UNIT – II: TYPES OF LASERS AND OUTPUT MODULATION METHODS

Solid State Lasers – Ruby and Nd-YAG Laser – Gas Lasers – He-Ne and CO2 lasers – semiconductor lasers – Heterojunction Lasers – Liquid Dye Lasers – Q switching and mode locking.

Several ways to classify the different types of lasers

- What material or element is used as active medium
- Mode of operation : CW or Pulsed

Classification may be done on basis of other parameters

- Gain of the laser medium
- Power delivered by laser
- Efficiency or
- Applications

Preference to classify the lasers on the basis of material used as Active Medium.

Broadly divided into four categories

- Solid lasers
- Gas lasers
- Liquid lasers
- Semiconductor lasers

TYPES OF LASERS

Based on the type of active medium, Laser systems are broadly classified into the following categories.

S.No	TYPES OF LASER	EXAMPLES
1.	Solid State laser Ruby Laser	Nd:YAG laser
2.	Gas laser He-Ne Laser,	CO_2 Laser, Argon – ion laser
3.	Liquid Laser	$SeOCL_2$ Laser, Europium Chelate Laser
4.	Dye laser	Rhodamine 6G laser, Coumarin dye laser
5	Semiconductor Laser	GaAs laser, GaAsP laser

olid state Laser - NdYAG LASER

It is a solid state and 4 level system as it consists of 4 energy levels. Nd ion is rare earth metal and it is doped with solid state host.Due to doping, yttrium ions get replaced by the Nd^{3+} ions. Also, the doping concentration is around 0.725% by weight.

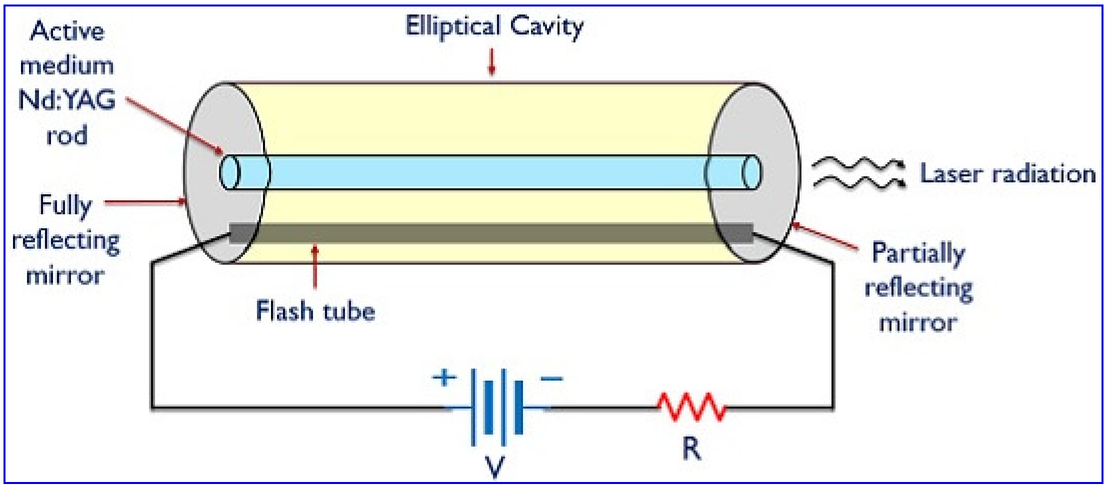
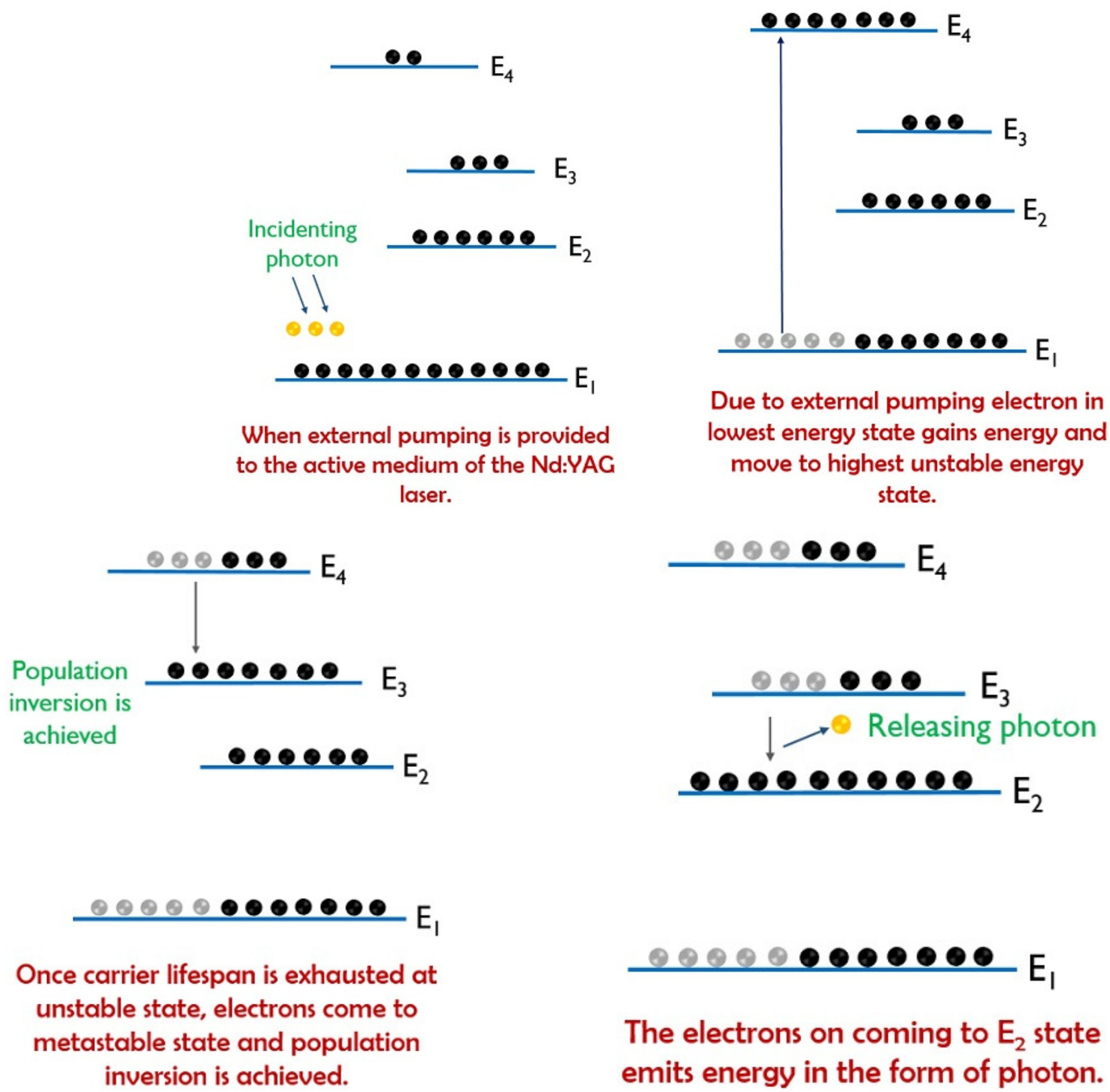


Fig. 2.1

Construction of Nd:YAG laser

- Active medium: when the external energy source is provided then the electrons from lower energy state moves to higher energy state thereby causing lasing action
- External Energy source: optical pumping, xenon or krypton flash tube is taken
- Nd:YAG rod and the flash tube are placed inside an elliptical cavity
- Optical resonator: two ends of the Nd:YAG rod is coated with silver. - to achieve maximum light reflection.
- other end is partially coated in order to provide a path for the light ray from an external source to reach the active medium.
- E_1 is the lowest energy state while E_4 is the highest energy level, electrons present in the energy state E_1 gains energy and moves to energy state E_4.E_4 is an unstable state.
- electrons that were excited to this state by the application external pumping will not stay at this state for much longer duration and comes to lower energy state E_3 very fastly but without radiating any photon.
- E_3 is the metastable state and exhibits longer lifespan. Thereby attaining population inversion.

- lifetime of the electrons at the metastable state gets exhausted then these electrons by releasing photons come to lower energy state E_2.
- E_2 also exhibit shorter lifespan like E_4. Thus, electrons present in E_2 state will come to E_1



Electrons by gaining single photon of energy releases the energy of 2 photons. Also, as the system is equipped with optical resonators so, more number of photons will get generated as the pumped energy will get reflected inside the active medium.

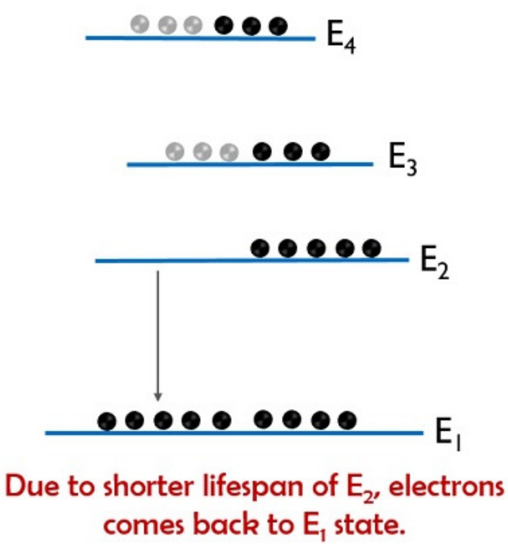


Fig. 2.2

several electrons on stimulation produce photons thereby generating a coherent laser beam of 1.064 µm.

Applications of Nd:YAG Laser

- Military applications to find the desired target.
- Application in medical field for the surgical purpose.
- Used in welding and cutting of steel and
- Used in communication system

Solid State Laser - Ruby Lser

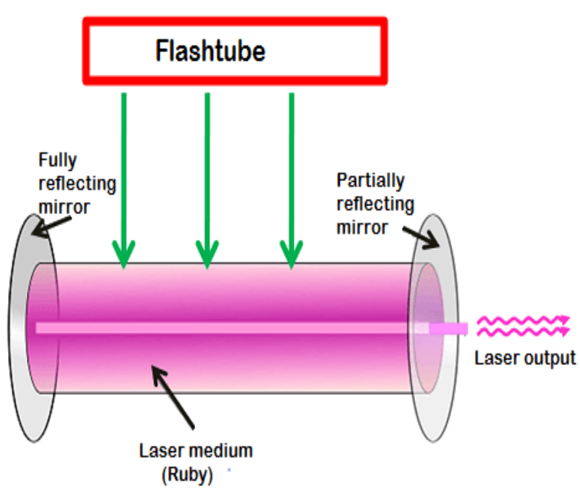


Fig. 2.3

Construction of Ruby laser

- Ruby is a crystal of aluminium oxide (Al_2O_3) in which some of the aluminium ions (Al^{3+}) are replaced by chromium ions (Cr^{3+}). This is done by doping small amounts of chromium oxide
- pink or red color depending upon the concentration of chromium ions
- Al_2O_3 does not participate in the laser action. It only acts as the host.
- Length of ruby crystal is usually 2 cm to 30 cm and diameter 0.5 cm to 2 cm.

High temperature is produced during the operation of the laser, the rod is surrounded by liquid nitrogen to cool

Active medium or active center: Chromium ions act as active centers in ruby crystal. So it is the chromium ions that produce the laser

Pumping source: A helical flash lamp filled with xenon is used as a pumping source. The ruby crystal is placed inside a xenon flash lamp. Thus, optical pumping is used to achieve population inversion in ruby laser.

Optical resonator system: The ends of ruby crystal are polished, grounded and made flat. The one of the ends is completely silvered while the other one is partially silvered to get the output. Thus the two polished ends act as optical resonator system.

Working

- ✓ Ruby is a three level laser system.
- ✓ there are three levels E_1, E_2 and (E_3 & E_4). E_1 is the ground level, E_2 is the metastable level, E_3 and E_4 are the bands. E_3 & E_4 are considered as only one level because they are very closed to each other.
- ✓ Pumping: The ruby crystal is placed inside a xenon flash lamp
- ✓ A part of this energy is absorbed by chromium ions in the ground state.
- ✓ optical pumping raises the chromium ions to energy levels inside the bands E_3 and E_4. This process is called stimulated absorption.

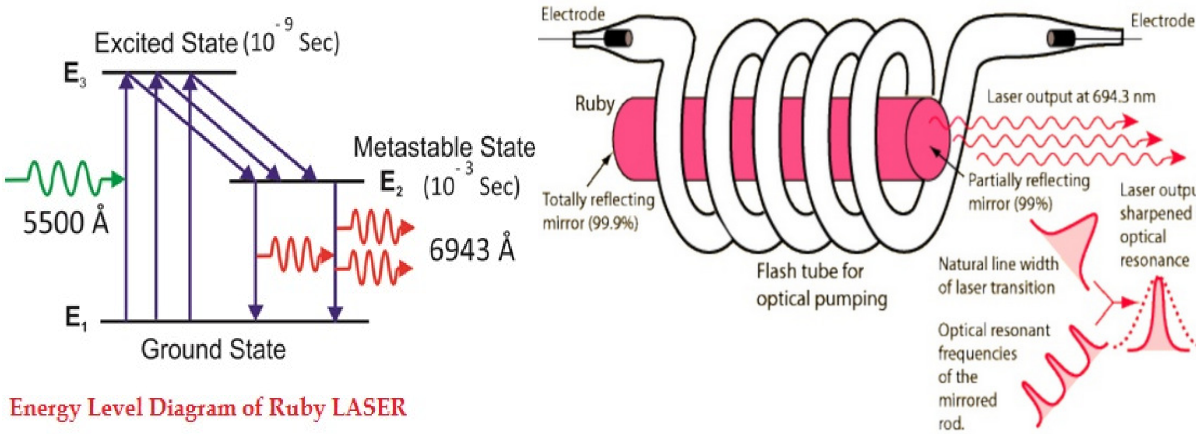


Fig. 2.4

Achievement of population inversion:

- Cr^{3+} ions in the excited state loose a part of their energy
- The transition from excited states to metastable state is non-radiative transition or in other words there is no emission of photons.
- The number of chromium ions goes on increasing in E_2 state, while due to pumping
- As a result, the number of chromium ions become more in excited state(metastable state) as compared to ground state E_1.
- Hence, the population inversion is achieved between states E_2 and E_1.
- Photon travels through the ruby rod and if it is moving in a direction parallel to the axis of the crystal, then it is reflected to and fro by the silvered ends of the ruby rod until it stimulates the other excited ions and cause it to emit a fresh photon in phase with the stimulating photon.
- Emitted photons will knock out more photons by stimulating the chromium ions and their total number sufficiently increases.

Output Measurement

In the energy level diagram, E2 is the upper laser level and E1 is the lower laser level because laser beam is achieved in between these levels. Thus, the ruby laser fits into the definition of three level laser system.

Output: The output wavelength of ruby laser is 6943 Å and output power is 10 raise to power 4 to 10 raise to power 6 watts and it is in the form of pulses.

Table 2.1

Type	Solid state laser; Three- level laser system
Active medium	Ruby rod (Cr: Al_2O_3)
Active centre	Cr^{3+} ion
Pumping method	Optical pumping
Pumping source	Helical flash lamp of filled with Xenon
Optical resonator	The ends of the ruby rod are kept in between two optically coated mirrors, silvered differently.
Output power	Low
Nature of the output	Pulsed (Spiked)
Wavelength emitted	693.4 nm

APPLICATIONS

1. Ruby laser has very high output power of the order of $10^4 – 10^6$ watts. It has wavelength of 6943 Angstroms.
2. Ruby lasers are used in industrial cutting and welding.
3. They are used for hair removal and tattoo
4. Holography, NDT, Decoration, Display and toys

GAS LASER

A gas laser is a type of laser in which a mixture of gas is used as the active medium or laser medium. Gas lasers are the most widely used lasers.

Gas lasers range from the low power helium-neon lasers to the very high power carbon dioxide lasers. commonly used in college laboratories whereas the carbon dioxide lasers are used in industrial applications.

The main advantage of gas lasers (eg: He-Ne lasers) over solid state lasers is that they are less prone to damage by overheating so they can be run continuously.

Helium-neon laser

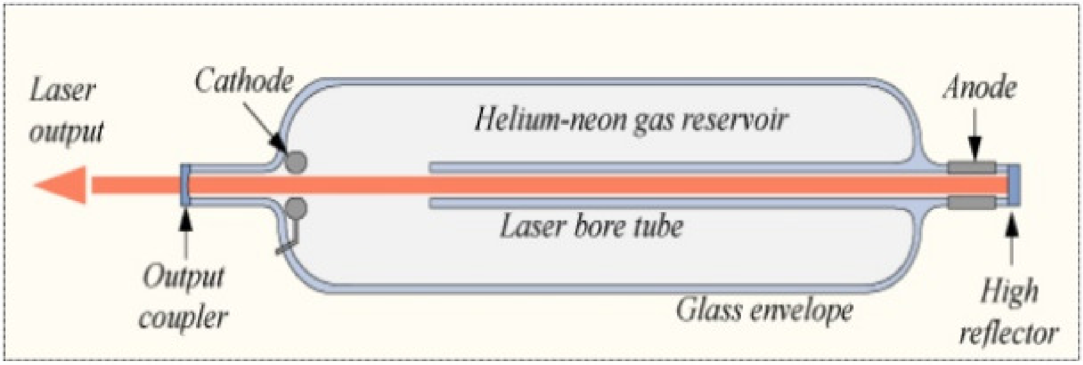


Fig. 2.5

- The helium-neon laser was the first continuous wave (CW) laser ever constructed
- The excitation of electrons in the He-Ne gas active medium is achieved by passing an electric current through the gas.
- The helium-neon laser operates at a wavelength of 632.8 nanometers (nm), in the red portion of the visible spectrum.

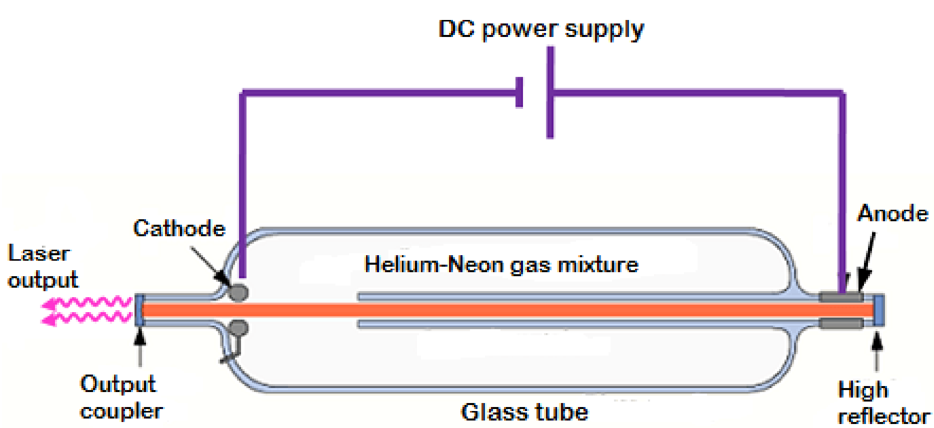


Fig. 2.6

Helium-neon laser construction

The helium-neon laser consists of three essential components:

- Pump source (high voltage power supply)
- Gain medium (laser glass tube or discharge glass tube)
- Resonating cavity
- High voltage power supply
- to achieve population inversion, we need to supply energy to the gain medium or active medium

- In helium-neon lasers, a high voltage DC power supply is used as the pump source. A high voltage DC supplies electric current through the gas mixture of helium and neon.

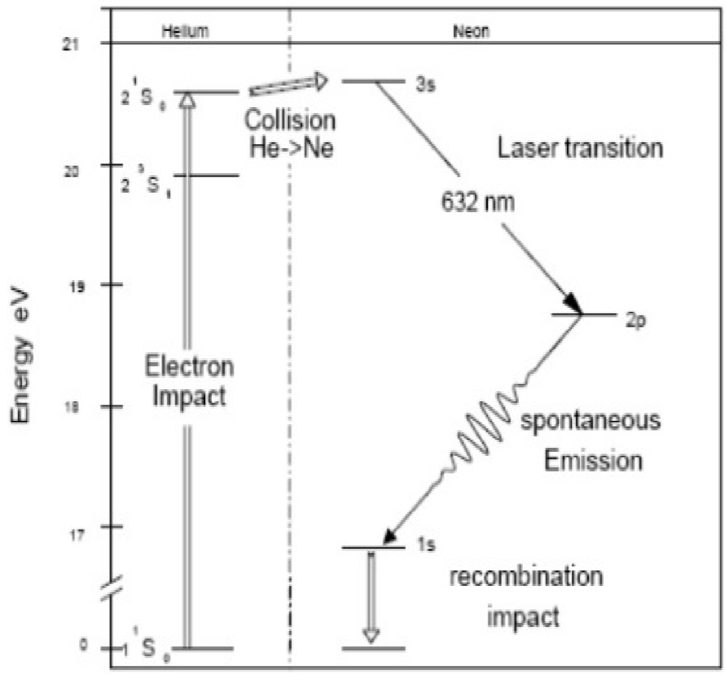


Fig. 2.7

Gain medium

- ✓ The partial pressure of helium is 1 mbar whereas that of neon is 0.1 mbar.
- ✓ to excite primarily the lower energy state electrons of the helium atoms.
- ✓ neon atoms are the active centers and have energy levels suitable for laser transitions while helium atoms help in exciting neon atoms.
- ✓ Electrodes (anode and cathode) are provided in the glass tube to send the electric current through the gas mixture. These electrodes are connected to a DC

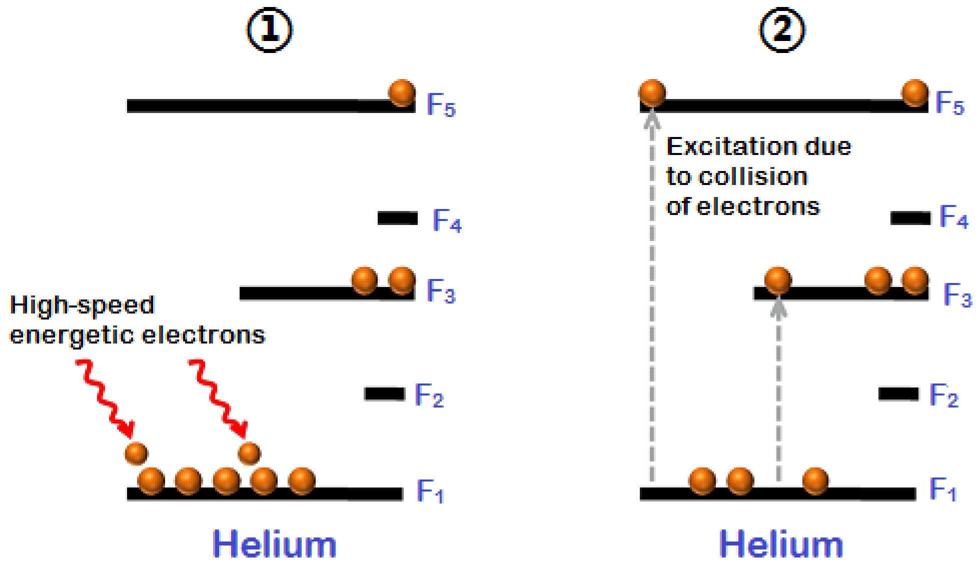
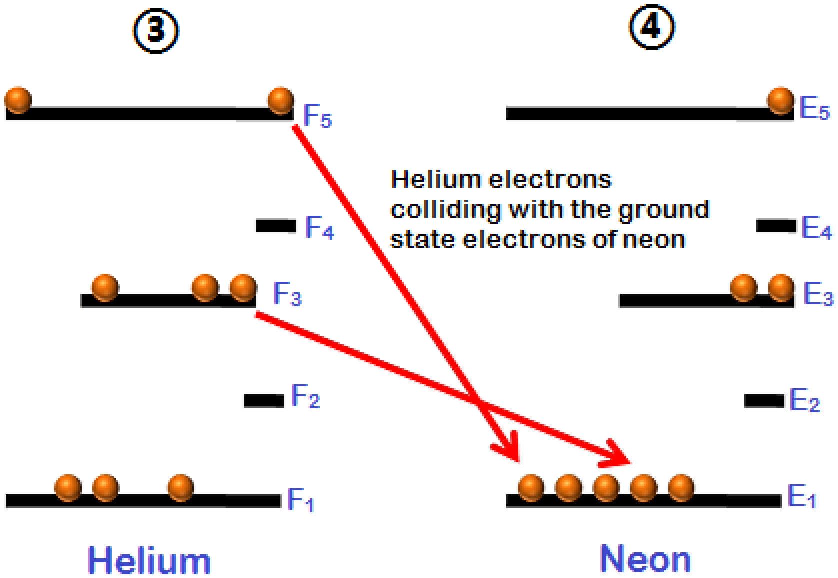


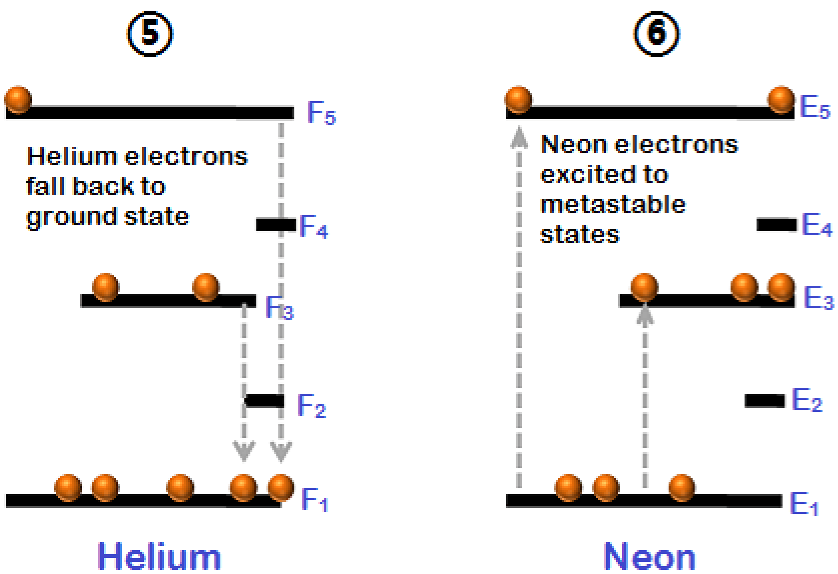
Fig. 2.1

the power is switched on, a high voltage of about 10 kV is applied It is enough to excite the electrons and are accelerated

- Electrons transfer some of their energy to the helium atoms, jumps into the excited states
- Assume that these metastable states are F3 and F5
- Metastable state electrons of the helium atoms, return to ground state by transferring their energy to the lower energy state electrons of the neon atoms.
- The energy levels of some of the excited states of the neon atoms are identical to the energy levels of metastable states of the helium atoms.
- Let us assume that these identical energy states are $F_3 = E_3$ and $F_5 = E_5$. E_3 and E_5 are excited states or metastable states of neon atoms.



the lower energy state electrons of the neon atoms gain enough energy from the helium atoms and jumps into the higher energy states or metastable states (E_3 and E_5) whereas the excited electrons of the helium atoms will fall into the ground state. Thus, helium atoms help neon atoms in achieving population inversion.



- millions of ground state electrons of neon atoms are excited to the metastable states having longer lifetime
- electrons (E_3 and E_5) of the neon atoms will spontaneously fall into the next lower energy states (E_2 and E_4) by releasing photons or red light.
- Neon excited electrons continue on to the ground state through radiative and nonradiative transitions.

- Photons emitted from the neon atoms will moves back and forth between two mirrors until it stimulates other electrons
- optical gain is achieved due to stimulated emission

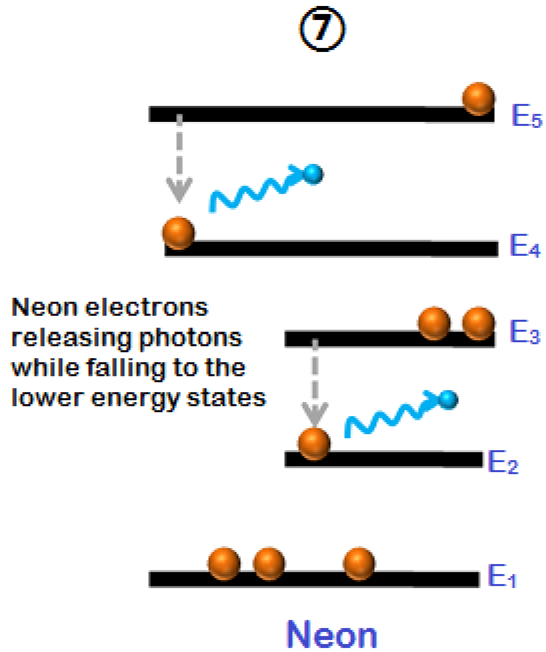


Fig. 2.8

photons emitted will escape through the partially reflecting mirror or output coupler to produce laser.

Advantages of helium-neon laser

- Helium-neon laser emits laser light in the visible portion of the spectrum.
- High stability
- Low cost
- Operates without damage at higher temperatures

Disadvantages of helium-neon laser

- Low efficiency
- Low gain
- Helium-neon lasers are limited to low power tasks

Applications of helium-neon lasers

- Helium-neon lasers are used in industries.

- Helium-neon lasers are used in scientific instruments.
- Helium-neon lasers are used in the college laboratories

MOLECULAR GAS LASER -CO_2

CO_2 Molecular gas laser: Principle, Construction, Working, Characteristics, Advantages, Disadvantages and Applications

In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous.

Molecular Gas laser

In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous.

In CO2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

CO2 **Molecular gas laser**

It was the first molecular gas laser developed by Indian born American scientist Prof.C.K.N.Pillai.

It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser.

Energy states of CO2 molecules.

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations. They are

a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

a. **Symmetric stretching mode**

In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.

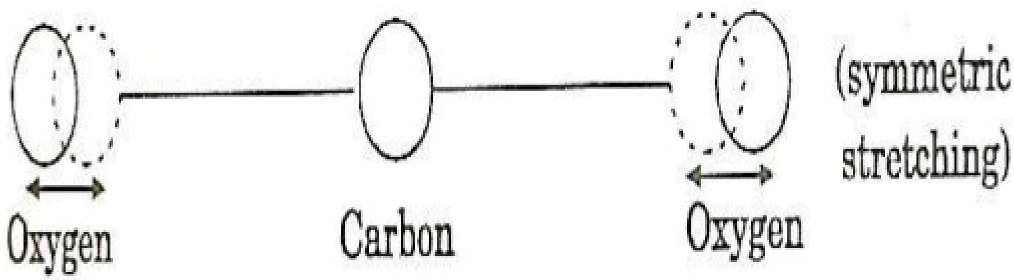


Fig. 2.9

b. **Bending mode:**

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.

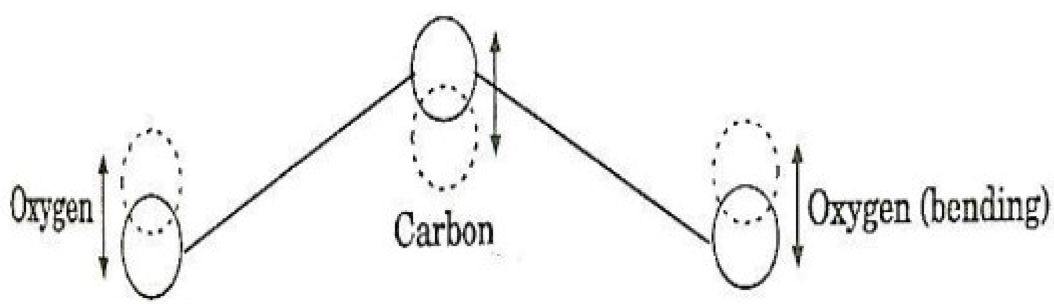


Fig.2.10 2.1

c. **Asymmetric stretching mode**:

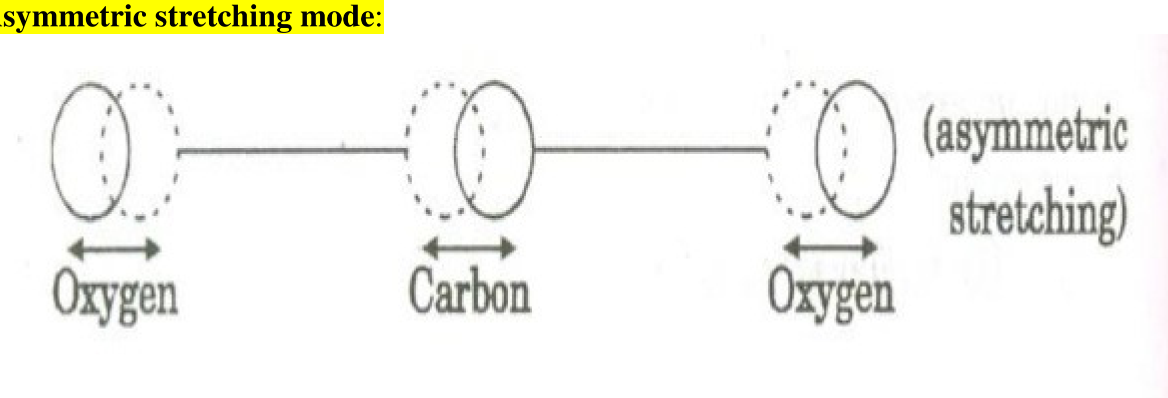


Fig. 2.11

In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.

Principle:

The active medium is a gas mixture of CO2, N2 and He. The laser transition takes place between the vibrational states of CO2molecules.

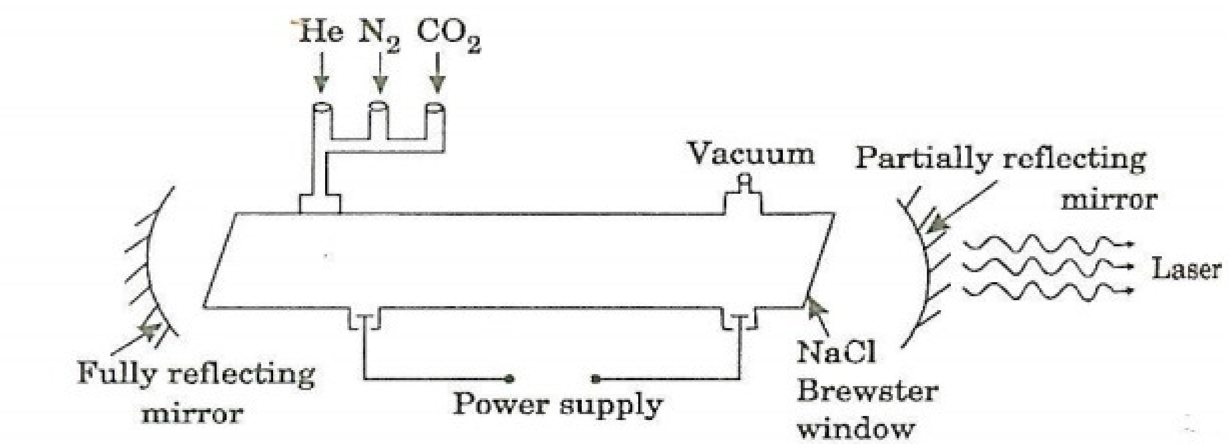


Fig. 2.12

Construction:

It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO2(active medium), helium and nitrogen with suitable partial pressures.

The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.

Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Working:

Figure shows energy levels of nitrogen and carbon dioxide molecules.

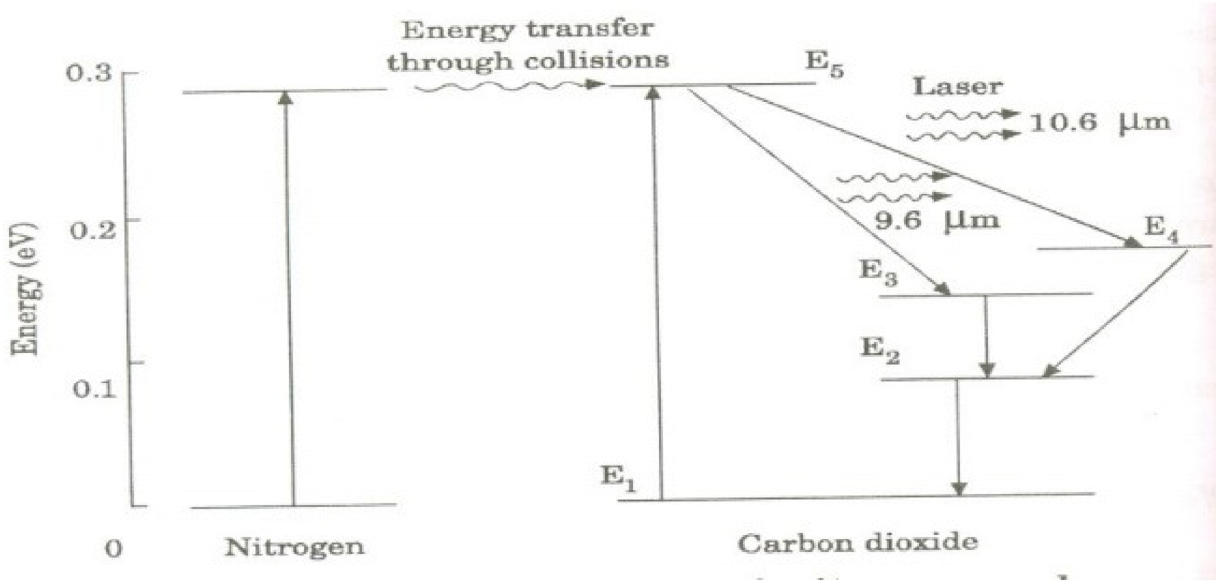


Fig. 2.13

When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

$$N_2 + e^* = N_2^* + e$$

N_2 = Nitrogen molecule in ground state e^* = electron with kinetic energy
N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

Now N_2 molecules in the excited state collide with CO2 atoms in ground state and excite to higher electronic, vibrational and rotational levels.
This process is represented by the equation N2* + CO2 = CO2* + N2

N2* = Nitrogen molecule in excited state. CO2 = Carbon dioxide atoms in ground state CO2* = Carbon dioxide atoms in excited state N2 = Nitrogen molecule in ground state.

Since the excited level of nitrogen is very close to the E5 level of CO2 atom, population in E5 level increases.

As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

1.Transition E5 to E4 :

This will produce a laser beam of wavelength 10.6μm

2.Transition E5 to E3 This transition will produce a laser beam of wavelength 9.6μm. Normally 10.6μm transition is more intense than 9.6μm transition. The power output from this laser is 10kW.

Characteristics:

1. Type: It is a molecular gas laser.
2. Active medium: A mixture of CO_2 , N_2 and helium or water vapour is used as active medium
3. Pumping method: Electrical discharge method is used for Pumping action
4. Optical resonator: Two concave mirrors form a resonant cavity
5. Power output: The power output from this laser is about 10kW.
6. Nature of output: The nature of output may be continuous wave or pulsed wave.
7. Wavelength of output: The wavelength of output is 0.6μm and 10.6μm.

Advantages:

1. The construction of CO_2 laser is simple
2. The output of this laser is continuous.
3. It has high efficiency
4. It has very high output power.
5. The output power can be increased by extending the length of the gas tube.

Disadvantages:

1. The contamination of oxygen by carbon monoxide will have some effect on laser action
2. The operating temperature plays an important role in determining the output power of laser.
3. The corrosion may occur at the reflecting plates.
4. Accidental exposure may damage our eyes, since it is invisible (infra red region) to our eyes.

Applications:

1. High power CO_2 laser finds applications in material processing, welding, drilling, cutting soldering etc.

2. The low atmospheric attenuation (10.6µm makes CO_2 laser suitable for open air communication.
3. It is used for remote sensing

4. It is used for treatment of liver and lung diseases.

5. It is mostly used in neuro surgery and general surgery.

6. It is used to perform microsurgery and bloodless operations.

SEMICONDUCTOR LASER

Laser action can also be produced semiconductors. The most compact of all the lasers in semiconductor diode laser. It is also called injection laser. There are two types of semiconductor diode lasers (***i.) Homo - junction laser (ii.) Hetero- Junction laser.***

HOMO – JUNCTION SEMICONDUCTOR DIODE LASER

Definition
It is specifically fabricated p-n junction diode. This diode emits laser light when it is forward biased.

Principle
When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other. During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.

Construction

Figure shows the basic construction of semiconductor laser. The active medium is a p-n junction diode made from the single crystal of gallium arsenide. This crystal is cut in the form of a platter having thickness of 0.5µm. The platelet consists of two parts having an electron conductivity (n-type) and hole conductivity (p-type).

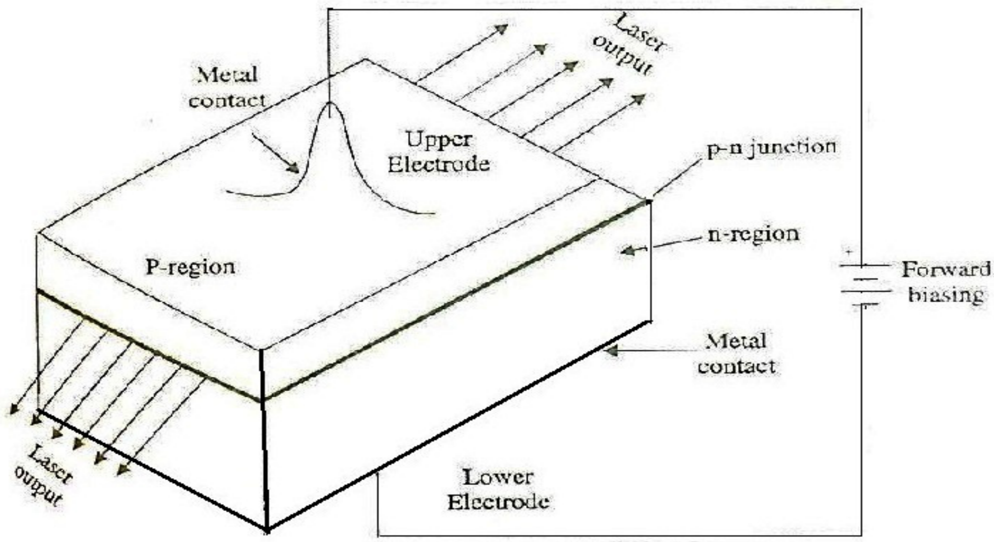


Fig. 2.14

The photon emission is stimulated in a very thin layer of PN junction (in order of few microns). The electrical voltage is applied to the crystal through the electrode fixed on the upper surface. The end faces of the junction diode are well polished and parallel to each other. They act as an optical resonator through which the emitted light comes out.

Working

Figure shows the energy level diagram of semiconductor laser. When the PN junction is forward biased with large applied voltage, the electrons and holes are injected into junction region in considerable concentration. The region around the junction contains a large amount of electrons in the conduction band and a large amount of holes in the valence band.

If the population density is high, a condition of population inversion is achieved. The electrons and holes recombine with each other and this recombination's produce radiation in the form of light. When the forward – biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger.

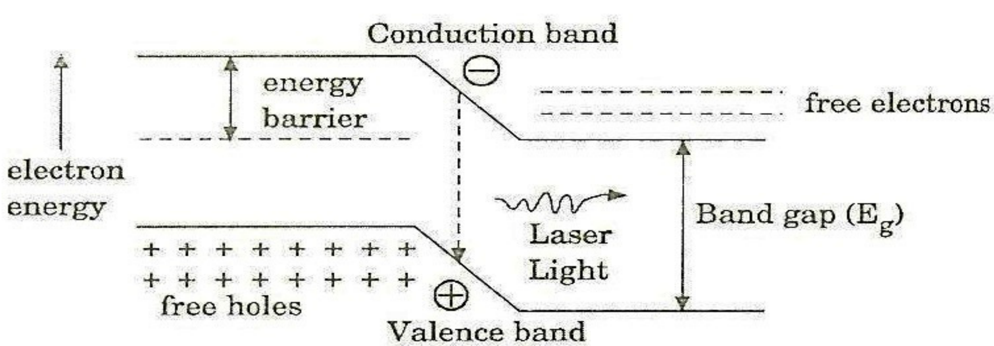


Fig. 2.15

These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength.

After gaining enough strength, it gives out the laser beam of wavelength $8400A^0$

The wavelength of laser light is given by $E_g = h\nu = h\frac{c}{\lambda}$

$\lambda = \frac{hC}{E_g}$ where Eg is the band gap energy in joule.

Characteristics

1. ***Type:*** It is a solid state semiconductor laser.
2. ***Active medium:*** A PN junction diode made from single crystal of gallium arsenide is used as an active medium.
3. ***Pumping method:*** The direct conversion method is used for pumping action
4. ***Power output:*** The power output from this laser is a few mW.
5. ***Nature of output:*** The nature of output is continuous wave or pulsed output.
6. ***Wavelength of Output***: gallium arsenide laser gives infrared radiation in the wavelength 8300 to $8500A^0$.

Advantages:

1. It is very small in dimension. The arrangement is simple and compact.
2. It exhibits high efficiency.
3. The laser output can be easily increased by controlling the junction current
4. It is operated with lesser power than ruby and CO_2 laser.
5. It requires very little auxiliary equipment
6. It can have a continuous wave output or pulsed output.

Disadvantages

1. It is difficult to control the mode pattern and mode structure of laser.
2. The output is usually from 5° to 15° i.e., laser beam has large divergence.
3. The purity and monochromacity are poor than other types of laser
4. Threshold current density is very large ($400A/mm^2$).
5. It has poor coherence and poor stability.

Application

1. It is widely used in fiber optic communication
2. It is used to heal the wounds by infrared radiation
3. It is also used as a pain killer
4. It is used in laser printers and CD writing and reading

HETERO - JUNCTION SEMICONDUCTOR DIODE LASER

A p-n junction made up of the different materials in two regions ie., n type and p type is known as Hetero junction.

Principle:

When a PN junction diode is forward biased, the electrons from the n region and holes from the p region recombine with each other at the junction. During recombination process, light is released from certain specified direct band gap semiconductors.

Construction:

This laser consists of five layers as shown in the figure. A layer of Ga-As p – type (3rd layer) will act as the active region. This layer is sand witched between two layers having wider band gap viz. Ga Al As-p – type (2nd layer) and Ga Al As-n- type (4th layer). The end faces of the junctions of 3rd and 4th layer are well polished and parallel to each other. They act as an optical resonator.

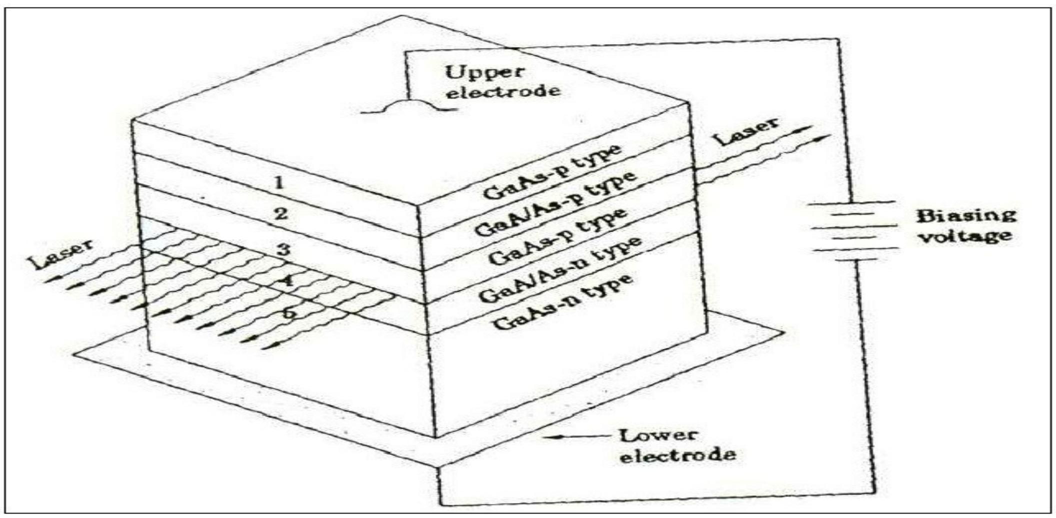


Fig. 2.16

Working:

When the PN junction is forward biased, the electrons and holes are injected into the junction region. The region around the junction contains large amount of electrons in the conduction band and holes in the valence band. Thus the population inversion is achieved. At this stage, some of the injected charge carriers recombines and produce radiation in the form of light.

When the forward biased voltage is increased, more and more light photons are emitted and the light intensity is more. These photons can trigger a chain of stimulated recombination's resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides and grow its strength. A coherent beam of laser having wavelength nearly 8000A^0 emerge out from the junction region.

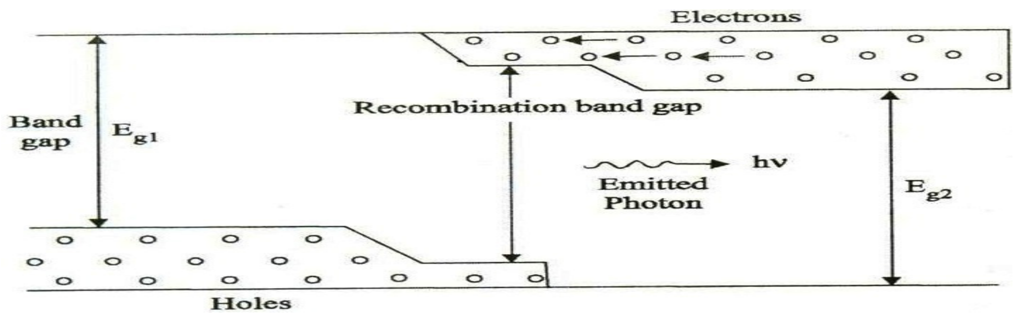


Fig. 2.17

Characteristics:

1. ***Type:*** It is a Hetero junction semiconductor laser
2. ***Active medium:*** PN junctions made from different layers.
3. ***Pumping method:*** Direct conversion method
4. ***Power output:*** The power output of laser beam is 1 mW
5. ***Nature of the Output:*** Continuous wave form
6. ***Wavelength of the output:*** Nearly 8000 A^0

Advantages:

1. It produces continuous wave output.
2. The power output is very high.

Disadvantages:

1. It is very difficult to grow different layers of PN junction.
2. The cost is very high.

Applications:

1. This type of laser is mostly used in optical applications
2. It is widely used in computers, especially on CD-ROMs.

LIQUID DYE LASER

Dye is a liquid laser with an active medium
Doped with Rhodamine B, Rhodamine 6G, fluoresein

Characteristics

- Output lies in UV, Visible or IR
- Using dye the output can be varied from 390nm to 1000nm
- Power output starts from 1 watt, beam diameter of 0.5mm
- Conversion efficiency is relatively high than 25%

Construction

It has two configuration

- The dye is pumped through the capillary tube from the storage tank
- It gets optically excited by the flash tube
- Output pass through the Brewster window

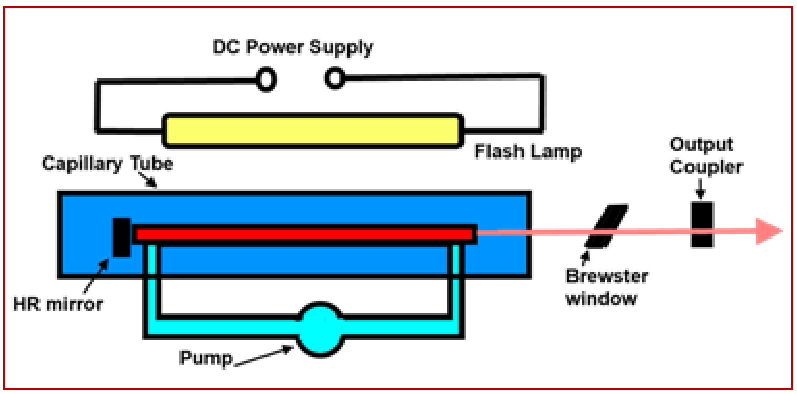


Fig. 2.18

2^{nd} Configuration

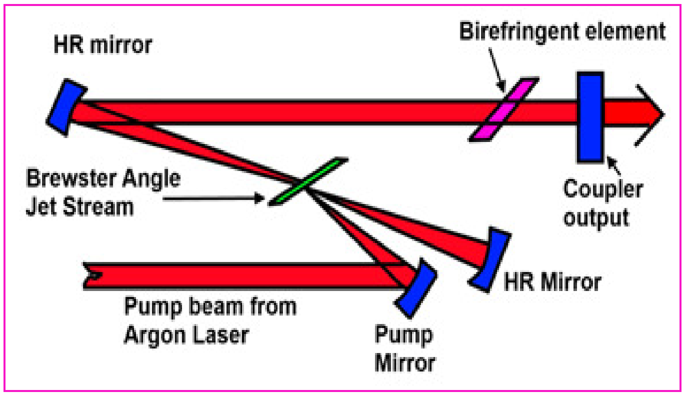


Fig. 2.19

The dye is pumped through the nozzle to form a Brewster Angle

Excitation mechanism involves here

Laser gets reflected from two HR mirror passed through the output coupler

Birefringent filter is used to tune the output of Laser

Working

- Active medium in Laser may be of organic dye mixed with ethanol, water
- Dyes like Rhodamine B, Sodium fluorisin it's difficult to determine the element
- So organic dye is prefered
- It provides the output in various ranges of wavelength
- The amount of amplification also varies
- Birefringent filter acts as a prism
- Filters certain specified frequency, it bends the other wavelength, tune the output with accuracy

Applications

It is used as research tool in medical Applications

Advantages

- It is available in visible and non-visible form
- Construction of a dye laser is not so complex
- Beam dia. is less
- Ranges of wavelength can be gained as output
- Having greater efficiency
- High power output is possible

Disadvamtages

- Cost of dye laser is high
- Using filter as birefringent makes it costly
- To determine the particular element of output, a complex dye has to be used

Q SWITCHING

Q switching is a technique for obtaining energetic short (but ot ultrashot) pulses from a laser by modulating the intracavity losses and thus the Q-factor of the laser resonator. The technique is mainly applied for the generation of nanosecond pulses of high energy and peak power with solid-state bulk lasers.

Generation of a Q-switched pulse

- The resonator losses are kept at a high level - As lasing cannot occur, gain medium enhanced by the pumping mechanism - spontaneous emission
- The losses are suddenly (with active or passive means) reduced
- The power of the laser radiation builds up very quickly in the laser resonator
- The saturation energy of the gain medium, starts to be saturated.
- When the gain equals the loss, peak of the pulse is reached
- The pulse duration achieved with Q switching is typically in the nanosecond range
- The energy of the generated pulse is typically higher than the energy of the gain medium
- In most cases, Q-switched lasers generate regular pulse trains via repetitive Q switching.
- Q-switched lasers have reached pulse durations far below 1 ns and repetition rates up to several megahertz
- laser systems can deliver pulses with many kilojoules of energy and durations in the nanosecond range.
- The first experimental demonstrations were performed in 1961 at Hughes Aircraft Company
- The resonator losses can basically be switched in different ways:

Active Q Switching
Passive Q Switching

In order to store many atoms in an upper level, the flow to a lower level must first be limited.
Thus, stimulated emission must be prevented by placing an attenuator in the cavity to stop light from travelling back and forth (note: this attenuator is usually a light modulator, rather than a mechanical shutter, which reduces the amplitude or power of the light beam).
In this case, for a radiative transition, the only decay to a lower level is due to spontaneous emission. When the pumping system supplies more atoms per second than lose energy by spontaneous emission, the population in the upper level can become very large

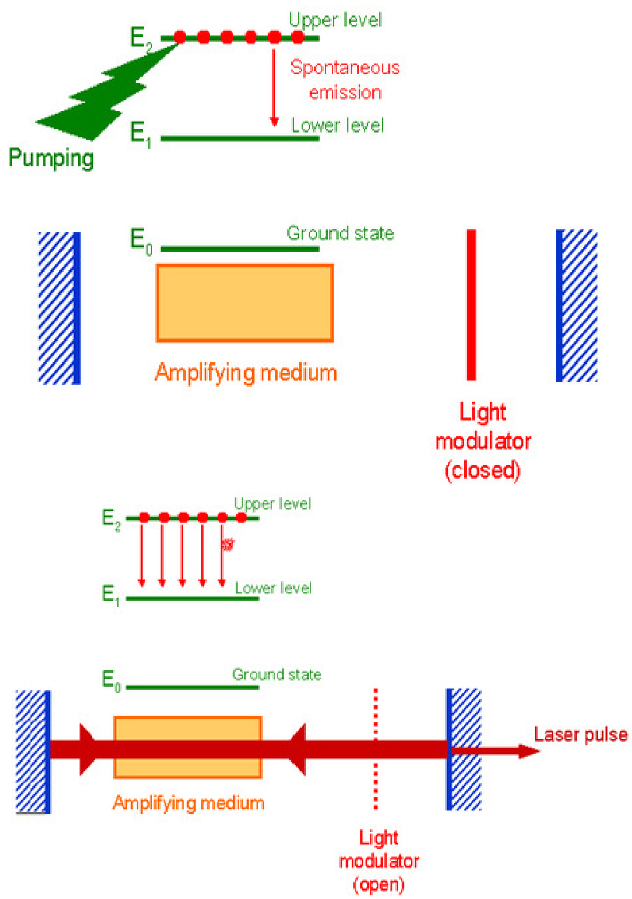


Fig. 2.20

- ✓ After a certain time, the energy losses in the cavity are suddenly reduced so that laser oscillation becomes possible.
- ✓ As there is a very large population in the upper level, stimulated emission becomes very probable and the laser is suddenly triggered.
- ✓ The flow due to stimulated emission is much greater than the other flows (filling by pumping and emptying by spontaneous emission): all the atoms stored in the upper level fall sharply, emitting stimulated photons (starting with the spontaneous emission trapped in the cavity).
- ✓ Thus, the laser cavity fills with stimulated photons at the same time as the upper level empties
- ✓ Eventually, the upper level is completely empty.
- ✓ There is no further stimulated emission and the cavity will also empty due to the losses created by the output mirror (in general, the cavity empties after only a few round trips)

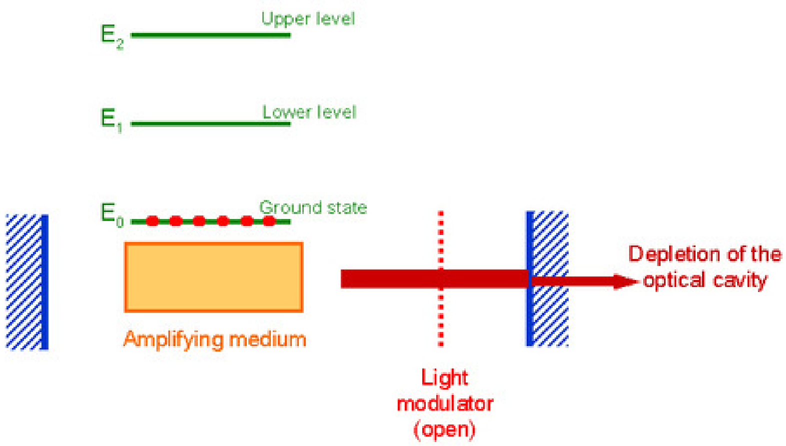


Fig. 2.21

- ✓ This process gives rise to a dramatic variation in the number of photons in the cavity (first by a significant amplification due to stimulated emission then by the complete emptying of the cavity at the end).
- ✓ The net result is the emission of a short pulse of light via the output mirror.
- ✓ Generally, several round trips are needed to completely depopulate the upper energy level and several more round trips to empty the optical cavity so the duration of the pulse is greater than one round trip.
- ✓ This means that for optical cavities shorter than a metre, it is possible to generate short pulses of only a few nanoseconds but several millijoules in power.
- ✓ The peak power (the pulse energy divided by its duration) of these lasers can be in the megawatt range or even higher.
- ✓ It should be noted that Q-switched lasers never reach a steady state as they stop functioning after several round trips of the light in the cavity.

Active Q Switching

For active Q switching, the losses are modulated with an active control element (active Q switch), typically either an acousto-optic or electro-optic modulator.

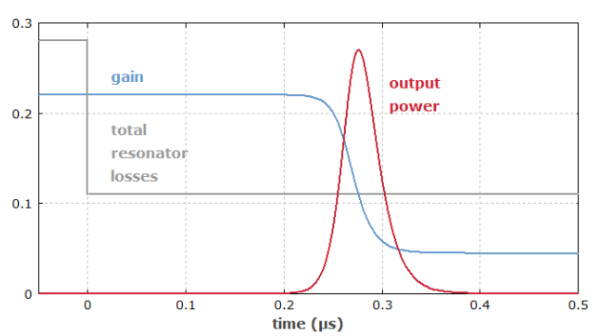


Fig. 2.22

the switching time of the modulator is not comparable to the pulse duration
For many applications, Q-switched pulses are generated in a periodic fashion, i.e., with a given pulse repetition rate.

Passive Q Switching

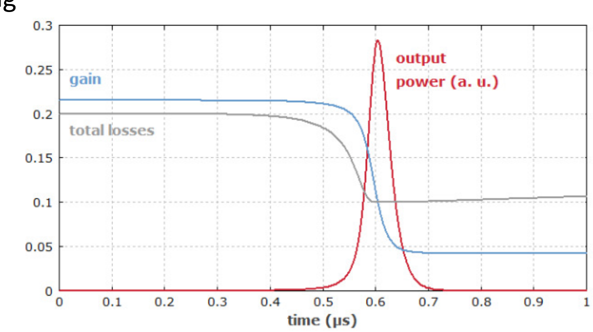


Fig. 2.23

MODE-LOCKING

- Operating technique is completely different.
- The cavity is filled with photons everywhere at the same time: only a packet of photons is allowed to propagate in the cavity.
- This pulse lasts for a shorter time than a round trip in the cavity. In other words, its spatial extension is markedly shorter than the length of the cavity.
- operating conditions consists a light modulator, that can chop the light in the cavity into periods of exactly the same length as a round trip.
- Those photons allowed to pass through the modulator in its on-state will be amplified

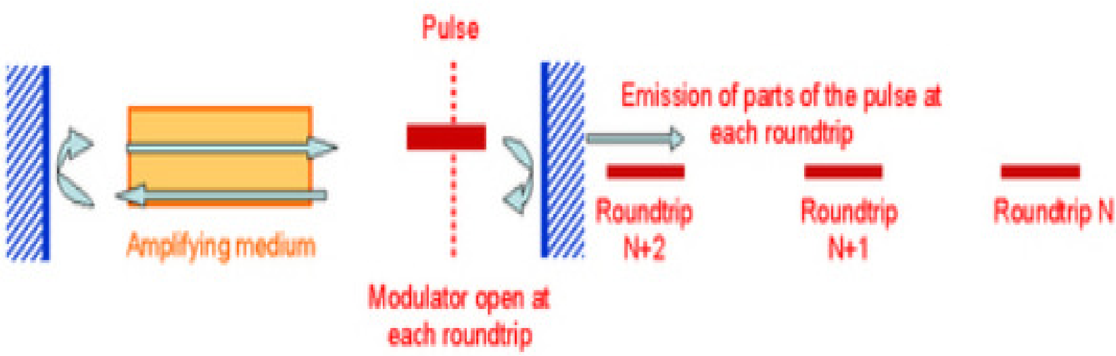


Fig. 2.24 *A pulse propagating in the optical cavity of a mode-locked laser*

- It reaches the modulator in this state after each round trip.
- The other photons elsewhere in the cavity will be subject to losses when they travel through the modulator.
- The pulses last for a much shorter time than a round trip in the cavity.
- photons allowed to pass, will be amplified
- the pulses last for a much shorter time than a round trip in the cavity.

- They are limited by the Fourier transform of the spectrum emitted by the laser: the wider the spectrum, the shorter the pulse.
- exceptionally wide - pulse generated will be only several femtoseconds long
- The pulse repetition period corresponds to the cavity round-trip time
- The average power of a mode-locked laser is of the same order of magnitude as that of continuous-wave lasers.
- In fact, in contrast to Q-switched lasers, these can also reach a steady state like continuous-wave lasers.
- The fundamental difference is that the stimulated photons are condensed in a packet rather than spread all around the cavity.
- During one round trip, only one laser pulse is emitted via the output mirror.
- The pulse energy is thus equal to the average power multiplied by the duration of a round trip.
- Generally, these energies are of the order of several nanojoules.
- The term "mode-locking" comes from the analysis of the various frequencies.
- A laser operating under these conditions will emit over several different frequencies due to the rapid modulation of the modulator.
- if the laser emits continuously at two frequencies separated by , the light output due to interference of the two waves will be modulated by a sinusoidal term of frequency
- modulation is generally very rapid, detected by photodiodes
- known as beating and results from the interference of beams with different frequencies
- When a large number of frequencies are emitted by the laser, the beat signal becomes quite complex.
- Its shape depends on the relative phase of the waves with different frequencies.
- However, the beat signal has a very regular shape in one particular case: when all the waves emitted by the cavity are in phase.
- Then, there are certain times and spots in the cavity where all the waves beat in phase and the interference signal is thus very powerful

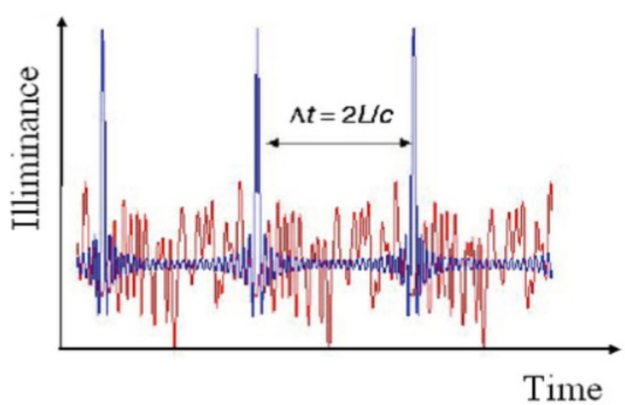


Fig. 2.25

- When the longitudinal modes are in phase, in the cavity where the electric fields add together constructively.
- Everything occurs as if a pulse was travelling inside the cavity

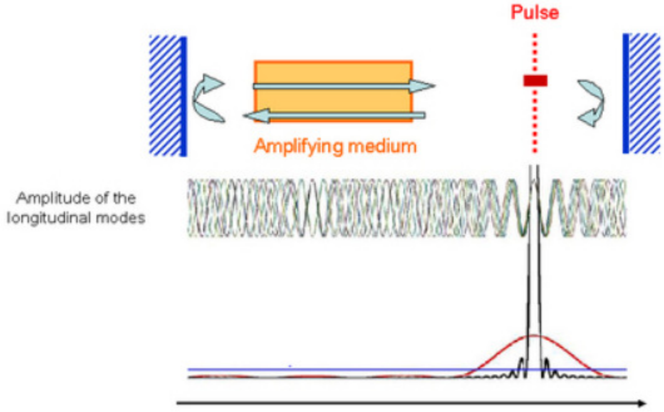
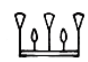


Fig. 2.1

LASERS MODES: THE SHAH FUNCTION

The Shah function, III(t), is an infinitely long train of equally spaced delta-functions. The symbol III is pronounced *shah* after the Cyrillic character III, which is said to have been modeled on the Hebrew letter שׁ (shin) which, in turn, may derive from the Egyptian  a hieroglyph depicting papyrus plants along the Nile.

The Fourier transform of the Shah function

$$= \int_{-\infty}^{\infty} \sum_{m=-\infty}^{\infty} \delta(t-m)\exp(-i\omega t)dt$$

$$= \sum_{m=-\infty}^{\infty} \int_{-\infty}^{\infty} \delta(t-m)\exp(-i\omega t)dt$$

$$= \sum_{m=-\infty}^{\infty} \exp(-i\omega m)$$

If $w = 2np$, where n is an integer, every term is $\exp(-2mnp\, i) = 1$, and the sum diverges; otherwise, cancellation occurs. So:

$$\mathscr{F}\{\mathrm{III}(t)\} \propto \mathrm{III}(\omega/2\pi)$$

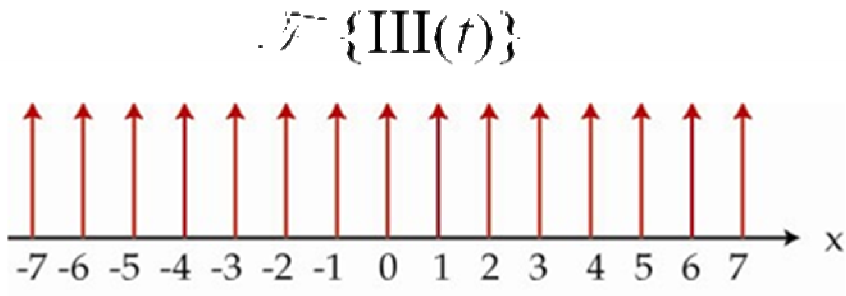


Fig. 2.1 The Fourier transform of an infinite train of pulses

An infinite train of identical pulses can be written:

$E(t) \;=\; \text{III}(t/T) * f(t)$

where *f(t)* represents a single pulse and *T* is the time between pulses.

The Convolution Theorem states that the Fourier Transform of a convolution is the product of the Fourier Transforms. So:

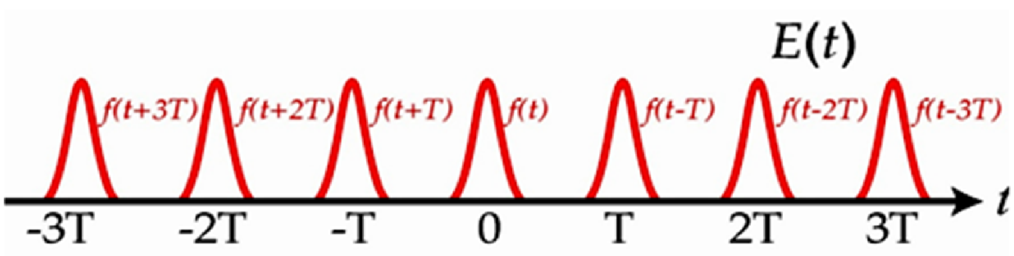


Fig. 2.1

$$\tilde{E}(\omega) \propto$$

$$\text{III}(\omega T / 2\pi)\, F(\omega)$$

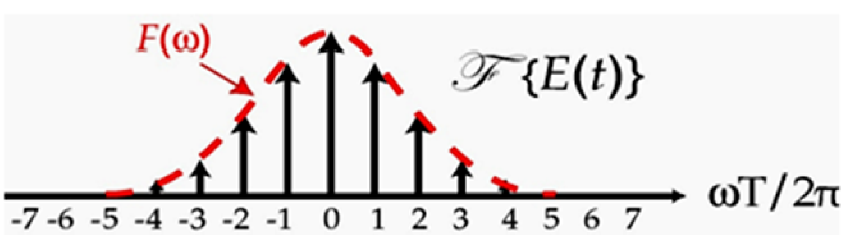


Fig. 2.1

A train of pulses results from a single pulse bouncing back and forth inside a laser cavity of round-trip time *T*. The spacing between frequencies—called laser modes—is then dw = 2p/*T* or **δn = 1/*T***.

MODE-LOCKED VS. NON-MODE-LOCKED LIGHT

Mode-locked pulse train:

$$\tilde{E}(\omega) = \sum_{m=-\infty}^{\infty} F(\omega)\,\delta(\omega - 2\pi m / T)$$

Random phase for each mode

$$= F(\omega) \sum_{m=-\infty}^{\infty} \delta(\omega - 2\pi m / T) = F(\omega)\,\mathrm{III}(\omega T / 2\pi)$$

$$\tilde{E}(\omega) = \sum_{m=-\infty}^{\infty} F(\omega) \exp(i\varphi_m)\,\delta(\omega - 2\pi m / T)$$

$$= F(\omega) \sum_{m=-\infty}^{\infty} \exp(i\varphi_m)\,\delta(\omega - 2\pi m / T)$$

Generating short pulses = mode-locking

Locking the phases of the laser modes yields an ultrashort pulse.

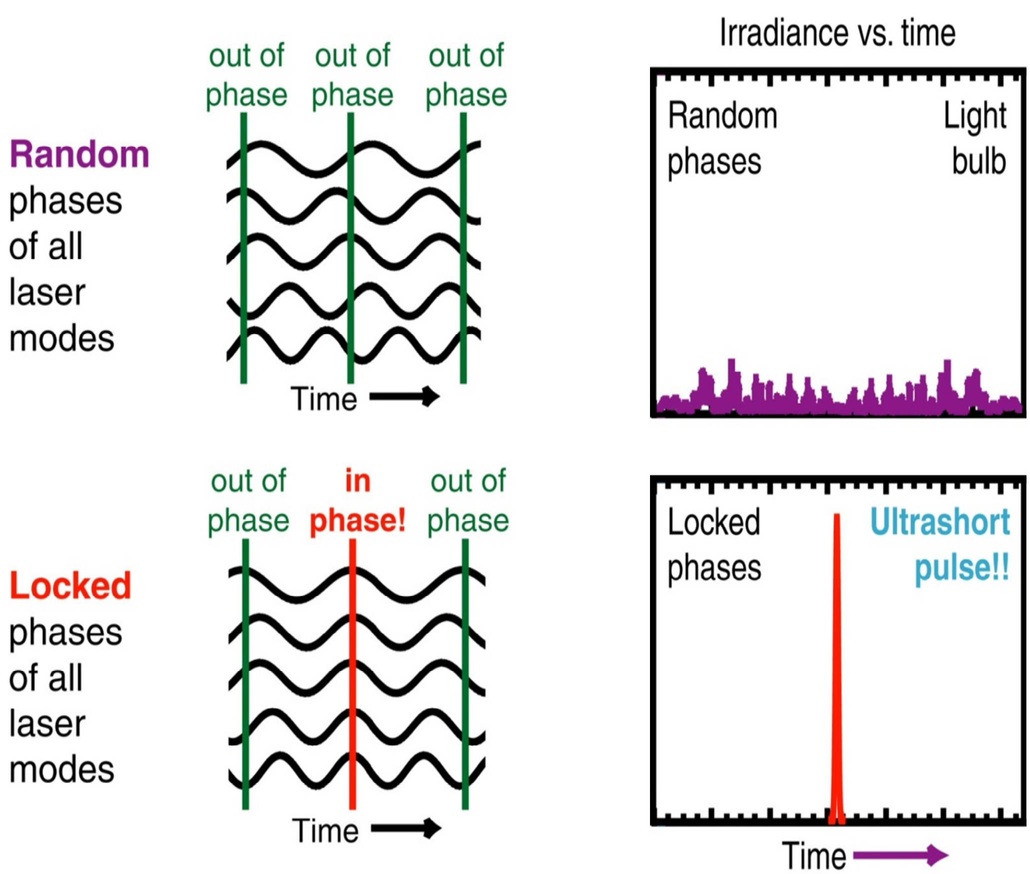


Fig. 2.1

Locked modes

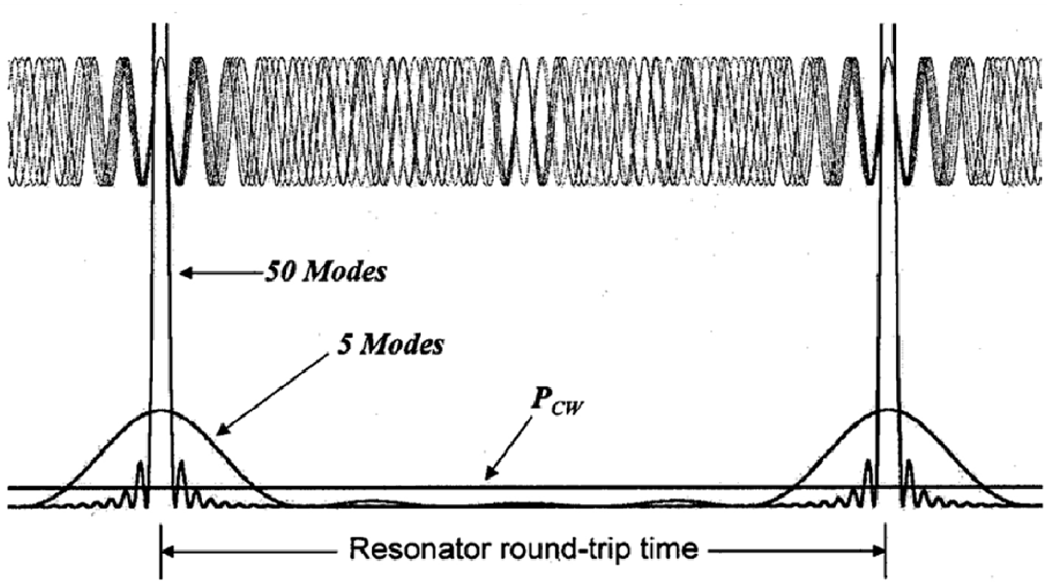


Fig. 2.1

Numerical simulation of mode-locking

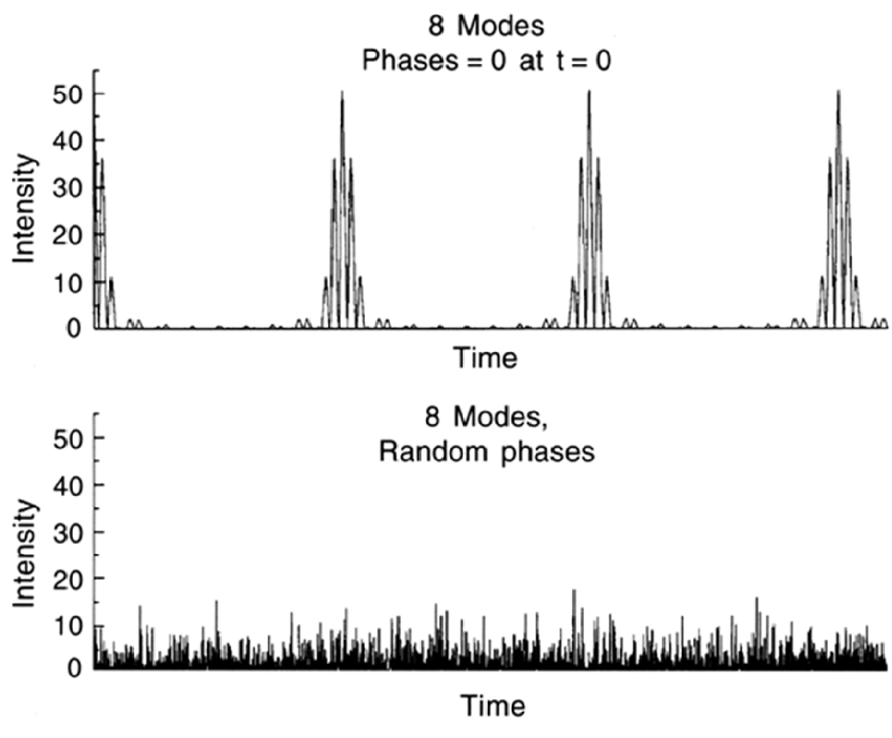


Fig. 2.1 Ultrafast lasers often have thousands of modes.

A generic ultrashort-pulse laser

A generic ultrafast laser has a broadband gain medium, a pulse-shortening device, and two or more mirrors:

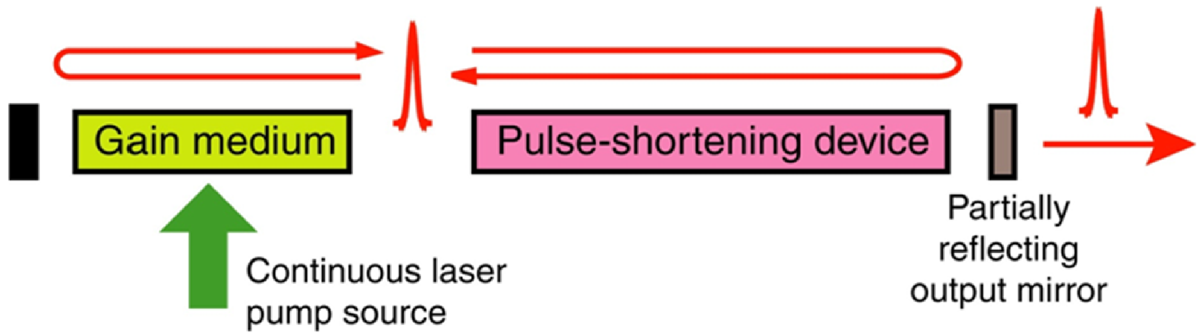


Fig. 2.1 Many pulse-shortening devices have been proposed and used.

Passive mode-locking: the saturable absorber

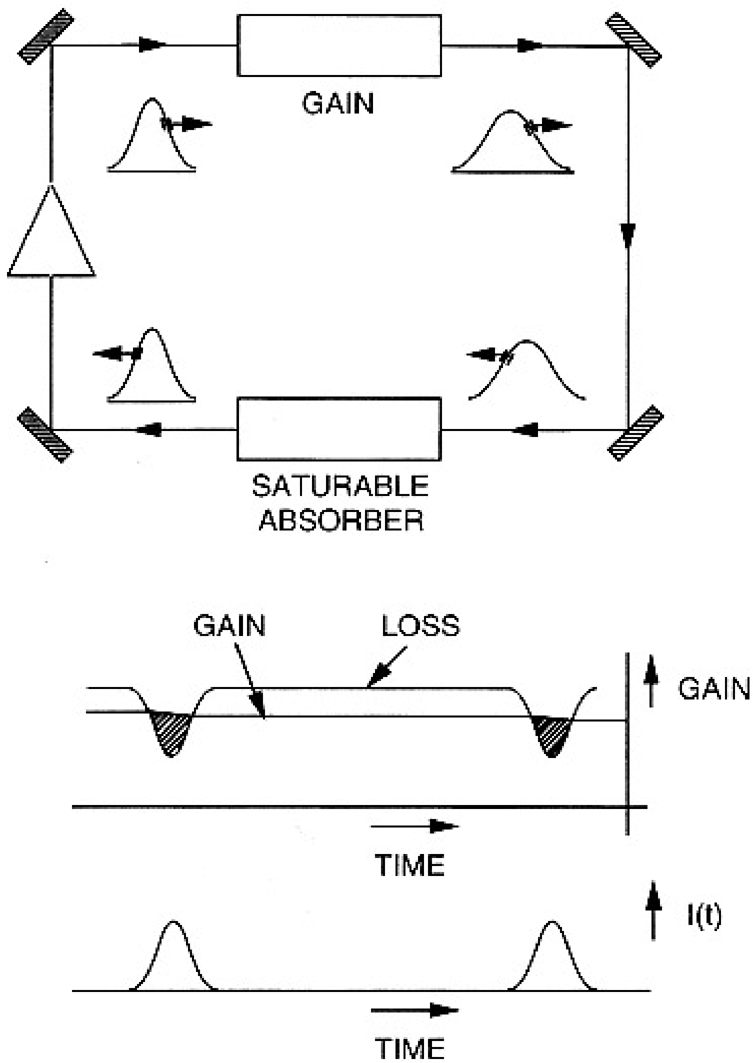


Fig. 2.1

High-intensity spikes (i.e., short pulses) see less loss and hence can lase while low-intensity backgrounds (i.e., long pulses) won't.

Passive mode-locking with a slow saturable absorber

- What if the absorber responds slowly (more slowly than the pulse)?
- Then only the leading edge will experience pulse shortening.

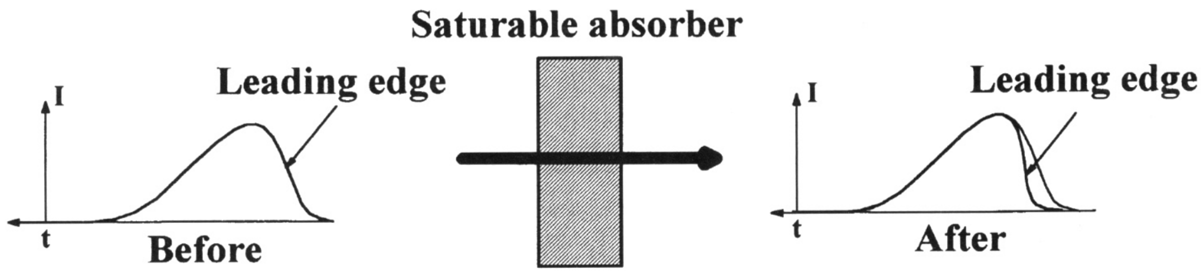


Fig. 2.1

This is the most common situat

The Passively Mode-locked Dye Laser

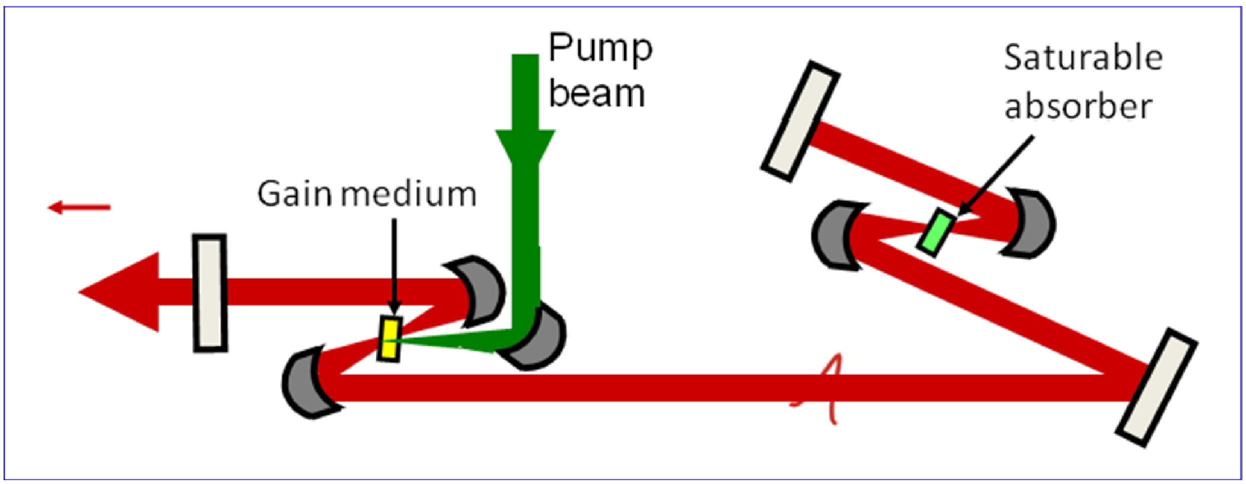


Fig. 2.1

- Passively mode-locked dye lasers yield pulses as short as a few hundred fs.
- They're limited by our ability to saturate the absorber.

Commercial fs lasers - Availability

- Ti:Sapphire
- Coherent:
- Mira (<35 fs pulse length, 1 W ave power),
- Chameleon (Hands-free, ~100 fs pulse length),
- Spectra-Physics:
- Tsunami (<35 fs pulse length, 1 W ave power)

- Mai Tai (Hands-free, ~100 fs pulse length)

Active mode-locking

- ✓ Any amplitude modulator can preferentially induce losses for times other than that of the intended pulse peak. This produces short pulses.
- ✓ It can be used to start a Ti:Sapphire laser mode-locking

Hybrid mode-locking

Hybrid mode-locking is any type of mode-locking incorporating two or more techniques simultaneously.

- ✓ Sync-pumping and passive mode-locking
- ✓ Active and passive mode-locking

However, using two lousy methods together doesn't really work all that much better than one good method.

Diode lasers use hybrid mode-locking

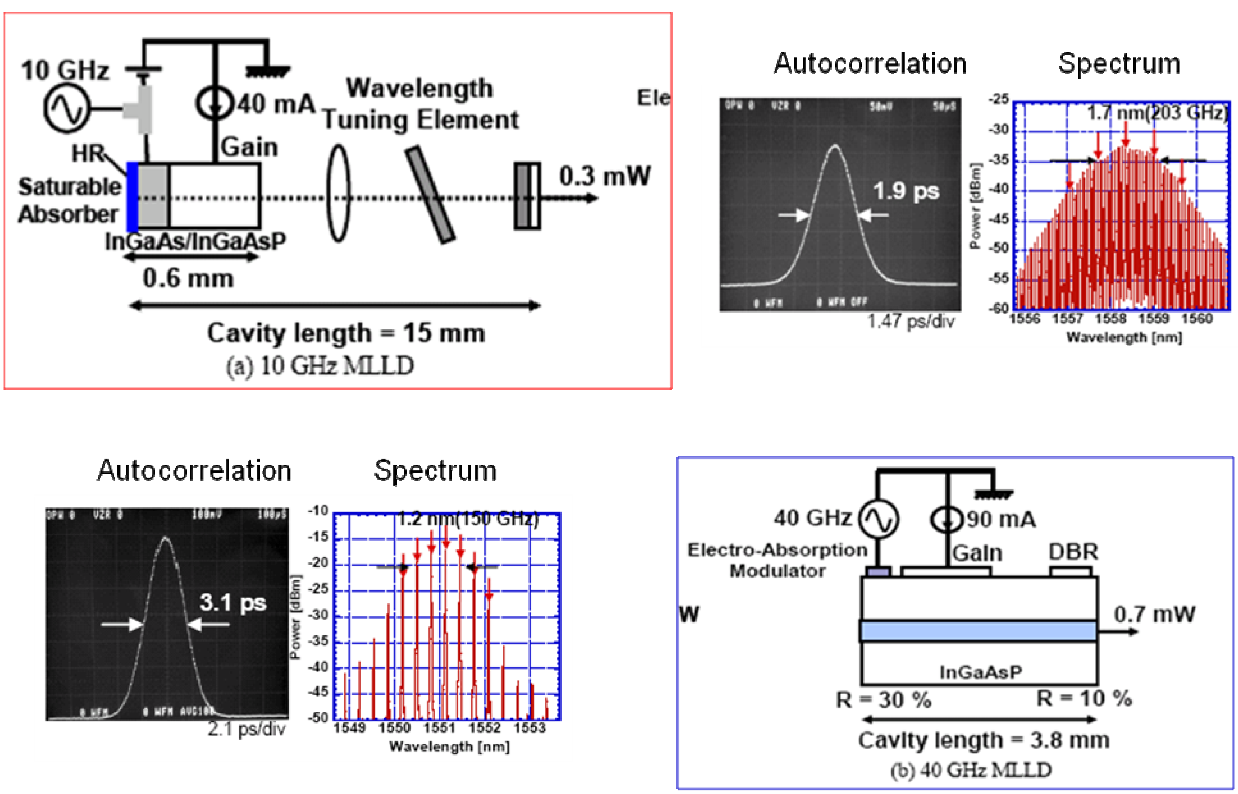


Fig. 2.1

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SCHOOL OF SCIENCE AND HUMANITIES

DEPARTMENT OF PHYSICS

UNIT – III - Applications of Laser – SPH1312

UNIT III - APPLICATIONS OF LASER

Application of laser in industry – cutting and welding – Drilling – Surface Hardening – Medical applications – Laser as diagnostic and therapeutic tool – Holography – Theory of recording and reconstruction – application of Holography.

3. Introduction

Lasers deliver coherent, monochromatic, well-controlled, and precisely directed light beams. A priori, therefore, lasers would seem tobe poor choices for general-purpose illumination, however, they are ideal for concentrating light in space, time, or particular wavelengths. Lasers have been regularly used to measure, cut, drill, weld, read, write, send messages, solve crimes, burn plaque out of arteries, and perform delicate eye operations.

Laser	Wavelength (µm)	Peak power (watts)	Pulse repetition rate (pulses per second)	Typical use
Nd:YAG (repetitively pulsed)	1.06	10^6	10	Drilling metals, scribing silicon wafers
Nd:YAG (repetitively Q-switched)	1.06	10^5	5000	Trimming resistors
Nd:YAG (continuous)	1.06	up to 5400	—	Cutting metals
CO_2 (repetitively pulsed)	10.6	10^5	100	Hole drilling in alumina circuit boards
CO_2 (TEA)	10.6	10^6	100	Marking components
CO_2 (continuous)	10.6	up to 20,000	—	Cutting metals, plastics, cloth
Copper vapor	0.512, 0.578	3×10^5	6500	Drilling metals
Excimer	0.193, 0.248	10^6–10^7	100	Drilling plastics, ceramics
Ruby	0.694	10^6	low (<1)	Drilling gemstones
Nd:glass	1.06	10^6	low (<1)	Drilling hard metals

Over and over again the laser has proved to be an extremely practical tool. Nevertheless, lasers have also proved their usefulness in non-practical applications, especially in the realm of art and entertainment. Lasers are involved in almost all aspects of these fields, from “light shows” to Compact Discs (CDs) and Digital Video Discs (DVDs), to special effects in the movies. Some other commonplace application of lasers are as Laser pointers, barcode scanners, laser printers, etc.

Still, much of the important modern day celebrated applications lie in the fiber-optic communication, laser machining and fabrication, trace element detection, laser metrology and medical imaging.

3.1 Laser Machining and cutting

Laser energy can be focused in space and concentrated in time so that it heats, burns away, or vaporizes many materials. Although the total energy in a laser beam may be small, the concentrated power on small spots or during short intervals can be enormous. Although lasers cost much more than mechanical drills or blades, their different properties allow them to perform otherwise difficult tasks.

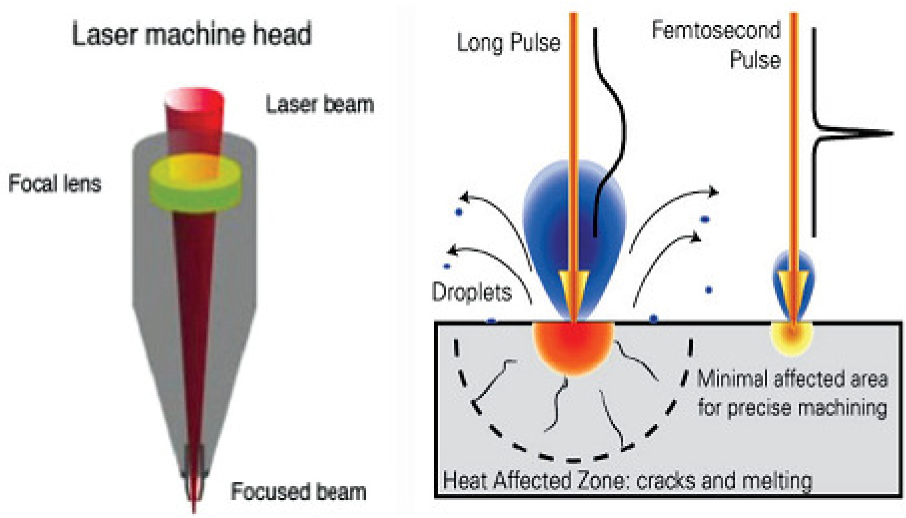


Fig. 2.1

A laser beam does not deform flexible materials as a mechanical drill would, so it can drill holes in materials such as soft rubber nipples for baby bottles. Likewise, laser beams can drill or cut into extremely hard materials without dulling bits or blades. Laser machining is not dependent on the material hardness but on the optical properties of the laser and the optical and thermo-physical properties of the material. For example, lasers have drilled holes in diamond dies used for drawing wire.Several recent research have shown that laser cutting is best achieved with ultrafast lasers (Fig. 2), as the material only ablates and does not get a chance to melt under such ultrafast time scale interactions.

3.2 Laser cutting

In the simplest terms, a CNC laser cutter uses a coherent beam of light to cut material, most often sheet metal, but also wood, diamond, glass, plastics and silicon. In the beginning, the beam was directed through a lens via mirrors, but these days fiber optics are much more common. The lens focuses the beam at the work zone to burn, melt or vaporize the material. Exactly which process(es) the material undergoes depends on the type of laser cutting involved.

Broadly speaking, laser cutting can be divided into two types: laser fusion cutting and ablative laser cutting. Laser fusion cutting involves melting material in a column and using a high-pressure stream of gas to shear the molten material away, leaving an open cut kerf. In contrast, ablative laser cutting removes material layer by layer using a pulsed laser—it's like chiseling, only with light and on a microscopic scale. This generally means evaporating the material, rather than melting it. Two other key factors distinguish laser fusion cutting from ablative laser cutting.

Fig. 2.1

First, ablative laser cutting can be used to make partial cuts in a material, whereas laser fusion cutting can only be used to cut all the way through it. This is due to fusion cutting operating with lasers either in continuous waves or with significantly longer pulses than ablative cutting (micro- or milliseconds vs. nanoseconds), which causes a molten pool to penetrate the entire depth of the metal. This molten material must be sheared away via gas stream, otherwise it can stay in the kerf and weld back cut edges upon cooling.

The second and more significant factor that distinguishes these two types of laser cutting is speed. "With sheet metal cutting—which makes up the bulk of the cutting industry. At the current state of laser technology, laser fusion cutting is much faster for those setups. Ablative cutting takes more time, for now.

Fiber Lasers vs CO_2

The two most common types of laser cutting machines are fiber laser and CO_2.

CO_2 lasers use an electromagnetically stimulated gas—typically, a mixture of carbon dioxide, nitrogen and sometimes hydrogen, xenon or helium—as their active laser medium. In contrast, fiber lasers—which are a type of solid-state laser—use an optical fiber doped with rare-earth elements, such as erbium, ytterbium, neodymium or dysprosium. As indicated by Houldcroft's experiments, the industry began with CO_2, and that technology dominated until only recently. "Potentially, CO_2 lasers will be replaced completely. If so, this would happen mid-term while the fiber laser technology further evolves. Currently, CO_2 lasers still have some specific advantages, e.g., better edge quality in thick material and smaller burrs.

CNC laser cutters are used on a wide range of materials in a variety of industries. Since cutting sheet metal is the most common application, it's worth focusing on the particularities involved. For instance, reflectance and surface thickness are two of the most important factors to consider.

Laser cutting uses high-pressure gas—5-25 bars for nitrogen cutting—so you need the parts to either be supported by their own weight, which works if they're thicker than 2-3 mm and relatively large in size, but for the parts that are thin and small, to resist the force of the gas stream, small sections need to remain uncut," Sarrafi said. "These micro-joints are very small, 0.2-0.4 mm wide, so they're easy to break in post processing, but sometimes they're necessary to connect the parts to the frame so the parts don't fly away

3.3 Laser welding

Laser welding is used more frequently in industrial processes because it has wider application than traditional welding as less heat is created because the beam is so focused. This means that heat transfer to the workpiece is much less and the metallurgical structure is less affected and the quality of the weld is much higher than with traditional forms of welding.

Laser welding is a much more accurate manufactoring process and welds can be as small as one hundredths of a millimetre. Small pulses of heat are used to create the weld which leads to a higher quality finish which is stronger providing a better depth to width ratio. Depending on the power of the laser, welding penetration up to 15 millimetre of steel or stainless steel can be achieved.

Another distinct advantage of laser welding over other methods is that lasers can weld a greater variety of metals such as high strength stainless steel, titanium, aluminium, carbon steel as well as precious metals like gold and silver.

With laser welding, welds are much more accurate and finish is superior as is strength. The manufactoring process is therefore excellent for fine components and it can be used in areas where there is limited access. Lasers enable precision and quality where required for fine components.

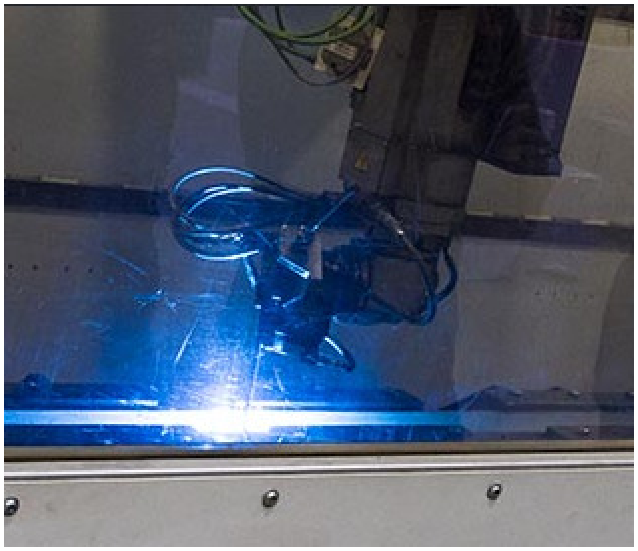


Fig. 2.1

Summary of Laser Welding Advantages

- Aesthetically better weld finishes
- More suited to high value items such as jewellery
- Great for inaccessible places
- Ideal for solenoids and machined components
- Perfect for medical devices where weld quality is vital for hygiene and precision
- Better weld quality for a variety of metals and metal depths
- No concerns for weld weaknesses due to minimal distortion
- Workpieces can be handled almost immediately because heat transference is low
- Overall improved productivity

The benefits of laser welding for modern processes over traditional welding are many. Laser welding overall has a much wider application and an ability to weld a greater number of metals to a much higher quality which is vital where precision engineering is required.

Laser - Hole drilling

We will describe the physical processes that occur in the interaction of high-power laser radiation with surfaces. An understanding of these processes is important for understanding thecapabilities and limitations of laser vaporization. We will emphasize metallic targets, but muchof what is said applies to other absorbing surfaces as well.

Lasers used—The Nd:YAG laser has often been used for drilling holes in metals. It can deliver an irradiance of 106–109 watts/cm2 to a target surface. For most metals, it offers lower reflectivity than the CO_2 laser, so that less light energy is lost by reflection. It also offers high processing speed. The CO_2 laser, with a wavelength 10 times larger than the Nd:YAG laser, has less importance in drilling of metals, because the beam cannot be focused to as small a spot, and because the absorption is not so high as for the Nd:YAG laser. But for many nonmetals, like alumina, the absorption is much higher for the CO_2 laser than for the Nd:YAG laser. Thus, CO_2 lasers have an important role in the drilling of materials like ceramics and plastic. The copper vapor laser, with a high pulse repetition rate, has also found a role in the drilling of metals. Excimer lasers offer material removal with relatively little heating of the surrounding material, because the chemical bonds in the target can be broken by shorter, ultraviolet wavelengths of the excimer laser. The material is removed without significant thermal conduction of heat into the interior of the workpiece. Thus, excimer lasers may be used for hole drilling in materials that are sensitive to heat, like plastics.

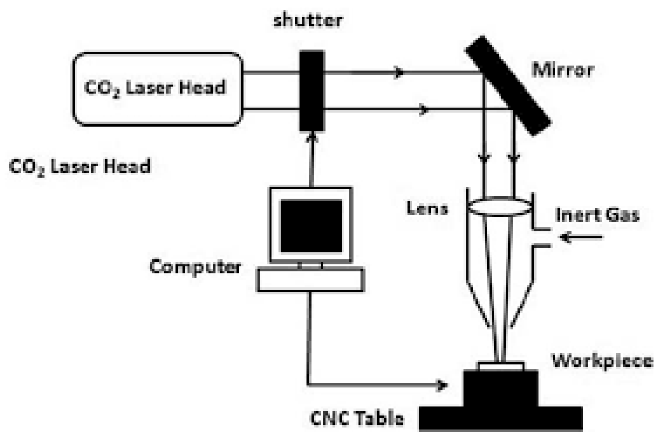


Fig. 2.1

Depth of holes—When high-power laser radiation is absorbed by a target, the surface is heated by the incoming laser light. The surface temperature goes quickly through the melting point and reaches the vaporization temperature (boiling point). Material begins to vaporize and a hole is produced in the surface. When a pulsed laser beam with duration around 1 millisecond interacts with a surface, the process of material involves conventional heating, melting, and vaporization. The time scale is 10 Optics and Photonics Series, Photonics-Enabled Technologies: Manufacturing long enough so that vaporized material can flow away from the point of the interaction. Vaporization occurs at a continually retreating surface.

	Absorbed laser irradiance (watts/cm^2)		
Metal	**10^5**	**10^6**	**10^7**
Lead	118 μs	1.18 μs	12 ns
Zinc	128 μs	1.28 μs	13 ns
Magnesium	245 μs	2.45 μs	24.5 ns
Nickel	1.84 ms	184 μs	184 ns
Iron	1.86 ms	186 μs	186 ns
Aluminum	2.67 ms	26.7 μs	267 ns
Molybedenum	5.56 ms	55.6 μs	556 ns
Copper	8.26 ms	82.6 μs	826 ns
Tungsten	10.46 ms	104.6 μs	1.05 μs

Advantages

Hole drilling with lasers offers many advantages over competing techniques.

1. There is no contact of external materials with the workpiece, and hence, no contamination.
2. Hard, brittle materials that are difficult to drill with conventional techniques are often easily drilled with lasers.
3. The heat-affected zones around the holes can be very small.
4. It is possible to produce very small holes in thin materials.
5. Laser drilling is compatible with automation, so that it is possible to produce large numbers of holes and complex patterns of holes in a completely automated process.
6. There is no wear of expensive tool bits, so that in some cases, laser drilling offers an economic advantage.
7. Holes can be drilled with high throughput rate, so that the cost is low.

Limitations

Laser hole drilling, of course, will not completely replace conventional hole drilling. There are a number of limitations for laser hole drilling.

1. Laser energy is relatively expensive and may not compete economically with other processes for specific applications.
2. The holes drilled by lasers tend to have limited depth. One might think that one could use a CO_2 laser and allow it to dwell on a spot for a long time. But the heat then spreads over a 1arger volume and much of the advantage in using lasers is lost.
3. There may be a recondensation of vaporized material around the entrance to the hole, which forms a crater-like lip. The lip can be removed fairly easily, but this adds one more step to the laser-drilling process.

3.4 Surface hardening

Laser beams are invisible electromagnetic radiations in the infra-red portion of the spectrum, and are increasingly being used for surface-hardening of ferrous materials to improve mechanical properties like wear resistance and even fatigue resistance. There are two main type of Lasers used- YAG Solid-state type and the carbon-dioxide gas type. The output of YAG laser has much shorter wavelength, 1.064 μm, whereas the carbon dioxide laser emits radiations with 10.8 μm wavelength. Carbondioxide laser is more commonly used and is suitable for surface hardening, particularly when the process requires more than 500 W of power.

The power density of laser beam is usually expressed as watts per square centimeter. The power densities used in laser surface hardening are in the range of 500 to 5000 W/cm2 with dwell times in the range of 0.1 s to 10 s. For carbon steels, power densities used are from 1000 to 1500W/cm2 with dwell time of 1 to 2 s.

During Laser surface hardening, a laser can generate very intense energy fluxes at the surface of the component, when the Laser radiations impinge on it, and are absorbed to generate heat energy. This heat is then conducted inside the component. When the power density of the laser beam is high, the rate of heat generation is much higher than the rate of heat conduction. The temperature of the surface layer increases rapidly to soon attain the austenitising temperature.

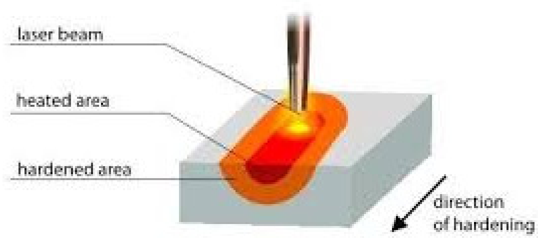


Fig. 2.1

A moderate power density of 500 W/m2, results in temperature gradient of 500°C/mm. The laser beam may be moved over the surface of the component as illustrated in Fig. 8.78. The surface which meets the laser beam gets heated up. Once the beam passes over, the heated volume gets subsequently ‘self-quenched’. Thus, by selecting power density and the speed of the laser spot (i.e., the dwell time), a desired case depth can be hardened.

Laser-surface-hardening is similar to any other surface-hardening method such as induction, or flame, except that the laser beam is used to generate heat here. The heating time to the austenitising temperature, particularly in laser heating, is very short-fractions of seconds to few seconds. The dwell time cannot be made very large as surface melting may occur which is undesirable.

Alloy steels intended to have higher hardenabilities should have very fine carbides particles even then their dissolution is difficult. Diffusion of carbon though faster than alloying elements requires longer dwell time (low speed of motion of laser spot) to obtain homogeneous structure.

$$Y = -0.11 + 3.02\, P/\sqrt{D_b\, V}$$

where,

Y = depth of hardening (mm),

P = Laser power (W),

Db = incident beam diameter (mm)

V = travel speed (mm/s)

but with a considerable scatter of experimental data. At a constant value of P/√DhV, the depth of hardening can vary by a factor of 2.

Advantages and Disadvantages of Laser Hardening:

1. Non-hardenable steels like mild steels can be surface hardened.

2. Hardness obtained is slightly higher than conventional hardening.

3 Closer control over power inputs helps in eliminating dimensional distortion.

4. Beam (with the help of optical parts) can easily reach the inaccessible areas of components, and re-entrant surfaces.

5. No vacuum or protective atmosphere is required.

6. The last optical element of the Laser and the component to be surface hardened may be far-placed.

7. Very long and irregular-shaped components can be hardened easily.

Disadvantages:

1. High initial cost particularly of large lasers.

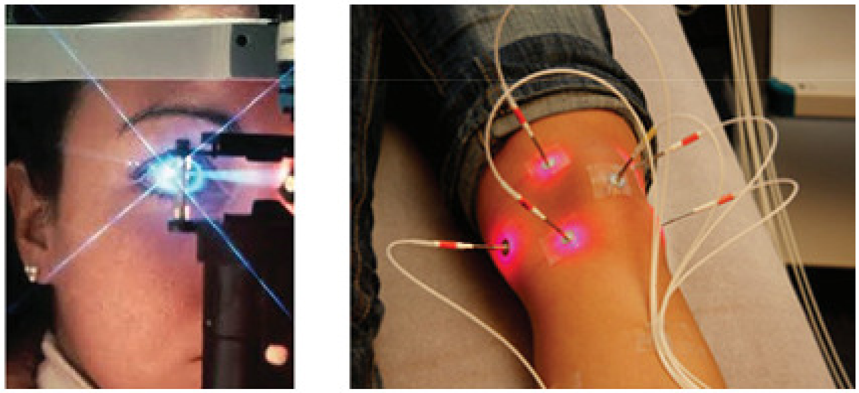
2. Lasers use 10% of the input energy, i.e., there are inefficient.

3. The depth of case is very limited.

4. Working cost is high.

3.5 Medical Applications

Surgical removal of tissue with a laser is a physical process similar to industrial laser drilling. Carbon-dioxide lasers operating at 10.6 micrometers can burn away tissue as the infrared beams are strongly absorbed by the water that makes up the bulk of living cells. A laser beam cauterizes the cuts, stopping bleeding in blood-rich tissues such as gums. Similarly, laser wavelengths near one micrometer (Neodymium-YAG Laser) can penetrate the eye, welding a detached retina back into place, or cutting internal membranes that often grow cloudy after cataract surgery (Fig. 5a). Less-intense laser pulses can destroy abnormal blood vessels that spread across the retina in patients suffering from diabetes, delaying the blindness often associated with the disease. Ophthalmologists surgically correct visual defects by removing tissue from the cornea, reshaping the transparent outer layer of the eye with intense ultraviolet pulses from Excimer Lasers.



(a) (b)

Fig. 2.1 (a) Schematic of Laser Eye Surgery. (b) Laser energy delivery to precise spots in joints for arthroscopic surgery.

Laser light can be delivered to places within the body that the beams could not otherwise reach through optical fibers similar to the tiny strands of glass that carry information in telephone systems. One important example involves threading a fiber through the urethra and into the kidney so that the end of the fiber can deliver intense laser pulses to kidney stones. The laser energy splits the stones into fragments small enough to pass through the urethra without requiring surgical incisions. Fibers also can be inserted through small incisions to deliver laser energy to precise spots in the knee joint during arthroscopic surgery (Fig. 5b). Another medical application for lasers is in the treatment of skin conditions. Pulsed lasers can bleach certain types of tattoos as well as dark-red birthmarks called port-wine stains. Cosmetic laser treatments include removing unwanted body hair and wrin-kles.

3.6 Biomedical Imaging and superresolution

Confocal microscopy (Fig. 6) is a ubiquitous imaging tool for imaging thick specimen in a wide range of investigations in biological, medical and material sciences. It uses UV or visible light for the single photon excitation of fluorophore from ground state to the excited state followed by deactivation through fluorescence emission which is detected through high quantum efficiency photomultiplier tube (PMT) in the range of near ultraviolet, visible and near infrared spectral region. The basic difference of confocal Light Scanning Microscope with the conventional optical microscope is the confocal aperture arranged in a plane conjugate to the intermediate image plane and thus, to the object plane of the microscope. The PMT can only detect the light that passed the pinhole. As the laser beam is focused to a diffraction limited spot, which illuminates only a point of the object at a time, the point illuminated and the point observed are situated in conjugate planes, i.e. they are focused onto each other. The perfection of focused beam which is connected to the resolution has always been a matter of concern in the far-field fluorescence microscopy. Still, optical microscopy remains the best choice for monitoring live specimens despite the resolution advantage of, say electron microscopes, since the energy deposited in electron microscopy adversely affects the viability of live specimens. This practical compromise implicitly sets resolution enhancement as one of the most important development in optical microscopy. Finally, all these images are combined into one super-resolved image with complete structural information. They demonstrated this method first in 2006 and called it Photo Activated Localization Microscopy (PALM)

3.7 Laser Imaging and Holography

Holography is a much broader field than most people have perceived. Recording and displaying truly three-dimensional images are only small parts of it. Holographic optical elements (HOE) can perform the functions of mirrors, lenses, gratings, or combinations of them, and they are used in myriad technical devices. Holographic interferometry measures microscopic displacements on the surface of an object and small changes in index of refraction of transparent objects like plasma and heat waves.

The coherence of laser light is crucial for interferometry and holography, which depend on interactions between light waves to make extremely precise measurements and to record three-dimensional images. The result of adding light waves together depends on their relative phases. If the peaks of one align with the valleys of the other, they will interfere destructively to cancel each other out; if their peaks align, they will interfere constructively to produce a bright spot. This effect can be used for measurement by splitting a beam into two identical halves that follow different paths. Changing one path just half a wavelength from the other will shift the two out of phase, producing a dark spot. This technique has proved invaluable for precise measurements of very small distances. Holograms are made by splitting a laser beam into two identical halves, using one beam to illuminate an object. This object beam then is combined with the other half—the reference beam—in the plane of a photographic plate, producing a random-looking pattern of light and dark zones that record the wave front of light from the object (Fig. 4). Later, when laser light illuminates that pattern from the same angle as the reference beam, it is scattered to reconstruct an identical wave front of light, which appears to the viewer as a three-dimensional image of the object. Holograms now can be mass-produced by an embossing process, as used on credit cards, and do not have to be viewed in laser light.

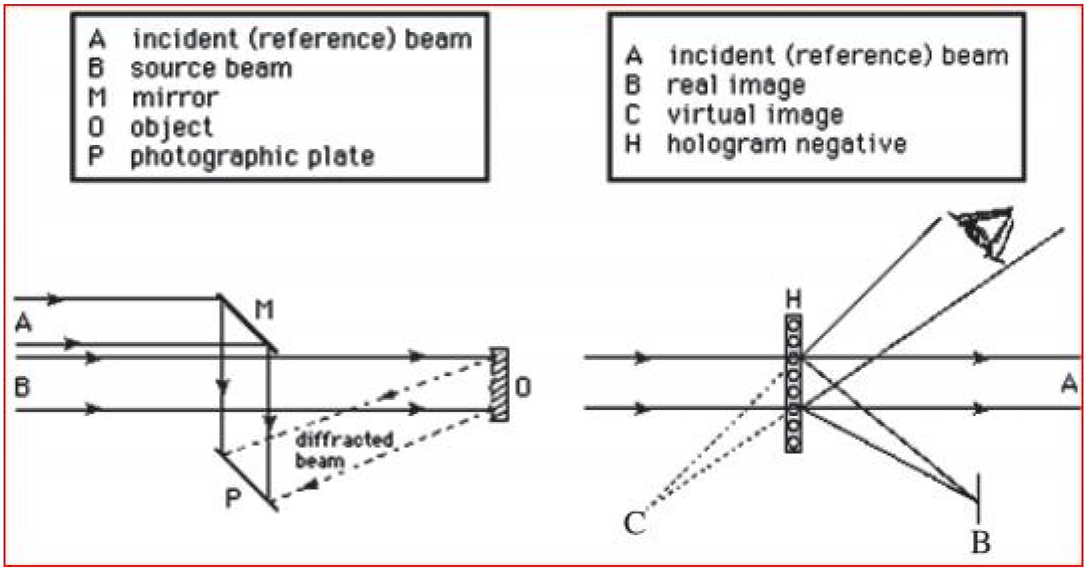


Fig. 2.1 Schematic of Holography process where the laser beam is split into three components. First two beams are needed to create the hologram which is viewed with the help of the third.

3.7.1 TYPES OF HOLOGRAMS

A hologram is a recording in a two- or three-dimensional medium of the interference pattern

formed when a point source of light (the reference beam) of fixed wavelength encounters light of the same fixed wavelength arriving from an object (the object beam). When the hologram is illuminated by the reference beam alone, the diffraction pattern recreates the wave fronts of light from the original object. Thus, the viewer sees an image indistinguishable from the original object.

- The reflection hologram
- Transmission holograms
- Hybrid holograms

3.7.2 Recording and reconstruction of holograms

Recording of hologram. The recording of hologram is based on the phenomenon of interference. It requires a laser source, a plane mirror or beam splitter, an object and a photographic plate. A laser beam from the laser source is incident on a plane mirror or beam splitter. As the name suggests, the function of the beam splitter is to split the laser beam. One part of splitted beam, after reflection from the beam splitter, strikes on the photographic plate. This beam is called reference beam. While other part of splitted beam (transmitted from beam splitter) strikes on the photographic plate after suffering reflection from the various points of object. This beam is called object beam.

The object beam reflected from the object interferes with the reference beam when both the beams reach the photographic plate. The superposition of these two beams produces an interference pattern (in the form of dark and bright fringes) and this pattern is recorded on the photographic plate. The photographic plate with recorded interference pattern is called hologram. Photographic plate is also known as Gabor zone plate in honour of Denis Gabor who developed the phenomenon of holography.

Each and every part of the hologram receives light from various points of the object. Thus, even if hologram is broken into parts, each part is capable of reconstructing the whole object.

Reconstruction of image.

In the reconstruction process, the hologram is illuminated by laser beam and this beam is called reconstruction beam. This beam is identical to reference beam used in construction of hologram.

The hologram acts a diffraction grating. This reconstruction beam will undergo phenomenon of diffraction during passage through the hologram. The reconstruction beam after passing through the hologram produces a real as well as virtual image of the object.

One of the diffracted beams emerging from the hologram appears to diverge from an apparent object when project back. Thus, virtual image is formed behind the hologram at the original site of the object and real image in front of the hologram. Thus an observer sees light waves diverging from the virtual image and the image is identical to the object. If the observer moves round the virtual image then other sides of the object which were not noticed earlier would be observed. Therefore, the virtual image exhibits all the true three dimensional characteristics. The real image can be recorded on a photographic plate.

3.7.3 Applications of holography

- The three-dimensional images produced by holograms have been used in various fields, such as technical, educational also in advertising, artistic display etc.
- Holographic diffraction gratings: The interference of two plane wavefronts of laser beams on the surface of holographic plate produces holographic diffraction grating. The lines in this grating are more uniform than in case of conventional grating.
- Hologram is a reliable object for data storage, because even a small broken piece of hologram contains complete data or information about the object with reduced clarity.
- The information-holding capacity of a hologram is very high because many objects can be recorded in a single hologram, by slightly changing ...

3.8 Holography –Future Applications

Holography is a very useful tool in many areas, such as in commerce, scientific research, medicine, and industry.

Some current applications that use holographic technology are:

- Holographic interferometry is used by researchers and industry designers to test and design many things, from tires and engines to prosthetic limbs and artificial bones and joints.
- Supermarket and department store scanners use a holographic lens system that directs laser light onto the bar codes of the merchandise.

- Holographic optical elements (HOE's) are used for navigation by airplane pilots. A holographic image of the cockpit instruments appears to float in front of the windshield. This allows the pilot to keep his eyes on the runway or the sky while reading the instruments. This feature is available on some models of automobiles.

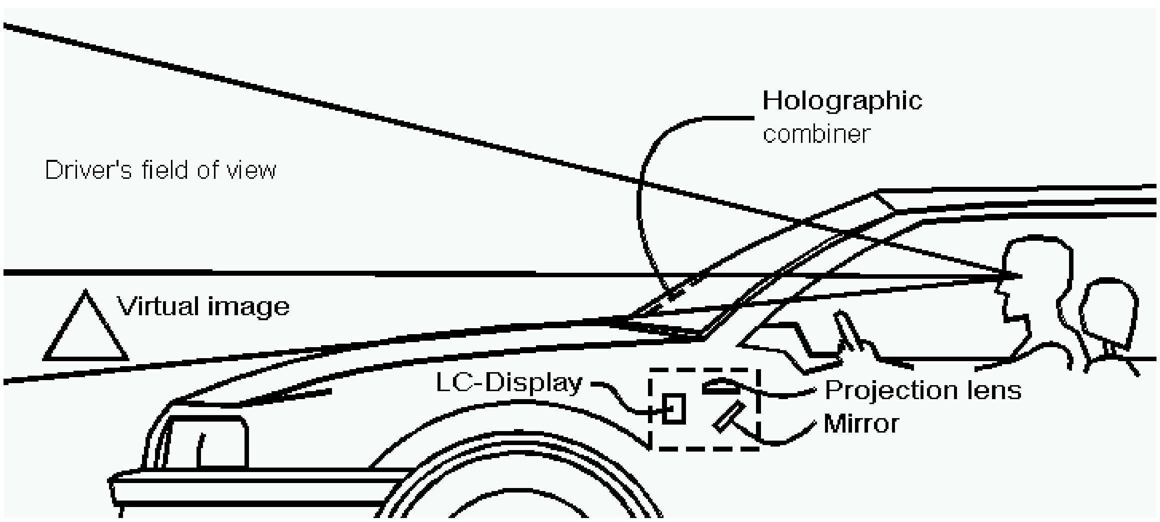


Fig. 2.1

- Medical doctors can use three-dimensional holographic CAT scans to make measurements without invasive surgery. This technique is also used in medical education.

- Holograms are used in advertisements and consumer packaging of products to attract potential buyers.

- Holograms have been used on covers of magazine publications. One of the most memorable Sports Illustrated covers was the December 23, 1992 issue featuring Michael Jordan. Holograms have also been used on sports trading cards.
- The use of holograms on credit cards and debit cards provide added security to minimize counterfeiting.

- Holography has been used to make archival recordings of valuable and/or fragile museum artifacts.

• Sony Electronics uses holographic technology in their digital cameras. A holographic crystal is used to allow the camera to detect the edge of the subject and differentiate between it and the background. As a result, the camera is able to focus accurately in dark conditions.

• Holography has been use by artists to create pulsed holographic portraits as well as other works of art.

Future applications of holography include:

• Future colour liquid crystal displays (LCD's) will be brighter and whiter as a result of holographic technology. Scientists at Polaroid Corp. have developed a holographic reflector that will reflect ambient light to produce a whiter background.

• Holographic night vision goggles

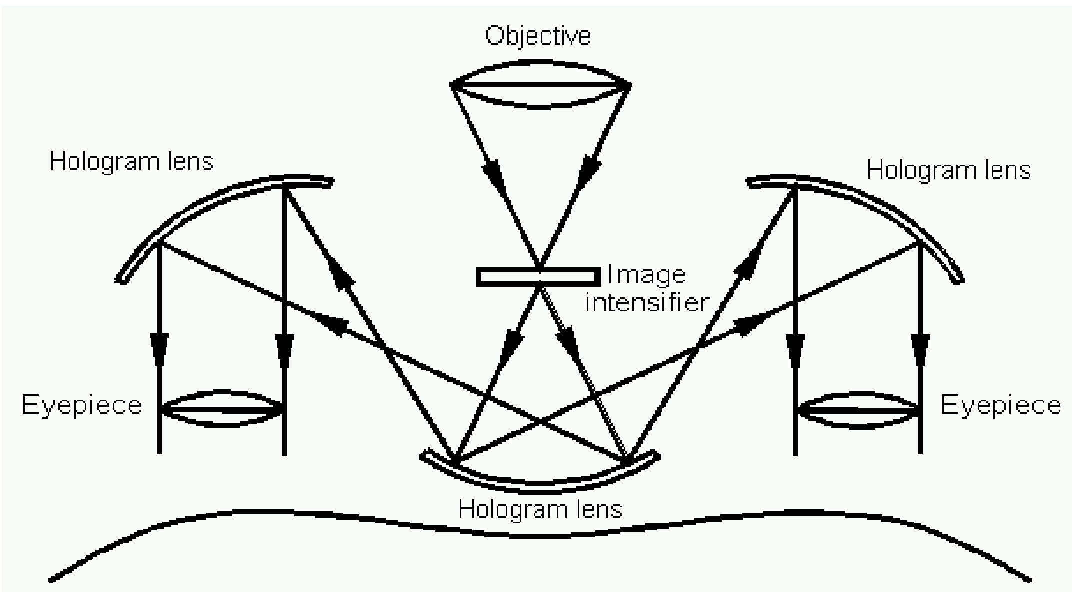


Fig. 2.1

• Many researchers believe that holographic televisions will become available within 10 years at a cost of approximately $5000. Holographic motion picture technology has been previously attempted and was successful in the 1970s. The future of holographic motion pictures may become a reality within the next few years.

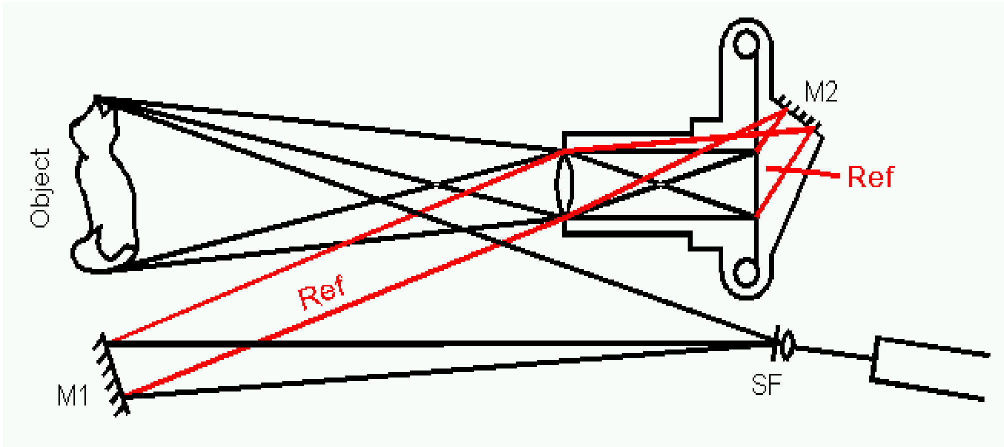


Fig. 2.1

- Holographic memory is a new optical storage method that can store 1 terabyte (= 1000 GB) of data in a crystal approximately the size of a sugar cube. In comparison, current methods of storage include CD's that hold 650 to 700 MB, DVD's that store 4.7 GB, and computer hard drives that hold up to 120 GB.

- Optical computers will be capable of delivering trillions of bits of information faster than the latest computers.

3.9 MEDICAL ENDOSCOPE - FIBER OPTIC: CONSTRUCTION AND WORKING

Optical fibers are very much useful in medical field. Using low quality, large diameter and short length silica fibers we can design a fiber optic endoscope or fibroscope.

MEDICAL ENDOSCOPE

Optical fibers are very much useful in medical field. Using low quality, large diameter and short length silica fibers we can design a fiber optic endoscope or fibroscope. A medical endoscope is a tubular optical instrument, used to inspect or view the internal parts of human body which are not visible to the naked eye. The photograph of the internal parts can also be taken using this endoscope.

Construction

Figure shows the structure of endoscope. It has two fibers viz., 1. Outer fiber(f0)
2. The inner fiber (fi).