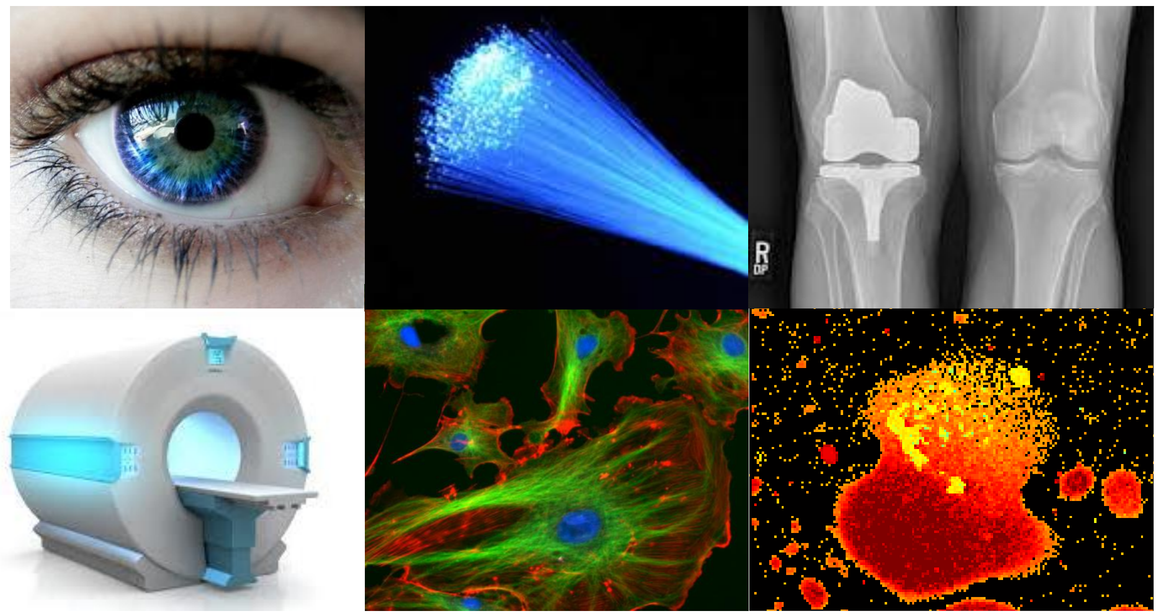
Lasers e Ótica Biomédica



Pedro Jorge

Requirements for LASER action

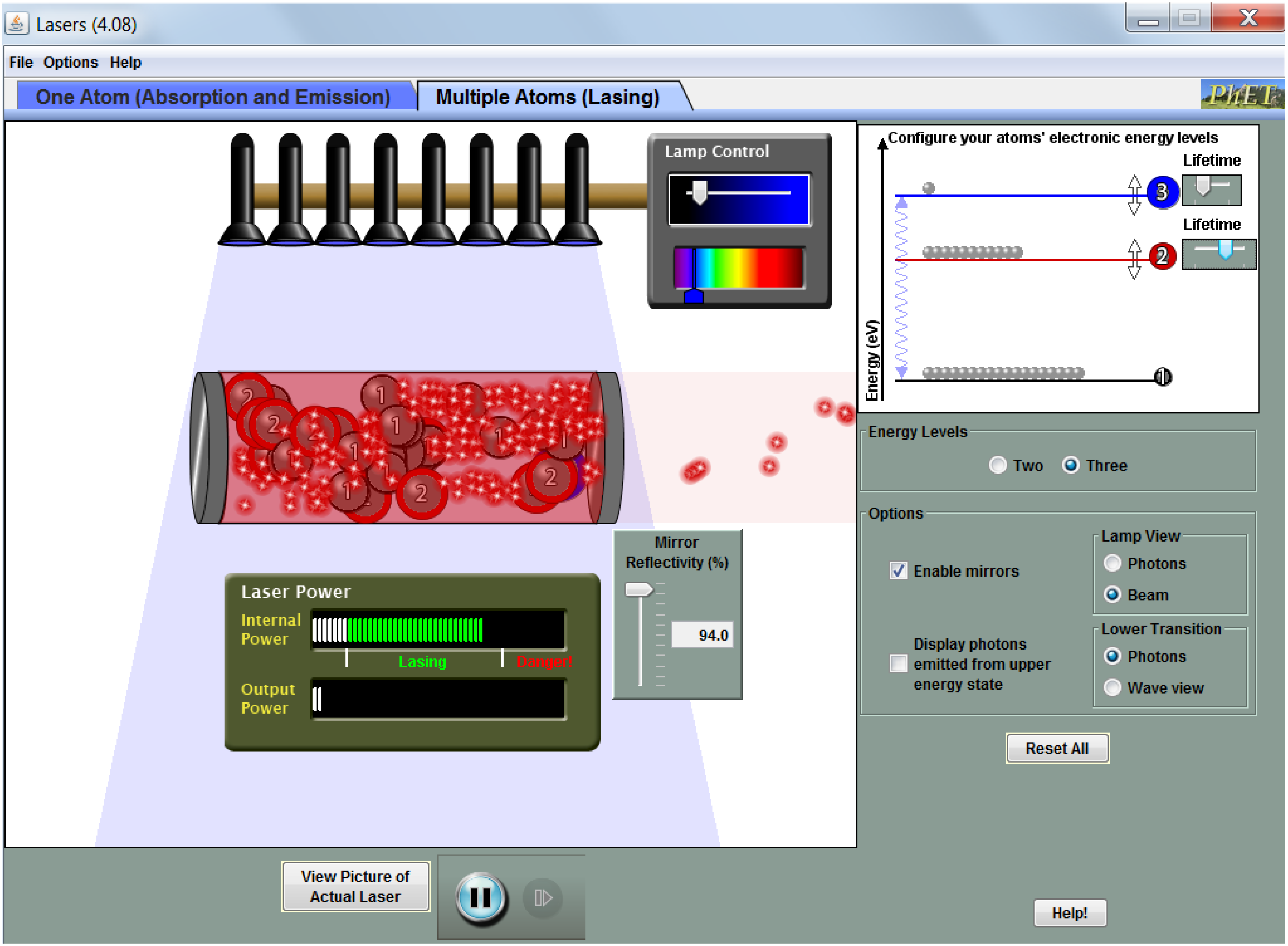
- **Stimulated emission**
- **Population Inversion**
- **Feedback**

External energy source

Gain

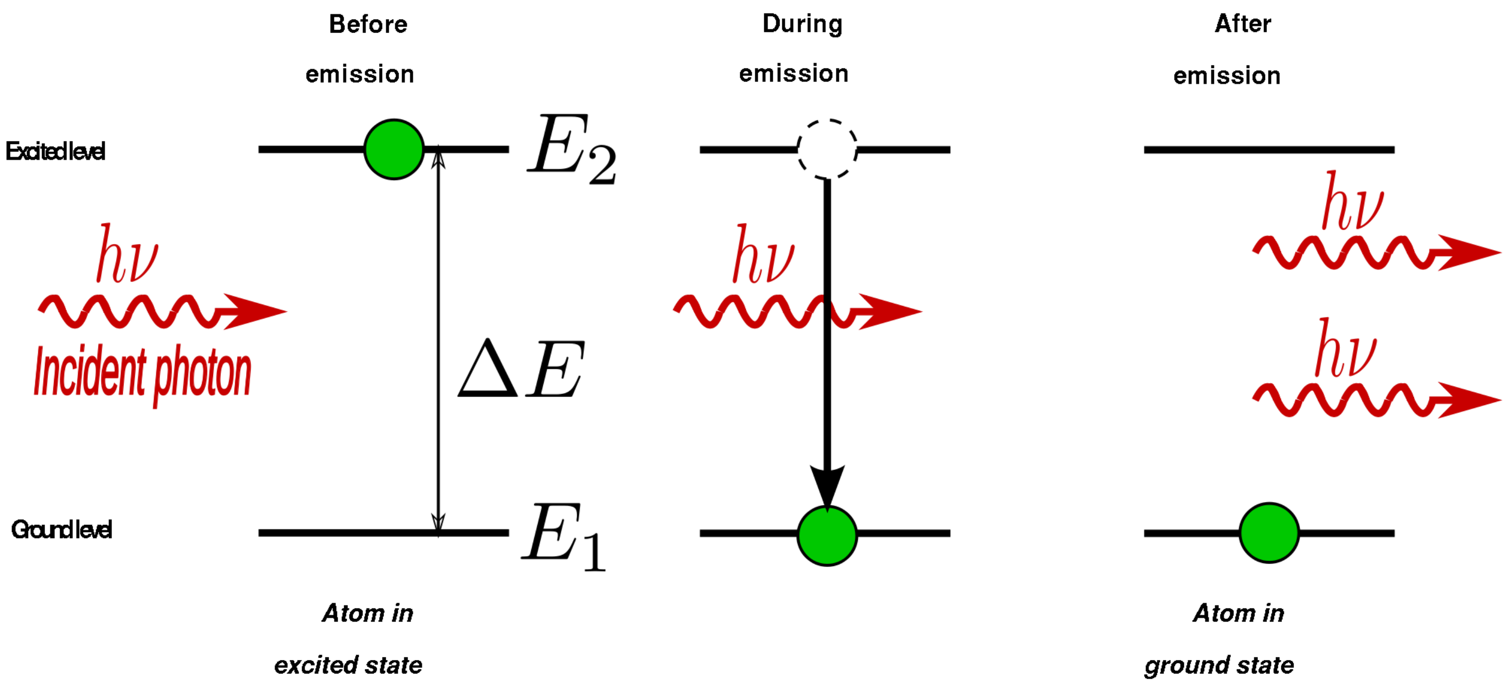
Lifetime of energy levels

Let’s build a LASER



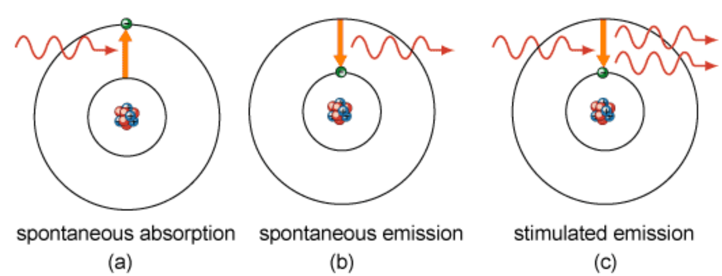
Laser

Absorption, spontaneous emission and stimulated emission

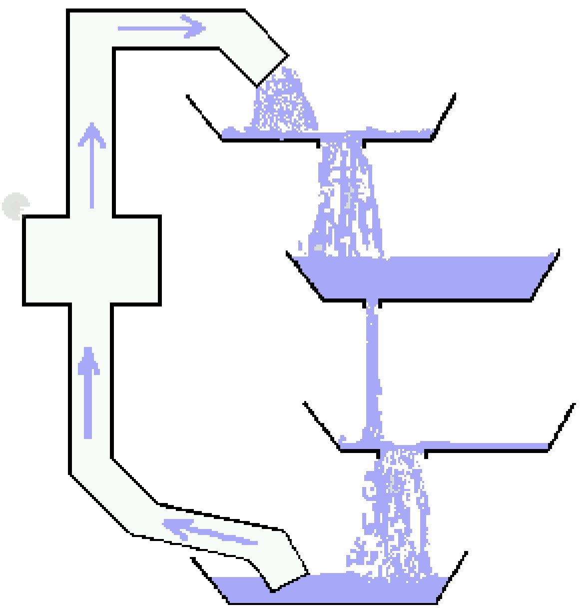


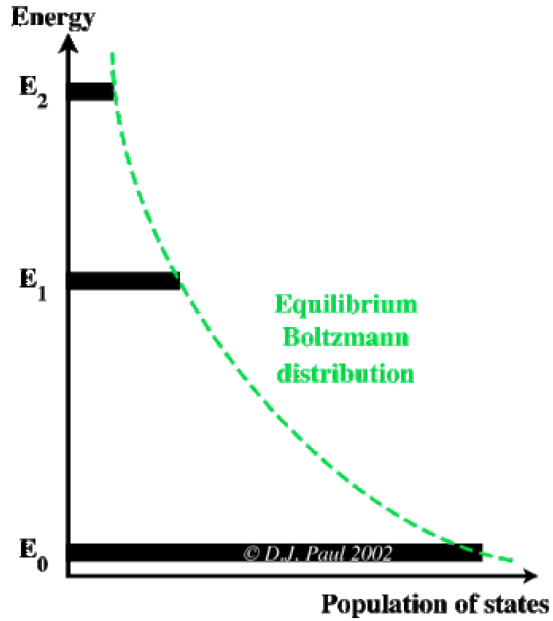
$$E_2 - E_1 = \Delta E = h\nu$$

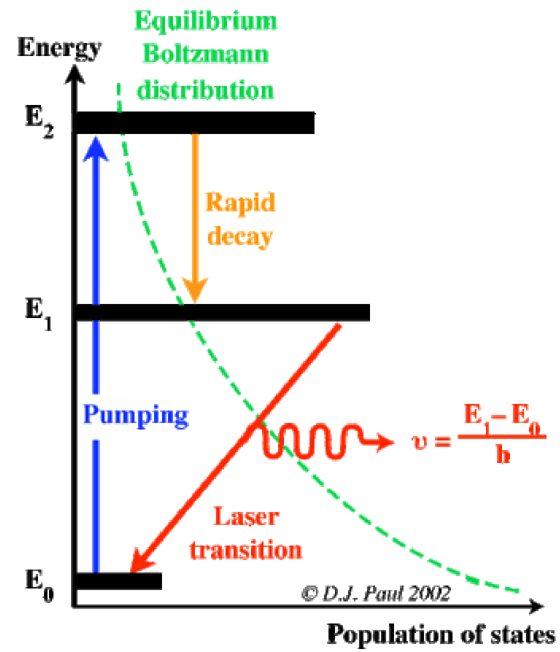
Stimulated emission introduces coherence. Photons having identical characteristics of phase, direction of propagation, wavelength and polarization.



Laser Population Inversion







$$N_i = N_0 e^{-\mathcal{E}_i/k_B T}$$

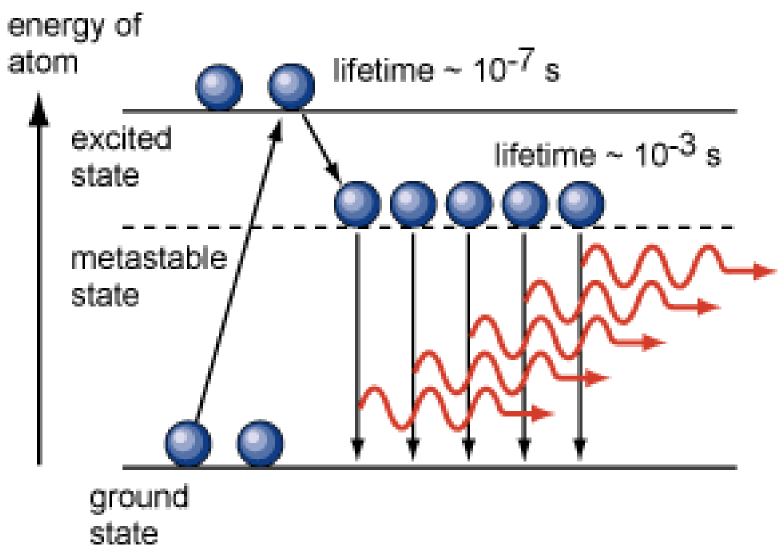
$$N_j = N_i e^{-(\mathcal{E}_j - \mathcal{E}_i)/k_B T} = N_i e^{-h\nu_{ji}/k_B T}$$

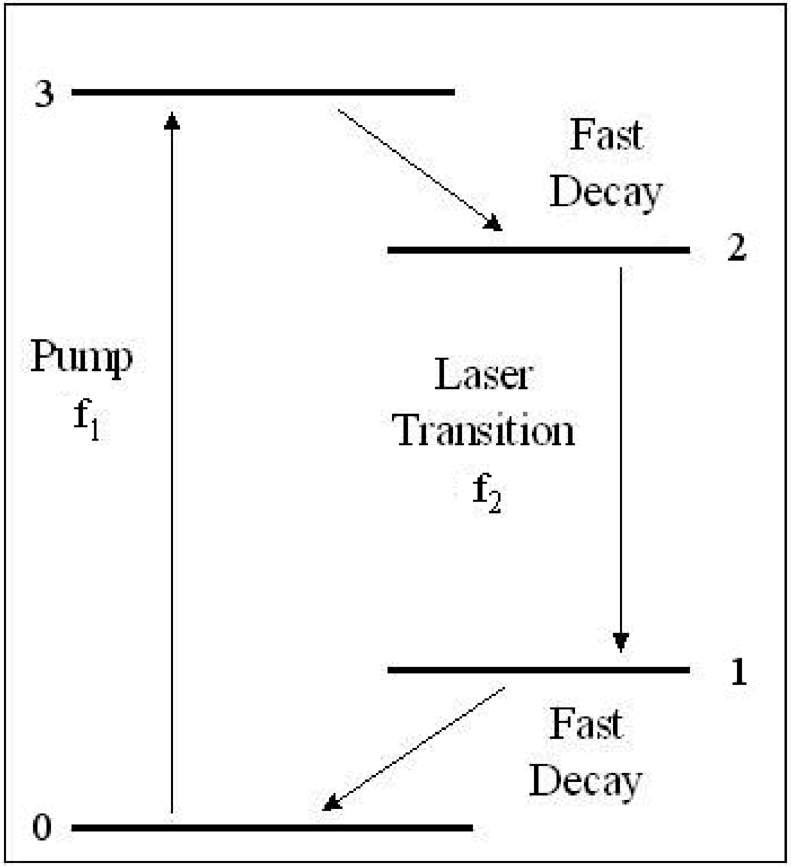
The relation between the emission rates and lifetimes of the levels involved, are critical to obtain population inversion and gain.

t21<t10

http://www.aml.engineering.columbia.edu/ntm/level2/ch02/html/l2c02s04.html

Laser Population Inversion





Four Level Scheme

With 4 levels it is much easier to obtain population inversion, initial population at N1 is generally much lower than in N0 (therefore easier to surpass by populating N2 with relatively smaller pumping powers.

Laser ‘pump’

It is necessary to have an external energy source to excite the ‘active media’ to attain population inversion and gain .

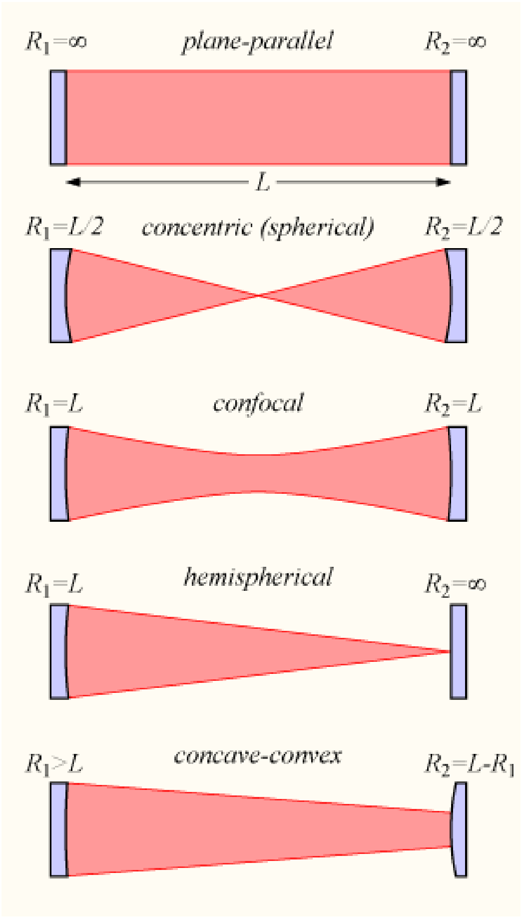
The type of energy source will depend on the type of LASER:

- Optical pump (flash lamp, or other LASER)
- Electrical pump
- X Ray
- Chemical Pump (chemical reaction)

Having the energy source and the active media to provide optical gain.

Is there something missing to get a working LASER!??

Laser Resonant Cavity (spectral selection and feedback)



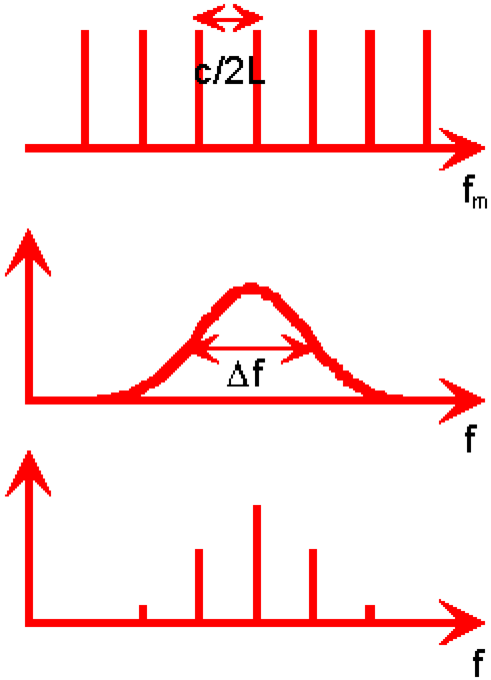
Mirrors increase the effective interaction path of the photons in the cavity, increasing the **probability of stimulated emission**.

The cavity supports only certain types of **longitudinal modes**, which comply with the cavity boundary conditions.

Only certain modes overlap with the absorption band of the active media.

$\Delta E \Delta t \sim \hbar$

$\Delta f \Delta t \sim 1/(2\pi)$



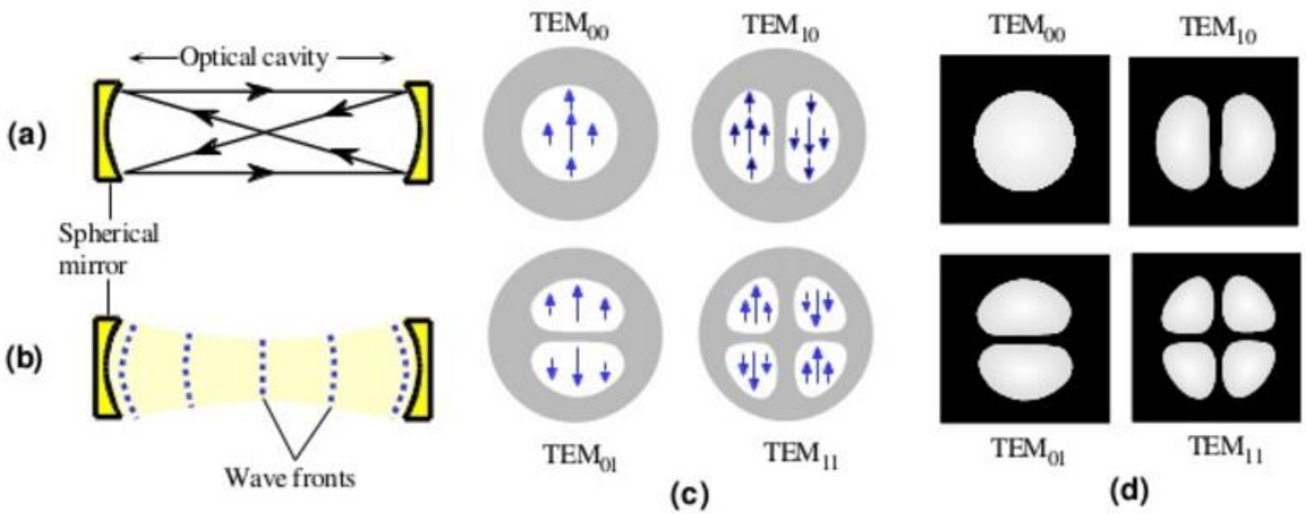
$m\lambda = 2L$

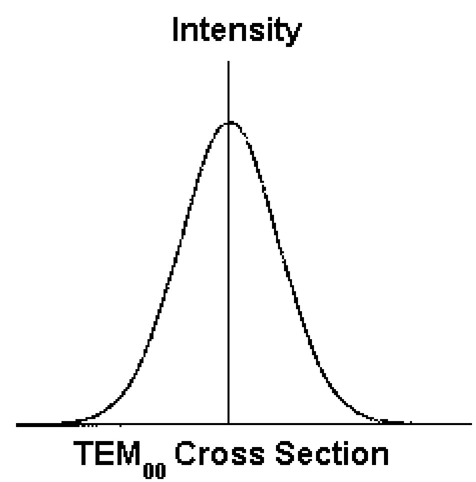
$f_m = c/\lambda = mc/(2L)$

$\Delta f = c/2L$

HeNe Laser632.8 nm
L = 30 cm
m= ?; Δf =?
If Gain Bandwidth Ne =1.6 GHz
m=

Laser Resonant Cavity (Transversal Modes)





Laser Modes (a) An off-axis transverse mode is able to self-replicate after one round trip. (b) Wavefronts in a self-replicating wave (c) Four low order transverse cavity modes and their fields. (d) Intensity patterns in the modes of (c).

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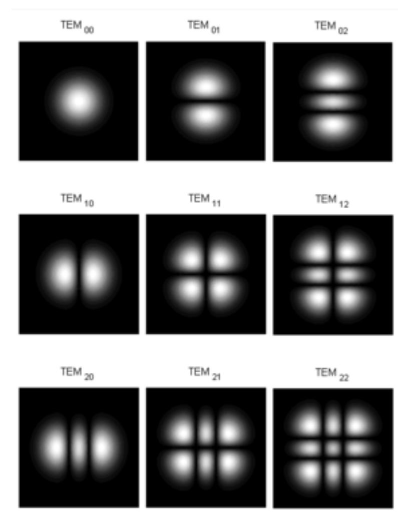
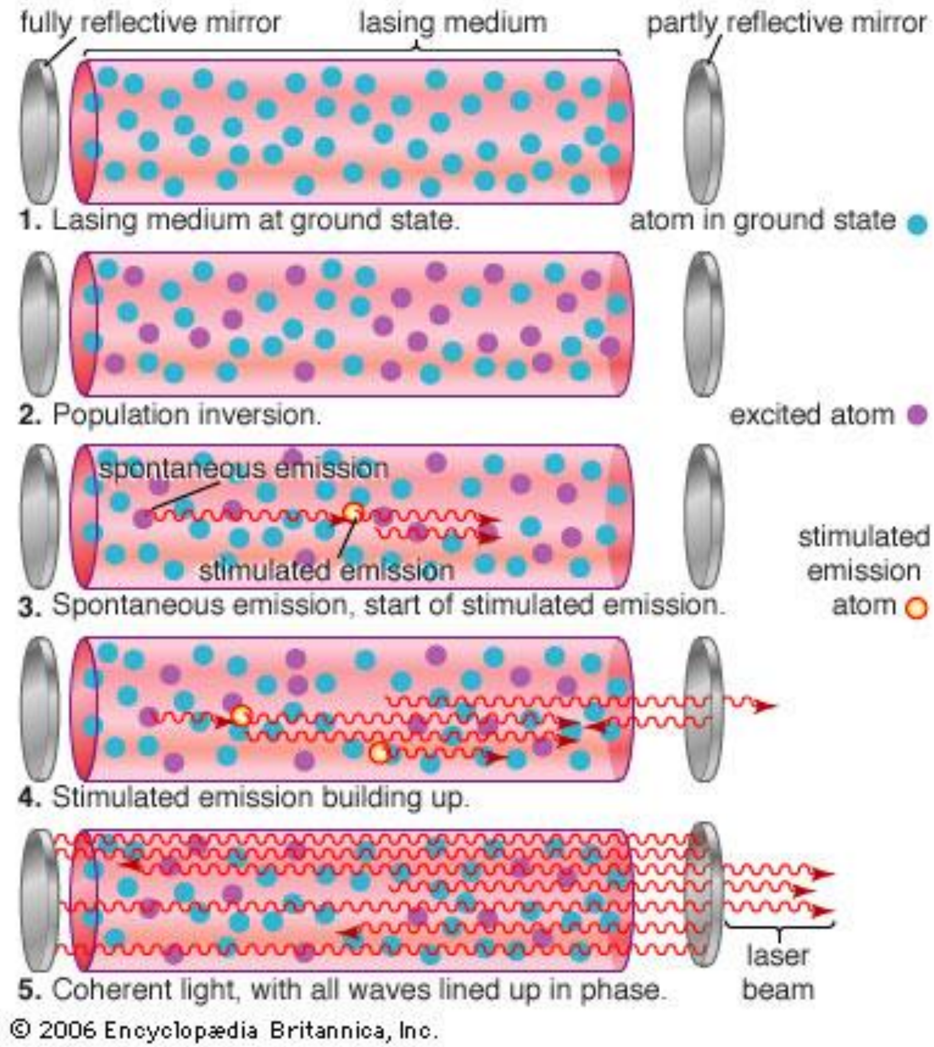
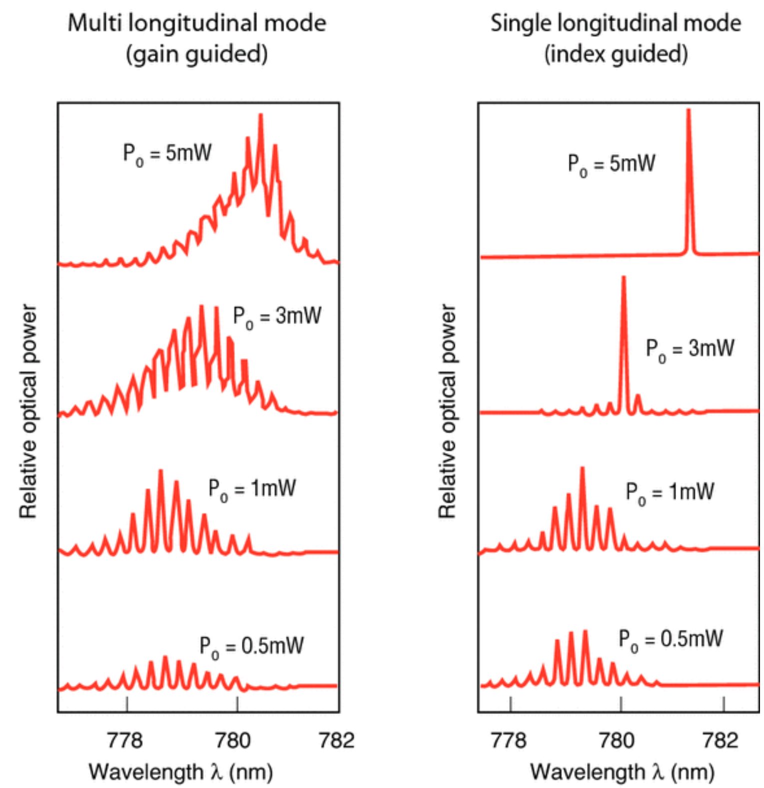


Laser – Stimulated Emission inside an optical cavity

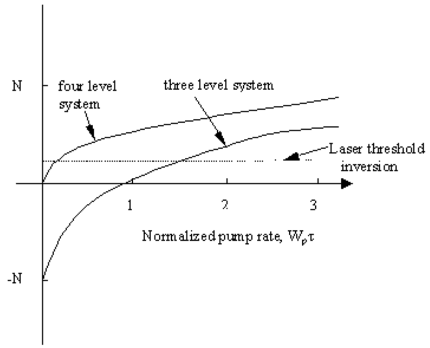


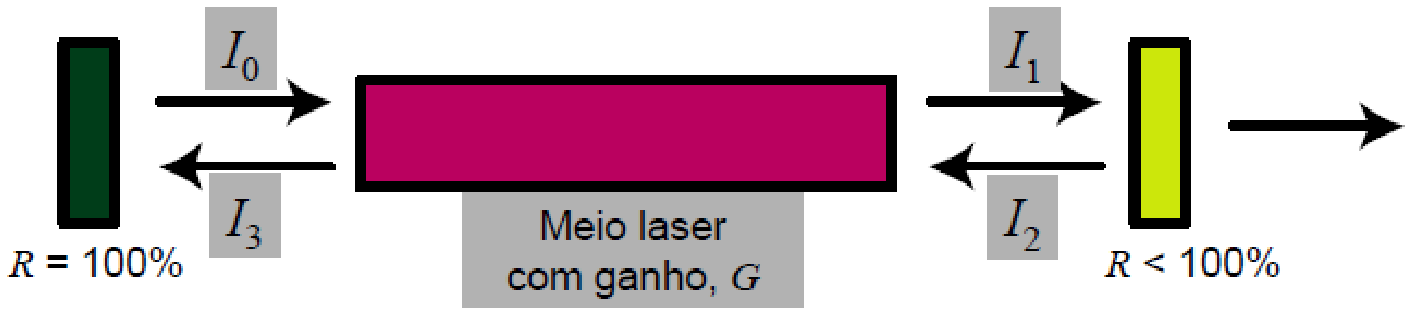
Optical Cavity enables feedback and spectral filtering



The LASER

The LASER is made by a medium that stores energy, in between mirrors –where one of the mirrors is partially reflective, allowing part of the light to exit the cavity.





For a laser to work as such, the intensity must be higher after a round trip around the cavity

$$I_3 \geq I_0$$

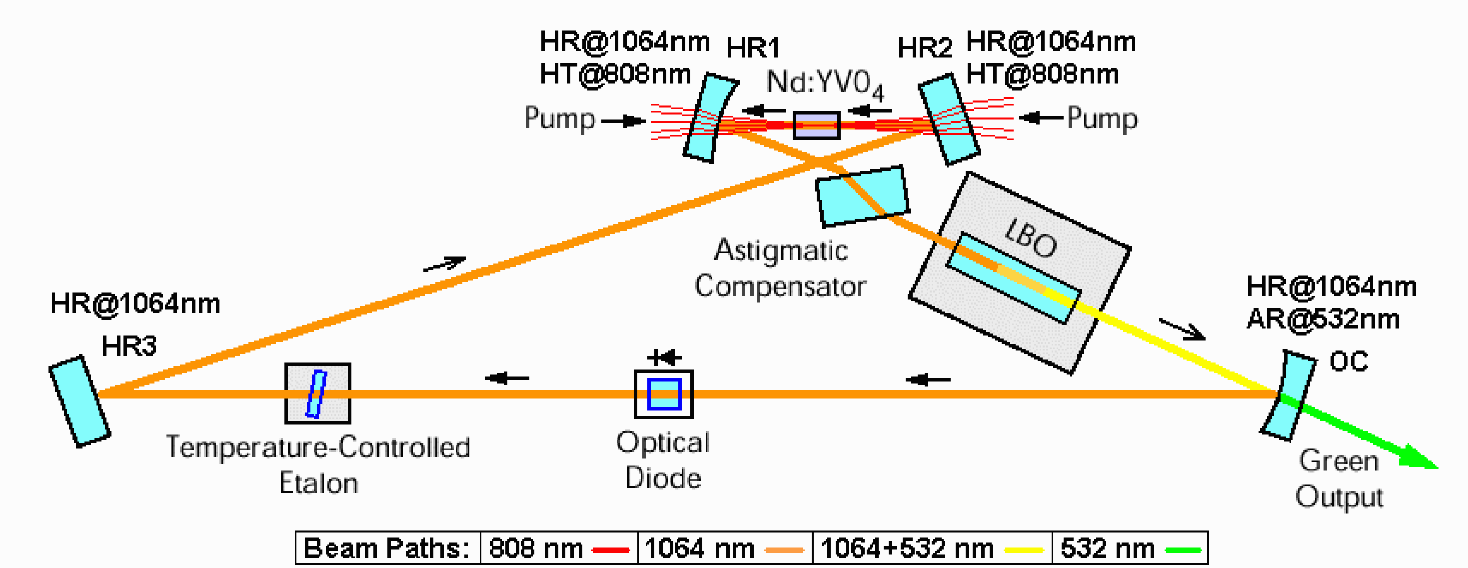
Losses from absorption, scattering and reflections take place inside the cavity. In general, the LASER radiation will be emitted only if:

$\boxed{\text{Gain > losses}}$

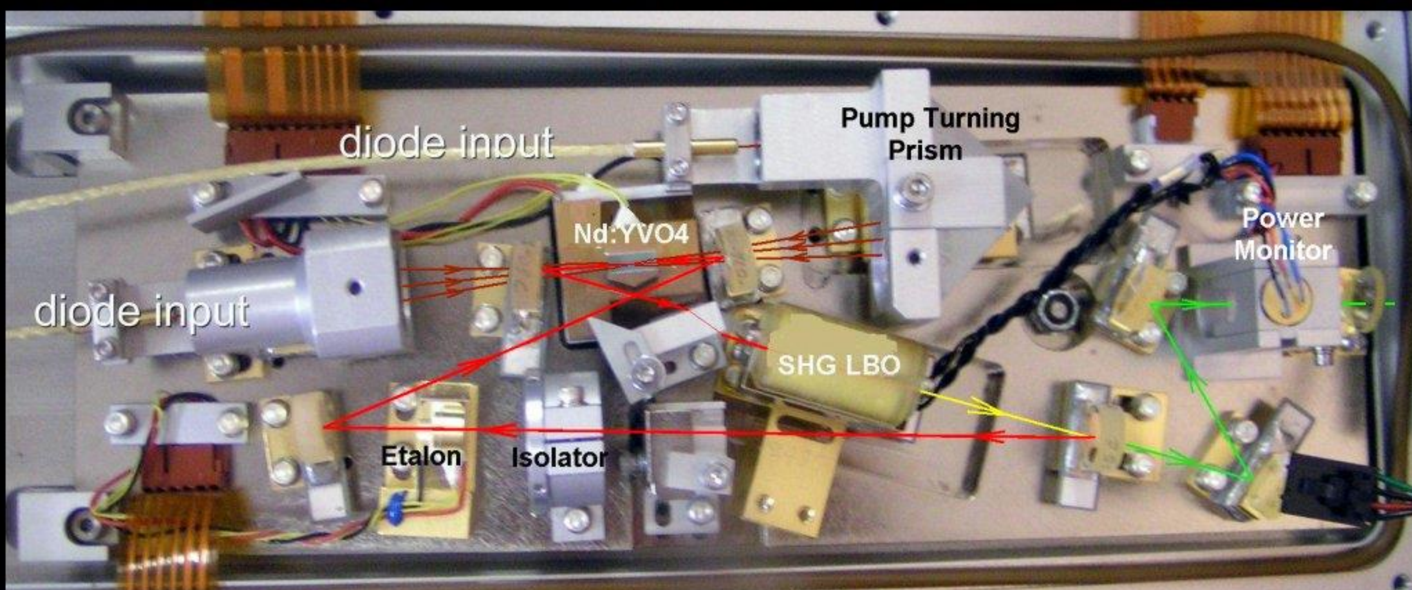
When Gain just overcome Losses, it is said the "Threshold" condition.

A beam of LASER light is:

- **Monochromatic**: It has a specific narrow wavelength λ (well defined colour). The emission λ is determined by the amount of energy released by the electron in transition to a lower quantum, level.
- **Coherent**: Light is "organized" – each photon is a clone of its stimulated pair. All photons have similar properties of phase, wavelength, polarization and direction.
- **Collimated**: The LASER beam is tight and directional, very bright with very small divergence. As opposed to a flash light, which emits light in all directions, diffuse and low brightness.
- It can be operated with continuous or pulsed emission.



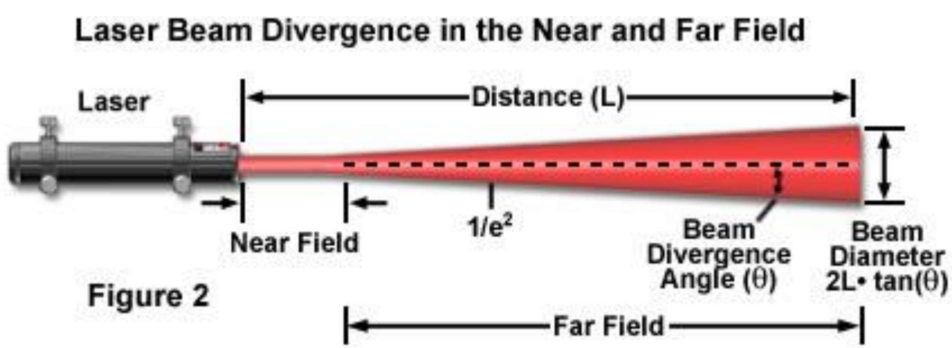
Ring Cavity Resonator of Coherent, Inc. Verdi Green DPSS Laser

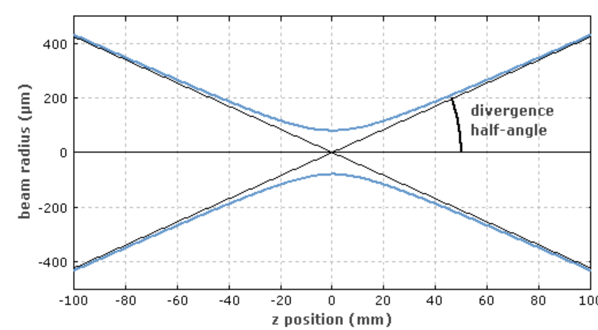


Coherent Verdi DPSS Laser Cavity with Components Labeled

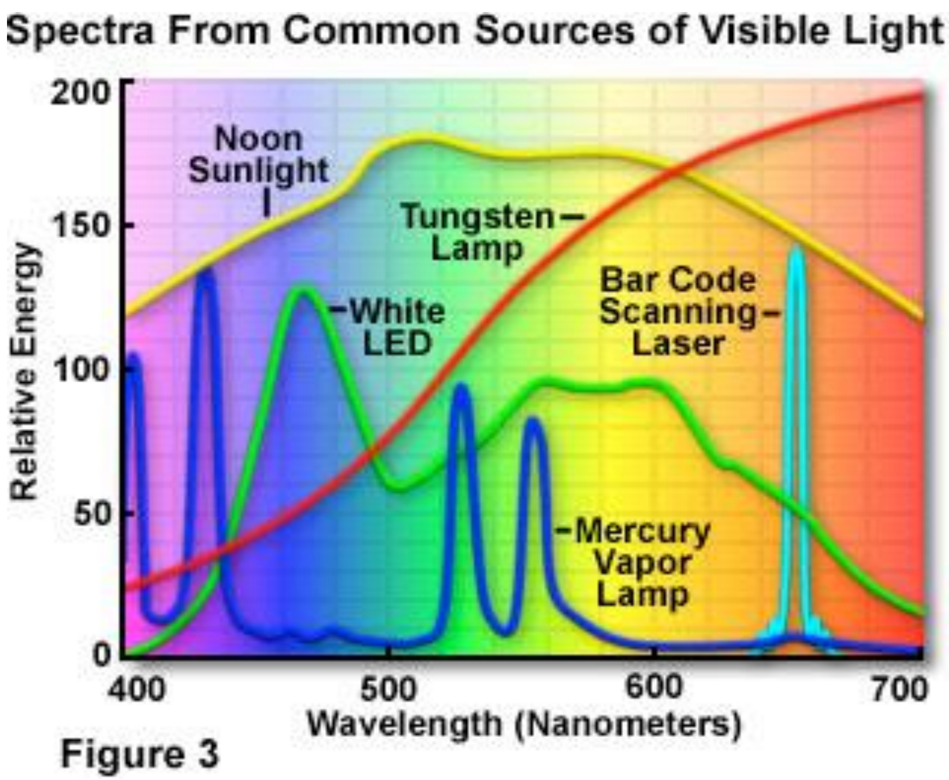
Directionality

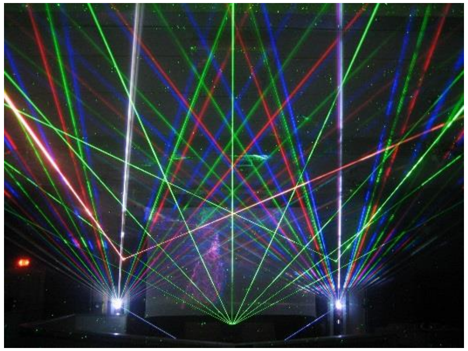
Divergence: Lamp >180º
LED: 15 º
Laser: mrad (1/100´s of deg)





Monochromatic (very narrow spectral bandwidth)

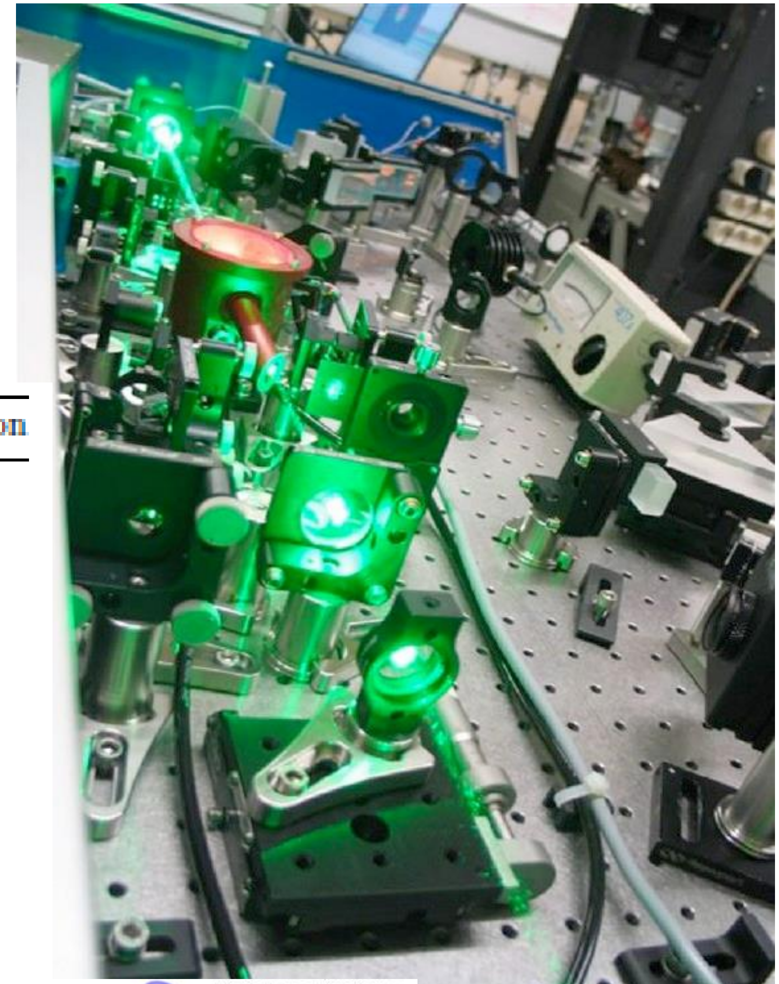




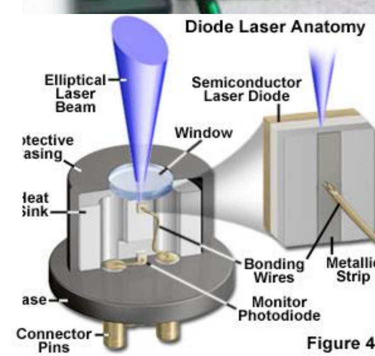
Sun, tungsten lamp: 100´s nm
LED: 20 nm
Laser: sub pm! (khz)

Types of Lasers

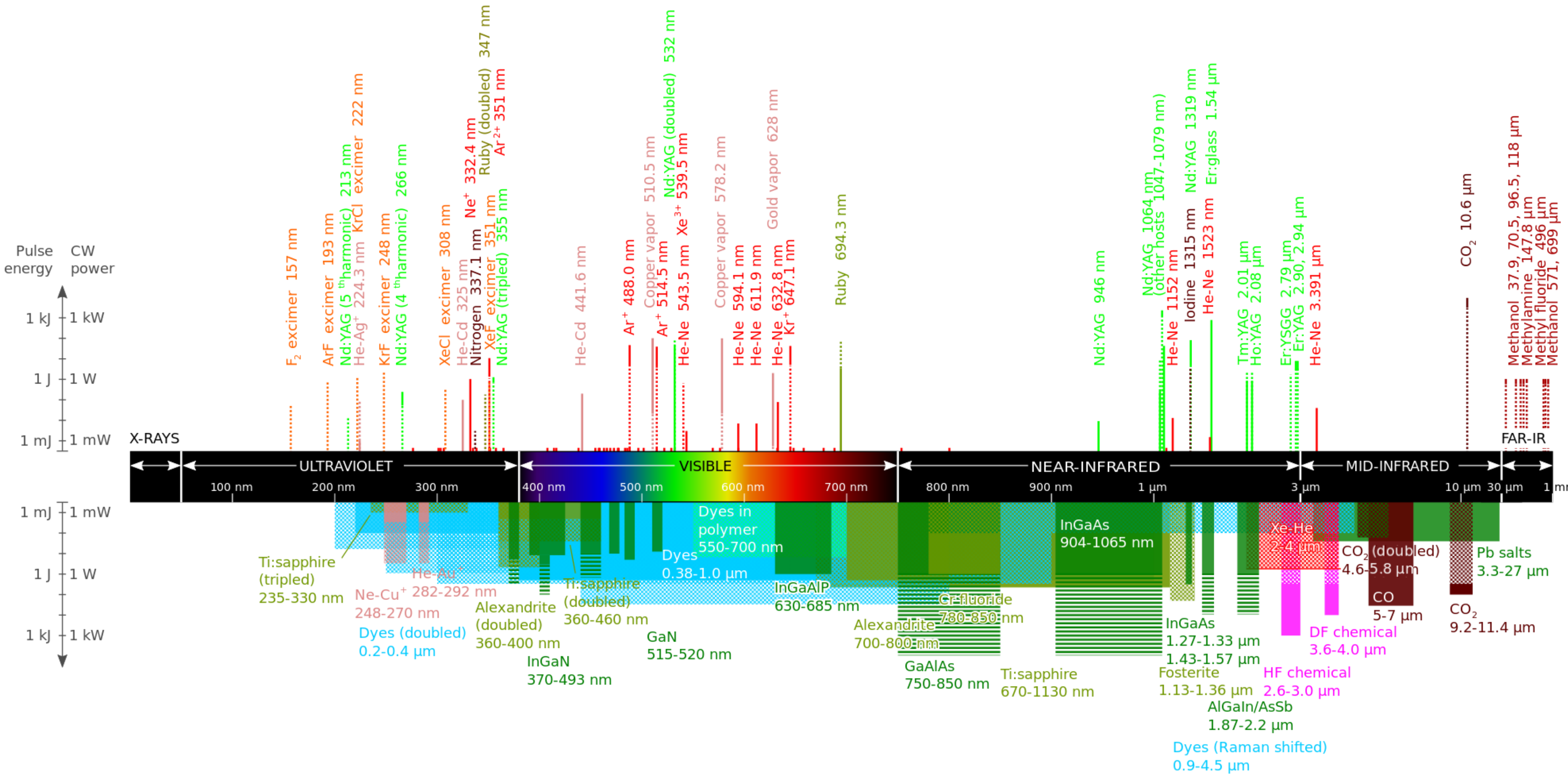
- Crystals (eg. Rubi, Nd:YAG)
- Semiconductors (InGa As)
- Gas (eg. He-Ne, KrF)
- Dyes (Rodamine)



Laser type	Wavelength	Typical pulse duration
Argon ion	488/514 nm	CW
Krypton ion	531/568/647 nm	CW
He-Ne	633 nm	CW
CO_2	10.6 μm	CW or pulsed
Dye laser	450–900 nm	CW or pulsed
Diode laser	670–900 nm	CW or pulsed
Ruby	694 nm	1–250 μs
Nd:YLF	1053 nm	100 ns – 250 μs
Nd:YAG	1064 nm	100 ns – 250 μs
Ho:YAG	2120 nm	100 ns – 250 μs
Er:YSGG	2780 nm	100 ns – 250 μs
Er:YAG	2940 nm	100 ns – 250 μs
Alexandrite	720–800 nm	50 ns – 100 μs
XeCl	308 nm	20–300 ns
XeF	351 nm	10–20 ns
KrF	248 nm	10–20 ns
ArF	193 nm	10–20 ns
Nd:YLF	1053 nm	30–100 ps
Nd:YAG	1064 nm	30–100 ps
Free electron laser	800–6000 nm	2–10 ps
Ti:Sapphire	700–1000 nm	10 fs – 100 ps



Lasers



http://www.gaotec.com/index.php/products-applications/clc-laser/about-laser-wavelengthandapplications

Exercises

2. Calculate the number of wavelengths of red light emitted by an He-Ne Laser, (λ= 632.8 nm), that fit in a sheet of paper with a thickness of 0.075 mm. What would be the length occupied by the same number of wavelengths, for microwaves at frequency of 10 GHz?

3. A flash lamp (3.0 V, 0.25 A) converts about 10% of its power into light (λ ~550 nm). If the beam has an initial section of 5 cm^2:
   a. How many photons are emitted per second?
   b. How many photons are the is each m of beam?
   c. What are the characteristics of the pointing vector (direction and magnitude?)? At the lamp output.

Bibliography and multimedia

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http://www.aml.engineering.columbia.edu/ntm/level2/ch02/html/l2c02s04.html

http://electron6.phys.utk.edu/optics421/modules/m5a/lasers.htm

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17/2	Semana 2	JAVA laser simulation. Pinciples of laser action and properties of laser ligth. Types of lasers.	1.6-7		13.1