Laser: Fundamentals and Applications
Prof. Manabendra Chandra
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture – 24
Solid state LASERs

Hello and welcome back. So, we were learning different types of laser. So, in the previous lecture I told you that there are several different types of laser.

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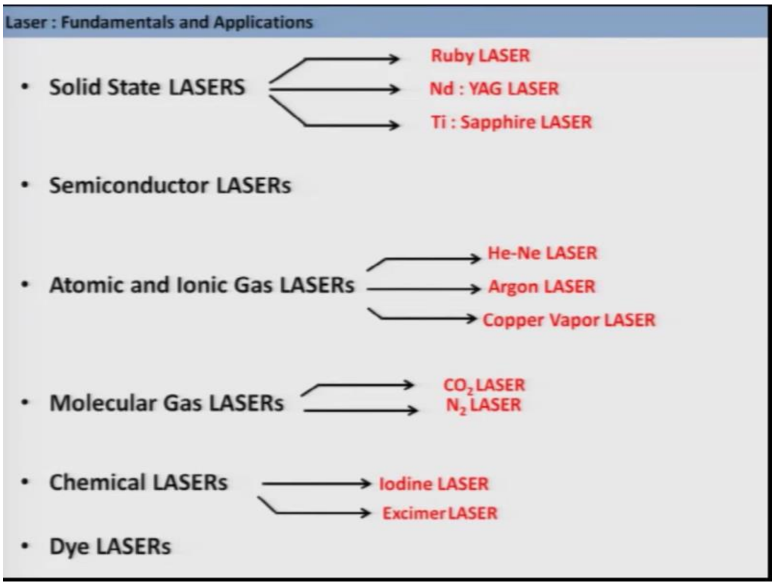

And we can categorize them into different sections like solid state laser, semiconductor lasers, gas lasers atomic as well as molecular gas lasers, chemical lasers dye lasers and so on so forth. So, today we are going to look into different types of laser belong into this different categories. So, we will start with the solid state laser. And the first one that we will look at is the ruby laser.

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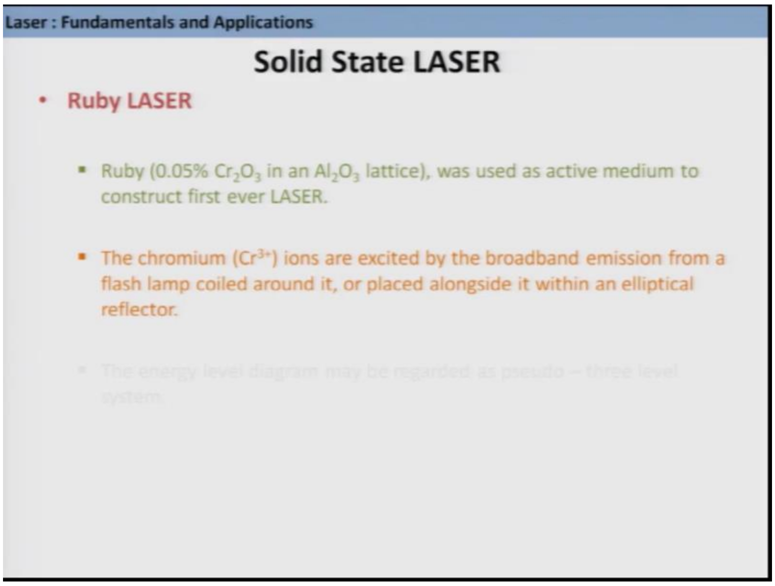

So, ruby laser was the you know first laser that you know was invented. So, what is a ruby? Ruby is a crystal I mean most of you are aware that you know this is also, regarded as a chain and you know it has ornamental use and it has a beautiful color which is known as ruby red color. Now what is the origin of this color? The origin is actually because of some impurity, impurity of chromium ions in an alumina crystal alumina crystal lattice. So, without this chromium impurity, the alumina crystal will be just color less whitish. Now a very little amount of chromium ion that is essentially present as Ci 2 O 3 and it exists in ruby by approximately 0.05 percent. So, you can imagine how little it is, but this little amount of chromium does the work be it is color or be it in the application in laser.

So, this particular chromium ions they provide the states electronic states that can give rise to population inversion and hence lacing. So, what is actually done? So, this chromium ions which are essentially chromium 3 plus, sitting in the you know alumina lattice. They are excited by a broad band light source. So, from a you know flashlight. So, a flash light can have you know a huge range of wave length. So, it can be you know a white light and that from that white light this chromium ions they can you know take up the photon and go to certain excited states.

Now, this flash lamps they can be placed either you know parallel to this ruby crystal. So, like ruby crystals how do they look like we will show you in a bit. So, essentially if you put this ruby crystal, which is as a rod and the flash lamp just side by side and this flash lamp you know continuously excite this you know, chromium within this ruby crystal.

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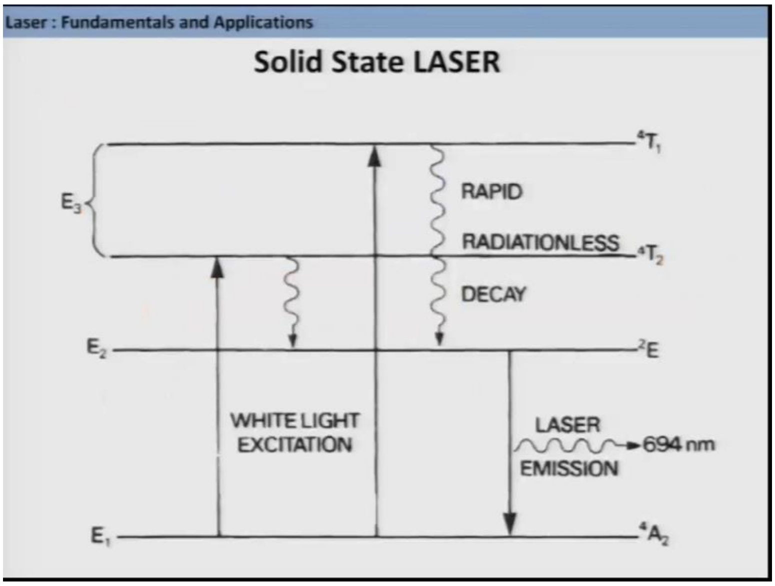

Or what you can do you can have a like a this flash lamp as a spiral. So now, what happens during this you now optical excitation. So, on your screen you can see the energy level diagrams for this ruby, which is essentially sitting in the you know aluminum matrix the chromium sitting in the aluminum matrix.

So, there are certain you know term symbols provided here. So, right now you do not worry about the particular term symbol many of you maybe already aware of this, but this one this course does not allow us to go through the detail of this term symbol. So, you take it as a you know the symbol which is given to particular you know electronic or other states, this term some logic. So, their energy levels are given by E 1 E 2 E 3 E 4 so on in case of ruby we have you know identified 4 such states, this 41 42 to E and 4 a 2.

So, though it has 4 levels, but it can be you know considered as a pseudo 3 d pseudo 3 d level system, why? Because this 2 states that is 41 and 42 both of them actually decay very rapidly to the state 3 that is here. So, initial excitation is we will take the molecule either to this 42 or 2 41, but both of them will rapidly decay to the state 2 E and this 2 E is the metastable state. So, the population inversion is created over the time and once the population inversion is created then a spontaneous emission can trigger the stimulated emission and stimulated emission can come out from the laser cavity as a burst.

So, once this population inversion is lost then again it will take time to create the population inversion. So, this is kind of inherently pulse laser we already have talked about this one.

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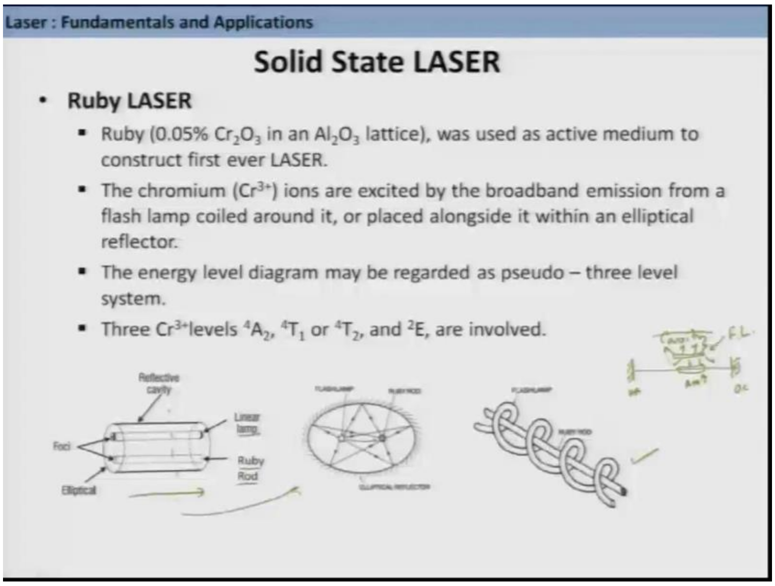

So, this was about the energy level diagram of this system. Now as I was saying how experimentally it is done. So, this ruby crystals they are like you know like innovative rod. So, if you place this ruby rod and this lamp which is like a you know tube linear tube side by side, then you can you know this lamp can excite this ruby crystal.

Now, also you can have a geometry like spiral this one also I was just talking about a couple of minutes back. So, this spiral will you know surround this ruby crystal. So, that enough excitation can be provided to the ruby crystal. Now there is something interesting here I would like to point out. So, we know that you know a cavity. So, is given like between 2 mirrors right. So, this is my cavity one is high reflected another is output coupler. So, this will define the access of the laser cavity.

Now, the active medium which is emitting photon. So, first the you know flash light. So, the flash light is suppose here. And my active medium is here. So, this is my active medium and this is my flash light or flash lamp. So, this are giving light to this active medium, but this is giving like to every other direction like. Now maximum amount of light will be lost they will not release the active medium if this is the only configuration that I have if you if I have this 2 mirrors active medium flash light. So, most of the lights that flash light keeps us will be lost. And that is you know a quite big amount of loss, because we are providing energy to the flash light and the flash light is you know transfer you know giving this energy in form of light to the active medium. Now if all the energy that we are pumping into the flash light term is not being convert it or not going to the active medium then definitely this is not a good thing from energy perspective.

So, we need to erase this lost, how can we do that? If we have a mechanism by which if there is a reflector and this light can be reflected back into this system to add active medium. Then we really can bring down the lost to a great extent. So, in practical world exactly that is what is done. So, this if you look at this picture. So, this ruby rod in the flash lamp both of them are put inside a reflector chamber. So, you can see that this as if there you know a jacket of some things around this ruby rod and the flash lamp. This jacket is essentially reflected. So, this is a curve reflected.

So, it is like a it is like a tube holler tube whose inner sides are all reflectors. So, you can imagine like the it is as if there is mirror inside this one, how you can do that? If you can polish the inner part of for that matter any surface of some metal or a you know metal coated surface then by the you know pretty owned property of the metal it can be highly reflective metals like cold are often used for this purpose. So, gold coated surface. So, essentially have a tube hollow tube at inner portion is inner side walls are gold coated and that can really reflect the lights coming from the flash lamp with a high degree of reflectivity. So, efficiency is very high and the light goes back to the active medium or 2 at that.

Now so, that is about in this direction. So now, one more thing one has to consider, even if I think about reflector all around this you know lamp and ruby crystal rod. It is not necessary that if there is light will reach tip medium that is ruby. So, we have to think about a particular geometry which can you know certainly do that. So, that is the reason that this hallow reflector is made in a way that a cross section of this hollow reflector you know reflected which I can leaps actually it is an ellipse and this cross section. So, if you take a cross section along this that is shown here. So, this is an ellipse and ruby crystal and the flash lamp are kept into the proxy of this ellipse.

What happen is given in this picture. So, the flash lamp gives light. So, the light can directly go to the ruby crystal. So, it can go directly here, but most of the light we go away correct. Now wherever it goes the cause of the geometry of the ellipse and it is posy it will go come back to this particular place. So, a simple knowledge of geometry will tell you this. So, we are not really losing light from the flash lamp. And the efficiency of excitation is increased by a great amount.

And this is very necessary because if you recollect in our you know first couple of weeks lecture when I we said that creating a population inversion in this kind of a 3 level system is really hard because it needs very efficient pumping, otherwise because the ground state is involved in the laser action creating population inversion is really very difficult. So, we need to pump really hard, and if I need to pump really hard I have to make sure that the you know pumping source that is a flush lamp does not lose it is most of it is light unnecessarily. And this kind of electrical reflected geometry ensures that we have a highly efficient reflection system ok.

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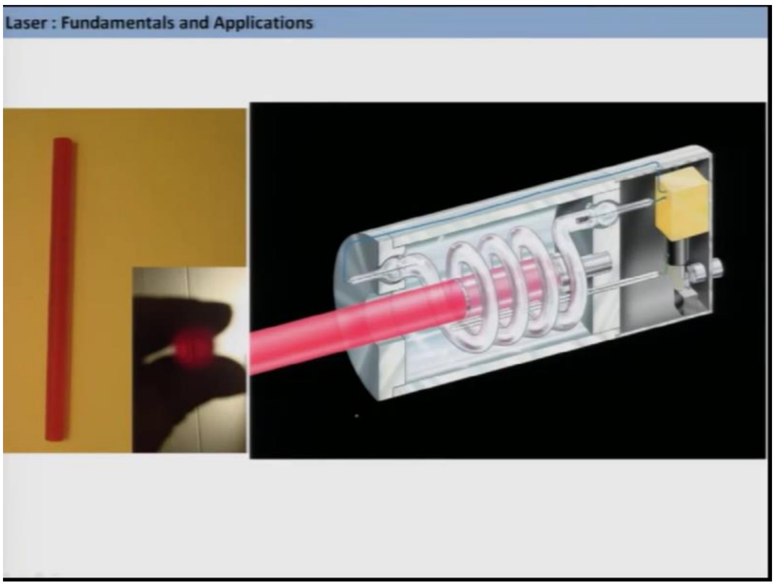

Now, share your screen you can see on the left side I have given an image of a ruby crystal. So, it has the ruby red color and here particularly you can see that this ruby crystal is to some extent transparent. So, for a given light this is definitely transparent.

So, this ruby rod is you know placed inside a cavity. So, one side of the ruby rod essentially attach to the high reflector. And this coil of flush lamp surrounds it and also you have the other alumina you have a liner flush lamp line ide by side as if they are sitting at 2 posy of an ellipse. So, this is the actual arrangement of the ruby laser.

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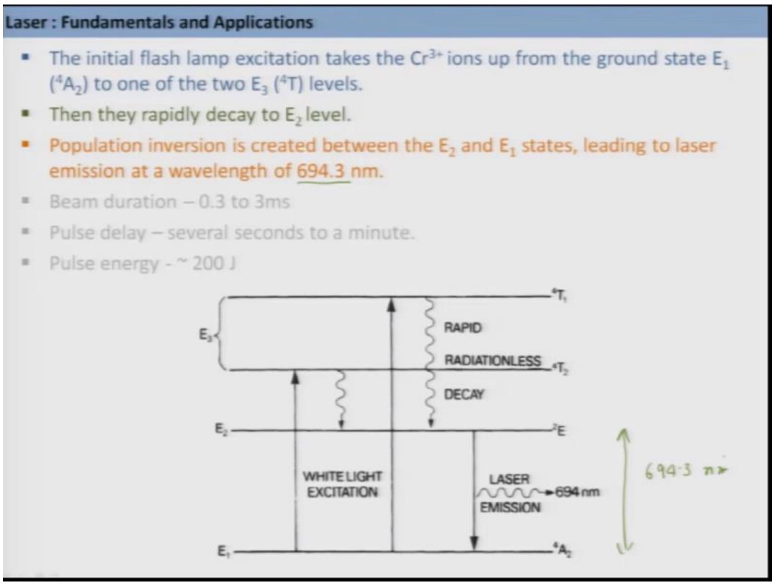

Now, there are few more things about this we have already told that initial excitation you now ultimately goes to the state 2 E creates population inversion and then from there it will lase. So, some practical consideration that is what is the frequency of the light coming out of ruby what are the pulse duration what is the pulse energy and all. So, ruby laser is keeps a particular wavelength of 694.3 nanometer that is equal to this gap. So, this is 694.3 nanometer. And the beam duration is pretty long. They are like you know 0323 millisecond and the pulse delay you can be really long because it takes time to build up the population. And the pulse energy can be really high it can be even you know 200 joule.

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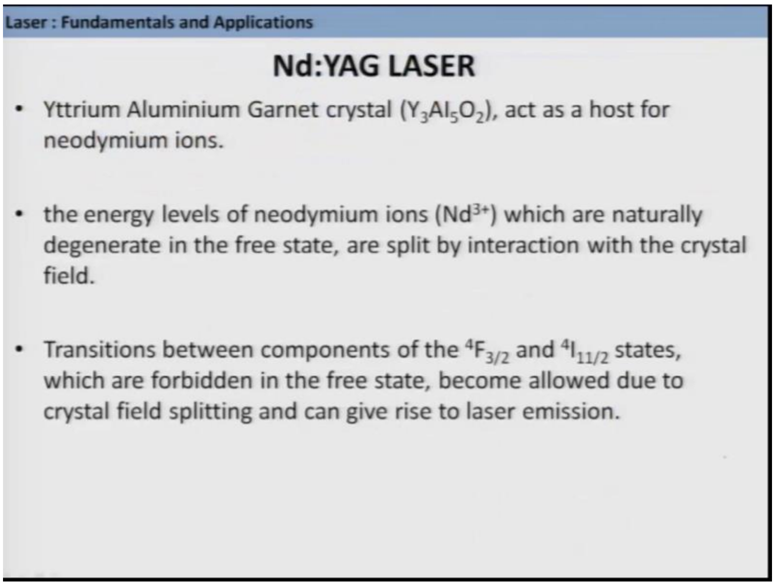

So, next we will talk about Nd YAG laser. Like in the case of ruby where the alumina was just a host and chromium was playing the role of providing states for the laser action. Here neodymium 3 plus ion they actually keeps us the you know states for laser action YAG. Or yttrium aluminum garnet which is which has this formula Y 3 Al 5 O 2 it just you know acts as host to this neodymium 3 plus ions. So, this energy levels of neodymium ions are naturally they are degenerate; that means, several states are there which has the same energy, when you do not part of the energy states. Now there is something called crystal field theory where it is said that if you provide a you know crystal field to this energy states this latency is lifted. So, before providing any field to eat by the surrounding environment or any approaching lagan, this states are degenerate in neodymium 3.

Once a field is applied by say this yttrium aluminum garnet they become you know separate. Now there are several energy states in a neodymium system. Now we will look into this particular energy state diagram in a bit now the transition between components of 4 F 3 by 2 and 4 I 11 by 2 states which are forbidden in the free state that is when they are still degenerate. Once the field is applied and degenerate is lifted they become allowed to and ultimately these 2 states get involved in laser action and they provide laser action.

So, here are the states that I was talking about. So, initially this particular state if I can just show. So, this is 4 I 11 by 2 and 4 F 3 by 2.

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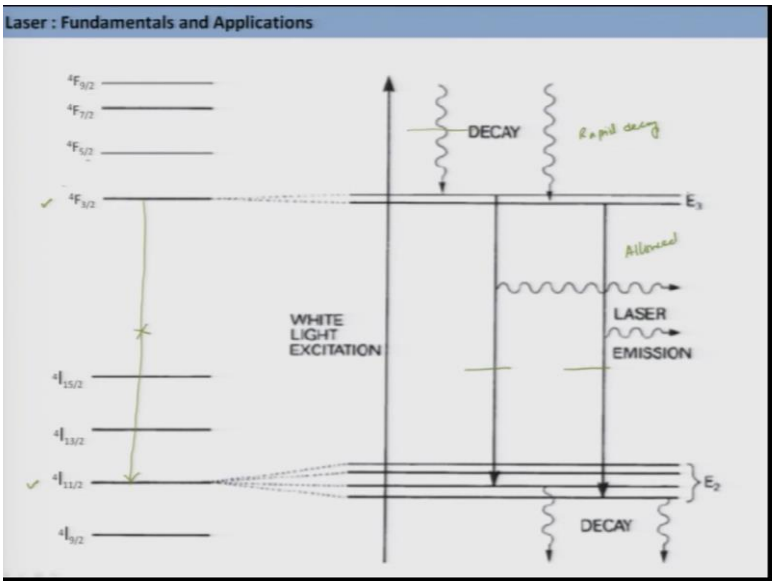

So, this is one and this is one step. So, before we had this crystal field effect this was you know the degenerate and several energy states where several states where and they have the same energy. And once the field id applied they are split like this. Now earlier this transition was forbidden, now this transition you know is allowed. Or you know transition you know 2 and from. So, if you are considering any transition from say this state. So, that is 4 F 3 by 2 to 4 I 11 by 2 essentially this is the one which was earlier forbidden.

Now, once it is lifted then this becomes allowed. So, these are now allowed. So, what happens, once we provide light energy provide photons from the flash lamp just like in case of ruby laser the n d 3 plus ions they make transition from the ground state to 4 F 9 by 2 and from there it rapidly decays to this 4 F 3 by 2. So, this is the rapid decay. So now from there it can come back to radioactively this 4 I 11 by 2 states, which are now split states after the crystal field is provided. So, you get laser emission due to the transition from this 4 3 by 4 F 3 by 2 states to 4 I 11 by 2 states.

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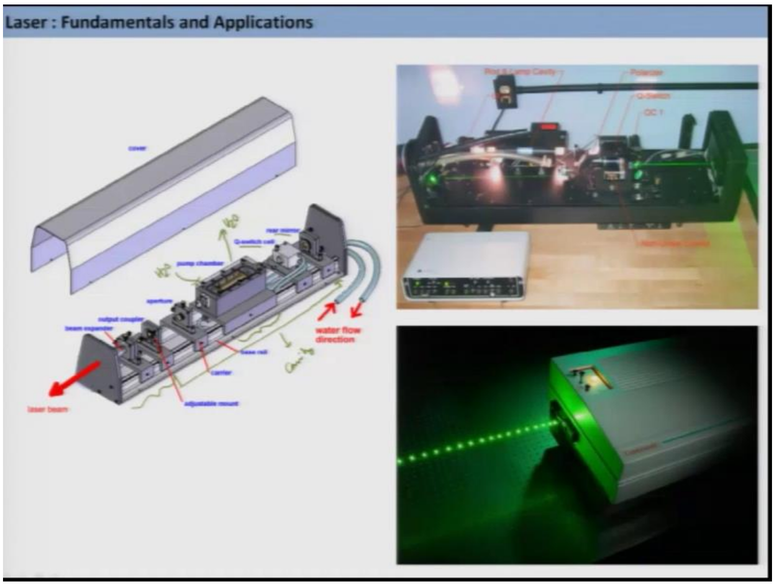

So now I will show you how an Nd YAG laser is constructed, how it looks like you know actually. So, this is the region. So, this part is the heart of the system, where you have the Nd YAG crystal and the flashlight flush lamp that kept. So, here also the same technique is used that is you wrap this flash lamp and the Nd YAG crystal in a elliptical reflector tube. Now there are some practical concerns, this flush lamp is you know flushing and it keeps very high amount of photon intensity.

So, you can understand that amount of energy is provided is very very high, and that keeps rise to hit and one has to cool down the you know Nd YAG crystal which sensors that hit. So, how do you do that? You have to put this whole system in water and you have to flow the water. So, what is done? You know pump in water and then you take out that water. And you have to maintain the temperature of the YAG rod t. So, this flush light will create lot of heat and you cannot allow the heat to increase you have to maintain the temperature, because all these you know states state population there also affected by the heat. So, the performances of the laser will be degraded if this you know increasing heat is not taken care of.

So, you do this by flowing cold water through that and you maintain a certain temperature, normally like you know 18 to 20 degree centigrade. So many occasions what you need to do you need to couple this you know water circulation system to a chiller unit , but the modern days lasers they are quite efficient. So, just circulating water without coupling it to a chiller unit is sufficient. So, these are called A I O chiller, air cold laser system. And apart from this active medium and flash lamp system the q switch is essentially placed within the laser cavity. So, the laser cavity is comprised of this high reflector. So, this is the real mirror or high reflector light here and you have the output coupler here. And this part is essentially not actually a part of the cavity this is some extra.

So, up to this you have the cavities. So, from this region to this region constituent my cavity. So, this q switch here it contains the pockel cell and polarizer combination. So, after the cavity the beam comes out and there you can do whatever engineering you can do with that particular you need to expand or you want to shrink the beam you can you know do with particular beam you need to expand or you want to string the beam you can do everything.

If you want to convert the you know wavelength of the light to some other things you can also do that you can to using something called non-linear optics. So, those part an outsider cavity for safety most of the time the you know some extra portion is also you know covered outside the cavity where you have this extra elements which is used to say expand a beam or shrink the beam or you know converting the web links to another all this. And here in this particular case an explicit laser system real laser system is shown, where you can see the what are inlet outlet system and you know this is the position of the rod and other side to be lamp and water will be circulating you know, through this pipes and you can see explicitly the place where the polarize is kept q switch is kept and the output coupler immediately.

And you can also see that you know the color of the light is green all though the Nd YAG laser it gives the wavelength of 1064 nanometer. So, which means that inside this one you kept under crystal, which can convert that 1064 to a visible green wavelength which is 532 nanometer; when we talk about the application part we will talk about how this can be done using the laser. And this particular image tells you that this is a q switch laser. So, which is a pulse now in this particular picture you cannot see any you know pulse out peat output, but here you can nicely see that they are pulse. So, like you know they are coming like a bunch of photons at a time and then there is no photon. So, you can take that picture by using an appropriate camera. So, that camera shat has speed should be synchronized with pulse repetition rate. So, in that way you can actually see this pulse stream flowing.

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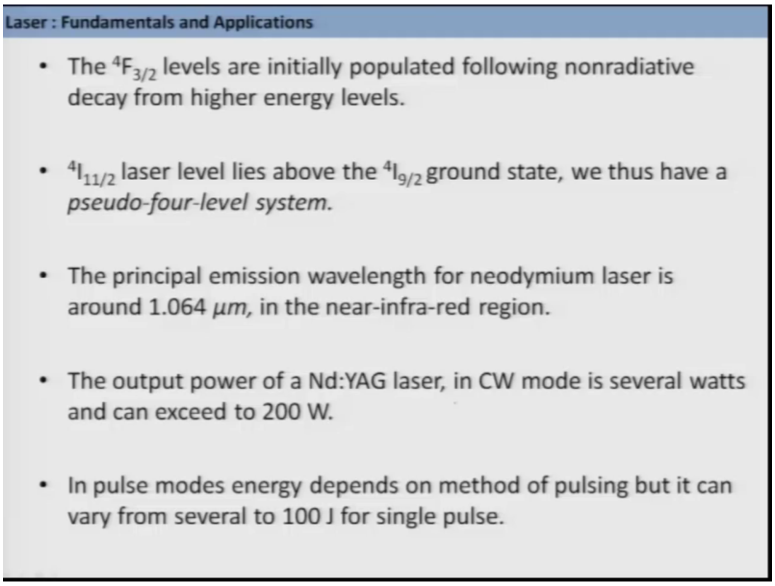

So now little bit detail into this Nd YAG system. So, this 4 F 3 by 2 levels which are initially populated due to the non radioactive decay from that higher level. So, next step what happens? You have an emission due to the jump of this you know in the 3 plus system from 4 F 3 by 2 to the 4 I 11 by 2 giving rise to 1064 nanometer near infrared laser light. A few practical things about Nd YAG laser that it is a very high power source of high power light of course, a power can be controlled, but you can go beyond 200 watt which is like really really powerful.

And you can operate it in continuous weight mode it is like a 4 level laser and it is actually a 4 level laser if you look at energy states you can see that the transition is taking place between this level and this level. So, the ground state is down somewhere here. So, this is essentially a 4 level kind of system and you use q switch to create the pulsed output and in case of pulsed operation the you know energy still can be quite high as high as 100 joule. So, we will continue discussing about other types of lasers in the following class.

Thank you very much.