Semiconductor Optoelectronics
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Lecture - 25
Electro-absorption Modulator-II
Device Configuration

In the last class, we discussed about electro absorption modulators. Basically we discussed the principle of operation of an electro absorption modulator, which is Franz-keldysh effect, and quantum confined stark effect.

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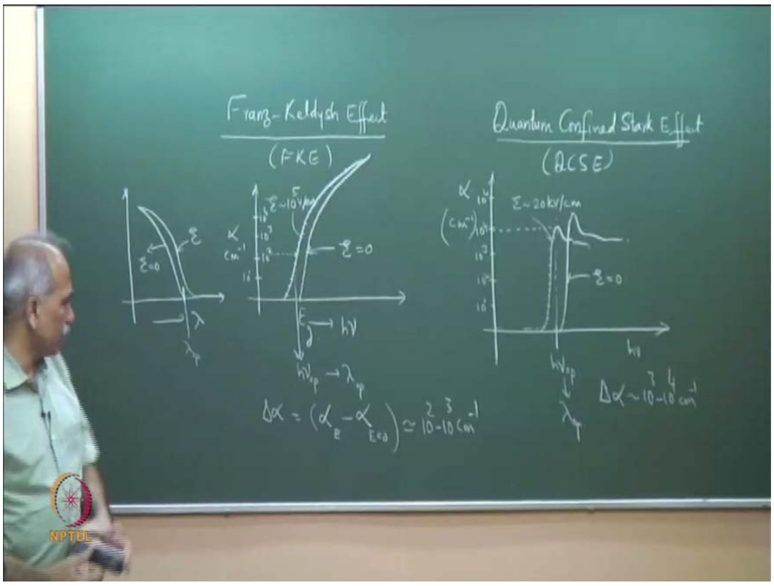

Both these can be used to realize electro absorption modulators; so if you re-call, the characteristic of Franz-keldysh effect, is shifting of the absorption edge, right shift of the absorption edge of semiconductor; that we have alpha; the loss co-efficient in semi centimeter inverse, verses the photon energy h nu. Then normally the semiconductor may have a loss which goes like this, starting from E g, then in the presents of an applied electric field the shifts, so the later one, is in the present of the electric field, just to dusting let me mark that graph. So, this is e equal to 0, applied electric field is equal to 0, and this is applied electric field e of the order of 10 to the power of 5 volts per centimeter, 10 to the power of 5 volts per centimeter; that is 100 kv, 100 kv per centimeter. So, if you use the operating wave length, somewhere here; that is if you use a lambda op or h mu op, op standing for operating, and corresponding this, there is a lambda op, if you choose the wave length such that your are here, then in the absence of the electric field, the absorption is very little, this is the absorption.

So, 10 to the power of 1, typically number, 10 to the power of 2, 10 to the power of 3 10 to the power of 4 and so on, centimeter inverse. So, before the application of the electric field, the absorption electric co efficient is very small, negligible here, but in present of an electric field. So, you have an absorption co efficient which is here, which is significantly larger now, this is Franz-keldysh effect. In the case of quantum confined stark effect, because of the step response of the absorption co efficient, and because of the present of the excitonic peeks, the change is very large. So, in the absence of the electric field, you have a response which is like this, which shifts to, in the presence of the electric field. So, this e is equal to 0, and this is typically you need a lesser voltage lesser, lesser electric field, so e of the order of 10 to 20 kilovolt per centimeter.

Here you need the order of the 100 volt kilo volt per centimeter, here 10 to 20 volt kilo volt per centimeter. So, if you again choose lambda op here. So, this is h mu verses alpha, similar numbers 10 to the power of. So, 10 power 1 10 power 2 10 power 3 10 power 4 centimeter inverse. And if you choose h mu operating, or a new operating, or corresponding to that the lambda operating; such that you are located here in energy. Then in absence of electrical field the attenuation coefficient here is negligibly small, and when you apply the electric field attenuation co-efficient jump to a large value. So, the primary difference here is, because of because of quantum confined stark effect, the primary difference is a large change in attenuation coefficient, and the peek here excitonic peek adds to it, because here there is no peek.

So, typically delta alpha that you can get, delta alpha, which means delta alpha equal to alpha, then e equal to 0. So, when e is in presence of minus alpha in presence of e equal to 0, delta alpha for change in attenuation coefficient e is order of 10 to the power of 2 10 to the power of 3 centimeter inverse. Whereas, in this case delta alpha here, is typically of the order of 10 to the power of 3 to 10 to the power 4 centimeter inverse, about 10 times more, otherwise both of them refer to right shift of the absorption edge of a semiconductor, absorption edge. Absorption edge refers to the wave length or the energy, where the absorption co efficient suddenly start shooting down; that is the absorption edge. So, the red shift, shifting to lower energy, or shifting to higher wave length.

So, if you want to plot the same graph of in terms wave length, it could have been the other wave, so mu damp, so this is lambda, and then in the present of electrical field it would shift like this. So, this is the e, and this is the e equal to 0. So, red shift, shifting towards longer wave length, so this is with the e, in the presence of e. And the lambda op that I was talking, is somewhere in between here, somewhere at the edge, so lambda op, because normally we talk in terms of operating wave length in optics and optoelectronics. So, this is Franz-keldysh effect, and quantum confined stark effect. Sir why does he excitonic peek reduces on an application of electric field. The question is, why does the excitonic peek reduce due to an application of the electric field. When you apply electric field, as I had discussed in the last class. The wave function associated with the electron and hole, which form the exciton, tend to disassociate that is they tend to ionize.

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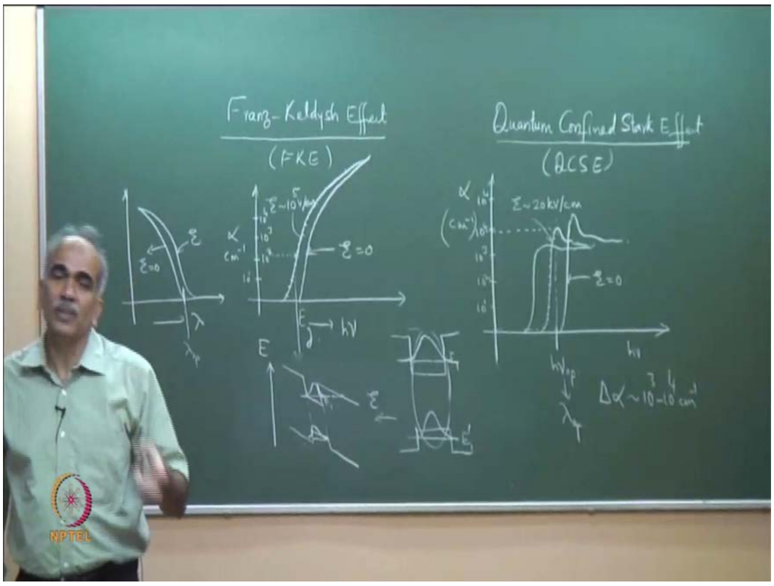

So, if you recall the quantum well structure here, a single quantum well, showing you a single quantum well, and there is the wave function here, corresponding this is the lowest state, and you have a wave function corresponding to this, this state. And similarly you have a hole here, corresponding to that there is wave function like this. You can show it inverted or this way does not a mater, so we have e 1 and e 1 dash. So, these are over lapping and they are folding together, due to columbic attraction, and therefore it forms a exciton. In the presence of applied electric field, the well bends, so in the presence of applied electric field, they well take this form.

So, this after application of electric field there is the change in the energy e 1, but more importantly, because of applied electric field, the wave function becomes asymmetric, and its tend to be located more to the other side, because there is a positive potential here, therefore the electron has an attractive potential to this end, which means simple terms a electron wants to move towards the positive end, which means a probability of locating the electron is more to this end, witch. Means the wave function is more shifted to this end; and that why the wave function becomes symmetric, here it is perfectly symmetrically, but here it become asymmetric. Similarly this wave function associated with the whole, tends to move to the other hand. Now, this tends to move, they are not separated, because of quantum containment still blocks them, but the movement you have this one coming down. Please see here, corresponding to this axis is energy, everywhere vertical axis energy.

Corresponding to this value of e, there is a state, and this electron of this energy can tunnel and go out, which means this electric has a probability to tunnel, which means the probability of dissociation, increased probability a dissociation, and therefore excitonic peek goes top. It is just like a increases the temperature, that excitonic peek goes down. So, exactly like that because the electron now has probability to tunnel, the de association probability is increases, and therefore the resonant peek goes down. This is why when you apply. In fact if you apply stronger electric field this is completely gets dissociated, and you will not see any peek. If you apply more stronger field, it will shift to this site. So, the typically I would show this, so you will have something like this, and if you apply further, there will be nothing for the higher electric field.

We do not want to go up to that, because of we want if the peek is present, then the step change the delta alpha is larger. If peek is not there you see immediately now, delta alpha is little less. So, we would like to use the excitonic resonance peek. Today we will see how to apply, we will see how to apply we togged on 20 kv per centimeter 10 kv per centimeter, how to apply the electric field, and what is the device configuration. So, we will discuss this today. First let we discus device based on quantum confined stark effect, early devised based on this, but now the reason another way of using new configuration, where you can use Franz-keldysh effect as well as QCSE, both can be use independently. There was an early article in physics today.

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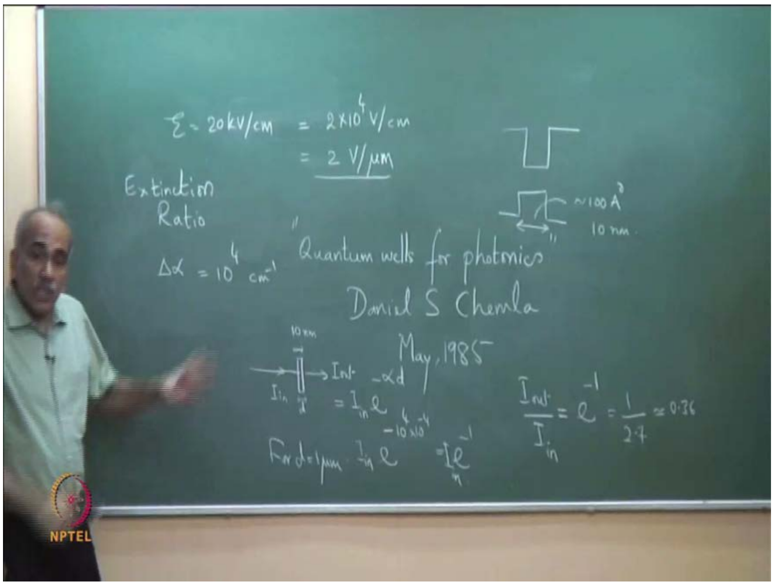

I would recommend you to read this article, this came in physics today an article titled quantum wells for photonics by Daniel S Chemla bell off your Daniel S Chemla. This is popular level article May 1985, easy to understand, the old article 25 years back, but still a very nice and relevant. The concepts are given very nicely, quantum wells for photonics may 1985. Please see this article, it is quite nice. So, the question is, how to apply a large electric field, like 10 to the power of 5 volt per centimeter, or 20 kilovolt per centimeter. So, e equal to 20 kilovolt per centimeter, 20 kilovolt per centimeter, so this is equal to 2 into 10 to the power of 4 volt per centimeter, and 1 centimeter is 10 to the power of 4 microns, so that is equal to 2 volt per micrometer. 20 kilovolt per centimeter is 2 volt per micro meter, is if you can apply 2 volt across 1 micro meter.

So, this 1 micro meter thick, if you can apply 2 volt across this, you are getting the field, so it not big idea. So, it is not a very big number, provided you apply it across a small thickness, so 2 volt per micro meter. This is the kind of electric field that is required. Now if you take a quantum well, one quantum well, typically you see the logic here, the birth of quantum well here is typically of the order of 100 angstrom, which means 10 nanometer, typically width. Now if I take this quantum well, it is 10 nanometer thick nanometer. There is light incident i, i in, then i out, i out will be equal to i in into e to the power minus alpha in to d, where d is thickness. Alpha is the absorption coefficient; even alpha is 10 power 4 centimeter inverse. So, this is i in into e power minus alpha, 10 to the power of 4 centimeter inverse.

And therefore if I substitute d is equal to 1 micron; for example, if I substitute d is equal to 1 micron, then this will be equal to 10 to the power of minus 4. If d is for d is equal to 1 micron, for d is equal to 1 micron, this is equal to 10 to the power of minus 4, which is equal to e to the power minus 1, i input into e power minus 1. this all right And therefore i out divided by i in equal to e power minus 1; that is 1 by e. normally the parameter called extinction ratio. So, extinction ratio, I will discuss about this with field and without field, I will discuss about this a little latter. So, which is nothing, but e is approximately 2.7, so approximately of this order, which mean you see the i out as drop down, by a factor of about 3 or so; that is considering e equal to 1 micro; 1 micro is 1000 nanometer. If you take 1 quantum well, it is only 10 nanometer.

So, we need at least 100 quantum well, to have 1 micron thickness, so that may this ratio is significant. You see this is of the order of 0.33 or something like that, so 0.3536 something like this. So, to have the output drop by this much, more than half, you need one micron which needs 100 quantum well. Indeed if you want to have significant attenuation, we had delta alpha equal to 10 to the power 4 centimeter inverse. So, even if the absorption changes by a 10 power 4; that multiply by length of device will give a total attenuation, and that total attenuation to be signification you have to have at least 1 micron, which need 100 quantum well. Indeed the early devices, the first devices early in 1980’s 1984 1985 used to quantum well; one of the early experimental bell labs, used multiply quantum well structure MQW structure.

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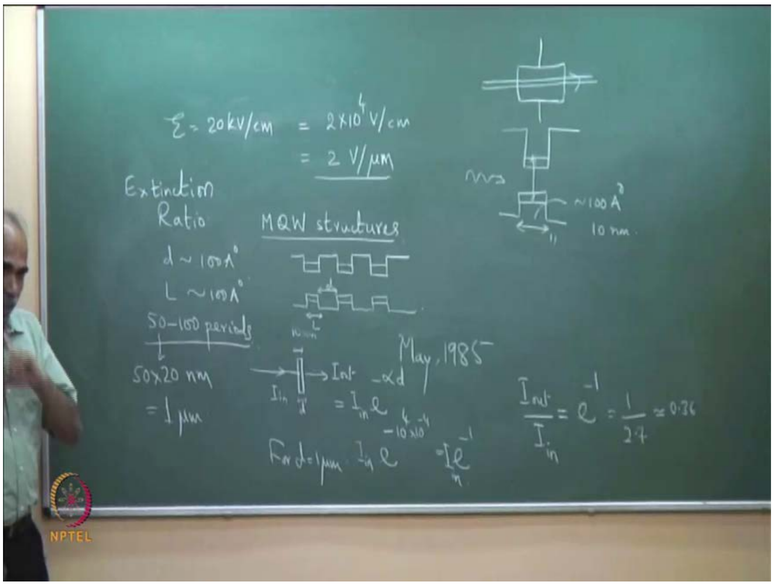

MQW structure, which mean you have wells barriers, wells barriers. This is the well, and if they are non interacting, then the energy remain same, and all the properties remain the same. So, typically well with d of the order of 100 Armstrong, and l the separation, so this is l, and this d, we are taken a problem of the order of 100 Armstrong. And about 50 to 100 periods, one period mean, one well and one barrier, one period mean one well and one barrier is one period. So, if I say that it is 100 angstrom width 100 angstrom width, so totally 200 angstrom; that is 20 nanometer. If I have 50 well, so 20; if it is 50 period, which mean 50 into 20 nanometer, which is 1 micron; if you used 100 periods, than you will have 2 micron. So, the well width, the total well width, where attenuation, please remember attenuation is only here; outside there is no attenuation, why there is no attenuation. Because of photon energy is corresponding to this band edge, outside if I take single quantum well. Please see we had e 1 here e 1 dash here. The band edge corresponding to this energy gap; the band edge, where the attenuation suddenly is start shooting up corresponding to this.

And we have bias state, just at the band edge. The input photon which is coming here, you recall in the principle that we discuss in the last class light beam passing through this, and electric field is applied to the structure. And output will be full or no output, depending on whether you applied electric field or not, this is the principle, but now we want see with number, what is the real device. If I have h nu corresponding to this, outside it will not absorb, because bandwidth is larger, absorption take place only in the well region. Therefore I have 100 period I have 100 well of 10 nanometer, which mean total thickness of semiconductor, where absorption take place is only 1 micron.

And therefore this calculation I have done 1 micro 10 to the power of 4 is alpha, alpha into d applies for 100 well. In other word, to have signification measurable attenuation, you need large number of quantum well, single quantum will not do, but we are using properties of single quantum well, but to enhance the effect, we have to use large no of well. So, the structure that we have to use is MQW; multiple quantum well, multi quantum structure. So, typically 50 to 100 periods are used; one I have still not told how to apply the electronic field. First, have that we need, if you are using to going to using quantum confined stark effect, we need at least a 100 period, 100 quantum well, to have significant effect, how to apply the electric field. We have to apply this mean, which mean two volt per micrometer.

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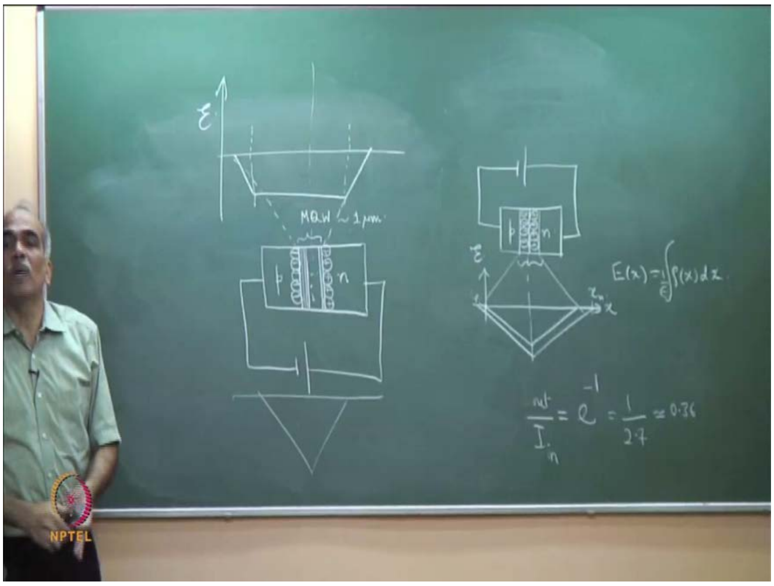

In electronic, we know a singular idea; that is if I take p n junction, we are already discussed this, p n junction. Then you know that the depletion region here, and from p side holes move to other side, so living behind negatively charged immobile ion and positively charged, so that is fields here p n junction. If you apply reverse bias, we apply a reverse bias, then this depletion region is spread further, and the potential, build in potential have become larger. Now if you see the electric field, I just zoom this little bit, we are already discussed this, how to calculate the electric field, because e of x is equal to integral row x d x, and by epsilon. They called d e by d x is equal to row by epsilon by gauss law del dot divergence of e is equal to row divided by epsilon, from there if you take one dimension, and if they are in same direction, it is d e by d x; therefore e is equal to this. Which mean if you are finding the electric field, the electric field is start from here, so it is negative. So, electric field increases in the linearly, and then as you add positive charge to the negative electric field decreases, and then it is comes down here.

So, what I have plotted; the electric field, electric field verses distance. This is the electric field, beyond this no electric field, which means the entire electric field is appearing across the depletion region, and what is the thickness that we have here. Typically the thickness of depletion region is of the order of one micron or two micron. So, if you apply the reverse bias, then this field may spread a little bit more, so this will spread, and you will have the electric field varying like this, what I have shown here in, this is x verses electric field, this is width of p region many time it denoted of x p, and width of the n region x n in the depletion region. And this entire width is of the order of one micro. So, the point is, that applied voltage one volt, two volt, three volt, whatever reverse bias that you are applying, is appearing across the junction. The entire electric field is across the junction, and therefore what is the electric field that we have here.

This is of the order of 10 kv per centimeter. It is 2 volt per micrometer, but it is 20 kv per centimeter. So, if you use, using this concept, if you use a p i n structure. So, what is the device configuration, almost all device use reverse biased p i n structure. So, the structure look like this, and I will show you a better, this is a dramatic representation, this is p side, n side, and this is the intrinsic region, which compress of quantum well structure. So, the i here is MQW, the intrinsic region, and then we apply the reverse bias. So, p i n, where the intrinsic region compress of multiple quantum well structure, typically 50 to 100 period. So, the entire, if you plot electric field across this how does it look.

So, if you plot the electric field, the charges here will be negative, and the charges here will be positive, and the intrinsic region there is very little charges, and therefore if you plot this, you will have electric field varying rapidly like this, and then in the intrinsic region, entire intrinsic region, approximately constant and then dropping down like this. This is at the junction p and intrinsic junction, this is n and intrinsic junction, and in the intrinsic junction the electric field remaining almost constant. Electric field is equal to charge in to d x integration, so you integrate it all the negative charge here, so the field increased up to that and hardly any charges here in the intrinsic region. So, the field is remaining constant, when you reach this region the negative charge compensated positive charge. So, the sum is decreasing, so the electric field is decreasing. In the case of p n junction, we had the electric field variation like this.

In the case of p i n the electric field almost remain constant, therefore the little bit slop depending on which p side is more dot or those n side more dot, but almost constant, remember this axis is electric field. So, we have a uniform electric field of the order of the order of 10 to the power of 5 volt per centimeter, applied to the intrinsic region, and what is the thickness of the intrinsic region, is still about 1 micro, or 1 to 2 micro, 100 quantum well, 2 micro is the total thickness of this. We are able to supply a large electric field at the junction region. This is the device configuration which is used, a practical device look like this, this is the schematic expression. So, practical device look like that we show you practical device, how is look like. So, you start with gallium arsenide, this is the procedure we illustrated here Gallium arsenide and this you deposit aluminum gallium arsenide, and this by deposition and h e, you grow multi quantum structure.

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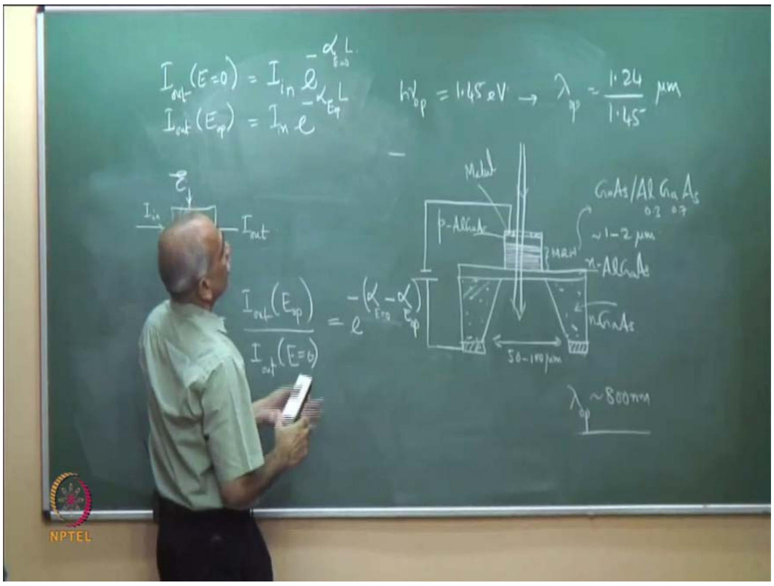

First, we start with n gallium arsenide, so n gallium arsenide substrate. On this you deposits n aluminum gallium arsenide, then you deposit multi quantum well stricter MQW here. This MQW comprise are gallium arsenide, aluminum gallium arsenide Al 0.3, Ga 0.7, arsenide, MQW structure. Over that you have p type aluminum gallium arsenide substrate and over that the metal electrode. Now the substrate is ached from the back side, till you reach to this position is ached away, and then ached away the material here is attached. It will become clear why that is done, so this is the substrate, and then you deposit angular electrode. I could have shown the structure directly, but I just wanted to illustrate the procedure also. So a substrate on which epitaxially these layer are deposited and, then this is ached away ,and angular electrode angularly, why angular electrode is required, because light external from here. This is the path of the light. You see the structure, here you apply, this is negative electrode, so n, and therefore you have to apply positive.

This plot, this vacancy plot is for light to pass. This is gallium arsenide, aluminum gallium arsenide quantum well. This is for operation around 800 nanometer, lambda operation around 800 nanometer, because of material is gallium arsenide aluminum gallium arsenide. The band gap is about 1.42 for a gallium arsenide, so 1.44 1.45 will give a approximately 800 nanometer as the lambda operating wave length. I hope it clear, you recall that if you had h mu here for gallium arsenide bulk it was here, this is 1.42, and then for the quantum well it was here, this is may be about 1.46 kilo volt. So, you are operating voltage has to be somewhere here, say one point h mu op is 1.45 kilo volt, which mean lambda operating is equal to 1.24 divided by 1.45 micrometer; that is about 800 nanometer, 0.85 approximately around that region, because I have used gallium arsenide.

If you want use the electro absorption modulator for optical communication, it will be based on indium for substrate, and indium gallium arsenide quantum well substrate, indium gallium arsenide phosphide, the quandary compound is used. In this picture clear, that this is n on which intrinsic gas algas as layers which are quantum well. This is the p aluminum gallium arsenide. Please note that we have attached this, so that there are gallium arsenide does not reabsorbs this, when this peek is shifted here gallium arsenide could absorb the light. Light is coming at 800 nanometer, so gallium could absorb 800 nanometer somewhere here, so absorption co-efficient is large. So, to avoid absorption by this gallium region, it has been ached off. Whereas the region here is aluminum gallium arsenide, the region her is aluminum gallium arsenide, they do not absorb, because they have larger band gap. Aluminum gallium arsenide has a larger band gap compare to gallium arsenide. So, this is the early structure of electro absorption modulation, based on quantum confined stark effect.

Typically dimension here, so this is substrate of typically about 100 micron, 60 to 100 micron, and this slot, which is kept open is also typically this slot, and the slot here is 50 to 100 micrometer, and this thickness of MQW is the order of one to two micrometer, as discussed in the principle, and it is the reverse bias p p i n structure. So, p i n, this is p alga as n alga as and p i n structure, and reverse bias, this is the devices configuration. But today there are better device configuration, because one of the important restriction that that we have is, one micron two micron, you have to write 100 period. The period have to be identical, if the period are non identical the energy is different, and then the effect will be different, it is not enhanced it will start broadening, and therefore easier and more better.

Please see the extinction the different is given by minus delta in to l ,what this delta alpha; please see i output with e is equal to 0 is equal to i in into e power minus alpha, with the e is equal to 0 into l. When there is no applied electric field, I have this device, I don’t know what is the device, this is electro absorption modulator. There is an input which is i in, there is an output i out, i out with e equal to 0 is i in into e to the power alpha is the attenuation co-efficient, without any electric field. We are applying the electric field from here, that are this is e field. In the presence of electric field i out with e equal to i in, into e power of minus alpha in to e, e is equal to 0 in to l, e is may be 10 kilovolt per centimeter, 20 kilovolt per centimeter whatever, e is operating.

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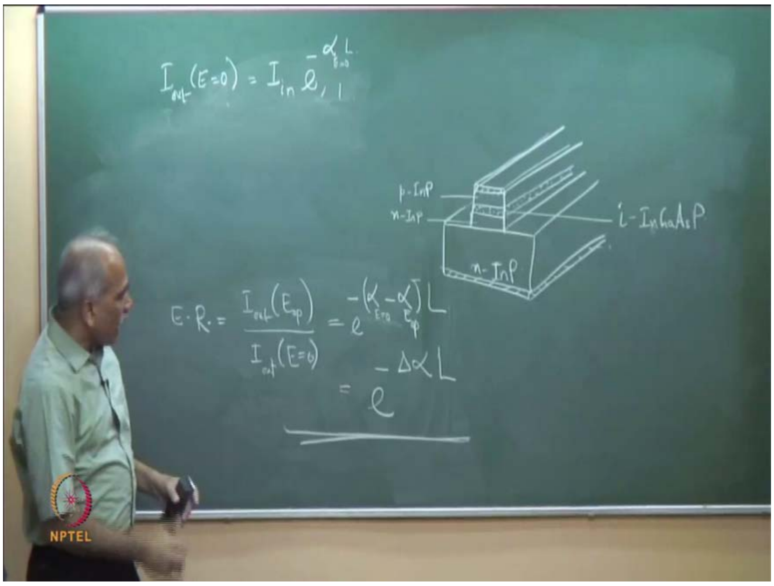

So, let me put e op, operating electric field EOP, this is the output, when there is no applied electric field, and there is the output, when there is electric field, what is the modulation. Modulation is the ratio between this two in the presence of electric field and in absence of electric field, modulation is the modulating the output intensity based on the applied electric field. Modulating means what, so you are applying an electric digital pattern, electric field to this, and you are saying how like is modulated. So, modulation ratio, the modulation index is given by which is also called the extension ration in this case. So, the extenuation ratio E R is equal to i out with electric field divided by i in without electric field, i out without electric field, in is constant, i out without electric field. This is the extinction ratio, and that is equal to i in i in cancel. So, we have e power minus alpha with e equal to 0 minus alpha with e operating into l. So, let me erase the structure. I want discus the new structure, in to l this is what I had written as delta alpha. So, this is equal to e power delta alpha, delta alpha is a change in attenuation co-efficient, because of applied electric field. This was without field; this is with the applied field. So, change in attenuation co-efficient in to l, and this change, what is the point to see extinction ratio or equivalent to modulation index, the modulation.

The difference between in the presence of electric field and in the absence of electric field, depend on the product delta alpha in to l, 1 is, if I have a large delta alpha that would be wonderful; that is why be said quantum confined stark effect is better than Franz-keldysh effect, because the change in alpha is much large in the case of QCS. However I have second parameter l, suppose I make l large then I can use even Franz-keldysh effect. It is not necessary I should go, because it is the product which will determine the extension ratio. And hence a new device currently it is the wave guide modulation which is used. So, this extension ratio, which clearly tells that, it depends on the product of delta alpha. Delta alpha is change in attenuation co efficient, due to applied field, multiplied by the length of the devices.

So, the current device are; let me shown the first three d picture and much easier to fabricate, and much easier to realize. I will first show you the structure, than I will explain what in structure is, let me make 3 d. So, this is actually the ridge wave guide structure, so you have the substrate, let us say n indium phosphide, let me drawn say n indium phosphide. All the violent writing gallium arsenide gallium arsenide, let me write indium phosphide, and here is, this is the substrate, and this is p indium gallium arsenide phosphide, for communication wave length, just to distinguish this internal layer. I will mark it with the dotted line. So, this is n type, so n indium phosphide, sketch with draw n indium phosphide. It could be some other material also, and this p indium phosphide, and on top is the metal. This is the contact, and at the bottom there is a contact. Let me draw the structure and then we will discuss.

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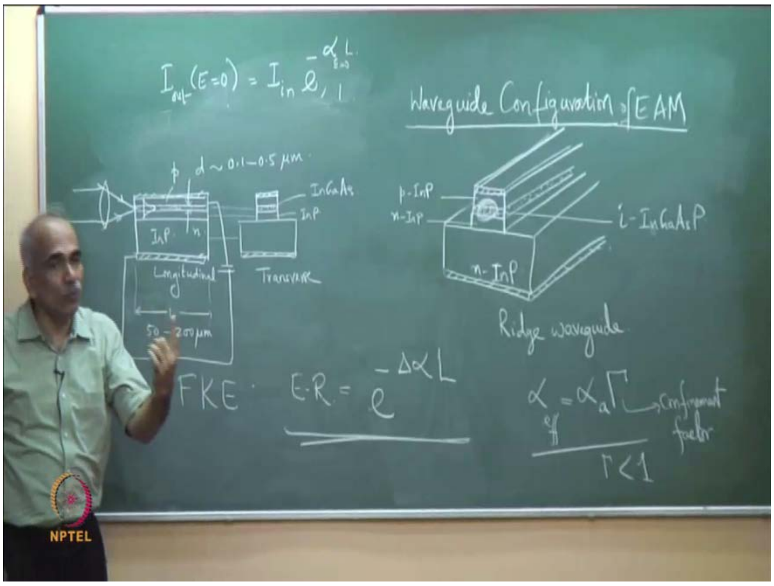

So, what I have drawn is. So, extinction ratio is equal to this, what I have drawn, is a ridge wave guide. If I will show you only the front end, it will be like this. This is the contact, this is the bottom contact, and here is the. So this is indium phosphide, and this is indium gallium arsenide, this is a ridge wave guide, it is call ridge wave guide structure. I will explain what I mean that, if I show a longitudinal cross section, it will look like this, this is transverse cross section, the end that you are seeing, and if I show longitudinal cross section, it will look like that one to one correspond. See this is the same as this, this is the same as this, this is the substrate, so this is longitudinal cross section. I hope you longitudinal cross section like this, and other one is this. So, this slice is like this, this slice like this, longitudinal cross section, so one to one. So, this is indium phosphide. Light is lunched in to this structure, so let me show the length and light lunched into this hare, this structure. This indium gallium arsenide phosphide forms an optical wave guide, what is an optical wave guide. A high index layer sandwich between two low index material.

The guiding field and cladding, outside is the cladding. Indium phosphide has a lower refraction index, it has high band gap therefore the lower refractive index compared to indium gallium arsenide phosphide, this has a higher refractive index. Therefore this structure is optical wave guide, so here it is. So, it is propagation in this direction, and the thickness of this, this larger here guiding layer, this is d typically 0.1 to 0.5 micro meter. And the length here, this is longitudinal, this is transverse cross section. So, l the length here of the wave guide l, is typically 50 to 200 micro meter. I have a 0.2 or 0.3 micro thick optical wave guide, the thickness. And then this already can see that, this is n this is p, upper one is p. This structure similar structure we will see for a laser diode, but laser diode, which is a double hetro structure.

Laser diode is operated in forward bias; here your objective is to apply the reverse bias across the extrinsic region. If we apply the reverse bias here, so this one is negative; so I apply negative bias, and this one positive here. So, reverse bias, than across the intrinsic region here you have the same field. What is the gain by this structure is l, earlier my l have just 100 quantum wells I had, and I the thick as only one micron or two micron has l. Now l is 50 to 200 micrometer; therefore I do not even need any quantum well structure. This is not quantum well structure, this is not quantum constrain stark effect. This is Franz-keldysh effect. I apply an electric field the absorption of this region shifts, the change is small, delta alpha now will be 10 to the power of 3, not 10 to the power of 4, delta alpha is small, but my l is not one micron 100 micron.

So, we can realizes the same extension ratio, even by Franz-keldysh effect under this configuration, this is called wave guide configuration of electro absorption modulator, wave guide configuration of EAM; electro absorption modulator. So, the structure looks like this, it is a ridge, elevated ridge. We make a ridge, because we want beam to the confine, it not otherwise if you do only this it will become planar wave guide, and that is why we are made are ridge. So, that if you see the optical mode optical energy will confined here like this. So, is a ridge which is carrying light, so this is the optical mode. One last point, is the alpha that you have, the attenuation co-efficient alpha effective will equal to alpha a in to gamma, alpha a is the actual absorption co-efficient of the material, which we shift effective is equal to alpha an into gamma, where gamma is. In laser physics which is called confinement factor, or overlap factor, confinement factor.

When you lunch light of some intensity i, note that because of the optical mode the fraction of energy is outside this layer, not the entire energy is in alpha a, alpha a is attenuation co-efficiency, actual attenuation co-efficient of the material, but the energy is not seeing is this alpha a, a fraction is outside. The outside fraction docent see any absorption co-efficient, because the material outside is a higher band gap material; that is not absorbing, and therefore the actual effective alpha. We have to substitute here, effective alpha to calculate the real extension. Typically this gamma is anywhere from

0.5 to 0.9. So, it is not very simple, but a cross section factor needs to be applied, to take that now you have an optical mode. In the earlier structure I showed you a beam passing through the quantum well.

It was not a mode, but now it is optical mode, and therefore a correction factor gamma is required, this gamma is less than 1. Typically 0.6 0.7 0.8, 0.6 to 0.9 is the gamma. Please see the thickness is very small 0.2 micrometer, and therefore even if you apply 1 volt 2 volt, you will get 20 kilometer per centimeter electric field. So, a all switching voltages required are only few volt 1 to 2 volt, today commercial device are available, and just one to two of switching volt, for electro absorption modulator. we will discuss the actual structure a little latter, when I discuss about laser package, this come in butterfly packages what are called 14 pin butterfly packages, we will discuss and how the device actually look like, is look like small i c a very small (()), we will stop here.