LASER

engineering overview

MUSE meeting INFN

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OPTOPRIM srl

Optoprim is a distributor for optoelettronic components, and laser sub systems. We have offices in France, German and Italy.

Optoprim S.r.l. has been founded in1999

9 people in Monza (main office)

3 people in Roma

4 senior Sales Engineer; 2 junior Sales Engineer

3 Tecnichian for installation, service and process development

We have an internal lab with laser and equipment to prepare samples and for process validation in accordance with customers requests.

Market and products

Laser Processing

Laser: fiber, DPSS, ps, fs, direct diodes
Process head for: cutting, welding and cladding
Laser machine for high end custom applications
optics, F-theta, galvanometer

Scientific/R&D

Instrumentation (laser and light sources analysis and characterization),
Coherent and wide spectrum light sources
Non-destructive superficial and volumetric analysis of materials
Laser protection systems

Medical:

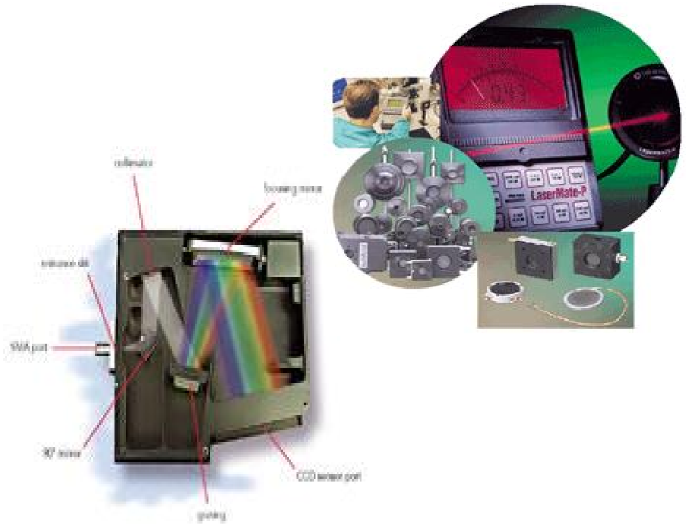
Diodes: free space ed fiber coupled, optics, protection goggles,
power meter

Military, defence and aerospace:

Laser, optics, Instrumentation

Product range:

Laser & Optics



Test & Measurement

Positioning

Summary

Concepts of laser theory and laser light features.

Main laser types

Principal laser applications

LASER

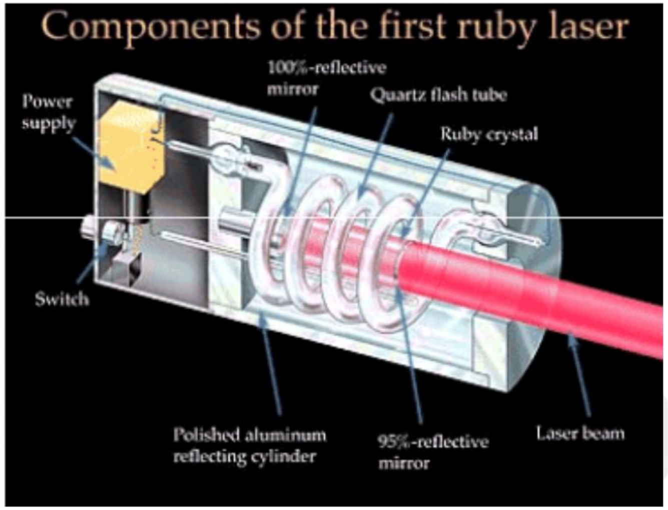
Light Amplification by Stimulated Emission of Radiation

1917: Einstein states the stimulated emissions theory to explain the Plank black body law

1954: Gordon designs the MASER (Microwave Amplification

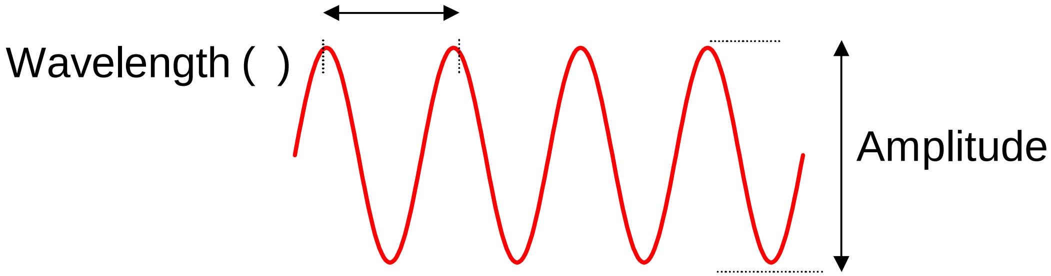
1960: Basov, Krokhin e Popov develope the laser theory

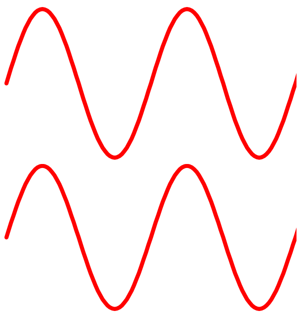
1960: Maiman manufacture the first laser (ruby based)



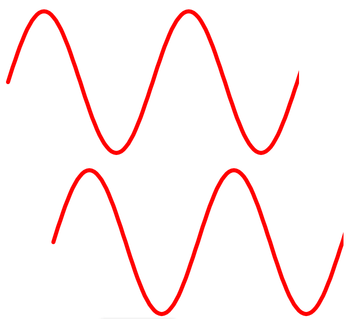
Electromagnetic radiation

Light is an elettromagnetic wave sum of photons, each with an associated Wavelength and Amplitude





Photons can be in phase

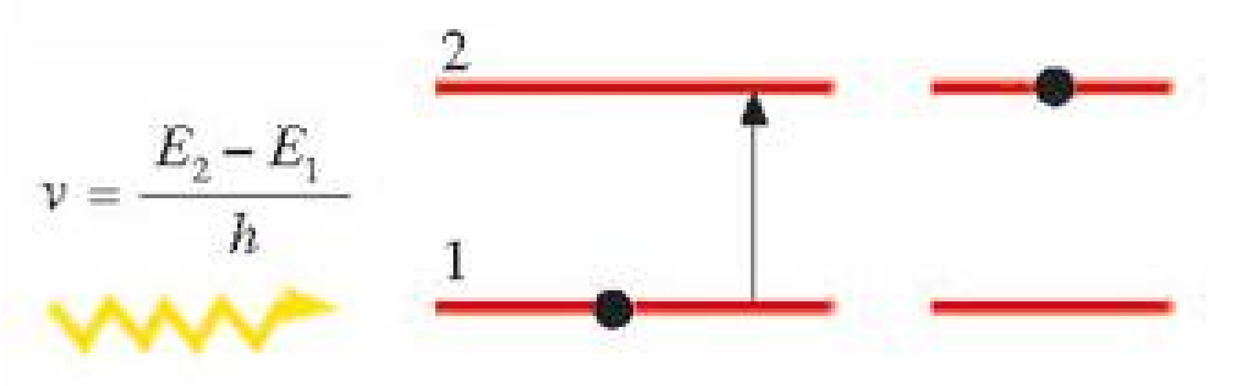


phase

Light sources: absorption and excitation

Light generation occurs within the atom structure.

Energy absorption processes excite the electron to a higher energy level.



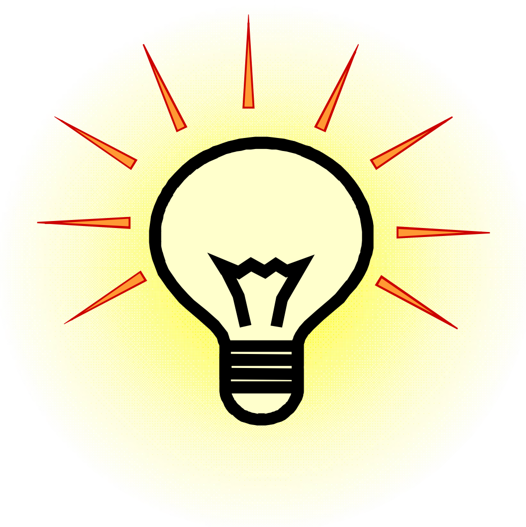
If energy is supplied to the atom (absorption), an electron can "jump" to an higher energy state. The atom gets excited, and has more energy than before. On the opposite, if the electron decays to a lower energy level, the atom decreases its energy and releases a photon.

Spontaneous emission

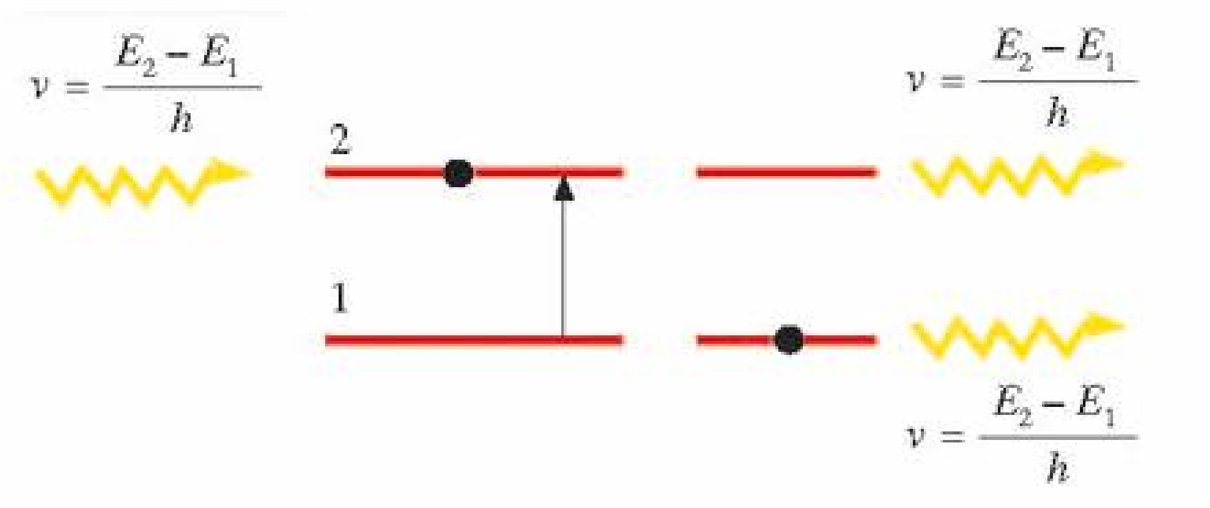
This process happens randomly: photons (of different energy) are emitted in all directions and the associated waves are out of phase.

For example, in a light bulb the current warms the filament, bringing its atoms into a variety of excited state.

Subsequently, they decay by emitting light.



Stimulated emission



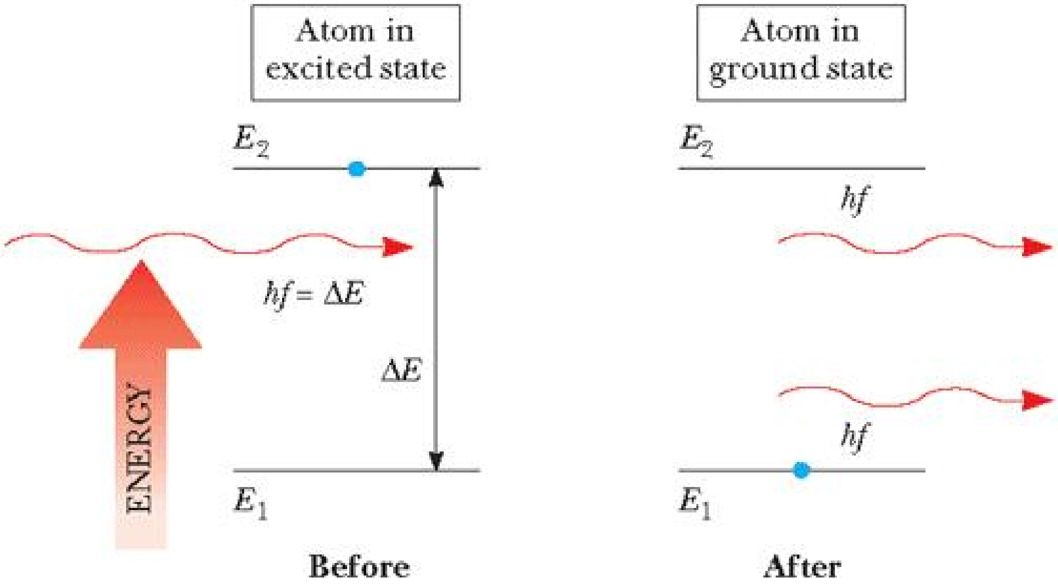
The stimulated emission consists in the decaying of the excited level by a photon of the same energy (theorized by Einstein).

Thus, two quantizes of identical em radiations are obtained, that is, coherent (with the same phase), with the same wavelength and in the same direction.

laser

The laser generates from the stimulated emission phenomenon.

If you have a population of atoms in an excited state and they are hit by an energy radiation equal to the excitation level, the electrons will immediately fall into the lower orbit, emitting photons of the same energy, phase and direction of the incident one.



Conditions required

To generate a laser from the stimulated emission process, it is required to have an electron accumulation in the excited state of the system. To achieve this status, the following three conditions must be met:

1) Inversion of population;

2) The excited state must be a metastable state;

3) The emitted photon must be able to stimulate other photons of the system and must therefore be confined.

1. Inversion of population

Atoms are usually in the fundamental state, so an incident radiation has a greater chance of being absorbed rather than producing stimulated emission.

It is therefore necessary to carry several atoms in a higher energy state, leaving almost empty the lowest state .

This condition is called POPULATION INVERSION.

An incident photon could cause an "avalanche" of stimulated electrons, all perfectly in phase. Such stimulating wave would continue to increase in intensity while propagating through the active medium, as long as the inversion of population can be maintained.

1. Inversion of population

The population inversion condition is achieved when:

N2> N1

That is, when the number of atoms excited in the active medium is greater than the number of atoms in the fundamental state.

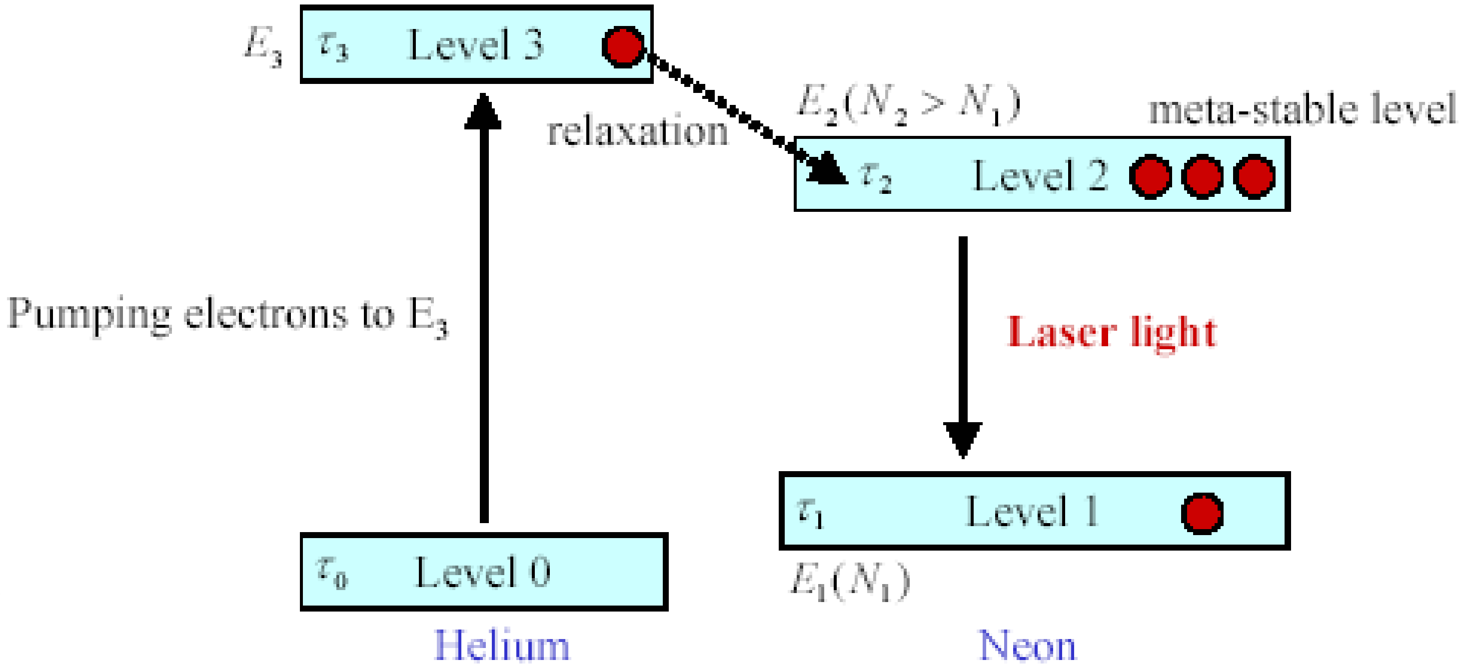
In a two-level laser design you can get at the most: N2 = N1

This is therefore not a beneficial device.

Lasers structures are then designed as 3 or 4 level systems.

2. metastable excited state

If the excited state is metastable (that is, it has a long average life compared to the short time of excited states ~10^{-8} s), then the stimulated emission is more likely to occur than the spontaneous emission.



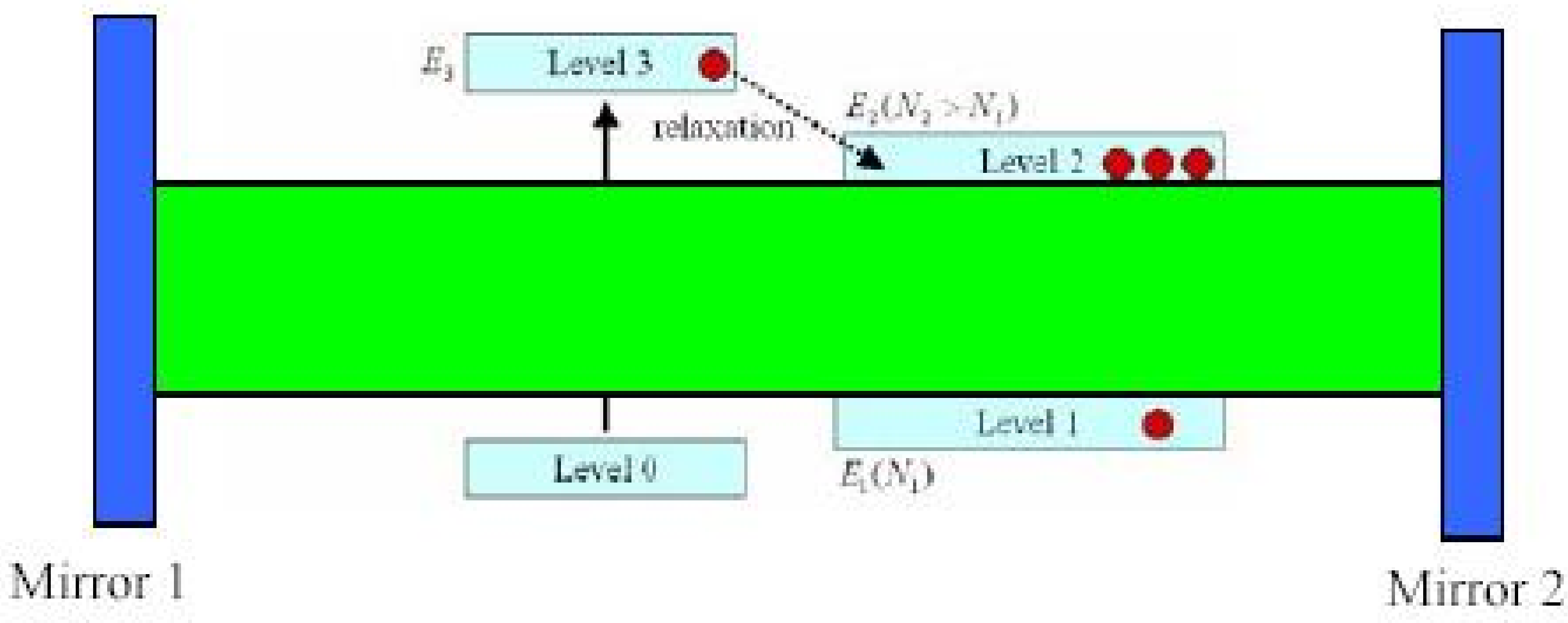
$_2 >> \; _3$

$N_2 > N_1$

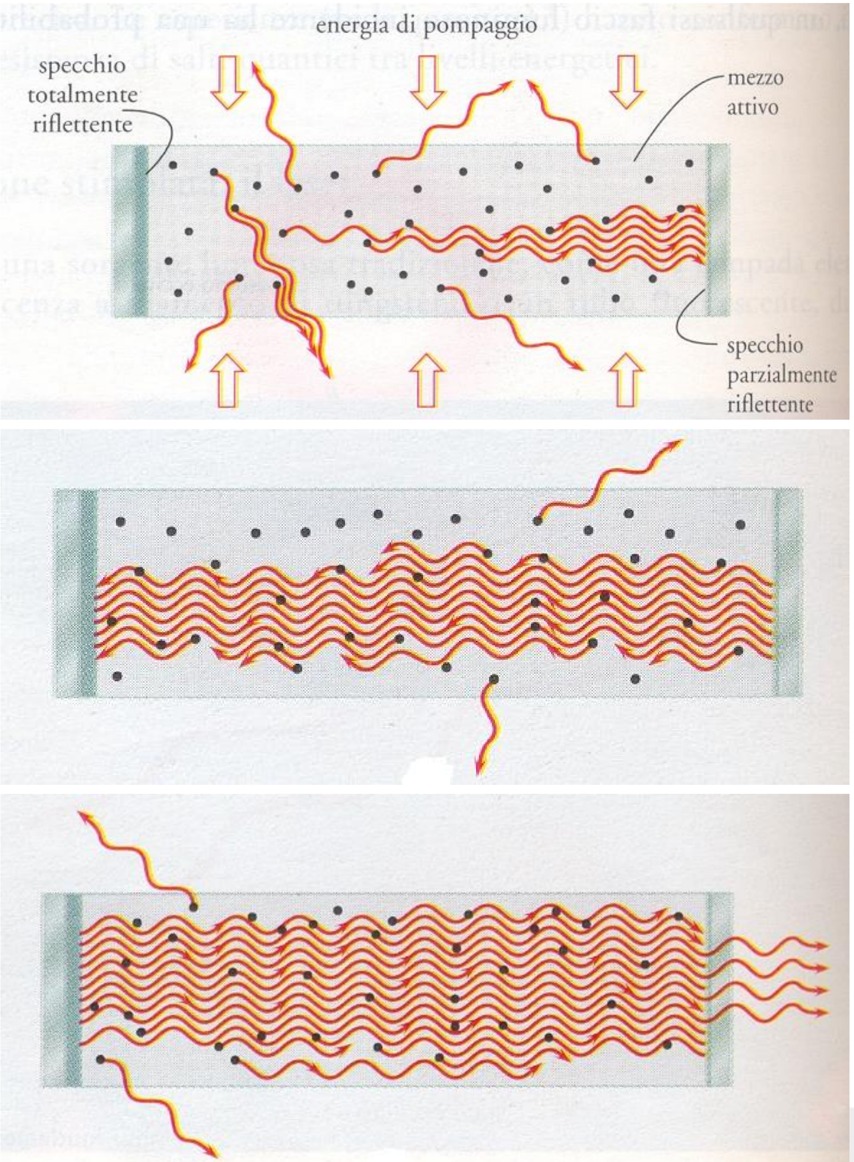
Popultaion inversion

3. Resonant cavity

The process can be promoted by placing the active medium between two mirrors, so that the light wave, reflecting back and forth, crosses the medium several times (from which Amplification of Stimulated Emitted Radiation).



3. Resonant cavity

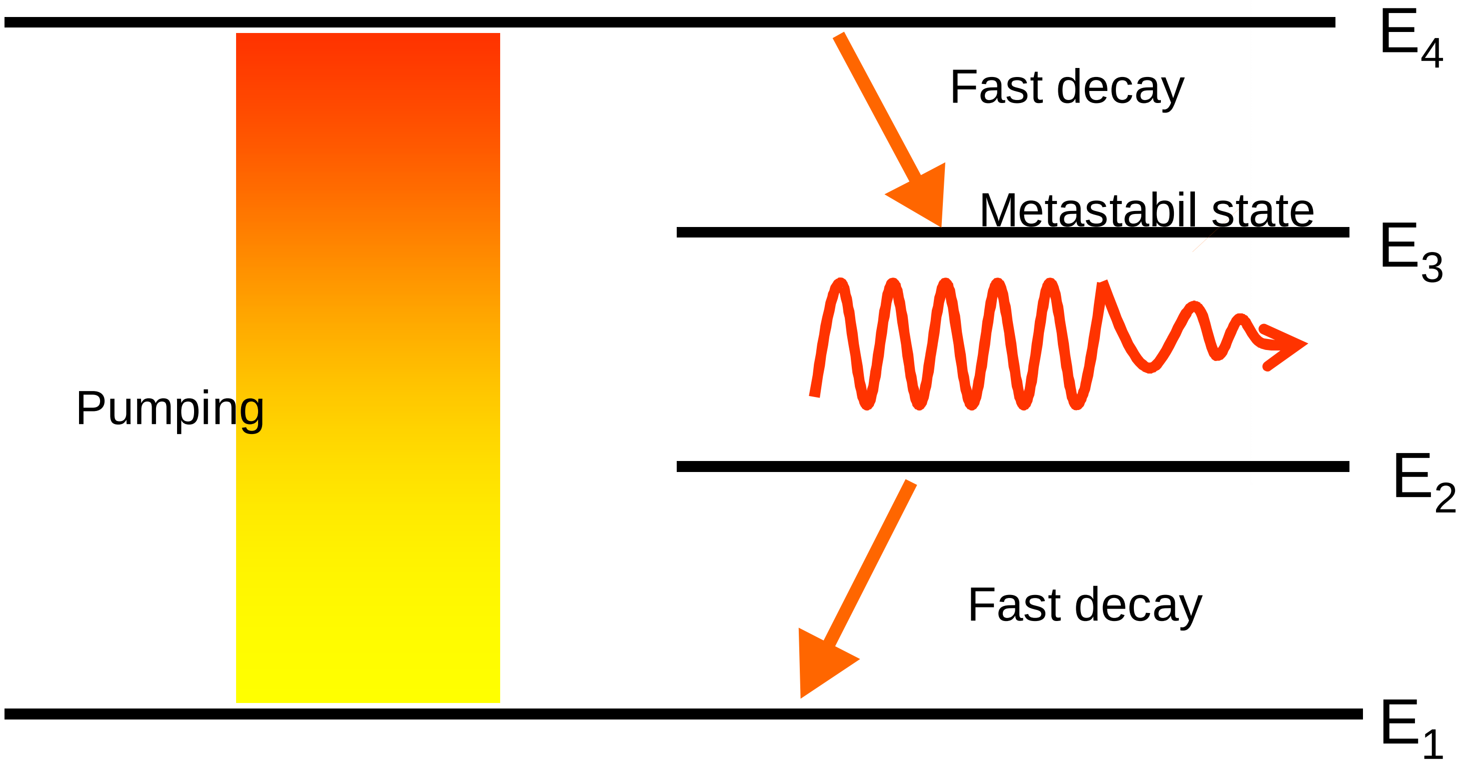


One of the mirrors has a R ~ 100%, the other has a R <100% to allow the light to go out as laser beam. The rest remains trapped and continues the stimulated emission process.

The two mirrors, which confine the photons into the cavity, form a resonant cavity: they allow to propagate only wavelengths which are an exact multiple of the cavity length.

In addition, only photons directed along the cavity axis are propagated and amplified.

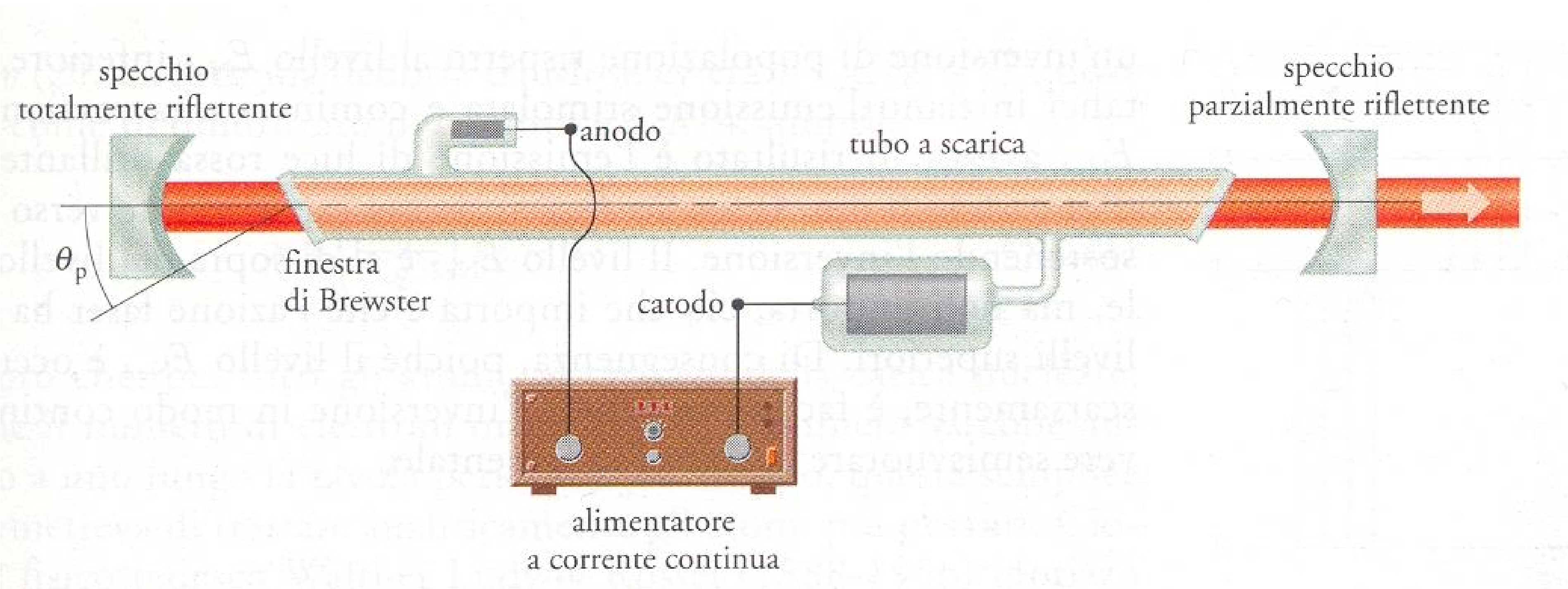
Four levels laser: general scheme



Quantum efficiency: $\frac{E_3}{E_1}$

Laser sources simplified scheme

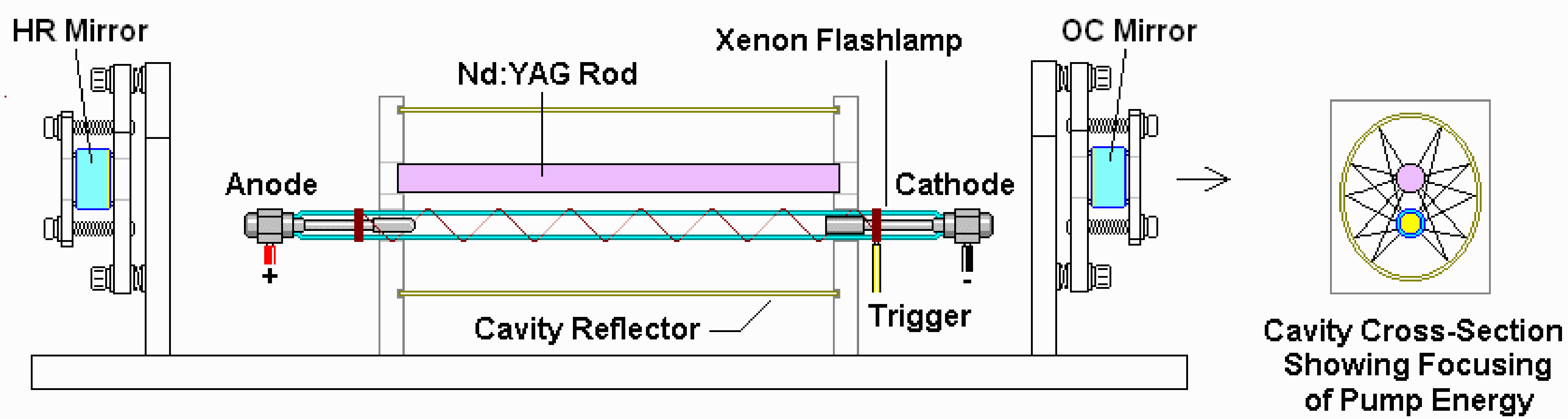
Gas Laser



Es: He-Ne ; CO2, Argon

Laser sources simplified scheme

CW Laser solid state (flash and diode pumped)



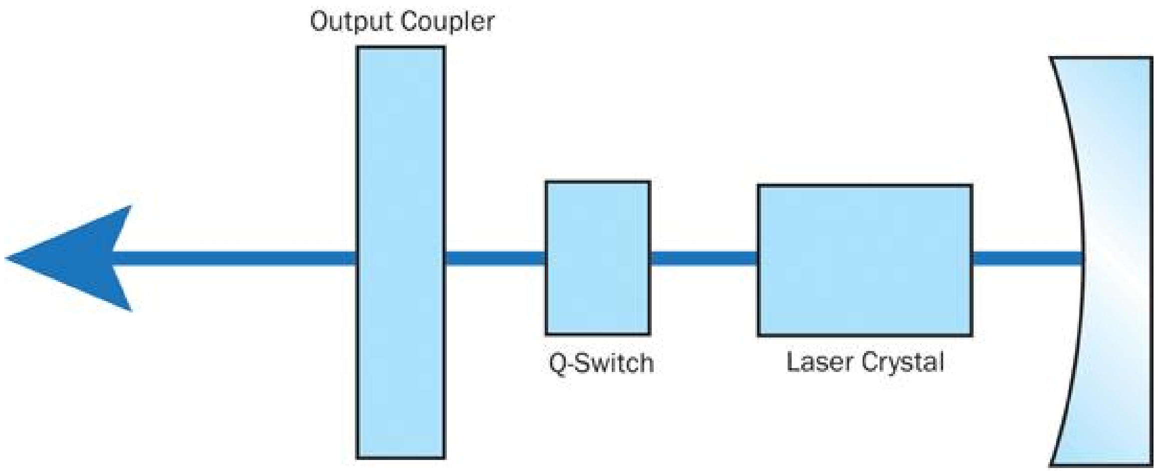
Home-Built Pulsed Solid State Laser Assembly

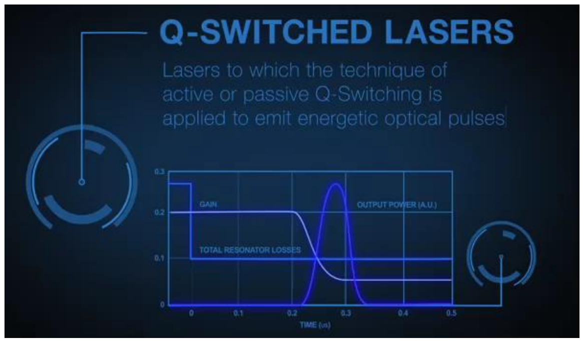
Es: Nd:YAG; Erbio

For industrial applications, CW laser use up to tens of KW

Laser sources simplified scheme

Solid state laser - (flash or diode pumped)
Pulsed Q-Switched

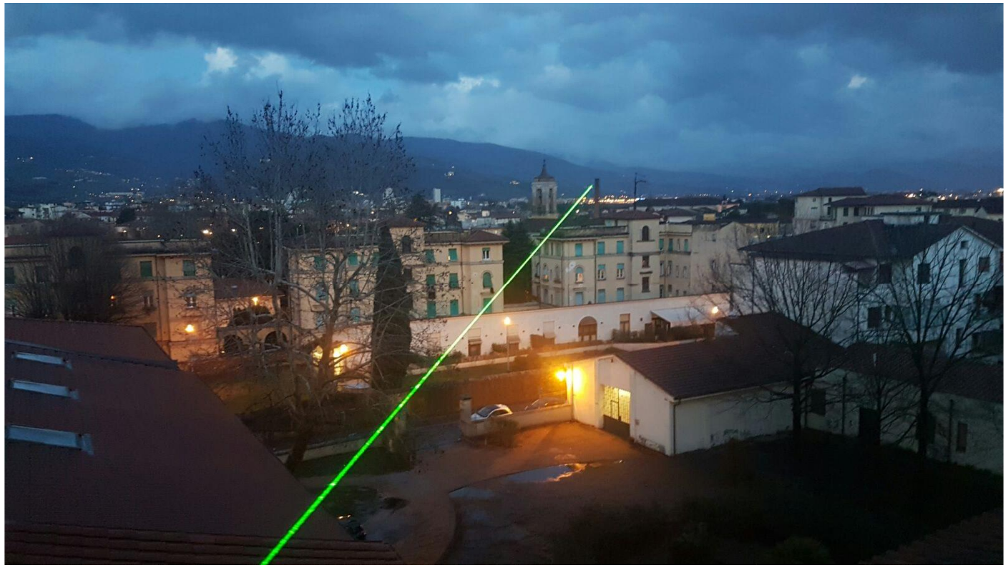




There are several technologies used to generate pulsed laser, exploiting which today is possible to generate ultra-short pulses (the record is 67 as 10^{-18}s) or amplified systems that emit peak power of PW (10^{15}W)

Laser light properties: Unidirectional

A laser beam propagates with a minimal divergence: a green Argon laser beam starting with a diameter of one centimeter extends to a diameter of three centimeters over a 500-meter journey.



The laser light propagates indefinitely in a well-defined direction, unlike the light of a regular incandescent bulb that emits light in all directions.

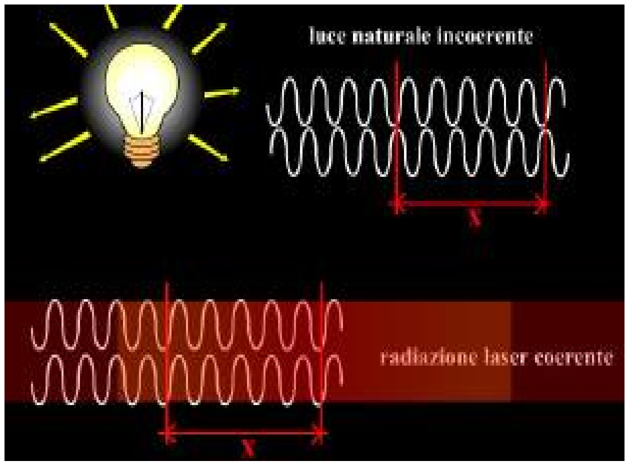
Properties of laser light: Monochromatic

Laser radiation always has the same frequency/wavelength while an incandescent bulb emits radiation consisting of photons with different energy.

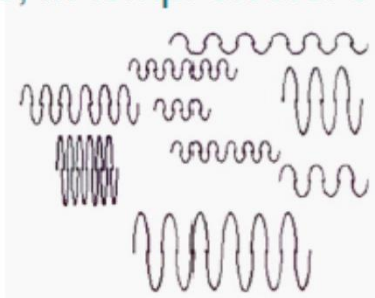
Monochromatic is linked to the generation of photons by decaying electrons between defined levels and hence with fixed and constant energy. Different active mediums/dopants generate different wavelengths (193 nm - 12000nm)

Laser light properties: Spatial and temporal coherence

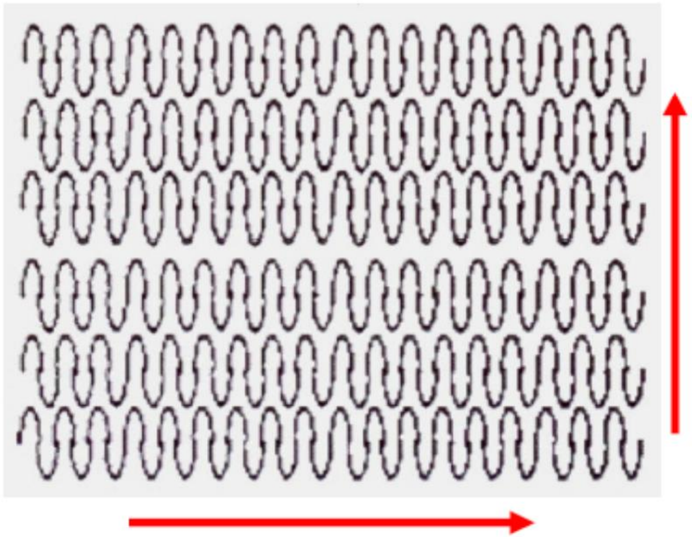
Spatial coherence is a consequence of the structure of the resonant cavity of the laser made of two parallel mirrors located at a distance such as to keep the traveling beam in phase with the photons extracted during the stimulated emission process. Time coherence results from the simultaneous extraction of all the photons during the stimulated emission process.



Emissione incoerente: i fotoni vengono emessi casualmente, in tempi diversi e con fase diverse



Emissione coerente: i fotoni vengono emessi simultaneamente e con la stessa fase



***Coerenza spaziale**: le onde hanno la stessa fase in tutti punti della sezione del fascio*

***Coerenza temporale**: le onde conservano la stessa fase nel tempo*

Laser Light Properties: Brightness

An important applicative property of laser and consequent of the first two is the defined as the power emitted by the surface unit under a solid unit angle Ω

$$B = W / S \cdot \Omega$$

laser are

<u>coherent, monochromatic and with very high brightness</u>

light sources

Overview of Laser models: medium

	Laser Name	Oscillation Wavelength	Application
Gas Laser	Helium-Neon Laser	Red/Monochrome 632.8 nm	Optical Axis Alignment Adjusted Length Measurement
	Argon Ion Laser	Blue to Green Multi-line	Optical Axis Alignment, Laser Printing, High-speed Camera Light Source
	Carbon Gas Laser	Infrared 10.6 μm	Metal Welding, Fusing, Processing
	Excimer Laser	Ultraviolet 126 nm to 351 nm	Polymer Micro-processing, Light Source for Academic Purposes (LIF)
	Nitrogen Laser	Ultraviolet 337 nm	Low-priced UV Laser
Solid-state Laser	Ruby Laser	Red 694.3 nm	Holography
	YAG Laser	Red 1064 nm	Metal Micro-processing, Light Source for Academic Purposes (LIF), High-speed Camera Light Source
	Glass Laser	Infrared 1.06 to 1.08 μm	Holography
	Nd (Neodymium) Laser (Nd: YAG, YLF, YVO_4, $YAlO_3$)	1064 nm 1047 nm 1053 nm	Optical Axis Alignment / Laser Excitation Micro-processing / Stage Display Light Source
	Titanium: Sapphire	660 nm to 1180 nm	Variable Wavelength Laser
	Fiber Laser	1050 nm to 1620 nm	Long Distance Communication High Temperature Processing
Metal Laser	Helium-Cadmium Laser	Blue White	Medicine Laser Printing
	Copper Vapor Laser	Dual-wavelength 511, 578 nm	Stroboscopic Light Source for High-speed Cameras Uranium Enrichment Pump Laser, Metal Micro-processing
	Gold Vapor Laser	Red	For Medicine, Skin Therapy
Semiconductor Laser	Semiconductor Laser	Red to Infrared	Communication, Solid-state Laser Excitation Light Source, High-speed Camera Light Source, Metal Processing, Laser Pointer Optical Pickup Light Source
Liquid Laser	Dye Laser	300 nm to 1200 nm	Variable Wavelength Laser

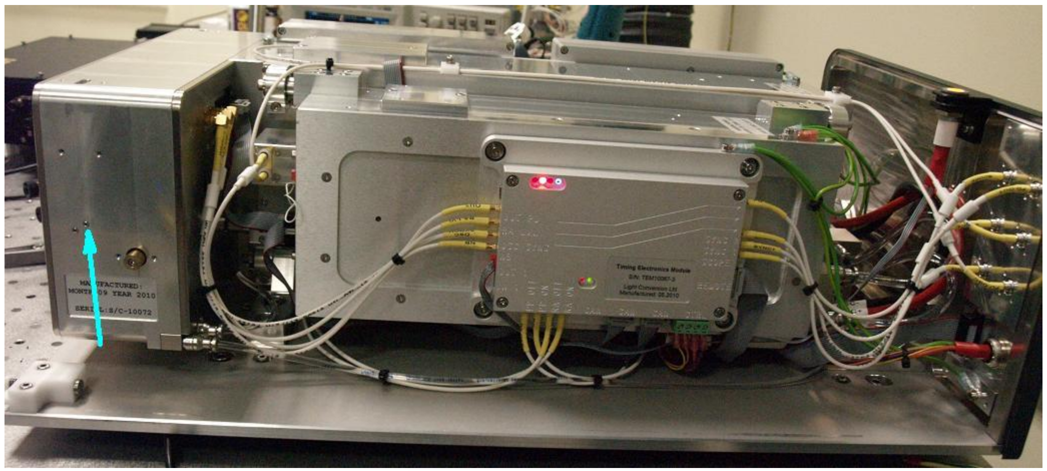
Overview of Laser models: pulse duration

Pulsed Lasers

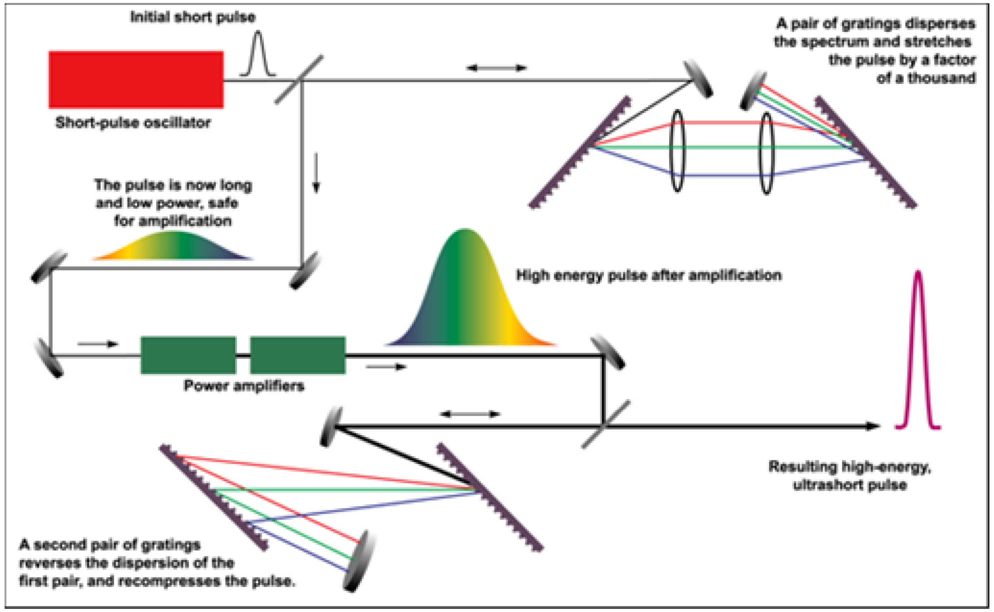
A pulse forming mechanism is needed otherwise lasers run "continuous wave" (CW)

Three types of pulsed operation

1. Gain switched (micro or millisecond pulses typically) turn gain on and off (flash lamps, modulate pump)
2. Q-switched (nanosecond pulses) modulate cavity loss on times scales > round trip time
3. Modelocked (picosecond to femtosecond pulses) modulate cavity loss periodically at roundtrip time



Simplified scheme for mode-locked fs laser



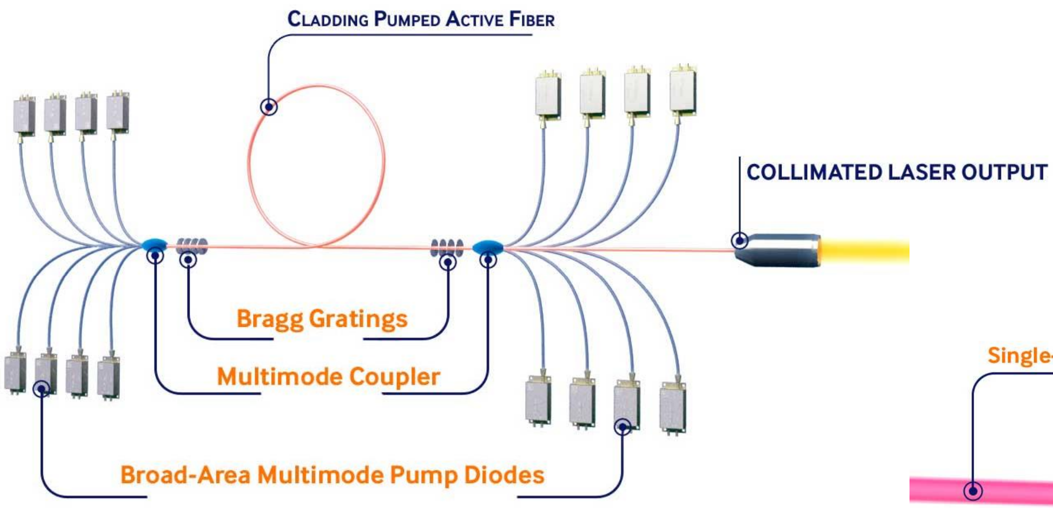
Fiber laser: a breakthrough in high power laser tech

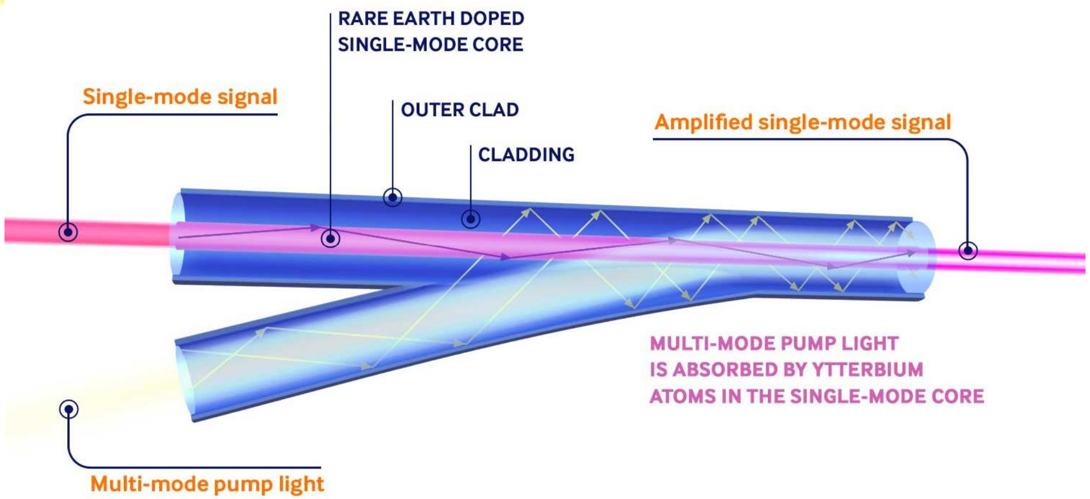
Unlike most other types of lasers, the laser cavity in fiber lasers is built monolithically by fusion splicing different types of fiber;

Fiber Bragg gratings replace conventional mirrors to provide optical feedback.

Fiber lasers are pumped by semiconductor laser diodes and can be CW or pulsed.

They are by far more compact, electrically efficient in respect to Nd:YAG technology





PHAROS

Femtosecond Lasers for Industry and Science

FEATURES

- **190 fs – 10 ps** tunable pulse duration
- **2 mJ** maximum pulse energy
- **20 W** output power
- **1 kHz – 1 MHz** tunable base repetition rate
- Pulse picker for pulse-on-demand operation
- Rugged, industrial grade mechanical design
- Automated harmonics generators (515 nm, 343 nm, 257 nm, 206 nm)

THE TUNABLE LASER LIGHT SOURCE
C-WAVE

SPECIFICATIONS

	VIS [a]	IR [b]
Wavelength range	450 – 650 nm [a] ± 1 nm	900 – 1300 nm [b] ± 2 nm
Wavelength selection	computer controlled	
Accuracy of wavelength setting		
· internal	± 1 nm	± 2 nm
· with external wave-length measurement	< 1 MHz [c]	
Power		
· with 1.5 W pump laser	> 80 mW	> 200 mW
· with 5 W pump laser	> 200 mW	> 400 mW
Amplitude noise	< 5 % [c]	< 1 % [c]
Beam polarization	> 1000:1	
Beam profile	TEM_{00}, $M^2 < 1.2$ [d]	
Beam radius ($1/e^2$)	0.5 mm [c]	0.2 mm [c]
Divergence	0.5 mrad [c]	2 mrad [c]
Linewidth	< 1 MHz [e]	
Mode-hop-free tuning	> 20 GHz [e]	> 10 GHz [e]

Laser applications

Research and industry have made extensive use of laser properties, employing them in the most diverse fields and applications. Its peculiar characteristics make it a flexible, selective and accurate tool and, at the same time, extremely powerful.

Unidirectional and collimated:
- Rangefinders
- Alignment
- Pointing
- Atom cooling

Monochromatic:
- Selective machining
- Excitation of defined quantum states
- Spectroscopy
- Atomic clocks

Brightness (High Energy Density):
- Cutting, marking and welding
- Fiber coupling (and associated benefits)
- Nuclear fusion

Coherence:
- Telecommunications
- Metrology
(Gravitational Waves Detection)
- Punctual monitoring variation of physical quantities over wide extended areas (fiber sensing)

The new application frontier is
electrons with photons to increase computing speed

Thank you

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