**Biophotonics**
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**Module 05: LASERs for Biophotonics**
**Lecture 21: Laser Principles and Operation**

Welcome to the Biophotonics course, we will continue our studies and today we are going to start the new module in which I am going to discuss lasers, lasers for biophotonic applications. Let us get on with it.

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So, if you are someone like me you will consider laser to be one of the most significant human discoveries of the past century, there are several seminal discoveries that humankind have made and that have resulted in a quantum jump from, in the human civilization, the discovery of the fire, the discovery of agriculture, the discovery of wheels.

Lasers are one such discovery that has helped human being take a quantum leap, take a jump per se in advancing its civilization, in advancing its civilization, so to rectify my previous statement in which I said that perhaps lasers are one of the most seminal discoveries of the last century, I would go one step further and I would say lasers are perhaps one of the most seminal discoveries of human humankind during its entire time in this planet.

Laser is all over us, laser is all over us, it is all around us, we use it on a daily basis, obviously, in biophotonic applications you have laser eye surgery everybody of you have heard or you must have been to discotheques, I know some of you most definitely have or you have seen laser source, there are laser welding that we see in manufacturing processes and ubiquitously we see it in laser pointers.

Nowadays, if you have been to any presentation whatsoever you have seen it in laser pointers, so hardly there is any aspect of life that have not been invaded by laser, from military applications, laser based guns, laser aircraft, laser carriers, laser is everywhere and especially this one, especially this one if for those of you who know what this is you are awesome and you know that the force is going to be with you always.

So, let us see how this thing came about what is laser and how did this simply a light a new source of light became this popular, this ubiquitous, this useful and this prevalent all over the planet and have helped us take a quantum leap, take a quantum jump in technology.

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So, some history lessons, well you obviously know who Albert Einstein was, this was the gentleman who first postulated about stimulated emission, I will come to a moment what stimulated emission is but those of you who are from physics or related background will know what laser stands for light amplification by stimulated emission of radiation. So, what is

stimulated emission? It is some kind of a different type of emission other than spontaneous emission, we have discussed spontaneous emission in fluorescence.

So, stimulated emission is a new type of emission which is completely opposite to that of absorption, in absorption the electron, say for example electron at this present moment though other examples are there which I will give, in absorption an electron absorbs, eats a photon and goes to the upper level, electron eats a photon and goes from the lower level to the upper level.

Stimulated emission could be considered as vomiting, I know bad analogy but still bear with me, stimulated emission could be considered as vomiting in which whatever it has eaten, whatever frequency, phase or the property of the photon which it has eaten it will return it back, it will vomit it back, it will emit it back upon activation by another photon of the exact same kind, everything will be clear just bear with me.

This new phenomenon that there is a second type of emission or as they said or as Rudolf Ladenburg who was one of the first German scientist, first Jewish German scientist who immigrated to America during the 1930s due to the prevalent political situation back home in Germany. He coined the term negative absorption, negative absorption, absorption is where light is eaten, light is consumed, negative absorption in is where the exact same light, exact same type of light, exact same photon is emitted is or I is to say vomited.

So, these two gentlemen were seminal in developing the overall theory that there can be a second type of emission, not just fluorescence, remember we discussed fluorescence previously was actually discovered by sir Stokes and later professor Jablonski described it properly and what spontaneous emission is doing.

These two gentlemen came up with this idea that there could be another type of emission as well which is stimulated emission which is equivalent to absorption but opposite in effect hence, they call it negative absorption, hence, they call it negative absorption, exact absorption, exact absorption but in the opposite way, exact in the opposite way.

Spontaneous emission is on the other hand there is a mismatch, whatever is eaten is usually not vomited something else, something else, here it is the same thing whatever goes up comes down upon your intervention, upon your intervention, upon being activated by something else. So, it is

a controlled process or it is something that is a intervatory process it is not just spontaneous or it not just natural.

So, several people were working on similar things since the 1930s and 1940s, the theory was developed by Einstein and Landenberg, later people started working on maser (microwave amplification by stimulated emission of radiation**)** can we have microwave amplification using stimulated emission of radiation and they were able to solve some of the major problem both American scientists were working on it as well as Soviet scientists who were developing it independently, measure was actually demonstrated it worked for a very small period of time, it stuttered and more or less it went along its way.

During the 1950s there was this PhD student, a graduate student called Gordon Gould he was a New Yorker and he was doing his PhD in Columbia University in New York. During his time, during his PhD shift, during his graduate studies Bell laboratories Townes and all were working on thinking of if maser property can be taken into optical domain, mid infrared or even visible range because that would be cool and they will find several different applications and they were working on some kind of a maser like property in visible or infrared and they were debating which one is better, which one is nice, which one is feasible.

When this gentleman this Gordon Gould around 30 something PhD student who was working on his PhD thesis on thallium, the radioactive material thallium came up with the idea that maybe, just maybe we have the technique, we have the operational feasibility, we have the design of something which he coined as laser, light amplification by stimulated emission of radiation, he used the aser part as a suffix, as a suffix and he used it for several different terms radio aser, razor or microwave aser, measure or aser stands for amplification by stimulated emission of radiation, u aser, ir aser but laser is the one which stuck.

So, this guy while talking with Bell laboratories Townes came up with this idea or he already have had this idea and he wrote this in this notebook and this is an interesting story, he wrote this in this notebook you will see the design and he thought that this might be something important, so he went to the nearest candy store, store that sells candies and that had as a part-time business a notary shop, you know notary which affixes stamps, write it in stamp paper.

So, obviously you might have seen this neighborhood corner shop that usually sells this, sells you product sells you sweets but at the back corner there is also a photo copy shop, a mobile phone repair shop, telephone shop, a notary shop. So, he went to the nearest well he is his favorite candy shop, I assume it is his favorite and got this notarized but by the time actually well he left his PhD studies thinking that he needs to prove to get it patented, notarization is not patenting but he started working on making a laser.

But by the time with huge amount of time money and energy Bell laboratories have already beaten him in producing some of the simplest demonstration of lasers and he went into a huge court case with Bell laboratories and others that I was the first and there was huge amount of controversy, he has to wait 30 years for his due to be credited but while these two people were fighting Hughes laboratories Theodore Maiman in 1960 actually utilized ruby, ruby as in the popular semi-precious stone and demonstrated, actually demonstrated the laser or lasing effect.

In the meanwhile there were soviet physicist Aleksandr Prokhorov as such who did seminal work, so there is no one such discoverer of laser, who invented laser you probably do not see this question coming up because there was not one single person who discovered laser, it was an effect of all human beings coming together, maybe not always together sometimes acrimoniously but it is the overall fruit of human genius from all over the place Germany, New York, Moscow, etcetera, all come coming together to develop what we call is a laser and how it has changed the world.

I like to have a reading of the lives and times of these scientists because usually we identify scientists with a particular formula or a particular concept, but remember scientists are also human being, they are living breathing human being, they had setbacks, they had failures, they had preempts they have their own personal problems, they fought in war, they loved music and talking or learning about them humanizes.

For me the overall concept they have developed, a human being is much more complicated than simply E equal to MC square or a concept, that person was once a human being like me and had to go through similar trials and tribulations and how that person have struggled to meet those achievements and despite all his general faults he came up with something this profound is actually inspiring, some people like it, some people do not so if you dislike it just let me know I

will keep the history lessons little less. So, let us understand how laser or what stimulated emission actually is.

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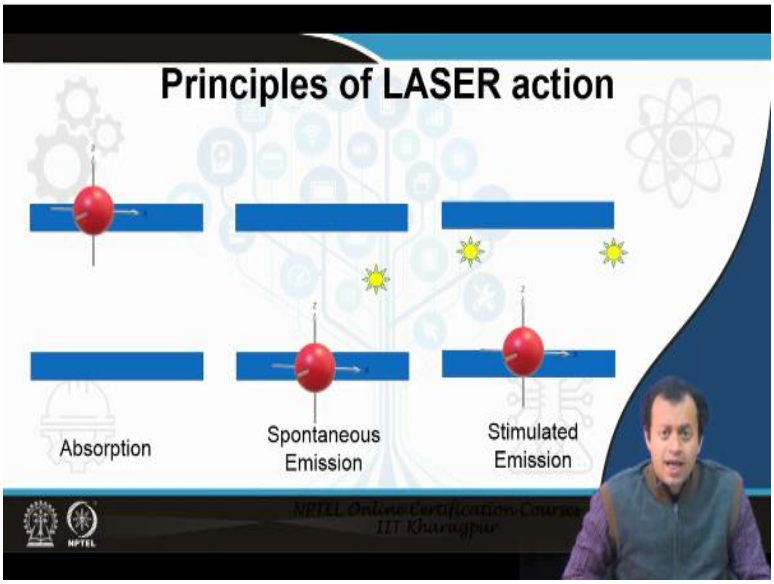


So, we know what happens in absorption, this has been discussed, so you have say for the time being electron at a lower energy level, upon absorption of a photon when a photon is hitting it, when a photon is exciting it, it goes to the upper level, it goes to the upper level and the photon disappears, it has consumed the photon, the photon has taken the electron from the lower level to the upper level.

Provided of course, the photon has sufficient amount of energy, the photon has sufficient amount of energy to at least, remember for your fluorescence lecture at least breach this gap, it cannot be somewhere in between or less, it has to have sufficient energy we are assuming that the energy of the photon is equal to the band gap, is equal to the band gap, life would be easier. So, the photon which has affected or which has interacted with it the electron consumed it and moved to the upper level.

Now, when the electron has consumed the photon as moved to the upper level by nature after some time randomly it will come back to the original place and emit the photon that it had consumed or if you if it is not fluorescence, if it is fluorescence with a different frequency of photon, if it is just elastic, then it will emit the same amount of photon.

Spontaneous emission, two things you need to be clear, this is spontaneous, this happens automatically without any intervention, so the electron goes up, the electron goes up the upper level is unstable after some time randomly it returns back, it can be at any specific time, any random occurrence of time, the electron will return back and will emit a photon, and will emit a photon.

So, this is rather a spontaneous and hence by definition more or less a random emission, we can somehow understand that what will be the energy of the photon and we can also may ascertain that it will be a within a nano second time, 10 nanosecond time, it will be emitted but we cannot pinpoint, we cannot exactly say because it is a random event, if there are thousands of energy levels and thousands of electrons have gone out, all of them might come down within a nanosecond time but they will be of different characteristics, their occurrence within that nanosecond will be at different intervals.

So, all I am saying, all I am saying that this is randomly emitted it will go up upon its volition it will come back and it will emit a photon and we can have some amount of prediction but overall it is uncertain, it is a random event, it will come back and if you have 10 different electrons 5 different energy levels etcetera the photons that is coming out are of different frequency, different phase, different energy as such.

Stimulated emission, now let us talk about stimulated emission. Stimulated emission happens, stimulated emission happens when there is already existing an electron in the higher energy level. Please pay attention this is crucial this you need to know, even physics student that there is an electron already existing in higher energy level and it has not emitted anything yet.

Meaning it has not done any spontaneous emission and it has not returned back to its original ground state or low energy level, it is still in the upper level, it is still in the upper level, while it is in the upper level, whilst it is in the upper level you are intervening from outside, you are intervening from outside with a photon of the exact same energy as that of the band gap, of the exact same energy as that of the energy gap.

You are intervening, you are externally supplying, you are taking a photon from outside, you have figured out what is the gap, what is the energy gap, you have created, you have synthesized

a photon of that particular energy and you are throwing that photon to itself while it is up, while it is still up, remember if it happens in absorption when the electron has come back down and you are supplying some energy it will consume and it will go up.

So, here it needs to be understood that the electron is already up, while it is up you are sending a photon of the same energy that it has previously consumed, so there is no difference in the energy of the photon that it has consumed and gone up. So, when it is already up, it is already full it has eaten till its hearts contain, it is full up till this you are adding more food into its mouth, what will happen?

It will come down and it will throw up, it will vomit whatever it has already eaten, I know very, very bad examples or very, very bad analogies but consider yourself this example, you have eaten full as much as you can, the fullest capacity you have eaten and now I have taken the same quantity of food that you have eaten and now I am trying to show it down your throat, what will happen, now not only you will not eat the next set of food you will vomit whatever you have consumed.

As a result, as a result when you have put one photon, two photons comes out, one photon from the original which is unconsumed that is the food, the next set of food that you could not consume and the food that you have previously consumed that is vomited. I know, I know no one has taught you laser actions using these sorts of metaphors and analogy, yes, I know trust me.

So, two things needs to be clear here, first stimulated emission will only happen when the electron is at the higher level, the electron is at higher level, usually electrons are mostly in the lower level, these levels are higher level, hence unstable, so you know if an electron goes to the upper level after some intervention it always have the tendency to come back, so we do something called population inversion.

All of you know what population inversion is, we try to reverse the process, we try to ensure that the population of the higher level, the population of the electron at higher level is more than the population of electrons at lower level, only then when the electrons are at higher level, when more electrons at higher level then more prominent laser action will take place.

No laser action will takes place if the electron is at lower level, if the electron is at ground level no laser action will take place, laser action will only take place when all of these electrons are at higher level or most of them or a majority of them are at higher level, hence we call that inversion in population.

Usually there are more electrons at lower level, less electron in upper level, here we have reversed the process where more electron has gone into the upper level, some of them have been absorbed or we have sent some amount of energy all of them have absorbed, all of them have consumed and gone up, while they are up we our self while they are up, while they are still up, while they have not come down we are supplying extra energy, we are supplying external photon while they are up and that made the electron throw up, that makes the electron vomit, that makes the electron emit whatever it has consumed before.

It will only happen, it will only throw up if you give an energy or if you give a photon of the same kind that it has previously consumed. Now, since I have lots of students from physics, M Sc and physics doctorate I have a question, what will happen if this photon is of a different energy, will you get a stimulated emission, will you get a stimulated emission if this photon is of a higher energy?

You see this is not part of our biophotonics but I want to ask a fundamental question why do we have stimulated emission, why do we have stimulated emission, why does electron throw up, why does not upon activation by this energy, this photon it goes further up, it could go further up why it is not going?

Please physics student enlighten us, please answer this question I will give you a hint obviously, I will give you a hint this is fascinating but I got some comments that the physics part is quite less, so I am asking your help to add some amount of physics part here.

The idea here I would like to make is say the energy of this electron at the upper level is this difference, energy of this electron is this gap, the energy of the photon is exactly same. So, can I say somewhat that the energy level of photon and electron are same, if the energy levels are same if the energy of this coming photon when the electron is at upper level is exactly same can there be an energy change, can there be an energy difference, think of it like this.

There are two bodies both are at the exact same temperature 23 degree Celsius, 23 degree Celsius you add them together will there be an energy difference or will there be an energy flow or electronics engineer students you know current flow when there is a potential difference, when there is no potential difference, when there is zero voltage what will be the current, when there is zero voltage what will be the current?

Someone of you may say zero current then, so if there is no energy change, if the electron has already consumed this and this energy is only sufficient to take it from here to here and it is already here, then what can it change, what can it interact the energy will not be change the energy is same, can the momentum change, can the spin change, momentum and spins are these fundamental quantities, momentum determines direction, momentums determines direction.

The life science students or biotechnology students need not go into this deep to intervene what stimulated emission is but I am asking a question to those of you who are interested to think about or to understand or try to see what stimulated emission or why stimulated emission is 100 percent or almost majority of books actually tell you what stimulated emission is.

My question is why, why does it happen, why does not it go further up, why does it have to come down, why it did not go to somewhere else, for the time being I will keep it as open question for you to search, I am not Google, I am not going to give you every single answer, in the live session maybe we will have a debate, we will have a discussion regarding this.

But for the time being understand that when you give the same amount of energy that it has already consumed, the term the emphasis is on the term same, same, same, same amount of energy has been given it will come down vomiting what it had already consumed and therefore, you have the original which you have intervened, which you have externally supplied and the electron is going to give you something else, the electron is going to give you the same thing that it has consumed before.

So, you started with one photon you now get two photon. In other word you have amplification, you have one photon converted into two photon and this so on and so forth two becomes four, four becomes eight, eight becomes sixteen you have amplification as this photon propagates by stimulated emission of radiation and this is basically stimulated emission of radiation.

Here two things needs to be absolutely cleared first and foremost as I said we are assuming its electronic states or electrons going up and down, not necessarily for laser action to happen, you can have it with simply molecules, molecules going from a lower vibrational state to upper vibrational state.

Remember your spectroscopy course, lower energy level to higher energy level, lower vibrational level to higher vibrational level, carbon dioxide laser is a prime example which does not use electrons movement up and down to generate photons, it generates vibration levels of molecules of CO2 molecules to generate laser.

Secondly, the lower level does not necessarily has to be ground state, the lower level does not necessarily has to be the lowest state of the molecule, lowest state of the atom, it can be anything below the higher state. So, remember we said S naught, S1, S2, S3 in fluorescence, in fluorescence we discussed all of that levels, the stimulated emission can happen between S2 and S3, the stimulated emission can happen between S5 and S6 upper and lower it does not necessarily needs to be between S naught, S0 and S1, S2 or S3 or S4.

It has to be between any two upper level and lower level, as long as they are upper and lower stimulated emission can takes place provided you have supplied energy matching the energy gap or matching the band gap between these two bands, between these two energy states, it does not necessarily has to be from ground state, from the lowest energy states itself, it can be any state in between that is stimulated action.

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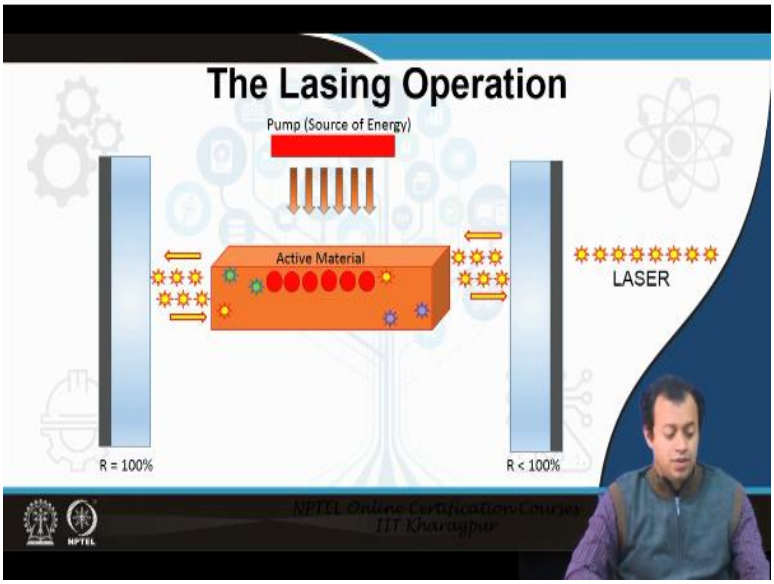


So, pay attention what actually happens in laser, how exactly laser operates. So, in a laser to operate though it is stimulated emission you will see that all three absorption, spontaneous emission and stimulated emission, all three needs to be operated one after another in a actual laser to work.

So, in lasing operation you need three things basically, you need an active material, a material which basically will lase a material which has either electrons or molecules which will go from lower level to higher level, any lower level to any higher level and you will have a pump which is a source of energy that is the one which will give you external photon, that is the one which will energize not necessarily external photon but it is a source of energy you will see why, that will energize the electrons in the active material or molecules in the active material to go from lower level to higher level.

This is the source of energy that this will intervene that this will consume and go up and you will require two sets of mirrors, you will require two sets of mirrors and this thing this two mirror in between which you have put the entire active material and the pump is considered as an optical cavity, this optical cavity has a very, very important function I will come to all of them each one of them one at a time.

So, this is the active material, this is the pump source and this is the mirror, R stands for reflectivity I will be describing you what this is in a moment. So, let us start with the operation of a laser. You have an active material it has say assuming electrons most the semiconductor lasers are electronic electron based and that is the most common one, so you will utilize it.

So, you have an active material which has large number of electrons, supposedly at a lower energy state may be ground state. You pump some amount of energy this energy can be an electric current, that can be a chemical reaction, it can be optically pumped, it can be light from another laser, so this is some sort of a laser that will activate, that will energize or that energy will be absorbed by these electrons in the active material and they will move to the upper level, they will move into the upper level.

After some time when this has been switched off the pump has been switched off say they will return back to their original ground state by emitting different amounts of photons, by emitting different amounts of photons in spontaneous emission, in spontaneous emission they come back and they after sometime return back to this original position this will come back to its original position, that animation I was unable to make, this actually will return to the original ground level position and the color represent different types of photons that will, that it will emit, different photons at different times because different electrons moved at different time at different level and they returned back and randomly emitted different types of photons.

Now, these two mirrors, they act as optical cavity or optical resonator or in a sense optical filter that will filter or that will allow only one, only one type of photon to survive inside the cavity, inside their chosen area. These are the two mirrors due to constructive and destructive interference, we will talk about little bit about optical resonators at the end, these are optical resonators, optical mirror, optical cavity they act as a filter, they will allow only one type, only one frequency, only one energy of photon to survive inside the entire cavity.

So, of the different randomly generated photon only one is picked up rest of them are attenuated, rest of them are killed off, only one of them of the photon, only one type of photon that the active material is emitting due to spontaneous emission is kept, rest of them are killed off by this Fabry Perot cavity, by this optical resonator, by this cavity.

These photons are allowed to survive into the system, these photons of all these different type of photons are allowed to survive inside the cavity, inside the system, inside the two mirrors. Well these are mirrors, so what do you think when photon or when light hits upon them, they will be bounced back into the system, they will be bounced back into the system.

So, are you getting where I am getting at? So, this is the exact photon that has now gone into the system to now generate stimulated emission. So, those electrons which are in the upper level and whose energy difference matches that of this photon will now be interacted, now be interfered by them.

When this will interfere with those photons that has consumed the exact same photon earlier and still has not come back because spontaneous emission is random, it may or may not come back, those of them which may not have come back or you can switch on the source of energy once again for it to go up but that is besides the point.

All those electrons which has consumed this specific with an underline under the term specific photon and has gone up will now be interfered only by this type of photons and stimulated emission will happen which will generate more of the same kind of photon which will again hit the mirror and return back into the active material and this process will built in and built in and here the beauty is only one type of photon, rest of them the, rest of the types of photons are killed by these two mirror.

The other photons are killed off by these two mirror, these two mirror is acting as a filter, as a resonator by constructive and destructive interference, it is allowing only one type, one frequency, one energy of the photon to survive which is the yellow one and it will only interact upon those molecules, those atoms, those electrons that has consumed the same thing, that has consumed the same thing and still up it is intervening it, that electron throws up generates one of the same thing the matching photon that again goes out, hits the mirror returns back and you have an amplification building up, building up, building up.

What do we do next? These sets of two mirrors one is perfect, whatever falls on it gets reflected back since reflectivity is 100 percent, this one the reflectivity is little less meaning, this is not a 100 percent perfect mirror, so whatever light or whatever photon falls into it, a tiny percentage

can go out, this tiny percentage that can actually go out that prevents the system from overloading is your laser.

You can rewind it several times to see what I just said. All three, all three actions take place absorption, spontaneous emission and stimulated emission, you absorb the material goes up the molecules, the electrons goes up after some time it tries to come down by spontaneously emitting photons, several photons comes out of it at a random interval these random interval photons some of them are killed off only one type is selected that is bounced back into the system that bounced back photon, that bounced back photon contributes to the stimulated emission that act upon those electron who are still up who have consumed exact same photon and it generates two photon out of it or it amplifies the photon.

This thing goes on and on and on while energy or the photon starts building up into the system and through an imperfect mirror, a small stream of light, a small stream of photons are taken out and as in stimulated emission has the exact same type, so all the photons that are coming out in laser have the same momentum, have the same energy, have the same phase everything remains as it is, yes, that is simply how laser works.

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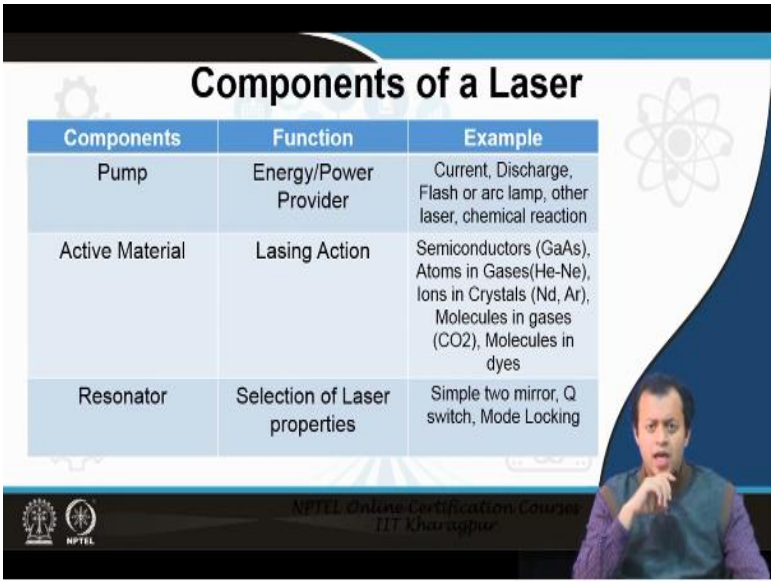


So, what are the function? The pump is an energy provider, it can be a current, a discharge, flash, chemical reaction, other laser. The active material more or less we have utilized everything as an

active material even single atoms have been shown to lase, as long as you have two levels, only thing we find difficulty is metals, why do you think metals do not provide lasing action? I am not going to give you every single answer.

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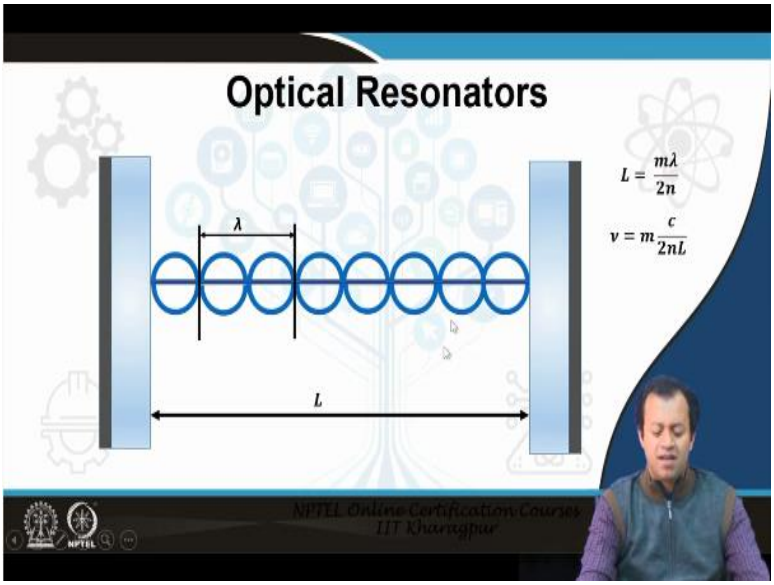


Resonator is the one which select the property, simple two mirror, Q or so many people will ask me what optical resonator is, just go through any normal physics textbook I will tell you that resonator is the one depending on the length based on the formula, depending on the length is determine the frequency it allows. So, this is given by this formula where n is the refractive index of the material in between these two, c is the speed of light, L is obviously the length, so L is obviously the length, m is the number of mode 1, 2, 3, 4, n is the refractive index.

So, it depends on this particular formula in air, if this is air you have put two Fabry Perot of cavity in an air, then this becomes 1 so L by 2, meaning, only those lambda, only those wave that can make a full circle or that matches, the lambda needs to match with the length.

So, by changing the length of the mirror you can change the lambda, if you can change the lambda you can or you can select the lambda that can survive only that wave can survive inside these two mirror which has a full round circle when it comes back to the original position, it has gone through the exact 360 degree phase shift, it has come back to the original position, any

other lambda will no longer be accepted m is mode 0, 1, 2, 3, 4 and n is refractive index if n is 1 then this becomes or m is 1 and n is 1 this becomes lambda by 2.

So, L stands for lambda by 2 very easy, any normal physics textbook will do, that the lambda, only those lambda, only those wave will survive whose energy falls which allows it for constructively interfere with one another.

A specific type of photon, so basically you can select which photon to you can select which photon you want to accept by changing the length, by changing the length of this resonator because length of the resonator will determine the lambda, lambda will determine the frequency, the frequency will determine the energy and what particular energy that energy needs to match with the upper level energy and lower level energy of a specific material.

So, this is it optical resonator is simply there to see to ensure there is a proper full cycle or constructive interference of the wave that goes through. Yes, I know I toggle between wave matter, wave and particle nature of light and everybody does that because you know the bad reasons.

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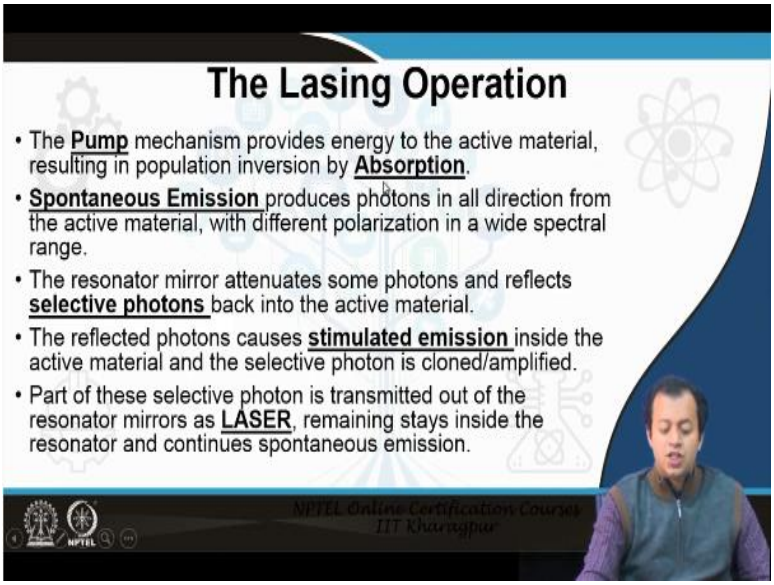


So, let us summarize. The pump mechanism provides energy for absorption. The spontaneous emission produces photons in all direction in the active material. The resonator mirror attenuates some photon and reflect selective photons back into the active material.

The reflected photons cause stimulated emission inside the active material and the selective photons are cloned or amplified. Biological students will know, will chuckle at why I use this term cloned. And part of the overall building process chain reaction is transmitted out by an imperfect mirror and that light is your laser, that is it that is the end of story.

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Wait, wait what happened to all the rims of mathematics you guys used to do, come on what happens to the tons of mathematics all of you used to do to understand what laser is, what happened to them? This is my revenge, I am challenging you as well as me to see if you can understand the basic concepts of physics however difficult it might be those concepts which has been monopolized by physics, quantum mechanics, laser this, that without touching mathematics, can you understand, can you understand the concept.

Now, think about the laser pointer you have, what do you think is the pump here? I would say it is the battery and it has a small crystal, a gallium arsenide crystal which is the active material, your energy from the battery is absorbed by the crystal it has population inversion and that crystal is put into small mirrors or inside a cavity, an optical resonator and the same process which you have now understood results in stimulated emission.

Look at your laser pointer and you can tell me what you understand. See, physics is poetry, mathematics is the grammar, when you are looking at the poetry, when you are reading a poetry

is the rhythm, it is the words that are connected together that matters, that is the spirit of poetry, everyone understands that without grammar nothing will be there but the spirit, the essence of a poetry is in its rhythm not on the grammatical concepts that makes all those words coming through and you know who said that?

Richard Feynman, I know, I know by this time I have lost half of my physics audience, half of my physics student because this is blasphemous and prior to that I have lost half of my biology student because I used electronic truth table to describe how data is coded in DNA and yes, I know my fate is waiting in seventh hell or as the cool kids say Habia Dosak, once I die because of this blasphemy to both physics and biology and I await my fate, absolutely no problem, but understand this the concept has to be clear, mathematics will help you polish the concept but the concept needs to be clear.

I have seen several of the students who have gone through tons of mathematics yet they still do not understand the basic concept of laser, laser is simply this you have an absorptive material which absorbs, goes up it emits different type of photons randomly of those random photons it has emitted, one is selected it is returned back into the system that energizes other elements, it energizes other electrons some of the electrons which are down can absorb and go back and the next photon it is heating will allow it to vomit and so on and so forth.

So, the same type of photon can only survive into the system it is building up, building up and one of it is removed, one or couple of them are transmitted the transmitted one forms laser. Please be my guest and go through all those mathematical calculation to understand how beautifully this and that happen but I will stick to this one because I am teaching to an interdisciplinary group, I understand that some of you might be terribly upset and this is not the way but well lets deal with it anyways.

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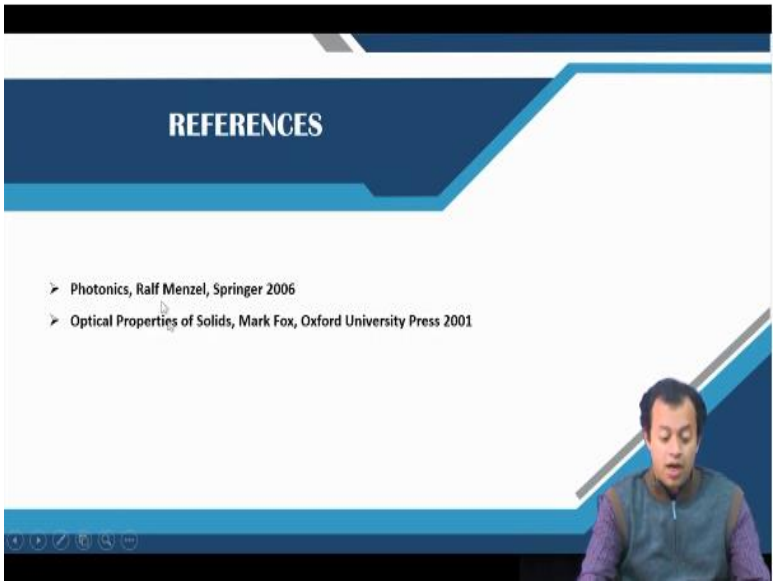


So, these are the concepts that I have covered stimulated emission, optical resonator, laser components and laser operation and please if you want to deal more on the laser part, especially the basic go through the Photonics by Ralph Menzel and Optical Properties of Solids. I shall continue with my topic in next day. Thank you, thank you very much.