Laser-Fundamentals and Applications
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Lecture – 25
Semiconductor LASERs and Gas LASERs

Hello and welcome, let us continue our discussion of different types of lasers, we will start today with titanium sapphire laser.

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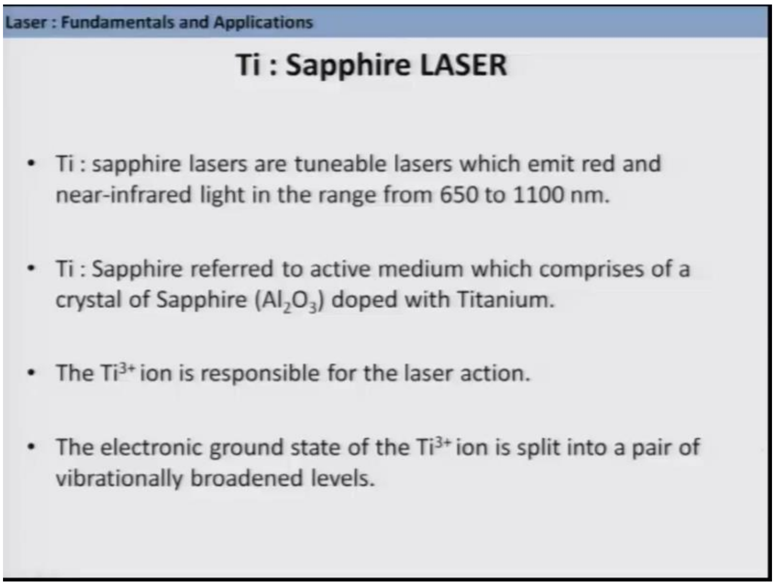

So titanium sapphire laser is one of the most important laser in chemistry and biology; particularly for those people who want to understand the dynamics of certain processes which occur at a very very small time scale; as small as like you know a picosecond to a femtosecond label. So, what is titanium sapphire laser? This is a solid state laser and from the name you can guess, that this titanium is playing the major role in having the laser action.

So, this titanium sapphire lasers are tunable lasers; you can actually tune the laser wavelength over a quite broad range; we will see how you can do that. And this tuning range is more or less like you know 690 to 1040 nanometer so, in reality so this is the most, the maximum limi, but ideally it is from say 690 nanometer to 1040 nanometer. Most of the commercial titanium sapphire laser which are available; they can be tuned over this range, 690 to 1040 nanometer. Now, this ti saph; it refers to the active medium which comprises of a crystal of sapphire doped with titanium.

So, this is again pretty similar to ruby and instead of chromium; here it is the alumina is doped with titanium. This titanium 3 plus ion is actually responsible for laser action while the alumina plays the role of host. So, the electronic ground state of this titanium ion is actually split into a pair of vibrationally broadened levels. Now, one thing I must mention here system like this ti sapphire is of great interest because it is tunable.

Now, why it is tunable and also there is a good possibility of mode lock in this laser system. Now, this is because they have a very broad ignition band; so, we mentioned while discussing about mode locking that more the number of modes within the spectral bandwidth, smaller is the pulse width. Now, for titanium sapphire system the spectral bandwidth is like enormous; they are really is like you can see like going from 650 to 1100 nanometer, it is really a broad spectrum.

And within this broad envelope; you have a huge number of modes operating. Now also one more thing that; in this kind of system like titanium sapphire, the electronic excitations are also coupled to the vibrational states and due to this, the overall spectral broadening is much more. So, more the spiritual broadening I can you know exploit it in a particular way like shortening the pulse or achieving the tenability; so, this is a plus point here.

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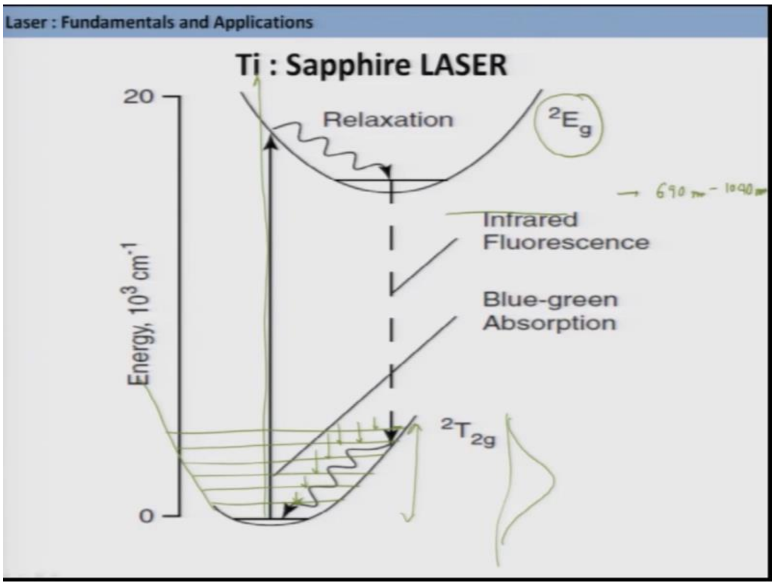

So, here it is shown how this excitation and emission takes place; so, when you excite it goes to apart excited state which is given by this term symbol 2 E g, and its lower state is the triplet 2 g state. Now, this is one of the excitation; it can have you know various other excitation. So, it can go from here to a higher state following the francolin principle. And from there, they can come down to the lowest vibrational state through vibrational cascading or vibrational relaxation.

From there, they will come down to the ground state. Now, they can come down to various different vibrational states. So, not only in at this state; so you can imagine that this if I continue this one. So, you have vibrational states, so just for simplicity; I am giving the equal space between the vibrational level. But you know for actual systems they are not equal, so the gap between the vibration level reduces as you go up in the energy.

So, now it can come down here, it can come down here, it can come down here, it can come down here. So, the corresponding energies of the emitted light is different. So, you have a wide range of energy that will come out in terms of emission. And you have an emission band like this, so this is the source of this broadening; here in this case one of them. So and also let me mention here; that if this emission is from the lowest vibrational level here to the highest vibrational level in the ground state, by ground state I mean the lowest state between the two states in involved in lazing.

So, this transition to the highest vibrational level in the lowers state involving lazing, will give you the infrared region of light, while the other one that is coming here; this will give you near infrared. So, you have a range from visible to near infrared as we said from 650 to 1100; so, quite a broad range.

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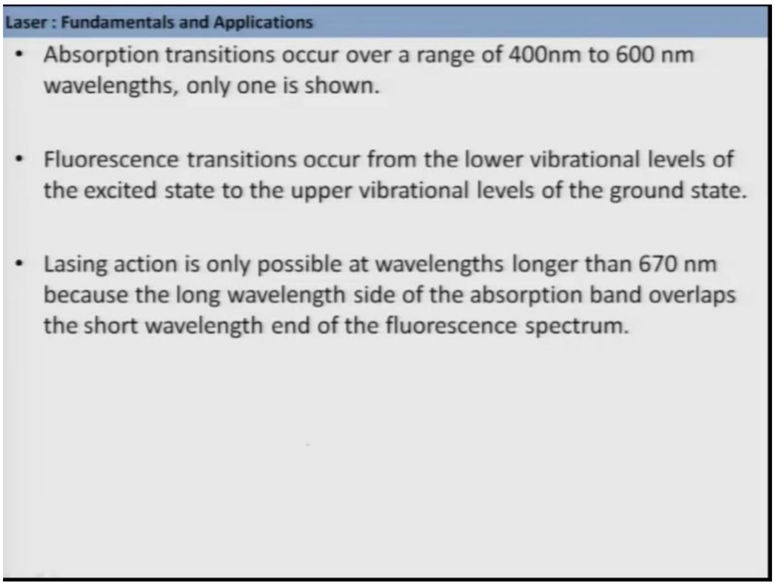

And it is preceded by the absorption; so, absorption can be anywhere from 400 to 600. So, that is the region where you can have a good amount of absorption following Franken and principal. Now, normally what is done? You pump something around you know 530, 550 nanometer light and you get the excitation and then you follow the emission; we get the laser action out.

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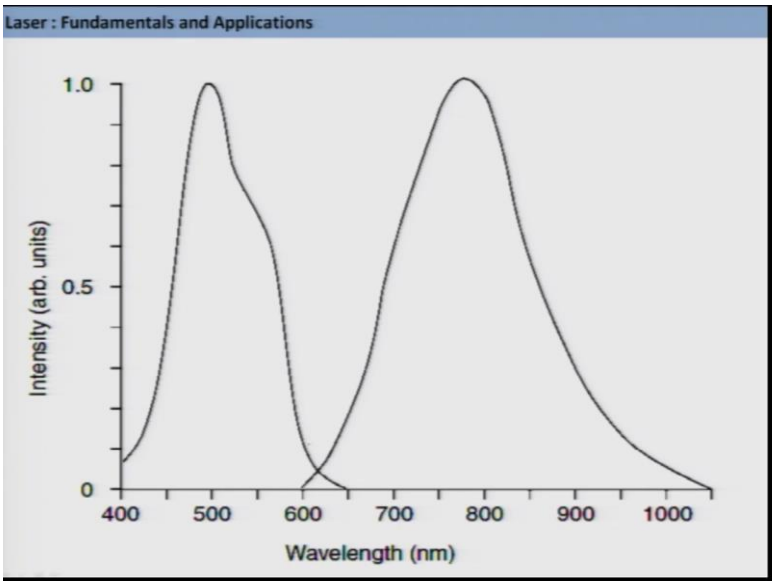

Now, one practical thing is that though if you look at the absorption and emission curves for the ti sapphire system, you will see that it can actually ideally emit from here. But you see there is a substantial amount of absorption over this range. So, this goes to 650 or little more; so, if the lazing takes place in this region. So, virtually I can say in this region; due to the presence of the absorption band or in other word sufficient absorption cross section over that wavelength region; my lazing will not be efficient.

So, essentially the range from here onwards will be the effective laser wavelength. So, that is what is said in this last paragraph.

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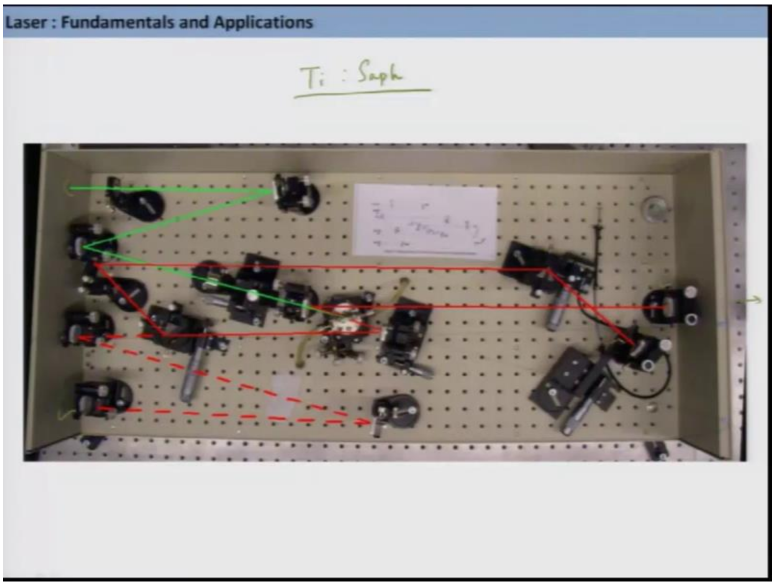

Now, here is the actual layout of a titanium sapphire laser; so, this is a ti saph laser layout. The crystal of this titanium sapphire is essentially housed here, so you hold the titanium sapphire crystal and then you pump it. Now you see; here in this arrangement you do not see any flash lamp, this is totally different from what we were seeing in the previous two cases of ruby laser or indiac laser. On the other hand, you see something is entering from this particular port here and this is a green light.

So, this green light comes here and it hits this titanium sapphire crystal here, which now emits light which is red in colour and that travels back and forth between these two mirrors. So, here is one mirror and then you have another mirror here, so that constitute the overall cavity so, the two end mirrors. Now, this green light which is entering here is essentially coming from another laser which is a continuous wave laser that can be anything; that can be you know a doubled indiac laser or you know N D Y vio 4 laser; which is similar kind of laser or it can be a diode laser, we will talk about that one.

So, pumping this ti saph is; it needs sufficient power and if you can excite it at around this position, then you achieve the maximum excitation. So, this corresponds to green light, this 500 or 530 that range over which; so, maximum excitation can be achieved if you excite at a absorption maxima or near that region. So, if you do that then you get maximum fluorescence also. So, that is what is done; you use a green laser which is a continuous wave laser, pump it up and then you take the emission out from this ti saph crystal and allow it to travel back and forth within the cavity, and you also put something for mode locking.

So, there are different type of mode locking are possible that we have already discussed. So, here in this particular case you can use car lensing or you can use you know passive mode locking, you can use acousto-optic modulator or electro optic modulator. So, in this particular case in electro optic modulator is used. So, you can get an output from this end and you can get a very short pulse from this particular laser and there are ways to even you know shorten the pulses.

So, one thing probably I missed out while discussing the mode locking thing; that you can create these short pulses, but the short pulses mean that this spectrum is broad. This is because this time and frequency, they are related by uncertainty. So, due to this broad pulse it is very easy to create a charm, which will change the pulse rate of the light output. Now, there are ways to compensate this, the velocity distribution which is known as a group velocity distribution so that you can maintain the pulse width as it is. So, if time permits, we will talk about that toward the end of this course; how to compress the pulse if it gets stressed due to (Refer Time: 14:06) velocity dispersion.

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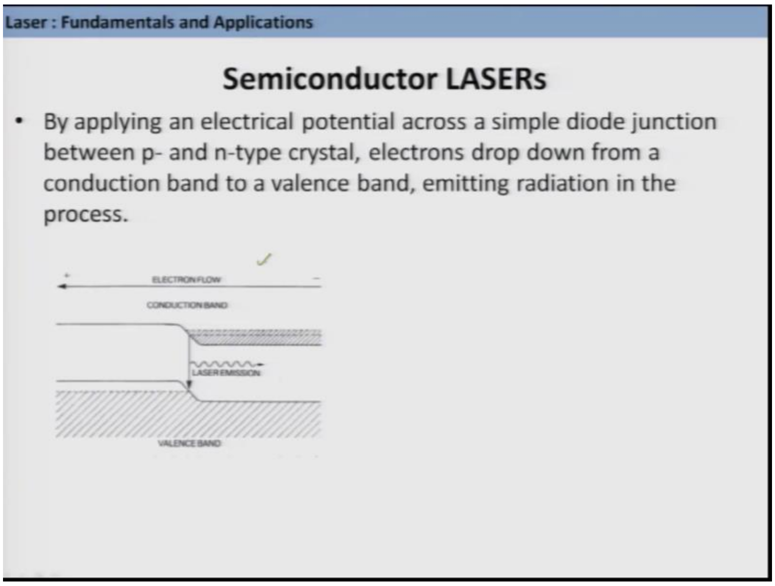

So, now let us move on to other types of lasers. So, one laser that most of you have probably used in your life; it is the laser which you use for; as a pointer, this diode laser which are very small in dimension, it can be really really small which is extremely cheap, but yet you can do lot of things with that, and it falls in the category of semiconductor laser.

So, what is done here in semiconductor lasers; many times we call it diode lasers. So, by applying electrical potential across a simple diode junction between a p-type and n-type crystal; electrons drop down from a conduction band to a valence band, which emits radiation and that is our; if you can utilize this you can get laser output from that. So, this is the basic idea of the semiconductor laser operation. So, I will just pick to really show how it is done.

So, if you have a p and you know n-type crystals attached to each other and if a potential difference is applied; so like here, the electron will jump from this conduction band to the valence band. And this jump will also be associated with an emission of light, now this is a very simple idea; now how actually this is implemented to form the device.

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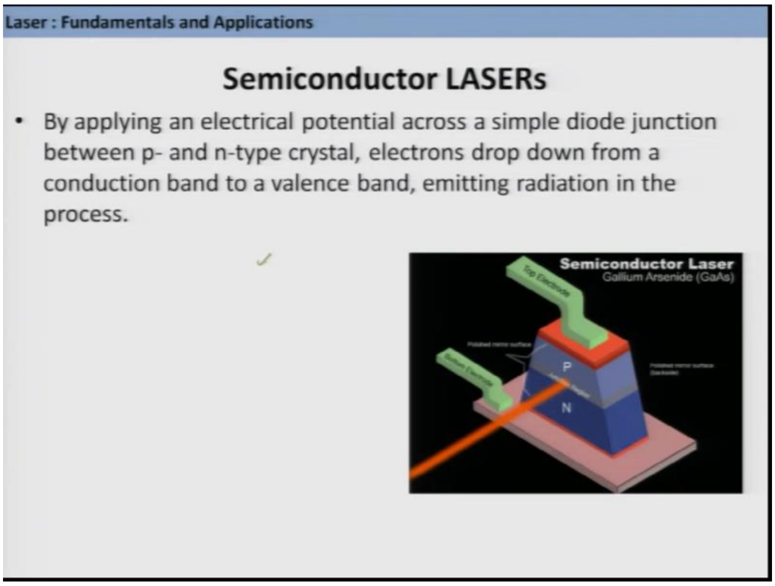

So, here it is shown; so, you have this p-type crystal here and n-type crystal here and they are given a bias by putting two electrodes and what it is done. So, this surface here and the back that is behind this one; in this direction we put two mirror surface. So, mirror will face this p and n type crystal. So, essentially what I have? I have a p-type crystal and n-type crystal, so they are just like this. Now, I bring two mirrors; so, this is the mirror surface and this is my p, n system and I put this mirror like this and bring another mirror from this side and put it here.

One of this will be highly reflective; another will be partially transmitted as it always. And from partially transmissive mirror; I can get that laser output when I give the adequate voltage to my system. Now there are different types of semiconductor system which are used for getting laser. So, gallium arsenide is one of the famous one; so, gallium phosphide, gallium arsenide, indium phosphide there is several kinds of semiconductor you can make laser out of.

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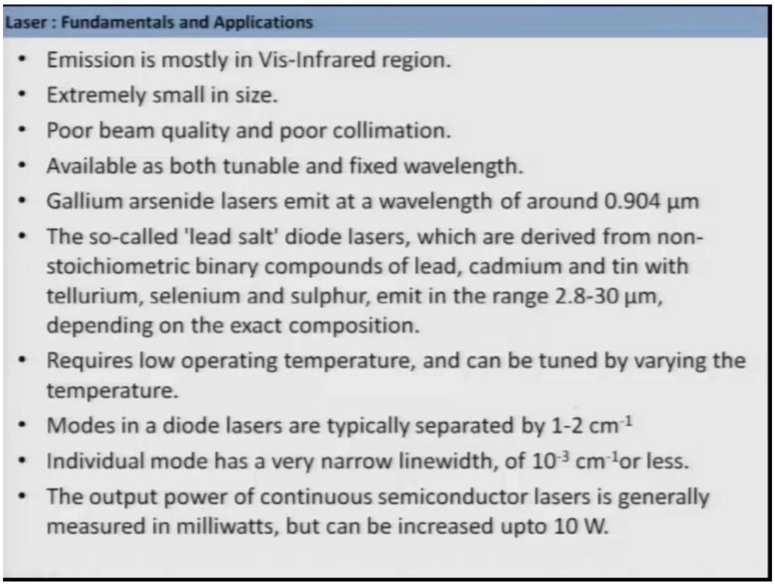

Now, there are a few things to know for this semiconductor laser. So, you can get laser output in visible or in infrared region. So, you can get different types of lasers with different wavelengths across the visible and infrared region using semiconductor lasers. Their advantages, as I said they are extremely small. So, you can imagine if you can take a pretty tiny p-type crystal and n-type crystal, couple them together; put tiny mirrors in the two sides and very tiny electrodes attached to those surfaces; you can get a laser.

So, it can be smaller than you can imagine; so that is their advantage, you can make a very small laser. Disadvantage, the beam quality is quite poor, the collimation is extremely poor; so, that divergence is very very very high. So, it is difficult to achieve collimated beam out of this as, so you need to use some external optics to collimate them. Now, as I said like you can control the wavelength that will come out of the laser by proper choice of semiconductor material. So, you can use different materials and ultimately achieve tunable laser output, you can also play with voltage that you give. So, you can get either a single fixed wavelength laser.

But also you can tune this laser wavelength in case of semiconductor laser. So, for example, we were talking about this gallium arsenide in the previous slide. So, that gives around 900 nanometer of light and there are something like this lead salt diode lasers which are derived from non-stoichiometric binary compounds of lead, cadmium and tin with tellurium selenium and sulfur that emit in the range of 2.8 to 30 micron.

So, you get like mere infrared region also covered by that, so if you can play with the composition; you can play with the emission wavelength. So, I was just telling that a few seconds back; another advantage is, another thing to note is that semiconductor laser it needs a low operating temperature. At high temperature they do not function well and this temperature variation of laser is very well known in semiconductor.

Now that can be again used in other scenes that if you vary the temperature, you can vary the wavelength output. So, if you go to any company website which provides this semiconductor laser or diode lasers, you will see the emission curves are provided as a function of temperature. So, if you are at 10 degree centigrade, 20 degree centigrade, 30 degree centigrade, 40 degree and so on; their emission curves changes. So, by changing the temperature you can actually tune the emission wavelength and the longitudinal modes in diode lasers, they are typically separated by 1 to 2 centimeter inverse; which is very small.

And these individual modes have extremely narrow line width, which is like 10 to the power minus 3 centimeter inverse or even less. So, another thing to know is the output power of continuous semiconductor lasers is approximately in few millivolts. But you know a properly designed semiconductor laser can have a very high amount of power say like up to 10 watt or so. So after the solid state laser next we will talk about gas lasers and among gas lasers first we talk about the atomic or ionic gas lasers.

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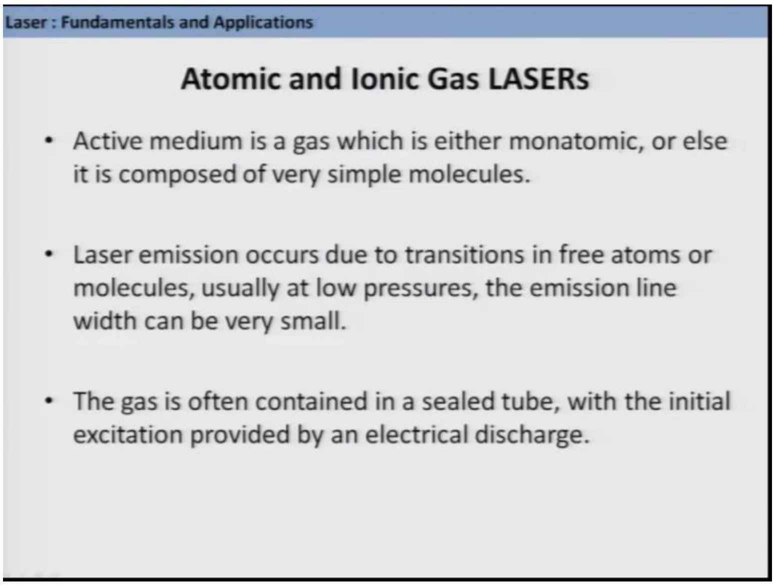

So, in this case as a name as the name suggests the active medium is a gas which can be a monatomic gas or it can be an ion and gas lasers can be constituted of the molecules also that we will discuss shortly. So, in this particular case of atomic gas lasers; the laser emission occurs due to transitions in free atoms or ions and they are usually operated at low pressure because you are handling the gases. So, they are kept in low pressure normally and for this gas lasers, the advantage is that their spectral band width of the laser; not the active medium, active medium is also small, but a spectral bandwidth that you get is really really narrow.

And that is why lot of state resolved experiments can be done with the gas laser output. So, normally what is done is you take the gas in a sealed tube and you have to excite this active medium which is a gas and normally it is done with electric discharge. Unlike the solicited laser where we saw all of the excitation is done using either flash lamp or another solid state laser, here the excitation is done by electrical pumping; by electrical giving electrical discharge.

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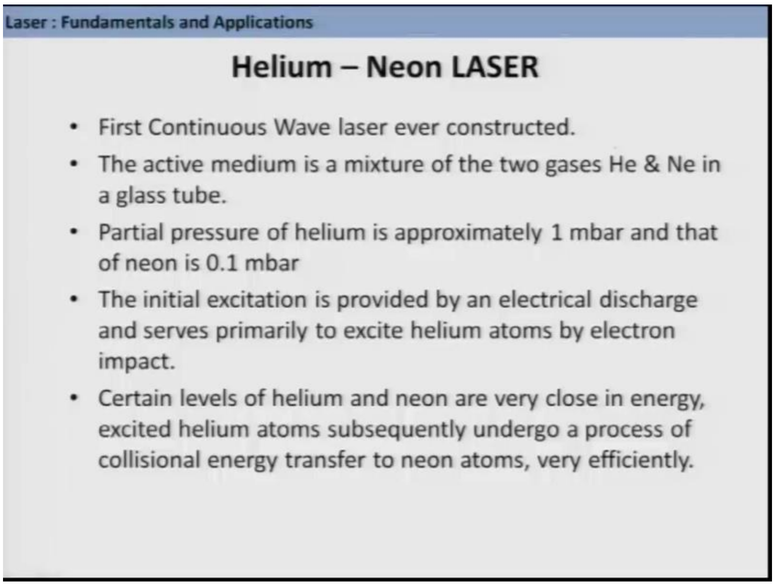

So, I want this atomic gas lasers; the first one that we will talk about is the helium laser. I am sure you have heard about this laser which is all the time in short called hene laser. And I think while talking about history of laser development, I said that this is the first continuous wave laser that was ever constructed. And here the active medium is not a single gas, but it is a mixture of two gases and the important thing to note here that both helium and neon; they are inert gases.

So, you mix them in a container, in a sealed tube and use them as an active medium and a practical number that I will give you is that the partial pressure of helium is kept approximately 1 millibar and that of neon is 0.1 millibar. So, the helium is you know in quite excess among the two constituents. Now, first the electrical discharge which gives the excitation; it serves primarily to excite, the initial excitation which is provided by the electric discharge; it primarily excite the helium atoms by giving electron impact.

And certain levels of helium and neon are very close to each other in terms of energy. Now, this excited helium atoms they collide with this neon atoms and the energy of the excited helium atom gets transferred to the neon and the electronic states of this neon then do the rest of the job that is a laser action.

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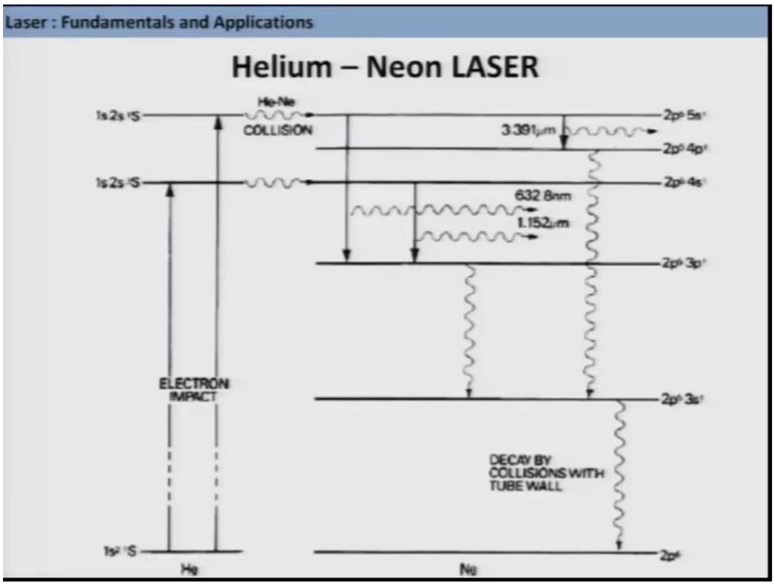

So, here I show you the energy state diagram for this helium neon system; so, you can see the energy states of helium and neon they are very much comparable and this is very much beneficial. So, what is done first the electron discharge will provide the electron impact so the electron impact will cause the excitation from helium; 1 s state to helium 2 s state; so, and also to this sorry helium 3 s state and also to 1 s state.

Now, these two states of helium is very much similar to the 2 p 6; 5 s 1 and 2 p 6; 4 s 1 of neon. So, that allows the energy transfer when one excited helium and a neon atom collides with each other. So, this is a collisional energy transfer from one to another; so I do not directly excite neon, but I excite helium which then transfers that excitation energy to neon.

So, now there are several states below this 2 p 6; 5 s 1 or 2 p 6; 4 s 1; few of them take part in lazing action. So, the lazing action takes place between this state and this state and the corresponding wavelength is 3.391 micron; while it can have 3.391 micron transition between these two states, it can also jump from here to here that is up to 2 p 6; 3 p 1.

So, the corresponding wavelength is 632.8 nanometer and also it can laze from this state and can jump down to this state and give 1.152 micron wavelength light. Most common wavelength for hene laser is 632.8 nanometer light but the other wavelengths are also obtainable. So, today we are out of time and we will come back in the next class with some more different types of lasers and we will discuss them in detail.

Thank you very much.