**Advanced Optical Communications**

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**Module No. # 01**

**Lecture No. # 17**

**Laser – III**

In the last lecture, we saw that inside a material, there are three processes which takes place, namely the spontaneous process, the stimulated process and the absorption process. And then we saw that the stimulated process takes place on its own.

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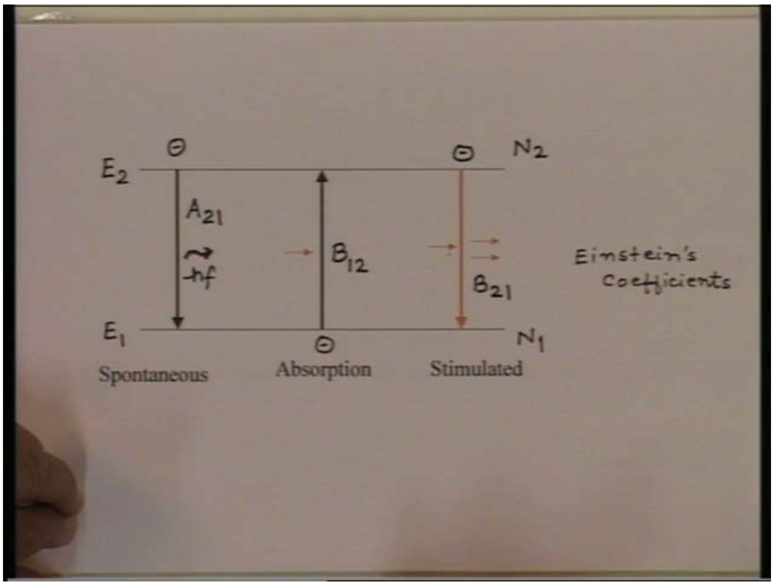


So, if the electron is there in the higher energy state, the naturally it has tendency to relax to the lower energy state and in that process of photon is released which we call as spontaneous photon. Then the two processes which take place in the presence of a photon, that is, the absorption process that is when the photon is incident on the material, the photon is lossed an electron makes an upward transition. In the other case this photon may stimulate a downward transition of the electron and in that process we have 2 photons which are emitted. And these two photons have same properties as the original photons, one other words these two are the coherent photons. And then we saw that this process is more like a multiplicative process, because one photon can create two photons and then two photons can create further photons and so on.

So, once this process start taking place the spontaneous emission does not have much scope the show off. And that is the reason in the following discussion, we essentially concentrated only on two processes, one is the absorption processes and other one is stimulated process. And then, we quantitatively load the equation of the growth of the photon flux as the function of time. You also saw that inside a material the probability of and upward transition and downward transition in the presence of photon is equal. That means, when the photon is incident, we cannot predict whether this photon will get lost, an electron will make an upward transition. Or will the photon stimulate this process and are this process to emit one more photon.

And then we saw that, if this process has to dominate then we should have more electrons in the upper level. And then we saw some three energy level systems and four energy level system and so on. And from there we concluded that, we can manipulate they energy levels and the life time of the electrons in a different energy levels. So that, there is net, what is call population inversion. Let me, there are more electrons in the upper state compare to the lower state and there in the presence of a photon, the stimulated process will start. And then you will have the coherent emission coming out of the material. With this understanding, then we wrote the equation for the growth of the photon and then we said the rate of change of the photon flux that is now difference of the downward transition and the upward transition.

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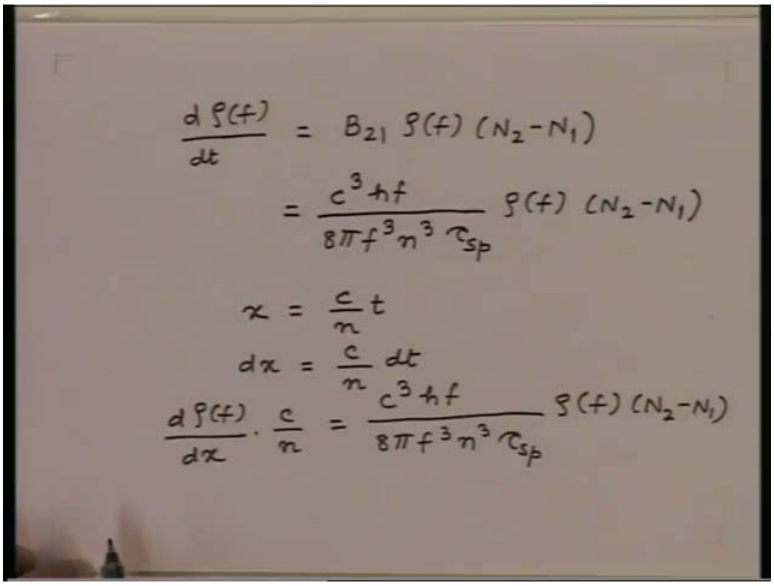


So, this is the probability of the transition, this is the density of the photon flux and N 2 and N 1 are the electron densities in the upper and lower energy states. And then, we also had found out from the black body radiation, that this quantity B 2 1 can be return like that in terms of the life time, what is call the spontaneous life time. And then we saw that when the photon is there inside the material it is not stationary, it moves with velocity of light. So therefore, we have distance travel by the photon which is velocity of light inside the material which as refractive index and multiplied by t.

So, we could convert this equation which is with respect to time in terms of distance x. So that, if equation was converted into this equation which was further simplified to get an equation which was this.

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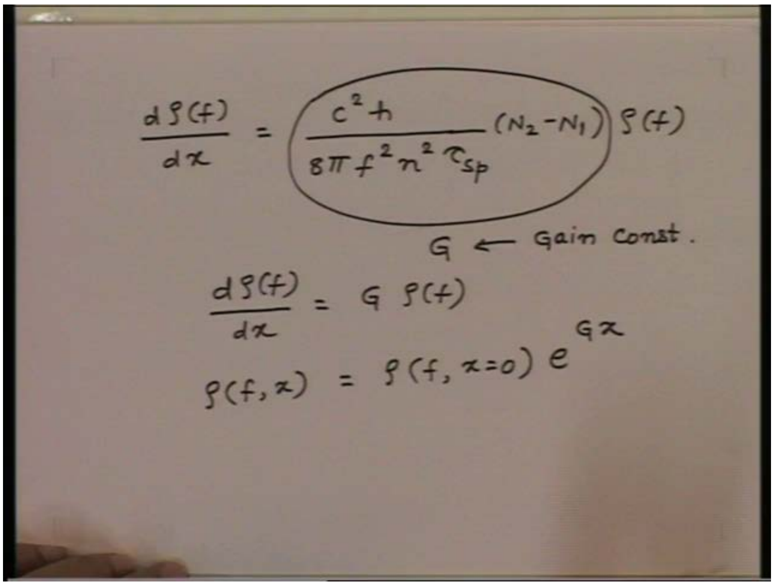


So, we had a differential equation for the photon flux as the function of distance which could be return as some constant G multiplied by the photon flux. So, this says that, the photon flux growth exponentially or decade exponentially depending upon sign of this G when it travels inside the material.

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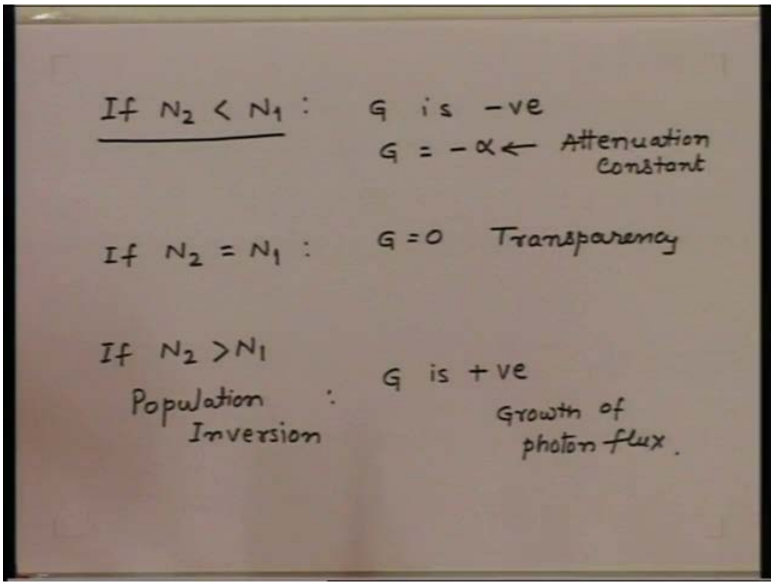


And then we saw 3 conditions, that is, if N 2 is less than N 1, then this G is negative, then the photon flux essentially exponentially dies down as you travels and the material. And this quantity there, one can call as the attenuation constant so, G will be negative so, G is equal to minus alpha. Whereas, if you are having N 2 is equal to N 1, then the photon flux which is incident now the material. Essentially, the same number of photons come out so, not that internally nothing has happen to these photons. Again some photon got absorption some photon got emitted and so on.

But the net photon flux which is coming out is same as the net photon flux which was impinging on the material, this condition then we call as the transparency condition. So, in that process the G is 0 so, photon flux neither grows, nor decays when it travels inside the material. And third condition we had is, if N 2 is greater than N 1 which is the condition for population inversion and that is what we are interested in. Then G becomes positive and then the photon flux grows exponentially inside the material. So, what that essentially means is that, as the photon travels more and more inside the material and if the population inversion is maintained, then the photon flux will go on increase in exponentially.

So now, at this status essentially we want to now create a mechanism by which the photon can be made to confine more and more inside the material. And when it is travels more and more inside the material, its number of photons grow. So, essentially have a growth of radiation which is the coherent radiation. Before we get into that aspect, let us look at this quantity here, which we call as the gain coefficient which is this. This depends upon firstly this quantity which is the frequency. It also depends upon the spontaneous life time which is tau s p and also depends upon the refractive index of the material and of course, the population inversion which is N 2 minus N 1.

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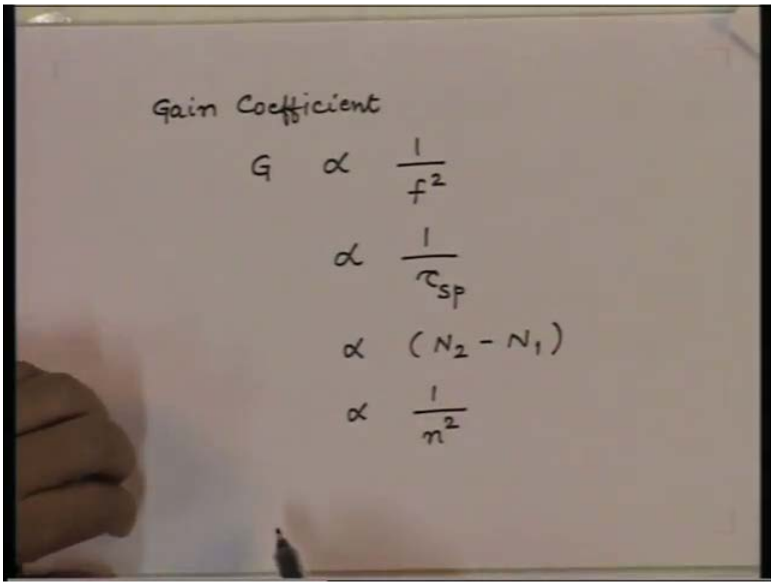


So, if you want to write explicitly this quantity gain coefficient G, this is proportional to 1 upon f square. This quantity also proportional to 1 upon tau s p and is proportional to the population inversion which is N 2 minus N 1 and is proportional to one of the refractive index square. Seen the refractive index square is nothing, but dielectric constant of the medium, the gain is inversely proportional to direct constant of the medium. But if I look at now these parameters here, what you find is for the given parameters like population inversion and spontaneous life time in so on, the gain is inversely proportional to square of the frequency. That means, lower the frequency higher will be this gain.

What an other words what that means is that, a system can be laser very easily at low frequencies compare to the high frequencies. And that is the reason creating a laser at low frequencies or longer wave length, a relatively easier. Then making the lasers to operated low frequencies; high frequencies or shorter wave lengths. So, later on we will see that, when we are having material, which are having various energy levels and in the population inversion is created. Then, longer wavelengths will have a tendency to less faster and one they start lasing, essentially the population inversion which is created get diverted to the amplification of the longer wave length signals.

The second thing to be noted here is that the gain is also mostly proportional to thus spontaneous life time. That means, shorter the spontaneous life time, higher will be the gain, what that physically means is that if the tau s p is small. That means, the electrons are naturally willing to jump down, even if this stimulated process was not there, it would have jump down, because spontaneous process, because tau s p is very small. So, electron is eager to make a transition which is downwards and which makes this stimulated process easier. So, you get higher gain, but at the same time, if the electron is willing to jump down even without the presence of another photon or without stimulated process.

That means, we will have lot most spontaneous emission which will be coming out of the system now. But in other words lot more electrons are going to may downward transition or population inversion will deplete very fast. So, you have to keep replenishing the electrons at much faster rate, if this quantity is small, but by doing this essentially we get the higher gain into the system. Then of course, we have the gain proportional to the population inversion and it depends upon the dielectric constant also. So, at this stage one can now say that, if electrons make transition if there is a population inversion. Then depending upon the frequency and the spontaneous life time, the photon flux growth will change inside the material and the radiation will grow exponentially as it travels inside the material.

So, up till now essentially, we were seeing this whole process, the stimulated process as the amplification process and infect this process is an amplification process. So, if you recall, when we start a discussing this process, we said this photon which comes here. It triggers this transition down; this whole process is stimulated by this photon which is incident. So, if this photon is not there, then of course, this process will not get stimulated and there is no question of this two photon getting generated there is no question of stimulated emission.

So, when we are trying to use this system as an amplifier, that is what principally laser is, it is light amplification by stimulated emission of radiation. Then, this photon is supplied externally, that is the photon which is to be amplified, that is optical signal which is to be amplified. But when we are discussing now this source laser, we want this laser to generate light. For optical communication of course, we may use laser for amplification, but at this point of time we are looking for an optical source. So, what that means is that, now this photon which is going to trigger this process is not going to come from outside.

If the photon does not come from outside, then of course, this process cannot take place. But if you note that if the photon was not present here and if you create population inversion, that means if we create more number of electrons to the upper level, then naturally this will make a transition and this photon will be emitted. Once this photon is emitted now, the photon is available and this photon now can trigger a process which will be stimulated process. So, even if one transition takes place here, the photon is going to emitted and now this photon is capable of starting this process which is this stimulated process.

But what that means is now that the seed which is coming for the stimulated emission is internally generated due to spontaneous emission and since this process is only an amplification process. One of the characteristics of this photon which is created by the spontaneous emission, they are going to reflected into this photons also. Because this process is essentially creating more number of photons, which are having same characteristics as the original photon. Now, this photon which is making because of this transition here, is an incoherent radiation, because this photon which are spontaneous emission. They do not have relation with respect to each other so, they do not travel in same direction, there is no special coherency between these photons.

So, you will see that, if these photons were not specially coherent, even the photon which are going to be emitted here will not be specially coherent. So, if this seed has to come from inside, then the emission which were going to get even because of the stimulated process will not have the special coherency. Temporal coherency will be there, because we are taking about very sharp discreet energy levels. Later on we will see that, the spontaneous process inside a material like semiconducting material these bands are not sharp and this photon also will have a spectral width. And then we will not have even temporal coherency into the stimulated emission.

So, first thing what we not here is the seen the seed is coming from inside. Though, amplification is going to be there and number of photons are going to be large, they will not have complete coherency. But the same problem we had in other amplifies also, when we talk about electrical amplifiers. When we have an amplifier we can always convert an amplifier into an energy source which is called oscillator and then also the signal is generated internally because of noise. Then, if you want to create the coherency, which electrical signal which means creating sinusoidal signal from oscillator, what do we do? We essentially get their output signal and have a frequency selective feedback.

So, the photons, which are generated, which are of random nature, which are spontaneous nature in this case, they will give you amplification. And now if you make sure that all the photon which are going to come here, do not get amplified, but very selectively the photons are feedback into the system. So, the gain is selectively for certain frequencies, then essentially the coherency into the system is increased. So, the first thing what we have to do is, we have to create some kind of a frequencies selective mechanism so that, the coherency into this radiation can be increase in the system.

Now, coming to the semiconducting material lasers, if I look at this expression here which is the gain coefficient is quantity (No Audio From: 18:09 to 18:16) give this all parameters here, the spontaneous life time which will become the non radiative recombination life time here. This is the frequency which will depend upon the band gap of the material, but the quantity here which is N 2 minus N 1, this is nothing but the injected carriers in the p n junction under the forward bios condition. So, if we inject the electrons and holes inside the junction, then this quantity N 2 minus N 1 equivalently means that, I have electrons and holes for available for recombination.

And this can recombine and once the photons are generated because of this spontaneous recombination, then this photons can trigger the stimulated process. And there will be much faster recombination would take place which will give the stimulated emission. So, this quantity here N 2 minus N 1 is exactly same as the product of the electron density in the conduction band and the whole density in the wireless band. And we have already seen that this quantity has a spectral distribution which is nothing but the l e d emission. Now, what we find is that, this quantity here N 2 minus N 1 which we have, it has spread in the energy and this exactly is same as what we see for the l e d.

But in other words what we are saying is, that this quantity here gain which we are talking about, now, that is going to have a shape which will be similar to what we have seen for the l e d spectral. So, the gain function essentially goes has, what we have seen for the l e d?

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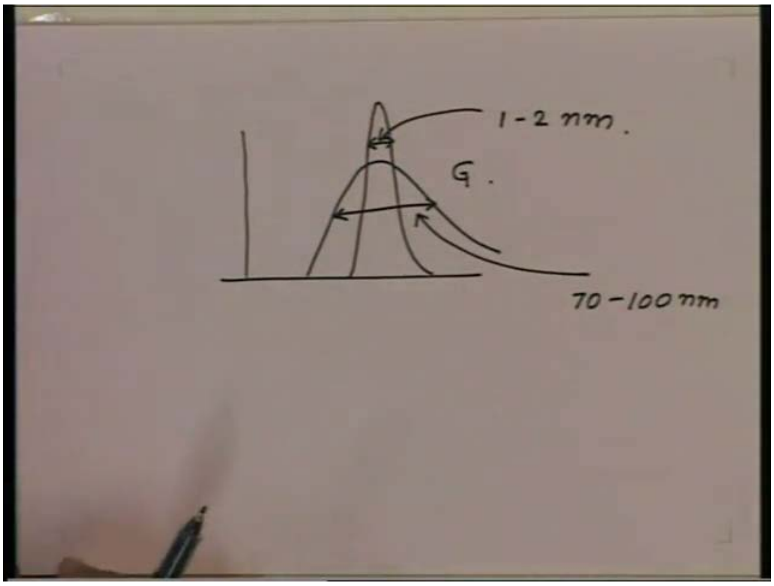


So, it has a variation which goes something like that. This is now going to be the gain variation, because this function essentially is controlling this quantity here which is N 2 minus N 1, but since this quantity here G is now writing on the exponent of this. If I write down the spectrum of this photons flux as the function of frequency, that will be much sharper compare to this, because now this is not the spectral distribution of the photon flux. Photon flux has a respected distribution which is e to the power this quantity G. So, we get a photon flux distribution which will be much narrow or like this one other word the spectral width of this is going to be much much smaller compare to the spectral width of this.

So, first thing which we have noted for a l e d, that l e d has very large spectral width and which is not very good for optical communication because it gives large dispersion. We now see that, if we take the same semiconducting material and trigger the stimulated process inside this. Then the spectral width of the photon flux will reduce considerably, because this function here now is going to write on an exponent. So, as we seen this spectral width for l e d was typically of the order of about 70 to 100 nanometer. Where as if you go for the spectral width of laser, then this spectral width will be typically of order of about 1 to 2 nanometer.

So, idea here is very simple now, that we take the same p n junction, inject the carriers inside that and when the recombination take place, the photon which are going to be generated because of this spontaneous recombination. They will trigger the stimulated process and if the stimulated process dominates over the absorption process, then we will have a stimulated emission coming out of this. But the spectral width of this stimulated emission will be much narrow compare to the spectral width of the spontaneous emission. (No Audio From: 23:11 to 23:17)

So, one reason for which we wanted to go for lasers and that was the reduction in this spectral width that has been achieved by the spontaneous emission here. So, the same p n junction l e d, if we do some manufacturing tricks and if we inject in a current inside the p n junction, then we can get an emission out of this. Which will be having a spectral width which is much smaller compare to what otherwise it would have given. So, one purpose has been achieved in this process. Second thing now coming to the efficiency aspect of l e d, there we saw that, the photon which are born can move arbitrarily in different directions. And because of that very small fraction of photons in merge out of this device which lie within the critical angel cone and that is very efficiency of this devices very very small.

Let us now see, how that has been taken care of in this process. So we are mention here, if the whole process is started by the spontaneous emission and just spontaneous emission is isotropic in nature. Then the radiation which is intrinsically going to be coming because of even for stimulated emission will be isotropic in nature, there is no special coherency. So, how do you introduce special coherency and as I said special coherency can be introduce by giving certain feedback. So, putting the photons back inside the system only for certain directions and making the photons leave, which are not travelling in that direction. If you could do that then essentially, we have created the special coherence into the system. So, the sort precisely is done here.

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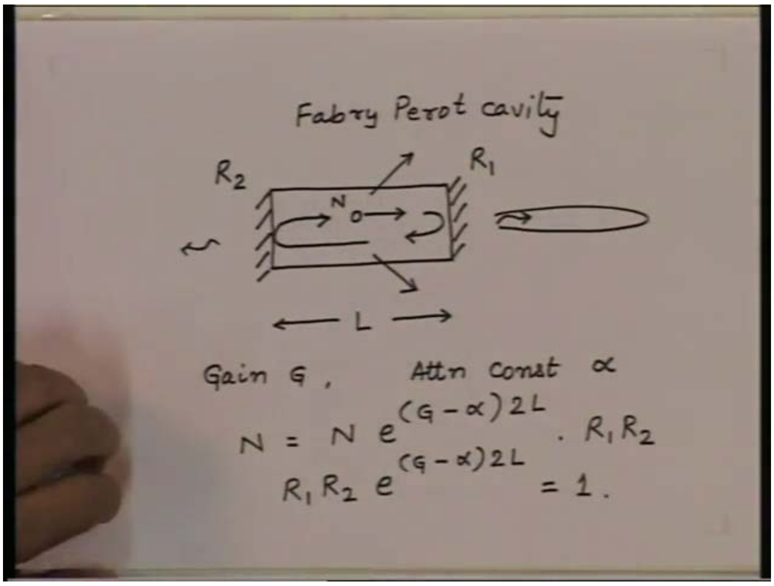


So, let us say now we are having a medium, in which the amplification takes place. So, this material excited, you have got population inversion inside this. And let us say the photon, because of spontaneous process is created. This photon has a probability of moving in all direction equally so, certain photons will move in this direction also. So, let us say a photon moves in this direction. Now, when the photon reaches on this one, let us say we put a mirror on the phase of this medium. So, the photon will reach up to this point and will get reflected from this. The photon will travel all the way back up to this phase and weight comes to here let us say, if you had a mirror here also, the photon will come will get reflected again and travel back inside this.

So, the photon which has travel perpendicular to this mirror say if these mirrors are parallel, then the photon which are moving in this direction, will come back to this location here. Whereas, if the photon is not moving perpendicular to these two plains, it will move, and it will simply get lost. So, those photons which are moving in this direction, they will get lost. They will not be confined inside the medium whereas, the photon which is moving perpendicular to this mirrors, it will be confined inside the medium. And as we saw that if the photon is confined to the medium it travels more distance inside the medium and therefore, it grows in number.

So, this photon which are moving in this direction, they will travel short distance said the medium. So, they will get amplified during this process, but after that they will be the medium and they will lost. Where as the photon which is moving in this direction will travel this distance which is much longer compare to these photons and therefore, will grow in numbers substantially. So, what we have done in this process? We have essentially diverted the amplification process though, only the photon which are moving perpendicular to this planes.

So, let us say in general case this mirrors are not completely opaque, they are not reflecting complete number of photons. Because if that happens the photons are completely confined inside this box and no stimulated emission will come out of the system which is not even use. So, we want that whatever photons are moving and this exponent fraction of photon should leak out and those photon which are leaking out will have same characteristics as the photon which are confine inside this region. So, let us say if we start some N number of photons from this location they move in this direction let us say, that travel distance L and then the again come back to the same location.

So, in that process, they would travel distance which is equal to 2 L. Also if the reflectivity of this mirror is given by R 1 and the reflectivity of this mirror is given by R 2. Then the N photons we started from this location, would grow exponentially which is N times e to the power G into total length travel which is equal to 2 L. But the part of the photons are going to leak also from here and from here. So, the photon which are going to be confined here will be multiplied by this reflection coefficient is R 1 similarly, reflection coefficient here R 2.

Also it is possible when the photons are moving inside this, there will be some other mechanism by which the photon make get lost. It may recombine it may again get lost because of the recombination or because of absorption. So, we have a stimulate process which gives you gain, but there are many some other process which might create a loss for the photon. So, we have a gain inside the system let us say this is G and we are having attenuation constant for this material which is let us say given by alpha. So, when the photons move inside this, we will has a net gain coefficient which will be G minus alpha.

So, now one can say that, if we start with N photon from here after one round trip, the photons which reach here will be N e to the power G minus alpha into the distance traveled which is 2 L, multiplied by the reflection coefficient, which are R 1 and R 2.

Now, if we want that the whole system is a study state condition that means, even after leaching this photons out, the total number of photons which are confined inside this region. There is unchanged is a function of time, then the number of photons which started from here that should remain same after one round.

But other words what we are saying N should be equal to N e to the power G minus alpha, into 2 L, multiplied by the reflection coefficients which is R 1 R 2 and will cancel. So, essentially we get R 1 R 2 e to the power G minus alpha, into 2 L is equal to 1. This is then condition for the sustained oscillations inside this region, which is same as the Barkhausen condition for an electronic oscillate. So, if this condition is satisfied, then the photon flux neither growths not dies as a function of time inside this region. So, considering all losses inside this medium and also the partial reflection, which are going to take place from the mirrors? If this condition is satisfied, then you will have the net flux of the photons constant inside the region and also the net photon which are leaking out will be constant.

So, we will have a constant radiation coming out of this system, which will have same property of the photons which are inside this. And inside this region, the photons are coherent so, this radiation which is coming from here also will be coherent. So, intrinsically we had temporal coherency, because spectral width of that was very small. It corresponded to the energy levels, but originally did not have special coherency. And now I putting this mirrors here what we have done is, we are introduce the special coherency. Because now only the photon which are moving and this directions, they get amplified, but the photon which go in this direction do not gets significantly amplified.

So, this emisssion which is coming out from here will be specially coherent also. On the other words radiation comes from here will be highly beamed radiation. So, it will be narrow beam in which the radiation will come out from this, because this radiation corresponds to essentially the photons, which are bouncing back and forth between these two mirrors. So, this is the very important condition for the sustained oscillation inside this region. Now, when we look the photon here, the photon up till now we were treating more like a particle and we talked only about the number of photons and so on, but photon essentially is an electromagnetic wave.

So, when we are saying the photon is moving from here and then coming back like this and going like this. Essentially, the electromagnetic wave is bouncing back and forth between these mirrors. So, if the electromagnetic wave travels at distance, which is equal to 2 L, it under goes to a phase change. So, after one round trip, even if the total number of photons are conserved, that means, this condition is satisfied, but if the phase of the photon after one round trip is not multiples of 2 pi. Then the photon which is reaching here after one round trip will not be phase with the photon which is born there that instant of time. So, these two fields will cancel each other when other word it will have a destructive interference.

So, for a sustain oscillation only this condition is not adequate. This condition should be there, but in addition to that, we must also satisfy the phase condition for this wave which is travelling inside this. Now, not here this is the bound structure were having a bound medium here and this wave is travelling inside this. So, essentially we are talking about a propagation of an electromagnetic wave inside a bound dielectric medium which is nothing but wave guide. So, we have here propagation of light inside this medium and this structure is like a wave guide extractor.

And since we are putting some reflecting boundaries on the two ends of this, the electromagnetic wave is reflected from here and at bounds is back and forth in this. Or a other word this structure essentially has become a resonant cavity of electromagnetic wave. And therefore, this is what is called the Fabry perot cavity so, we have here (No Audio From 37:40 to 37:49) cavity. So, this structure where photons are confined by putting the mirrors on two sides of this is what is call the Fabry perot cavity.

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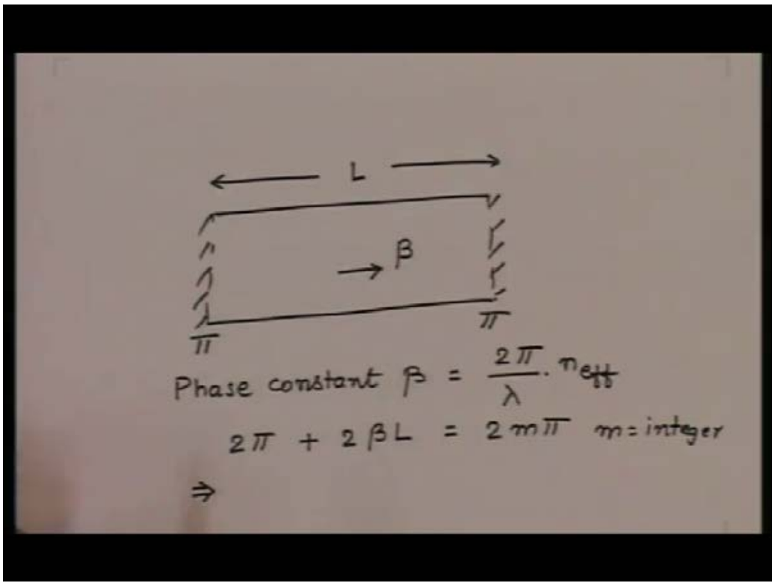


Now, what we are saying this, we are having now a wave guiding structure which is like this and electromagnetic wave is going to move inside this. And then you are going to put the boundary conditions here in the form of mirrors which will reflect the wave. So, we will have a resonance inside this structure. Now, with no come or basic knowledge of wave guides that electromagnetic wave when it is travels inside this bound; medium. It may not travel like a uniform plane wave, it travels in the form of molt. So, it is certain distributions in the transpose direction, which is this direction and will have a propagation constraint in this direction. And we know the propagation constraint is characterize by the wave length of that mode inside this wave guide.

So, you can say that, you have now the phase constant which is in this direction which is given by beta. And beta which is phase constant which is equal to 2 pi divided by lamda is the wave length, multiplied by N effective of this medium. Now, note here we are using the term N effective and not that refractive index of this medium, because when the electromagnetic wave travels inside this, it is going to travel in the form of modes and the velocity will not be same as uniform plane wave in that medium. So, if we calculate the ratio of the velocity of light in vacuum to the velocity of light of a mode inside this medium, that number will not be same as the refractive index of the medium. But that number is the one which we call as the effective refractive index. So, for a particular mode of this wave guide, we have a refractive index which is given by this.

So, now what we are saying is, if the length of this thing is L and let us say, you are having the mirror which are completely reflecting mirrors here which introduce the phase shift of pi. So, we got a phase shift of pi here, a phase shift of pi here and the wave as traveled distance which is 2 L into beta. So, the net phase change which we get in this process in one down trip that will be equal to pi plus pi which is 2 pi plus 2 beta into L. And we are saying for constructive interference this phase change must be equal multiples of 2 pi. So you want 2 m pi, where m is an integer, we can absorb this 2 pi on this side. So, what that mean essentially is that, if this condition 2 beta L is equal to multiples of 2 pi integer multiples of 2 pi.

Then, we will have a constructive interference and then we can have the oscillator working and getting a core and emission out here. So, for a coherent emission to come out or the laser toward, we should have two condition satisfied. One is this condition which is R 1 R 2 e to the power G minus L, into 2 L equal to 1. And second condition which is a phase condition, we says that 2 beta L is equal to multiples of 2 pi. We can substitute now from here.

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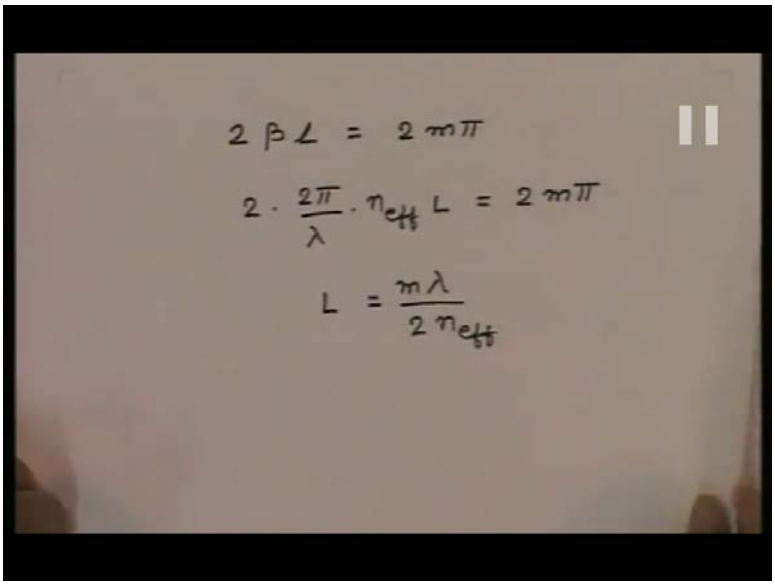


So, you want a condition 2 beta L equal to multiples of 2 pi which is 2 m pi. We can substitute for beta so, 2 into 2 pi divided by lamda into n effective into L that is equal to 2 m pi. 2 pi will cancel so, you will get L from here that is equal to m into lamda upon 2 n effect. So, what that means is that there length of this cavity should be multiples of lamda by 2 divide by the effective index of the material. So, there what it means is, that if the length is equal to lamda by 2. Essentially, we have a standing a pattern inside this resonator.

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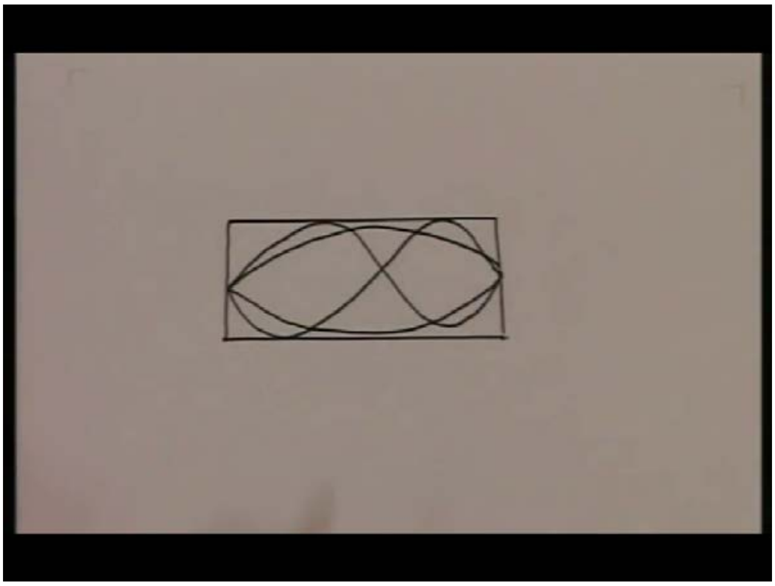

So, this is the cavity, the field has to be 0 at this two ends, where reflections coefficients you have taken as minus 1. So, we can have a pattern, how look like that, if this is equal to lamda by 2 which will be the first resonance or we can have like this which will be second resonance and so on. So, what that means is, if the material has population inversion and if it has lent L, then we can have many values of m which mights satisfy this condition, but note here that m is an integer. So, essentially the discreet wave lengths would satisfied this condition. So, even if you are having a population inversion which can amplify a broad radiation, every frequency within that band will not satisfy the phase condition.

And as we seen that, the profile which we have got for the emission photon flux, which looks something like this. What we are saying now within this band also where the amplification is taking place, every frequency cannot satisfy the phase condition. So, by and large the gain condition will be satisfied by this profile, but phase condition will be satisfied only discreet number of frequencies or wave lengths within this spectral. So, let me exaggerate this picture little bit.

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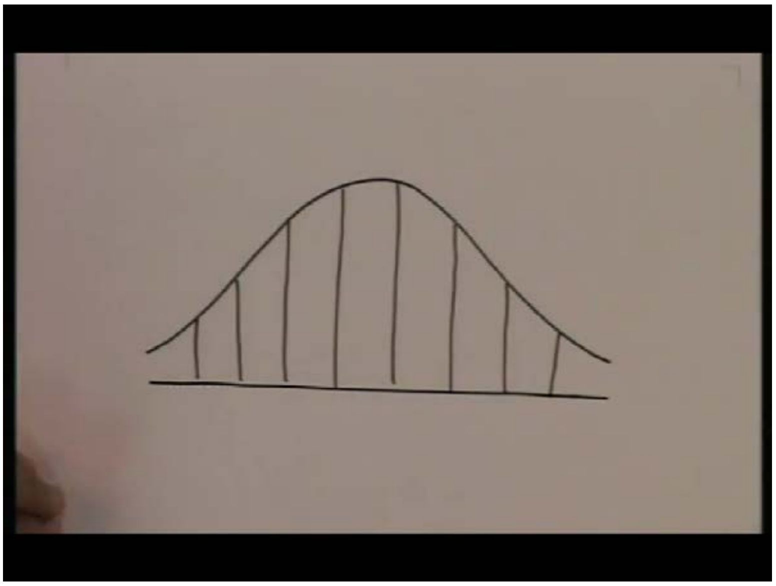

We say that, the spectrum is like this which we get because of the population inversion and all other parameters of the material. Then, within this spectrum certain frequencies only will satisfy the phase condition. So, a spectrum will not be continues spectrum for the laser emission, it will be essentially set of this spectral lines. Because these are the lines which will satisfy this phase condition this phase condition here. So, two things should be noted here, when we talk about an emission from the laser. That is although we are having the population inversion which has a very large energy range as you saw in case of l e d, it gives you spectral width of about 70 to 100 nanometer.

The same population when generates stimulated emission, it has much narrows spectral width because that N 2 minus N 1 that function essentially writes on and exponent. And because of that the effective spectral width of the photon flux is much smaller. Secondly within that narrow spectral width also only discreet frequency will satisfy the phase condition and therefore, even that narrow spectral will not be continues in nature. It will be consisting a set of spectral lines so, then if I look at now the spectrum of this structure.

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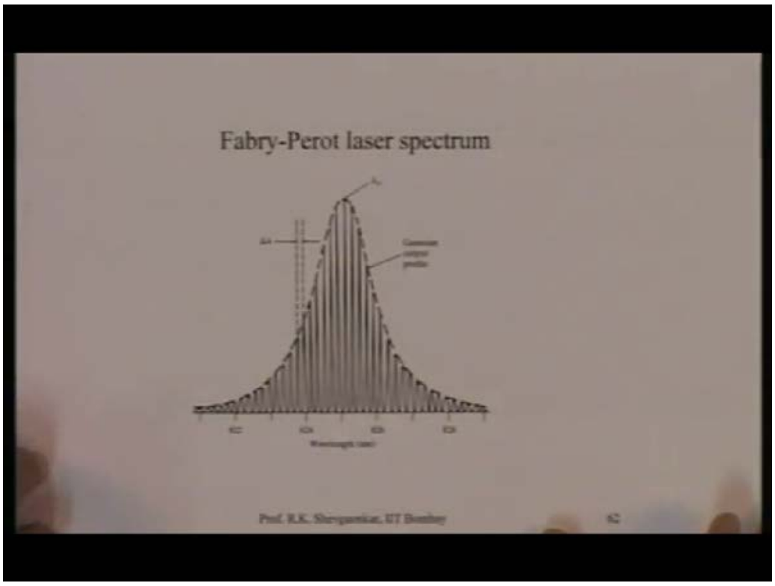


This will actually look something like this. So, you see this is the spectral width, which were going to get intrinsically because of the population inversion and these are the lines, which satisfy the phase condition. So, if you wanted to make a true laser that means, if you wanted to create a single frequency or single wave length from this laser. One of the wave is to create this cavity in such a way that only one frequency lies in this band where the gain is possible and the other frequency lies outside this band so, that will not can amplified.

Or in other word what you a saying is only once fundamental mode can be excited inside this cavity and even if the second mode is not excited, we will get only once spectral line which will be generated by this laser and which will be very very narrow spectral line very narrow spectral width. But if we do that that means, that the length of this cavity here should be such that even m equal to 2 should not be possible. Or in other words, the length of the cavity should be less than lamda of the radiation, which we want to amplifier.

Now, since we are talking about the emission which is typically of the order of about one micron wave length, what that means is, a length of the cavity must be less than one micron. Now, we will note that already inside the p n junction, where the recombination take place is the depression region that as a very small length. If you make this length also which is very small about one micron, then the total volume over which the stimulated amplification takes place is extremely small. So, this region cannot really sustain a very high photon flux density. So, in principal it is possible there by reducing the size of the Fabry perot cavity one should be able to excite only one line.

And therefore, get a very narrow spectral width of the laser where is in practice, the length cannot be very very small. And in other words is the length not very small many more values of m would satisfy this condition. And typical spectrum from the laser would look like that. So, by doing this, we have got significant improvement in the characteristics of radiation, we got a very narrow spectral width compare to l e d. Also as we have seen earlier, we now created the special coherence so, the photons are now going to come out which are perpendicular to the mirror.

And they are going to come in a cone, which is very narrow and if this cone now is much smaller compare to the critical angle cone for the material, most of the photons will come out of the system. What in other words, we got a large efficiency for the device. So, what we conclude from here that, if you take a semiconductor p n junction and if you make the stimulated process to overcome the absorption process, then the stimulated emission will have a very large efficiency. Most of the radiations will come out this radiation will have much narrow spectral width compare to what one would get from l e d. And therefore, this source will be much superior compare to the l e d for long distance communication.