Biophotonics
Professor Basudev Lahiri
Department of Electrical & Electrical Communication Engineering
Indian Institute of Technology, Kharagpur
Module 05: LASERs for Biophotonics
Lecture 22: Types of Laser.

(Refer Slide Time: 0:13)

Welcome, I hope some of you are still with me reeling from the shock of previous lecture. Those of you who are still with me you are awesome and let me continue with my discussion on laser for biophotonics. Today, we are going to discuss what are the different types of laser?

So, one thing you need to understand that this population inversion part where electrons or molecules go from lower level to higher level it is usually difficult to sustain yourself into the higher level and for laser action to happen, you need to keep it at the higher level for a maximum period of time, you need to keep it into the maximum period of time so that the laser action can actually take place.

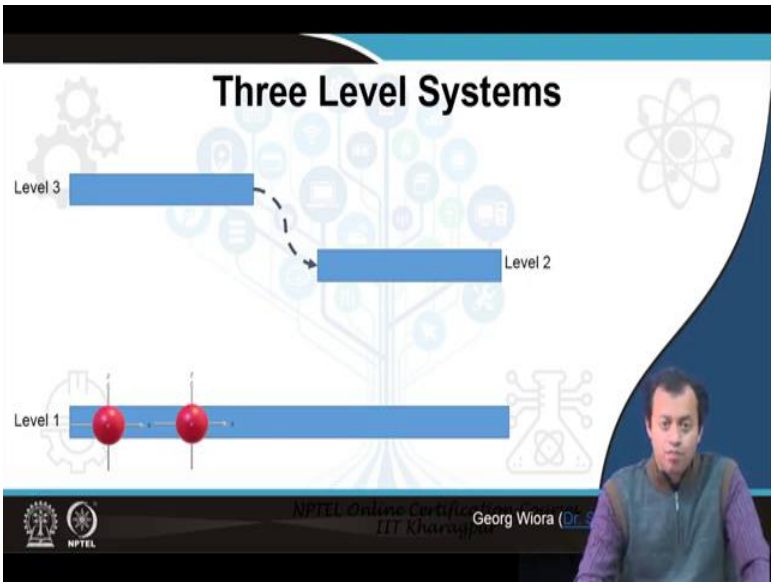
It may so happen that your photon, that external photon has come but by that time all of your electrons at the higher level has jumped back, has returned to its original lower energy level, maybe or maybe not ground state, it has already returned. So, what are it

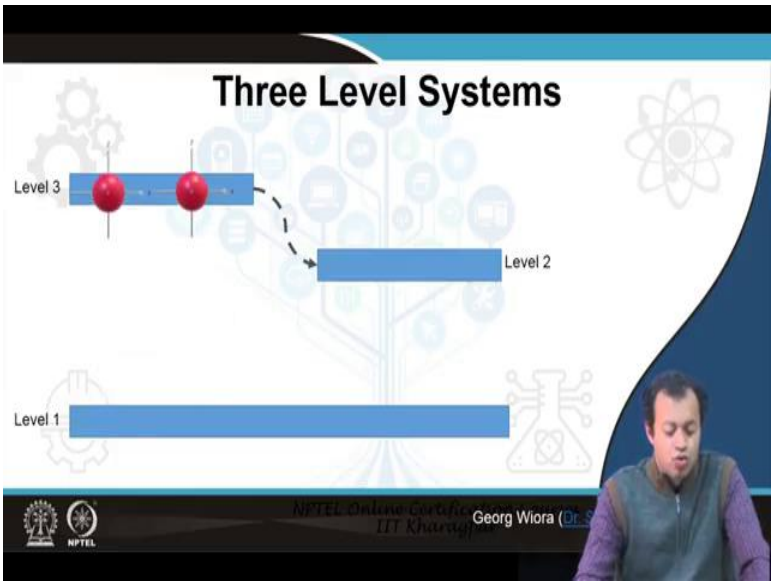
going to affect or what it is going to interact with and therefore, you will not have stimulated emission.

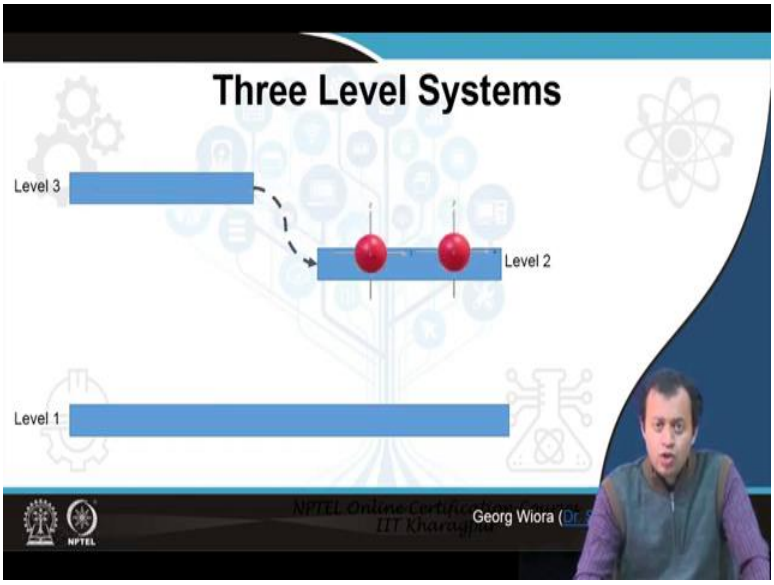
So when they first thought of doing that they found out that theoretically it is possible, but since, the time period, the electron are staying an upper level is very less, very unstable, laser is going to be overall a unstable process. We can have it for few seconds at the max and then it will disintegrate or it will not show its characteristic properties.

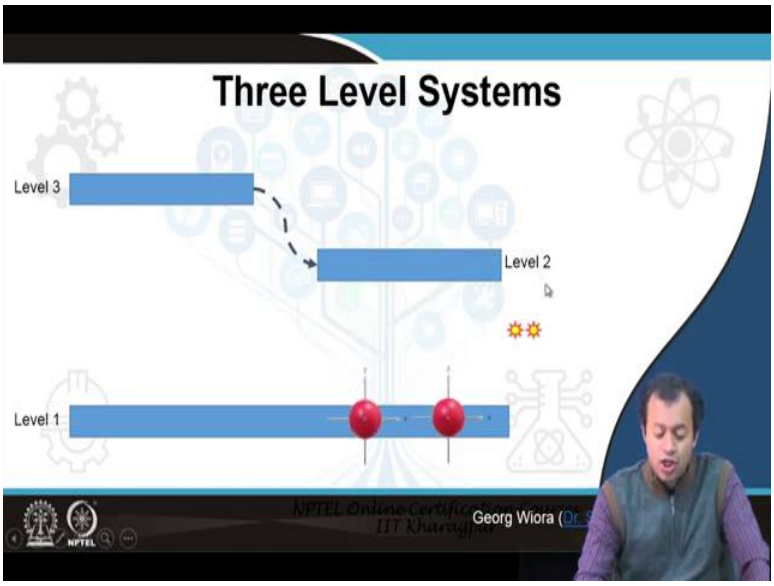
We saw similar problems happening with maser, but that was for some other reason as well, some engineering problem as well. So, it was Theodore Maiman who came up with these concepts, though it was developed on the back of several other concepts, that instead of a two level system, upper level and lower level let us have an intermediate level.

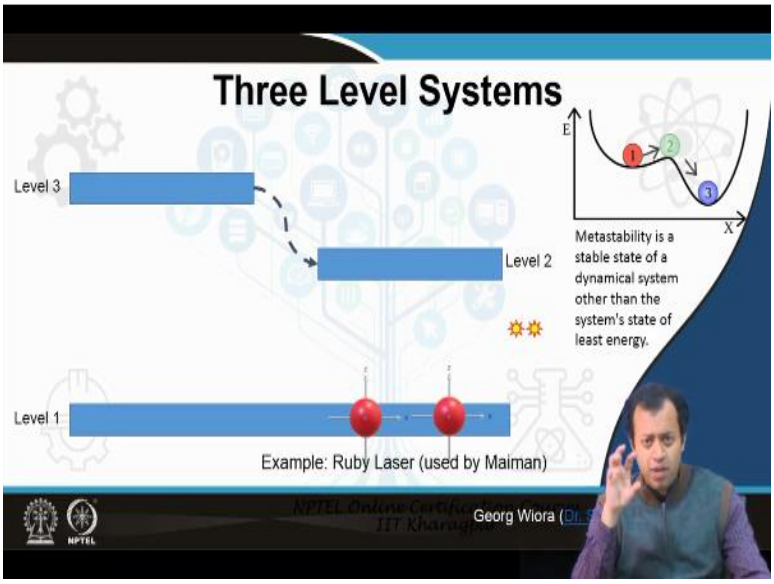
(Refer Slide Time: 2:14)




Three Level Systems
Level 3
Level 2
Level 1
Georg Wiora (Dr.


Three Level Systems
Level 3
Level 2
Level 1
Georg Wiora (Dr.





Let us have a three level system, a third level is added, though I am calling it level 2 because these numbers determines the energy, you have level 1 with the lowest energy state, level 3 as the highest energy state and level 2 as the intermediate energy state which is a metastable state.

So, let us see what happens? Upon intervention by a light, upon intervention by a photon, upon intervention by an energy the level 1 electrons goes on to the level 3 because you have given energy of this proportion, it has gone to the level 3 like normal processes.

Since, level 3 is quite unstable it would not like to stay in level 3 per se, but it has moved through internal conversion without emitting photon, internal conversion simply by shaking off, simply by phonon, simply by heat it has moved on to a level 2 which we call as a metastable level. From metastable level this is somewhat stable, stable, stabler, unstable, it has moved to the intermediator level.

The intermediary level a metastable level, meta is or different or pseudo or something, it is metastable level it goes to level 2 where it can survive for a longer period than level 3. Remember since level 2 is still above level 1 it is still population inversion, it is still population inversion and when your photon interacts with this it returns back to the original position emitting the photon it has consumed, emitting the photon it has consumed, emitting the photon that is from this to this.

Now, the question might come why have we not put it directly here because well, I have to go into quantum mechanics but when you send something directly from one level to another level it has a tendency to return back to its equilibrium position but when you make something intermediator, when you make something intermediator upon it has a tendency to fall back to the intermediator level.

And how to say this, this is bad analogies, but it needs some time to orient itself in a level 2 and it thinks that since I am below level 3, below the highest energy level, I have some breathing ground, I might stay here for a longer period of time, slightly longer period of time than level 3. If we directly send it, it might not happen it will come back.

So, what exactly is this metastable state? You have a state like this and this, by the way this photon that is emitted is the difference between this, not the difference between this, some of it gets consumed, some energy is consumed by crossing IC, internal conversion. So, what is this metastable state?

These are quantum defects, these are quantum defects, some kind of anomaly, usually they should not exist, but energy gap or a metastable state or a defect can exist. It can be considered as, this level 2 can be considered as this particular valley. Since, energy levels are not always straight line or flat grounds like this, it has these valleys and depths.

So see though level 1 or though part 1 is at a higher energy level but it has somewhat of a valley, somewhat of a depth as compared to this part and this part, so for a period of time if you look at billiard balls, if you are throwing billiard balls down this kind of a valley, this is obviously the lowest state, the most stablest energy state, but there also exists some kind of a valley point where the electron can exist, where the billiard ball can exist with a somewhat quasi stability.

So, this is this valley part, usually we should have something like a straight line coming down, highest energy to lowest energy but since energy levels are not, these are simply pictorial representation, not flat remember, your EK diagram energy momentum diagram, the energy levels have kinks, valleys in between, valleys in between.

So, in between there is a valley at a higher energy level, which can harbor the electron for a small period of time at a stable rate. Remember we need few, around some nanosecond or some microsecond will be enough for us to develop our stimulated emission, as long as not femtosecond or attosecond, we will be able to generate laser, though statutory warning that what I said is not entirely correct.

Nowadays we are regularly since the technology has developed that much we are counting 1 photon, we are doing super conducting, we are doing plasmonic lasers, we are doing nano lasers, we are looking at lasers in 1 atom state even probably hydrogen or helium has produced atoms of these have produced lasers.

So, that could also be done but it is much better, it is much stable if you have a metastable state, again metastable is this defect position, is this extra energy state that comes between two energy level, it should not come it, should not be there it is an anomaly or it is a defect.

How do you think you can have a defect in a crystal, to make life easier say you have a semiconductor, do you know how to produce defects in semiconductors? An anomaly change the energy of a semiconductor crystal by I do not know maybe you have heard adding some kind of additional atom, have you heard of this thing?

I know, I know electronics engineers and physics are chuckling, I think everyone else of you are chuckling as such, but think about it in which direction I am going, you do know that most of the laser these days are diode lasers or semiconductor lasers.

How do you think you can generate defect state into it, how do you think you can generate defect states into it, would impurity addition or as you cool kid call it doping help, what do you think actually doping does? It increases the conductivity, any school going child knows, but since you are higher level, I hope assume some of you are of a higher level, can we say that it changes the energy level a bit?

Maybe, maybe not, so example is the Ruby laser, this is the first type of laser used by Maiman and it was stable, previously they were unable to achieve it because theoretically it was possible but as soon as the electron goes up before the next photon has hit it has already returned back due to spontaneous emission, spontaneous emission has happened very, very fast.

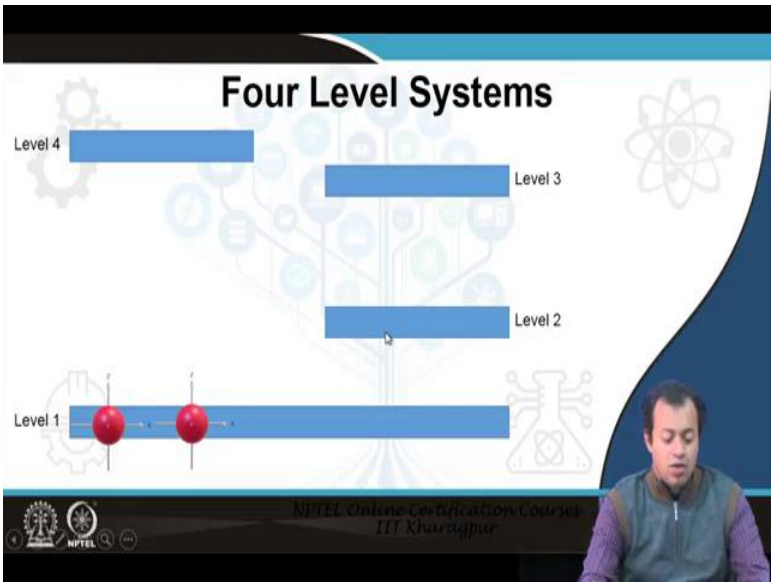
Remember, Jablonski was working separately in the spontaneous emission by that time when these was going on spontaneous emission part was not 100 percent fully achieved, he had shown several organic compounds which gave spontaneous emission at nanosecond or even little late and we did not have that technology or his paper was still in the process of making.

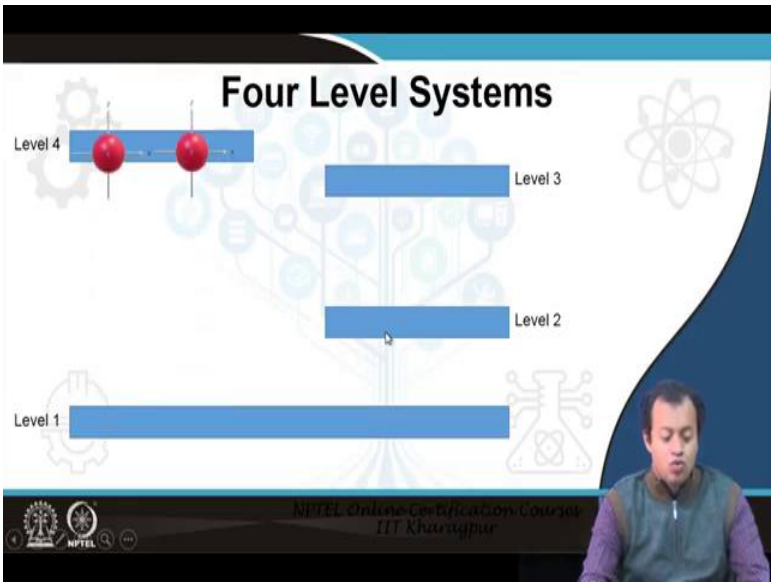
Nowadays we do a lot of dye laser because fluorescence dyes can keep it the spontaneous emission can happen at a longer interval of time, so dye lasers have become very, very popular, semiconductor technology was also not developed.

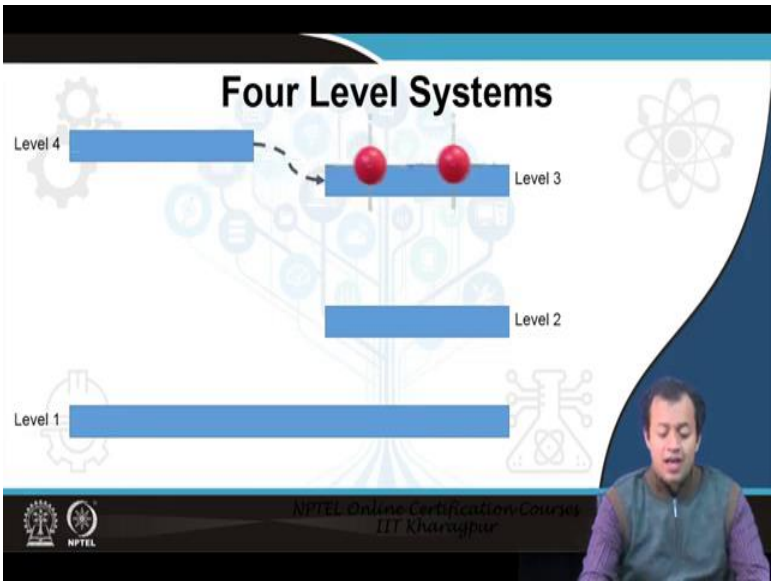
So, the 3 level system was quite common, where a metastable state was used for to achieve stability, the electrons moved up to the level 3, Ruby was not a semiconductor, Ruby already has several defects in it, you read a little bit about Ruby this semi precious stone used in jewelry and they automatically had some of its impurities.

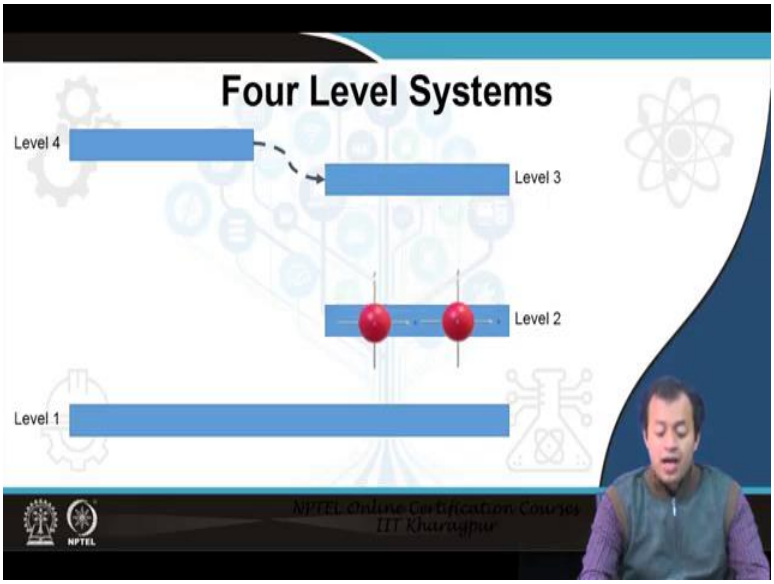
Therefore, some metastable state was already present and Maiman was able to show from Hughes laboratory that this can produces sustainable laser, but immediately people found out that still the stability of a 3 level system is not up till that good.

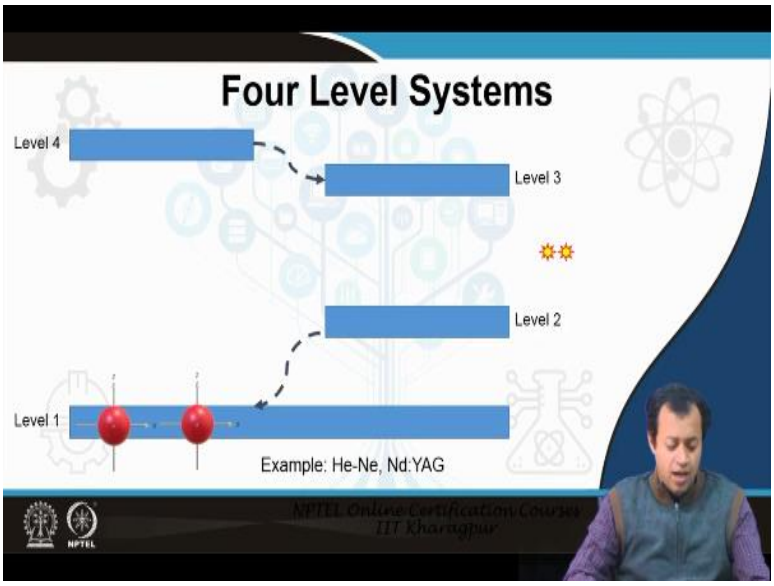
(Refer Slide Time: 11:06)






Four Level Systems
Level 4
Level 3
Level 2
Level 1
NPTEL Online Certification Courses
IIT Kharagpur


Four Level Systems
Level 4
Level 3
Level 2
Level 1
NPTEL Online Certification Courses
IIT Kharagpur



So, they went for a four level system, remember I told you that it is no longer required for the electron to return to its ground position as long as there are 2 energy levels, one up one down it can happen. So, what happens in the 4 level system?

In the 4 level system is the same thing photons react with these two electrons at the ground level, it goes to level 4 by absorbing a photon after internal conversion, it moves to level 3, from level 3 it stimulated emission happens it goes back to level 2 releasing some amount of light. And finally it returns back to its original position using another internal conversion.

So, the laser light is happening here, laser action is happening between level 2 and level 3, level 4 and level 1 are simply there to achieve population inversion. So, obviously, here the fast pump energy is a different from this energy, the pump energy is simply to it can be electric, it can be chemical discharge, it can be voltage to take it from level 1 to level 4.

After that internal conversion happen it goes to level 3, level 3 to level 2 generate some amount of this intervening light which you have 2 mirrors here, it comes back into the system, does it think stimulated emission more comes out it again goes back into the system and finally some of them are transmitted out.

Level 2 is the home and then from here it again as vibration or as heat returned back to level 1, most laser these days are like helium neon or neodymium YAG, YAG stand for yttrium, aluminium, garnet, so you have more number of all those defects levels, all those extra additional levels, meta stable levels.

These allows usually helium and neon, remember these two are almost noble gas, they should not be forming compound but when you actually are able to form compounds think about the energy bands that they could form or neodymium onto yttrium, aluminium, garnet these kinds of things, these kinds of active materials.

So they can form this meta stable state or several defect state, defects within the original energy states and we utilize these defects, defect is good, perfection does not work always, defect is good and these defects helps us stabilizes the 4 level system, stabilizes the laser and one such defect is 4 level system.

I have a question for electronics engineers, all of you electronics engineers out there, all of you know how semiconductor works, right? Electron moves from valence band to conduction band upon absorption, easy question is that population inversion? Population inversion is where you have more electron in the upper energy level, conduction band by definition is upper energy level.

So can you have population inversion by simply supplying energy to your semiconductor and it will go back to, it will populate the electrons present in the ground level, present in the valence band will populate, will go into the conduction band leaving holes, holes basically are void of electrons.

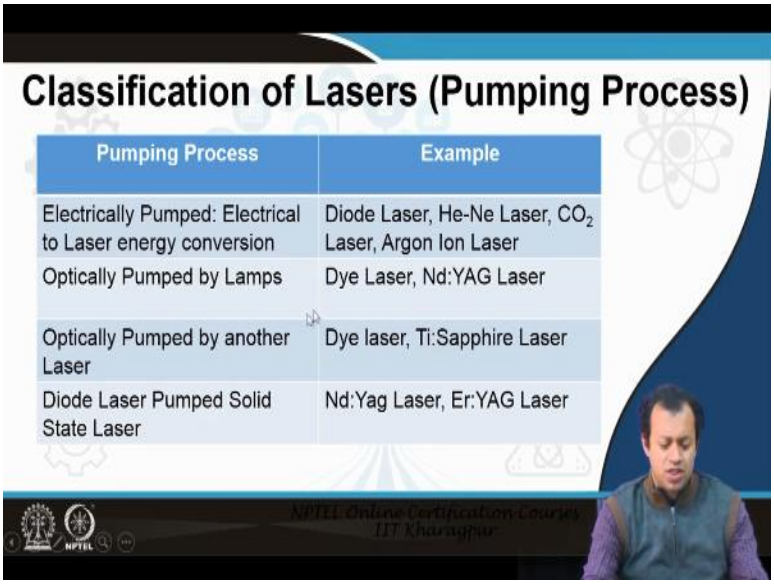
So, your lower level, your valence band is empty of electrons and your conduction band is getting filled up by electrons, is this population inversion and if this is population inversion can we utilize this for lasers?

Think about it and then you have added defects into it, say for example, you have added dopant material into it, can you see lazing action? Do you know the difference between direct band gap semiconductor and indirect band gap semiconductor? Can we utilize

direct band gap semiconductor to do this or maybe indirect band gap semiconductors as well, will it not work, why not? None of these are concepts of biophotonics.

So, I will not bore the life science students with this but this is something for electronics engineer as well as physics people to ponder upon, think about it and then tell me what you actually think, what does that laser pointer that you are so fond of utilizing uses, I think I gave you the answer in prior class anyways, but if you are watching this video independently, you get to choose.

(Refer Slide Time: 16:05)



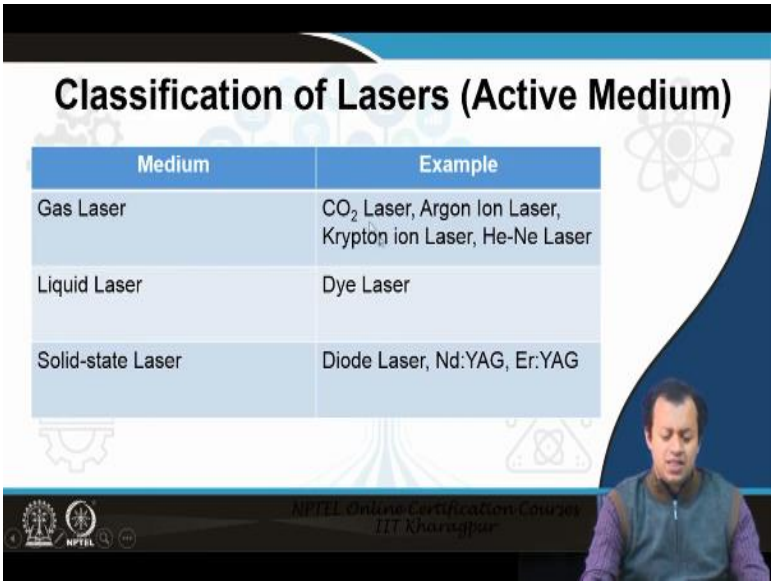
So, let us classify the lasers, the lasers can be classified according to their pumping processes, electrically pumped, electrical to energy laser energy convention, diode lasers are usually electrically use voltage to for the electrons to go from lower level to higher level, helium neon laser, CO2 lasers, remember CO2 is not electronic, it is molecular, you have optically pumped by lamps, you shine light on it and thereby electron moves up.

Dye laser, dye laser absorbs UV light and can happen or any other type of light can also be depending on the dye actually, optical pumped by another laser, one laser can activate another laser, you have made somehow a laser however bad it might be but then since it

has a coherent light, since it has the same type of light it is intervening other types of laser.

Ti-Sapphire laser and diode laser pumped solid state laser Nd: Yag these are more and more complicated you get according to the different pumping processes. So, pump is just simply energizing for the electron or molecule to go from lower level to upper level. So, therefore, you can have electrically pumped, optically pumped, chemically pumped, arc discharge it does not matter.

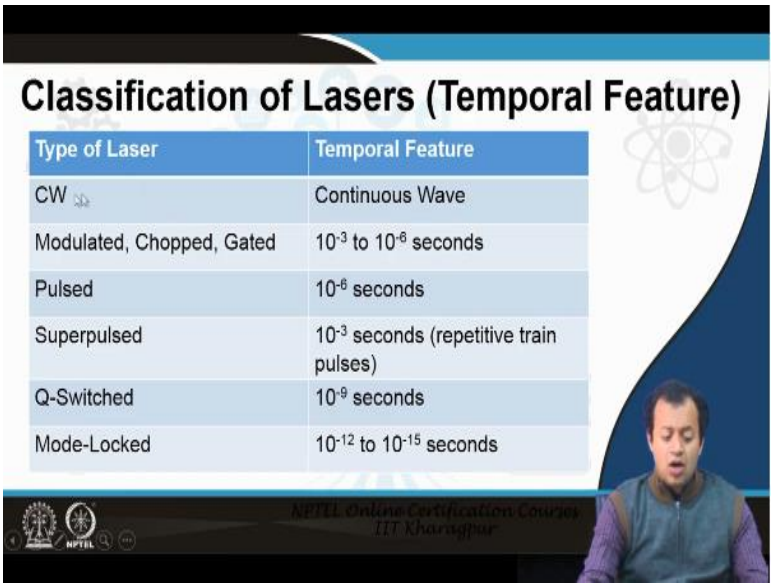
(Refer Slide Time: 17:19)



Similarly, medium, what is the active medium? It can be solid, liquid, gas, you have CO2, Krypton, Argon laser, Helium Neon laser these are gaseous laser, where the active material is actually gas, why not gas, why cannot as long as it has atoms, as long as it has energy levels gases have as a good energy levels, you have a container 2 mirror container, 2 at the end like a tube, you have put 2 mirrors in between them and it has gas in between, so why not, why cannot gas laser work.

Liquid laser, dye laser where fluorescent dyes are mixed in some kind of a water and put in a container as well, if you can put gas in a tube you can obviously put liquid in a tube. And solid straight laser these are semiconductor laser, these days Er: YAG and Nd: YAG those lanthanides and actinides, those do have some energy bands that are coming up.

(Refer Slide Time: 18:13)



And classification by temporal features, Continuous Wave, Pulsed, Superpulsed, Q-Switched and Mode-Locked these are the different types of laser according to the temporal features, how long the each pulse or the laser, each pulse of the laser will work. So, suppose, the pump that you have is sending, sending energy in pulses, you have not switched on a voltage or a current continuously.

But you are sending energy for the electrons to go to the upper level in sets of pulses, that will generally generate pulse output, because at one particular time instance the electrons are going up and coming down, then it is going up coming down, if you have switched on the battery, switched on the voltage things are always up, if it goes down it can absorbs and go up and more or less things are already up.

So, it requires a continuous wave can come out, this is usually what you have in your laser pointer where a battery, where electric current is always making sure that there is a potential difference, the electrons are always up and stimulated emission is always happening and therefore, you have got a continuous ray of light no matter what as soon as you in switch on the light comes out.

Pulse laser on the other hand simply send pulses because the energy level is pulsed because the, sorry, not the energy level, beg your pardon I misspoke, the pump is pulsed,

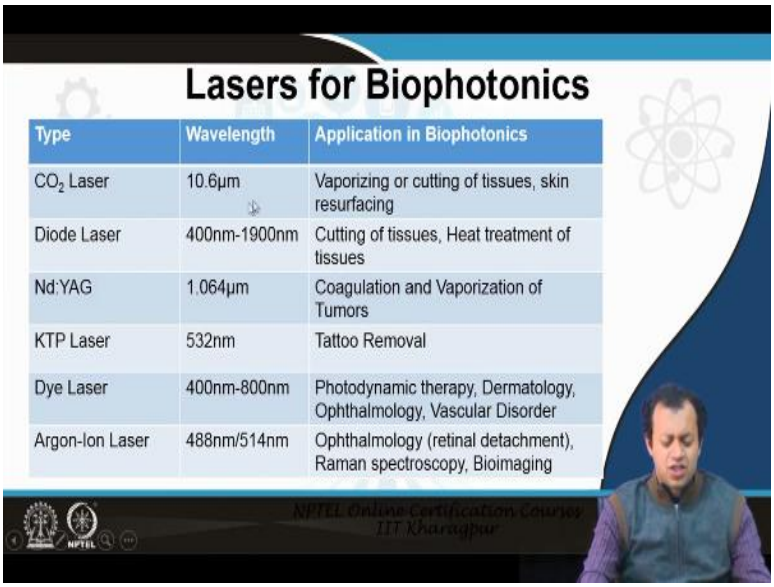
the pump itself is pulsed it can be optically given. Q-Switched and mode locked are little bit higher level, Q-switched is where the quality factor inside the cavity is simply maintained using some kind of an optical element like a acousto-optic switch or a shutter.

Well, acousto-optic switch can act as a shutter, here the quality factor, optical students or physics students know what a quality factor is, here we quality factor is slightly increased or slightly modulated or slightly changed and as a result different things happen. Mode Locked is happening where all the different phases of photons that are generated by spontaneous emission are all locked together with a phase difference specific to one another and utilizing that you can have a very, very small pulses of laser existing for a very small second.

These as you can see these are important because if you utilize lasers for a very small period of time your electron will move and your nucleus will not move, yes, remember that, your electron will move but your nucleus will not move, meaning you might get away with doing less damage to the tissue from a biological point of view, where you are hitting it, the heat will not be probably spread out thereby, preventing tissue damage.

What kind of laser of this do you think you utilize in our cataract operation? You sometimes do cataract operation, cataract operation uses laser or laser is used for a completely different thing, medical students please write it in the comment below for all of us to get enlightened.

(Refer Slide Time: 21:38)



So, what are the different types of laser that we apply in biophotonics. This is quickly I will go through, just read at your own leisure you will have this material, the wavelengths and the different types of laser. So, carbon dioxide laser is mostly for vaporizing or cutting of tissues, skin resurfacing, this is infrared.

Diode laser cutting of tissues, heat treatment. Coagulation and vaporization of tumor, these are quite interesting Nd:YAG somewhat of a good enough energy, this is vaporization of tumor, remember light tissue interaction, you can vaporize tissues, here we are vaporizing tumor-based tissues.

Dye laser on the other hand goes for photodynamic therapy, remember I discussed a bit about photodynamic therapy where you are doing generating raw species etcetera. Ophthalmology very, very important dye laser is used in ophthalmology, vascular disorder, vascular disorder where you have blockage inside a vein, where blood has difficulty flowing through.

Dermatology, these days acne removal or laser hair removal, these things are usually done by dye laser. Argon-Ion laser is also used very much in ophthalmology, retinal detachment it finds ophthalmology and of course, you must remember that several of these lasers are actually used for Bioimaging, to actually image something.

You want to image a particular cell without disturbing the cell, a cell is made up of complex number of molecules and electrons, maybe you need something which only energizes the electron and do not disturb too much of the nucleus, do not changes too much of the conformation and allow you to see.

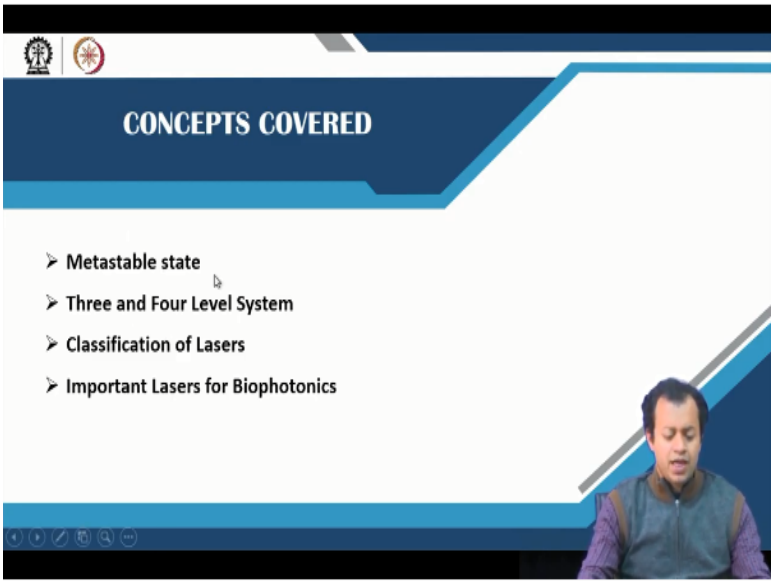
Bioimaging is our next module, we are going to see some of the applications of Argon-ion laser there. We will be discussing a very good interesting topic with laser based imaging at the end of this module, before the end of this particular series, set of lecture. So, there are several other lasers utilizing, being utilized in biophotonics, this is obviously not an exhaustive list and we need to know several of them.

But by this time I understand that no matter what are the type of laser all of you who are from a life science background, who did not know thus far how laser work, I hope that now it is somewhat clear to you what is the basic mechanism of laser, any laser be it your pointer, be it the laser gun you shoot, be it the laser you use in your day-to-day medical practices.

I saw in my NPTEL enrollment some of you are dermatologist, one or two of you are ophthalmologist, so now, if you have not known already obviously I am not patronizing you, if you have not known already I hope that some of you already, some of you by now know how the basic mechanism of all those lasers that you used in your day to day practice, utilizes.

Physics and electronic student now you know probably how to go for making newer type of lasers, can we go for a better, newer version of lasers, what about 5 level, do we require 5 level or 6 level instead of 4 can we go for 6 level, will that help?

(Refer Slide Time: 25:27)



So, these are the concepts cover metastable state, three and four level system, classification of lasers and important laser for biophotonics.

(Refer Slide Time: 25:35)

In the next class I am going to discuss about non-linear process, non-linearity is a part of photonics, we want to see non-linearity of photonic application in non-linearity of laser

application in biological matter, hope some of you are still with me, not being terribly upset thank you very much I shall see you in next class. Thank you.