References

1- **FUNDAMENTALS OF LIGHT SOURCES AND LASERS, Mark Csele,P247.**
2-Lasers: Fundamentals, Types, and Operations

- Gas lasers are widely available in almost all power (mw to MW)
- Wavelengths (UV-IR) can be operated in pulsed and continuous modes.
- Based on the nature of active media, there are three types of gas lasers atomic, ionic,andmolecular.
- Most of the gas lasers are pumped by electrical discharge.
- Electrons in the discharge tube are accelerated by electric field between the electrodes.
- These accelerated electrons collide with atoms, ions, or molecules in the active media and induce transition to higher energy levels to achieve the condition of population inversion and stimulated emission

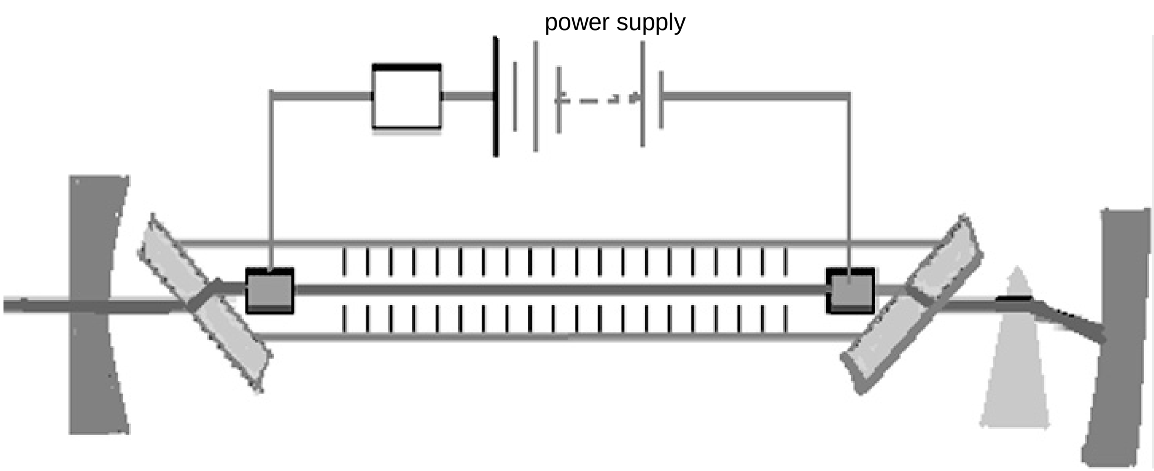


Figure 1: Construction of gas laser system (argon ion laser with prism-based wavelength tuning).

Gas lasers

I. Atomic Gas Laser; He: Ne Laser

The helium neon (HeNe) laser was the first continuous wave laser ever and is one of the most important laser sources in modern measurement technology. For laser operation, the actual laser active gain medium is neon whereas helium is added in order to support the excitation process (comparable to the function of helium in carbon dioxide lasers). A typical gas composition for HeNe lasers is 1 mbar of of neon.

The electrons generated in this way cause the excitation of helium atoms to different higher excited states, finally accumulating in the comparatively long-lasting metastable states 23S and 21S, as shown in figure 2.

These metastable states show energies quite similar to two selected states, 2s and 3s, of the neon atom, which can thus be easily excited via two-body collisions, resulting in a resonant energy transfer from excited helium to neon and a population inversion at the above-mentioned higher states of neon. Laser light is finally emitted during the de-excitation from higher s-states to lower p-states.

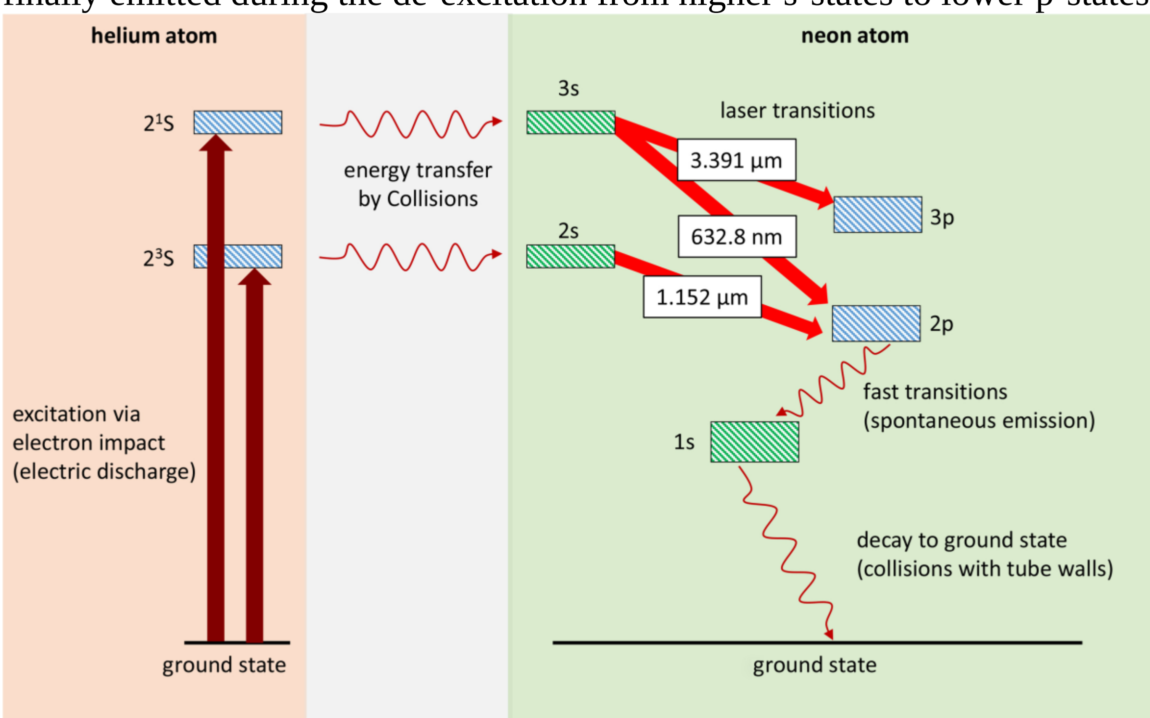


Figure 3: . Scheme of energy levels of helium and neon including the dominant transitions

Properties, parameters and characteristics

- Laser active gain medium: gaseous neon.
- Gas mixture (typical): He:Ne – 10:1.
- Emission wavelengths: 543.3 nm (green), 594.1 nm (yellow), 611.8 nm (orange), 632.8 nm (red), 1152.3 nm (infrared), 1523.1 nm (infrared), and 3391.3 nm (infrared).
- Efficiency factor: < 1%.
- Laser power: typically 1–5 mW, up to 100 mW possible.
- Beam guidance by fibres possible.

Application of low power lasers(below 10 mW)
-Laser as a telecom transmitter;
-Laser as a spectroscopic sensor;
-laser a medical diagnostic tool:
Applications in medicine

- Classical targeting or pilot laser.
- Light source for spectroscopy in diagnostic.
- Light source for therapeutic applications

-Laser as write-read tool;
-laser as bar code reader,etc.

Application of High power lasers(> 10 KW)
-laser as a industry tool;
-laser as a surgery instrument;
-laser as a weapon;
-laser as a free space transmitter,etc.

II. Ionized Gas Laser

The most common ionized gas lasers are from the **noble gases Argon (Ar^+)** and **Krypton (Kr^+)**.

Ion lasers

Krypton gas may be used in an ion laser as well with various wavelengths, covering the entire visible spectrum from violet to red.

Active medium: krypton-ion (Kr^+) laser.

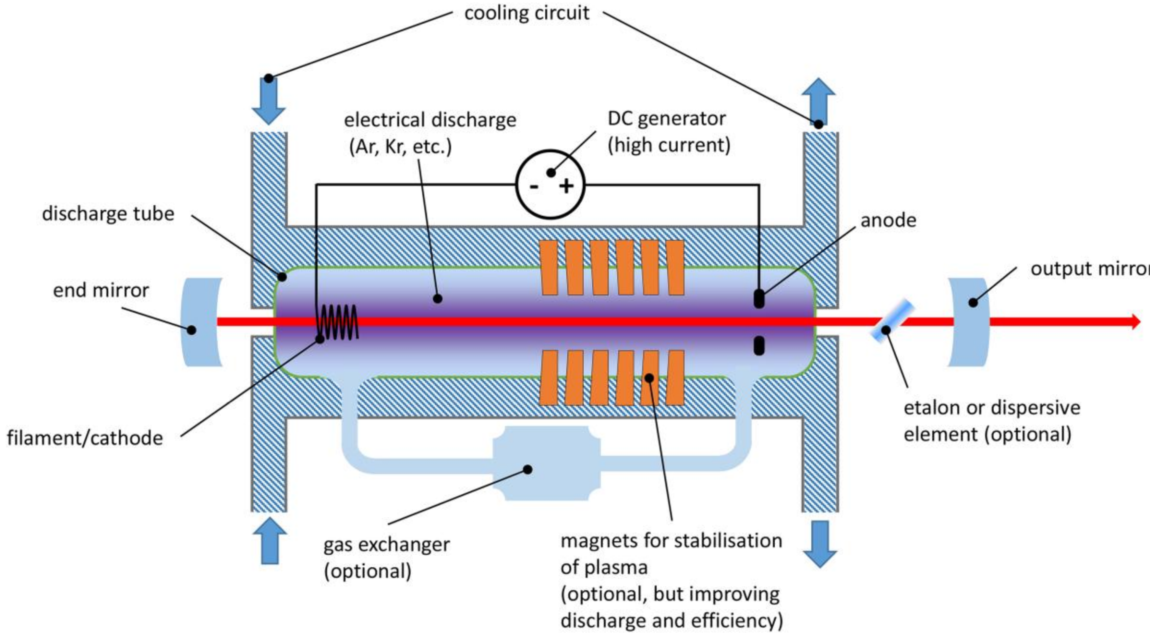


Figure (1): Basic setup of an ion laser.

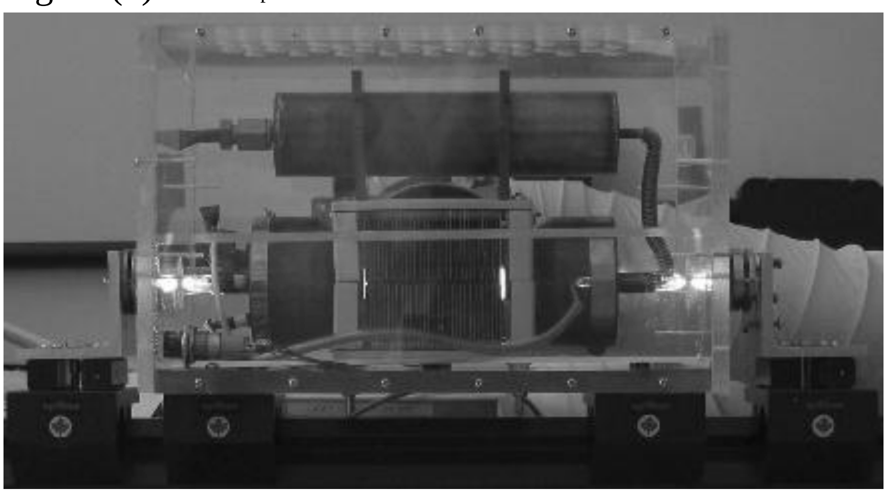
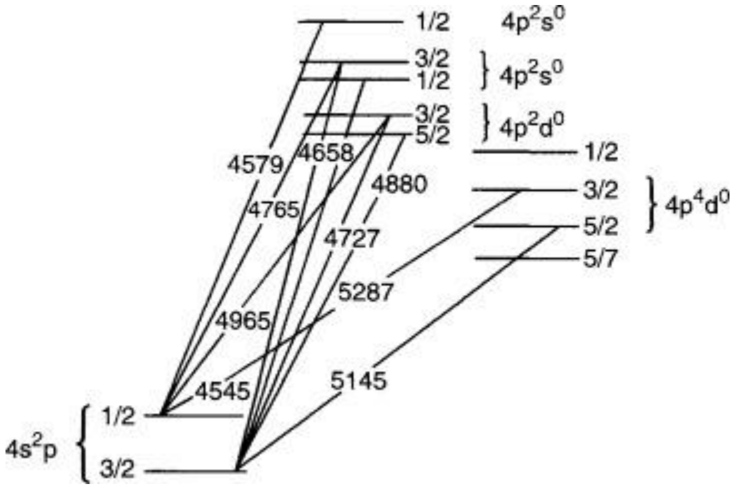


Figure :Small krypton-ion laser



Krypton-ion lasers are based on the same working principle as described above.
In this case, laser irradiation in a spectral range from 350 to 800 nm is generated.
The most intense laser lines are found at 530.9 nm and 568.2 nm, i.e. green laser light, and at 676.4 nm, which is red laser light.
Physically, krypton laser tubes are similar to argon tubes with the exception that krypton lasers require a large ballast volume. Krypton, however, is less efficient than argon, so output powers are lower than those for a comparable argon laser (the most powerful lines of the krypton laser are only one-fifth the power of the most powerful argon lines). The wider range of visible wavelengths available, however (including a powerful red line and a yellow line, both lacking in the argon laser spectrum), make this laser a popular choice for entertainment purposes.

Krypton lasers are generally not used in multiline mode but rather, with optics, to select the red (647.1 nm) line alone, both the red and yellow (568.2 nm) lines, or white-light mode, in which three or four lines are allowed to oscillate.

Properties, parameters and characteristics

• Laser active gain medium: ions of inert gases, e.g. argon or krypton.

• Emission wavelengths: 350–800 nm, depending on the inert gas used.
• Efficiency factor: < 1%.
• Pulsed or continuous wave (cw) operation possible.
• Typical pulse duration in pulsed operation: a number of picoseconds.
• Guidance by fibres possible.
• Water cooling necessary.
• Output power up to 30 W (argon-ion laser) and 10 W (krypton-ion laser),

Applications in medicine

• Treatment of vascular diseases.
• Removal of pigments.
• Laser-based diagnostics, e.g. multi fluorescence microscopy or flow cytometry.

Uses • Krypton: used as a better filler gas for high-quality light bulbs, also in halogen lamps • Xenon: gas-discharge lamps, are used as filler gases for lamps, sometimes as constituents of gas mixtures • High-purity gases are required for these applications.

2- Ion Laser: Argon Ion Laser

Physical Construction

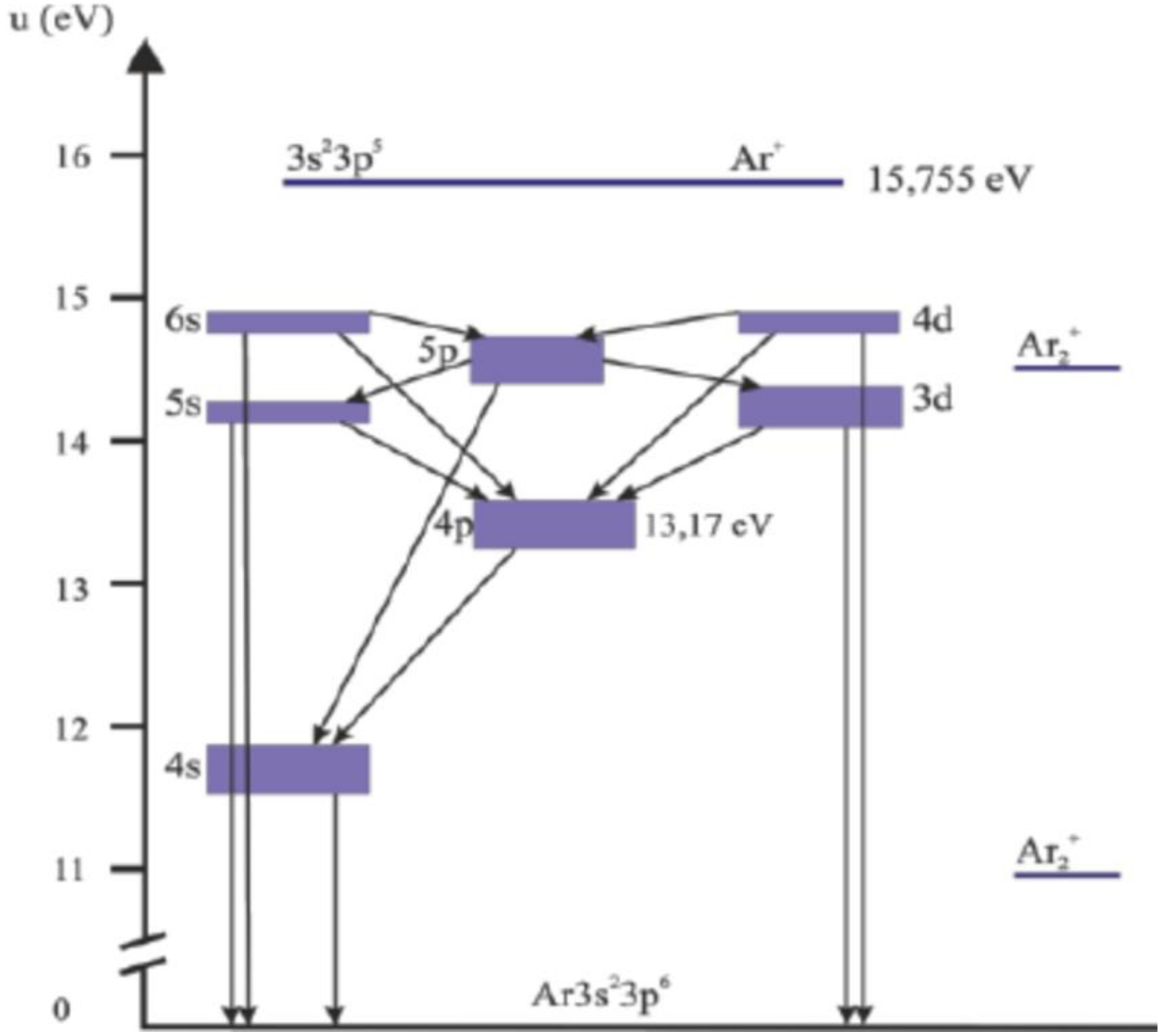
Argon ion laser is one of the widely used ion gas lasers, which typically generates several watts power of a green or blue output beam with high beam quality. The core component of an argon ion laser is an argon-filled tube made of ceramics, for example, beryllium oxide,
- electrical discharge between two hollow electrodes generates a plasma with a high density of argon (Ar^+) ions.

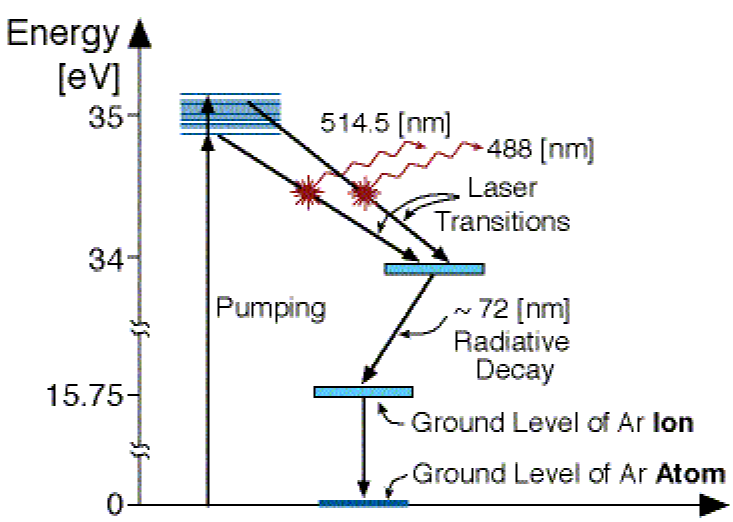
Argon ion laser contains a tube filled with Argon gas which transforms into **plasma** in an excited state.
(**Plasma** is a state of matter in which the electrons are separated from the atoms and molecules, which means that it contains free electrons and ions).

A typical device, containing a tube with a length of the order of 1 m, can generate 2.5–5W of output power of laser beam in the green spectral region at 514.5 nm, using several tens of kilowatts of electric power. The dissipated heat is removed with a chilled water flow around the tube. The laser can be switched to other wavelengths such as 457.9nm (blue), 488.0nm (blue–green), or 351nm (ultraviolet) by rotating the intracavity prism. The highest output power is achieved on the standard 514.5nm line.Without an intracavity prism, argon ion lasers have a tendency formultiline operation with simultaneous output at various wavelengths.

Working of Ar Ion Laser

The argon ion laser is a four level laser, which facilitates to achieve population inversion and low threshold for lasing. The neutral argon atoms filled between two hollow electrodes inside the plasma tube (Figure above) are pumped to the 4p energy level by two steps of collisions with electrons in the plasma. The first step ionizes atoms to make ions in the 3p ($E1$) state, and the second one excites these ions from the ground state $E1$ either directly to the 4p4 levels ($E3$) or to the 4p2 levels ($E4$), from which it cascades almost immediately to the 4p2 ($E3$). The 4p ions eventually decay to 4s levels ($E2$), either spontaneously or when stimulated to do so by a photon of appropriate energy. The wavelength of the photon depends on the
specific energy levels involved and lies in between 400 and 600 nm. The ion decays spontaneously from 4s to the ground state, emitting a deep ultraviolet photon of about 72 nm. There are many competing emission bands as shown in Figure 1


u (eV)
16
15
14
13
12
11
0
3s²3p⁵
Ar⁺
15,755 eV
6s
5p
4d
5s
3d
Ar₂⁺
4p
13,17 eV
4s
Ar₂⁺
Ar3s²3p⁶


Energy
[eV]
35
34
15.75
0
514.5 [nm]
488 [nm]
Laser
Transitions
Pumping
~ 72 [nm]
Radiative
Decay
Ground Level of Ar Ion
Ground Level of Ar Atom

The two main laser transitions are at visible wavelengths:

Blue 488 nm green 5145 nm

But the Argon ion laser emits also in the **UV spectrum**:

351.1 nm]

363.8 nm].

Application:

1- **Industrials: Argon** and helium are used in the welding, cutting, and spraying of metals; used in metallurgy as a protective gas. • Neon: high-voltage tubular lamps • Argon: mixture with nitrogen, used as filler gas for conventional light bulbs

2- **MEDICAL USES**

Liquid argon can be used to destroy cancer cells, while blue argon lasers are used to repair arteries, destroy tumors, and correct defects in the eye

3- Three-dimensional printing is a relatively new technology that's gaining in popularity.

Molecular Laser:

Unlike isolated atoms and ions in atomic and ionic lasers, molecules have wide energy bands instead of discrete energy levels.

Structure

They have electronic, vibrational and rotational energy levels. Each electronic energy level has a large number of vibrational levels assigned as *V*, and each vibrational level has a number of rotational levels assigned as *J*. Energy separation between electronic energy levels lies in the UV and visible spectral ranges, while those of vibrational–rotational (separations between two rotational levels of the same vibrational level or a rotational level of one vibrational level to a rotational level from other lower vibrational level) levels, in the NIR and far-IR regions. Therefore, most of the molecular lasers operate in the NIR or far-IR regions.

.1 **Carbon Dioxide (CO_2) Laser**

Carbon dioxide is the most efficient molecular gas laser material that exhibits for a high power and high efficiency gas laser at infrared wavelength.

<u>Construction</u>

The gas used for this special type of gas laser is a mixture of helium (82%), nitrogen (13.5%), and carbon dioxide (4.5%) which fills an arc discharge tube as shown in figure

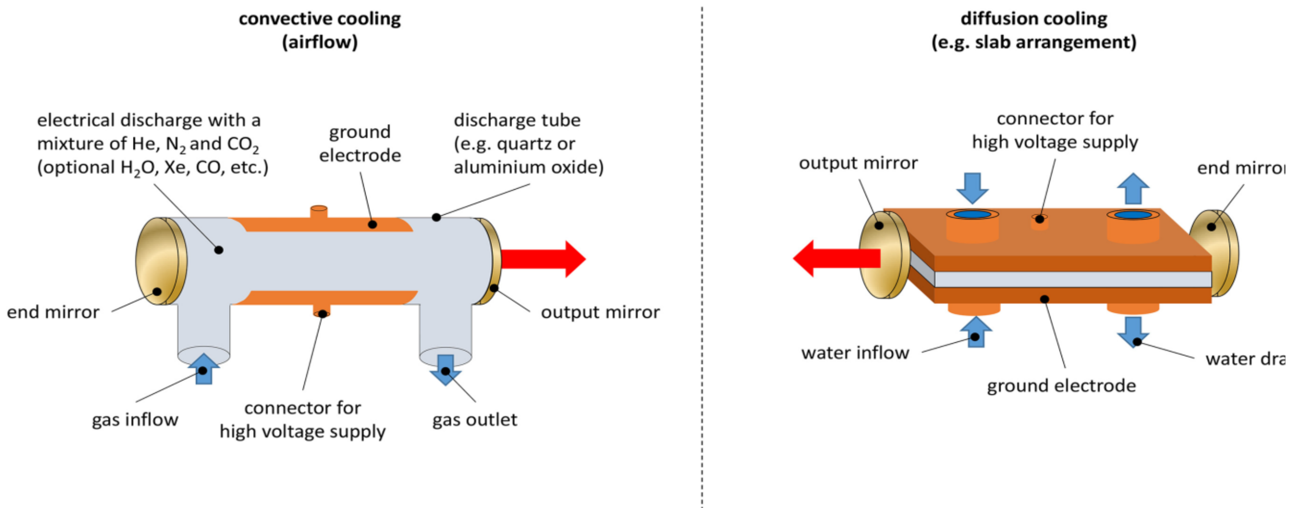
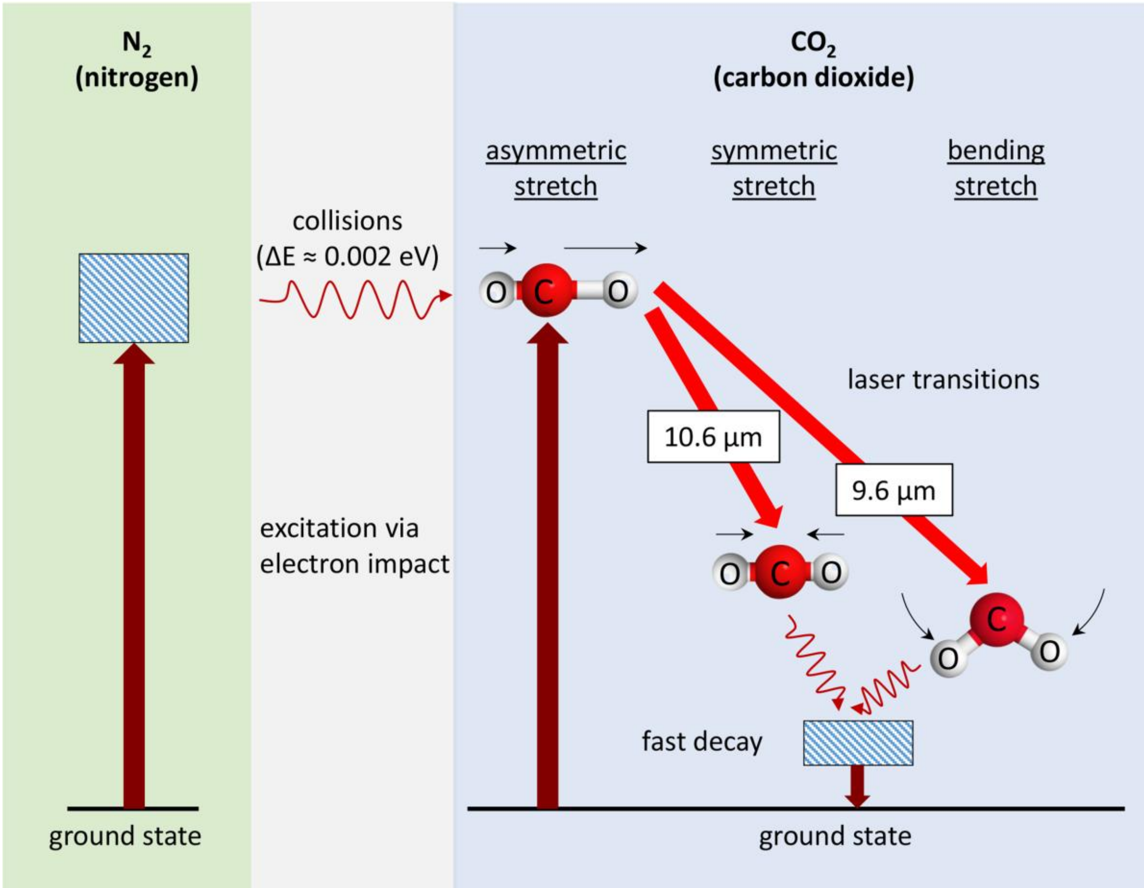


Figure 4. Basic setup of a CO_2 laser.

Properties, parameters and characteristics

- Laser active gain medium: gaseous carbon dioxide.
- Gas mixture (typical): CO_2:N_2:He – 1:1:8.
- Emission wavelengths: 10.6 µm and 9.6 µm.
- Efficiency factor: up to 30%.
- Pulsed or continuous wave (cw) operation possible.
- Simple and robust setup without any hazardous gases.
- Laser power: up to a number of megawatts in cw operation.
- Beam guidance by mirror systems.
- Penetration depth into tissue: some tens of microns (typically 10–30 µm).



Figure

Application

1- industrial applications including cutting, drilling, welding, and so on. It is widely used in the laser pyrolysis method of nanomaterials processing.
2- laser surgery
   For cutting materials such as cotton (used in making jeans), the CO_2 laser is ideal. It is also used in surgical applications since the wavelength is readily absorbed by flesh vaporizing it; the heat also serves to cauterize the cut, thus reducing bleeding.

. Very similar to the role of He in He–Ne laser, N2 is used as intermediately in CO2 lasers. The first, *V* = 1, vibrational level of N2) as compared to the difference between the energy levels of He and Ne (20 eV) in He–Ne laser; therefore comparatively larger number of electrons in the discharge tube of CO2 laser having energies higher than 0.3 eV are present. In addition to The quantum system of CO_2 laser uses a scheme similar to that of the HeNe laser, in which the pump level for this four-level system is in a separate species from the lasing atom

4.2.4 Excimer Laser

What Is Excimer Laser ➔ The term "excimer" stands for excited dimer. ➔ An excimer laser is an ultraviolet (UV) laser that uses a compound of noble gases andhalogen

The excimer laser is a special type of gas laser which exclusively emits laser irradiation in the ultraviolet wavelength range from 126 to 351 nm. Its laser active gain medium consists of so-called excited dimers, which is the origin of the abbreviation ‘excimer’.
It thus decomposes into a noble gas atom and a halogen atom within a number of picoseconds after the actual laser process. In order to initiate this process, the gas mixture is brought between two high-voltage electrodes, as shown in figure, and excited by an electric discharge.
This electric discharge can be classified into two stages: first, free electrons are generated between the electrodes by a primary discharge, allowing a homogenous ignition by the subsequent main discharge. As a result of this principle of excitation, excimer lasers can only be operated in the pulsed regime where the pulse duration typically amounts to ten to some hundreds of nanoseconds. Even though buffer gases, for example helium or neon, are further added to the actual laser active gas

Suitable dimers are noble gas dimers such as argon (Ar_2) or xenon (Xe_2) or noble gas halide bonds, e.g. argon fluoride (ArF) or xenon chloride (XeCl).

A typical potential curve of a noble gas halide bond in the ground state and the excited state is shown in figure

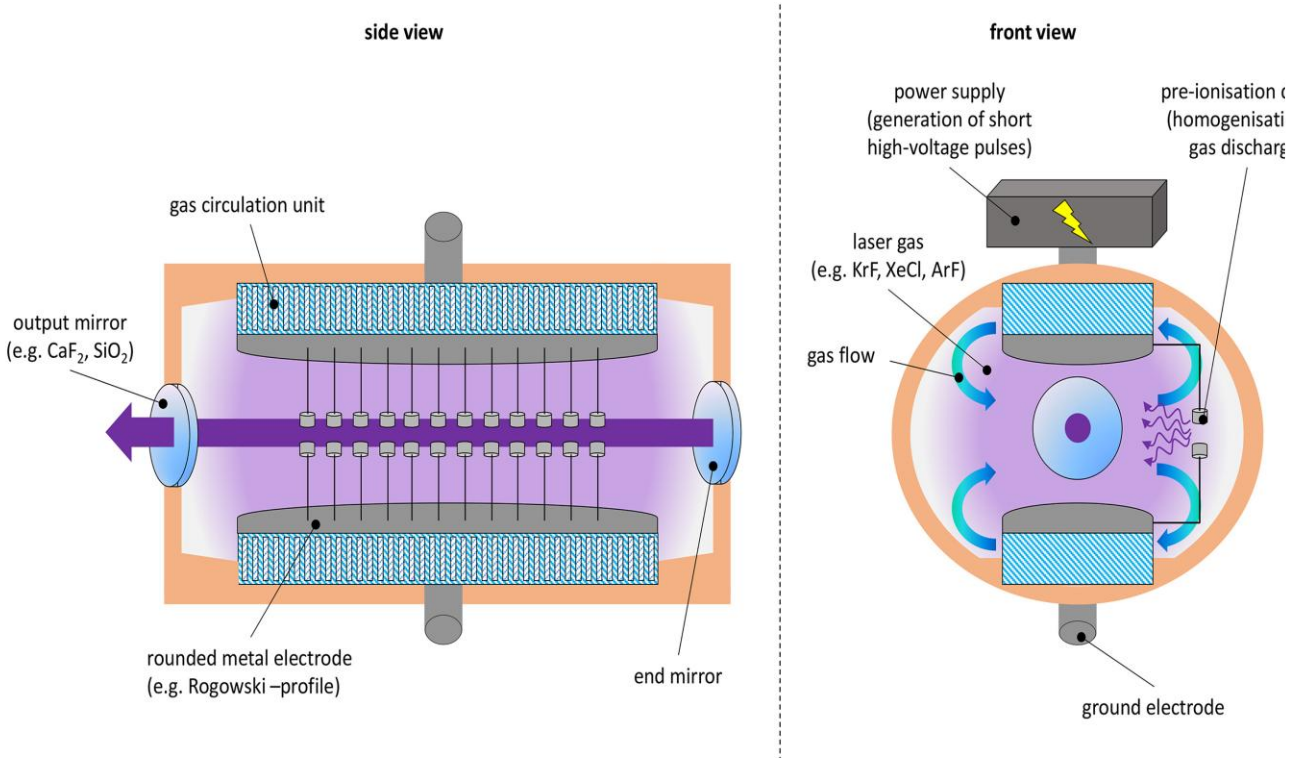


Figure 6. Basic setup of an excimer laser

Working and Construction

As discussed earlier all lasers consist of three components: a pump (energy source), a gain (or laser) medium, and an optical resonator. The pump provides energy which is amplified by the gain medium. This energy is eventually converted into light and is reflected through the optical resonator which then emits the final output beam.

2. Construction

Like most gas lasers, Excimer laser power is provided by an electrical current source. The laser medium is a tube filled with three different types of gases: ➔ A noble gas (argon, krypton, or xenon) ➔ A halogen gas (fluorine, chlorine, or bromine) ➔ A buffer gas (typically neon or helium) ➔ The image below lays out the basic parts of an excimer laser.

Working ➔ Excimer lasers rely on the interaction between the noble gas and the halogen gas to produce a high-powered beam. ➔ The current source pumps the gas medium using very short, high voltage pulses transmitted through metal electrodes; the pulse excites the gas atoms and causes them to fuse together into atomic pairs called dimers. (The term "excimer" stands for excited dimer.) ➔ For example, pumping an Argon Flouride (ArF) laser causes asymmetric molecules of ArF to form.

. Working ➔ Excimers only remain bound in an excited state, so that following the pulsed electrical discharge the atoms separate once again. ➔ While active, though, the excimers emit a burst of electromagnetic radiation before quickly dissociating into separate gases. ➔ This rapid dissociation prevents molecular reabsorption of the emitted radiation, making it possible to achieve high gain using a relatively small concentration of excimers. The radiation is then reflected by mirrors placed at both ends of the gas tube (representing the optical resonator) until the beam is emitted via the front mirror.

Properties, parameters and characteristics

- Laser active gain medium: excited dimers.
- Emission wavelengths: 126–351 nm.

as its gain medium ➔ Typical examples being ArF excimer lasers (wavelength of 193 nm), ➔ KrF excimer lasers (wavelength of 248 nm), ➔ XeCl excimer lasers (wavelength of 308 nm), ➔ and XeF excimer lasers (wavelength of 351 nm).

- Efficiency factor: 2–4%.

high efficiency for lasers in the ultraviolet range

- Laser power: typically 200 W.
- Exclusively pulsed operation possible.
- Water cooling required.
- Partially use of hazardous gases (e.g. fluorine, chlorine).

Laser Power average power of 50 W

❑ Safety is an important topic when discussing excimer lasers due to their high power ratings within the UV spectrum.

eye damage; excimer lasers, which are capable of power levels of several hundred watts, are easily capable of considerable damage to an operator's eyes or skin.

Applications in medicine in ophthalmology

1. . Laser Power and Safety have applied in a variety of fields such as industry and medicine (vision correction surgery such as LASIK.

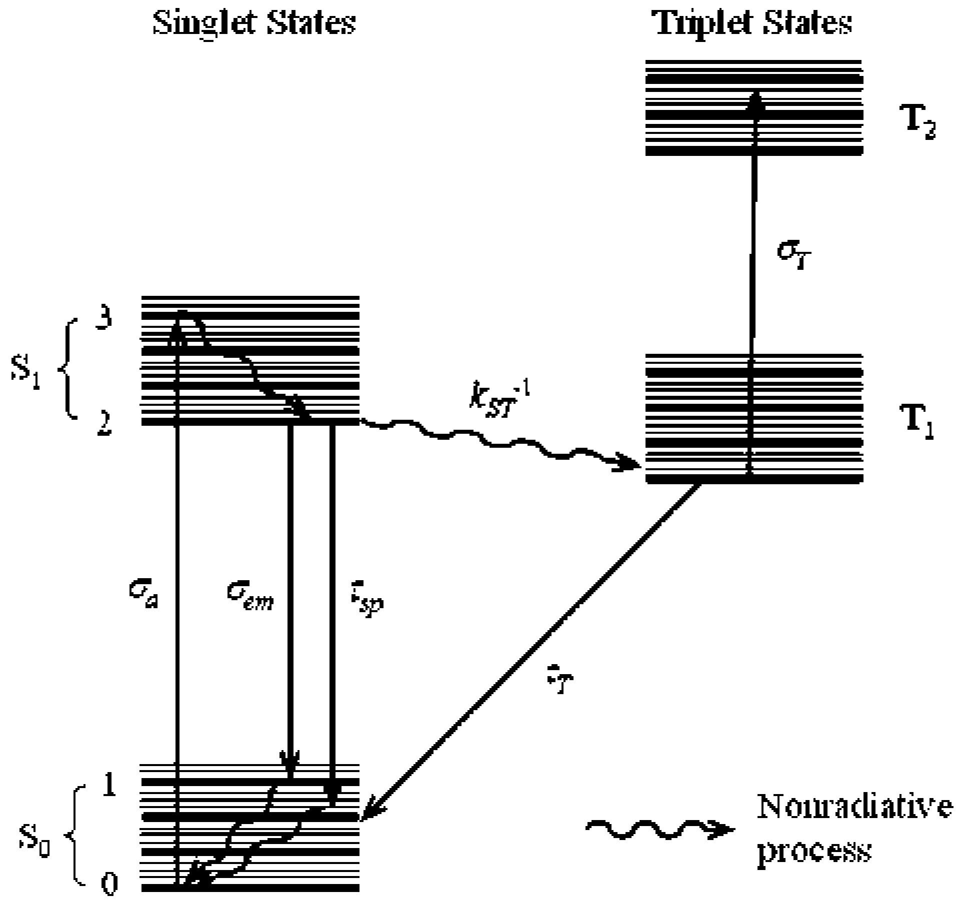
❑ The principal advantage of excimer lasers is that they are capable of producing a very small, precise spot at a very low (UV) wavelength.

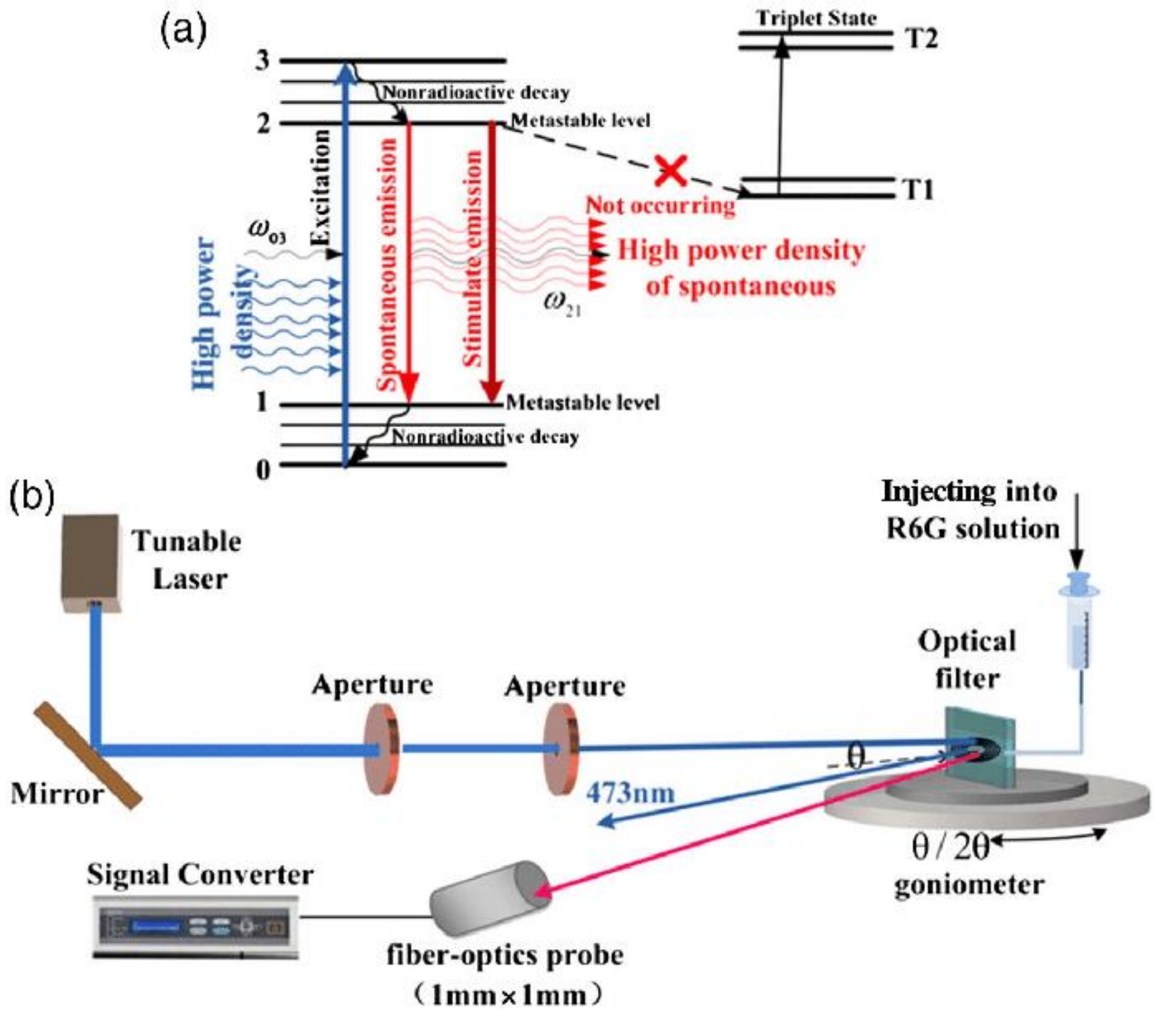
❑ Excimer lasers are excellent for removing excess material through laser ablation due to the fact that they are able to precisely destroy material with little to no thermal buildup. f" material during ablation.

❑ Photolithography, especially in semiconductor manufacturin

4.3 Dye lasers

Dye lasers could also be referred to as liquid lasers since the laser active medium is a radiant dye, dissolved in a carrier liquid. In contrast to most other laser sources, dye lasers can be tuned within a broad range of laser wavelengths. For a single dye, the range amounts to 50–100 nm and the availability of a number of different dyes, see figure 4, allows the generation of laser irradiation in the visible and near infrared wavelength range from 400 to 900 nm.


Singlet States
Triplet States
T2
σT
S1
3
2
kST-1
T1
σa
σem
τsp
τT
S0
1
0
Nonradiative process



The well-established and widely used dye Rhodamine 6G, for instance, emits laser light in the green and yellow wavelength range from 555 to 585 nm where the maximum is found at 566 nm. In a dye laser setup, shown in figure b, the particular dye is dissolved in a carrier liquid such as methanol and placed in a cuvette. In practice, the liquid is permanently circulated by a pump circuit and cooled in order to exchange and to regenerate the liquid volume which is subject to the pump energy which induces population inversion. Pumping is performed optically by flash lamps or laser irradiation from solid state pump lasers, usually Nd:YAG lasers. In the first case, the cuvette is placed within an elliptical or cylindrical mirror and the light emitted by the flash lamp is focussed into the liquid, resulting in the excitation to a higher laser level and the subsequent generation of laser irradiation.

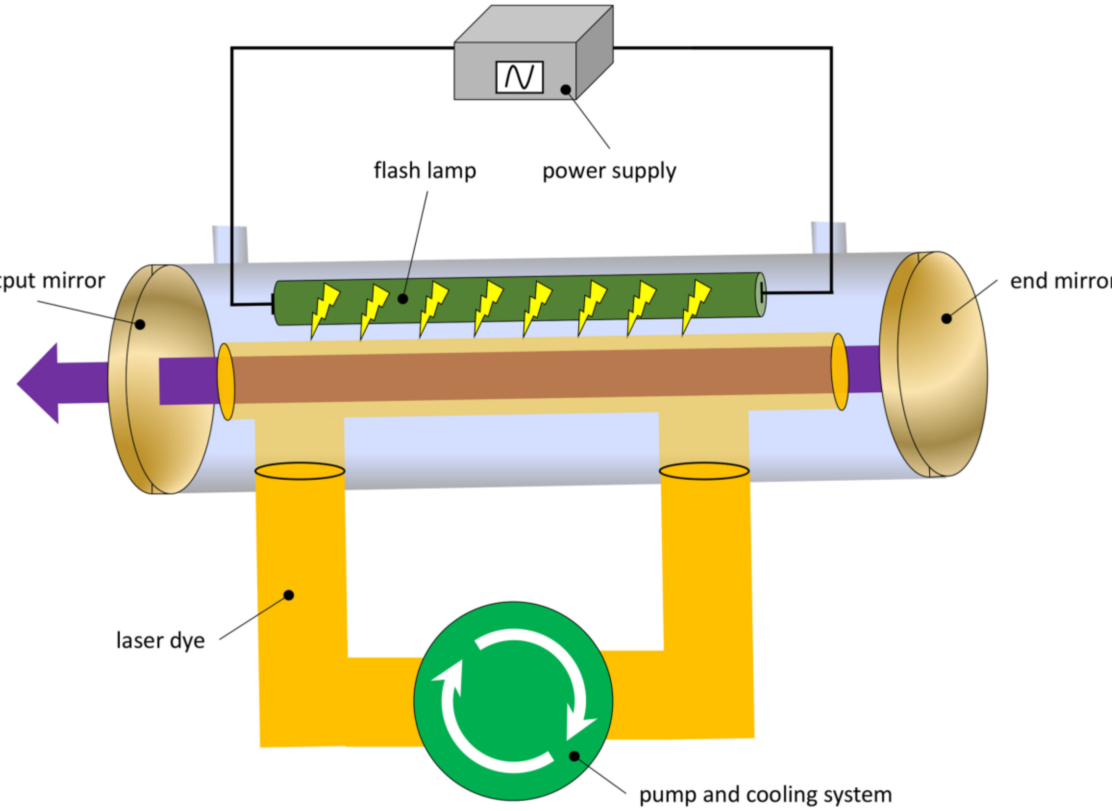


Figure 5. Setup of a flash lamp-pumped dye laser

Properties, parameters and characteristics

• Laser active gain medium: fluorescent, radiant dyes.
• Emission wavelengths: 400–900 nm.
• Spectral bandwidth of single dye: 50–100 nm.
• Efficiency factor: approximately 0.5%.
• Pulsed or continuous wave (cw) operation possible.

Advantages

 Low cost Tuning possible with multiple means

 No degradation of the optical properties of the organic dye.

 More robust (professional) and compact systems.

Disadvantages

 Limited lifetime.

 Limited output power

. Applications

 Dye lasers are used to spectroscopy, holography and in Medical applications. A recent application of dye laser was in isotope separation.

Applications in medicine

• Treatment of vascular malformation (dysplasia) in dermatology
• Light source for spectroscopy for the examination of tissue
• Light source for laser scanning microscopy (LSM) in diagnostic.

References

1- Lasers: Fundamentals, Types, and Operations

Subhash Chandra Singh, Haibo Zeng, Chunlei Guo, and Weiping Cai

2- **Fiber Lasers Continue to Gain Market Share in Material Processing Applications**
February 1, 2016

By **Bill Shiner**Vice President Industrial Laser

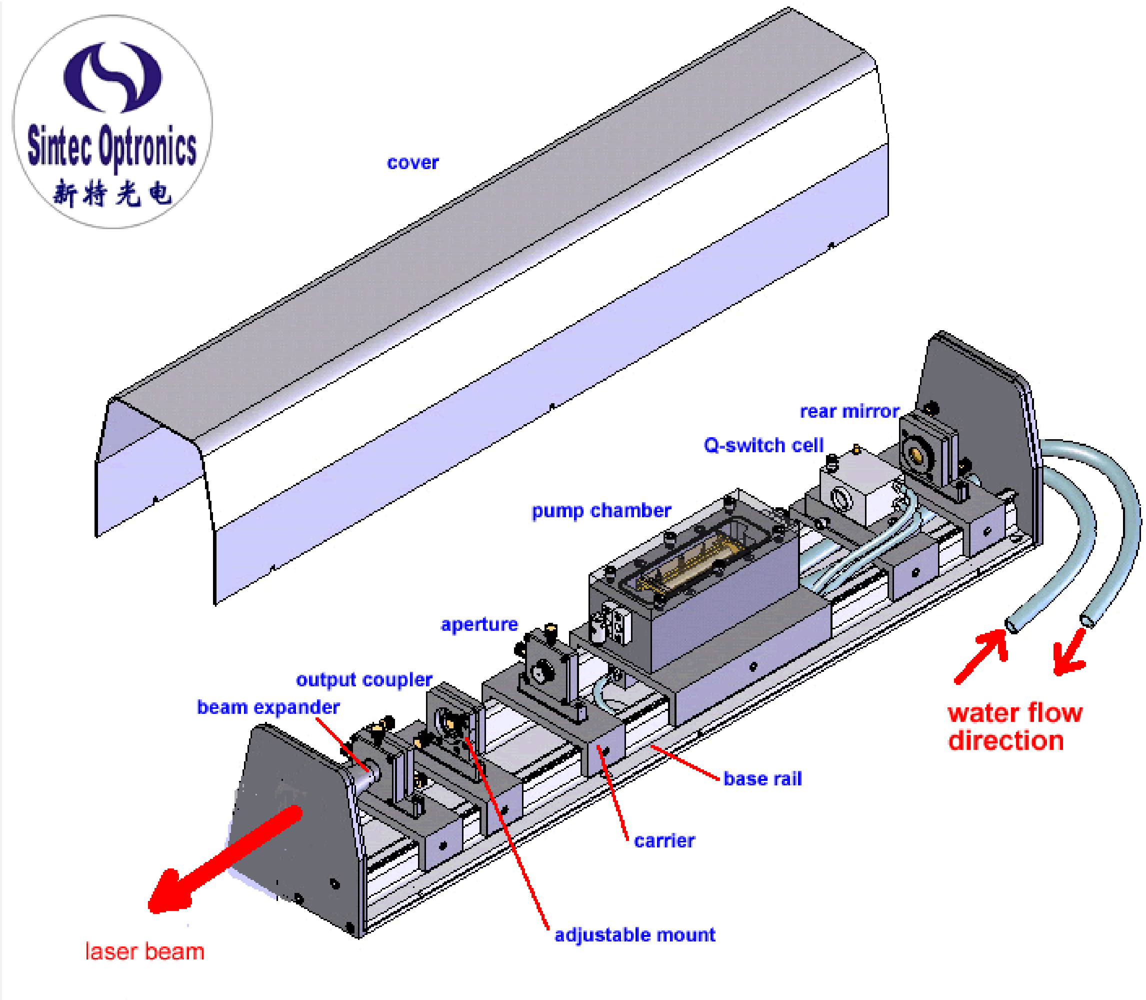
3- Zervas, Michalis N.; Codemard, Christophe A. (September 2014). "High Power Fiber Lasers: A Review". *IEEE Journal of Selected Topics in Quantum Electronics*. **20** (5): 219–241. Bibcode:2014IJSTQ..2020

Chapter Four: types of lasers (general Description and working)

4.1 solid state lasers:

Main components of solid state lasers

In spite of the difference in the sizes and types of laser devices, they consist of three common elements; they are Active medium, Energy sources & resonant cavity. Solid state lasers have active media obtained by embedding transition Metals (Ti^{+3}, Cr^{+3}, , Co^{+2}, Ni+2, Fe+2, etc.), rare earth ions (Ce^{+}3, Pr+^{3}, Nd^{+3}, Pm^{+3}, , Ho^{+3}, Er^{+3}, Yb^{+3}, etc.), and actinides only responsible for lasing actions, while physical properties such as thermal conductivity and thermal expansivity of the host material are important in determining the efficiency of the laser operation Arrangement of host atoms around the doped ion modifies its energy levels. Different lasing wavelength in the active media is obtained by doping of different host materials with same active ion.
$Y_3Al_5O_{12}$, $YAlO_3$, $Y_3Ga_5O_{12}$, $Y_3Fe_5O_{12}$, $YLiF_4$, Y_2SiO_5, $Y_3Sc_2Al_3O_{12}$, $Y_3Sc_2Ga_3O_{12}$,Ti:Al_2O_3, MgAl2O4 (spinel) etc…….
(Alexandrite), and so on, are some of the important hosts.



Main components of a laser

Transition metal and rare earth ions have partially filled and unfilled 3d and 4f subshells, respectively. For example, the electronic configurations of trivalent Cr and Nd ions are as follows:

Cr^{+3}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^3$

Nd^{+3}: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}\ 4s^2\ 4p^6\ 4d^{10}\ 4f^3\ 5s^2\ 5p^6$

4.1.1. Ruby laser

Ruby laser definition

A ruby laser is a solid-state laser that uses the synthetic ruby crystal as its laser medium. Ruby laser is the first successful laser developed by Maiman in 1960.

Ruby laser is one of the few solid-state lasers that produce visible light. It emits deep red light of wavelength 694.3 nm.

Since this laser type is a three-level system, more than 50% of ions have to be excited in order to obtain population inversion and laser operation, respectively

Construction and operation

Excitation is accomplished by flash lamps; ruby lasers are thus generally pulsed laser systems and modern ruby lasers can reach pulse energies up to 20 J.
The same as for alexandrite lasers, the actual laser active medium of ruby lasers is the chromium ion Cr3+ which replaces aluminium ions (Al3+) within the host crystal ruby where the concentration of chromium ions is 0.05 at%.
Optical pumping of this laser gain medium results in population inversion from the ground state 4A2 to the excited states 4F1 and 4F2, respectively, of the chromium ion.
As shown in figure 1, suitable pump wavelengths are 410 and 560 nm where ruby crystals feature high absorption.
After pumping a fast radiationless decay from the excited states 4F1 and 4F2 to the upper laser level E2, a metastable level occurs. Laser light is then emitted as a result of the de-excitation from this level to the ground state 4A2. Since the metastable level E2 consists of two neighbouring levels which slightly differ in terms of energy, the emitted laser light can principally feature two different wavelengths, either 694.3 nm or 692.7 nm. Usually, ruby lasers are operated at an emission wavelength of 694.3 nm. Due to such laser emission in the visible spectral range, guidance of ruby laser beams can be realised with classical refractive optical elements and fibres, but also mirror-based jointed arms are often used in clinical applications.

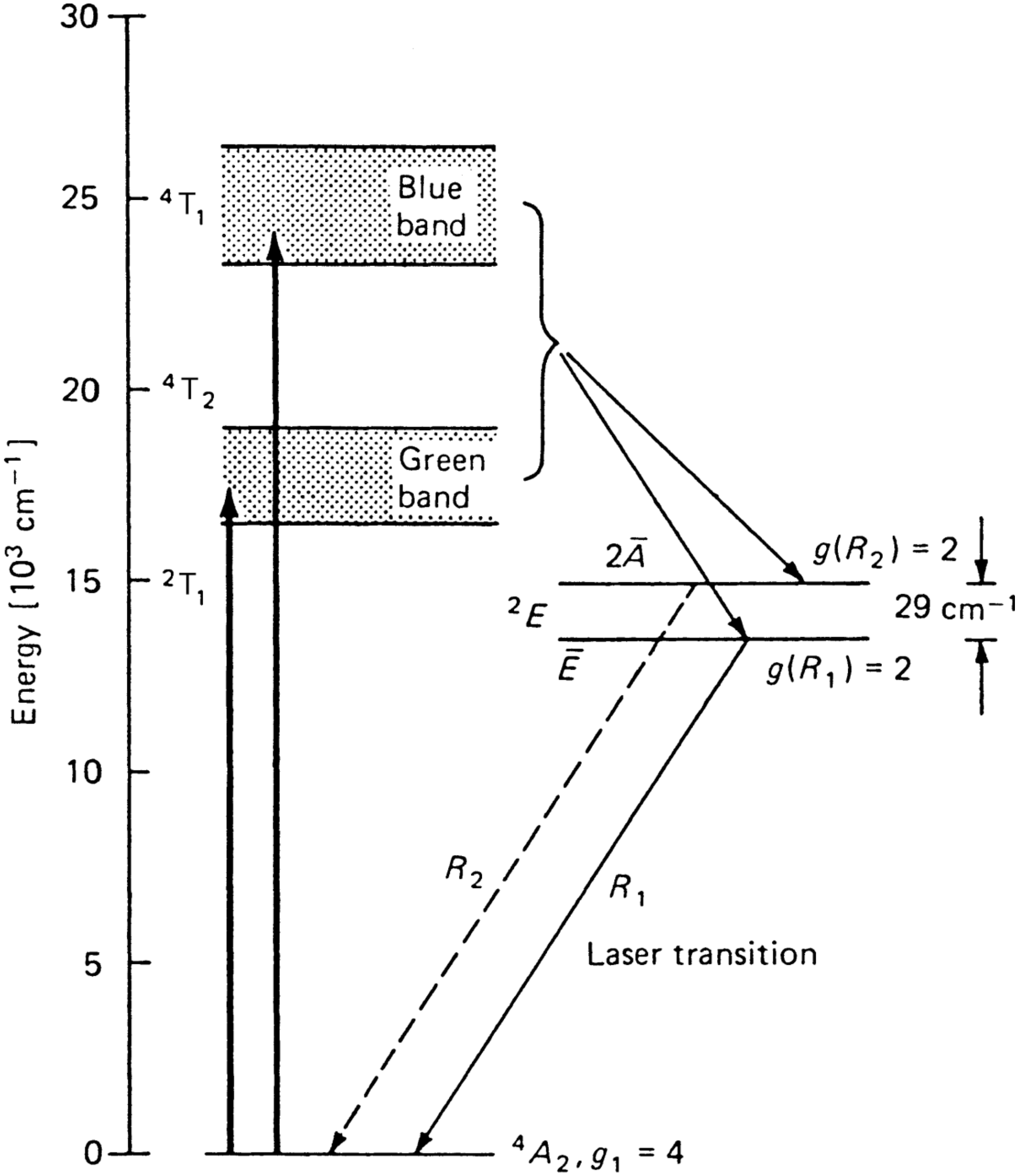


Figure (1) :Scheme of a ruby laser

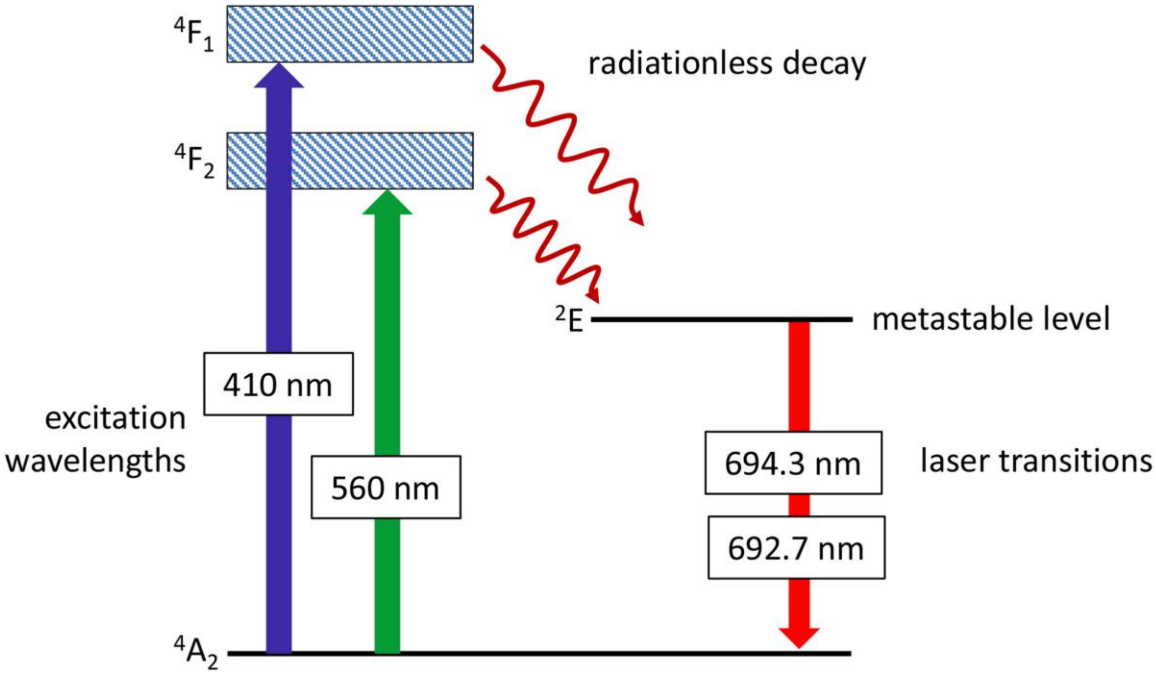


Figure (1) :Scheme of a ruby laser gain medium including the relevant transitions.

Properties, parameters and characteristics

• Laser active gain medium: ruby crystal, doped with the actual laser active chromium ion.

• Emission wavelength: 694.3 nm (typical) or 692.7 nm.

• Exclusively pulsed operation possible, The ruby laser is a pulsed laser of low repetition rate—the repetition rate being the number of pulses that are sent by a laser per 1 second.

• First operable laser source.

Applications:

1- **Applications** in holography and dermatology. The ruby laser is utilized in dermatology to remove tattoos and pigment defects of the skin.

Applications in medicine

• Dermatology (compare applications of alexandrite lasers listed).

• Removal of dark (e.g. black or blue) tattoos [

• Laser epilation .

- plasma diagnostics

The titanium sapphire laser

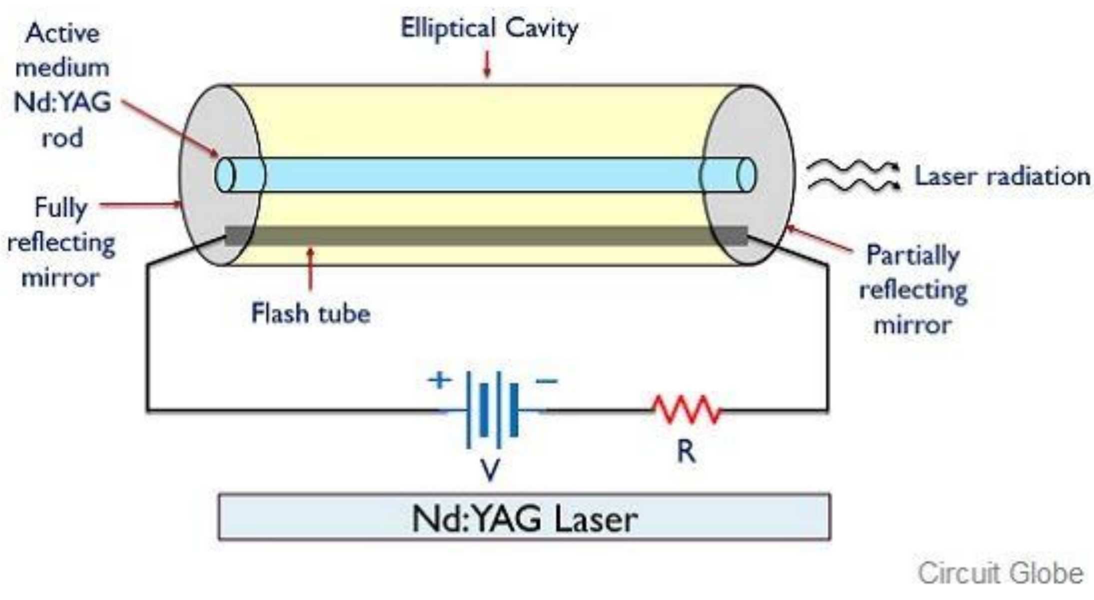
The laser active medium of titanium sapphire ($Ti^{3+}:Al_2O_3$, usually abbreviated Ti: sapphire or TiSa) lasers is the titanium ion Ti^{3+} which replaces aluminium ions (Al^{3+}) in the host crystal sapphire (Al_2O_3). This crystal can efficiently be pumped at any wavelength in the range from 400 to 600 nm

4.1.2. Nd: YAG –

The Nd : YAG laser is a solid-state laser whose active medium is a solid rod of the crystal yttrium aluminum garnet (YAG). The YAG, an artificial, diamond like structure, is not pure but includes impurity ions of the rare earth element neodymium (Nd). The emitted radiation is not in the red (like that of the ruby laser) but rather in the near infrared—1.06 μm. Lasers with power levels lower than 60 W can be operated without water cooling, using a single-phase 220-V (or 110-V) outlet.

Nd: YAG laser construction

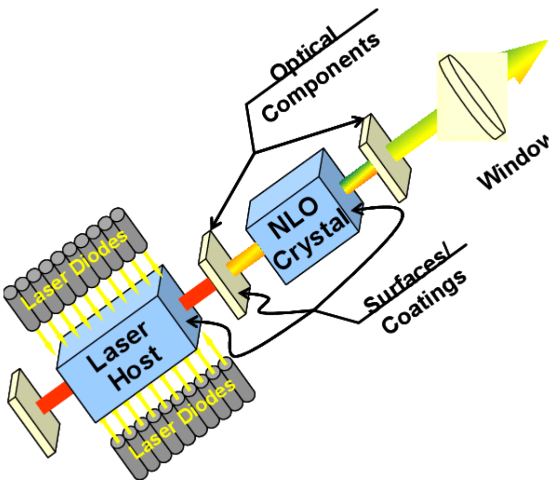
Nd:YAG laser consists of three important elements: an energy source, active medium, and optical resonator.



Nd:YAG Laser Construction and Operation or Working of define :Nd:YAG laser

The schematic diagram of Nd:YAG laser head as, consists of oscillator section, rear mirror, quarter-wave plate, Pockel cells, polarizer, pump
chambers, injection seeder, output coupler, D-Lok monitor, fold mirrors, amplifier section, harmonic generator (HG), temperature controller, dichroic mirrors, and

Beam Lock pointing sensor, The Nd:YAG may be used in the application of cavity ring-down spectroscopy, which is used to measure the concentration of some light-absorbing substance.



Here, the energy levels and the laser transition of Nd:YAG is shown where the Nd3+ ions are found in the ground state initially. As a consequence of absorption of incident pumping light provided by flash lamps or pumping laser diodes, these ions take an excited state in the excitation bands (2) and the upper metastable and longlasting laser level (3) is populated due to fast and radiationless transitions. Light emission at a wavelength of 1064 nm (i.e. near infrared light) then follows from the population inversion between the transition of the third and fourth level where some commercially available Nd:YAG lasers also generate radiation at a wavelength of 1320 nm (transition of level (3) to (4′)). Subsequent frequency conversion using nonlinear phenomena in suitable media such as potassium titanyl phosphate (KTiOPO4, usually abbreviated KTP) further allows the generation of shorter green laser light at a wavelength of 532 nm is generated by such a frequency conversion of the second harmonic, whereas the third and fourth harmonic feature a wavelength of 355 nm and 266 nm, respectively

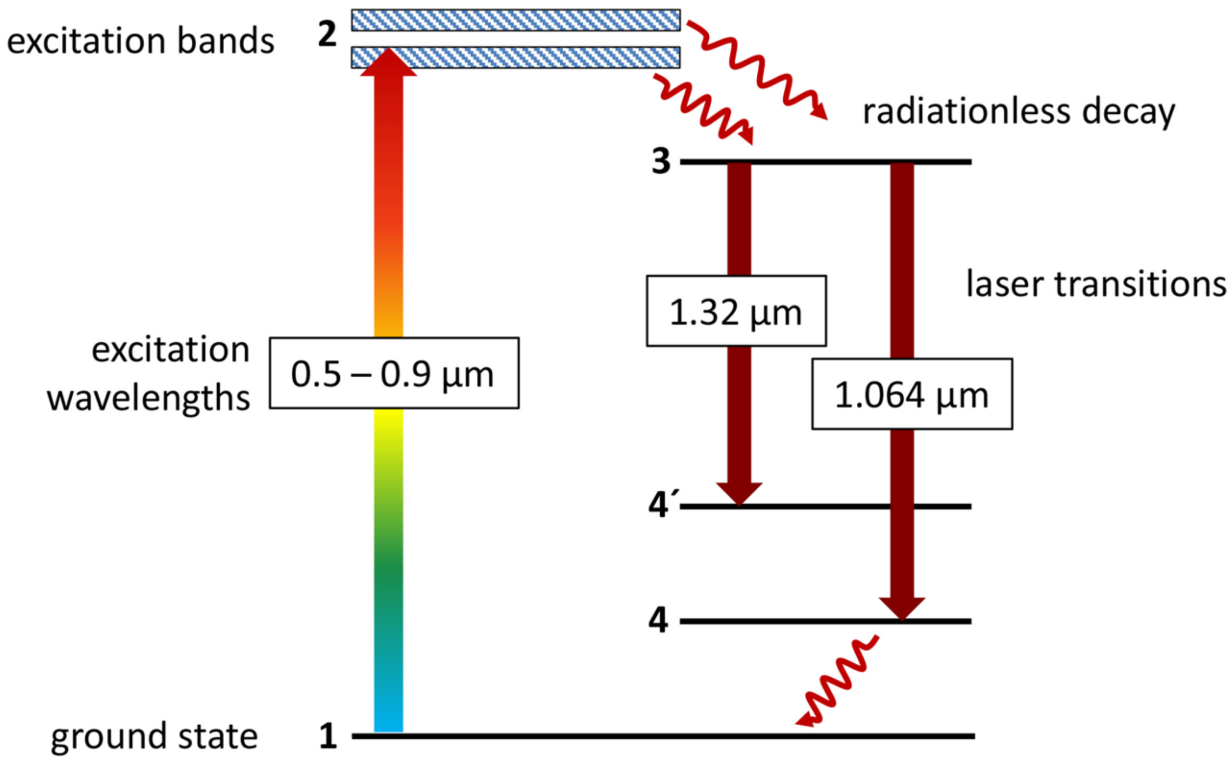
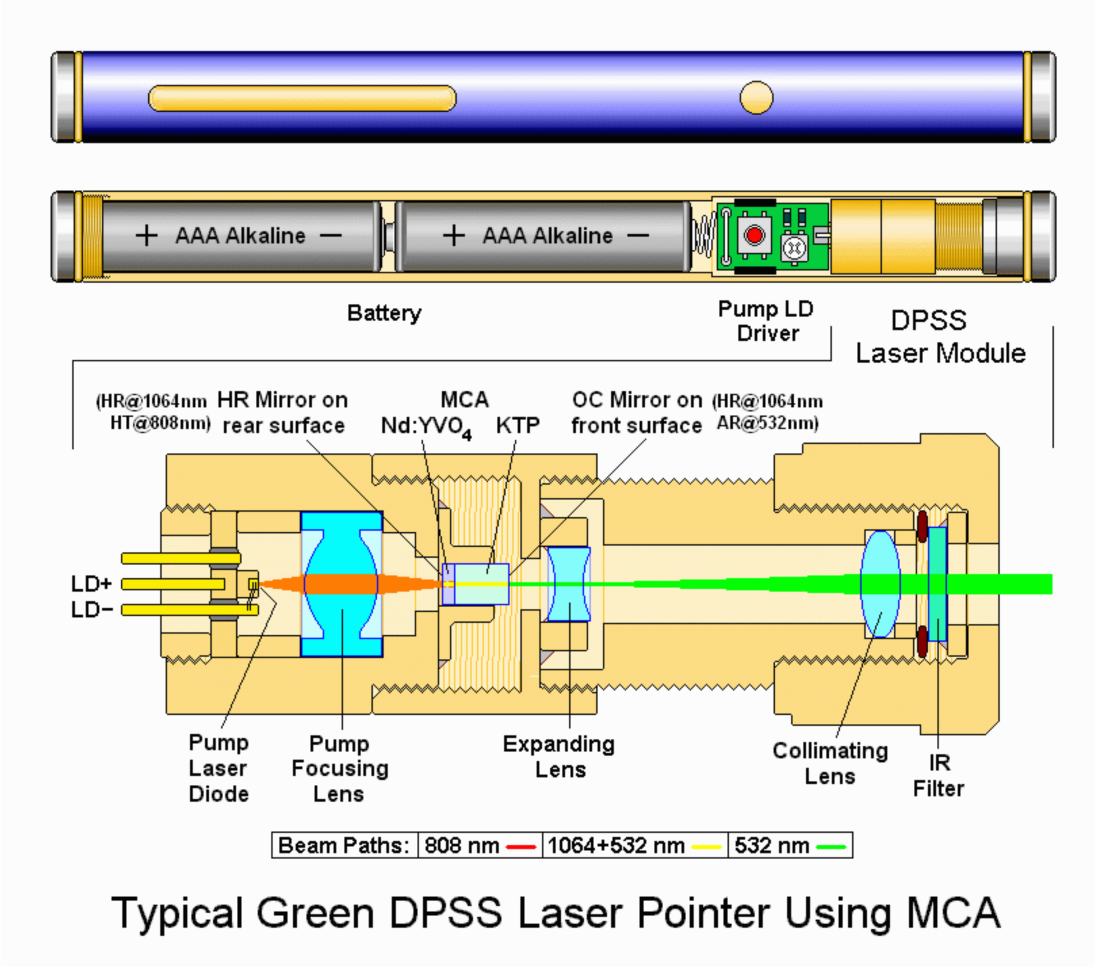


Figure 2. Energy levels and laser transition of the four-level laser gain medium Nd:YAG.

Pumping: In the past, flashtubes are mostly used as pump source because of its low cost. However, nowadays, laser diodes are preferred over flashtubes because of its high efficiency and low cost.

Pumping of the laser active transition is usually realised using inert gas (e.g. krypton or xenon) arc discharge flash lamps. Such lamps feature emission bands in the range of 500–900 nm which conform quite well to the pump levels. Here, the total efficiency amounts to approximately 2%. The use of laser diodes with an emission wavelength of 805–808 nm as pump source allows increasing the

Efficiency up to approximately 15% at an output power of 10–15 W



Properties, parameters and characteristics

- Laser active gain medium: YAG-crystal, doped with the actual laser active neodymium ion.
- Emission wavelength: 1064 nm.
- Efficiency factor: typically 1–2% for flash lamp-pumped systems and up to 15% for diode-pumped systems (at 10–15 W).
- Pulsed or continuous wave (cw) operation possible.
- Typical pulse duration: 5–20 ns.
- Guidance by fibres possible.
- Simple, compact and robust setup.
- Penetration depth into tissue: approximately 2–8 µm.

Applications:

the neodymium-doped yttrium aluminium garnet (Nd:YAG) laser is the most important and well-established solid state laser and is used in a number of different fields of application such as materials processing, metrology and laser medicine.

Applications of Nd:YAG laser

Military

Nd:YAG lasers are used in laser designators and laser rangefinders. A laser designator is a laser light source, which is used to target objects for attacking. A laser rangefinder is a rangefinder, which uses a laser light to determine the distance to an object.

Medicine

Nd: YAG lasers are used to correct posterior capsular opacification (a condition that may occur after a cataract surgery).

Nd:YAG lasers are used to remove skin cancers.

Manufacturing

Nd:YAG lasers are used for etching or marking a variety of plastics and metals.

Nd:YAG lasers are used for cutting and welding steel.

Applications in medicine

- Continuous wave (cw) laser for surgical applications such as cutting and drilling
- Continuous wave (cw) laser for laser-induced interstitial thermotherapy (LITT),
- Long-pulse laser for dermatological applications such as bleaching and dentine sealing
- Q-switched, pulsed laser for laser-induced shock-wave lithotripsy (LISL) or

- the removal of tattoos

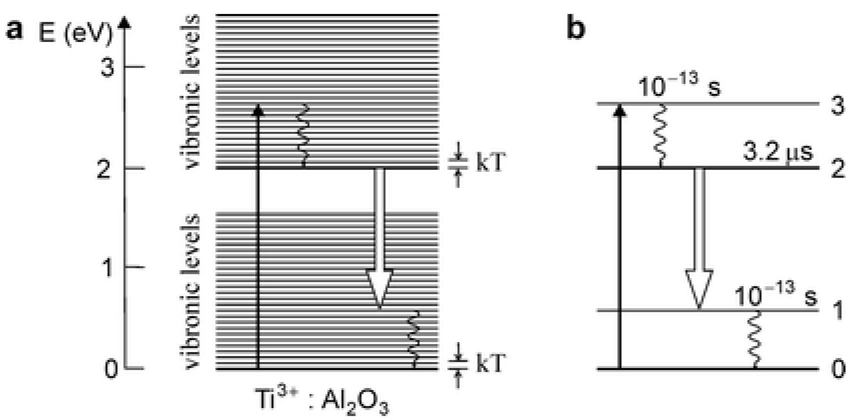
4. 1.3 Tunable solid state

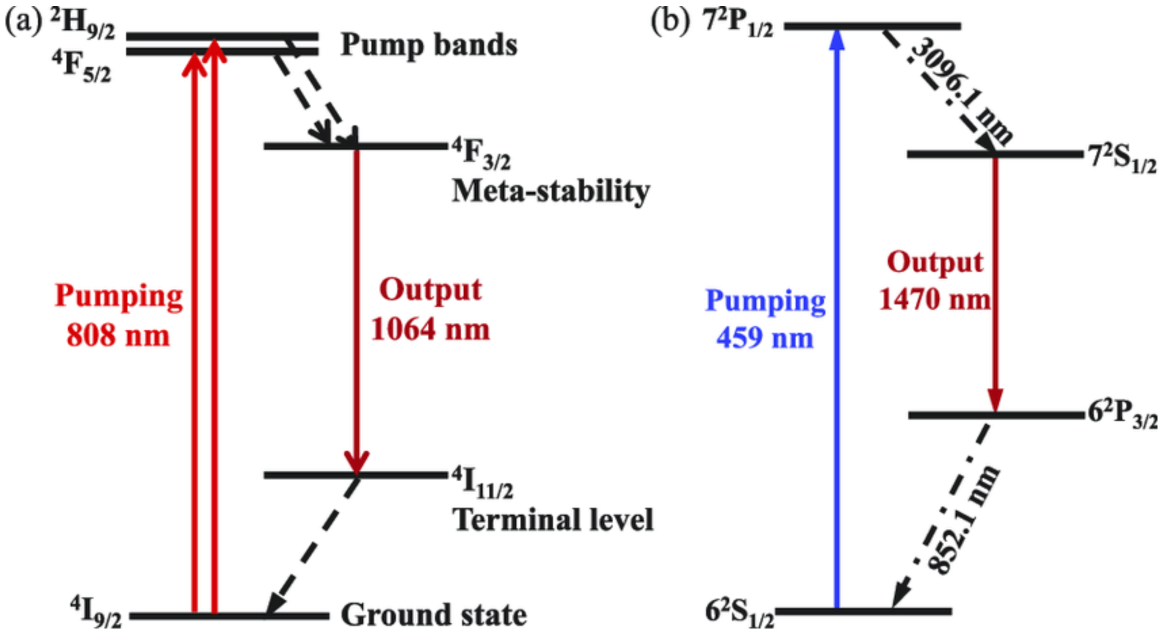
Tunable Lasers

In a typical laser, such as Nd:YAG, the laser transition occurs between discrete energy states which produces a narrow line width output beam. Tunability of the emission in solid-state lasers is achieved when the stimulated emission of photons is intimately coupled to the emission of vibrational quanta (phonons) in a crystal lattice.

4.1.4 Titanium –Sapphire laser

The laser active medium of titanium sapphire (Ti^{3+}:Al_2O_3) . lasers is the titanium ion Ti^{3+} which replaces aluminium ions (Al^{3+}) in the host crystal sapphire (Al_2O_3). This crystal can efficiently be pumped at any wavelength in the range from 400 to 600 nm where maximum absorption is found ally abbreviated





Tisapphire lasers are pumped by the second harmonic of pulsed Nd:YAG laser irradiation at 532 nm. Principally, titanium sapphire crystals exhibit a broad fluorescence band, such laser systems are thus tuneable and can provide laser irradiation in the wavelength range from 660 to 1160nm where the maximum intensity is found at approximately 800 nm. Another special feature of Ti:sapphire lasers is the possibility of the generation of ultra-short laser pulses with pulse durations in the range of some tens to hundreds .

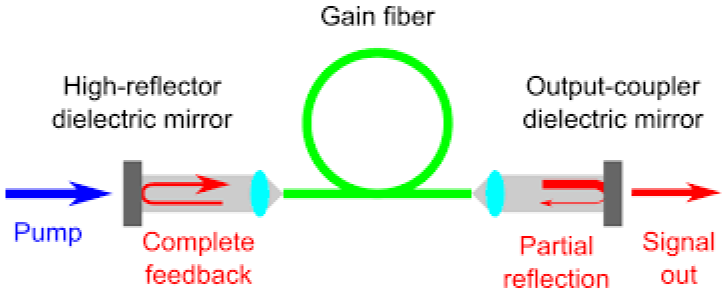
<u>Properties, parameters and characteristics</u>

• Laser active gain medium: sapphire crystal, doped with titanium.
• Emission wavelengths: 660–1160 nm, maximum intensity at approximately 800 nm.
• Pulsed or continuous wave (cw) operation possible.
• Very short laser pulse duration possible (down to approximately 4 fs).
• High laser power possible (up to 300 TW).

Applications in medicine

• Two-photon-excitation in microscopy for biophotonics
• Laser in ophthalmology

4.1.5 Fiber laser



A fiber laser is a laser in which the active gain medium is an optical fiber

doped with rare-earth elements such as thulium , neodymium, ytterbium, erbium, dysprosium, praseodymium and holmium

They are related to doped fiber amplifiers, which provide light amplification without lasing. Fiber nonlinearities, such as stimulated Raman scattering or four-wave mixing can also provide gain and thus serve as gain media for a fiber laser

Properties, parameters and characteristics

- fiber lasers over other types of lasers is that the laser light is both generated and delivered by an inherently flexible medium, which allows easier delivery to the focusing location and target.
- The fiber's waveguide properties reduce or eliminate thermal distortion of the optical path, typically producing a diffraction-limited, high-quality optical beam.
- high output power compared to other types of laser
- It can support kilowatt levels of continuous output power because of the fiber's high surface area to volume ratio, which allows efficient cooling. Fiber lasers are compact compared to solid-state or gas lasers of comparable power, because the fiber can be bent and coiled, except in the case of thicker rod-type designs, to save space.
- several kilometers long, and so can provide very high optical gain
- They have lower cost of ownership. Fiber lasers are reliable and exhibit high temperature and vibrational stability and extended lifetime
- **Applications:**

- . High peak power and nanosecond pulses improve marking and engraving.

- This can be important for laser cutting, welding, and folding of metals and polymers
- telecommunications, spectroscopy, medicine

4.1.6 Semiconductor lasers or Laser Diode

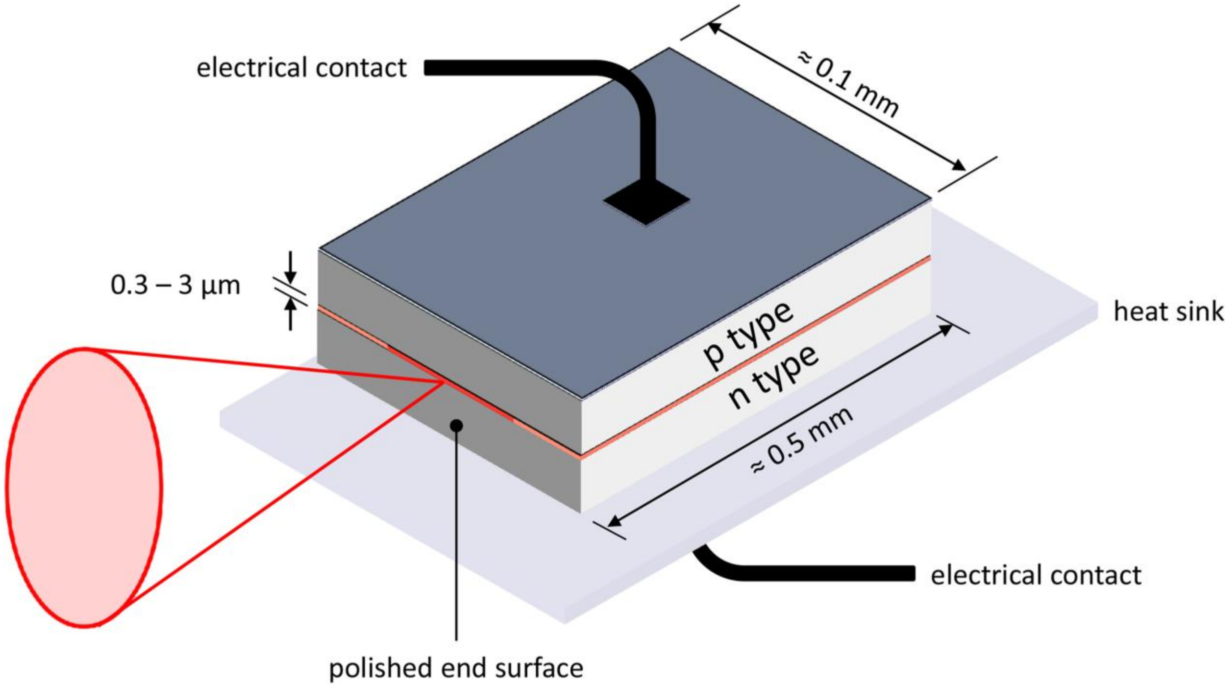
Definition: A semiconductor device that generates coherent light of high intensity is known as laser diode. **Semiconductor** lasers also known as *quantum well lasers*
.They are basically p-n junction diode, which produces light of certain wavelength by recombination of charge carrier when forward biased, very similar to the light-emitting diodes (LEDs). Different from LED, the PN junction of laser diode produces coherent radiation. Coherent radiation means the light waves generated by the device have the same frequency and phase.

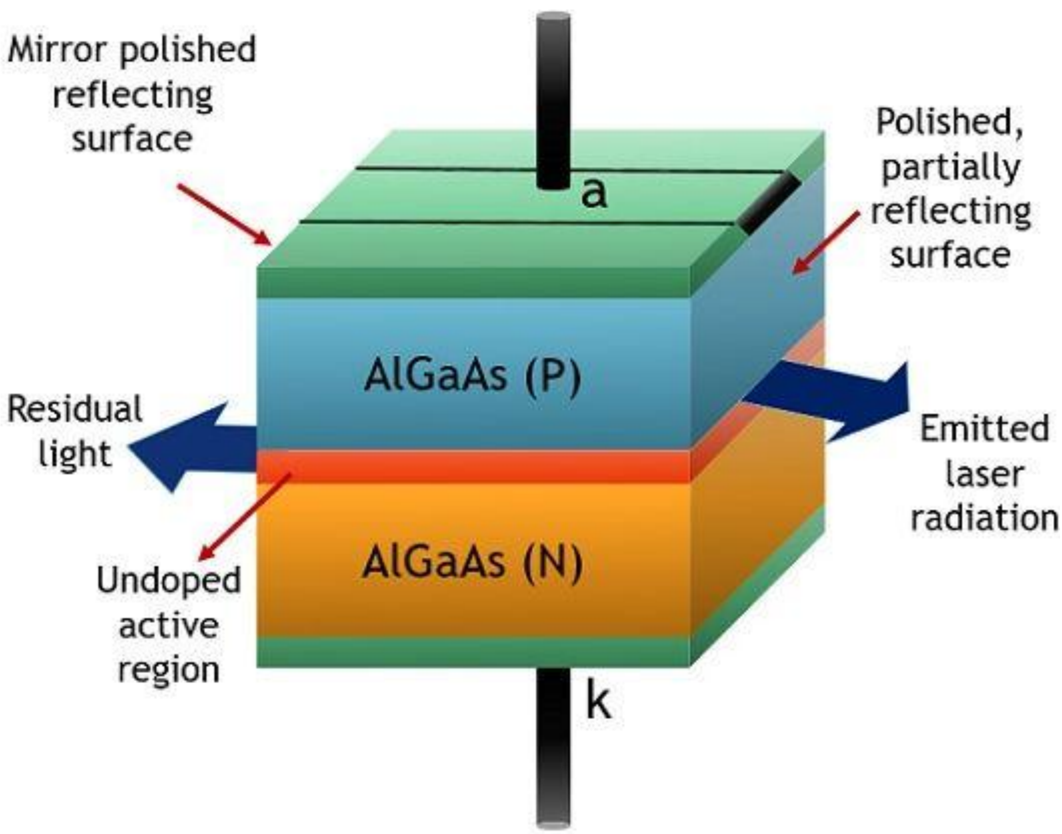
Construction of laser diode

The figure below shows the basic construction of a laser diode:

It is formed by doping aluminium or silicon to gallium arsenide material in order to generate n-type and p-type layer. Along with this, an additional active layer of undoped GaAs is placed between the two layers.

In laser diodes, polishing at the two ends of the junction is done in order to provide a mirror-like surface. Through reflection from this surface, more electron and hole pair gets produced. Resultantly that produces more radiation through the device.





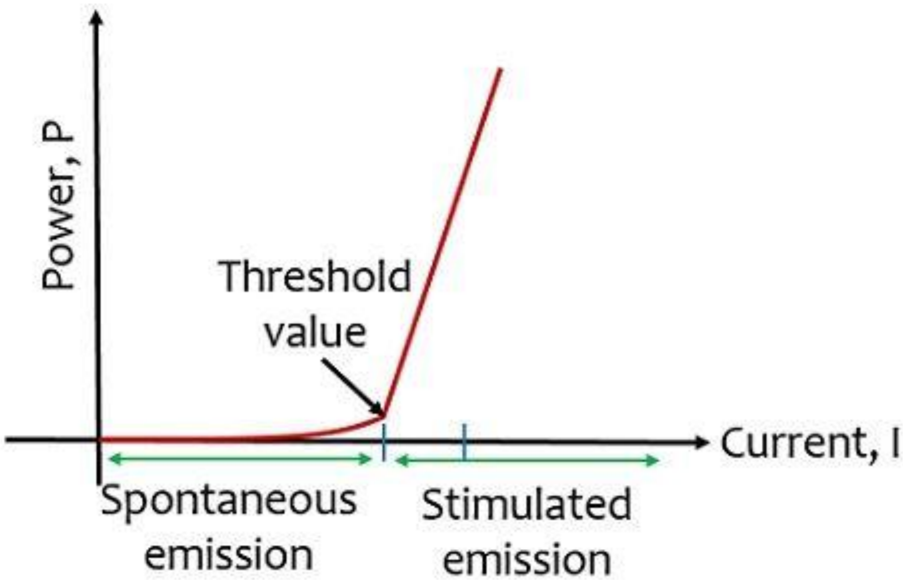
Constructional detail of laser diode

Working of laser diode

The working of a laser diode involves 3 processes: absorption, spontaneous emission and stimulated emission.

Characteristics of laser diode

The figure below shows the characteristic curve of a laser diode:



Characteristic curve of laser diode

Here, horizontal line denotes current and vertical line shows the optical power of light produced. It can be clearly seen from the figure that a gradual increase in power is noticed until a threshold point is reached.

After the threshold value, a rapid increase in power is noticed even for a small increase in the current. The power produced by the laser diode also depends on the temperature associated with the device.

Properties, parameters and characteristics

- Laser active gain medium: doped semiconductors.
- Emission wavelengths: typically 350 nm to 11 µm, but up to 50 µm possible.
- Extremely high duration of life (theoretically up to 100 years).
- smallest, cheapest, can be produced in mass, and are easily scalable

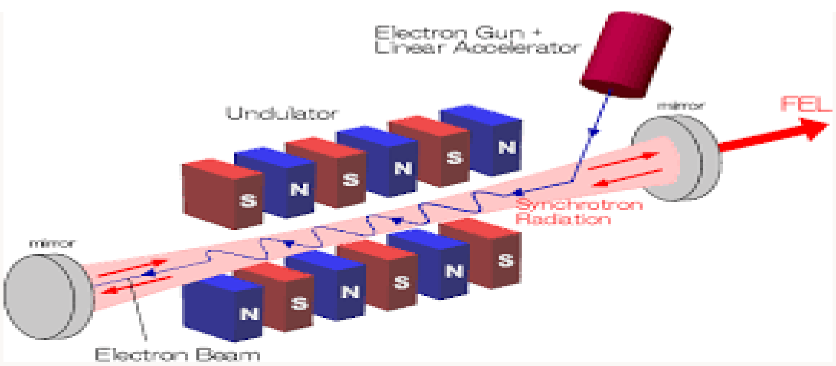
- The output power of a single laser diode is limited to approximately 10–40 W.

Application

- The combination of a number of such single diodes to diode laser stacks allows the realisation of diode laser systems with high output power of up to a number of kilowatts, which allows even industrial materials processing applications
- and especially in telecommunications and laser medicine

Applications in medicine
• Light source in diagnostics, e.g. for detection of blood flow velocity via laser Doppler velocimetry (LDV)
• Realisation of tissue reactions such as coagulation, cutting, vaporization
• Light source for photodynamic therapy (PDT)
• Targeting or pilot laser for medical equipment.

Free Electron Lasers (FEL)
In contrast to the other laser sources, free electron lasers (FELs) have an active medium that consists of a beam of free electrons, propagating at relativistic velocities in a spatially periodic magnet (undulator). Here, electrons experience the Lorentz force, execute transverse oscillations, and emit synchrotron radiation in the forward direction (Figure 7). We know that an accelerated charged particle



PRINCIPLES OF OPERATION

In an FEL a beam of relativistic electrons produced by an electron accelerator passes through a transverse, periodic magnetic field produced by a magnet called an undulator and exchanges energy with an electromagnetic radiation field. Efficient energy exchange requires that the electrons experience nearly resonant forces from the radiation and undulator fields. This resonance is achieved when the radiation wavelength λ, the electron-beam axial velocity $c\beta z$, and the undulator period λ_0 satisfy $\lambda \approx \lambda_0(\lambda - \beta_z)$, where c is the speed of light. The resonance relationship shows that the FEL can be continuously tuned by changing the electron-beam kinetic energy $(\gamma - 1)mc^2$, where $\gamma = (\lambda - \beta_\perp^2 - \beta_z^2)^{-½}$ is the relativistic Lorentz factor, m is the electron mass, and $c\beta_\perp$ is the transverse electron velocity. It also indicates that the FEL mechanism can be designed to operate over a large range of wavelengths, from centimeters to nanometers. The actual feasibility of operating in a given wavelength range depends on several factors, including the FEL gain and electron-beam quality

The length of the undulator is several meters inside the optical resonator mirrors, which are separated by about twice the undulator length, or about 10 meters

Summary

Resonant optical wavelength can be estimated using $\lambda=\lambda_0(1+K^2)/2\gamma^2$, where γ is the relativistic Lorentz factor and $E=\gamma mc^2$.The electron micro pulse length is σ_z and in most cases is close to the optical pulse length. However, the optical pulse can net up to five time longer than the electron micro pulse, dependent on the adjustment of mirror position

PROPERTIES (FEL)

These properties are summarized below.

1. *Tunability*. Because the FEL uses a single gain medium, the relativistic electron beam, and because the resonant condition can be easily tuned by changing either the electron beam energy or the magnetic field strength, FELs are broadly and easily tuned. A factor-of-10 tunable frequency range has already been demonstrated with the same accelerator and undulator.
2. *High peak power*. Because waste energy is carried away at nearly the speed of light and because the lasing medium cannot be damaged by high optical fields, FELs can produce very high peak powers. Gigawatt peak powers have been demonstrated.
3. *Flexible pulse structure.* Because the pulse structure of the radiation follows the pulse structure of the electron beam, the mature RF technology of linear

4. Picosecond pulses with sub-picosecond jitter can be produced, the interval between pulses can be varied, and there is the possibility of producing complicated pulse structures.

the possibility of producing complicated pulse structures.

4. *Good laser characteristics.* FELs easily achieve desirable properties associated with conventional lasers, such as a single transverse mode, high spatial and temporal coherence, and flexible polarization properties.

Broad wavelength coverage. Because the gain medium is transparent at all wavelengths, FELs in principle can produce radiation at any wavelength.

4. At present, the shortest wavelength that has been achieved in an FEL is 240 nm, and significant use of FELs for scientific research has been restricted to the infrared. There are proposals to build vacuum ultraviolet and x-ray FELs.

Size and cost.

Application

FELs have been used principally in central facilities, where their utilization in scientific research involves associated costs of maintaining and operating the facility in addition to the cost of the device itself

Compare between lasers solid, liquid and gas lasers