Semiconductor Optoelectronics
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Lecture - 33
Laser basics

In the next couple of lectures, we will discuss about the semi conductor lasers. So, today I will discuss basics of laser or laser fundamentals. Some of you would have done a course on lasers, but some of you would not have done. So, this is basically reviewing laser physics and recalling the fundamentals of lasers. So, let me start with the basic question what is the laser?

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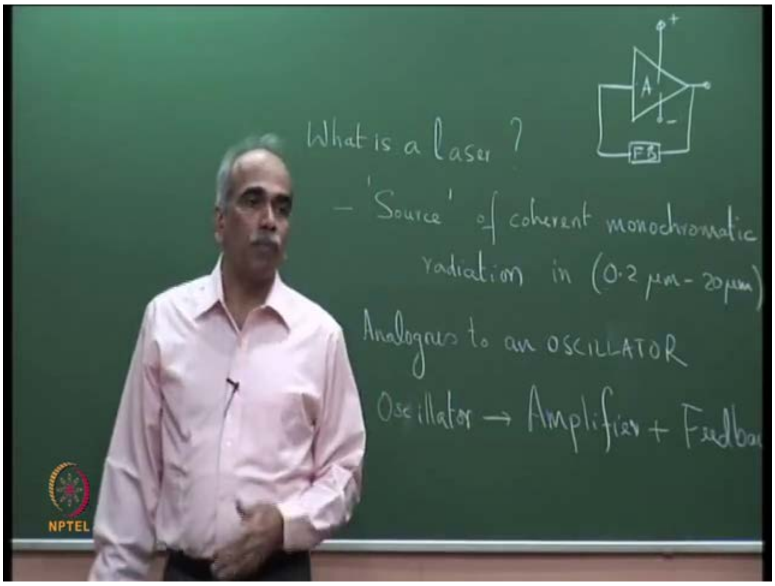

And we all know, what is the laser? Laser is a source of coherent monochromatic radiation, in the optical region of electromagnetic spectrum. So, laser is the source important point here is it is the source, it is the source of coherent monochromatic radiation. Radiation in the optical region, so in typically optical region means approximately 0.2 micrometer to 20 micrometer approximately.

There is no in this region, it is the source on monochromatic radiation and it works on the principles of laser that is light amplification by simulated emission of radiation. When it is a source it is a analogous, it is analogous to an electronic oscillator to an oscillator. So, it is analogous to oscillator an electronic oscillator is a source of RS and we know that an oscillator is comprises of an oscillator is basically an amplifier and a feedback amplifier plus feedback.

An amplifier followed by a feedback circuit gives you an oscillator. So, typically you could show the oscillator by an amplifier A here, with as an output and with feedback circuit, feedback. It general oscillator has an amplifier, it is an active device an active device and a feedback circuit. The active device is able to provide amplification and when you power it for example, you have supply plus minus.

So, this forms the general oscillator, the feedback circuit may have RC or may have inductor, may have capacitor and so on. But therefore, laser is the source of radiation in the optical region of wavelengths and it is analogous to an oscillator, therefore it has an amplifier and a feedback circuit. Amplifier in general consists of an active medium or active device which is pumped which is powered by a power supply. Therefore, in general the 3 important components of a laser the three components of the laser.

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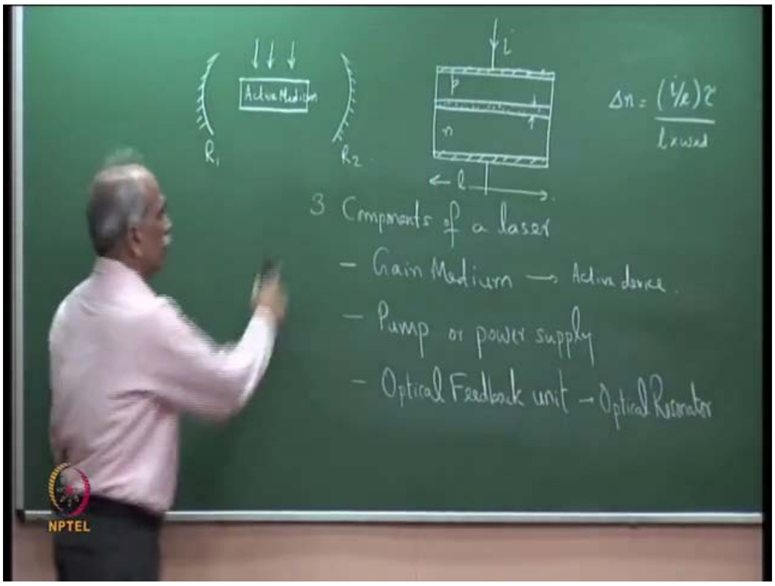

In general this is not necessary semi conductor laser, any laser has 3 components. First the gain medium the gain medium or the active medium which provides gain when pumped. And therefore, you need pumped pump or power supply and an optical feedback optical feedback unit. These are the 3 components, this could be an active device which provides amplification when powered properly or when pumped properly.

And then optical feedback unit this is optical resonator optical resonator optical feedback unit this is nothing, but optical resonator.

These are the 3 components of laser. So, when the active medium is pumped it provide gain and the resonator has a certain loss associated with it. Whenever gain exceeds loss you have net amplification (( )) at the laser can start oscillating. So, let me show a general schematic of the laser both for bulk and semi conductor. So, let me and then have a comparison, in general if you take bulk laser say Nd-Yag laser. There is an active medium the active medium which is pump externally may be by flash lamp, may be by another divert laser external pumped.

And the amplifying medium is placed inside an optical resonator between to media. Let us say of reflectivity R 1 and R 2 and this forms the basic schematic of a laser the bulk laser. The semi conductor laser also have almost similar structure, so we have the schematic, the active medium here I am not drawing all the layers. So, these are the electrodes, this is the longitudinal cross section longitudinal cross section of our laser and this is our active medium. And current flow through this forward bias PN junction is a current I, this is p, this is n and there is the electrode.

We know that if it is pumped properly, when the injection of current is sufficiently large. We can have the separation between Fermi levels, please recall that delta n is equal to I by e into tau divided by l into w into d where, d is the thickness of the active region, w is the width for the front side if you see, and l is this is l. So, depending on the current through the device, delta n can be large and if delta l is large, the Fermi level the separation between the Fermi level can be large enough.

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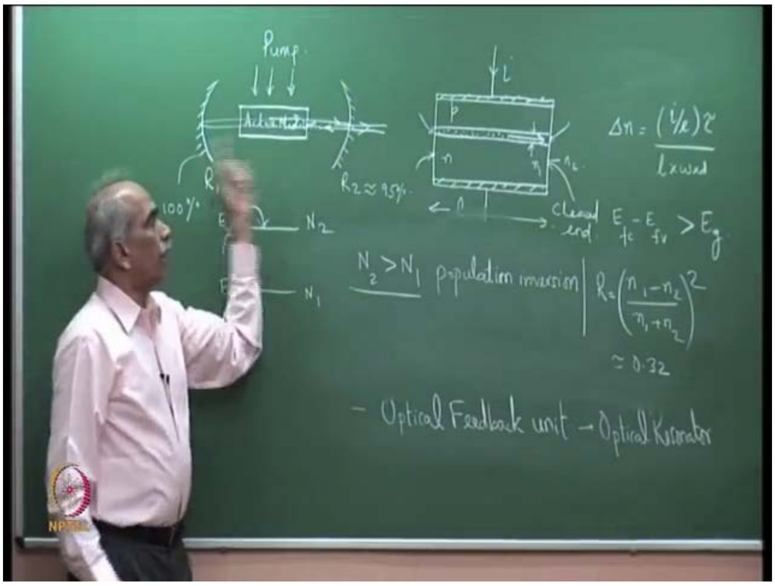

So, that we have the situation, where E f c minus E f v is greater than E g or greater than h nu. So, in this situation you can have gain in the medium. So, the gain medium here, the active forms gain medium, when you pump it sufficiently, strongly to reach such a situation. In this case we should an atomic system, so gain is for simple terms. So, if you are with familiar with laser physics. It is a if you have N 1 and N 2 as the number of atom per unit volume in the energy level E 1 and E 2.

If you pump sufficiently hard that is raise atoms from the ground state to the higher state through mechanism in a 2 integral normally. You do not have steady state oscillation, but through some mechanism if you pump and create a situation where, n 2 is greater than n 1 which is called population inversion population inversion. We have gain, so this medium become a gain medium this becomes a gain medium. That is why you are pumping externally to the pump here, just taking the same role as the current.

And the pumping leads to population inversion, it is possible to have population inversion which means this becomes the gain medium this becomes the gain medium. Here the gain medium is placed inside the resonator, so that there is light which is travelling in this direction. Guess feedback light which goes in this direction could come back which acts as an optical feedback. Because, the same light is spread into the gain medium, the same thing happens here, if you cleaved ends, this is the cleaved ends. So, cleaved ends both the ends are cleaved.

Cleaving is the initiating a break along epsilon of plain. So, that it results in mirror light finish. It is not cutting it cleaning, so you have to scribe and initiate cleavage, when crystal is cleaved along a crystallographic plane. You have perfectly reflecting inner like surfaces. So, if you have this medium reflecting index n 1 and this medium reflecting index as n 2 which is outside air. Then the reflectivity here, at this end light which is generated which reaches this end has the reflectivity R which is equal to n 1 minus n 2 divided by n 1 plus n 2 whole square.

And if you put the numbers as we already discussed if you 3.6 here, 1 here outside you get approximately equal to 0.32 that is 32 percent reflectivity due to the cleaved ends. In normal laser do not have any mirrors at the end and the feedback is obtained by the 32 percent reflection at the feed at the 2 ends of the cavity. So, in this case the cavity is here, so the light goes back and forth. The optical resonator, the mirror the active medium placed inside the mirror here forms the optical cavity or the resonator.

Where, as in this case the active medium with the 2 cleaved ends here this end here and this end here. Cleaved ends form the optical resonator, it acts like the mirror. The reflectivity’s are just about 32 percent, but in a bulk laser normally you have 1 of the mirror almost 100 percent reflectivity, very high reflectivity. And the other 1 partial reflectivity of approximately 90 percent or 95 percent, because so that a part of the light goes out. In every reflection part of energy goes out which forms the useful light for you. For which I redraw the same diagram again, if we redraw the schematic here.

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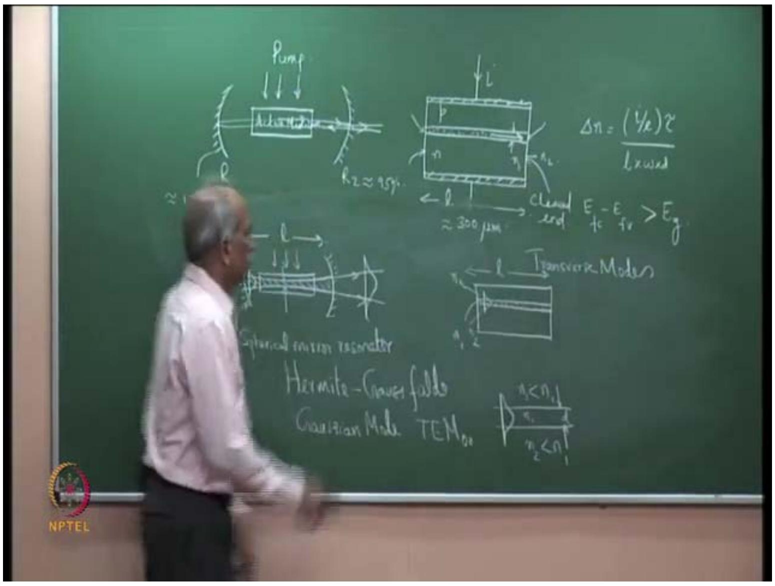

Therefore, the laser would look like this, so you have the active medium and just again drawing the other than showing there. So, you have the laser beam which is going back and forth, and the part of that coming out. So, this is are the 2 mirrors and this is the beam which is formed here. The rays which are going back and forth, if you have spherical mirror, you can show that in a spherical mirror resonator spherical mirror resonator.

You can show that the most of the resonator are hermite gauss fields or leger gauss fields hermite gause fields. Fundamental modes of this family hermite gauss fields represents the whole family of the modes. The fundamental mode of this is the Gaussian mode T E M 0 0 mode, those of few are familiar, this is transpose electromagnetic mode. The fundamental mode is T E M 0 0 and this is a feal profile which is like this. So, what I am drawing here is the amplitude distribution and the same mode is coming out here.

So, the bulk laser is I have taken a spherical mirror resonator typical, Nd-Yag lasers are of this form. You have the mirror radius of curvature could be above 80 centimeters 100 centimeters is a radius of curvature. it is almost flat and the Gaussian beam forms the resonator mode and this is the active medium which is placed which is pumped. If you see the semi conductor laser, let me draw a gain. Here also there is a optical mode which is formed, the mode here is determined by the optical wave guide.

Recall that this active region has the higher reflective index n 1 and the cladding regions have the reflective index n 2 which is less than n 1. So, it is like an optical wave guide a simple slab wave guide, so this is n 1 and this is n 2. So, n 2 is less than n 1 and n 2 is less than n 1. The modes of this structure are actually cosine and exponential, but they also look like this. Approximately, the feed inside is cosine and outside it is exponentially decaying.

You can solve the Maxwell's equation for this with the boundary conditions and you will see that they are cosine inside and they are exponentially decaying fields outside. So, the mode fields will also look like a Gaussian, this is not a Gaussian, but almost look like a Gaussian. So, in this case the modes I am referring to modes transverse modes so the transverse modes. We have one more mode which is for the longitudinal modes, transverse modes transverse modes are determined by the reflecting unit n 1, n 2 and the thickness t.

And here is a Gaussian? Gaussian with a waste width here which is again determined by the radius of the covertures of the mirrors here. And the separation d, separation l, so this is l in this case this is l, I have shown you here although, I have shown almost of the same size. A typical Nd-Yag laser l is order of 1 meter big Nd-Yag lasers, there are compact lasers also divert pumped solid state lasers or now quite compact, but still may be 10 centimeters, this l here is approximately 300 micrometers. So, this is very small, very compact and this is big size, but I have shown this together just to bring out a comparison.

And those of you have studied laser physics can immediately relate the 2. So, this is regarding the structure, so the basic structure has an active medium which is pumped and there is the resonator. The resonator determines the modes of the structure, the modes of the laser. We will discuss the resonator a little bit more, but let me first discuss about the gain. It is the gain medium play in an optical resonator; let me first discuss little bit more about the gain. And then we come to the modes. The simplest basic laser theory is very simple, basic laser theory is quiet simple laser dynamics.

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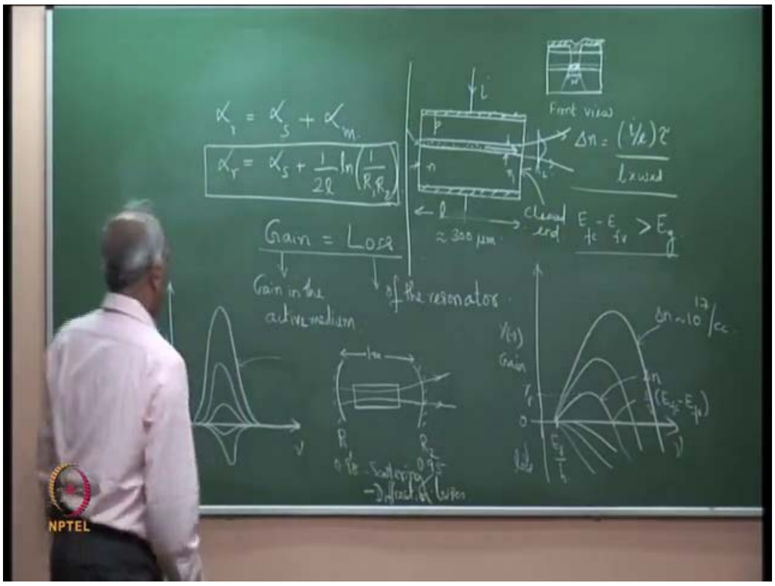

Laser dynamics or laser theory at steady state, because there are transient analysis which is a more involved. At steady states the laser theory is just this types gain equal to loss, I will simply write gain equals to loss. The laser theory is very simple gain equal to loss, gain here refers to gain in the active medium the gain in the active medium or laser loss here refers to loss of the resonator or in the resonator. First let us discuss about gain we had seen for a semi conductor laser.

So, let me draw for semi conductor laser and just for comparison let me also draw the bulk laser. So, this is mu versus gain codification gamma of mu, we had expressions for gamma of mu. So, this is gamma of mu and this is. So, semi conductor laser if you pumped the laser, so that this condition is satisfied. Then we had work down in detail that you have gain profile which goes like this. Then it will becomes (()) starts approximately around E g. So, this is for a particular current or a particular delta n, some value of delta n.

If you had not pumped then the medium was absorbing recall that medium was absorbing. And therefore, it had some curve like this or maybe it was doing like this. As I pump started doing like this, see pc what I am showing is this is the here it is 0. Therefore, this side it is loss coefficient and that side it is gain this side gain. Hence when gamma is greater than 0 is gain and gamma is less than 0 it is loss.

You have not pumped than the medium of absorbing, we are discussing this in detail and the absorption coefficient is varying like this. Stating from E g and increasing energy, if you starting pumping and you are able to maintain this, then gain will become positive, so this value here correspond to this value mu. Then this is E g by h so e g by h and what was the value here energy correspond to here E f c minus E f d. we therefore, 1 by h into E f c minus E f b.

So, the bandwidth was this region, this region called amplification band width. Amplifying the frequency range over which we can get amplification and this is the p gain equation, this is gamma p. We pump harder, that means if we inject more forward current, then this would go up. And this will also go up because the separation is increasing I plot for that for another value. So, what I have plotted here is gamma as a function of delta n, different values of delta n. And recall the expression here, so if you know what is the current.

So, if you are sending 50 milliampere, 100 milliampere then you can immediately calculate what is the delta n? Because e is to know this is the combination time. These are the dimensions, so d is this thickness, so l is this one and w is width from front side. So, recall that let me show briefly here, the front side then you have, if I place the electrode width, if you replace the electro width blocking layer here silica, then this is how the carrier still flow.

And therefore, this is the region where you can have gain in the front view front view. This is longitudinal the profession, so this is that light is coming like this in this case light is coming to the sides light is coming here. So, I have than the field distribution which is coming out. So, this width here is w, this is w typically 5 to 10 micro. So, you can substitute the value and find out what is delta n if you take for typical materials than this delta n is order of 10 to the power of 17 per cc.

Practical numbers you can put some numbers for laser amplifiers and that is of that order delta n correspond to 10 to the power 17 per cc. So, as you pump the gain available increases, gain band width increases. Those of you done laser physics course you would know that this case also when you have not pumped to the medium you would have a loss which is characterized by this. And you start pumping than this increase, becomes smaller than beyond a certain pumping is a you will have the gain curve showing this.

Usually symmetric in the case of atomic systems the same thing gamma of mu as a function of nu. And these step normally they correspond to either Lorantzian which corresponds to homogeneously broad and median and or Gaussian. So, homogenously or in homogenously broad and media give spent of. So, they are showing this because they are identical what are this curves? This are gain curves for different pumping powers different pump powers, here it is gain curve for different injection current and therefore, different delta.

They are identical if we study 1 laser system that is why I showed that comparison. There is also mirrors here also you have mirrors, no separate bulk mirrors, but mirrors is formed by curved ends of the semi conductor laser. So, gain equal to lose this is what we know, what is the gain, What is the loss? The loss of the resonator, what kind of loses do we have. If I take this balk resonator here, so loss in the resonator the beam is going back and forth, the mirror have finite reflectivity of R 1 and R 2 may be almost 1 or 0.98.

That means, 98 percent reflecting and this is 95 percent say I have to number just taken example, R 1 and R 2. This is the separation may be 1 meter and this is the medium, the beam is going back and forth in the medium. When it goes back in forth in the medium there are 2 types of loses which you encounter. One is catering losses in the medium and medium they can be catering because of homogenates they can be catering loses in the medium. And second loses because it is a finite beam using there is the diffraction losses.

So, you have catering loses and diffraction loses and loses due to finite reflective of the mirror. It is 95 percent reflecting mean 5 percent is going out. This 5 percent is your useful output power, but as far as a resonator is concert resonator is losing 5 percent from this side 2 percent from this side. So, mirror are also the loses and therefore, you can show the loss qualification I will not go into the details of the derivations, but the resonator losses comprises of alpha s to plus alpha m. This is primarily due to scattering in the distraction and this is due to mirror.

So, this is equal to alpha s plus 1 over 2 l ln 1 over R 1 R 2. You can show this I leave this an exercise, it is simple derivation shows that the mirror loses 2l into you can see that if the reflectivity is the 1 that is 100 percent reflecting R 1 equal to 1, R 2 equal 1, ln 1 equal to 0. So, there is no loss due to mirrors, but reflectivity cannot be 1 and we do not want it also 1 because we needs useful output coming. So, this is the resonator loss, we have already derive the loss coefficient for expression for the gain qualification.

So, if you equate gain equal to loss that is it you get the expression for gain coefficient and gain equal to loss gives you the laser dynamics. So, what is this gain equal to lost let me write and explain me again very quickly, just recall it the basic laser physics. I am sure most of we have done those of done it is just here revision and those who had not done please refer properly at book.

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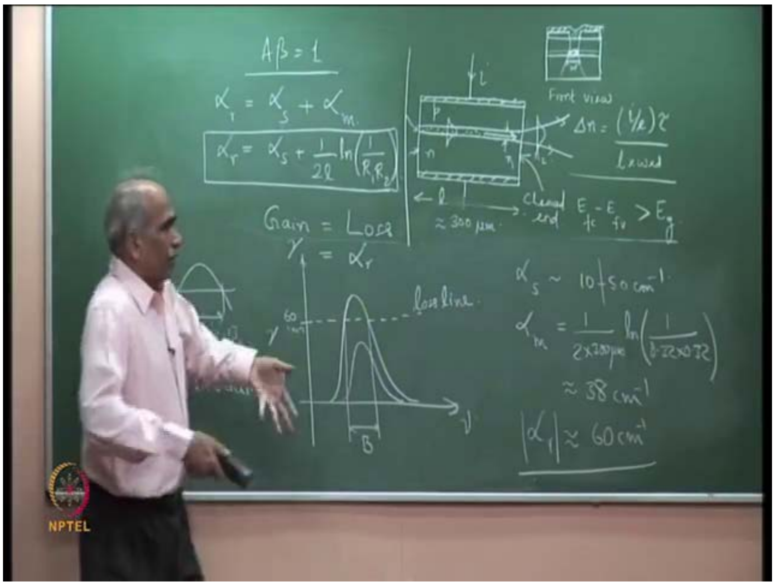

If I plot now for example, let me give you some number into the case of semi conductor into the case of semi conductors alpha s is of the order of 10 to 50 centimeter inverse. The scatting and diffractions losses is the order of this actually there are no diffractions losses because this are guide structure. In the case of bulk resonator there is no guiding without the beam is just going in free space where as inside the resonator, but here it is guided wave guide does not have diffraction.

So, there is no diffractions losses, but there are losses due to the wave guide scatting and imperfection at the boundaries and so on. So, that is typically in this range and it is substitute this alpha m is equal to 1 over 2 into 300 micrometer in here into ln. You substitute this 1 over 0.32 into 0.32 and we will see that this is approximately 38 centimeter inverse. You calculate and see that it is about 38 centimeters inverse, almost similar order as it. And therefore, the total resonators loss alpha r is approximately by 38 and 22, let me take somewhere between in 22 just make it to the round figure.

It approximately 16 centimeter inverse, just get feel for the number of what types of number that we have talking about alpha r. And we want gain equals to lost means what gamma much be equal to are alpha r gamma of mu much be equal to alpha r, which means to have gain equal to that mean you require a gain of about 60 centimeter inverse. If you want gain equal to lost satisfied, now what is happening? If I plot this more of alpha r, this is actually gamma and alpha r is actually negative minus gamma.

And but if I plot more of gamma here than 60 is here let us see this 60 centimeters inverse. So, this is shown we are plotting this as a function of frequency; the quantity is here are generally independent of mu over the range of interest. The reflectivity and the both alpha n and alpha s are almost independent of mu over the region of interest. What do you mean by the reason of interest? We call that the amplification bandwidth that we had calculated some number and I had said that we had calculated approximately into 10 to the power of 12 to10 to the power of 18 hertz the band width for semi conductor laser.

So, this is we have also seen the this is very small compare to the light frequency itself which is 10 to the power of 14 into 10 to the power of 15 hertz. And therefore, over this small range of this frequencies this does not change and you normally see looks that pro got at line like this and all this are loss line. So, what is loss line? Loss line is value of loss in the resonator if you start pumping the laser the gain is here, gain is less than loss. So the laser cannot (()).

If you pumped harder than you could for another pump power you may have the gain curve exceeding the loss curve with which means for these frequency is here. This frequency over band width b you have gain more than the loss it is the condition for starting of oscillations. You calls the electronic oscillations which have the (( )) criterion A beta equal to 1 when oscillations of minus 1. A is the amplification beta is feedback ratio, so A beta is equal 1, but the time starting oscillations A beta should be greater than 1.

And then due to saturation non linear saturation this will come out be 1 at that steady state. This is how the electronic oscillations work exactly, like this that you pump harder this gain will exceed the loss lines, but due to gain saturation gain saturation this is the dynamics. Actually, the gain saturation is the dynamics, I would origin to understand this clearly, but I do not wish to digest too much explain to you what is gain saturation. But gain saturation simply means whenever the gain is larger this will be pulled down by the dynamics, by the dynamics of the system this will be pulled down. What do I mean by dynamics?

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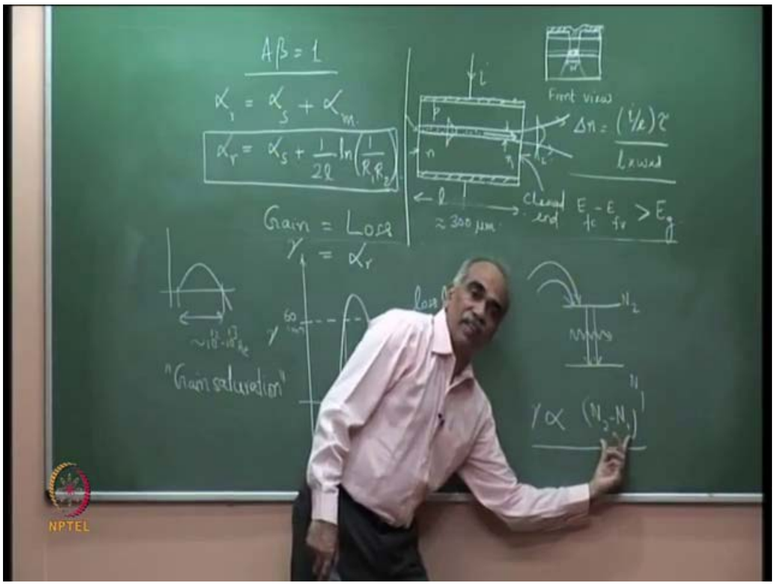

I do not want to get into, alright let me very briefly explain they cannot go so much into. We pump harder which mean create larger population inversion it is easy to understand here that is why I am showing you. Therefore, N 2 minus N 1 here, becomes larger which means gain becomes larger, when gain becomes larger than more radiation laser radiation intensity increases, when lasers radiation intensity increases here it will bring down more and N 2 downwards.

Therefore, N 2 minus N 1 decreases we see the gain coefficient gamma is proportional to N 2 minus N 1. If the laser intensity in the cavity increases it will bring down more atoms downward and more stimulated emissions. When more stimulated emissions occurred the N 2 decreases. And therefore, N 2 minus N 1 decreases, and therefore, the gain is pulled down.

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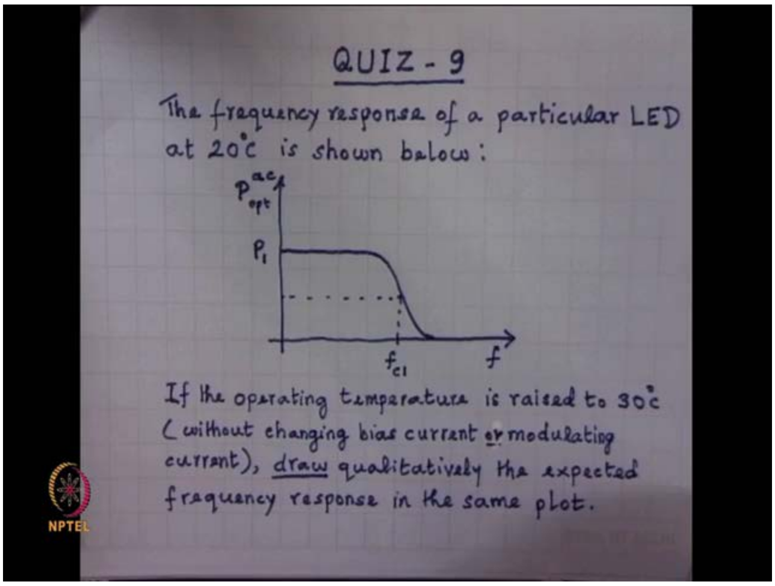

In others word at steady states equals to what I have drawn here is if I independent show you the loss line and independently show you the gain curve this is.

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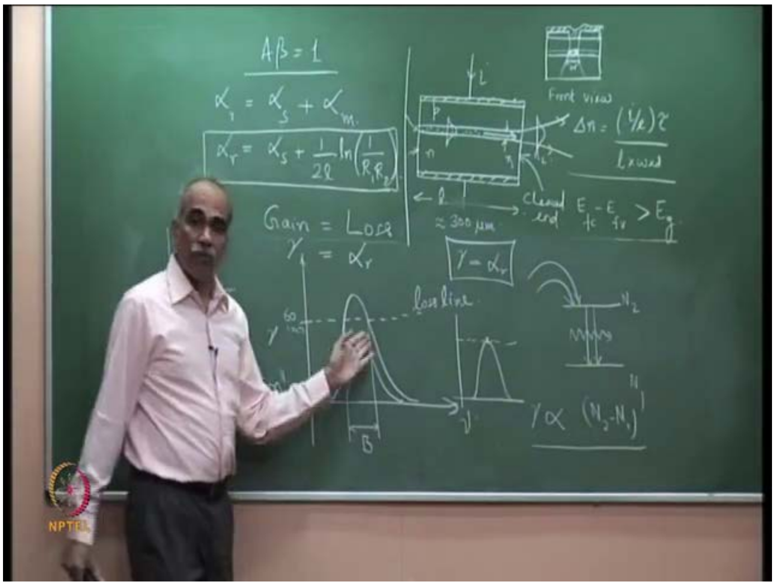

But, when a laser is oscillating in steady states the graph is this. This is the loss line and this is the gain curve that is when laser is oscillating steady states gamma is equal to alpha r always. Irrespective of the power output of the laser when a laser is oscillating in steady state, but gain coefficient is equal to loss coefficient that is why I written gain equal to loss.

There are you have to understand the more how this is, this is called gain clamping and gain is always clamped at that value, depending up on homogenously broaden or inhomogeneous broaden. There are what are called hole burning in the gain profile and so on. Let me not a going to this.

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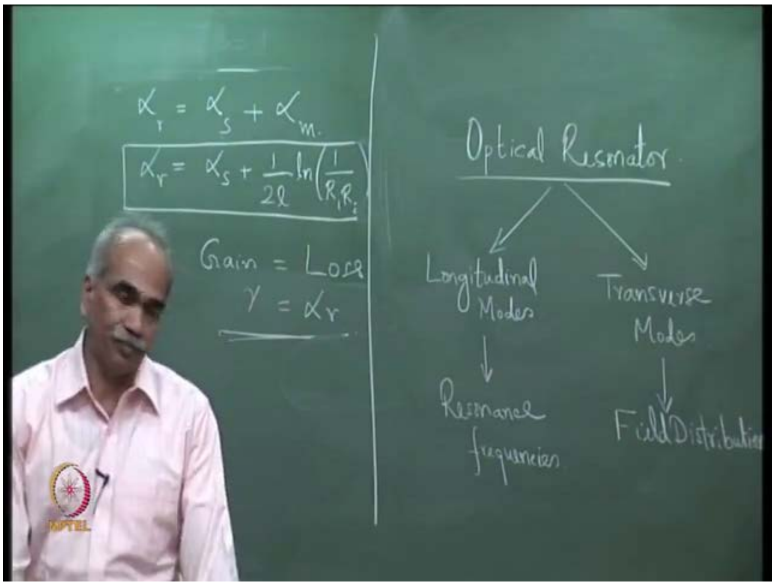

So, the main point is this when the laser is oscillating, gain equals to loss or gain co efficient is equal to loss co efficient. This is as far as the amplifying medium is concerned. So, the amplifying medium is the active medium which when pumped appropriately gives you gain.

Now, the second component is the optical resonate optical resonate the optical resonator determines 2 things that is the longitudinal modes, and the transverse modes longitudinal modes and transverse modes Longitudinal modes refer to resonance frequencies I will explain it in minute resonance frequencies, and transverse modes refer to field distributions or the modes.

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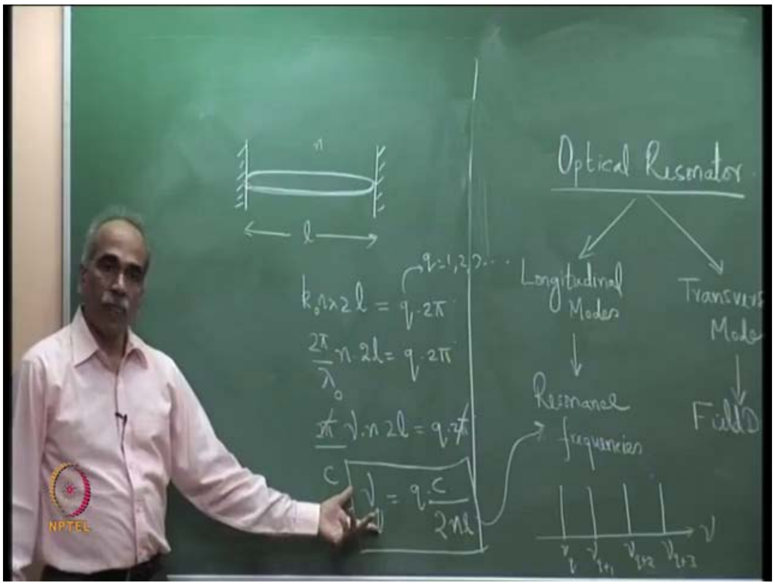

First let me talk about the longitudinal modes or resonance frequencies, of simplicity I will show the plain resonator this is l here. When light go back in forth inside the resonator it is going back in forth only those frequencies which satisfy. The round trip face equal to integral multiple of 2 pi will build up, because any light which is coming back after 1 round trip if it add in face with light which is generated.

Then it will start building up therefore, the condition is round trip face is k naught into 2 l equal to 2 l because round trip must be equal to integral multiple of 2 pie q times 2 pie. k naught is the if there is a medium of refractive index of n. Then you have to write k naught into n, if there medium of refractive index. So, 2 pi by lambda 0 into n into 2 l is equal to q into 2 pie. This lambda 0 I can write as C by nu. So, this is 2 pie into C into nu into n is the refractive index, q is the integer, q equal to 1 2 3 integer nu into n into 2 l is equal q into 2 phi. 2 pi 2 pie goes, so what you have left with this is nu q is equal to q times C divided by twice n l.

These are resonance frequencies, the resonance frequencies are allowed frequencies which build up inside the resonator. The resonator supports certain discrete frequencies which build up inside the resonator and they are given by the resonance frequencies I have added the suffix q to say that the q th order. So, if q is equal 1 it is the new 1, so what is this what we are showing is if you we are plotting on the new axis only the certain frequencies are allowed to build up.

These are called, so this the nu 1 or nu q nu q plus 1 nu q plus 2 nu q plus 3 and so on. The resonator determines which are the frequencies which will build up inside the resonator, because of the round trip face matching condition. These are the resonance frequencies, now let me complete this discuss of resonance frequencies.

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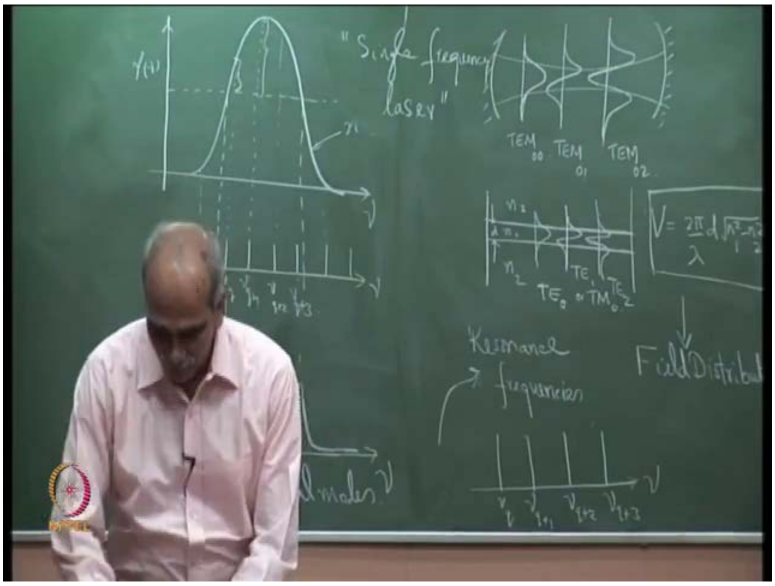


I just now showed you that for if this the gain, gain curve gamma of nu. This is axis nu gamma of nu and this is gamma of nu and if the loss line is here alpha r. Then all the frequencies which are in this range, they have gain more than loss. However, this amplifying medium has been placed inside an optical resonator, the resonator allows only certain frequencies. So, I just keep this graph here which means resonator stays only this frequencies can build inside.

This says all the frequencies in this range have net gain; however, resonator says only these frequencies are the 1 which can build up inside the resonator nu q plus 1 nu q plus 2 and so on. And therefore, only these frequencies will be there in the laser output, if you see the output of the laser. You will have if you see under the high resolution spectrometer, spectroscope, optical spectrum analyzer then you will see an output which look like this. This is the output of the optical spectrum analyzer, laser output you feed it when the optical analyzer, which mean it is resolving and you will see the output like this. The strength of the mode is proportional to the difference in gain. So, you can see if I take it here it will intersect here, this is the additional gain over loss. For this 1 all this details I will not be able to cover here it is part of the laser course, but it is proportional to this difference gain minus loss.

The strength of these modes in my diagram it should be bigger because I should have been drawn like this. Let me correct it because this is bigger than the other 1 and so on. All though there are other frequencies the resonator allows the other frequencies please see this, resonator allows all frequencies which are discrete. However, these frequencies for these frequencies gain is smaller than loss and therefore, they do not built up inside the laser.

Only those resonance frequencies for which gain is greater than loss build up inside the resonator and in the laser output you can see this. What you see are called the longitudinal modes of a laser. So, these are the longitudinal modes normally, if you take a laser there will be plenty of longitudinal modes. Why I am bringing this concept is we are next going to see special laser structure and divisor which will chose only 1 of them. To make it single longitudinal mode and that is why we have to know?

What is an longitudinal mode? Alright we quickly come to the field distribution and then we will stop we have to take a small quiz. The transverse mode I have already mentioned about the transverse modes I have already talk about this that our field distribution the transverse field profile. If you take a spherical measured resonator you can show that hermite loss field distribution which means fundamental modes looks like this.

The second mode looks like this and the third mode will have a field distribution approximately like this. So, this is T M 0 0. This is T E M 0 1 it depends on x direction I have shown 2 d. So, I can write 0 1. So, this is T E M 0 2, because there is 2 0 crossing, there is 1 0 crossing. So, that is why 1 2 0 crossing that is why 2 no 0 crossing. This is not 0 this is actually infinity is a syntactically going down, there is no 0 crossing. For a bulk laser in a semi conductor laser it is a wave guide which determine what are the modes it can support.

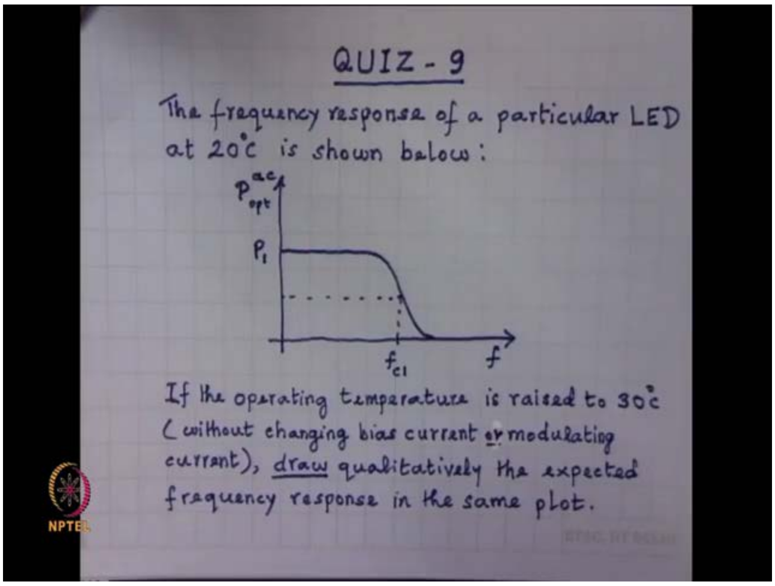
So, this is n 2 as before and this is n 1 and this is n 2. The fundamental mode is this here, so it is either T E or T M. There can be these are T E M this is Tem or Tm. So, T E 0 or T M 0. I do not want to again go into this model details, but you can find out T E 0 or T M 0, T E 1 looks the same way. So, this is T E 1 or T M 1, T E 2 is almost the same way and so on. The point is the mode field profile and how many modes will be there is determine by the optical wave guide.

That is what is the different between n 1 and n 2 and what is the thickness d here? Those of few you studied the optical wave guide you are familiar that there is a V parameter which is defined by the 2 phi by lambda into d into square root of n 1 square minus n 2 square. It depends upon V value for V less than pie it supports only 1 mode, V between pie and 2 pie supports 2 modes and so on. What is important to recognize is transverse modes refer to field distribution by appropriate choice of n 1 n 2 and d.

It is possible to make this oscillating only on a single transverse mode by appropriate measures. We will see what are these appropriate measure and it possible to make oscillate on 1 single transverse mode. A laser that operates on 1 single transverse mode and 1 longitudinal mode is called a single frequency laser. So, we will talk about single frequency laser also, single frequency single frequency laser does not mean it has only 1 frequency there is no source which is a strictly mono chromatic or 1 frequency, but single frequency laser means it operates on a single transverse mode and a single longitudinal mode.

Let me stop here and in the next class we will directly start with semi conductor lasers we have covered almost all the basics everything on the board. In the next class I will start the talk about PPT because we will now look at structures and designs and characteristics. There is no point in spending time on drawing the structure, so we will go over to PPT. Alright we will come to the quiz a very simple quiz very quick.

(Refer Slide Time: 54:36)



Ready all of you are ready here is the quiz, the frequency response of a particular led at 20 degree centigrade is shown below. That is what is shown is a P a c, optical verses frequency that is the normal frequency response. If the operating temperature is raised to 30 degree centigrade without any other change, I have written those bracket you do not have to read. Without any other change only temperature has been raised, draw qualitatively the expected frequency response in the same plot.

First please draw this plot and then on the same plot qualitatively draw the expected frequency response at a higher temperature which is 30 degree centigrade. What would be the shape of the frequency response? Please draw the given curve and then on the same plot, draw the expected frequency response variation. That is optical power ac optical power, we have discussed in the last class verses frequency. As we know the cut of is defined when P a c drops to half it is value, so this typical f c 1 is cut of shown. So, at a higher temperature please plot qualitatively what type of variation is expected no explanation are required, just plot.