# *Specific Laser Systems*

## **Electro-Optics & Applications**

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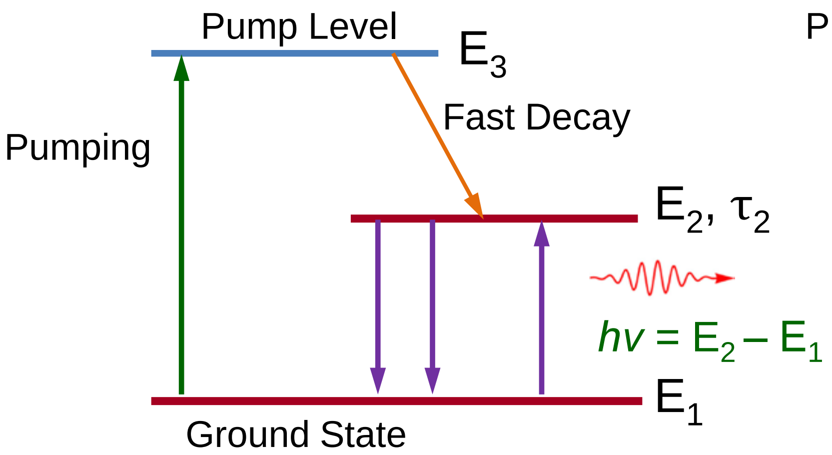
***National Technical University of Athens***

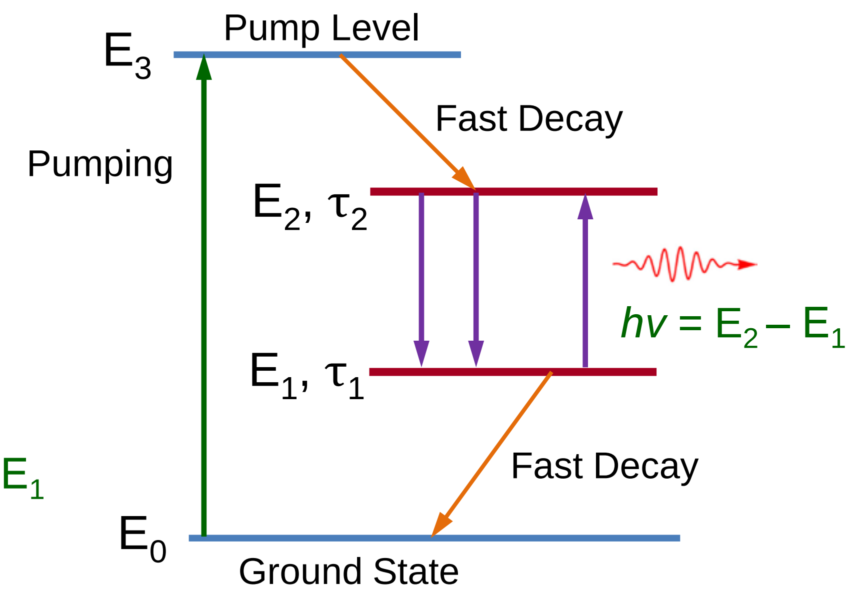
# Quantum Efficiency of Laser

## 3-Level System




$$\eta = \frac{E_2 - E_1}{E_3 - E_1}$$

## 4-Level System



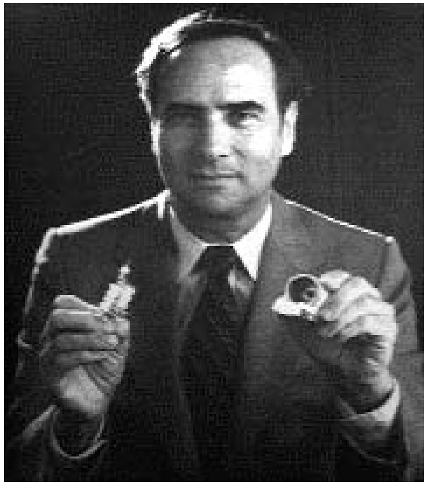

$$\eta = \frac{E_2 - E_1}{E_3 - E_0}$$

# Laser Excitation (Pumping)

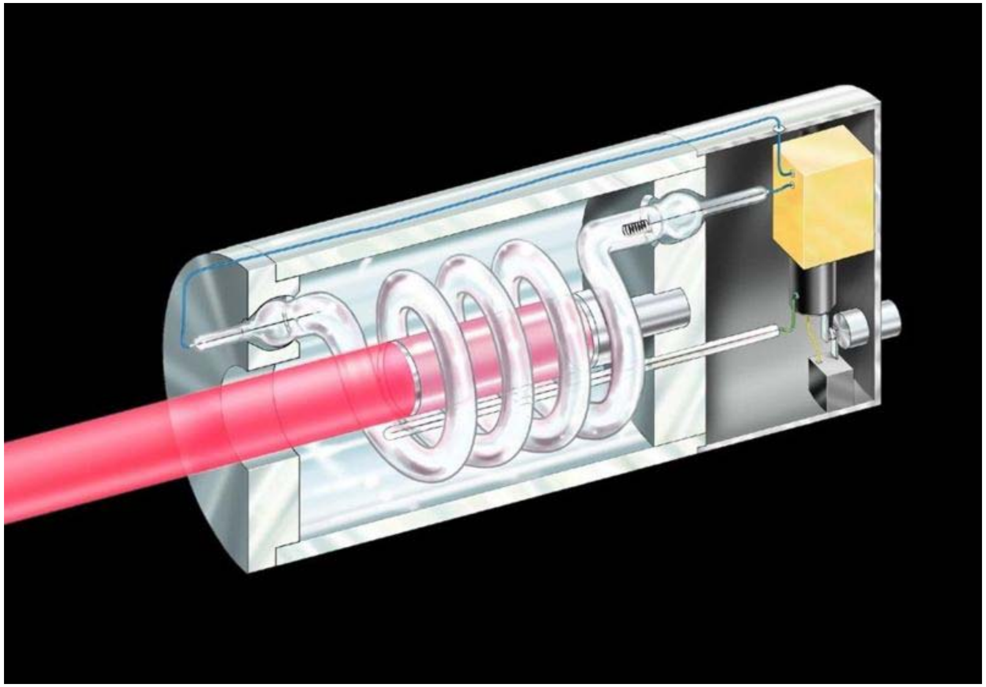
- Optical
  - Incoherent (flash lamp)
  - Coherent (another laser)
- Electrons
  - Gas Discharge (DC, RF, Pulsed)
  - Electron Beam
  - Electric Current (LD)
- Thermal Oven
- Chemical Reactions
  - Chemical Burn (flame)
  - Rapid Burn (explosion)
- Heavy Particles
  - Ion Beams
  - Fission Products
- Ionizing Radiation

From J. T. Verdeyen, “Laser Electronics”, 3rd Ed., Prentice Hall, 1995

# Invention of LASER (1960)

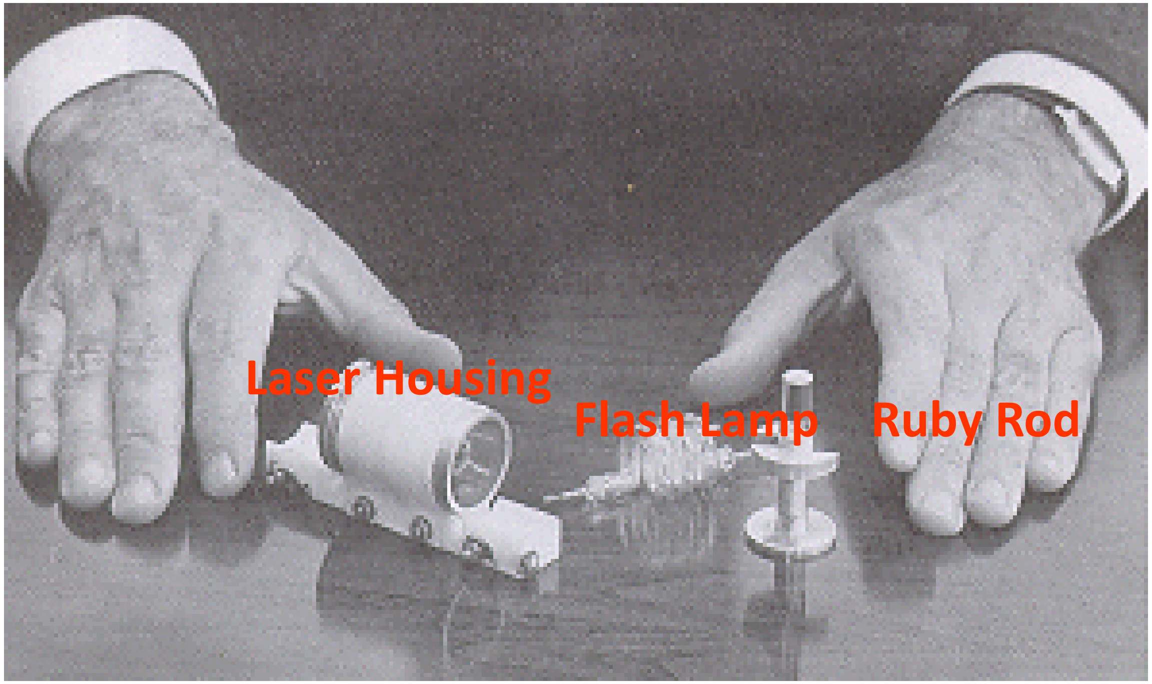


T. Maimann (1960)



Schematic of first Ruby Laser

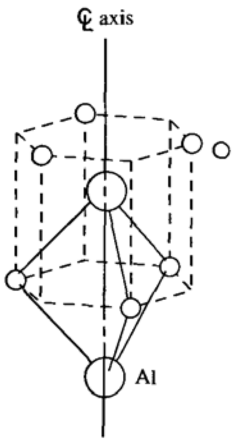
# Invention of LASER (1960)



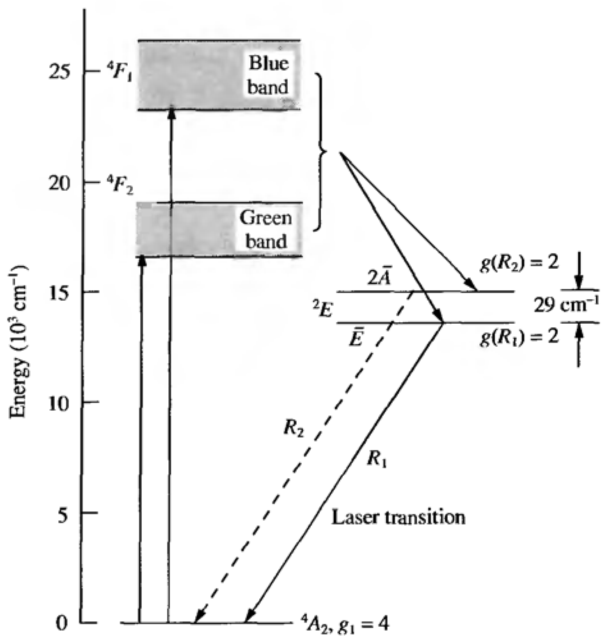

T. Maimann (1960)

- Freespace Wavelength of 694.3 nm.
- $\nu = c/\lambda = 5 \times 10^{14}$ Hz = 500 THz !!!

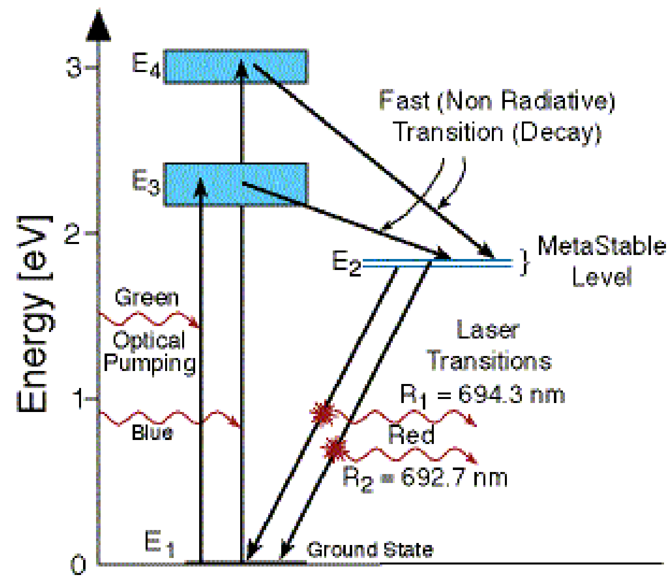
# Ruby Laser




(a)



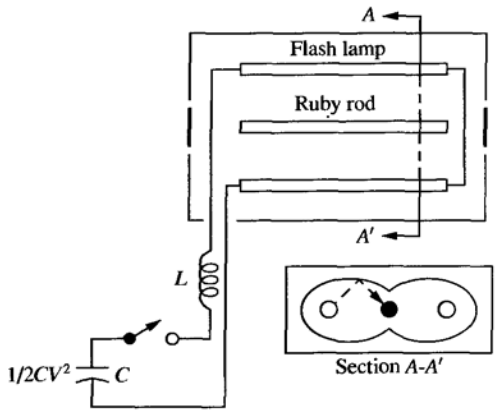

(b)




From J. T. Verdeyen, “Laser Electronics”, 3rd Ed., Prentice Hall, 1995

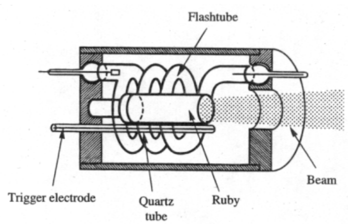
https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s2t1p2.htm

# Ruby Laser




(c)

**FIGURE 10.2.** Ruby laser. (a) Crystalline structure (chromium enters at an Al site.). (t
Energy-level diagram for $Cr^{3+}$ in $Al_2O_3$. (c) Typical pumping scheme using a dual ellipti
cavity.



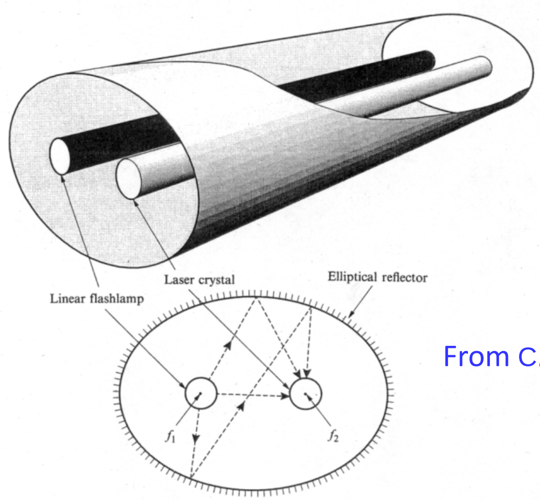




**TABLE 10.1** Physical Data on a Typical Ruby System*

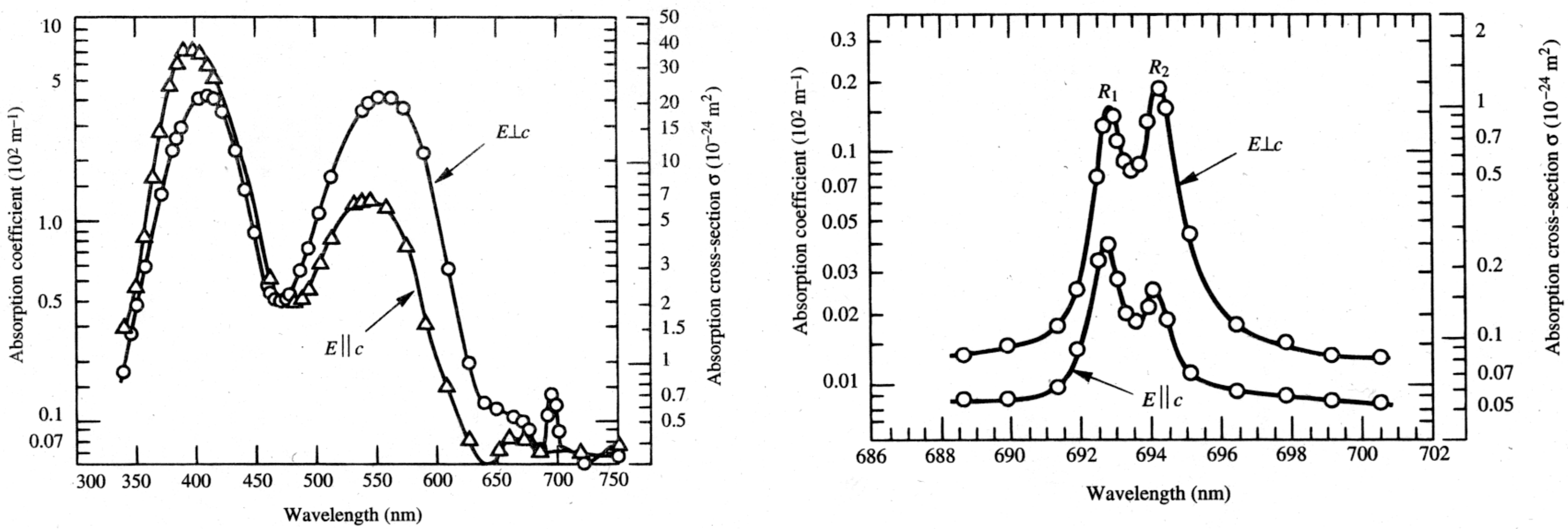
| Item | Value |
|---|---|
| $Cr_2O_3$ doping (% by weight) | 0.05 |
| $Cr^{3+}$ concentration | $1.58 \times 10^{19}$ cm$^{-3}$ |
| Output wavelength (at 25°C) | $R_1$ : 14403 cm$^{-1}$ ↔ 6943 Å |
| | $R_2$ : 14432 cm$^{-1}$ ↔ 6929 Å |
| Spectral line width (300°K) | 11 cm$^{-1}$ or 5.3 Å |
| Quantum efficiency (of pumping) | 0.7 |
| Absorption cross section of $R_1$ laser line | $1.22 \times 10^{-20}$ cm$^2$ |
| Stimulated emission cross section | $2.5 \times 10^{-20}$ cm$^2$ |
| Residual scatter losses in crystal at $R_1$ | ~ 0.001 cm$^{-1}$ |
| Major pump bands | |
| Blue (404 nm) | $\alpha_{\parallel} = 2.8$ cm$^{-1}$ $\alpha_{\perp} = 3.2$ cm$^{-1}$ |
| Green (554 nm) | $\alpha_{\parallel} = 2.8$ cm$^{-1}$ $\alpha_{\perp} = 1.4$ cm$^{-1}$ |
| Refractive indices | |
| Ordinary ray ($E \perp c$) | 1.763 |
| Extraordinary ray ($E \parallel c$) | 1.755 |

*Data from Koechner (Ref. 24).

From J. T. Verdeyen, "Laser Electronics", 3rd Ed., Prentice Hall, 1995

From C. Davis, "Lasers and Electro-Optics: Fundamentals and Engineering ," Cambridge University Press, 1996

# Ruby Laser




From C. Davis, "Lasers and Electro-Optics: Fundamentals and Engineering ," Cambridge University Press, 1996

# Nd-Based Lasers

In Nd laser **$Nd^{+3}$ ions** (as impurities of up to a few percent by weight) are replacing the atoms of the solid host in the active medium.

Three known solid hosts are used for Nd laser where $Nd^{+3}$ ions are added as impurities:

**Glass - amorphous.**
**YAG (Yttrium Aluminum Garnet) - Crystal.**
**YLF ($LiYF_4$) - Crystal.**

**Glass** is used as the host material when a pulsed laser is needed, with each pulse at high power, and the pulse repetition rate is slow. The problem with glass as a host is its poor thermal conductivity. Thus cooling the laser when it operates continuously or at high repetition rate is difficult.

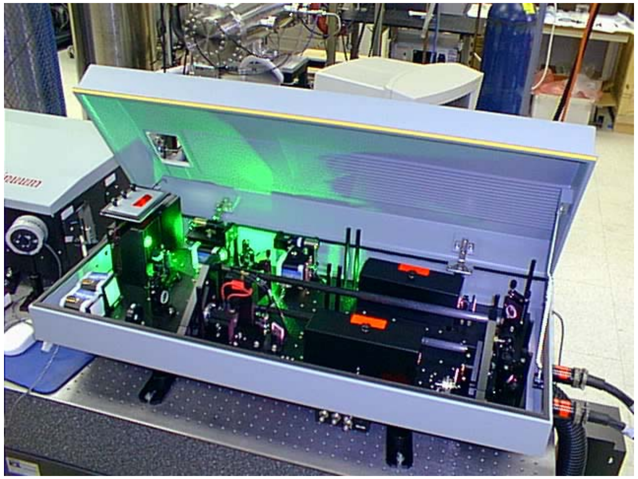
**YAG crystal** is used for high repetition rate pulses (more than one pulse per second). In this case a large amount of heat need to be transferred away from the laser, and the thermal conductivity of the YAG crystal is much higher than that of glass.
YAG crystal with the high quality needed for lasers.
The percentage of Nd ions in the YAG host is 1-4% by weight.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s2t2p1.htm

# Nd-YAG Laser

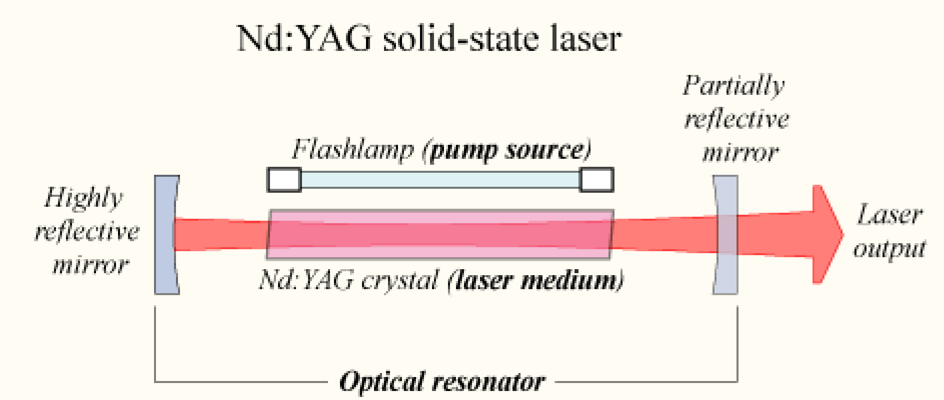
"YAG" = Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$)

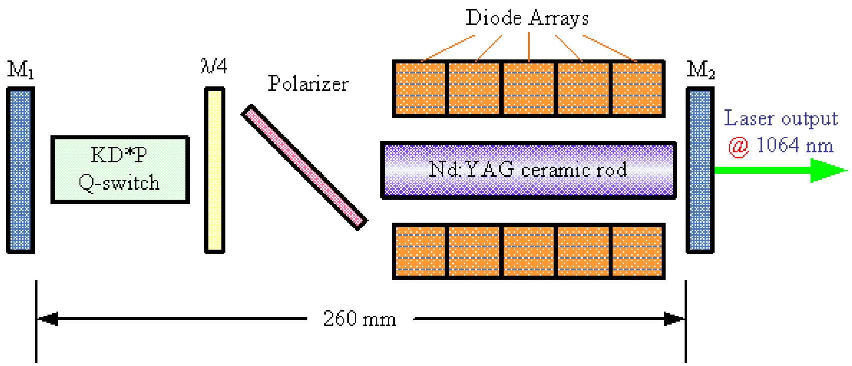
Nd:YAG laser rod



Nd:YAG laser with lid open showing frequency-doubled 532 nm green light

http://en.wikipedia.org/wiki/Nd:YAG_laser

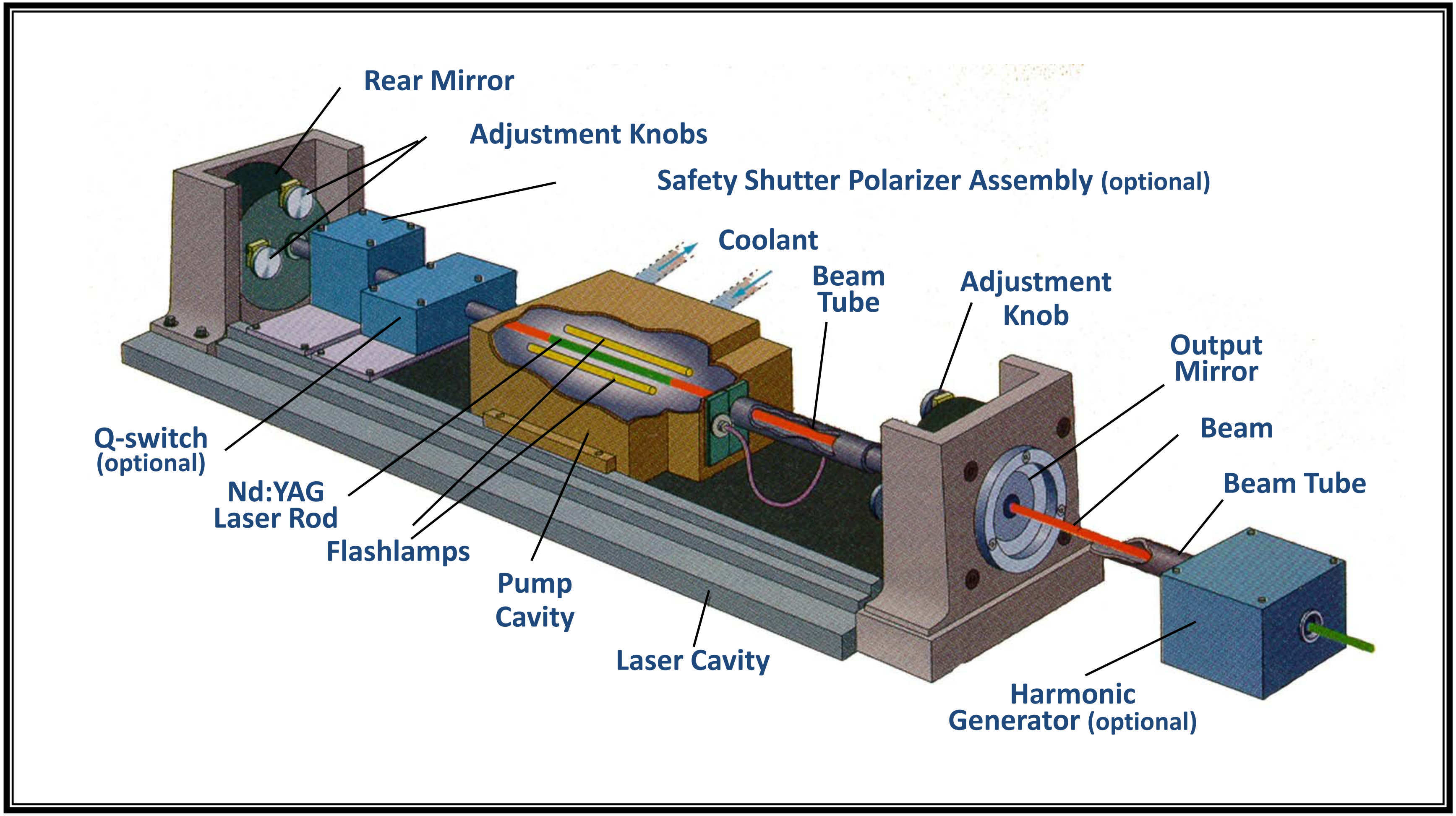



http://commons.wikimedia.org/wiki/File:Lasercons.png

http://www.intechopen.com/source/html/17616/media/image11.png

# Nd-YAG Laser




Courtesy of Los Alamos National Laboratory

# Nd-YAG Laser

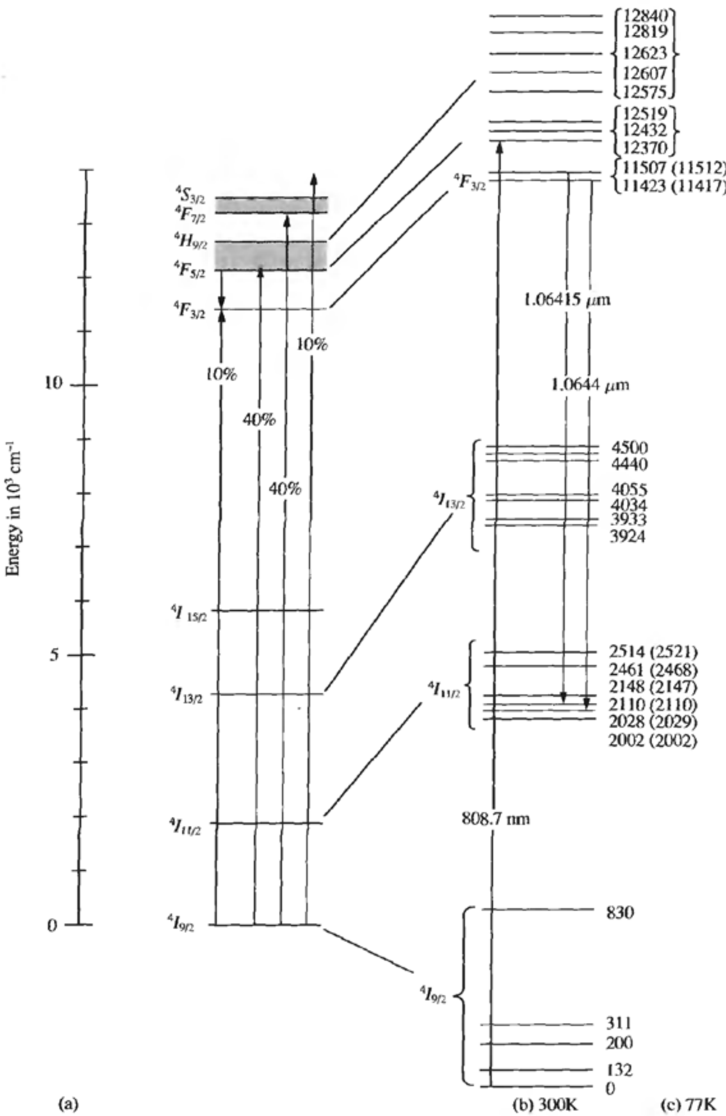



**FIGURE 10.5.** Energy level for neodymium in YAG. (a) Structure of YAG showing the pumping routes with the percentages referring to a pump with a broad spectral output. (b) Details of the manifold at 300 K showing the dominant transitions, the semiconductor laser pumping route is also shown. (c) Energy levels at 77 K. [Data from Kaminski [25]. See also Koechner [24].]

**TABLE 10.2** Characteristics of a Typical Neodymium-YAG Laser Rod

| Bulk parameters | Value |
|---|---|
| Chemical formula | Nd: $Y_3Al_5O_{12}$ |
| Weight % (Nd) | 0.725 |
| Atomic % (Nd) | 1.0 |
| Density of Nd atoms | $1.38 \times 10^{+20}$ cm$^{-3}$ |
| Index of refraction | 1.81633 (1.06 μm, 1% doping) |
| Scattering losses | 0.002 cm$^{-1}$ |
| Dominant transition | (11, 507 → 2111 cm$^{-1}$) 1.064 μm |
| Fluorescent lifetime of $^4F_{3/2}$ | 255 μs |
| Fluorescent efficiency of $^4F_{3/2}$ | 99.5% |
| Stimulated emission cross section | 2.7–8.8 × $10^{-19}$ cm$^2$ (doping and temperature dependent) |
| Lower state lifetime ($^4I_{11/2} \rightarrow {}^4I_{9/2}$ | ~ 30 ns |

From Koechner [24].

**TABLE 10.3** Detailed Data on $^4F_{3/2} \rightarrow {}^4I_{13/2}, {}^4I_{11/2}, {}^4I_{9/2}$ Transitions

| Transition | Wavelength (μm) | Branching ratio | Line width (FWHM in cm$^{-1}$) | σ ($10^{-19}$ cm$^2$) |
|---|---|---|---|---|
| $^4F_{3/2} \rightarrow {}^4I_{9/2}$ | 0.86–0.95 μm | 0.3 | | |
| $^4F_{3/2} \rightarrow {}^4I_{11/2}$ | 1.0521 C | 0.0383 | 4.5 | |
| | 1.0549 | 0.0023 | 4.5 | |
| | 1.0615 B | 0.0799 | 3.6 | |
| | 1.06415 A | 0.1275 | 5.0 | 2.9 |
| | 1.0644 A′ | 0.0533 | 4.2 | * |
| | 1.0682 | 0.0340 | 6.5 | |
| | 1.0737 | 0.0657 | 4.6 | |
| | 1.0779 | 0.0463 | 7.0 | |
| | 1.1055 | 0.0145 | 11.0 | |
| | 1.1119 | 0.0297 | 10.2 | |
| | 1.1158 | 0.0356 | 10.6 | |
| | 1.1225 | 0.0328 | 9.9 | |
| | | Σ = 0.56 | | |
| $^4F_{3/2} \rightarrow {}^4I_{13/2}$ | 1.3–1.4 | 0.14 | | |
| $^4F_{3/2} \rightarrow {}^4I_{15/2}$ | 1.74–2.13 | ~0.01 | | |

*Because of their proximity the A and A′ transitions contribute to each other. Thus the effective stimulated emission coefficient at 1.06415 μm increases when the shift, line width, and Boltzmann factor are included in the calculation.
From Koechner [24].

From J. T. Verdeyen, “Laser Electronics”, 3rd Ed., Prentice Hall, 1995

# Nd-YAG Laser

## Applications

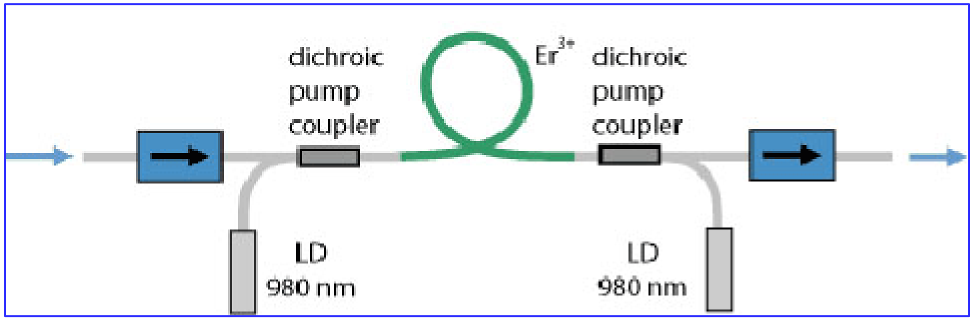
Most Common Operating Wavelengths

| |
|---|
| **1064 nm** |
| **940 nm** |
| **1120 nm** |
| **1320 nm** |
| **1440 nm** |

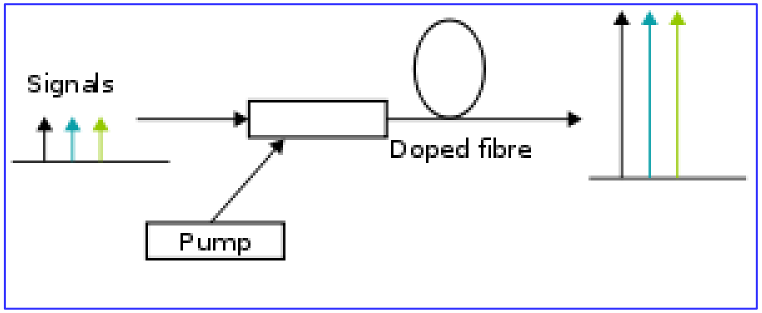
- Nd:YAG laser can be used in manufacturing for engraving and etching various metals and plastics, and for cutting and welding semiconductors, steel and other alloys. It is also employed for making subsurface markings in transparent materials such as acrylic glass or glass.
- It is used in ophthalmology, and oncology to treat benign thyroid nodules, primary and secondary malignant liver lesions and skin cancer.
- It can also be used for flow visualization techniques in fluid dynamics
- It is the most common laser used in laser rangefinders and laser designators
- It is used as pumping tunable visible light lasers
- It is used for research applications such as mass spectrometry, remote sensing and Raman spectroscopy.

http://www.azooptics.com/Article.aspx?ArticleID=470

# Erbium Doped Fiber Amplifier (EDFA)




http://www.exfiber.com/tutorial/Introduction-of-Erbium-Doped-Fiber-Amplifier-17.html

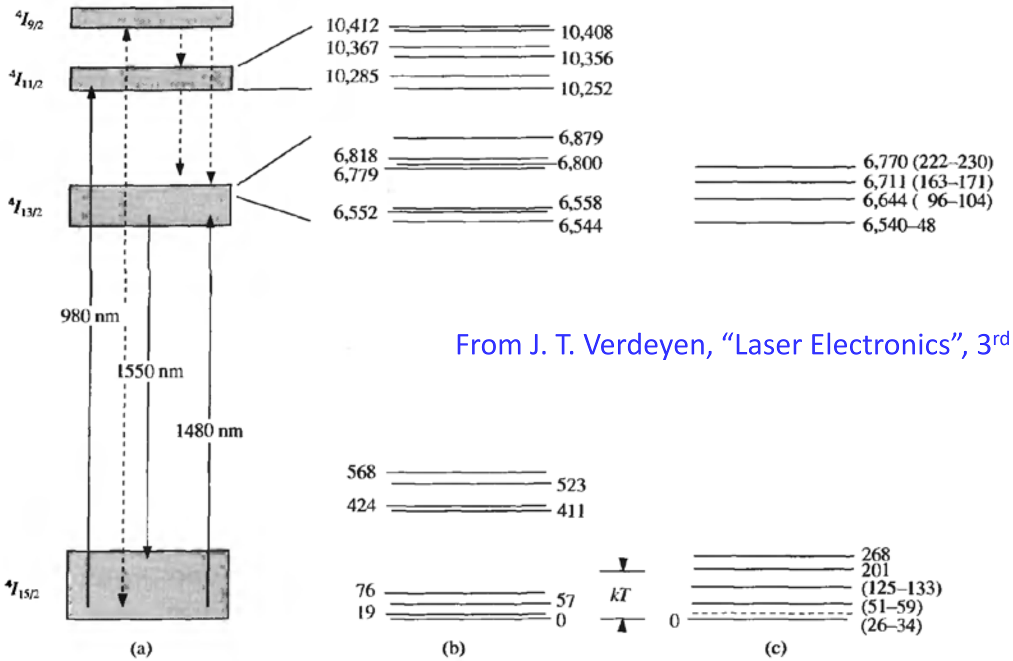



http://en.wikipedia.org/wiki/Optical_amplifier

Erbium Doped Fiber Amplifier's (EDFA's) have revolutionized the optical communications world by expanding the applications for which optical fiber is a solution. Today it is possible to have links greater than 10,000 km with EDFA's cascaded with 50 km spacings as opposed to repeaters being used every few kilometers. EDFA's allow for a complete optical link whereas repeaters required for electro-optic conversions and more components.

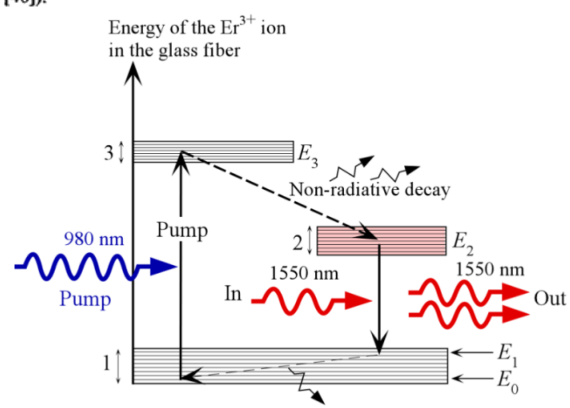
http://www-bcf.usc.edu/~willner/Keith.pdf

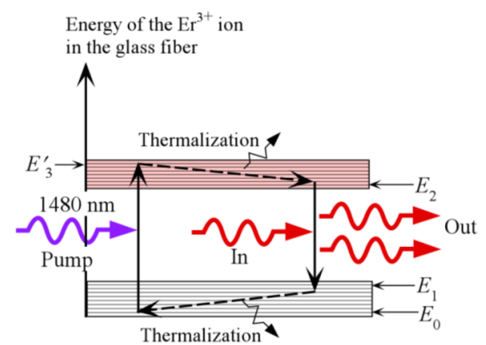
# Erbium Doped Fiber Amplifier (EDFA)




From J. T. Verdeyen, “Laser Electronics”, 3rd Ed., Prentice Hall, 1995

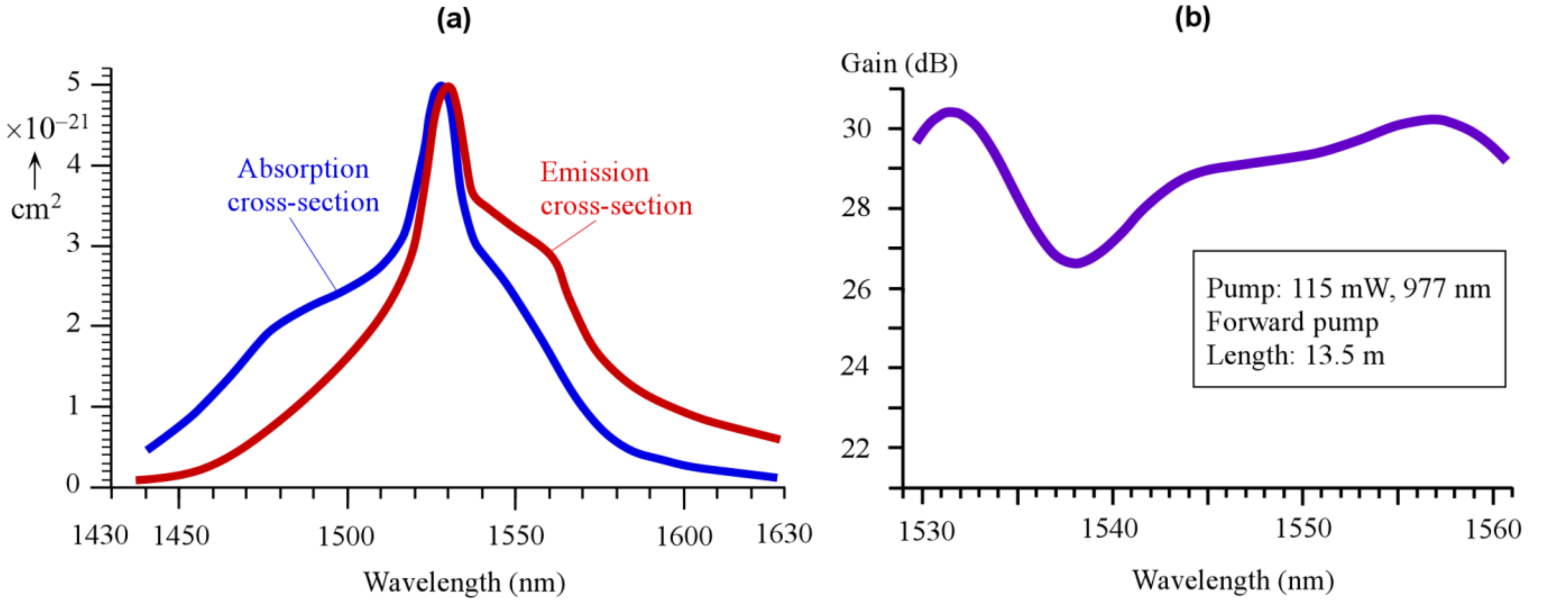
**FIGURE 10.11.** (a) Simplified energy level diagram of erbium in a solid host; (b) the Stark levels of $Er^{3+}$ in YAG (data from Table 4.9 of Kaminski [39]); (c) Stark levels in aluminosilicate glass (data from Desurvire and J. Simpson [40]).




S. O. Kasap, Optoelectronics and Photonics

# Erbium Doped Fiber Amplifier (EDFA)




a) Typical absorption and emission cross sections, $\sigma_{ab}$ and $\sigma_{em}$ respectively, for $Er^{3+}$ in a silica glass fiber doped with alumina ($SiO_2$-$Al_2O_3$). (Cross section values for the plots were extracted from B. Pedersen *et al, J. Light. Wave Technol. 9*, 1105, 1991.)

b) The spectral characteristics of gain, *G* in dB, for a typical commercial EDF, available from Fibercore as IsoGain™ fiber.Forward pumped at 115 mW and at 977 nm. The insertion losses are 0.45 dB for the isolator, 0.9 dB for the pump coupler and splices.

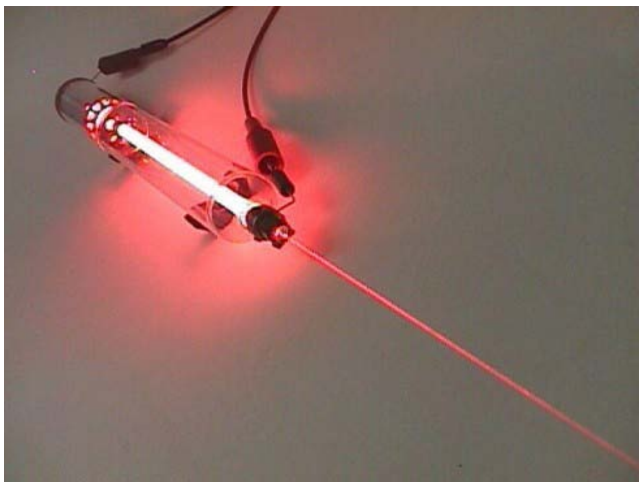
S. O. Kasap, Optoelectronics and Photonics

# Helium-Neon Laser

PHYSICAL REVIEW LETTERS FEBRUARY 1, 1961

**POPULATION INVERSION AND CONTINUOUS OPTICAL MASER OSCILLATION IN A GAS DISCHARGE CONTAINING A He-Ne MIXTURE**

A. Javan, W. R. Bennett, Jr., and D. R. Herriott
Bell Telephone Laboratories, Murray Hill, New Jersey



http://mellesgriot.com/products/Lasers/Helium-Neon-Lasers

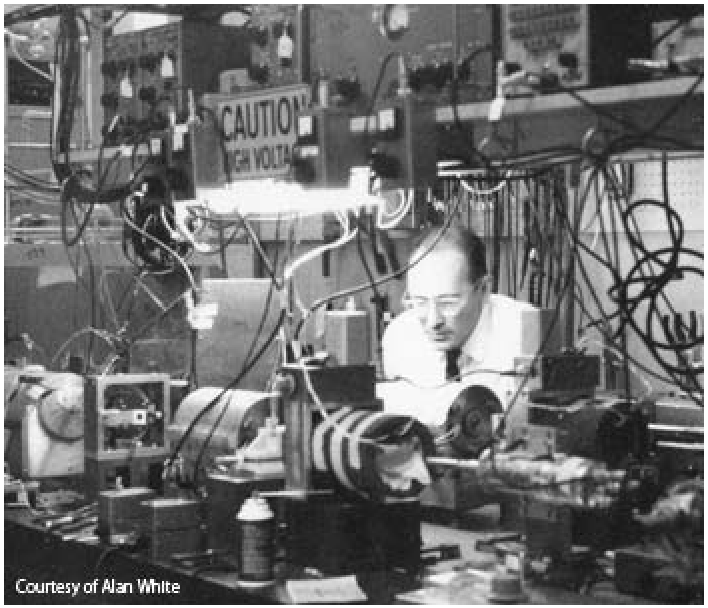
## Commercial He-Ne Lasers

| | |
|---|---|
| Wavelength: | 632.8 [nm] |
| Output Power: | 0.5-50 [mW] |
| Beam Diameter: | 0.5-2.0 [mm] |
| Beam Divergence: | 0.5-3 [mRad] |
| Coherence Length: | 0.1-2 [m] |
| Power Stability: | 5 [%/Hr] |
| Lifetime: | >20,000 [Hours] |

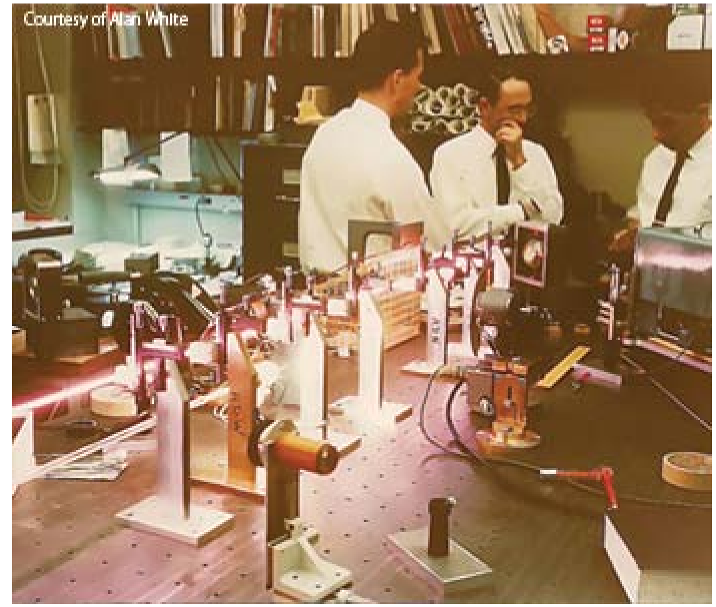
https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t1p9.htm

# Helium-Neon Laser

Alan White and Dane Rigden (Bell Labs) developed the first continuous visible (632.8nm) He-Ne laser in 1962



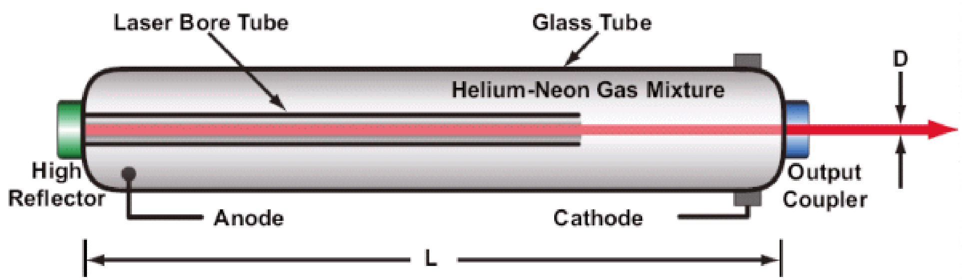

Alan White works on a red He-Ne laser in a very cluttered laboratory. A.D. White and J.D. Rigden. Proc. IRE **50**, 1697 (1962)

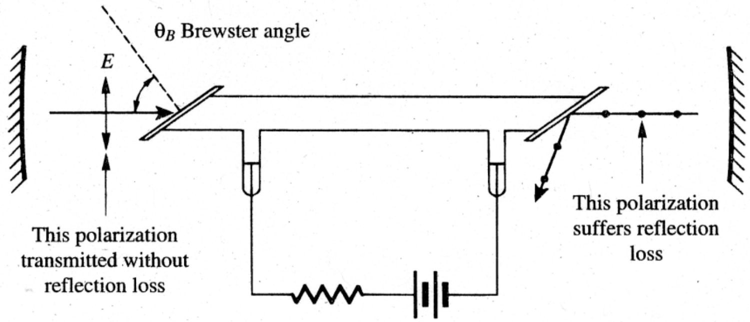


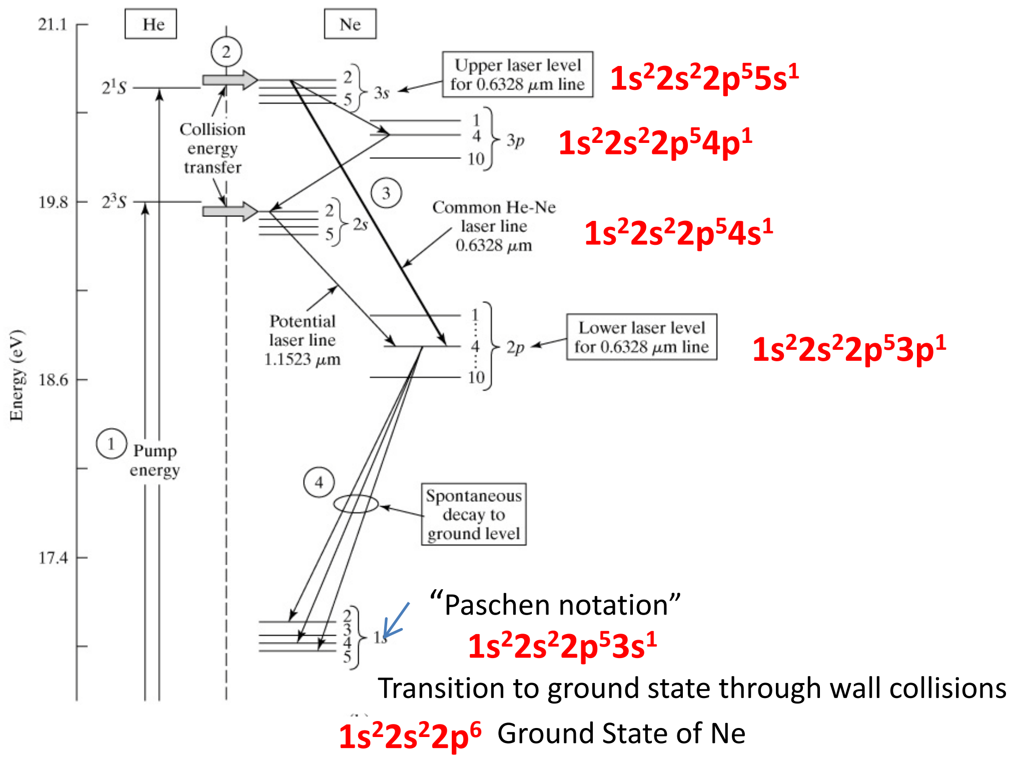

(Left to right) Dane Rigden, Alan White and Bill Rigrod having a discussion in the laser lab at Bell Labs, 1963. The long HeNe laser on the bench is emitting about 80 milliwatts of power at 632.8 nm.

http://www.osa-opn.org/home/articles/volume_22/issue_10/features/recollections_of_the_first_continuous_visible_lase/

# Helium-Neon Laser



# Helium-Neon Laser

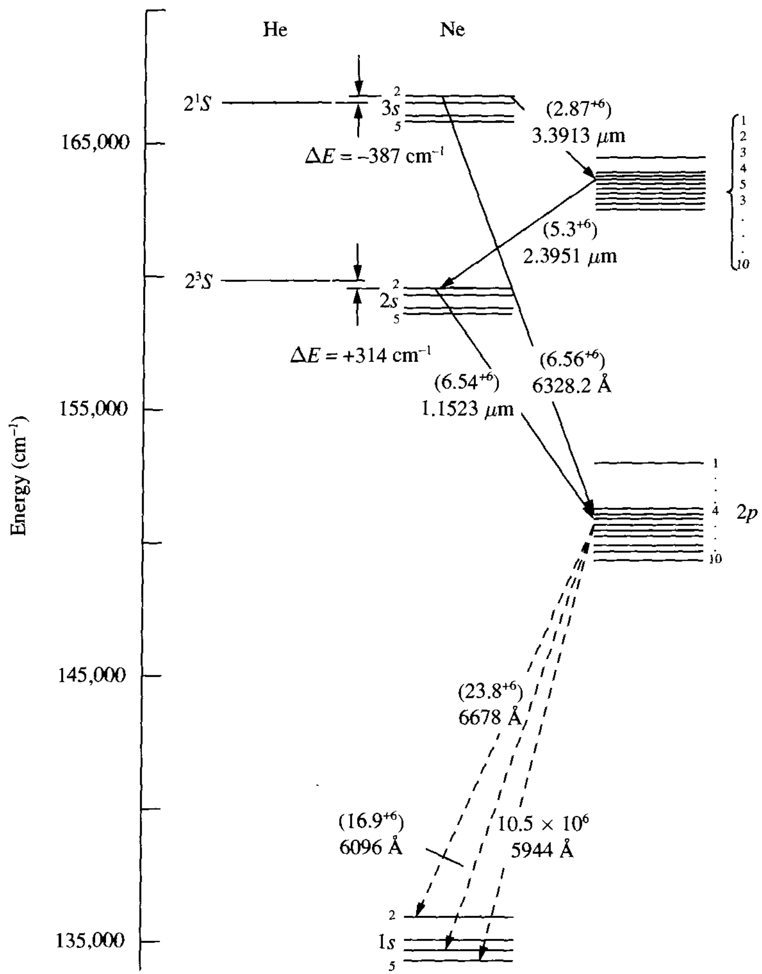



**FIGURE 10.28.** Energy-level diagram for the helium-neon laser. The solid line represents the common laser line; the dashed lines are spontaneous. The numbers in parentheses are the *A* coefficients.

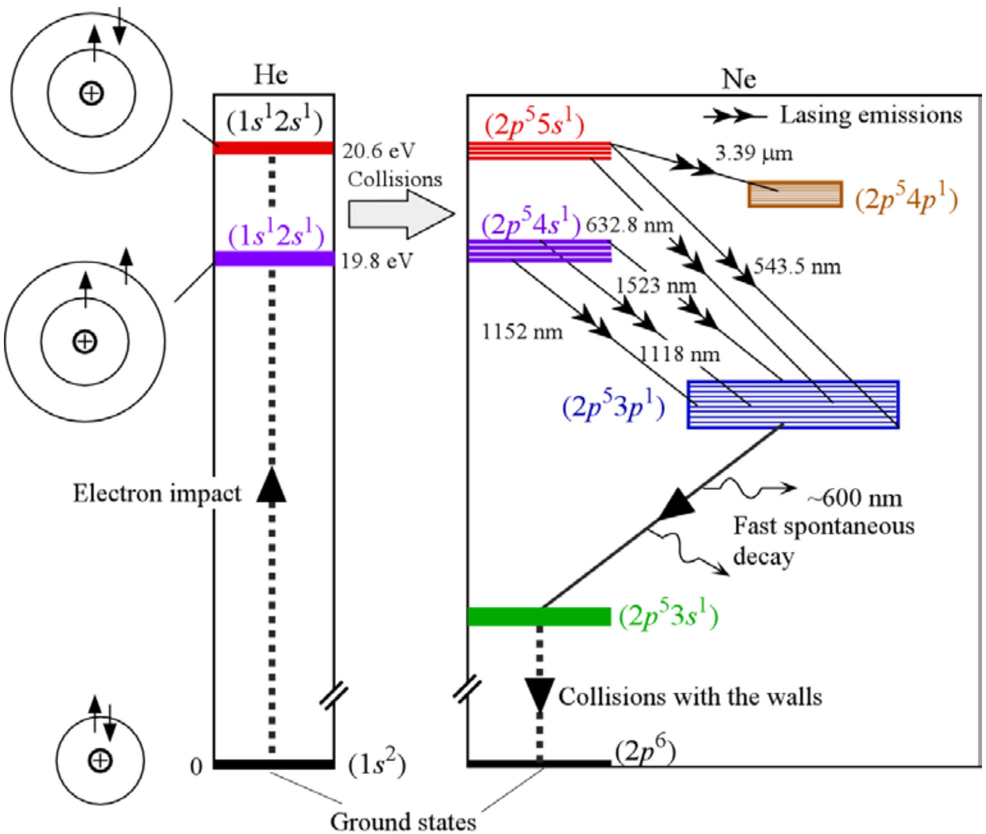
**TABLE 10.6** Data Associated with the Various States of Neon

| Transition | $J_{upper}$ | $J_{lower}$ | λ (Å) | $A(10^6\ sec^{-1})$ | Relative Intensity |
|---|---|---|---|---|---|
| $3s_2 \rightarrow 2p_1$ | 1 | 0 | 7304.9 | 0.48 | 30 |
| $3s_2 \rightarrow 2p_2$ | 1 | 1 | 6401.1 | 0.6 (est.) | 100 |
| $3s_2 \rightarrow 2p_3$ | 1 | 0 | 6351.9 | 0.7 | 100 (common "red" laser) |
| $3s_2 \rightarrow 2p_4$ | 1 | 2 | 6328.2 | 6.56 | 300 (common "red" laser) |
| $3s_2 \rightarrow 2p_5$ | 1 | 1 | 6293.8 | 1.35 | 100 (common "red" laser) |
| $3s_2 \rightarrow 2p_6$ | 1 | 2 | 6118.0 | 1.28 | 100 |
| $3s_2 \rightarrow 2p_7$ | 1 | 1 | 6046.1 | 0.68 | 50 |
| $3s_2 \rightarrow 2p_8$ | 1 | 2 | 5939.3 | 0.56 | 50 |
| $3s_2 \rightarrow 2p_9$ | 1 | 3 | 5882.5 | Forbid $\Delta J = 2$ | Not observed |
| $3s_2 \rightarrow 2p_{10}$ | 1 | 1 | 5433.6 | 0.59 | 250 |
| $3s_2 \rightarrow \Sigma 2p$ | 1 | — | Red-orange | 12.8 | — |
| $3s_2 \rightarrow 3p_4$ | 1 | 2 | 33913 | 2.87 | — |
| $3s_2 \rightarrow \Sigma 3p$ | 1 | — | IR | 5.24 | — |
| $2p_4 \rightarrow 1s_2$ | 2 | 1 | 6678.3 | 23.8 | 500 |
| $2p_4 \rightarrow 1s_3$ | 2 | 0 | 6234.5 | Forbid $\Delta J = 2$ | Not observed |
| $2p_4 \rightarrow 1s_4$ | 2 | 1 | 6096.2 | 16.9 | 300 |
| $2p_4 \rightarrow 1s_5$ | 2 | 2 | 5944.8 | 10.5 | 500 |
| $2p_4 \rightarrow \Sigma 1s$ | | | Red-orange | 51.2 | |

| Other transitions | $\Sigma A$ | | λ | $A(\times 10^6)$ |
|---|---|---|---|---|
| $2p_1 \rightarrow \Sigma 1s$ | 87.9 | $2s_2 - 2p_1$ | 1.5231 μm | 0.802 |
| $2p_2 \rightarrow \Sigma 1s$ | 116.6 | $2p_2$ | 1.1767 μm | 4.089 |
| $2p_3 \rightarrow \Sigma 1s$ | 61.7 | $2p_3$ | 1.1602 μm | 0.801 (first gas laser) |
| $2p_4 \rightarrow \Sigma 1s$ | 51.7 | $2p_4$ | 1.1523 μm | 6.537 (first gas laser) |
| $2p_5 \rightarrow \Sigma 1s$ | 53.3 | $2p_5$ | 1.1409 μm | 2.301 (first gas laser) |
| $2p_6 \rightarrow \Sigma 1s$ | 53.6 | $2p_6$ | 1.0844 μm | 7.543 |
| $2p_7 \rightarrow \Sigma 1s$ | 49.3 | $2p_7$ | 1.0621 μm | 0.816 |
| $2p_8 \rightarrow \Sigma 1s$ | 41.2 | $2p_8$ | 1.0295 μm | 0.726 |
| $2p_9 \rightarrow \Sigma 1s$ | 43.3 | $2p_9$ | Forbidden | — |
| $2p_{10} \rightarrow \Sigma 1s$ | 33.6 | $2p_{10}$ | 0.8895 μm | 1.708 |

From J. T. Verdeyen, "Laser Electronics", 3rd Ed., Prentice Hall, 1995

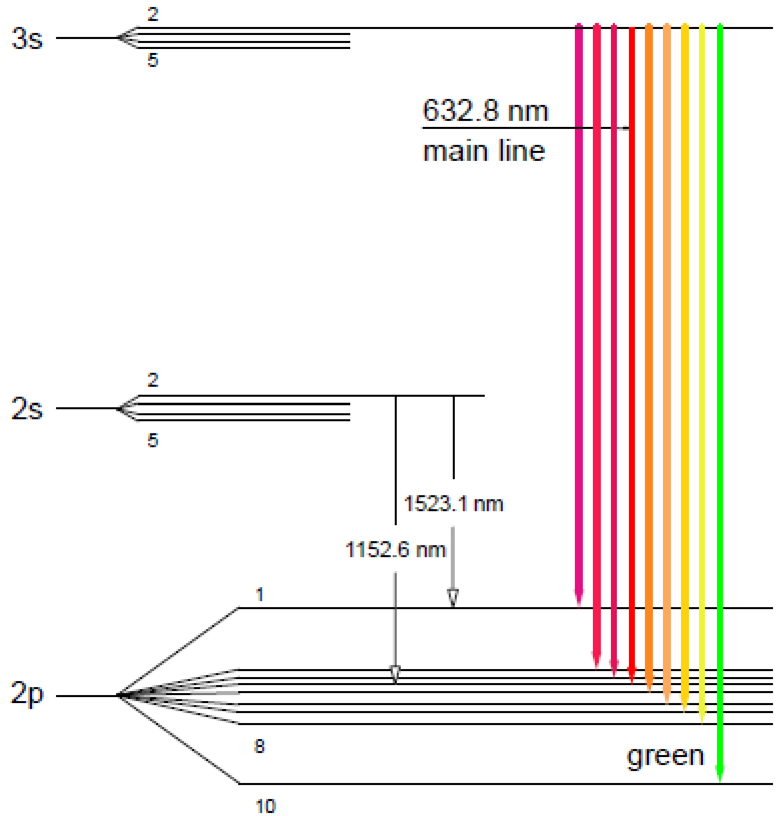
# Helium-Neon Laser




| Wavelength (nm) | 543.5 | 594.1 | 612 | 632.8 | 1523 |
|---|---|---|---|---|---|
| Color | Green | Yellow | Orange | Red | Infrared |

S. O. Kasap, Optoelectronics and Photonics

# Helium-Neon Laser




http://www.ld-didactic.de/documents/en-US/EXP/PHO/4747104EN.pdf?__hstc=98968833.6c11668db7aa6a8eda8150c95f068a7d.1642615269101.1642615269101.1642615269101.1&__hssc=98968833.3.1642615269101&__hsfp=893586191

| *Transition* | *Wavelength [nm]* | $A_{ik}$ $[10^8\ s^{-1}]$ | *Gain [%/m]* | |
|---|---|---|---|---|
| $3s_2 \rightarrow 2p_1$ | 730.5 | 0,00255 | 1,2 | ① |
| $3s_2 \rightarrow 2p_2$ | 640.1 | 0,0139 | 4,3 | ① |
| $3s_2 \rightarrow 2p_3$ | 635.2 | 0,00345 | 1,0 | ① |
| $3s_2 \rightarrow 2p_4$ | 632.8 | 0,0339 | 10,0 | ① |
| $3s_2 \rightarrow 2p_5$ | 629.4 | 0,00639 | 1,9 | ① |
| $3s_2 \rightarrow 2p_6$ | 611.8 | 0,00226 | 1,7 | ① |
| $3s_2 \rightarrow 2p_7$ | 604.6 | 0,00200 | 0,6 | |
| $3s_2 \rightarrow 2p_8$ | 593.9 | 0,00255 | 0,5 | |
| $3s_2 \rightarrow 2p_9$ | Transition not allowed | | | |
| $3s_2 \rightarrow 2p_{10}$ | 543.3 | 0,00283 | 0,52 | |
| $2s_2 \rightarrow 2p_1$ | 1523.1 | | | ③ |
| $2s_2 \rightarrow 2p_2$ | 1177.0 | | | ② |
| $2s_2 \rightarrow 2p_3$ | 1160.5 | | | |
| $2s_2 \rightarrow 2p_4$ | 1152.6 | | | ② |
| $2s_2 \rightarrow 2p_5$ | 1141.2 | | | ② |
| $2s_2 \rightarrow 2p_6$ | 1084.7 | | | ② |
| $2s_2 \rightarrow 2p_7$ | 1062.3 | | | |
| $2s_2 \rightarrow 2p_8$ | 1029.8 | | | |
| $2s_2 \rightarrow 2p_9$ | Transition not allowed | | | |
| $2s_2 \rightarrow 2p_{10}$ | 886.5 | | | |
| $2s_3 \rightarrow 2p_2$ | 1198.8 | | | ② |
| $2s_3 \rightarrow 2p_5$ | 1161.7 | | | ② |
| $2s_3 \rightarrow 2p_7$ | 1080.1 | | | ② |

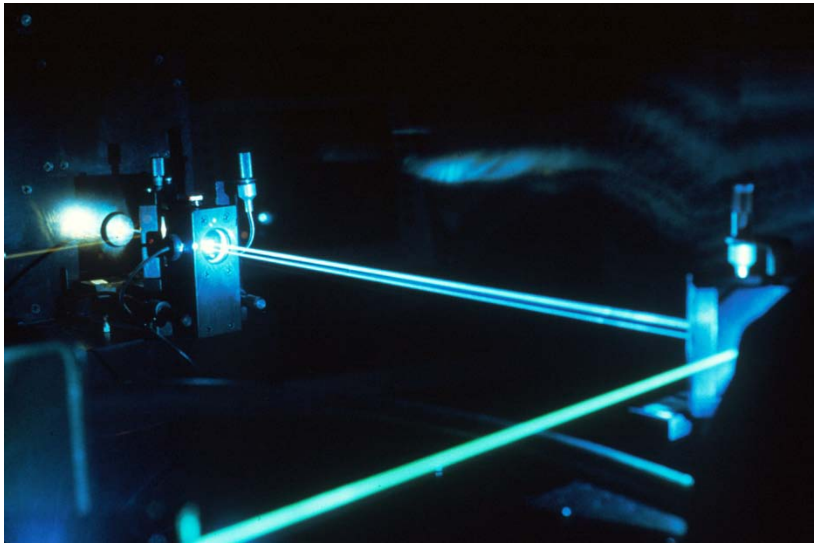
**Table 1: Transitions and Laser lines**

① Laser transition is demonstrated provided set of mirrors

② Laser transitions are demonstrated in the experiment with optional IR mirror set

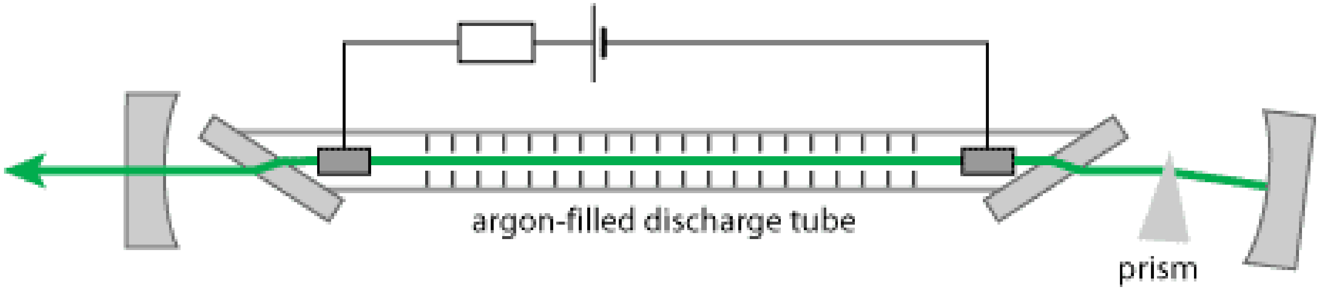
③ Laser transitions are demonstrated with special mirror set

# Argon-Ion Laser




https://www.hofstragroup.com/media/product_images/productimage-picture-coherent-innova-300c-457-9nm-56mw-argon-ion-laser-1022.jpg

http://upload.wikimedia.org/wikipedia/commons/e/e6/Nci-vol-2268-300_argon_ion_laser.jpg




http://www.rp-photonics.com/img/argon_ion_laser.png

# Argon-Ion Laser

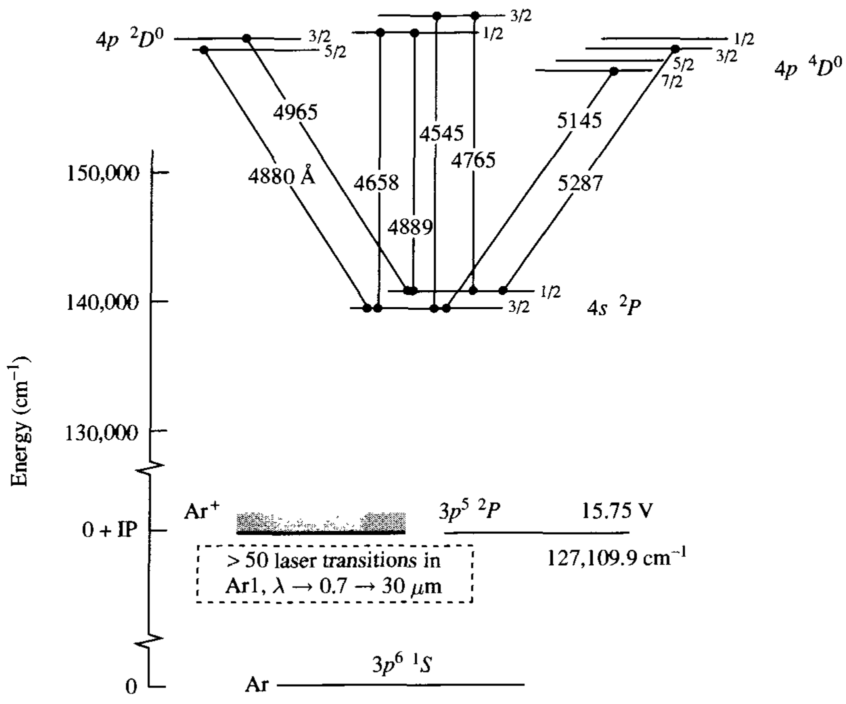
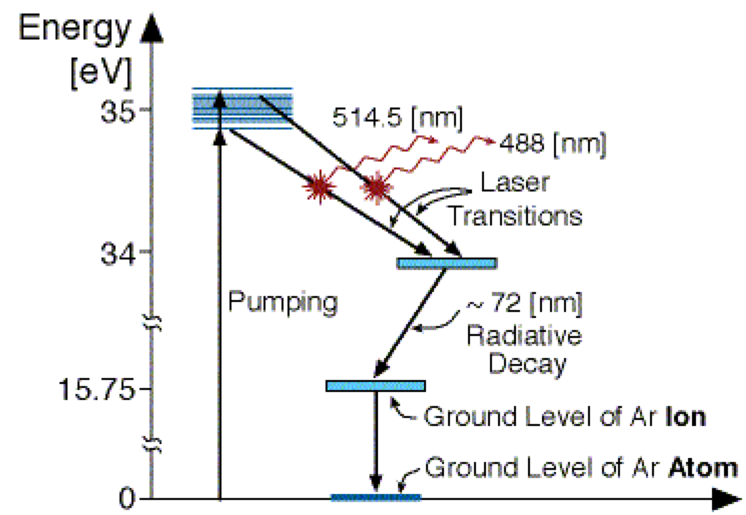



**FIGURE 10.30.** Energy-level diagram for the argon-ion laser.




From J. T. Verdeyen, "Laser Electronics", 3rd Ed., Prentice Hall, 1995

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t4p1.htm

Two main Ar-Ion Laser transitions are at visible wavelengths:

**Blue 0.488 [mm]**

**Green 0.5145 [mm]**,

Ar-Ion Laser emits also in the ultraviolet:

**0.3511 [mm]**

**0.3638 [mm]**.

# Argon-Ion Laser

**The Argon Ion Laser main applications:**

1. **A source for Optical Pumping** of other Lasers (**Dye Lasers & Ti-Sapphire Lasers)**.
2. **Entertainment** - in laser light shows, and laser displays.
3. **General Surgery** - for applications that use absorption at specific wavelengths.
4. **Ophthalmic** welding of detached retina.
5. **Forensic Medicine** - for fluorescence measurements.
6. **Holography** - Because of its high power in the visible spectrum.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t4p4.htm

# Carbon Dioxide Laser

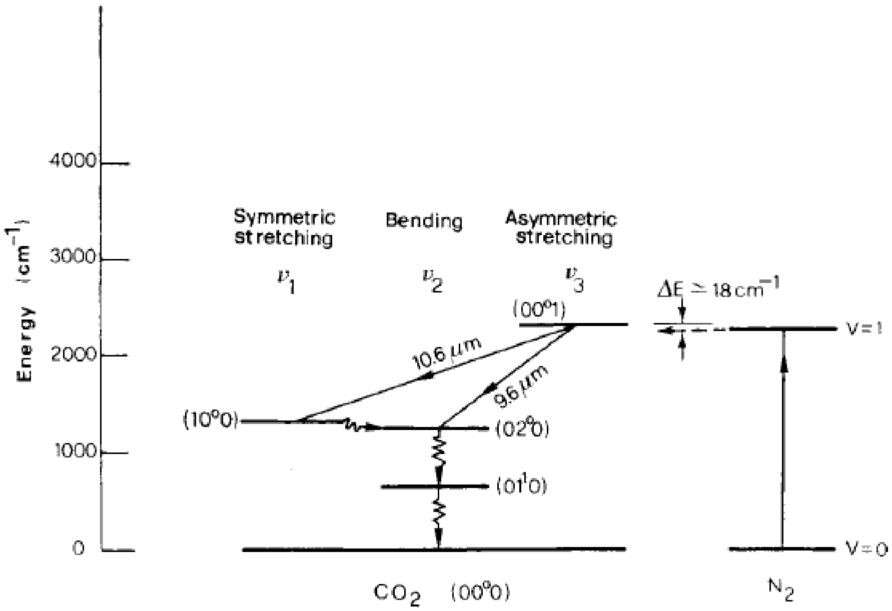
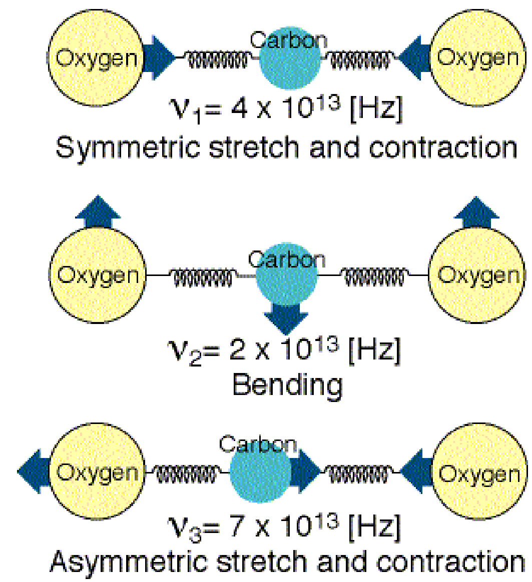
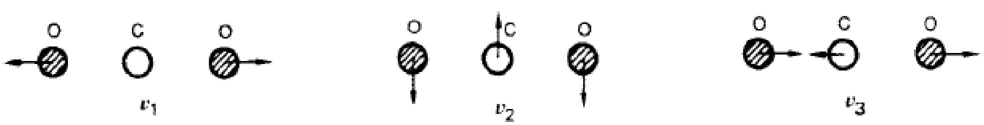



FIG. 10.9. The lowest vibrational levels of the ground electronic state of a $CO_2$ molecule and a $N_2$ molecule (for simplicity, the rotational levels are not shown).




https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t6p1.htm

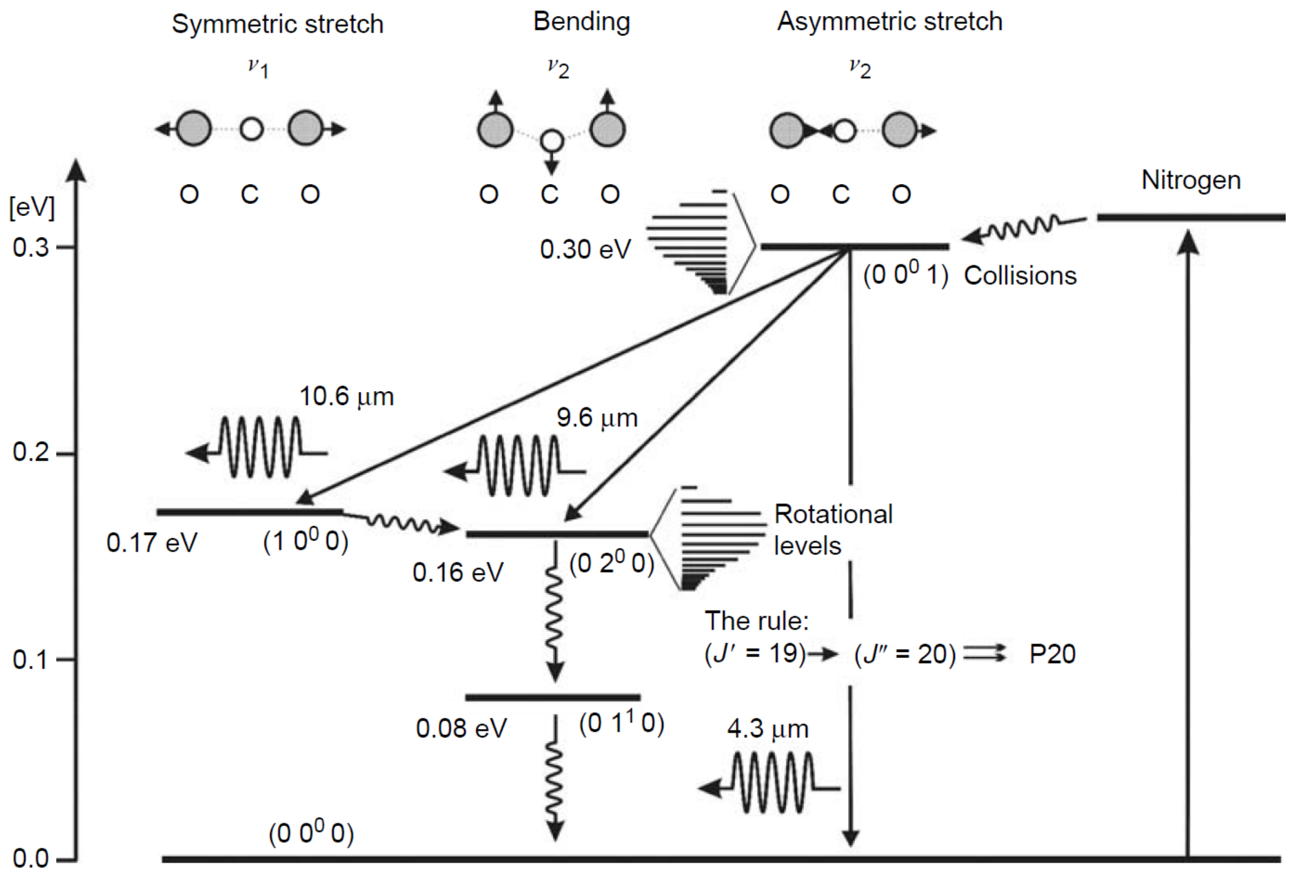
FIG. 10.10. The three fundamental modes of vibration for a $CO_2$ molecule: ($\nu_1$) symmetric stretching mode, ($\nu_2$) bending mode, ($\nu_3$) asymmetric stretching mode.

From O. Svelto, "Principles of Lasers", 5$^{rd}$ Ed., Springer, 2010

The standard $CO_2$ laser includes in the active medium a mixture of $CO_2$ with $N_2$ and He.
The optimal proportion of these 3 gases in the mixture depends on the laser system and the excitation mechanism. In general, for a continuous wave laser the proportions are: **$CO_2$:$N_2$:He - 1:1:8**

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t6p1.htm

# Carbon Dioxide Laser




Vibrational–rotational $CO_2$–$N_2$ laser energy level diagram. The vibrational energy state of a $CO_2$ molecule is described by three quantum numbers: $v_1$—symmetric stretch quantum number, $v_2$—bending quantum number, $v_3$—asymmetric stretch quantum number. For example $CO_2$ $(v_1\ v_2\ v_3)$=(0 0 0) indicates a molecule in the vibrational ground state. Vibrational state v=1 of nitrogen is also indicated.

From Endo and Walter (Eds.), "Gas Lasers" ,CRC Press., 2007

# Carbon Dioxide Laser

## Properties of $CO_2$ Laser

1. High output power. Commercial $CO_2$ Lasers produce more than 10,000 watts continuously.

2. Output spectrum is in the Infra-Red (IR) spectrum: 9-11 [μm].

3. Very high efficiency (up to 30%).

4. Can operate both continuously or pulsed.

5. Average output power is 75 [W/m] for slow flow of gas, and up to few hundreds [W/m] for fast gas flow.

6. Very simple to operate, and the gasses are non-toxic.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t6p8.htm

# Excimer Lasers

Excimer Lasers is a family of lasers in which the radiation is emitted from a molecule which only exists for a very short time. This molecule is composed of an atom of **noble gas**: Argon, Krypton or Xenon, and an atom of **halogen**: Fluorine, Chlorine, Bromine or Iodine.

An *Excimer* is a molecule which has a bound state (exists) only in an excited state. In the ground state this molecule does not exist, and the atoms are separated.

The excited state exists for a very short time (less than 10 nanoseconds).

The name *Excimer* comes from the combination of the two words: *exited dimer*, which means that the molecule is composed of two atoms, and exists only in an excited state.

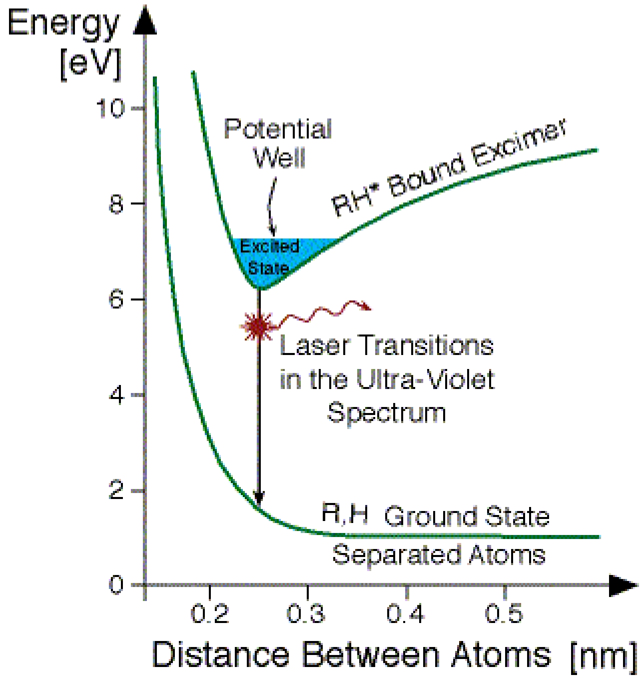
https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t8p1.htm

# Excimer Lasers

Characteristic Wavelengths

| Excimer Laser | Wavelengths [nm] |
|---|---|
| ArCl | 175 |
| ArF | 193 |
| KrF | 248, (275) |
| Xef | 351, 353, (460) |
| KrCl | 222, (240) |
| XeCl | 308, 351 |
| XeBr | 282, (300) |

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t8p2.htm




**R** represents the noble gas atom and **H** represents the halogen.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t8p3.htm

# Excimer Lasers

**Properties of Excimer Lasers:**

Excimer lasers emit in the Ultra-Violet (UV) spectrum.
The radiation is emitted only in short pulses.
The length of each pulse is between pico-seconds to micro-seconds ($10^{-12}$-$10^{-6}$ sec).
The gas pressure inside the laser tube is high: 1-5 [At].
The efficiency of commercial Excimer lasers is up to a few percent.

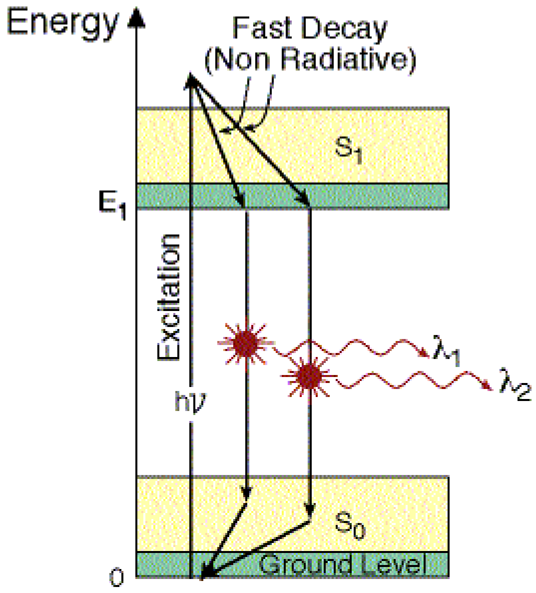
**Special Applications:**

**Photolithography** - Material processing at a very high degree of accuracy (up to parts of microns).
**Cutting biological tissue** without affecting the surrounding.
**Correcting vision disorders** - Cutting very delicate layers from the outer surface of the cornea, thus reshaping it, to avoid the necessity for glasses.
**Marking on products** - Since the short wavelength radiation from the Excimer laser is absorbed by every material, it is possible with a single laser to mark on all kinds of materials, such as plastics, glass, metal, etc.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s1t8p7.htm

# Dye Lasers

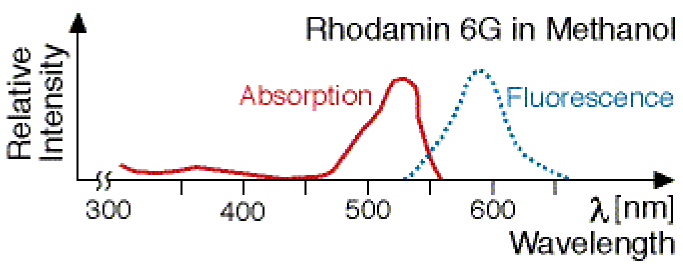
Dye Lasers contain big organic fluorescent compounds (color molecule, which comprise of a large number of cyclic structures).




The active medium in Dye laser is made of color molecule dissolved in **liquid** which is usually a type of alcohol.

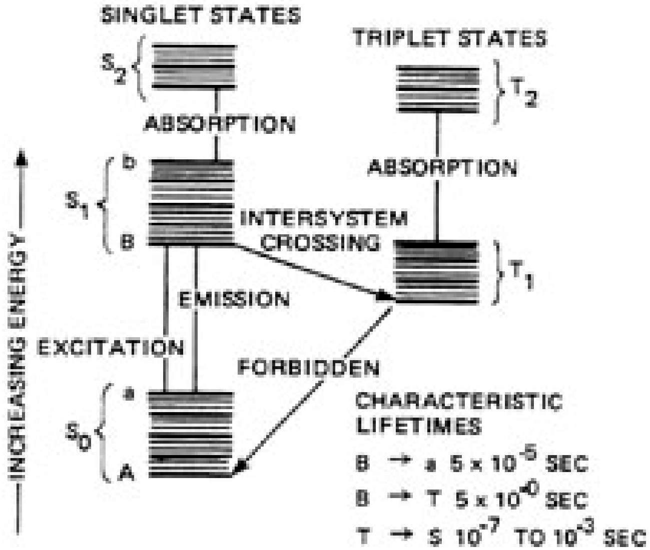
The interaction of the color molecules and the solvent, results in a broadening of the vibration energy levels.  As a result, wide spectrum bands are formed.

Solutions of organic color molecules have wide absorption and emission bands.  An example of the spectral bands for the common color: **Rhodamin 6G** can be seen in figure

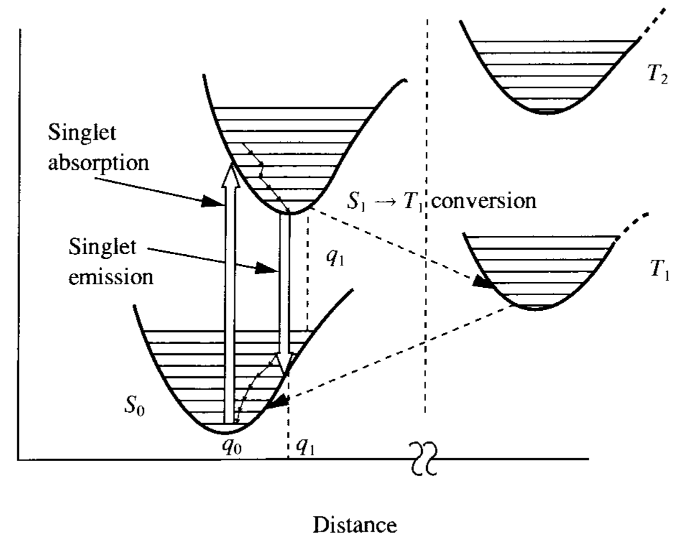



https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s4p2.htm

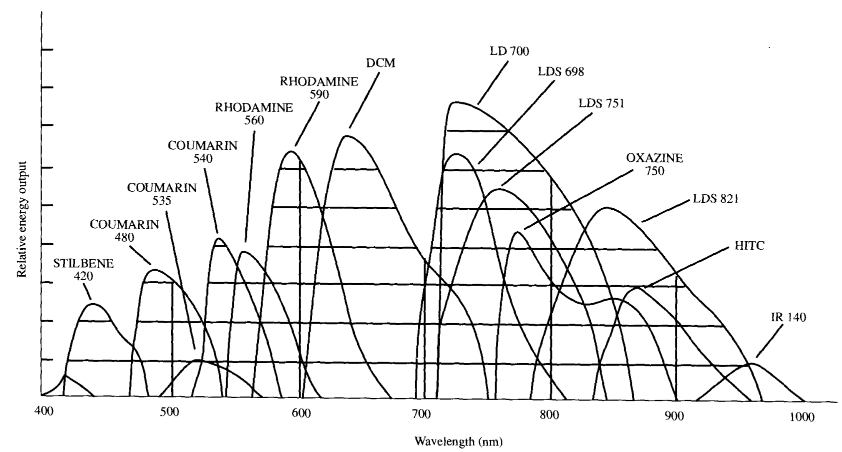
# Dye Lasers



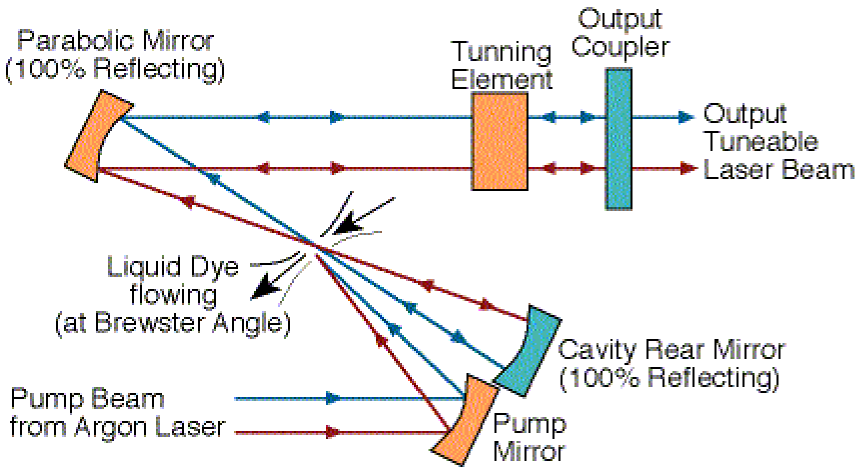

http://pe2bz.philpem.me.uk/Lights/-%20Laser/Info-999-LaserCourse/C03-M10-LiquidDyeLasers/mod03_10.htm

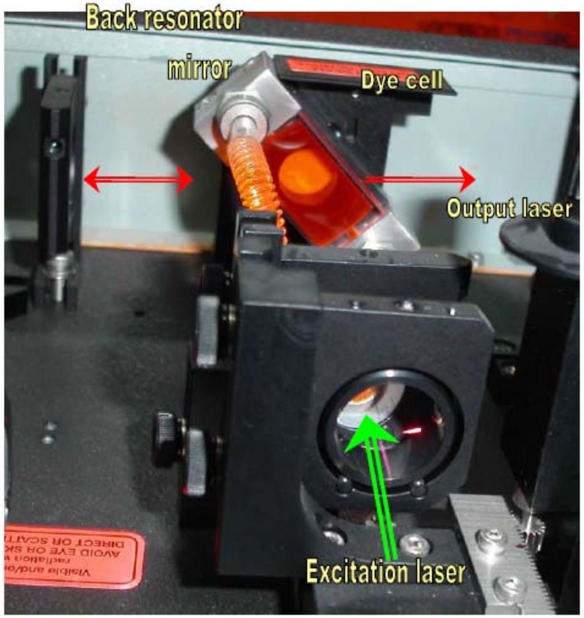



From J. T. Verdeyen, “Laser Electronics”, 3rd Ed., Prentice Hall, 1995



# Dye Lasers




https://www.google.gr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjq3PjyxMvRAhVIJsAKHT46DKIQFggYMAA&url=http%3A%2F%2Fphysics.bgu.ac.il%2F~golanami%2Fworks%2FDyeLasers.pdf&usg=AFQjCNHm_AkdiBkdynbKWH9sSbT7e6wSLg&bvm=bv.144224172,d.bGg

The liquid dye is inside a transparent container, and the optical pump energy is coming through the walls of the container.

The liquid dye is flowing through a special nozzle, and the optical pump energy is shining on it while it flows out of the nozzle

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s4p8.htm

# Dye Lasers

### Advantages of Dye Laser

1. Liquid is homogeneous by nature and therefore there are no defects.
2. It is relatively easy to change the type of liquid used as an active medium. Thus, the wavelength range of the emitted radiation can be changed.
3. The liquid carry with it the heat evolved during the lasing process, so cooling the laser is simple. The active medium is replaced continuously.
4. Very narrow linewidth.
5. Very short pulses.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s4p10.htm

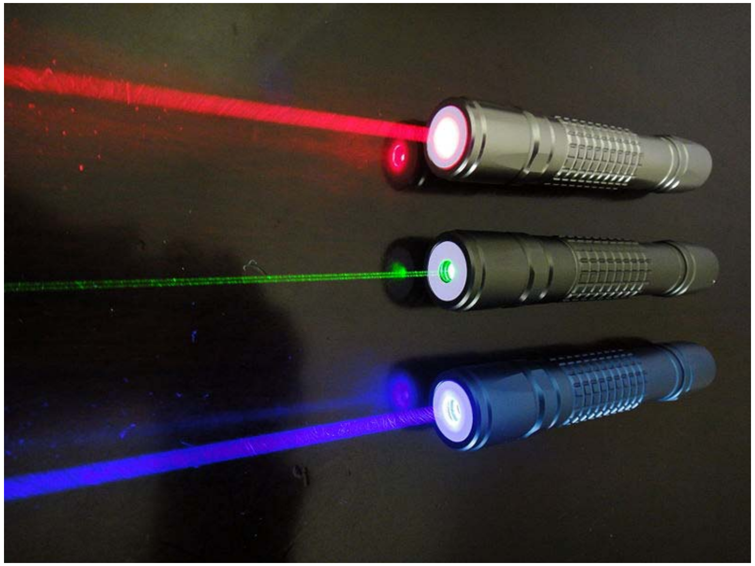
### Disadvantages of Dye Laser

1. Most Dye lasers use liquid as the active medium, which complicate maintenance of the laser.
2. The excitation is done by another laser, which complicate the system.
3. Short dye lifetime. Dye quality degrade with time, and need to be changed.
4. Continuing operating expenses.
5. Potentially toxic (poisonous) chemicals.
6. Volatile solvents.
7. Hazardous waste disposal.

https://web.phys.ksu.edu/VQM/laserweb/Ch-6/F6s4p11.htm

# Laser Pointers

http://preventdisease.com/images/red-laser-pointer-with-key-chain.jpg



https://commons.wikimedia.org/wiki/File:Laser_pointers.jpg

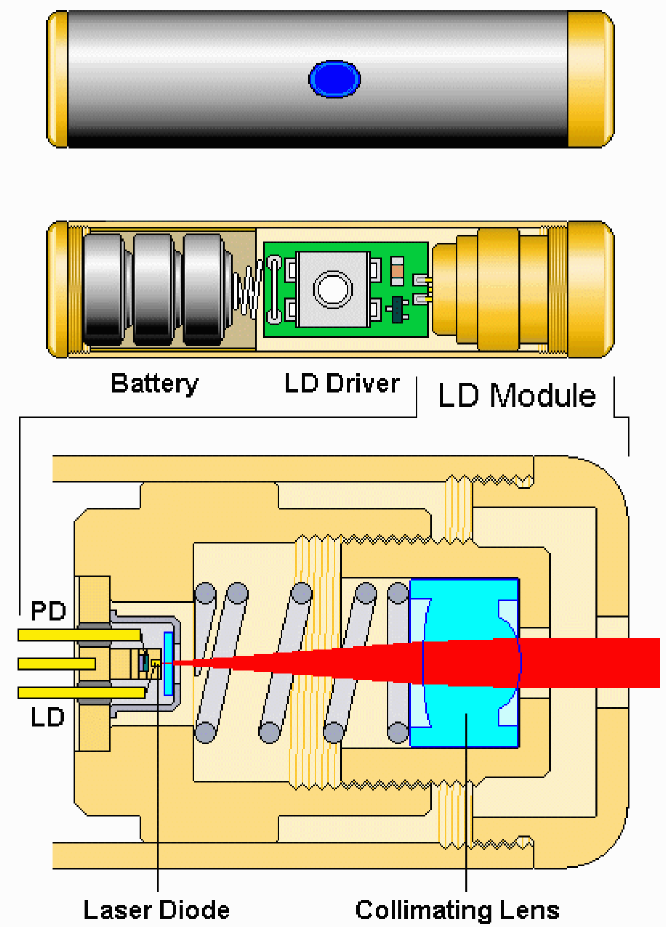
# Red Laser Pointers

**Red Laser Pointer**

- direct output of red light from the Laser Diode ("LD")

  λ = **633**nm, **650**nm, **670**nm, etc.
- output is monitored by the built-in photodiode detector ("PD")
- beam expands and is collimated by the aspheric lens

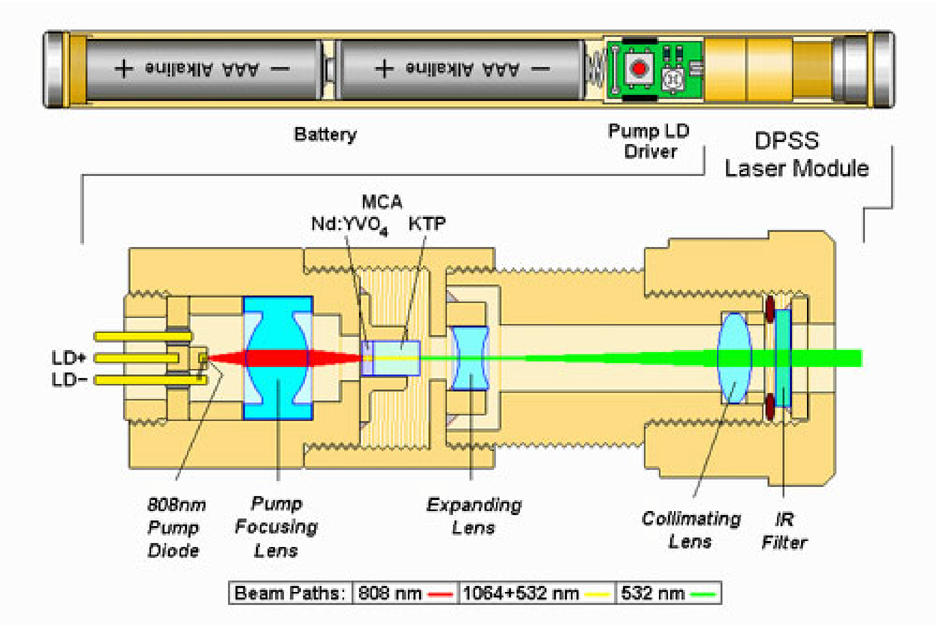
From Prof. Mike Nofziger, College of Optical Sciences, University of Arizona




Typical Red Laser Pointer

http://www.repairfaq.org/sam/laserpic/diodpics.htm#diodldd

# Green Laser Pointers

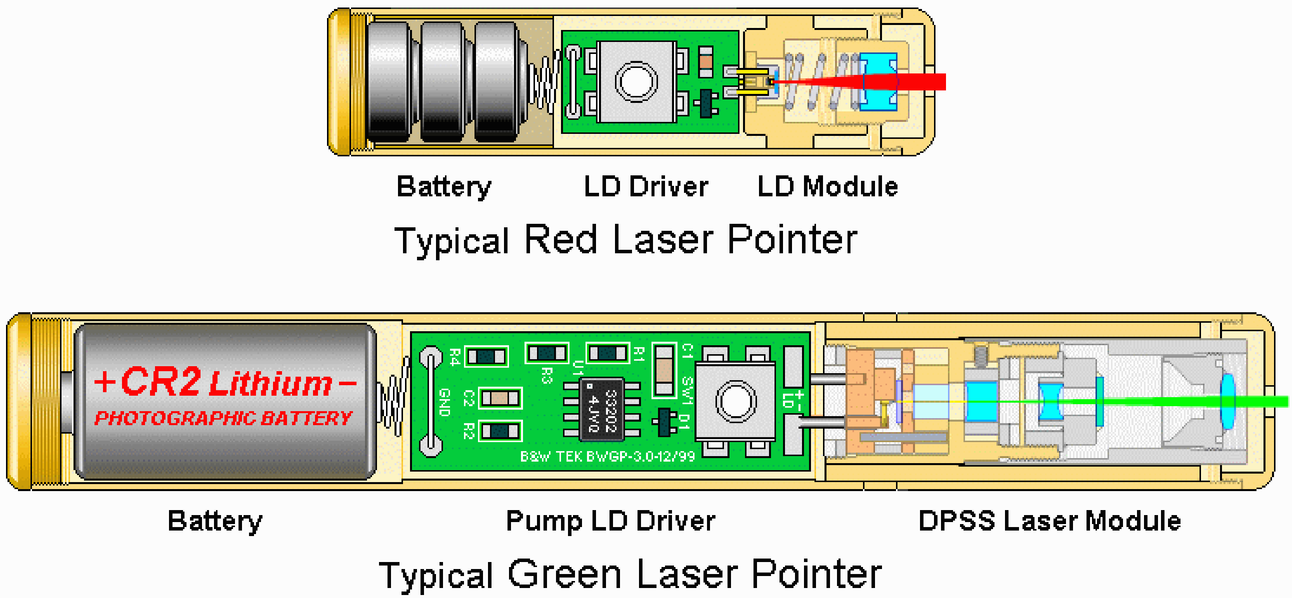



**Diode-Pumped Solid State** “DPSS laser”

- 808nm (near-infrared) pump diode laser 808nm energy converted to 1064nm by the Nd:$YVO_4$ crystal
- 1064nm energy converted to **532**nm green light by the KTP crystal
  - this is a non-linear process called “frequency-doubling”
  - the input frequency is doubled, and the output wavelength is cut in half
- beam is expanded
- beam is collimated
- beam is filtered to block the (powerful) original IR energy at 808nm

From Prof. Mike Nofziger, College of Optical Sciences, University of Arizona

# Red and Green Laser Pointer Comparison




Comparison of Red and Green Laser Pointer Complexity

http://www.repairfaq.org/sam/laserpic/glpdpics.htm