Apparative Cosmetics with Optical Radiation

What is LASER:

Intro:

The laser and pulsed light are simply sources of natural light. The visible light that we experience in our day to day is only one facet of a much broader physical phenomenon known as “electromagnetic radiation.”
Lasers are sources of electromagnetic radiation, or light, with some special characteristics that are different from other light sources, such as a car headlight or a lamp. The word laser is an acronym for **light amplification by stimulated emission of radiation**. We can divide this acronym into two well-defined parts:

- the *stimulated emission* phenomenon.
- the *light amplification.*

Stimulated Emission:

Light is a form of energy generated, emitted, or absorbed by atoms or molecules. To emit energy, the atom or molecule is raised to an excitation energy level, above its natural resting state (in which there is excess energy to be discharged). Atoms cannot maintain the excitement for long periods of time. Consequently, they have a natural tendency to eliminate the excess energy in the form of emission of particles or packets of light waves called photons. This phenomenon is called spontaneous emission of light. The wavelength (λ), or the frequency of the emitted photons, is related to the photon energy through the relationship:

$$E_{photon} = hc/\lambda$$

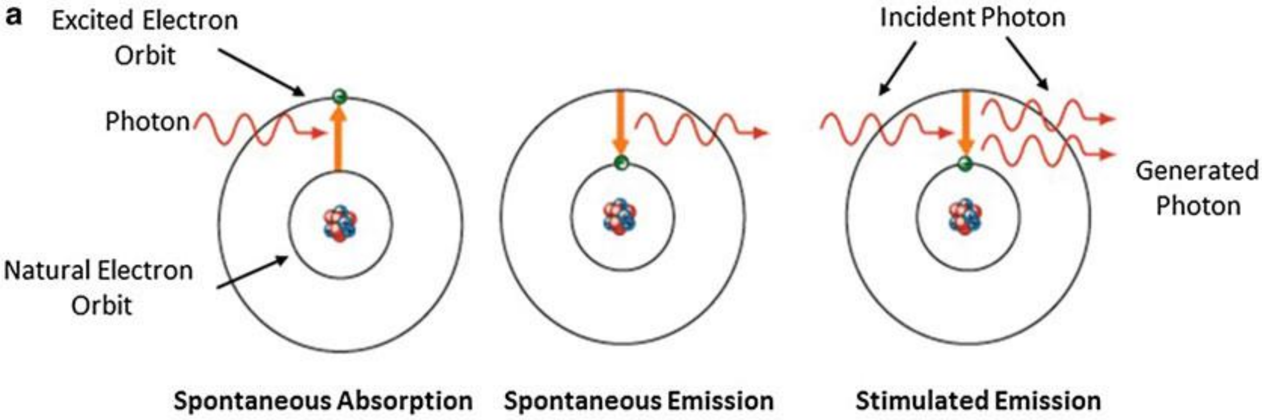
h – Planck universal constant $= 6.6260693 \times 10^{-34}$ J.s
c – Speed of light = 300,000 km/s
λ – Wavelength of the light (nanometers – nm)

Each atom or molecule in nature has different energy levels of excitement. Consequently, each element emits photons with different energies and different wavelengths (frequencies). All these primary radiations are monochromatic. The fact that the sunlight is polychromatic indicates that it is composed of a mixture of several distinct elements.
Atoms can be excited by different mechanisms: **heat, mechanical shocks** with other particles as an electrical discharge (collision with electrons), or when they **selectively absorb electromagnetic radiation** energy from other photons.

However, atoms can also decay producing light radiation in a **stimulated form.** In 1917, Albert Einstein postulated and proved the existence of this mechanism. When an excited atom collides with a photon, it instantly emits a photon identical to the first. This stimulated emission follows the following basic laws:

(a) The stimulated photon travels in the same direction of the incident.

(b) The stimulated photon synchronizes its wave with the incident; in other words, the waves of the two photons align their peaks adding their magnitudes and thereby increasing the intensity of the light. Photons with aligned peaks produce a coherent (organized) light. In a coherent beam, light travels in the same direction, at the same time, and with the same energy.

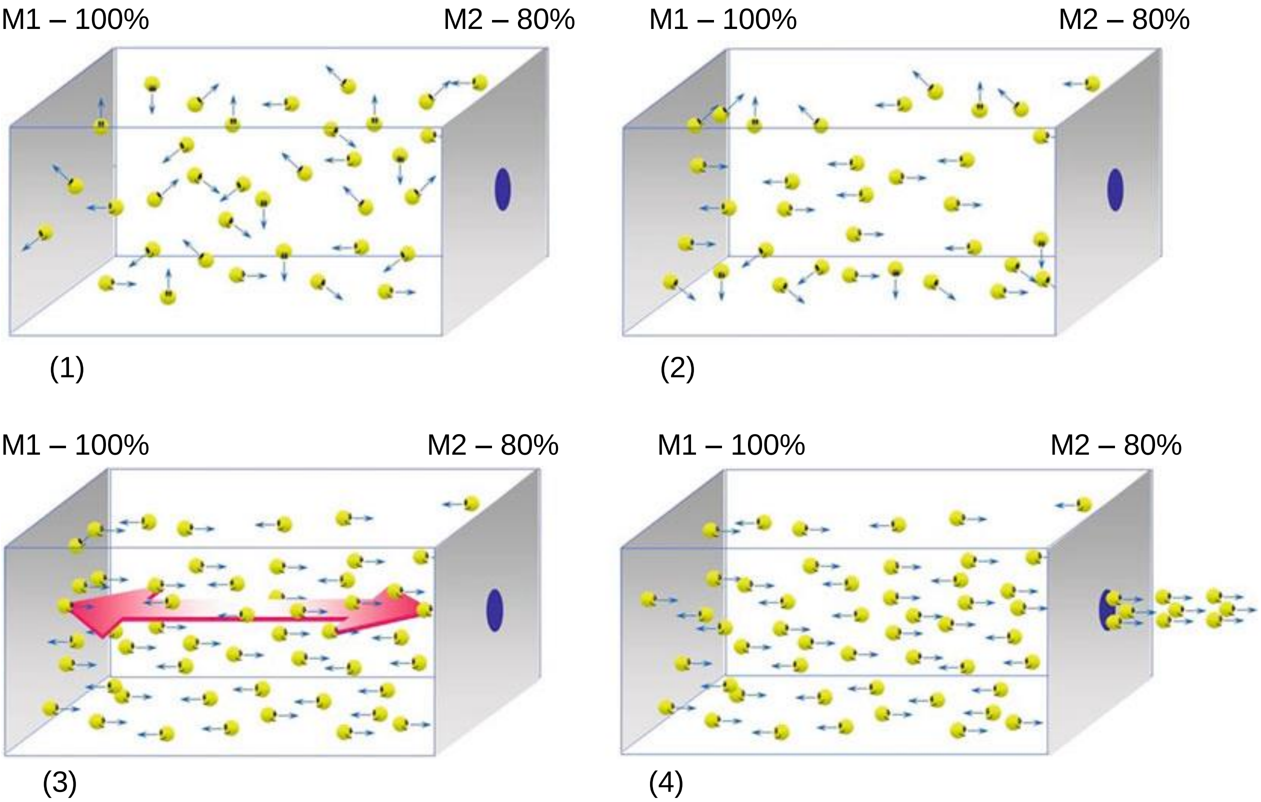


The end result of **stimulated emission** is then a pair of photons that are coherent and that travel in the same direction. *The stimulated emission of light is the working principle of a laser*, invented more than 50 years after the discovery of Einstein

Light Amplification:

To illustrate the generation of light inside a laser, let us first imagine a rectangular box or a tube, as a straight cylinder, with a large number of identical atoms or molecules, as an example, a fluorescent lamp tube with its gas. At each end of the tube, we place **mirrors**, which because of the construction will be parallel to one another. At one end, the mirror is *totally reflective* (100 % mirror), and at the other end (the exit window of the light – output coupler), the mirror is *partially reflective* (80 % mirror), so that part of the light is reflected back to the tube and part is transmitted through the mirror to the outside.
Let us also imagine that the atoms are excited to a higher energy level by an external source (a light source or an electrical discharge) as if we had activated the switch turning on the lamp. Through the mechanism of spontaneous emission, which takes place completely randomly, the atoms emit photons that begin traveling in various directions within the tube. Those hitting against the tube wall are absorbed and lost as heat, disappearing from the scene. On the other hand, the emitted photons traveling parallel to the tube axis are likely to find other exciting atoms and thus **stimulate the emission** of additional photons, which are consistent with the stimulating photon and travel in the same direction – i.e., along the longitudinal axis of the tube.
These two photons continue their journey, again with the likelihood of stimulating, through a similar process, two additional photons – all consistent with each other and traveling on the same axis. The progression continues indefinitely and 8, 16, 32, 64, etc., photons are produced, all traveling in the

same direction. It is clearly established a light amplification process that generates a large luminous flux in the longitudinal direction of the tube. The mirrors perpendicular to the tube axis reflects the photons back intensifying this effect of amplification. Each of these reflected photons traveling along the axis in the opposite direction contributes to the chain reaction effect generating a stream of coherent photons. When they reach the partially reflecting mirror, 80 % of the photons return to the tube continuing the amplification effect. The remaining 20 % goes out forming the laser beam.



(1) (2) (3) (4)

Fig. Light amplification and laser beam formation inside a laser resonator. M1 is the 100 % reflection mirror and M2 is the 80 % partial reflection mirror. The (1) and (2) are excited atoms that produce photons that begin to travel longitudinally along the resonator between the mirrors. The (3) and (4) are the photons traveling parallel to the axis of the resonator that stimulate new photons, producing the laser beam.

They represent in absolute terms a very intense beam of photons produced by the amplification effect. The tube and its exciting medium, together with the mirrors, are called the **resonator** (or oscillator) which are the basic components of a laser in addition to the excitation source.

Characteristics of a Laser Light:

As described above, laser light has unique properties that make them different from other light sources.

(a) Monochrome:

It is generated by a collection of identical atoms or molecules; thus, all photons emitted have the same wavelength, a single frequency. This feature is important because of the selective absorption of the human tissue, which will be presented in the next sections.

(b) Coherent:

Because of the stimulated emission and the way the light is amplified, which is only in the longitudinal direction inside the resonator, the photons are organized, like soldiers marching in a military parade. This is called spatial and temporal coherence. At any point of a laser beam, the photons (or light):

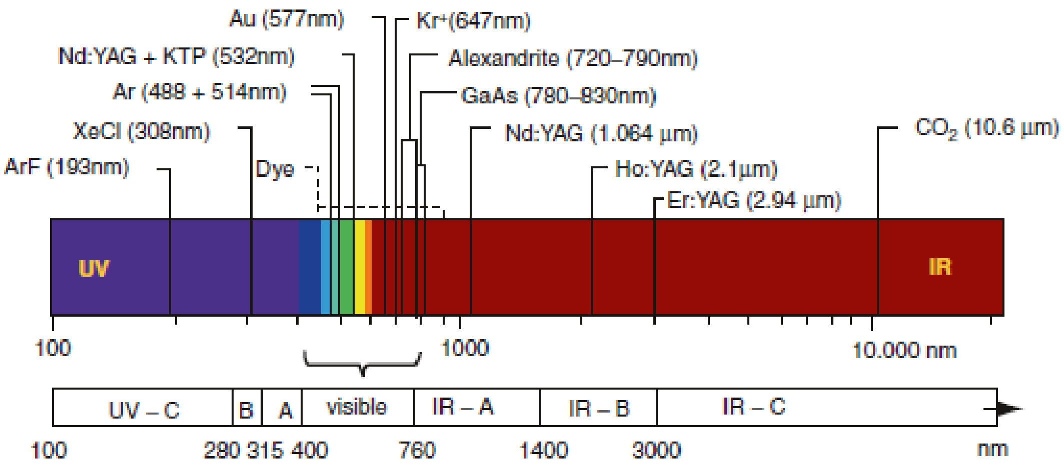
(1) Have the **same power**

(2) Travel in the **same direction**

(3) Travel at the **same time**

Medical Laser systems:

Since the invention and commercial availability of lasers, such systems have been widely used for medical applications in the treatment of soft and hard biological tissue. Following are the important classification of lasers:



Medical Lasers

A. Solid-State Lasers:

1. Nd YAG Laser:

The most important solid-state laser is the Nd:YAG laser, with **neodymium** as laser ion (Nd3+) doped with1–1.5% into an *yttrium-aluminum-garnet crysta*l (Y3Al5O12). Its fundamental wavelength is **1064.2 nm.**

The Nd:YAG laser is a four-level system. Other, weaker emission wavelengths are 1,320 and 1058.2 nm (Nd:CaWO4). The Overall efficiency of a flash lamp-pumped Nd:YAGlaser is less than 2%. Therefore, it must be cooled with water. Diode-pumped systems (805-nm laser diodes) reach efficiencies of about 15% at an output power of about 10–15 W.

USES:

- Nd:YAG lasers are used as *CW lasers* up to 100 W for **surgical applications**, e.g., long-pulsed lasers in dermatology.
- Q-switch lasers with-to 20-ns pulse length in **urology (lithotripsy)** and **dermatology(tattoo removal)**.

KTP Laser:

KTP lasers are frequency-doubled Nd:YAG lasers using KTP crystals inside the cavity or externally with an emission wavelength of 532 nm in the green part of the visible spectrum.

2. Er:YAG Laser:

The Er:YAG laser with a **2.94-mm** wavelength.**Erbium ions** are doped in high concentration (~50%) in *YAG* or other crystals (Er:YSGG:2.78 mm; Cr:Er:YSGG: 2.80 mm; Cr:Tm:Er:YAG:2.64 mm).
This laser exists only as a pulsed laser system because of the rather complex energy-level scheme of erbium with important energy-transfer upconversion (ETU) and cross-relaxation (CR) processes. Laser transition occurs from the energy level 4 11/2 to 4 13/2. The lower laser level has a longer lifetime of 9 ms compared to the upper laser level.

USES:

- They are used with a mean power of up to 30 W and repletion rates of up to 50 Hz in **superficial tissue ablation**.
- In **dentistry.**
- In **minimal invasive surgery.**
- **Skin resurfacing** (skin rejuvenation).

3. Alexandrite Laser:

This solid-state laser is tunable in the wavelength range **700–830 nm**, normally being operated at **750 nm**. Alexandrite laser medium is a **chromium**-doped chrysoberyl (Cr:BeAl2O4, gemstone alexandrite) and can operate in CW (up to 100 W) or pulsed mode.
Also not a true four-level laser, the vibronic transitions which this laser usually operates permits operation similar to a four-level laser.

USES:

- Because the light of this wavelength region is absorbed by melanin and eyes, but not significantly by blood, it can be used for the **destruction of melanin**-containing structures (**hair roots, pigmented lesions**).

- The first applications were reported in the fragmentation of **kidney stones.**

4. Ruby Laser ($Cr^{3+}:Al_2O_3$):

Although the ruby laser was the first laser, which was developed by Maiman in 1961, it was for a long time ignored and not used in medical applications. The Emission wavelength is **694 nm**. The laser is a three-level laser and therefore more than 50% of the ions in the ground state must be excited to get an inversion. Modern laser systems with advanced technology are able to produce high pulse energies up to 20 J.

The laser active ion is **Cr^{3+}** replacing Al ions, **Al^{3+}**, in the host material, *sapphire (Al_2O_3)*, at a doping concentration of 0.05% AU of Cr_2O_3. The two strong absorption bands in the ruby crystal are around **400** and **550 nm**.

USES:

The deep red color of the laser light is absorbed by melanin and dark pigments. Therefore, the medical applications are mostly in dermatology, similar to the alexandrite laser, to **remove hairs** or **tattoos** with black or blue color.

B. Gas Lasers:

1. Carbon Dioxide Laser:

With a power range from mW to tens of kW in the continuous wave (CW) mode and an efficiency of up to 30%, Carbon Dioxide Laser systems are compact and economic. The sealed laser tube is filled with a mixture of gases, **CO_2** (1–9%), **N_2** (13– 45%), and **Helium** (60–85%).

Excitation occurs by direct current high-voltage gas discharge or through high frequency (RF). The gas components have different reaction mechanisms during the laser process.

Structure:

The structure of the CO_2 molecule is linear, with the carbon atom in the center. Such molecule configurations can vibrate in symmetric and asymmetric stretch modes as well as in bending modes. The Energies associated with molecular vibration are quantized just like electron energies; therefore, only certain vibrational levels are possible. The possible forms of resonant vibration are referred to as the vibrational modes of a molecule.

Mechanism:

During gas discharge free electrons collide with N_2 Molecules and excite them. The CO_2 is excited through a collision with excited N_2 molecules. This transfer of energy occurs by a resonant effect. Because the vibrational energy levels of N_2 are metastable and have energy very close to that of the first energy level of the asymmetric stretch mode of CO_2, they have ample time to transfer their energy and excite the CO_2 molecules.The lasing occurs when CO_2 in the excited asymmetric mode makes the transition to the bending of symmetric stretch modes. The CO_2 then returns to its ground state through another collisional transfer of energy with the helium atoms. With this lasing process the CO_2 laser is a **three-level laser** with direct pumping into the upper laser level because the lower laser level is depleted very quickly through the presence of helium in high concentration. One receives a bunch of laser lines around the central laser wavelengths at **10.6 and 9.6 mm**.

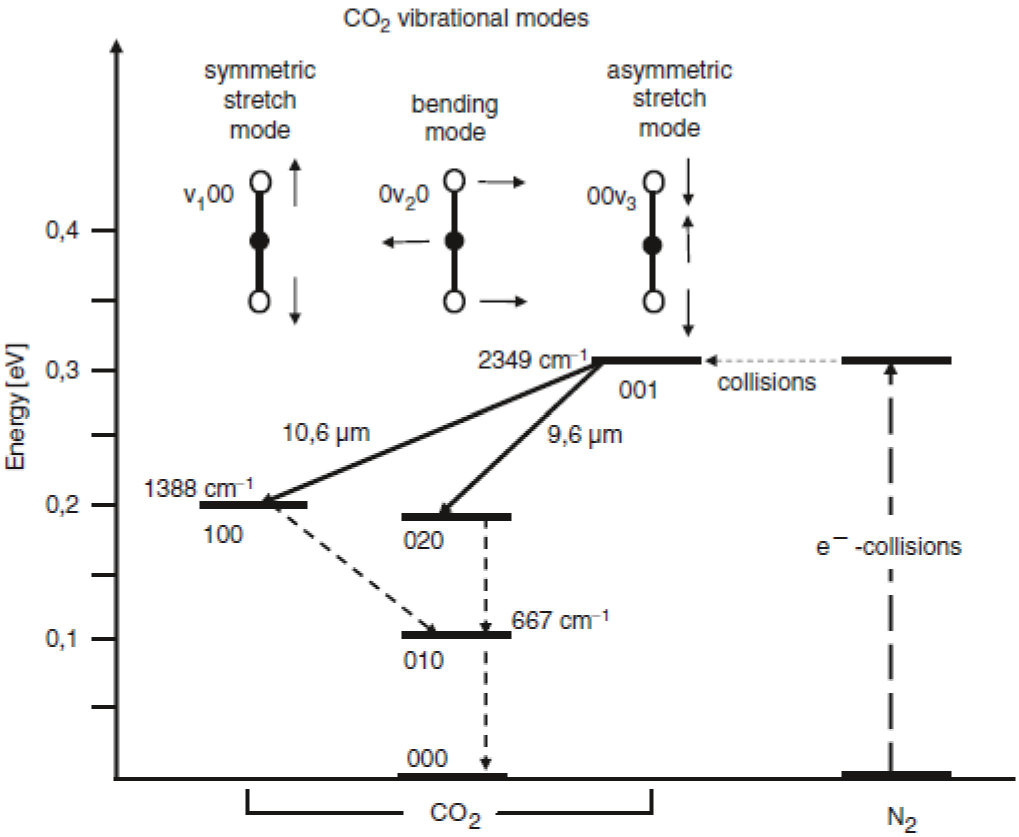


Fig. Scheme of the energy levels of a CO2 laser and the vibration modes of the linear CO2 molecule

USES:

- In **Endoscopic applications.**
- Treat **wrinkles, scars, warts, enlarged oil glands** on the nose**,** and other conditions.
- **Cancerous (malignant) skin conditions**

2. Excimer Laser:

Basov and his colleagues in Moscow first discovered in 1971 the stimulated UV emission of an excited **xenon dimer** (Xe2) at **176 nm**. Excimer is a short form of the expression “excited dimers.” Molecules, such as noble gas halides (ArF, KrF, XeCl, XeF), are stable only in their excited states and not in their ground states. The laser medium consists of such molecules in a buffer gas like helium or neon at a total pressure of 2–3 bar. The laser radiation occurs during transition from this excited state to the non-excited state of rare gas and halogenide. The efficiency of excimer lasers is about 2%. They exist only as pulsed lasers, with pulse widths ranging from several ns to 100 ns. Maximum Mean power is **200 W.**

The repetition rate is up to kHz. The wavelength of an excimer laser depends on the rare gas and the halogenide.

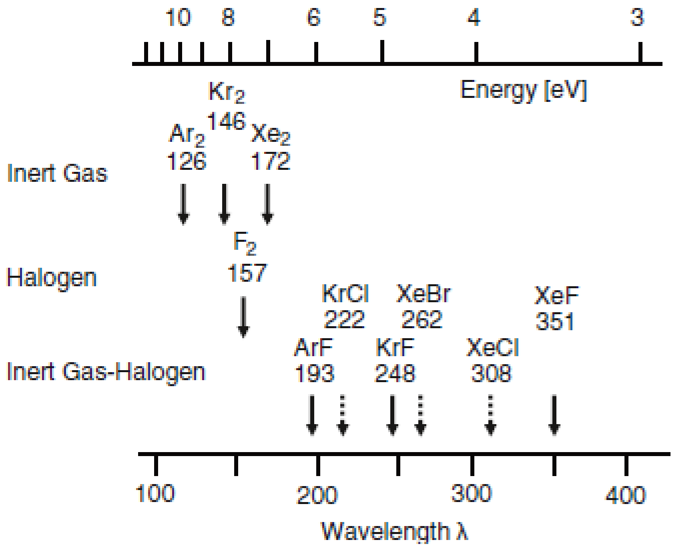


Fig. Laser wavelengths of the different excimers in nanometers

USES:

Including **psoriasis, vitiligo, hypopigmented disorders, alopecia areata, atopic dermatitis,** and in many other dermatologic diseases.

C. Diode Laser (Semiconductor Laser):

Hall and his team at General Electric were the first to demonstrate the emission of a semiconductor laser diode in 1962. Laser diodes are formed by doping very thin layers on the surface of a **crystal wafer** to produce an *n-type region* (negative, increase of negative free charges – electrons) and *p-type region* (positive, increase of free positive charges – holes), one above the other, resulting in a p–n junction. Applying a forward electrical bias causes the two species of charge carriers, holes, and electrons, to be injected from both sides of the p–n junction into the depletion zone, situated in the center of the p–n junction. Holes are injected from the p-doped semiconductor and electrons from the n-doped semiconductor. Recombination or annihilation of both charges results in spontaneous emission of a photon, with energy equal to the difference between the electron and hole states involved.

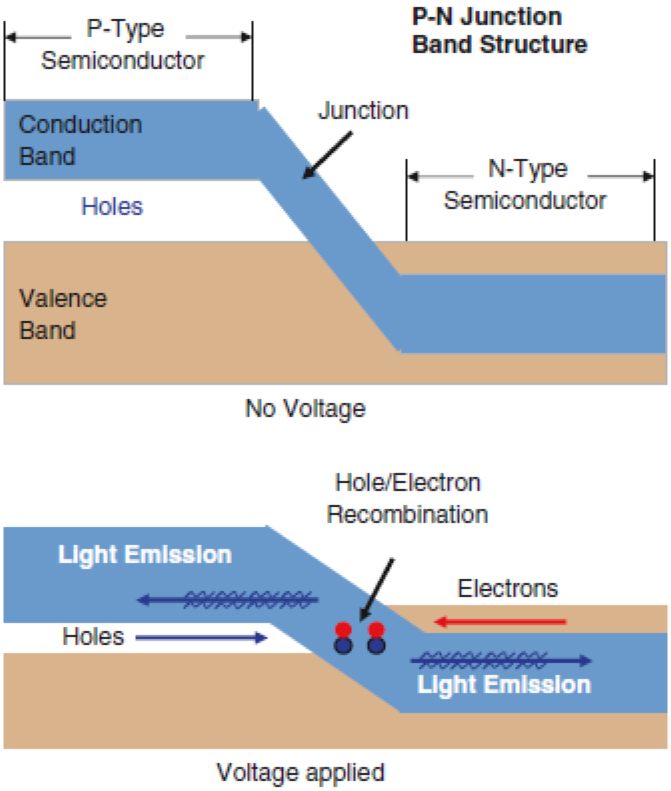


Fig. Band gap structure of laser diodes

USES:

- Laser diodes are very efficient, with an electrical current to light conversion of up to 60%. Therefore, they are well suited for medical applications because they are very powerful (up to **100W**), they are small devices, and they are flexible in wavelength. Laser diodes are available from the UV spectrum (for **chromophore excitation**) into the visible spectrum until the near-IR spectrum for **surgical applications**.
- It is widely used for **hair removal, non-ablative skin rejuvenation**, and treatment of vascular lesions. It is also used for pumping other lasers such as Nd:YAG, Nd:YAG/KTP, and fiber-optic lasers.

D. Dye Lasers:

The invention of the dye laser in 1966 by Fritz P.Schäfer was a chance discovery. When he directed the beam of a ruby laser through a glass cuvette with fluorescing dye he observed a lasting effect. The reflections of the glass walls were sufficient to react as a resonator. Later, T.W. Hänsch used the dye laser with frequency selective optical elements for spectroscopy.

The Advantage of the dye laser is its broad tuning range, up to 100 nm with one dye. Numerous dyes are available, covering the whole range in the visible spectrum.

Pulsed dye lasers are routinely used in dermatology for the treatment of vascular malformations. Some of the fluorescent dyes used in dye lasers are rhodamine 6G (R6G), fluorescein, coumarin, stilbene, umbelliferone, tetracene, and malachite green. The dye laser is a **four-level laser.**

USES:

- Treatments have been safely used to treat **benign facial redness** due to dilated or excess blood vessels for nearly two decades. The PDL uses a concentrated beam of light that targets blood vessels in the skin.
- It has been used in the treatment of **warts, port wine stains, hemangiomas, hypertrophic scars,** and **telangiectasias**.