Laser Based Manufacturing
Prof. Shrikrishna N. Joshi
Department of Mechanical Engineering
Indian Institute of Technology – Guwahati
Module # 01
Lecture # 03
Laser System: Construction and Types

Hello everyone. I welcome you all to the third lecture of Week 1 or Module 1 of the MOOC course on Laser-based manufacturing. In this lecture, we will be studying the laser system, its construction and various types of lasers which are used in the industry.

In our previous class, we have seen how exactly laser is getting produced, what its principle of operation, what is the meaning of the population inversion as well.

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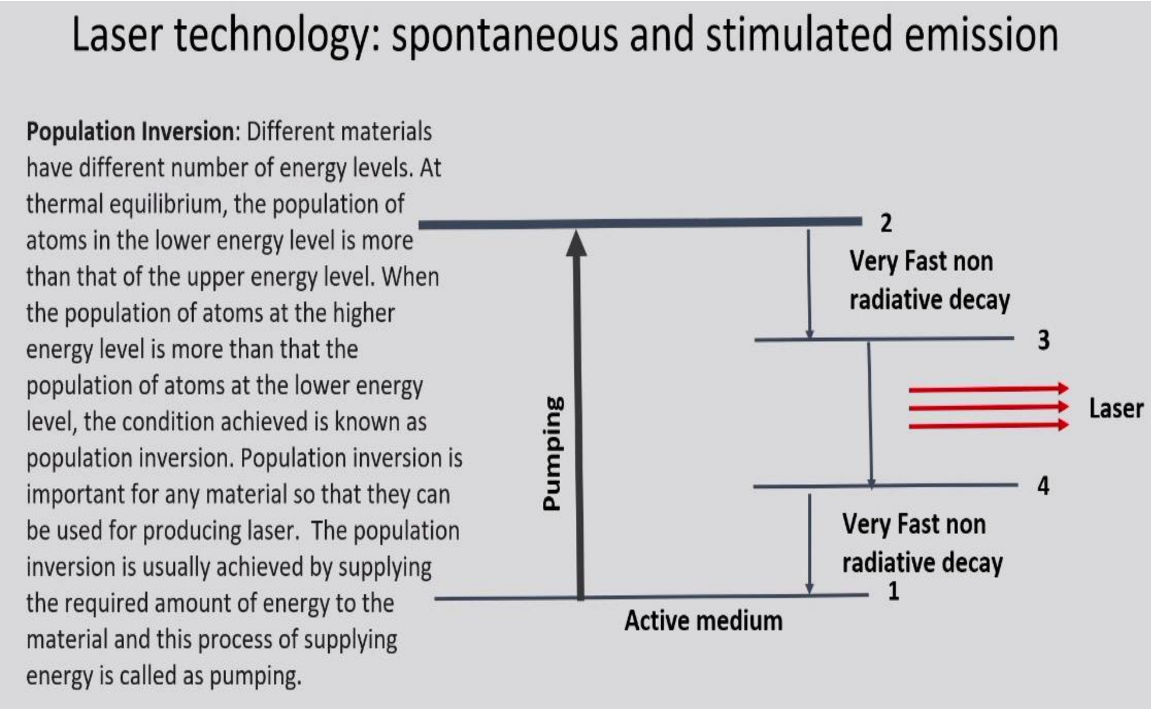

Let us revise again the concept of population inversion. As we have seen that to get the stimulated emission, we should have more number of excited atoms at higher quantum level and when they decay from higher energy state to the lower energy state they emit photons and when this photons are getting in line with or in phase with or with a similar wavelength of the passing photons, we are getting the coherent monochromatic and highly collimated beam of light, that is the laser.

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Terminologies related to Lasers

- **Population Inversion**: Different materials have different number of energy levels. At thermal equilibrium, the population of atoms in the lower energy level is more than that of the upper energy level. When the population of atoms at the higher energy level is more than that the population of atoms at the lower energy level, the condition achieved is known as population inversion. Population inversion is important for any material so that they can be used for producing laser. The population inversion is usually achieved by supplying the required amount of energy to the material and this process of supplying energy is called as pumping.
- **Metastable state**: Metastable state is an excited state of an atom or other system with a longer lifetime than the other excited states. However, it is a shorter lifetime than the stable ground state. Atoms in the metastable remain excited for a considerable time in order of 10^{-3} s
- **Active material**: To obtain a laser a population inversion should be created in a material or medium called active material or active medium. The material may be solid, liquid or gas.

Now, there are various terms which are being used in the industry and in the research of laser based manufacturing. The first term which is very popular and important is population inversion. There are various materials we use and these materials are having various or different number of energy levels. When we consider a material at thermal equilibrium, the population of the atoms at lower energy level is more than of the upper energy level.

But for production of lasers we want the population of atoms at higher energy level more than the lower energy level and this condition is called as the population inversion. This is a very basic phenomena very basic thing which is must to generate the laser beam. But to produce the laser we should continuously pump external energy to get that exact amount of photons or sufficient amount of photons to generate the laser beam.

Then, the next term is the metastable term. What is the meaning of metastable? It is an excited state of an atom or other system with longer life time than the other excited states. As we have seen that various materials are having various energy levels, the metastable state is an excited state of an atom when it is having longer life time than the other excited states. This particular state is very much essential to have the emission of photons from the process of population inversion. The metastable state is having lifetime of course shorter than the stable ground step and in general it is in the order of 10 raise to power (–3) second.

The third important aspect or term which is there in the laser-based manufacturing or laser technology is active material. We want to generate the photons which are producing the laser, but who will produce that laser, what material we have to utilize to generate the series of photons or the bunch of photons or a population of photons which will generate the laser beam.

That material which is being used in generation of the laser technology is called as the active material. This active material can be a gas, can be a solid or can be a liquid and this active material also being called as the lasing medium as well. We will see various types of this lasing materials or the source of generation of the lasers in our next few slides.

Now, let us start discussing about how exactly we produce the laser and what is its construction?

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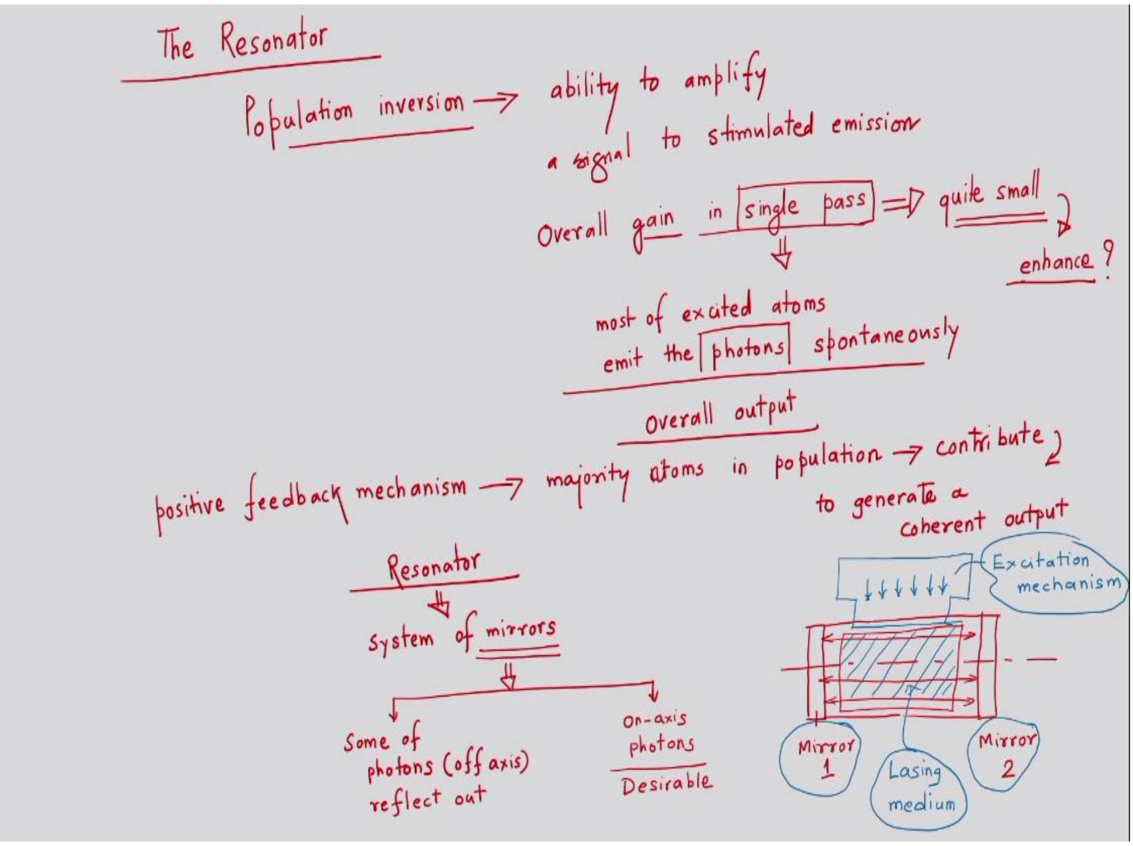

In laser we required a basic component that is called as resonator. We have seen that in population inversion we are getting stimulated emission. This emission is stimulated and we are getting lot of photons. Population inversion we can write here as it has a very huge capability to amplify the photons. This amplification - the population inversion has ability to amplify a signal to stimulated emission. But the problem during the population inversion is that during a single pass, overall gain in single pass - the gain means the enhancement that we get in the number of photons in single pass is quite small. Now, our target or our objective is to enhance this. We have to enhance the gain, we have to produce as much as number of the photons so that we can get high power density laser beam.

What is required to enhance this? Another point in the population inversion is that most of the excited atoms emits spontaneously. During this single pass most of the excited atoms are emitting the photons spontaneously and therefore we are not getting considerable output from the single pass amplification. Moreover, whatever the number of photons which are getting created due to this spontaneous emission will not contribute to the overall output. Overall output is the laser beam that we want at the end of the operation. These are not that much contributing - the spontaneous emission photons.

So, what do we need to have? We need to have a positive feedback system or positive feedback mechanism in which the majority atoms in the population will contribute. We want to enhance the contribution of the atoms so that majority atoms in the population should contribute. They should participate in generation of a coherent output - majority atoms in population should contribute to get a coherent output - meaning is that we do not want to have just a single pass. We need to have multiple number of passes of the photons that to be transmitted during the operation.

There the concept of resonator came into picture. Resonator is having a system of mirrors. Resonator is nothing, but a system of mirrors. These mirrors are arranged in a parallel way and the photons are just moving back and forth in between these mirrors. What is happening during this back-and-forth movement of the photons? Some of the off-axis photons they will get reflected out. Hence, these mirrors are also providing two basic operations: allowing back-and-forth movement of photons and some of the off-axis photons will be reflected out. Inside this cavity - the cavity made of two sets of mirrors, this is mirror number 1 and mirror 2, both of them are having high reflectivity. Photons are just moving back and forth and they are getting reflected by these mirrors.

But some of the photons which are off-axis, some of the photons are off-axis, so this set of mirrors will reflect them out because as we have seen that during the population inversion and the stimulated emission, large number of photons are getting generated, some of the photons are off axis photons which are generated by using the spontaneous emission, those photons are to be reflected out. The system of mirrors is reflecting out these off-axis photons and the photons which are on the axis along the axis - these on-axis photons are used to generate the collimated beams. These on-axis photons are desirable in our operation, and certainly, they will be moving back and forth inside this cavity, and when they move back and forth inside the cavity, they will further excite the other atoms. These photons are not only moving between mirror 1 and mirror 2, they are doing the work of excitation of the atoms, production of more number of photons and some of the photons again will be on the axis, and some of them may be off-axis. It is a process of amplification. These on-axis photons are helping to generate more to better amplification of the laser beam.

But how we will be doing this operation? To carry out this operation to generate we need to have a certain medium and that medium is called as the lasing medium. This would be done with the help of medium, certain material and that is called as a lasing material or lasing medium and to excite the atoms we need an external energy source, external excitation source which is also very useful for us. Here we are having the excitation mechanism. This excitation mechanism is pumping energy inside the laser system and that energy will be useful to generate more number of photons to get the required laser production.

There are three basic components of a laser-based system: a pair of mirrors, a laser medium and the excitation mechanism. These are the three main components elements of a laser-based system.

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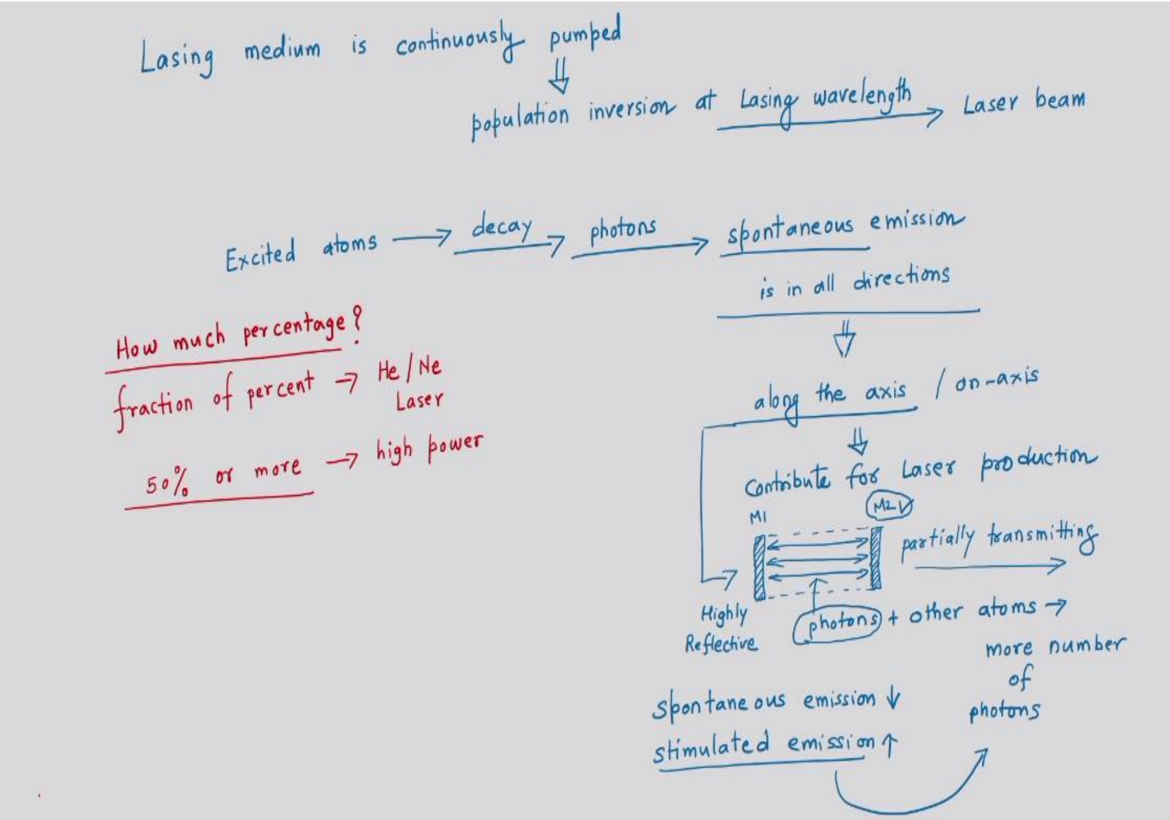

We can say that the lasing medium is continuously being pumped by the external excitation mechanism. Lasing medium is continuously pumped and that is generating the required population inversion at lasing wavelength. This is very important here. We want the population inversion it should be at the lasing wavelength only. Then and then only we can generate the required laser beam.

During this process, what is happening? The excited atoms which are moving back and forth, which are contributing for generation of the photons, they will get decayed and that decaying is generating the photons as we have seen using the spontaneous emission, but this spontaneous emission is in all directions. What we want the spontaneous emitted photons or the photons that come along the axis or on-axis which will contribute for laser production?

These along axis photons, when we allow them to move or allow them to reflect by using set of mirrors as we have seen previously, we are making them to act more and generate more number of photons by interacting with the other atoms. These photons are interacting with other atoms and then they are generating more number of photons. In this way the spontaneous emission will get reduced and slowly the stimulated emission will get enhanced.

How this stimulated emission is getting enhanced is due to the back-and-forth movement of these photons? But after certain time these photons will also get decayed - they will lose their energy during this movement. To enhance their energy and to generate more and more number of photons, we need to have the external excitation mechanism. Now, when these photons are moving back and forth between mirror 1 and mirror 2, after sometime we have to take out some of the photons for our intended purpose.

Consider we are having highly reflective mirror 1 - this is highly reflective and mirror 2 is also highly reflective. No output will be produced, no photon will come out from this cavity, from this region. What we make here? We are making this M2 partially transmitting, some of the portion or some of the photons are to be transmitted out, they are to be taken out from this cavity. To make this possible we are making M2 that is mirror number 2 partially transmitting. The photons will be keep on moving and some of the portion will be open and through that we are taking out a beam of photons and that would be used for our intended purpose.

Now the question is that, how much amount or how much percentage is getting transmitted out from this cavity? This maybe a fraction of percent. There are many types of lasers being used which transmitted a fraction of percent and the example is He-Ne laser (helium-neon laser). So, only fraction of percentage of the on-axis photons which are getting generated will get transmitted out. There are certain types of lasers which are transmitting out about 50% or more and these kind of lasers also available and these are the high power lasers which are very much useful in our manufacturing operation. These high power lasers are having more capacity to transmit out the photons from the optical cavity or the resonator.

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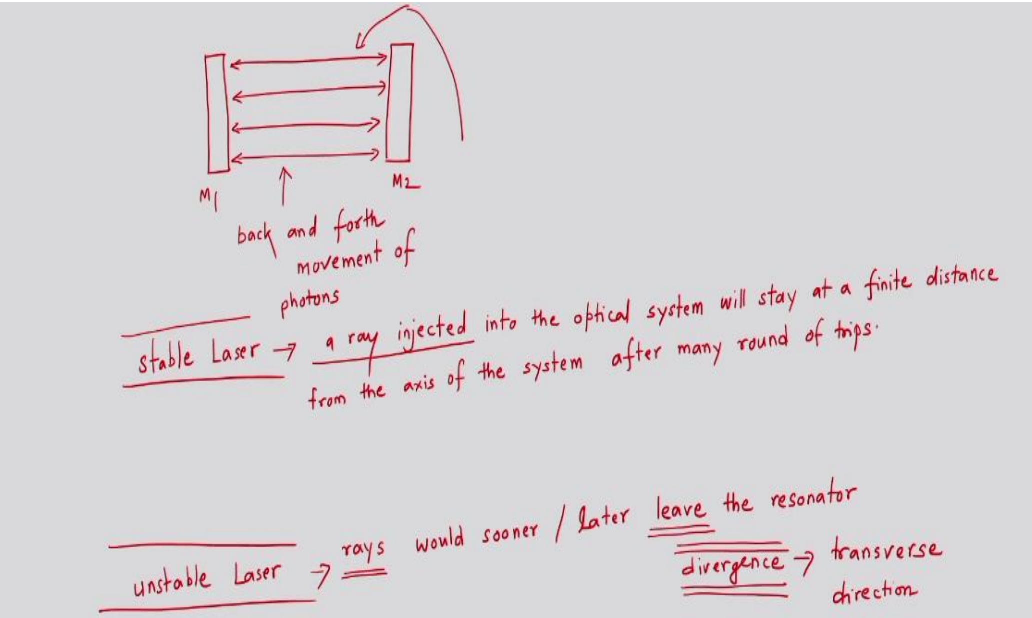

Now, when we consider a pair of mirrors and in between these pair of mirrors the photons are getting moving back and forth. This is the back and forth movement of the photons. There are basically two modes in which we can get the laser and that is called as the stable laser and the second one is unstable laser.

Let us see what is the meaning of a stable laser and unstable laser? Laser is called as stable, when a ray which is injected into the optical cavity or a beam of photons which is there in an optical cavity or optical system will stay at a finite distance from the axis. This ray will always be at a finite distance from what? that is from the axis. A ray we are injecting. We can consider these as rays and these rays are staying at a finite distance from the center of the system or from the axis of the system, in this case it is axis of the system. After many rounds of trips these rays are parallel to each other and there are finite distance from the center. That we call a stable laser. It is generally possible or all the laser which we are using from low power to the medium power they are the stable lasers.

But when we consider high power laser, when we want to have high output from a laser system, then we are applying more excitation energy, excitation mechanism and the rays which are coming out which are getting diverged from the axis of the system - that energy diverged photons we have to collect them and then we can use them for our intended purpose. Geometrically or technically, we can consider these as when the rays would sooner or later leave the resonator.

Why they are leaving? They are getting diverged from the axis. They will leave the resonator, optical cavity and that rays we have to collect them out and we have to take it out and use to generate a laser beam. And generally, this divergence is occurring in transverse direction. This leaving or the divergence is occurring in transverse direction, but still, we are making use of this high-capacity laser beam by collecting these diverged photons for our purpose. Let us summarize the constructional details that we have seen till now.

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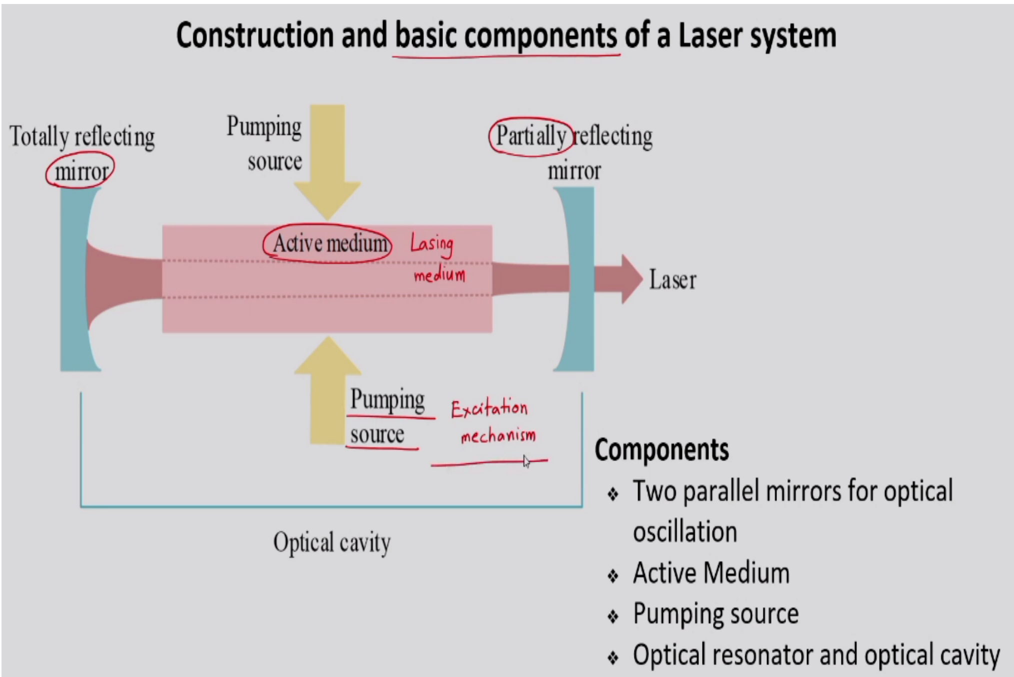

A laser is having some of the basic components and that basic components are set of mirrors that we have seen. We require one completely reflecting mirror, totally reflecting mirror and we required one partially reflecting mirror to get the output from the laser system, to get the photons coupled out from the laser system. The photons which are moving back and forth are generated by using an active medium or a lasing medium. This is the second component of the laser system and as we have seen that we need to have external excitation and this is the excitation mechanism - pumping source.

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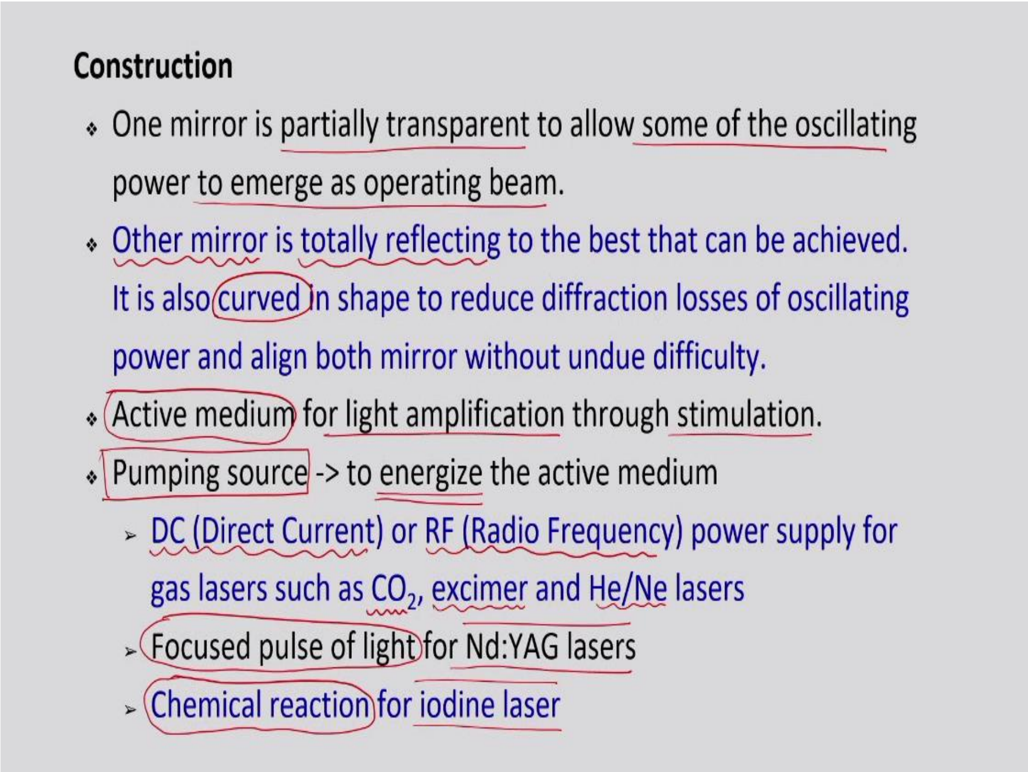

These are the constructional details. We required a mirror the same thing I have summarized in words in this particular slide. We require one mirror which is partially transparent or partially reflective and it is allowing some oscillating power to emerge as the operating laser beam. The other mirror is totally reflecting to the best it can be achieved and these mirrors are having curved shape, so that we can get a proper reflections and there has to be little diffraction, divergence should be as less as possible, diffraction losses should be as much as less possible. We required an active medium for light amplification through the stimulation and the last very important part is the pumping source and based on the pumping source itself there are various types of lasers which are getting used. And the function of the pumping source is to energize the active medium. There are many lasers which are also classified based upon the active medium as well.

What are the various types of pumping source being used, the electrical energy that we use either in terms of the direct current or the RF that is the radiofrequency power supply and these are in general use for the laser such as the carbon dioxide laser, excimer laser and helium neon gas lasers. We can also used focused pulse of light, we can use the light beams or the light as a pumping source and these are in general used for a solid laser that is the Nd-YAG laser. The pumping source can be a chemical energy as well – chemical reactions of some of the chemicals can be utilized to provide the external excitation and these are done in general the iodine lasers. One of the examples of utilization of chemical reaction is the iodine laser.

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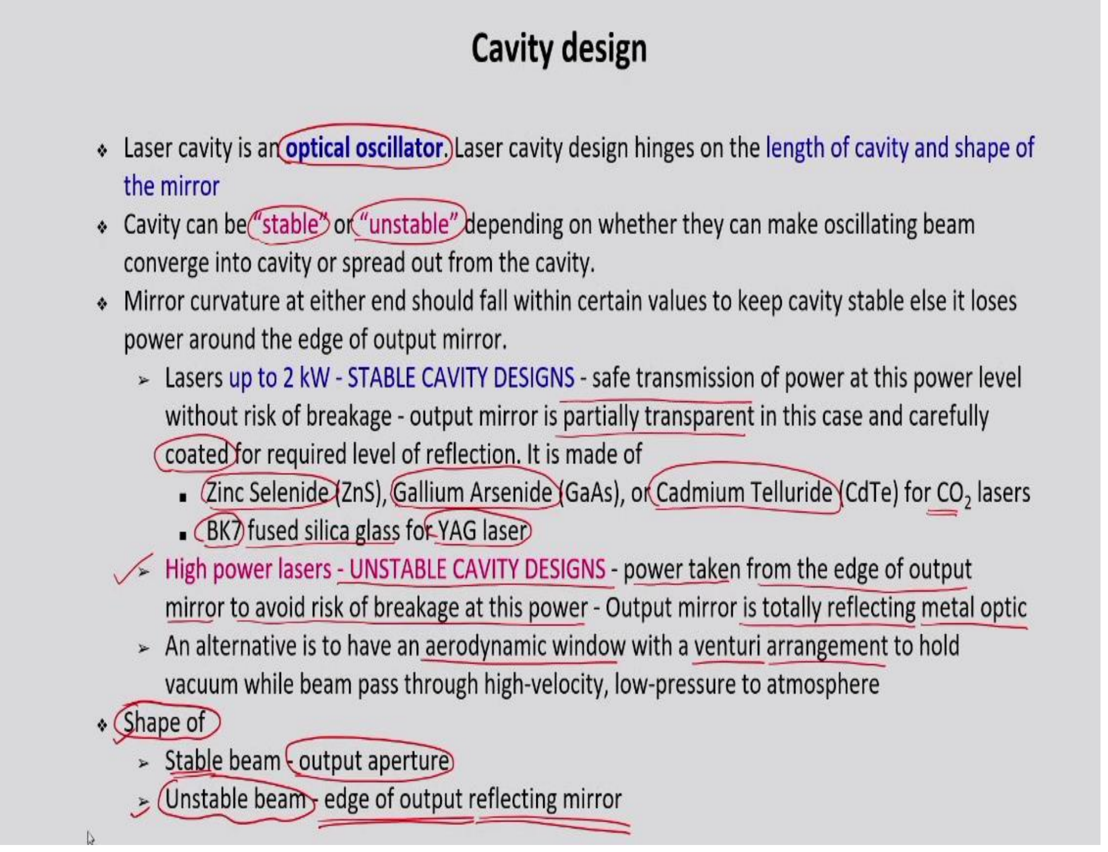

Now some aspects about the cavity or the resonator that we will see here. The laser cavity is an optical oscillator in which the laser beam or the photons are oscillating between the two mirrors. As we have seen that the cavity can be stable or unstable. It is all depends upon the convergence or the divergence of the laser beam in between the set of mirrors. When mirror curvature is at either end should fall within the certain value to keep cavity stable else it looses power around the edge of the output. If we are converging the power then we are getting collimated beam at the center or about the axis, but if the divergence is there of the laser power then we can get the laser power around the edge of the mirror. From that annular region the circular region about the mirror we can take out the laser power as well.

The lasers up to 2 kilowatts are called as the stable cavity designs. And they are providing safe transmission of power at this power level without risk of breakage. Whatever the photons which are oscillating or reflecting they will not harm the mirrors and the output mirror is partially transparent, the way we have seen in our previous discussion and this is possible; this partially transparency is possible by using certain coating materials and what are the various coating materials which are available is zinc selenide, gallium arsenide, cadmium telluride for the CO_2 type of lasers and BK7 fused silica glass for the YAG type of lasers.

In high power range for high power lasers the unstable cavity design is used and the power is generally taken from the edge of the output mirror to avoid the risk of breakage at this power. This divergence is expected, it is desired, to avoid the harm or to avoid the damage to the system. The output mirror is totally reflecting. It is a metal optic we are using here, but from the annular region we are taking out the laser beam for our application.

The stable cavity also has some sort of aerodynamic windows which are based upon the venturi arrangement so that we can get the collimated beam at the center at the axis of the laser system itself. The shape of the stable beam is basically dependent upon the output aperture. This shape is controlled by the output aperture for the stable type of the cavity design, but for the unstable beam the edge of the output, the shape which is at the edge of the output reflecting mirror will decide the shape of the beam in case of unstable beam.

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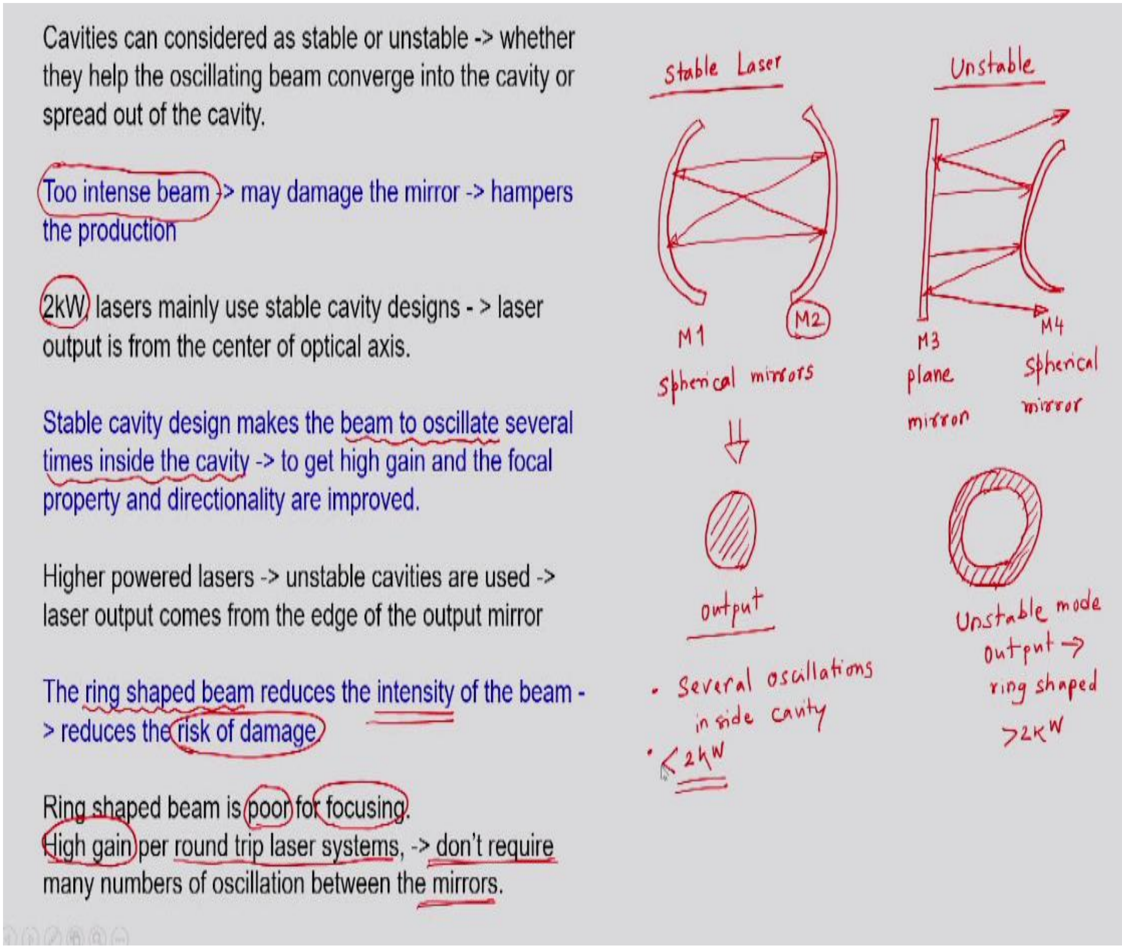

Now, let us understand the stable and unstable mode of the laser operation. As we have seen that in the stable mode the beam is oscillating several times inside the cavity. How it is possible to have the continuous oscillation of the laser beam inside the cavity? This is possible by using two spherical mirrors. Consider this is mirror 1 and we are having another spherical mirror that is mirror 2. When a beam is starting from mirror 1 it will get struck to the mirror 2 then from this place it is getting reflected it will come back to mirror 1. From mirror 1 again it is getting reflected and it will come to mirror 2 and then further it comes back to mirror 1 and it will keep on oscillating. In this way we can achieve a stable mode of laser operation. But during this continuous oscillation there maybe chances of having damage to the mirror if the beam is too intense. This is happening when we use the laser power more than 2 kilowatt. In these kind of scenarios we are using the unstable mode of laser operation. In unstable mode we are using a plane mirror, this is mirror M3 which is plane - it is a plane mirror and we are using one spherical mirror, this is a spherical mirror that we do have. Now, we start getting the reflection operation. Consider a mirror is starting from M3 - this has been starting from M3. It will get reflected from M4, it will come to M3 and from M3 it will get diverged, it will move in this direction and it will not converge but it will diverge, it will move away from the center or the axis of the system. In a similar way, we can have the divergence on the other side. With this kind of arrangement we are getting the stimulated emission. However, there is the divergence and that diverged beam will be utilized for our intended operation.

But if you keep on oscillating the laser beam in stable laser no output will be possible. What do here; we are making the mirror M2 partially transmitting and we will take out the output from the stable laser. In general the stable laser is producing a coherent output at its center. This is the coherent output that we get at the center from the stable laser. However, in unstable mode we are getting the output at the annular region, at the border or at the edge of that spherical mirror and in general we get the output in the unstable mode is of the ring shape. High intense beam will get diverged out and we are getting a ring-shaped laser beam in case of unstable output. In unstable mode the output is ring shaped. Naturally the ring shaped beam is reducing the intensity of the beam and that is reducing the risk of damage to the mirrors. The ring-shaped beam is poor for focusing. As we are getting the diverged laser beam, so naturally the focusing would be poor. However, we can get the high gain per round trip of the laser oscillation. The unstable mode does not required several number of oscillations between the mirrors. To get high density power in stable laser we must have several oscillations inside the cavity and this already we have seen that the stable mode is suitable for less than 2 kilowatt and unstable is more than 2 kilowatt.

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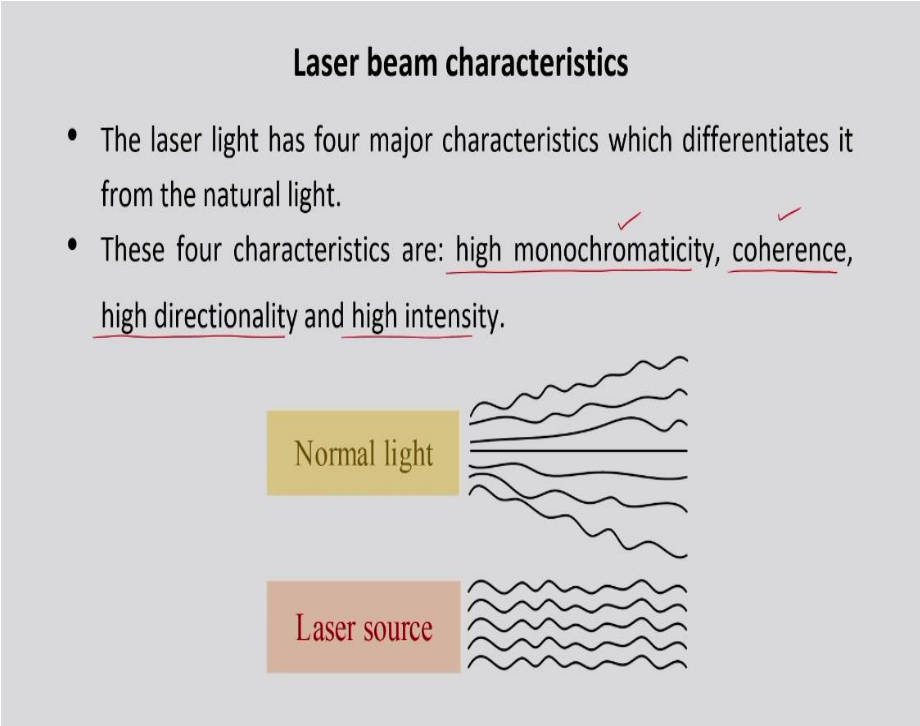

The laser beam characteristics in our previous class also we have seen there are basically four important characteristics of the laser beam. First is high monochromaticity, coherence and high intensity. Let us see one by one this laser beam characteristics.

In our previous class, also we have seen that the laser beam is different than or it is having a peculiar difference between the normal light in these four terms only. The high monochromaticity coherence, high directionality and intensity.

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Laser beam characteristics

- **High Monochromaticity**: The laser light being emitted from the active medium by pumping is a combination of photons having the same wavelength and same frequency as they are emitted because of the transition between the same atomic or molecular energy levels. Thus the laser beam has a single color.
- **Coherence**: The emitted photons by stimulated emission are emitted in phase with those already present in the resonator cavity in both space and time. This property clearly distinguishes laser light from the other kinds of light. High degree coherence in laser beam generates exceptionally high power laser.
- **High Directionality**: The photons emitted by the stimulated emission have identical direction of propagation. This property makes possible for the laser beam to be focused at far distance with little divergence.
- **High intensity**: The laser has high intensity because of its coherence and high directionality and it can be concentrated into a small spot.

Let us see one by one what is the meaning of high monochromaticity. The laser light being emitted from the active medium by pumping is a combination of photons having same wavelength and same frequency as they are emitted because of transition between the same atomic or molecular energy levels. Thus, the laser beam has a single color. Monochromaticity means the laser beam will have a single color and the photons which are coming out will have the same wavelength and same frequency.

The next characteristics is coherence. The emitted photons by stimulated emission are emitted in phase with those already present in the resonator cavity. The coherence is basically is dealing with the phase of the photons. When the phase of the photons is similar with the photons which are already present in the resonator cavity both in space and time, that particular characteristic or properties is called as coherence. In the laser whatever the photons that we are having they are in similar phase - same phase. High degree of coherence in laser beam generates exceptionally high-power laser. To have a very high power laser, highly coherent beam is very much essential.

The third important characteristic is directionality. The laser beams is having various photons. These photons are emitted by the stimulated emission and they are having identical direction of propagation. When these photons are moving in a same direction this property makes possible for the laser beam to be focused at a far distance with little convergence. When all these photons are propagating in a single direction, identical direction it is making the lasers to reach at a very far distance with little divergence.

The next important characteristic is intensity. The laser beams are giving us high intensity. The laser has high intensity because of its coherence and high directionality. These two characteristics that is coherence and high directionality are generating the laser beams which are producing highly intense laser beams, the power density is much more high because we can concentrate on a very small spot.

When the coherence is there, when high directionality is possible it can be concentrate into a small spot which is generating highly intense laser power.

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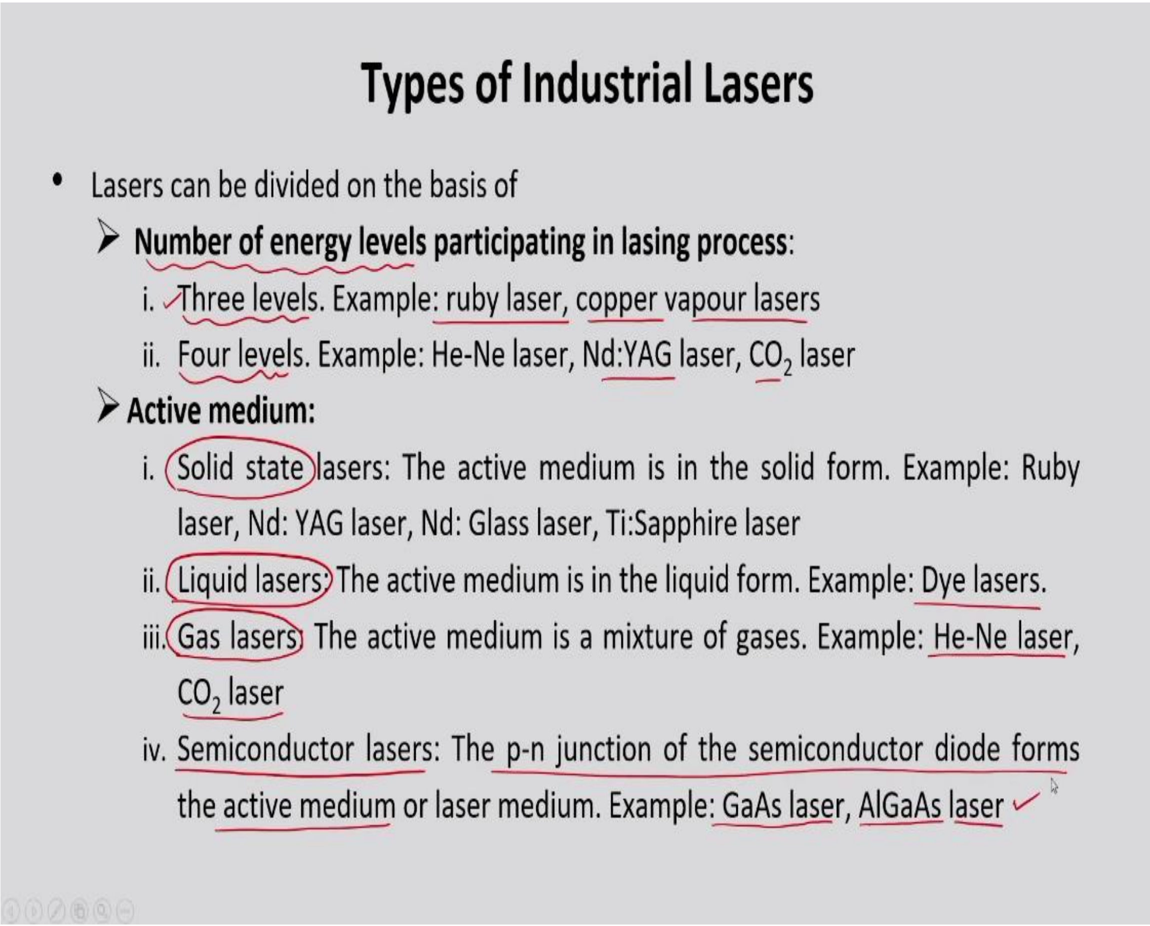

There are various types of industrial lasers are used in the industry and these can be divided or classified on the basis of various parameters.

The first parameter or the type is the number of energy levels which we can have like three levels of energy or four levels of energy. There are various lasers such as ruby laser, copper vapour lasers these are all coming into three levels of energy. He Ne lasers Nd YAG lasers and CO_2 lasers are coming in four levels.

Further, we can classify the industrial lasers based upon the active medium or the lasing medium as I mentioned. We can have a solid-state laser where active medium is in solid form, ruby laser, Nd:YAG laser or Nd:glass lasers and titanium sapphire lasers are the examples of solid-state laser. We can use liquid as well as an active medium and these are the dye lasers basically. We can use gas as an active medium and the examples are He-Ne lasers and the CO_2 lasers.

We will be looking at all these lasers when we discuss about the application of these lasers for the manufacturing operation. CO_2 lasers or Nd:YAG lasers are very widely used in material processing. We will be looking them into detail when we move ahead. Excimer lasers even diode lasers are also being used in a manufacturing operations.

When we use semiconductor material for lasing action that we call as semiconductor lasers, the P-N junction of the semi-conductor diode forms can be used as the active medium and the examples are GaAs lasers or AlGaAs lasers. We will be seeing these types of lasers in our next classes.

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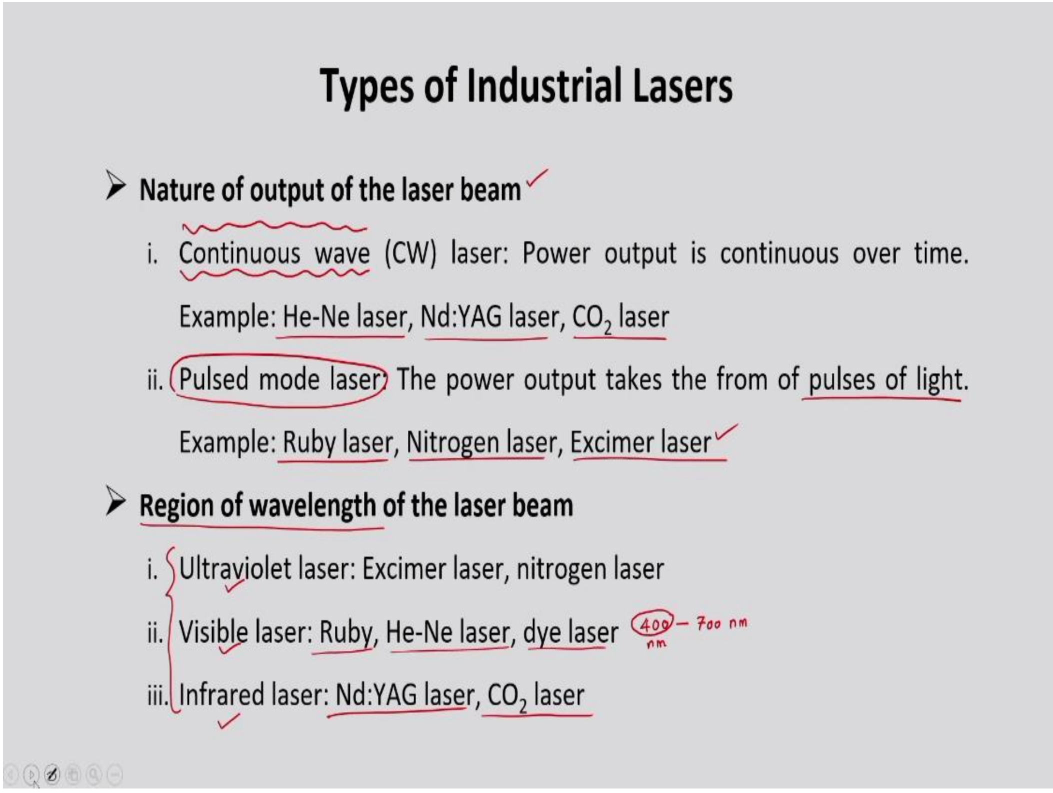

The industrial lasers also can be classified based upon the nature of the output of the laser beam. Either we can have the continuous wave when the output is in continuous format over the time that we call the continuous wave. We are getting the continuous output over the period of time. These are the He:Ne lasers, Nd:YAG lasers or the CO_2 lasers. Some of the solid lasers such as Nd:YAG can also be available in pulsed mode. When we apply the power in pulses in a discrete manner so that is called as the pulsed mode laser, is in the form of the pulses of light. These are the Ruby laser, nitrogen laser and excimer lasers are some of the examples of the pulsed mode lasers.

Then we can classify the industrial lasers based upon the region of wavelength of the laser beam. Already we have seen that there are three classes of the lasers based upon the wavelength that is ultraviolet, visible laser and infrared. As we have seen that the visible laser is having the wavelength between 400 nanometer to 700 nanometer and the ultraviolet light is having the laser wavelength below 400 nanometer. Infrared is having the higher wavelengths basically. Infrared are the Nd:YAG lasers or the CO_2 lasers. Visible lasers are the Ruby, He Ne and the dye lasers.

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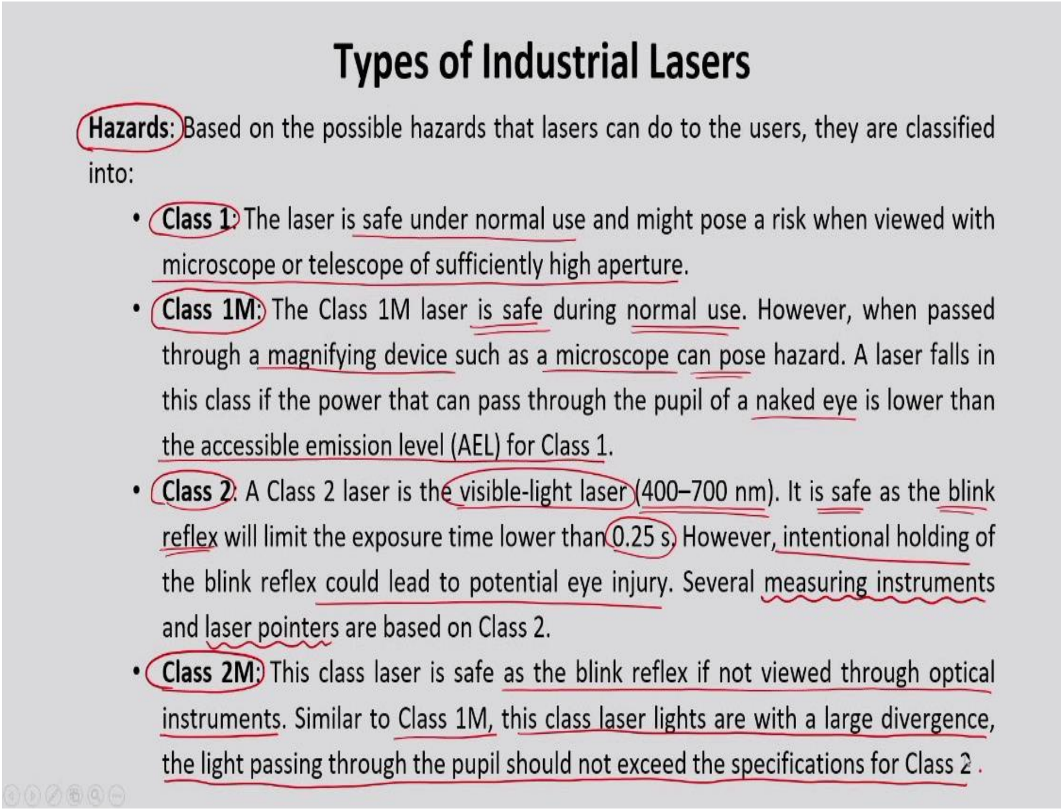

Then there is another interesting classification that is based upon the hazards. Lasers are to be operated very carefully. Based upon the hazards there is a classification the class 1 laser is safe under normal use, but it might have a risk when we viewed with the microscope or the telescope of sufficiently high aperture. These are the class 1 laser.

There is another class in one that we call class 1M. It is safe during normal utilization. However, when we pass through a magnifying device such as microscope it can create problem to us. If the lasers falls in this class and if the power that can pass through the pupil of naked eyes is lower than the accessible emission for the class 1.

In class 2 type of laser, it is in a visible range that is around 400 to 700 nanometer. These are the class 2 type of lasers. These are safe as the blink reflex will limit the exposure time lower than 0.25 second. Even though we are getting exposed these type of laser to our eyes the blink reflex our eye will control the exposure of this lasers to our eyes. However, the intentional holding of the blink reflex could lead to potential eye injury. When this laser is applied to our eye and if we intentionally hold the blink reflex the intensity of this class 2 laser may harm us will create problem to our eye. Several measuring instruments which are there in our laboratories or the lasers pointers are coming to this class 2 type of lasers.

Then there is another class here, the class 2M. This class laser is safe as the blink reflex if not viewed through the optical instruments. Similar to class 1M this class lasers lights are with a large divergence, the light passing through the pupil should not exceed the specifications for class 2. This is also to be taken care during the operation with our natural blink reflex.

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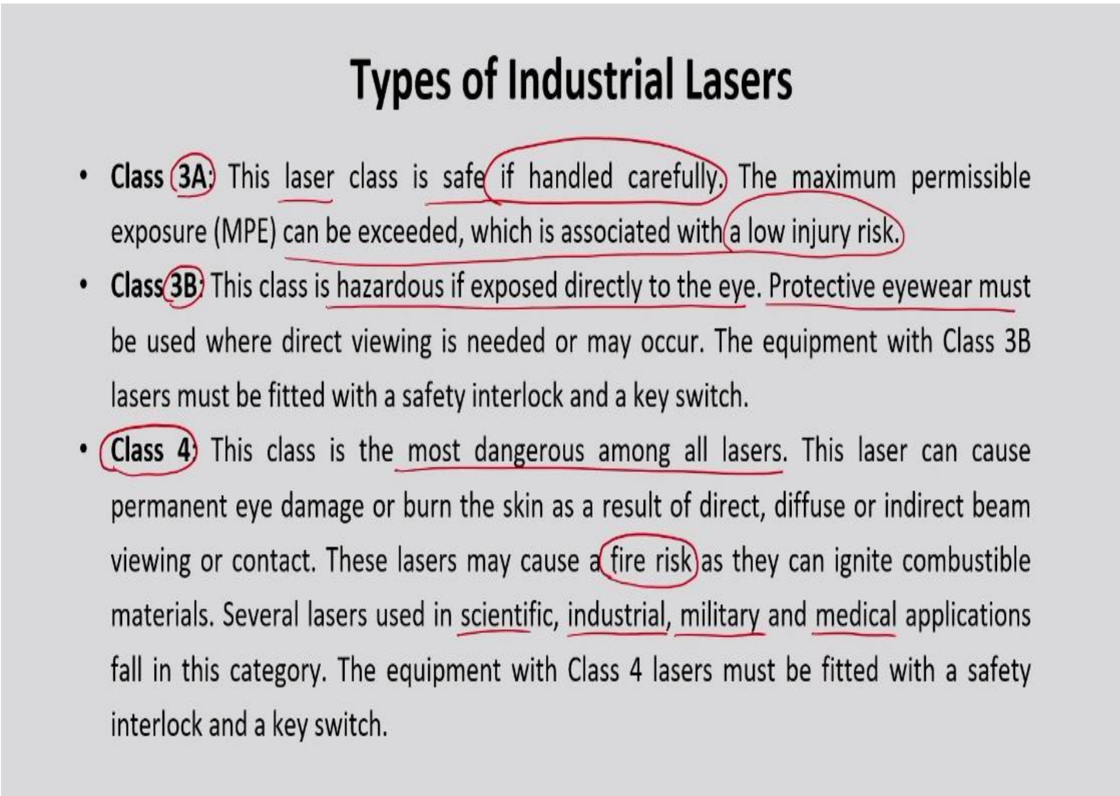

Then we are also having some other types of lasers classes based upon the hazard that is class 3A, in which the laser is safe if handled carefully. This is very important we will be working with a lasers, but if you do not handle them carefully, certainly it is going to harm you. The permissible exposure can be exceeded which is associated with low injury risk. This is class 3A lasers are quite careful to be handled otherwise we may have low injury risk.

Class 3 B lasers these are hazardous if exposed directly to the eye and we must have the protective eye wear during the utilization or during operation using this class 3B lasers.

The class 4 are most dangerous among all the lasers and these are basically being used in high power material processing. These are used in military operations, in medical operations, scientific and industrial applications. We must be very careful when we are using class 4 type of laser during our operation. There is a high amount of the fire risk during utilization of these kind of lasers. When we use this class 4 lasers we must have the system should have the safety interlock and a key switch.

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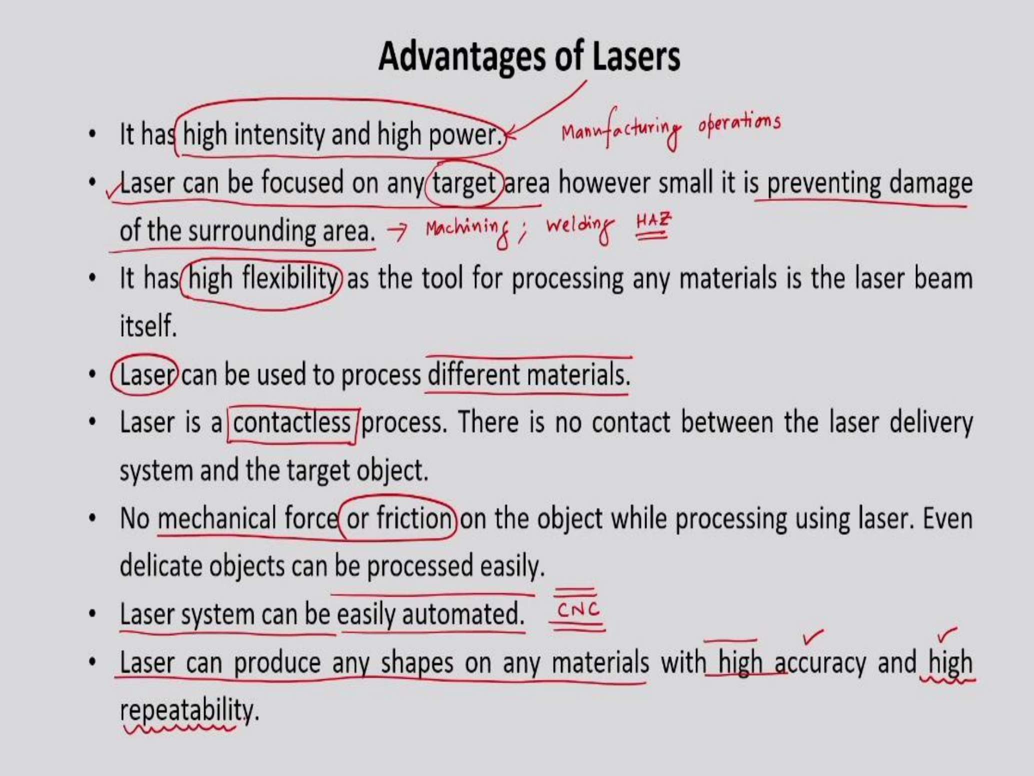

Now, what are the various type of advantages this laser technology provide us. Since last two classes we have seen that we require a high intensity and high power energy beam and that is provided by the laser. This is the biggest advantage as far as the material or the manufacturing processes are concerned. We are looking the lasers which are useful for manufacturing operations.

We have seen that lasers can be focused on a target area and it is preventing damage to the surrounding area. Wherever we want to have the processing that much portion will be targeted by the laser and it is not harming, it is not damaging the surrounding area. This is very useful advantage, we will see during our material processing that is machining and welding. In welding that we call the heat affected zone. In welding, there is a term we will be seeing in our coming lecture that is HAZ (heat affected zone). This heat affected zone is very less when we are using lasers. Lasers are having high flexibility, the conveyance is very simple through nowadays we are using fibers, fiber optic technology to transmit or to convey the lasers wherever it is required.

Lasers are used to process different material, they do have this peculiar capability that lasers can be used to process all types of materials, metals, non-metals, conductive, non-conductive materials, all sort of materials can be processed.

It is contactless process, it is a tool less manufacturing, there is no physical mechanical tool and that will save lot of lead time, no mechanical forces are present, no friction will occur and that is giving us a lot of saving as far as product development or product manufacturing time.

Lasers are easy in automation. Nowadays, we are using the CNC that is the computer numerical control systems. Lasers are very well compatible to the advanced CNC systems or the automation system.

Lasers can produce any shapes on materials with high accuracy. The accuracy levels of lasers are very high and they are providing us a very good repeatability.

In our next week class during machining these terms will come in frequent, the accuracy and the repeatability of the process that is in laboratories or in industries we must develop the systems with high accuracy and high repeatability. Lasers are providing solutions for the same.

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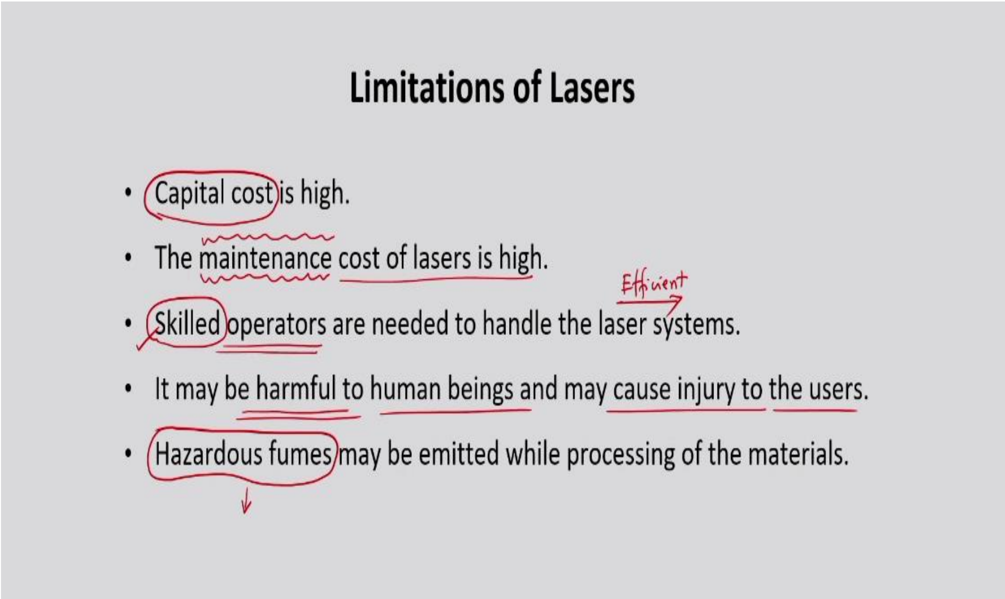

However, there are certain limitations to the laser system. The initial cost is little high in comparison with the other manufacturing systems conventional manufacturing systems, the capital cost is high. Lasers required regular maintenance and they are very delicate and very careful to be handled. So, maintenance cost is high in case of lasers.

To handle the lasers skilled and knowledgeable operators and technocrats are needed. This is obvious to have the efficient utilization will require the skilled operators and knowledge technocrats. If the lasers are not being used properly they may be very harmful to the human beings and may cause injury to the users.

In material processing, some of the lasers are producing hazardous fumes during the operation and these hazardous fumes are not good for the operator or the human beings.

With this I would like to stop for today’s lecture.

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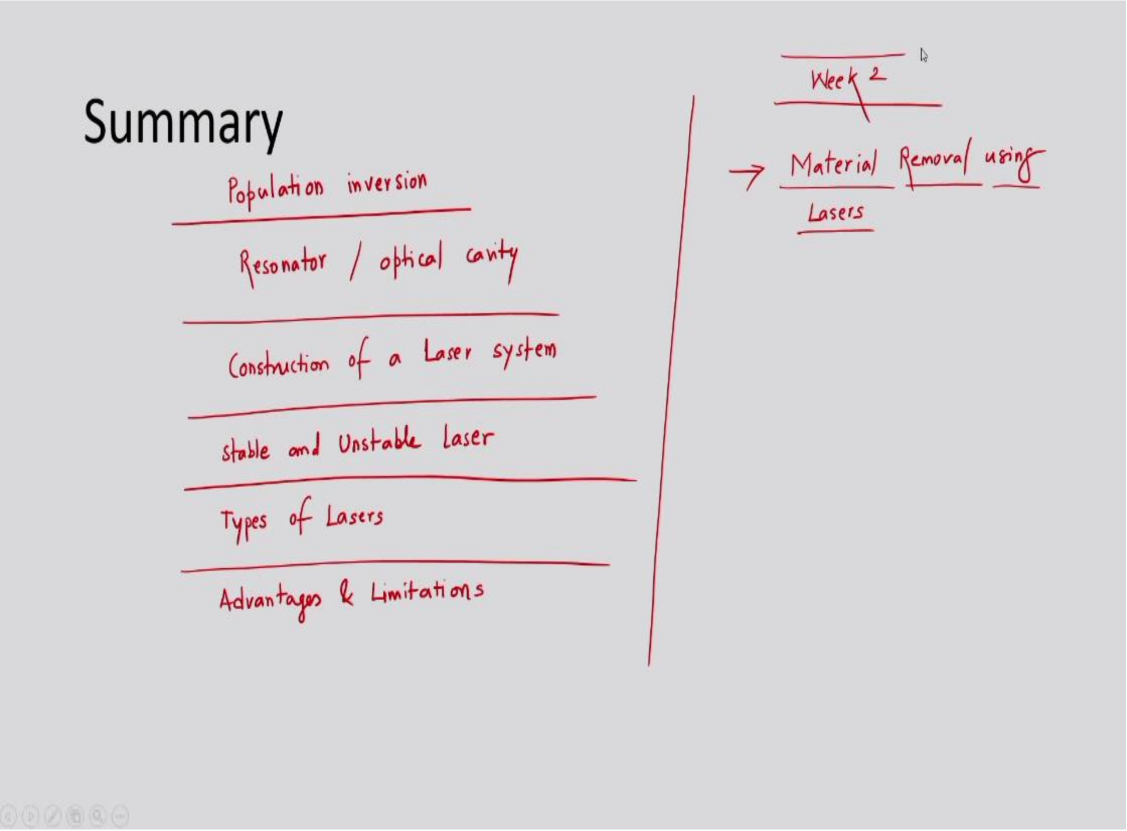

Let us summarize what we have seen in today's class. We revised the concept of population inversion and we have seen that how to get the population inversion by having a set of mirrors. We have seen the concept of resonator or the optical cavity, the construction of a typical laser, laser system, its parts.

We have also seen that what is the meaning of stable laser and unstable laser, types of lasers, a detailed classification that we have seen and at last we have seen the advantages and limitations.

This is the end of Week 1. In the next Week that is Week 2 we will be working on material removal using lasers. The material removal is the prominent application of the laser beam and there are various techniques, interesting techniques are there of using lasers for micro level removal, macro level removal and the meso level removal as well. We will be looking at the material removal aspects of lasers in the Week 2.

Till then thank you for watching this video and listening to the lectures. We will see in the next week Lecture 1 till then good bye. Thank you.