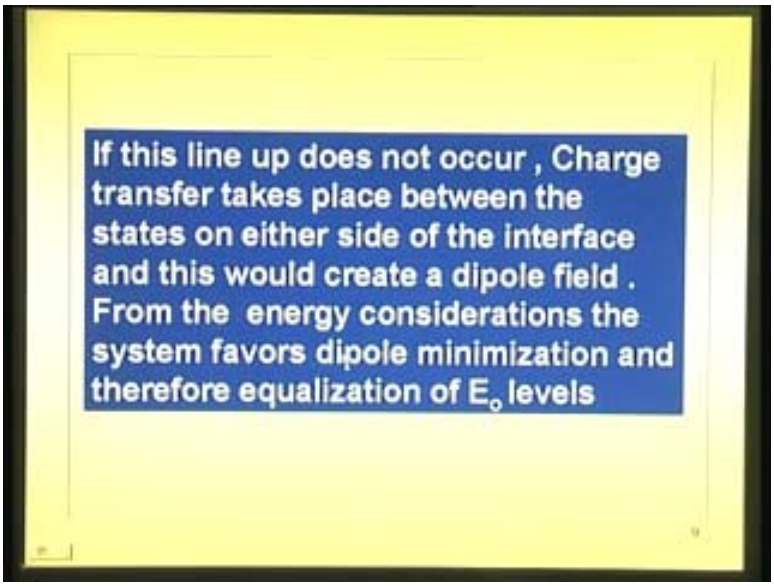
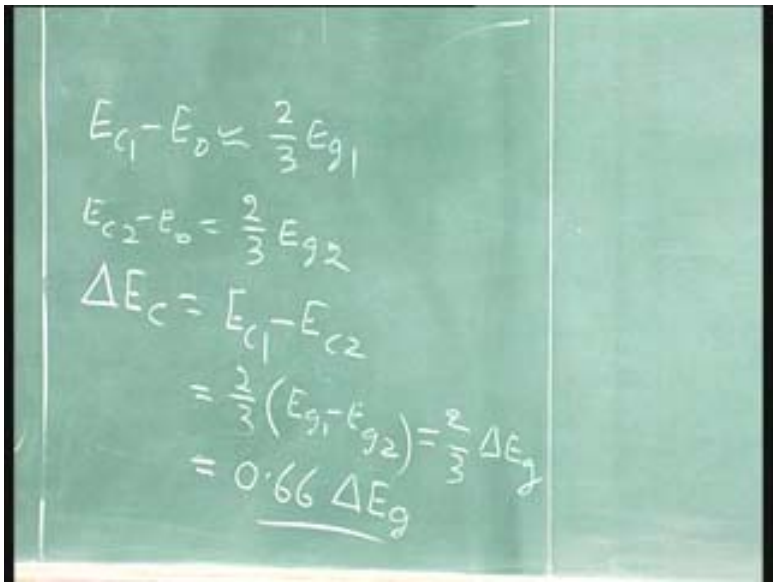


That is the statement I have put there now if you agree on that now we know how to work out the number how much is this delta E_c we can work out from that so the entire criterion is the alignment of neutral level so the charge difference this side and that side are same 0 charge on both sides are same is there is the difference there will be charged onto bring them closer to each other. So may not exactly match close to each other now let us see what the situation okay what is this quantity now is how much delta E_c is the our question how much this quantity let me put this as E_0 and this as remove all these things now okay this as E_{c1} conduction band one and E_0 and this is Ev one E not minus Ev one is actually equal to one third E_g and E_{c1} minus E_0 is actually equal to two third E_{g1}.

So this is Eg one i hope i have not written E_{g1} E_{g2} does not matter with reference this diagram this E_{g2} band gap okay and this quantity E_{c1} minus E_0 actually equal to approximately equal to two third of g one and this is E_{c2} and this is of course also Ev_2 E_{c1} there and E_{c2} is there E_{c1} minus E_0 equal to two third of E_{c2} this work out of course this is not mention in publications some how but it is mentioned that the neutral level tends to align then you can work out this if you know the neutral level you know what the discontinuity the formula we can work out.

delta Ec equal to this minus that okay is equal to E_{c1} minus E_{c2} that is actually equal to two third of E_{g1} minus E_{g2} which is point 6 time delta E_g that is actually equal to.

(Refer Slide Time:)



Once again a bit closer delta E_c equal E_{c2} or E_{c1} minus E_{c2} which is actually equal to two third of E_{g1} minus E_{g2} and I am just rewriting that which is actually equal to two third of delta E_g.

Now what they have seen in experiment is you can go back and see almost point 6 point 64 so that depends how much alignment is there between E_0 levels exactly aligned with that two third E_g that get point 6 is slightly different from that that is it not exactly aligning it is not possible some …. (5024) takes places after all it is governed by this band bending extra okay.

Now let us take further look into these things now I just want to take a look at this particular distribution of I will try to discuss a few things now related to this diagram this is actually the aluminum gallium arsenide hetero junction with undoped gallium arsenide doping concentration unintentionally doped thirteen per centimeter cube okay what we have shown here there is diffusion layer here because entire band bending has taken place all these are taken place because this layer is repeated okay and you have got the charge

taken place on that side it is depicted it is bending down this is depicted it is pending up that is we have discussed.

Now what I am trying to point out is compare to the homo junction if you add gallium arsenide n plus n gallium arsenide p-type undoes what would happen the potential layer distribution let us draw that let me draw the fresh diagram what we have gone there but see the slide is slightly the final diagram I have drawn let us take a look at that so if it is a homo junction gallium arsenide gallium arsenide what would have been this n plus this p lightly doped okay if I have that what would have been the given diagram n plus p minus p minus lightly doped what would have been the diagram the (noise) similar value you get depiction layer here. What is the barrier here that is potential and you have got here you can draw the same diagram that you have been drawing for the barrier energy distribution of a electrons and here energy distribution of electrons minorities the difference have taken place. Now if you take a look at the gallium arsenide what happens there is the notch here okay and just draw may be continue on the lecture just now if it aluminum gallium arsenide okay this for gallium arsenide.

I am drawing the conduction band same way let us not worry about what happens in here. It comes like this then it fits in the same potential, how it should have gone like that, what happens if it a same distribution? Same potential barrier as gallium arsenide then this is at higher level this is at lower level the whole thing is pushed down then more transfer of electron from aluminum gallium arsenide to gallium arsenide what about this that will come like that so in the case of single crystal you get homo junction if you get that potential barrier then you get more potential barrier I will discuss again some details about this in next lecture, we do not want to hurry it up.

What I am telling is there is additional potential drop here corresponding to delta e c that means there are additional electrons in there. How much electrons are there depends on the omega delta c. delta c is the whole thing which results in much and take up again in the next lecture but this is the point to note here; this is our I just have drawn only that portion; let me remove that; this is our algas; that I stop today.