Biomedical Engineering Department
Third Stage, Second Semester
Medical Lasers in Engineering
Lecture 3
Types lasers and applications (1)

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Medical Applications of Lasers

1. Laser Surgery

- **CO_2 Lasers** – Used in ENT surgery, dermatology, gynecology, and general surgery.
- **Nd:YAG Lasers** – Penetrate deep into tissues, useful in **prostate surgery and endoscopic tumor removal**.
- Advantages of Laser Surgery:
  - o Minimally invasive
  - o Reduced bleeding
  - o Faster healing and recovery

2. Dermatology Applications

- **Hair Removal** – Lasers target melanin in hair follicles (Alexandrite, Diode, Nd:YAG lasers).
- **Tattoo Removal** – Q-switched lasers break down tattoo pigments.
- **Skin Resurfacing** – Fractional lasers reduce scars and wrinkles.

3. Ophthalmology Applications

- **Photocoagulation** – Seals leaking blood vessels in diabetic retinopathy.
- **LASIK & PRK** – Excimer lasers reshape the cornea to correct vision.
- **Femtosecond Lasers** – Used in **cataract surgery** for precision incisions.

4. Oncology (Cancer Treatment)

- **Photodynamic Therapy (PDT)** – Uses laser-activated drugs to destroy cancer cells.
- **Tumor Ablation** – High-power lasers eliminate cancerous tissue.

5. Laser-Based Diagnostics

- **Optical Coherence Tomography (OCT)** – High-resolution imaging for the retina and blood vessels.
- **Laser Doppler Imaging** – Measures blood flow in tissues.
- **Raman Spectroscopy** – Detects early cancer by analyzing molecular changes in tissues.
- **AI-Driven Laser Applications** – Artificial intelligence enhances robotic surgery and precision treatments.
- **Nanoparticle-Assisted Laser Therapy** – Nanoparticles improve targeting of cancer cells.
- **Laser-Based Regenerative Medicine** – Potential applications in tissue engineering.

Types of Lasers

Lasers are usually classified in terms of their active (lasing) medium. Major types are:

1.Gas laser

Most elements can be made to lase when they are in the gas state. Also, many molecules (composed of a few atoms each) have been demonstrated to lase. A gas laser is a laser in which an electric current is discharged through a gas to produce coherent light. The gas laser was the first continuous laser and the first laser to operate on the principle of converting electrical energy to a laser light output. The first invented gas laser was Helium–neon laser (He-Ne) in 1960. It produced a coherent light beam in the infrared region of the spectrum at 1.15 µm one year after the first laser (Ruby) was demonstrated. In a gas laser, the laser active medium is a gas at a low pressure (A few milli torr).

The main reasons for using low pressure are:

- To enable an electric discharge in a long path, while the electrodes are at both ends of a long tube.
- To obtain narrow spectral width not expanded by collisions between atoms.

Excitation of a gas laser

Two main excitation techniques are used for gas lasers:

- Electrical Discharge.
- Optical Pumping.

Excitation of Gas Laser by Electrical Discharge

Applying high voltage to electrodes at both sides of the tube containing the gas causes electrical breakdown through the gas. Electrons are ejected from the cathode, accelerated toward the anode, and collide with the gas molecules along the way. During the collision, the mechanical kinetic energy of the electrons is transferred to the gas molecules and excites them.

Gas lasers are usually excited by an electric discharge. Also, a gas laser can be excited by an optical source with very narrow bandwidth (laser), which fits the narrow absorption spectral lines of the gas. This method is used for pumping Far Infra-Red (FIR) gas lasers by a CO_2 laser.

Groups of Gas Lasers

Gas lasers are divided into three groups:

1. Atoms: The laser active medium is composed of neutral gas atoms such as Helium-Neon and Copper Vapor.

2. Ions: The laser active medium is composed of ionized gas such as Argon ion gas or Helium-Cadmium gas.

3. Molecules: The laser active medium is composed of gas molecules, like

Carbon Dioxide (CO_2), Nitrogen (N_2), Excimer laser, Chemical lasers (HF), Far Infra-Red (FIR) laser.

Gas laser Characteristics:

- The active gas is used with other gases in a mixture.
- The extra gas(es) help increase the excitation efficiency.
- Maximum gain is achieved when the tube diameter is very small.

Gas lasers usually operate in the continuous mode

1. 1. Helium-Neon (He-Ne) Laser

A helium–neon laser or He-Ne laser, is a type of gas laser whose gain medium Consists of a mixture of helium and neon (5:1) inside of a small-bore capillary tube, usually excited by a DC electrical discharge. The best-known and most widely used He-Ne laser operates at a wavelength of 632.8nm, in the red part of the visible spectrum.

- The active medium is a noble gas Neon (Ne).
- Is a 4-level laser.
- Two meta-stable energy levels act as upper laser levels.
- Have two lower laser levels, so quite a few wavelengths can come out of the Transitions between these levels.

The important wavelengths are:

λ_1=632.8nm, λ_2=1152nm, λ_3=3391.3nm

Construction and operation

Fig.1, shows the structure of a typical mass-produced helium–neon laser. The discharge passing between electrodes at opposite ends of the tube is concentrated in a narrow bore, one to a few milli meters in diameter. This raises laser excitation efficiency and helps maintain good beam quality. The bulk of the tube volume is a gas reservoir containing extra helium and neon. Gas pressure within the tube is typically a few tenths of a percent of atmospheric pressure.

Mirrors are bonded directly to mass-produced helium–neon tubes by a high-temperature process that produces what is called a "hard seal, "which slows the helium leakage that otherwise might limit laser life time. The mirrors must have low loss because of the lasers low gain. The rear cavity mirror is totally reflective. The output mirror transmits only a few percent to f the intra cavity power to produce the laser beam. One or both mirrors have concave curvature to focus the beam within the laser cavity, which is important for good beam quality. The output power of helium -neon lasers depend on tube length, gas pressure, and diameter of the discharge bore.

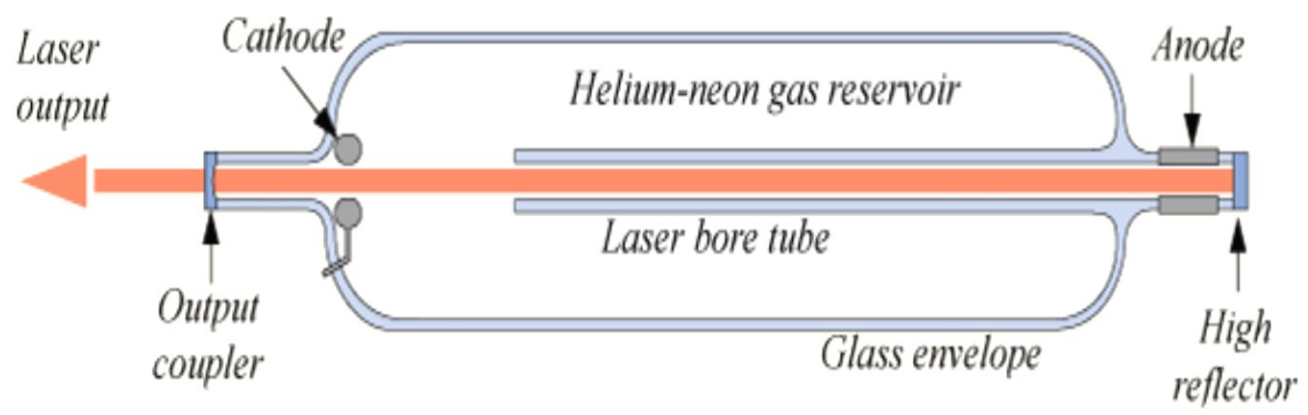

Figure (1): Schematic diagram of HeNe Laser

Lasing Mechanism

The helium neon (He-Ne) 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 o 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 Fig.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.

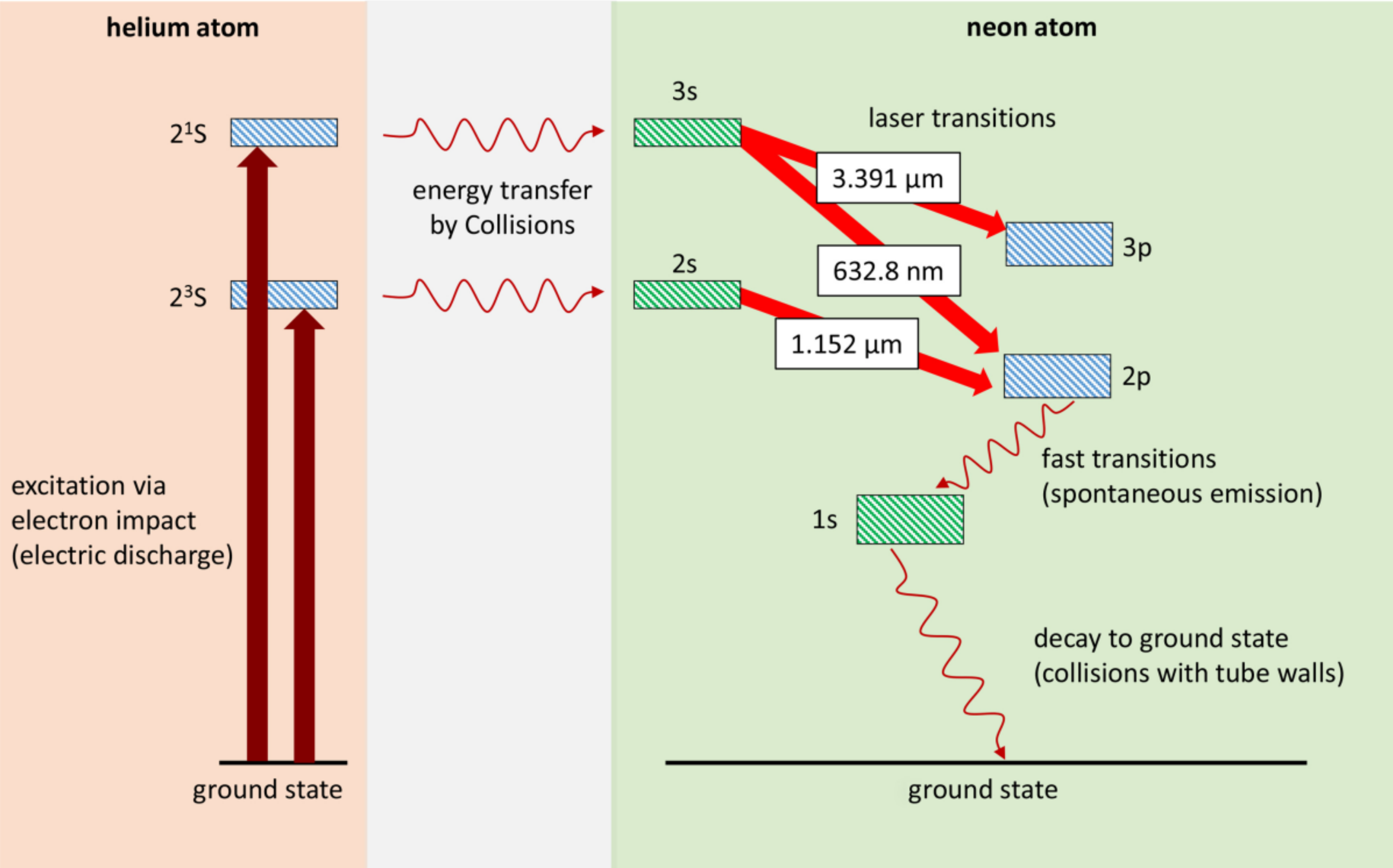

Fig.2. Scheme of energy levels of helium and neon including the dominant transitions

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.

1.2. 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.

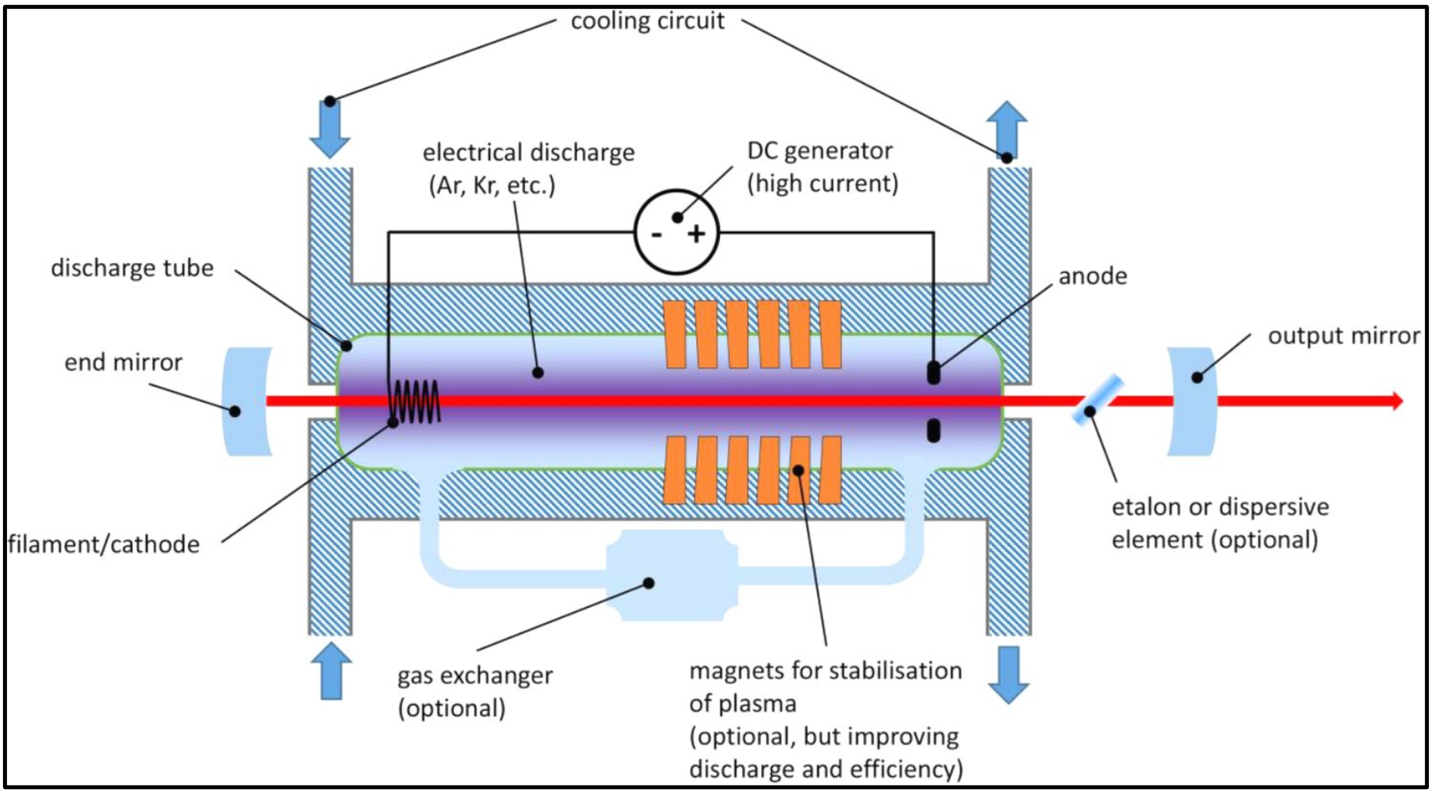

Fig.3

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.

1.3. 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

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 (*E*2), 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 Fig.3.

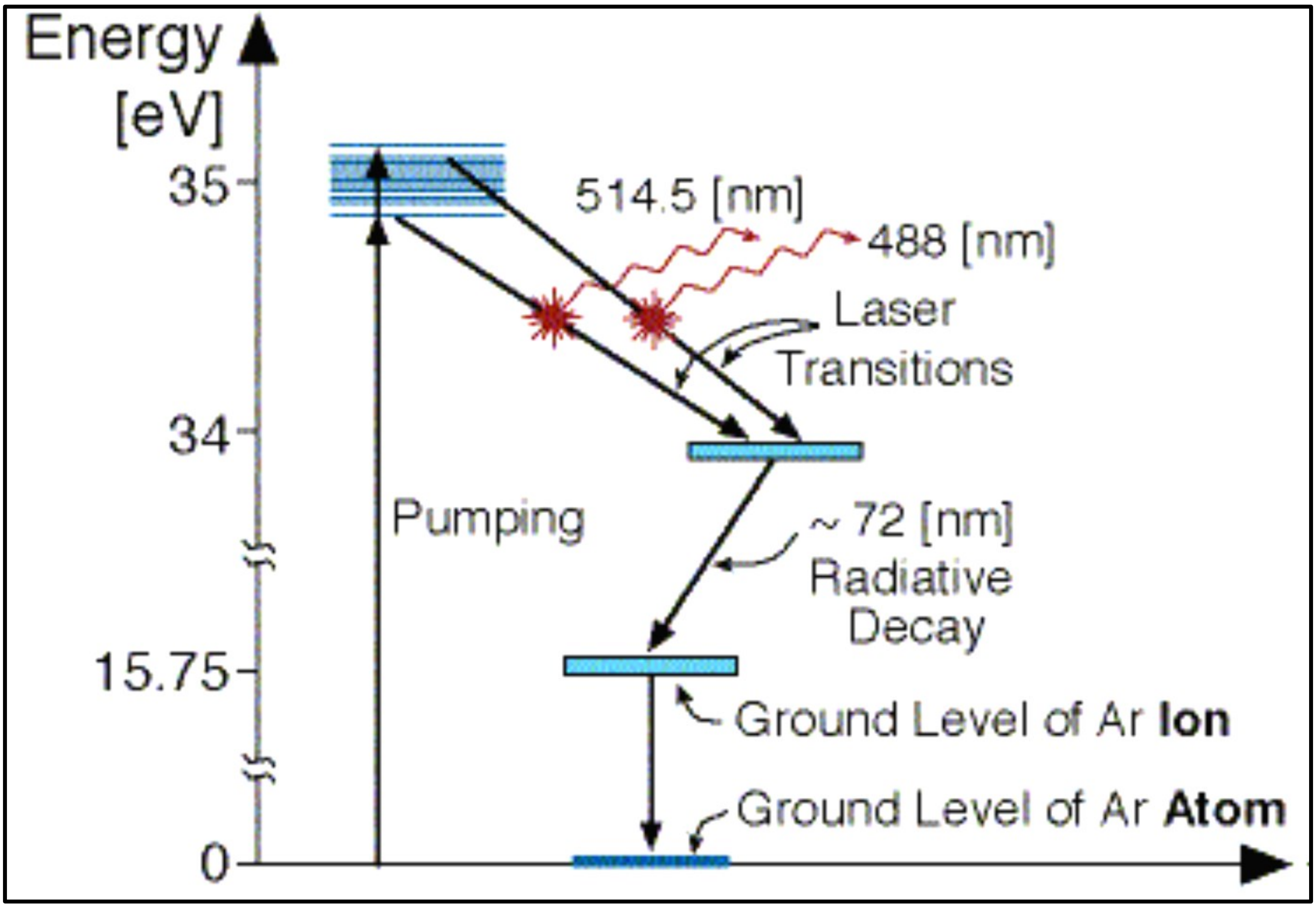

Fig.4

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.

2. 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.

2.1. 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.

Construction

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

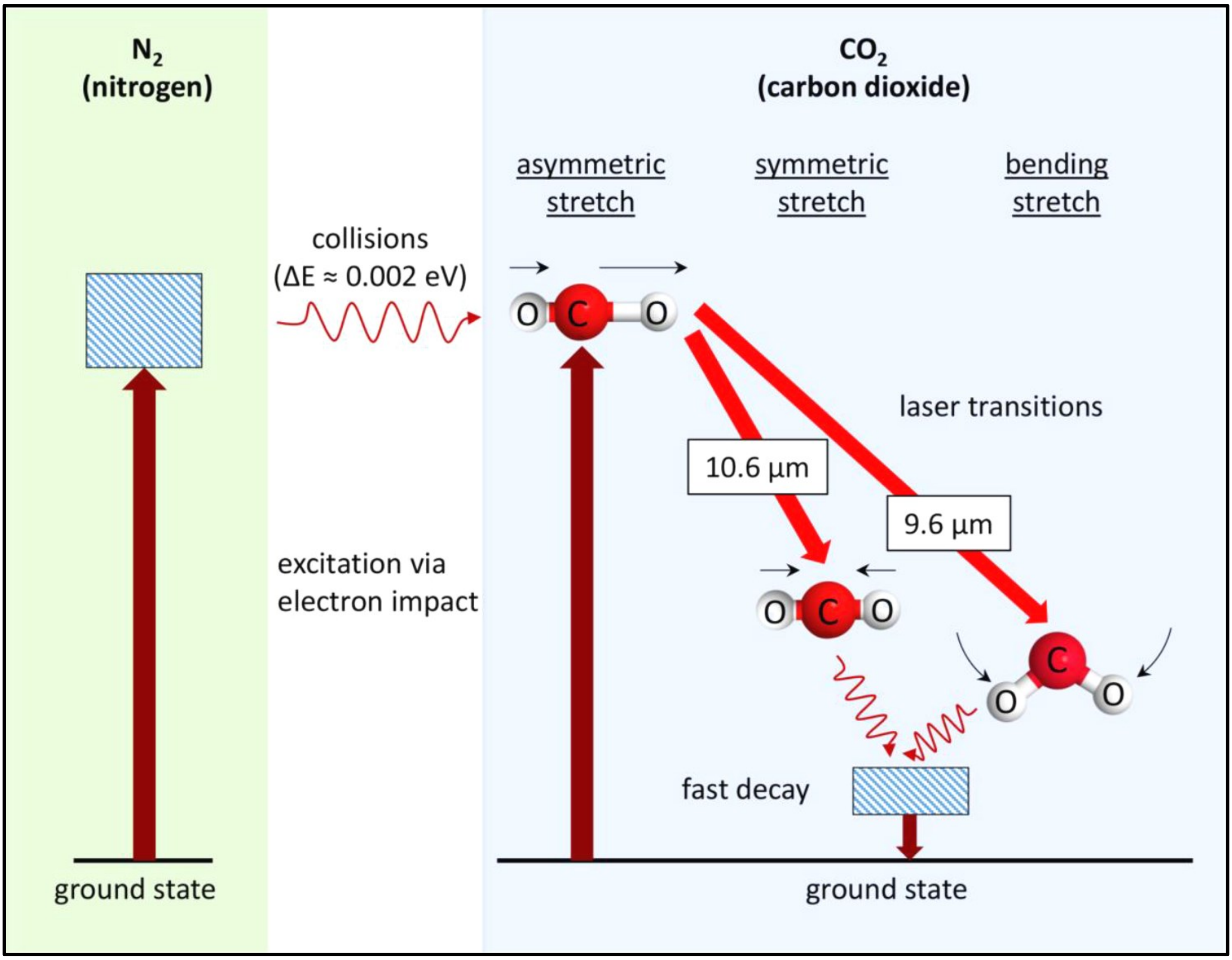

Fig.5. Scheme of energy levels of of a CO_2 laser.

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).

Application:

- industrial applications including cutting, drilling, welding, and so on. It is widely used in the laser pyrolysis method of nanomaterials processing.
- CO_2 laser in medical applications:
  1. **Brain surgery.**
  2. **Removal of precancerous lesions.**
  3. **Spinal surgery.**
  4. **Cancer removal.**

The CO_2 laser is a precise surgical tool, because; limiting the lateral damage of tissue. It can cut or vaporize (dissolve) tissue with fairly little bleeding. Laser light can be used to remove cancer or precancerous growths or to relieve symptoms of cancer. It is used most often to treat superficial cancers, such as skin cancer on the surface of the body or the lining of internal organs.