Introduction to LASER
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Lecture - 38
Laser Safety

Welcome to this MOOC on lasers. Today we have come to the last topic, as per the course plan and that is; Laser Safety.

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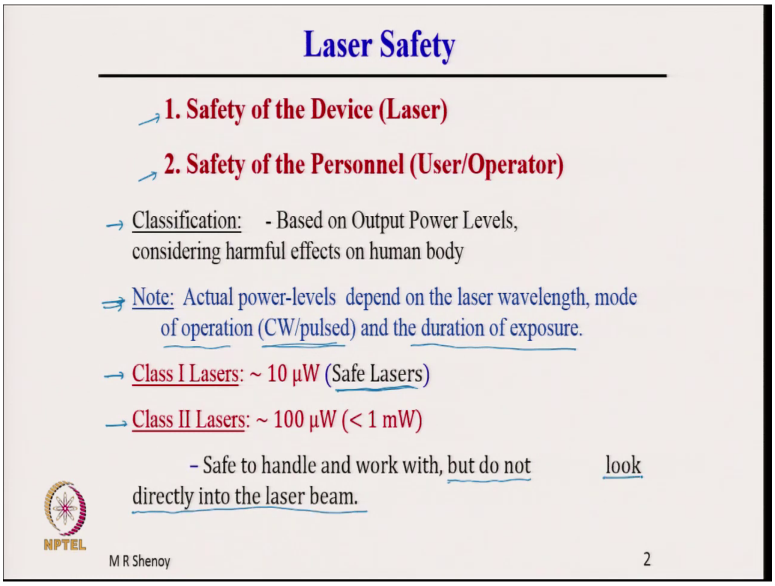

So, the laser safety refers to safety of the device and safety of the personnel or the user or the operator. So, lasers are classified based on the output power levels, considering harmful effects on human body.

So, that is the classification that we are now talking under laser safety. So, first let us look at the safety of the personnel that is; the user. So, what I have given in the following is the classification, as per ANSI that is American National Standards Institution. And the classification includes class I, class II, class III, class IV lasers and the power levels corresponding to this classification.

However, right at the beginning we must note that the actual power levels, I have specified a certain range of power levels, but the actual power levels, depend on the laser wavelength, the mode of operation that is; whether it is CW or pulsed mode and the duration of exposure.

However, an order of magnitude power levels are indicated corresponding to these different classes of lasers. So, there are class I, class II, class III and class IV lasers. So, let us first take up the class I laser. So, the class I lasers have powers of the order of 10 micro watt or 10 of micro watt are generally noted as safe lasers or almost harmless lasers.

Class II lasers, powers of the order of 100s of microwatt, but definitely below 1 milli watt are categorized as class II lasers. There are some specific experiments, where you need certain lasers of certain specific frequencies, but the powers involved are much smaller. And therefore, they are reasonably safe lasers, you can handle them without having to worry about additional precautionary measures.

It is safe to handle and work with, but the only advice is do not directly look into the laser beam. So, but do not look into oh the look is here, directly into the laser beam.

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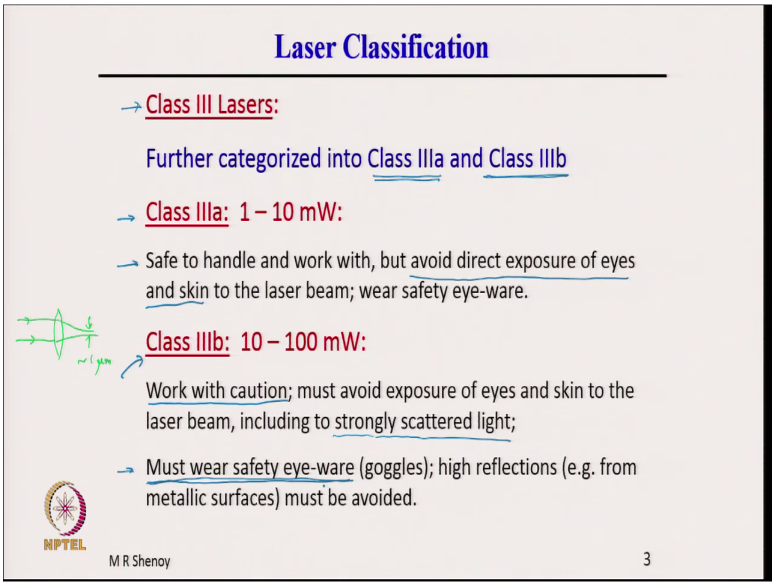
Let us go to the next class, which is called class III lasers.



This is further categorized into class IIIa and class IIIb. I must mention that there are many other classes, classification based on various other things, but these are the broad classifications. So, class IIIa and class IIIb lasers. Class IIIa power levels in the range of 1 to 10 milli watt, again they are relatively safe to handle the normal laboratory lasers, which we use in a laboratory; a teaching laboratory are in the range of 1 to 10 milli watt.

Let us say experiments in optics, interference, diffraction. Generally, we handle with helium neon lasers, which are of the power range of typically 5 to 10 milli watt and these are under class IIIa lasers. So, these are safe to handle and work with, but avoid direct exposure of eyes and skin to the laser beam. So, this is very important, because as we would know that, if there is a we have discussed, when we discussed the laser beam properties.

So, if we have a laser beam, a parallel laser beam incident on a lens, then it gets focused to a very fine spot of the dimensions of the wavelength that is of the order of 1 micrometer here.

And therefore, the power density becomes very high or the intensity at the focus spot becomes very high.

Our eye has a lens, and the lens can focus the laser beam to a fine spot with very high intensity on the retina and that could damage the retina and that is why, we say never look directly into a laser beam alright.

Now, we come to class IIIb lasers. So, class IIIb is typically 10 to 100 milli watt or 100s of milli watt. Here it says work with caution, because these are harmful to the human body and of course, eyes. Must avoid exposure of eyes and skin to the laser beam. Including to strongly scattered light.

So, strongly scattered means, if the laser beam is incident on a highly reflecting surface; such as metallic surface or maybe from some mirrors, then one has to take care that it is almost as strong as the direct beam and therefore, must avoid scattered beam as well. And it is mandatory, that must wear safety eyewear. This is a mandatory requirement or goggles.

And high reflections for example, as I mentioned from metallic surfaces must be avoided. So, handling this class of lasers requires caution and definitely, eyewear must be worn that is safety goggles must be worn. So, this is class IIIb.

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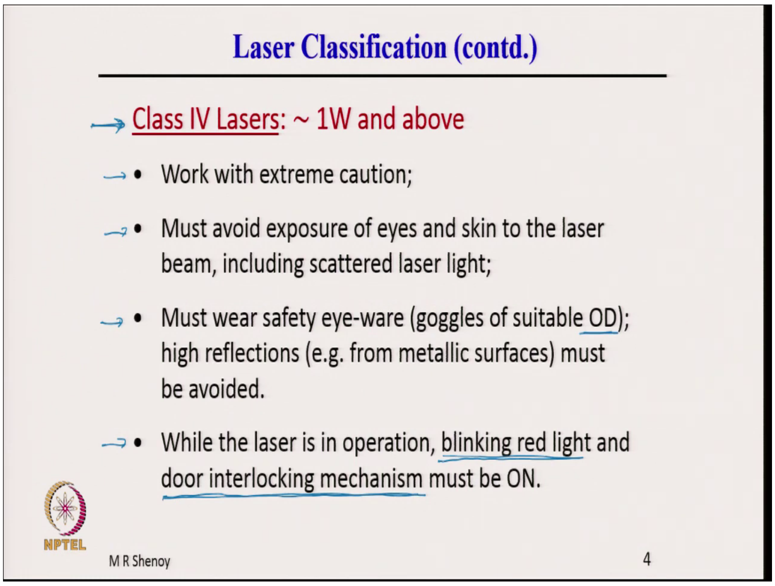

Now, let us go to the next class, which is the class IV laser. So, class IV lasers have powers of the order of 1 watt and above; all lasers with power greater than or of the order of 1 watt, sometimes even 500 milli watt is classified as class IV laser.

So, the points which are mentioned, work with extreme caution; must avoid this is the same as for the class IIIb, must avoid exposure of eyes and skin to the laser beam including scattered laser light, must wear eye wear goggles of suitable OD optical density. I will discuss about this in the next slide, what is this OD suitable OD. And high reflections must be avoided.

So, almost similar to class IIIb, but this is an additional mandatory requirement that, while the laser is in operation, blinking red lights and door interlocking mechanism must be on. This is an additional mandatory requirement, when class IV lasers namely high power lasers are in operation.

Now, the blinking red light; many of us must have seen, outside a laser laboratory they are always blinking red lights or a board which says laser on; which means you are not expected not supposed to enter the room. Whatever be the requirement you can make bell or knock at the door and wait till someone opens the door, never enter the room where it says laser is on.

By requirement, that the door should not be locked from inside and therefore, the door will remain open; open in the sense it is closed, but not locked from inside one can open from outside the door, but one should not when the laser red light is blinking or when the board says laser is on.

However, the door must have an interlocking mechanism, the door is provided with an interlocking mechanism that is; in the event of a mistake by a person who enters without knocking or without waiting at the door, when the laser is on the moment the door is opened, the laser will get switched off, that is called an interlocking mechanism.

If a door is inadvertently opened by someone, then the laser would get switched off or the beam would be cut off by the requirement, because the person who is entering is not wearing the safety eyewear. So, that is called the door interlocking mechanism. So, these precautions must be followed.

This is the essential ones, there are several others, but the essential ones which are listed here must be followed, when lasers are operated alright.

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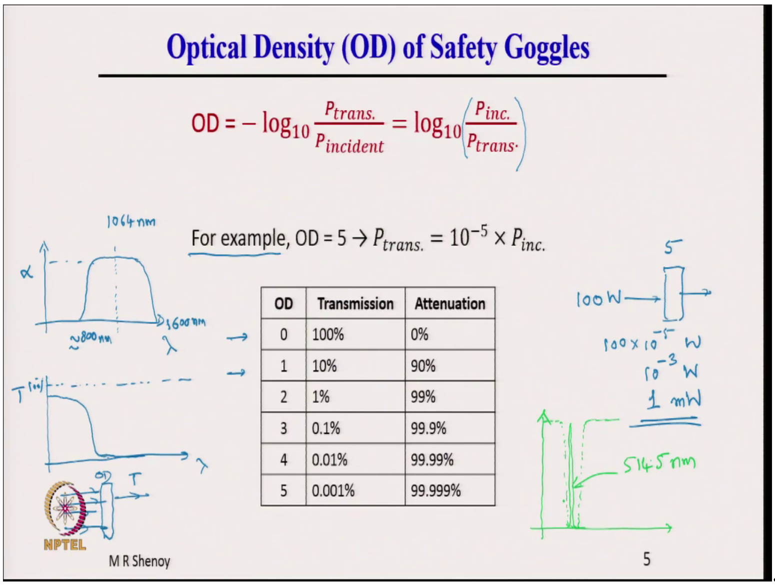

So, let me explain what is this optical density OD, because if you take a laser goggle or a eye safety wear, it is always written that OD equal to 5 or OD equal to 6, what does this OD mean? So, OD stands for optical density and it is defined as minus 10 log power transmitted divided by power incident or intensity transmitted intensity by incident intensity.

So, which is nothing, but it is minus log so, you can interchange it and make it as log to the base 10 P incident, power incident by power transmitted. Thus for example, if OD is 5; that means, if OD is 5; that means, this term here is 10 to the power of 5, because log of 10 to the power of 5 is 5.

Which means, the transmitted power is 1 by 10 to the power 5 times the incident power or 1 by 1000000 times; 1000000 is 10 to the power of 5. So, the transmitted power is cut down by 1000000 part.

So, for example, the table which I have shown here illustrates this if OD is 0 which means, there is no blockage that is P transmitted is equal to P incident, which means it is 100 percent transmission, 0 percent attenuation. If OD is 1; that means, the transmitted power is 10 percent and 90 percent of the incident beam is attenuated, 1 percent means that is OD is 2 means 1 percent is the transmission and so on.

And when OD is equal to 5, the transmitted power is 0.001 percent. So, if there is a 100 watt laser; so, let us say there is a 100 watt laser operating and by chance, the laser beam is incident on the goggles, which says the OD is 5, then the transmitted power will be 10 to the power of minus 5 times 100 so, 100 into 10 to the power of minus 5 watt, that is 10 to the power of minus 3 watt or 1 milli watt.

So, there are in particular when you operate with very high powers, 100s of watt OD of 6 or 7 is used. I have not shown here 6, normally when one operates with the Nd YAG lasers, which is of the order of 100s of watts, OD 6 or OD 7 is used.

Even though, you are not seeing the beam directly, but the scattered light itself could be harmful. And therefore, typically OD 6 or OD 7 is used. Now, one other point is; this is ok, if you are using Nd YAG laser so, all these safety goggles have a stop band and a pass band.

So, if you plot it as a function of lambda , then if you are talking of the attenuation alpha, then if you are operating an Nd YAG laser, generally it will have a stop band; this is what I have shown is the loss coefficient not transmission. So, generally around 800 nanometer here so, nearly equal to 800 nanometer to 1600 or so generally nanometer so this is the loss.

In terms of the transmission, then I could show so, this is lambda versus transmission if I plot, that generally. So, let us say this is transmission is 100 percent. Then when you use the goggle, then the transmission is slightly lower and then it drops down like this and almost blocks.

So, transmission what I mean is, if you have put the goggle here. So, I am showing the glass only and the laser beam is entering or the scattered light is entering, then transmission is the fraction which is coming here. So, this is the transmitted fraction and this is the incident and this is with a certain OD.

Then the wavelength spectrum almost it blocks the window, let us say if you are using as I mentioned this is Nd YAG. So, Nd YAG is at 10 64 nanometer and therefore, in the visible region, the transmission is reasonably good and therefore, you would be able to see all the laboratory components, equipments everything in such a case.

But suppose you are using a high power laser, which corresponds to the visible region, let me show here with a different color. So, suppose you have a laser, a high power laser which is giving output here. Let us say, like a the argon ion laser at 514.5 nanometer. Then you have to have a notch filter or at the filter transmission has to drop rapidly like this, around this. So, that it can block the laser light.

Because, if we block the entire region around this line, then the goggle will not permit the visible light to pass through and the laboratory would look like dark room and you would not be able to see the equipments. So, appropriate goggles have to be chosen. So, there are several issues involved in choosing the goggle.

But the most important is optical density, which has to cut down the laser beam. So, that it does not harm the eyes alright.

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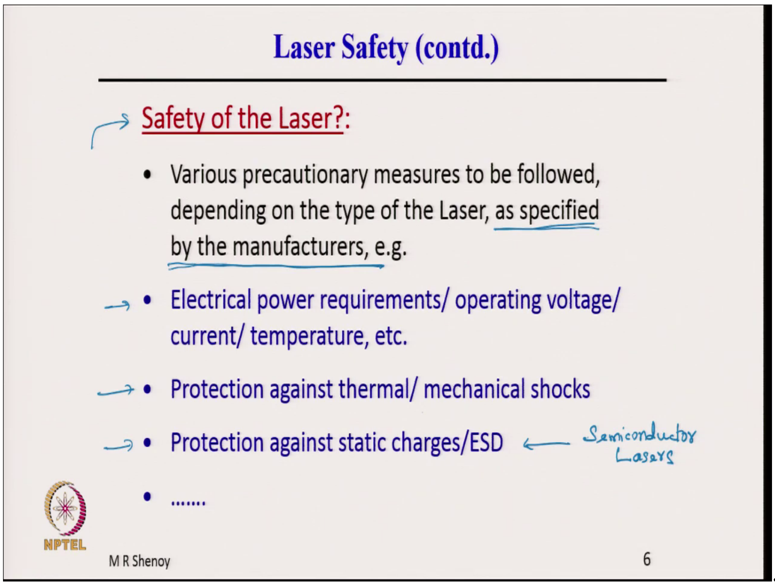

Next we come to safety of the laser; this is a very broad topic, because there are various precautionary measures to be followed depending on the type of the laser, as specified by the manufacturers.

So, what kind of precautionary measures? For example, electrical power requirements, the operating voltage, operating current, temperature, etcetera. Protection against thermal and mechanical shocks.

For example, if you are operating a helium neon laser, which contains a quartz tube inside, then one has to handle the laser head very carefully otherwise it could lead to damage to the tube and to the laser. And therefore, mechanical shocks, mechanical vibrations not all lasers can withstand.

So, that is what is meant by mechanical shocks. Thermal shocks sudden variation in temperatures can also damage the laser material. And then protection against static charges ESD; Electrostatic Discharge, this is very important particularly for semiconductor lasers so, semiconductor lasers.

In the case of semiconductor lasers is very crucial to take care of protection against static discharges, semiconductor lasers. So, there are various types of safety measures to be taken to take care of the laser or for the safety of the laser. There are; I have not listed many of them, because it depends on the type of the laser, as specified by the manufacturers alright.

That brings us to the end of this laser safety, there are many more issues which may be discussed here, but we will stop here on this topic. But before I stop the last lecture of this course, I want to a very quickly recap, what we have covered in this course.

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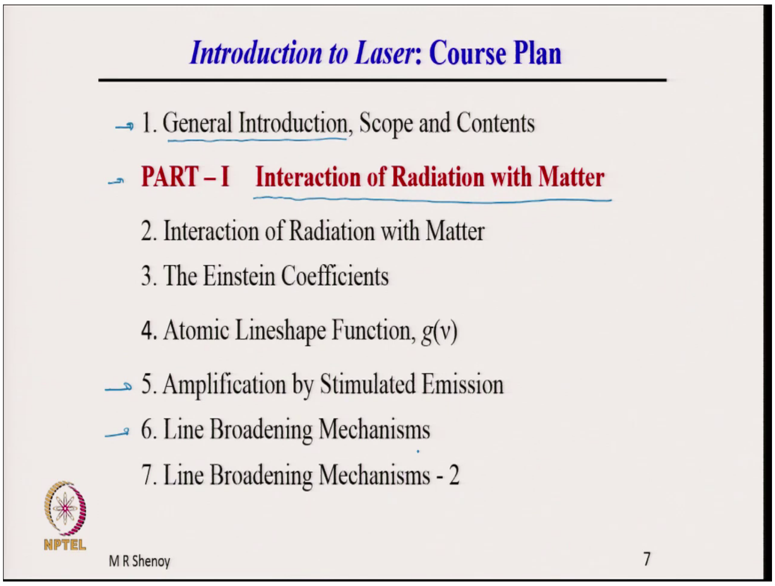

So, let me make a quick recap. So, this is the introduction to laser MOOC and as per course plan, we started with a general introduction here. So, these numbers here are the lecture numbers. General introduction where we discussed about what is a laser, what are the three components of the laser and then the scope and contents, we discussed in this first lecture.

The components as we know includes an active medium, when pumped appropriately gives rise to amplification and an amplification with a suitable feedback mechanism leads to an oscillator or the laser, which is the source of electromagnetic radiation, It is a coherent source of electromagnetic radiation.

And therefore, we picked up in PART I, the interaction of radiation with matter and in this we started with the Einstein coefficients, then we introduced atomic line shape functions and discussed the condition for amplification by stimulated emission and then we introduced line broadening mechanisms, which determine the line width of emission of the laser.

So, we discussed both homogeneous and inhomogeneous broadening mechanisms.

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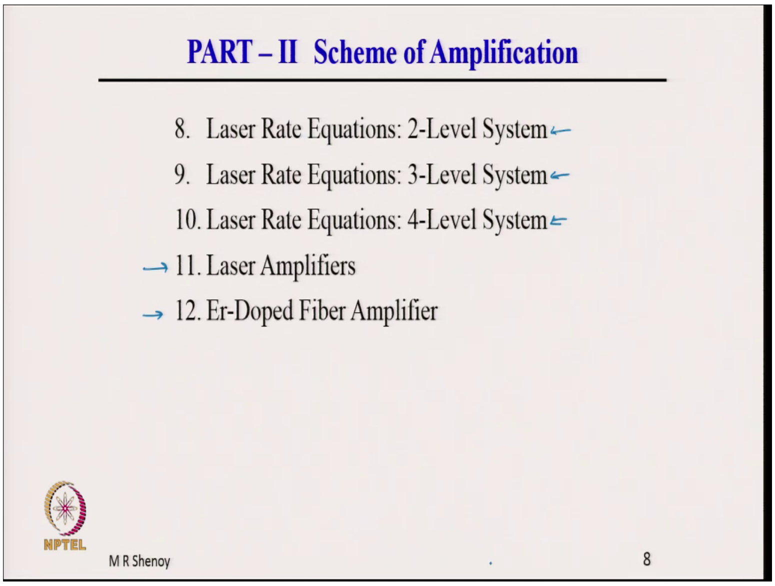

And then we continued on to PART II, where we discussed various schemes of amplification. And therefore, to discuss this we considered first a 2 level system and then 3 level system and 4 level system and under what conditions we can achieve amplification by stimulated emission.

The condition for amplification, we had shown earlier, that population inversion is the necessary condition for amplification. Now, how to achieve population inversion? This is what we discussed in this part on scheme of amplification. What is a suitable scheme to achieve population inversion and hence amplification?

Then I picked up laser amplifiers as an example and discussed the Nd YAG laser amplifier and Erbium doped fiber amplifier. This is a very important device in optical fiber communication, widely used. And therefore, I specifically took this and we discussed Erbium doped fiber amplifiers.

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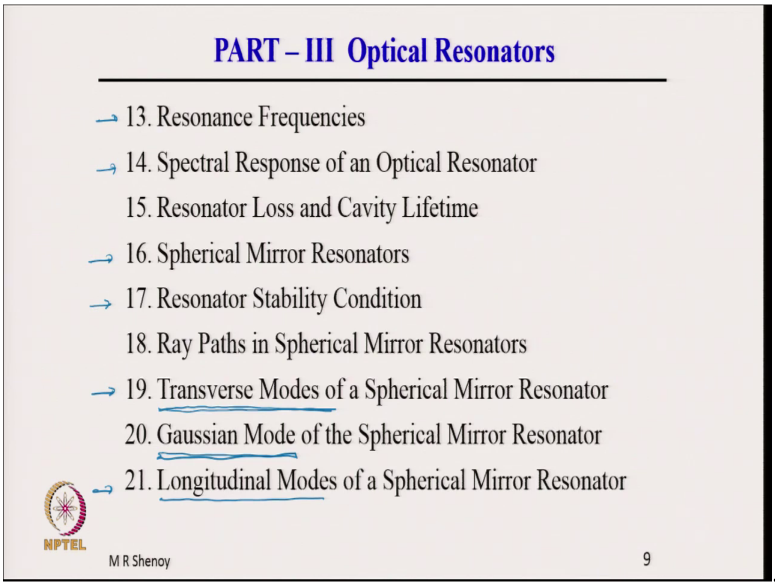

Then we came to PART III, because optical resonators is an essential part of lasers and it is the optical resonator, which determines most of the important properties of the laser. And therefore, we discussed the resonance frequencies, the spectral response of the optical resonator and how the resonator loss and cavity lifetime determine the spectral response.

Then we picked up spherical mirror resonators, which are the widely used resonators and using the ray theory we obtained the resonator stability condition, we then used a matrix approach to trace rays through the resonator, ray paths in a resonator and then subsequently, we went on to discuss transverse modes of the spherical mirror resonator.

So, these are the Hermite Gauss modes of the spherical mirror resonator. And the fundamental member of this family is the Gaussian mode, which we discussed in a little bit more detail. So, lasers have longitudinal modes and transverse modes. Longitudinal modes refer to the resonance frequencies and transverse modes refer to the field distributions, transverse field distributions supported by the resonator.

And in this section, we also discussed how to select a single transverse mode and how to select a single longitudinal mode, because this is very important to realize single frequency lasers, which oscillate in a single longitudinal mode and a single transverse mode.

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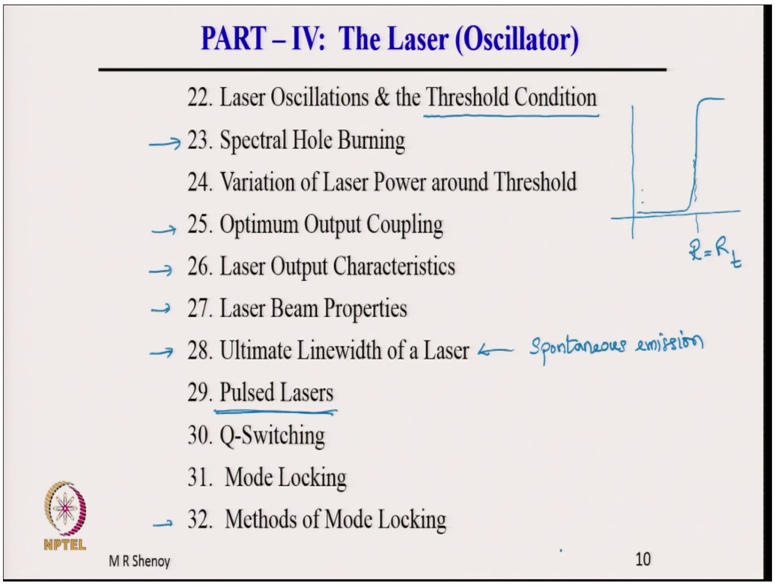

Then we came to PART IV where we combined the amplifier and the resonator to make the oscillator or the laser. And we discussed laser oscillations and the threshold condition for lasing, an important aspect of spectral hole burning in homogeneously; broadened laser medium is also discussed.

And then we discussed the variation of laser power around threshold that is as soon as you cross the threshold if we quickly recall the photon number shoots from a small number to a very large number by orders of magnitude around the threshold pumping rate R is equal to R t.

And then, we also discussed the optimum output coupling, which is a very important design issue in a laser, that at a operating power one can design the output coupler to have optimum reflectivity, which would give the highest output power.

So, then we discussed the characteristics of the laser output, the properties of the laser beam and also what determines the ultimate line width of a laser. And we have seen that, it is the fundamental limit is imposed by spontaneous emission, determines the fundamental limit of the laser line width spontaneous emission.

Then we took up pulsed lasers and the methods of pulsing various schemes of pulsing q switching and mode locking being two important methods. And specifically, I picked up the methods of mode locking in this part.

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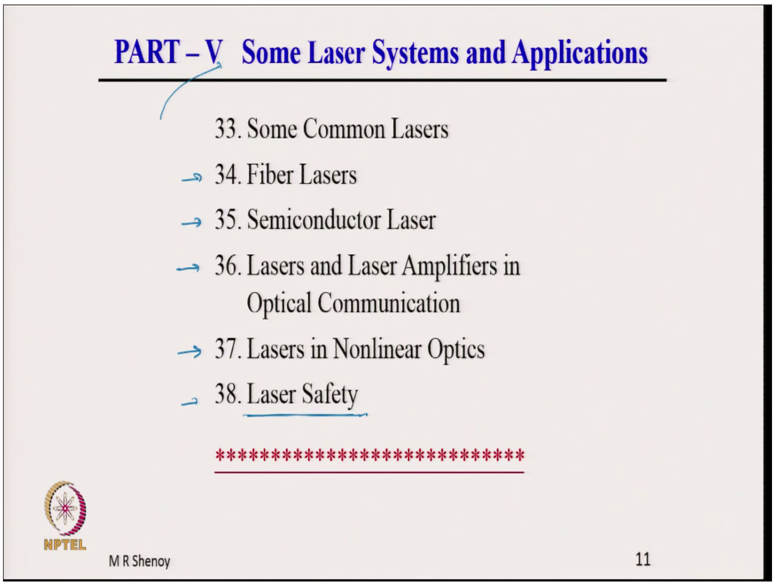

We then came to the last part, where we picked up some laser systems and applications. As mentioned there in; there are large number of laser systems. And each one has its own specific advantages, disadvantages, construction, output wavelength, power levels and so on.

Similarly, laser applications are enormous number of applications of lasers and these; there can be full courses on laser systems and laser applications. So, our objective was to just indicate some of the common laser systems. So, that we understand that yes, these systems indeed are consistent with the theoretical description, that we had undertaken alright.

In particular I picked up fiber lasers and semiconductor lasers in a little bit more detail, because these have very large number of applications both semiconductor lasers and currently fiber lasers for various industrial and commercial applications.

As an illustrative example of laser application, I picked up optical fiber communication, as one of the examples lasers and laser amplifiers, the erbium doped fiber amplifiers and the semiconductor lasers which are used in optical fiber communication. And a scientific application of lasers in non-linear optics. And finally, laser safety that is what we discussed today.

That brings us to the end of this course an introductory course on laser. I would like to emphasize that, it is an introductory course. Laser physics is much more involved; laser is a quantum electronic device. Therefore to go into the depth of lasers, it is necessary for us to understand quantum electronics.

A course on quantum electronics and quantum electrodynamics will prepare you to go into the depth of laser physics, but the objective here was to introduce the essential aspects of lasers alright.

With that we come to the end of this course, I have greatly enjoyed in presenting this course at this introductory level. And hope it motivates some of you, some of those who have attended this course to take up further into the depths.

So, before I stop this course, I have a slide which shows if you are interested; how would you pursue this area? So, that is what I will put as the last slide.

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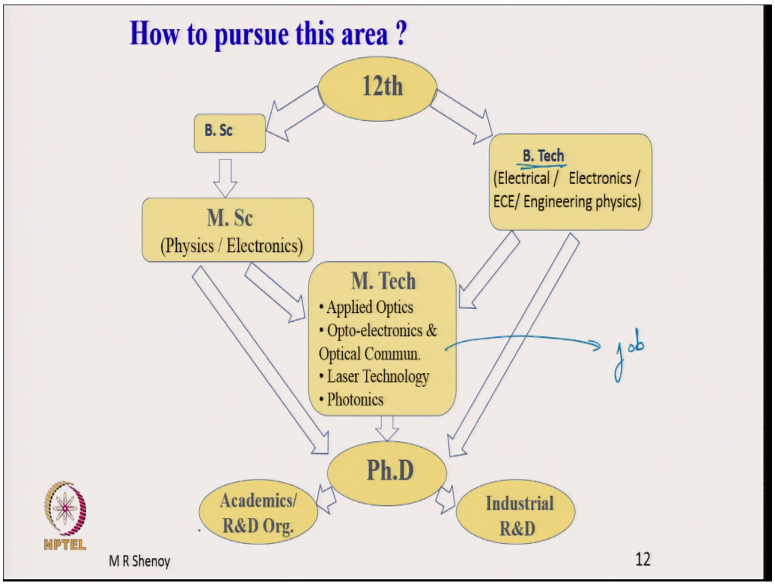

So, here so, this is of course, most of you would have gone beyond 12th and if you are doing B. Sc, then you could go over to M. Sc with physics or electronics, and then you could pursue any M. Tech in the areas of applied optics or opto electronics, optical communication, laser technology, photonics there are several M. Tech programs of these titles in the country.

And then you could if it interests you further, you could go for a Ph.D program or you could go from here itself, seeking some jobs after M. Tech or you could pursue a Ph.D. Similarly, if you are an engineer, if you are doing a B. Tech in electrical electronics ECE or engineering physics.

It is possible to get admission in these M. Tech courses or a Ph.D directly in this area of optics and lasers. And then, beyond Ph.D one could go to several industrial R and Ds or academic and R and D organizations. So, this is the way, which I have charted that one could pursue a future in this area, if the area interests you.

Thank you, I will stop at this point.