

## Nd: YAG Lasers

- Dope Neodymium (Nd) into material (~1%)
- Most common Yttrium Aluminum Garnet - YAG:  $\text{Y}_3\text{Al}_5\text{O}_{12}$
- Hard brittle but good heat flow for cooling
- Reason: only 5% efficient so lots of waste heat.
- Next common is Yttrium Lithium Fluoride: YLF:  $\text{YLiF}_4$
- Stores more energy, good thermal characteristics
- Nd in Glass stores less energy but easy to make

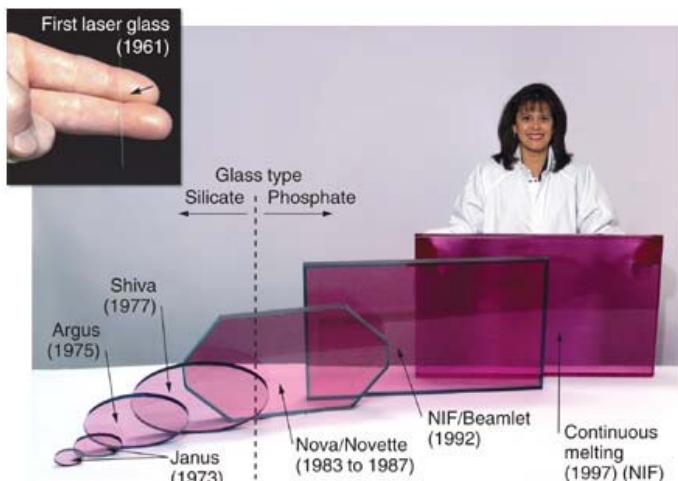
TABLE 22.1 Optical Characteristics of Major Nd Hosts for 1- $\mu\text{m}$  Line

Material	Wavelength, nm	Cross section, $\times 10^{-20}$ cm	Linewidth, nm	Lifetime, $\mu\text{s}$
YLF*	1047	37	—	480
	1053	26		
Phosphate glass	1054	4.0–4.2	28	290–330
GSGG	1061	11	—	222
Silicate glass	1061–1062	2.7–2.9	19–22	340
YAG	1064	34	0.45	244

\*YLF is a birefringent material with different refractive indexes for light of different linear polarizations; wavelength depends on the polarization.



Nd:Yag



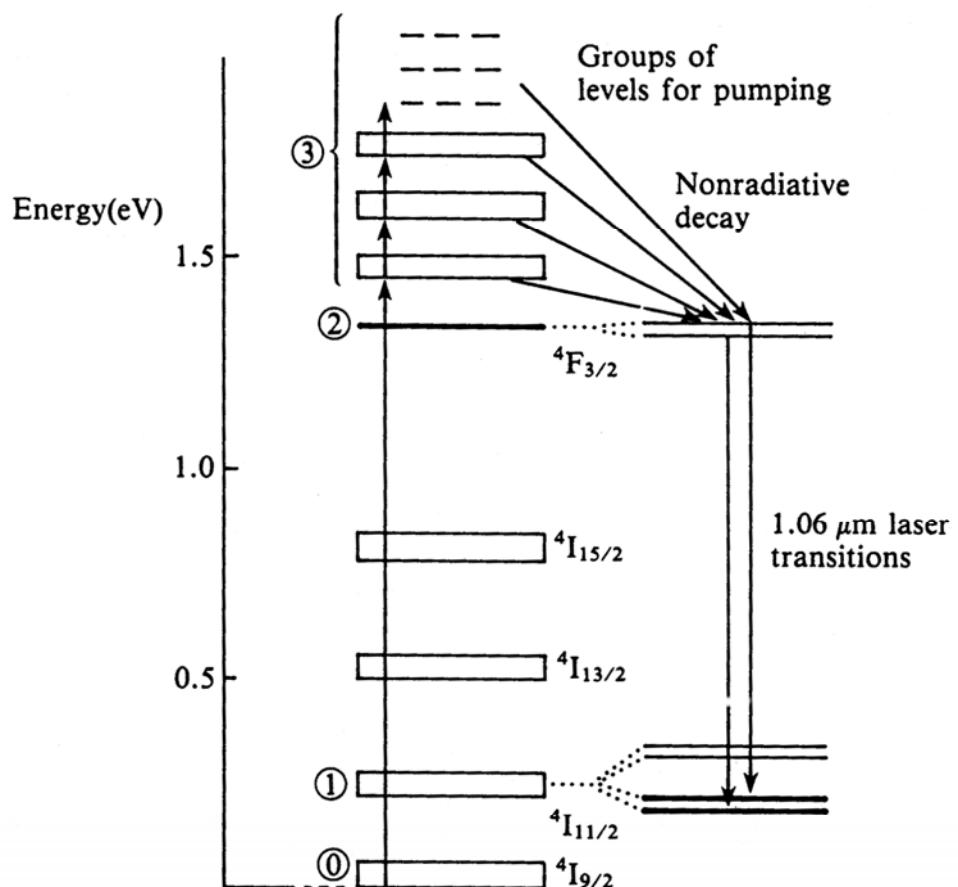
Nd: Glass



Nd:YLF

## Nd: YAG Laser Energy Levels

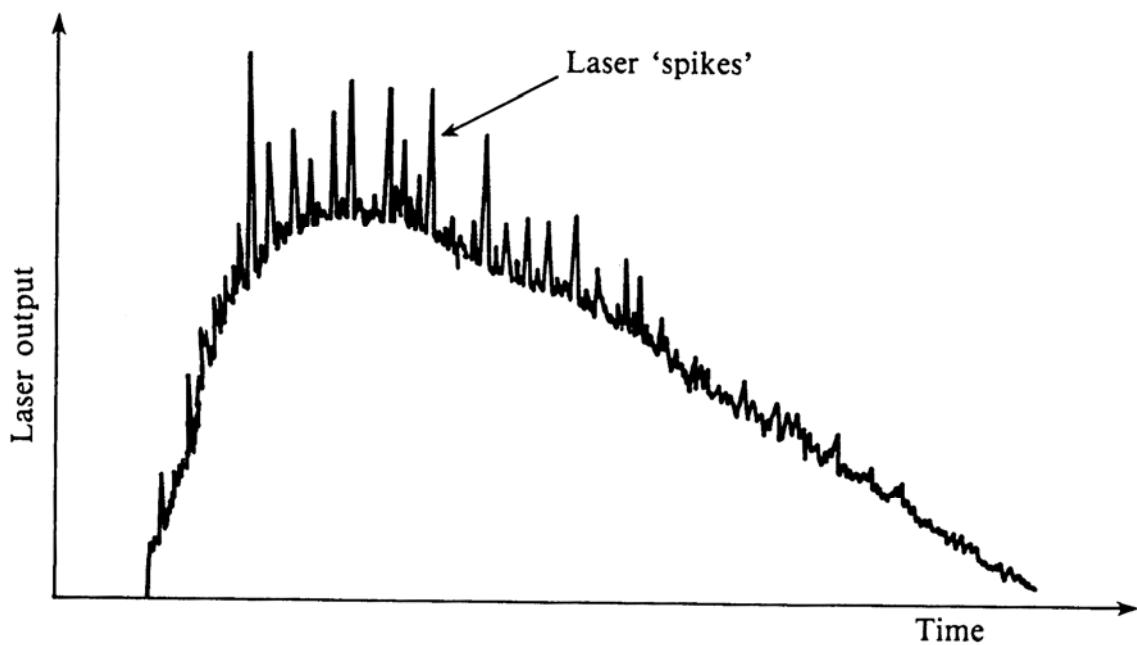
- 4 level laser
- Optical transitions from Ground to many upper levels
- Strong absorber in the yellow range
- None radiative to  $^4F_{3/2}$  level
- Typical emission 1.06 microns



**Fig. 2.7** Simplified energy-level diagram for the neodymium ion in YAG showing the principal laser transitions. Laser emission also results from transitions between the  $^4F_{3/2}$  levels and the  $^4I_{15/2}$  and  $^4I_{13/2}$  levels but at only one tenth of the intensity of the transitions shown.

## Nd: YAG Laser Output

- Note spikes in emission – many short emission peaks
- Pulse typically microseconds



**Fig. 2.8** Typical output from a flashtube pumped Nd: YAG laser, showing laser 'spiking'.

## Nd: YAG Lasers Energy Distribution

- Measure pulse output in total energy, Joules
- Generally trade off high power for low repetition rate
- Issue is the removing the heat
- High power, low rep rate
- Q switch pulse in nanosec range

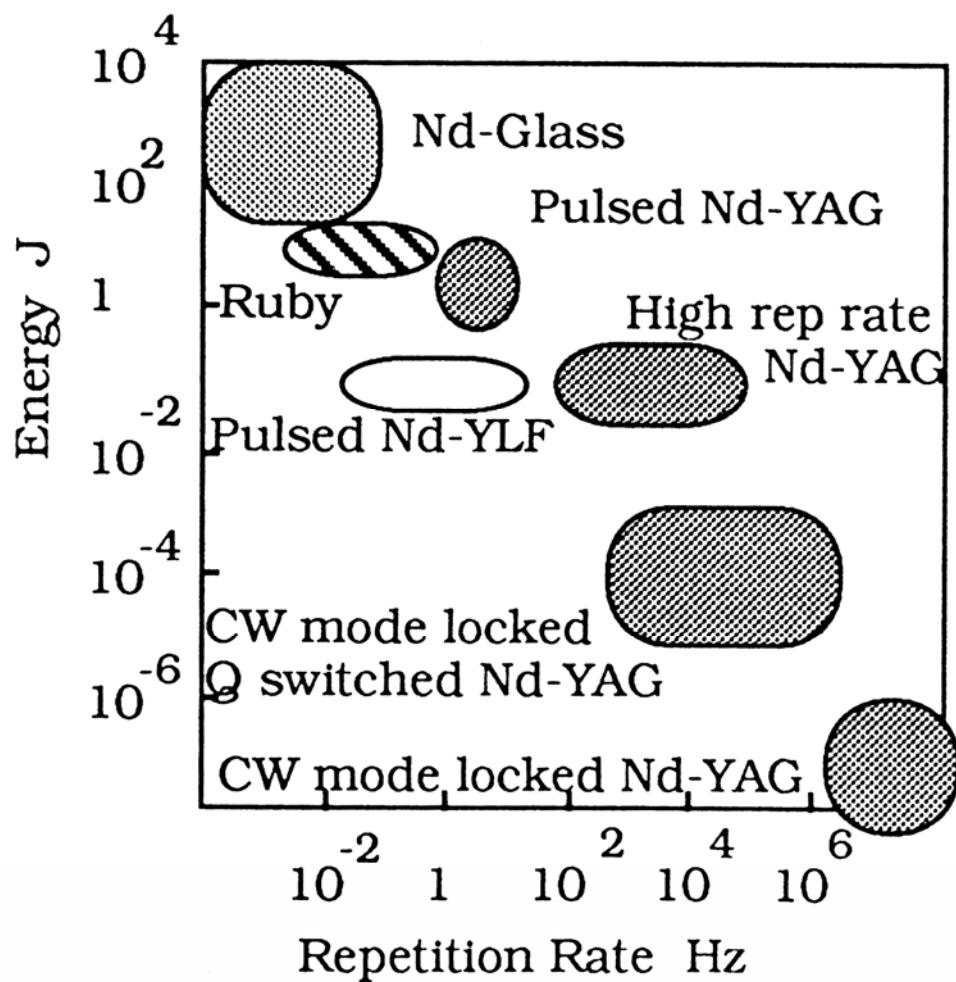


Fig. 3. Operating ranges of commercial solid state lasers.

## Typical Nd: Yag layout

- Small Nd:Yag use single rod gain, and flash lamp
- More powerful use a seed rod to create the pulse
- Then an amplifier rod (separately pumped) to generate final pulse

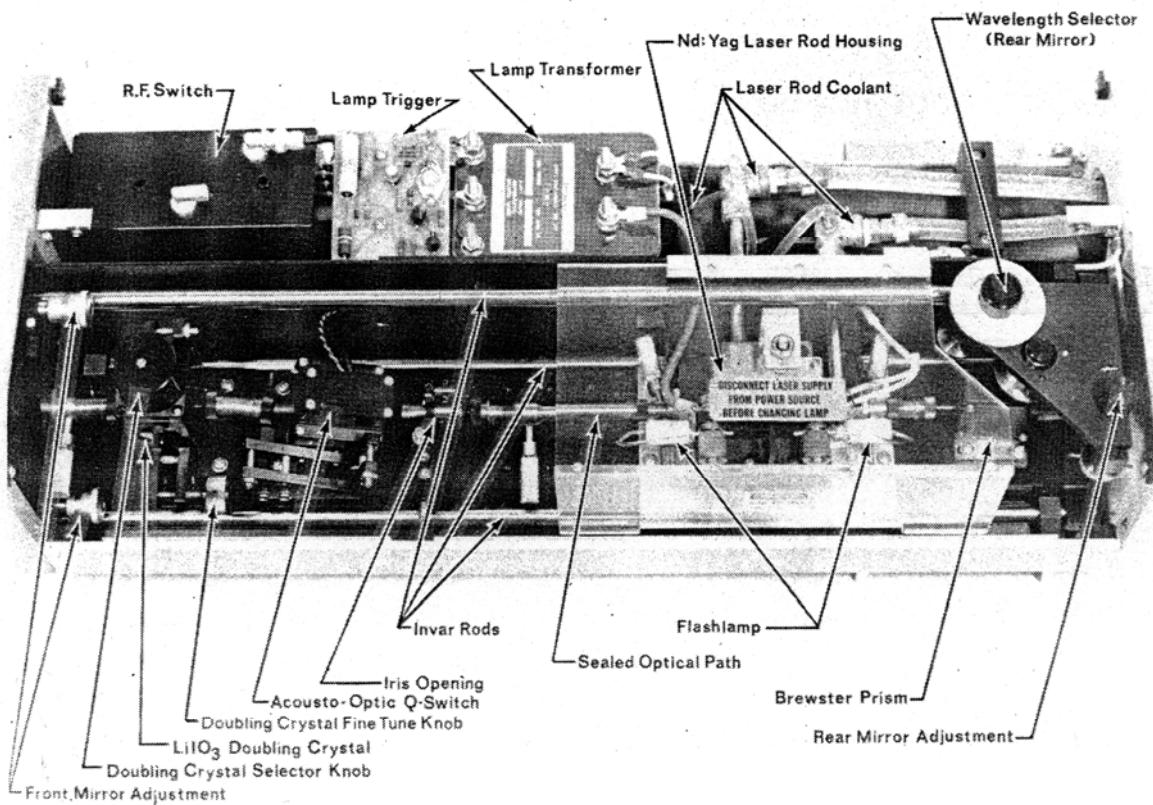


Fig. 6.18 Commercial Nd:YAG laser including frequency-doubling and *Q*-switching apparatus. Laser output at  $1.06 \mu\text{m}$  is converted to  $0.53 \mu\text{m}$  by frequency-doubling. (Courtesy of Chromatix.)

## Nd: Glass Lasers

- Can make very large laser disks - meters in diameter
- Large disks use to amplify solid state laser beam
- Used in Laser Fusion projects: National Ignition facility
- campus sized lasers - TeraWatts
- Slab type laser: beam bounces through Cavity

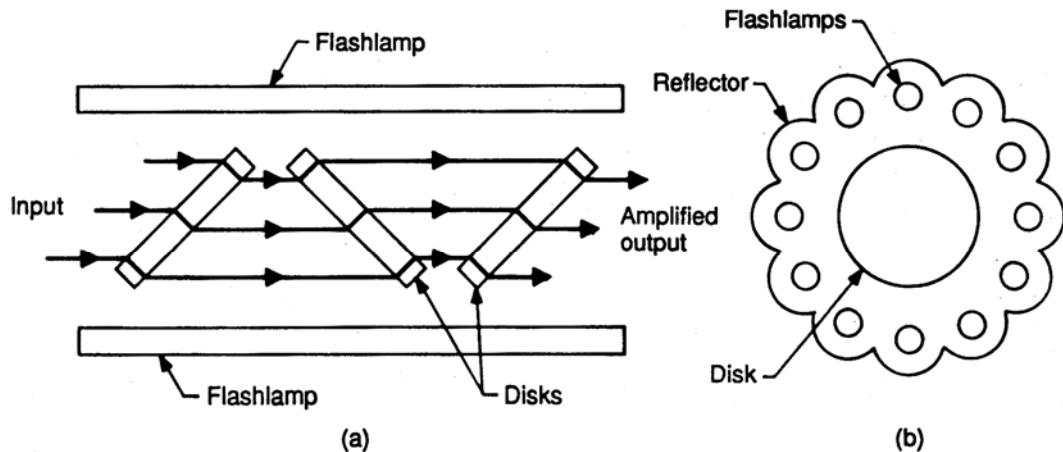


Figure 22.5 Disk amplifier, shown in (a) side and (b) end views.

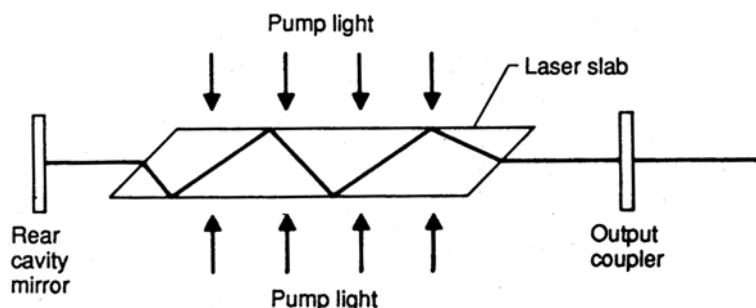


Figure 22.6 In a zigzag slab laser, the laser beam bounces back and forth between top and bottom of the slab, confined by total internal reflection. This design requires very flat top and bottom surfaces.



NIF laser Amplifiers

## Frequency Doubling & Higher Harmonics

- Nd:Yag is often run as frequency doubled or higher laser
- Generates visible or UV light that way
- Works due to non-linear optical effects in materials
- Called Second Harmonic Generation or frequency doubling
- Certain crystals have non-linear relation between E field polarization & applied E fields
- At high laser power E field from light causes effect
- Polarization P of the light becomes

$$P = \epsilon_0 (\chi_1 E + \chi_2 E^2 + \chi_3 E^3 + \dots)$$

- Where  $\chi_1$  is the linear polarization,  $\chi_2$  second order polarization
- Thus when a sine wave photon is applied then

$$E = E_0 \sin(\omega t)$$

$$P = \epsilon_0 (\chi_1 E_0 \sin(\omega t) + \chi_2 E_0^2 \sin^2(\omega t) + \chi_3 E_0^3 \sin^3(\omega t) + \dots)$$

$$P = \epsilon_0 \left( \chi_1 E_0 \sin(\omega t) + \frac{1}{2} \chi_2 E_0^2 [1 - \cos(2\omega t)] + \dots \right)$$

- Thus get both fundamental and 2<sup>nd</sup> harmonic light out

Frequency Doubling Inside a Nonlinear Crystal

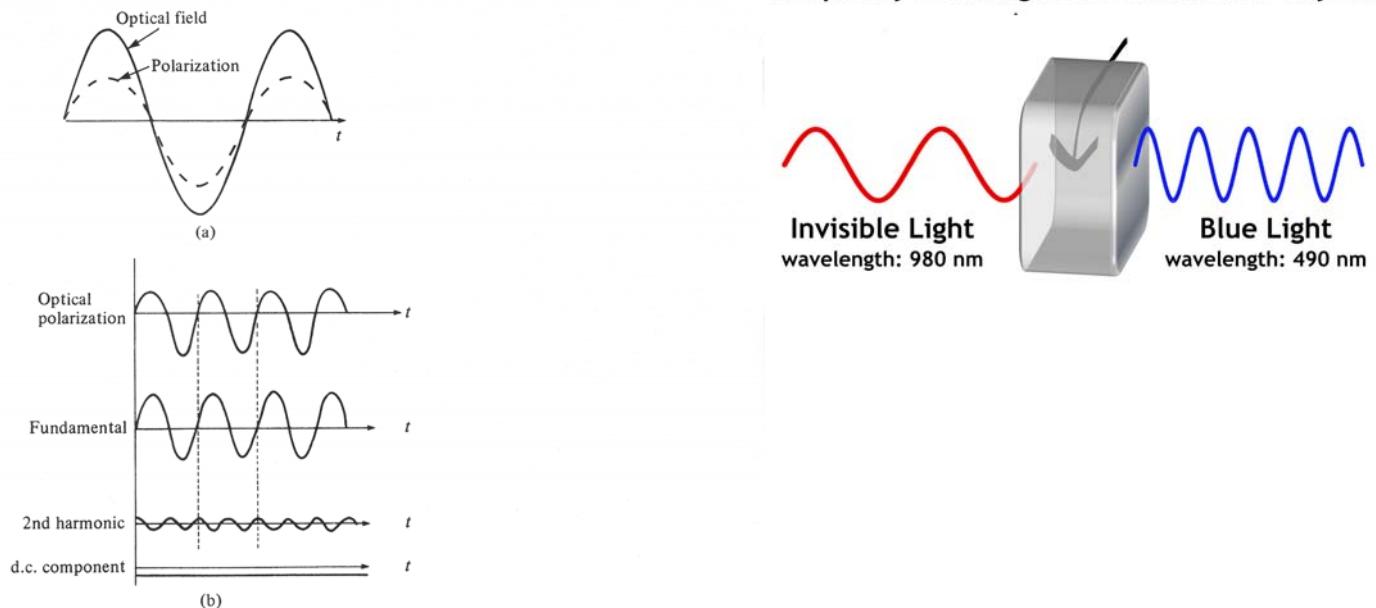


FIG. 3.24 Applied sinusoidal optical (i.e. electrical) field and the resulting polarization for a non-linear material (a) and Fourier analysis of the asymmetrical polarization wave (b) into (i) a fundamental wave oscillating at the same angular frequency ( $\omega$ ) as the wave inducing it, (ii) a second harmonic of twice that frequency ( $2\omega$ ) and (iii) an average (d.c.) negative component.

## Frequency Doubling

- Direct high power laser light at 2<sup>nd</sup> harmonic or higher crystal
- Done outside of laser cavity
- Generates visible or UV light that way
- For Nd:Yag get  $\lambda=1064$  nm &  $\lambda_2=1064/2=532$  nm
- Filter out fundamental and get a 2<sup>nd</sup> harmonic laser out in green
- Get ~70% efficiency of conversion for green
- 3<sup>rd</sup> harmonic 354 nm in UV much lower ~30-40%
- 4<sup>th</sup> harmonic use two doubling crystals 266 nm ~15% efficient
- 5<sup>th</sup> harmonic use 2<sup>nd</sup> & 3<sup>rd</sup> type crystals get 213 nm at ~6%
- Typical crystals KTP, Lithium Niobate
- Crystals have finite lifetime ~ few years depending on usage

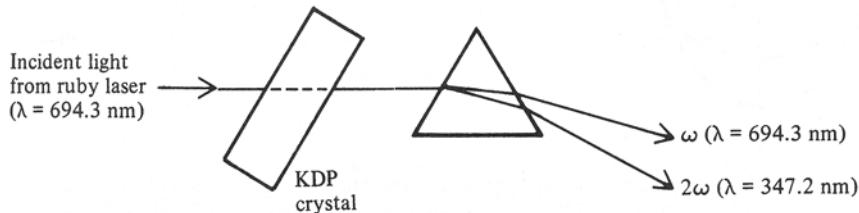
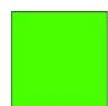


FIG. 3.25 Simplified diagram showing the arrangement for optical frequency doubling. The KDP crystal is mounted in the correct orientation for index matching.

Table 19.3 Typical OPO materials.

Nonlinear Crystal	Typical Pumping Laser	Wavelength Range
β-Barium borate, lithium borate	Frequency-tripled Nd:YAG, other Nd lasers, and XeCl excimer	~400 nm to ~2.5 μm
KTP and KTA	Frequency-doubled Nd: YAG, other frequency-doubled Nd lasers	~700 nm to ~4 μm
KTP and KTA	Nd:YAG, other Nd lasers, Yb	~1.5 μ to ~4 μm; shortest λ depends on pump λ and KTA versus KTP
LiNbO <sub>3</sub> , Lithium niobate	Nd:YAG, other Nd lasers, Yb	~1.4 to ~4 μm
Lithium niobate	Frequency-doubled Nd:YAG, other frequency-doubled Nd lasers	~700 nm to ~4 μm; can experience damage with green pumping
Periodically poled lithium niobate	~800-nm diodes, cw Nd:YAG; very high effective gain per unit power	~1.3 to ~5 μm; used with low-energy pulsed or cw lasers
Zinc germanium phosphide	2-μm Tm and Ho lasers, 3-μm Er laser	~3 to ~8 μm



Nd:Yag 2nd Harmonic  
532 nm

## Diode pumped Nd: YAG Lasers

- Newest used laser diode to pump Nd: YAG
- Diodes very efficient and  $\lambda$  tuned to max absorption of YAG
- Result: increase YAG efficiency for <5% to >50%
- Diode laser light can be carried by fiber optic to YAG cavity
- Means heat losses and power supply separate from laser
- Diode pumped laser fastest growing part of solid state laser market
- Eg. green laser pointers: diode pumped Nd:Yag & freq. doubler

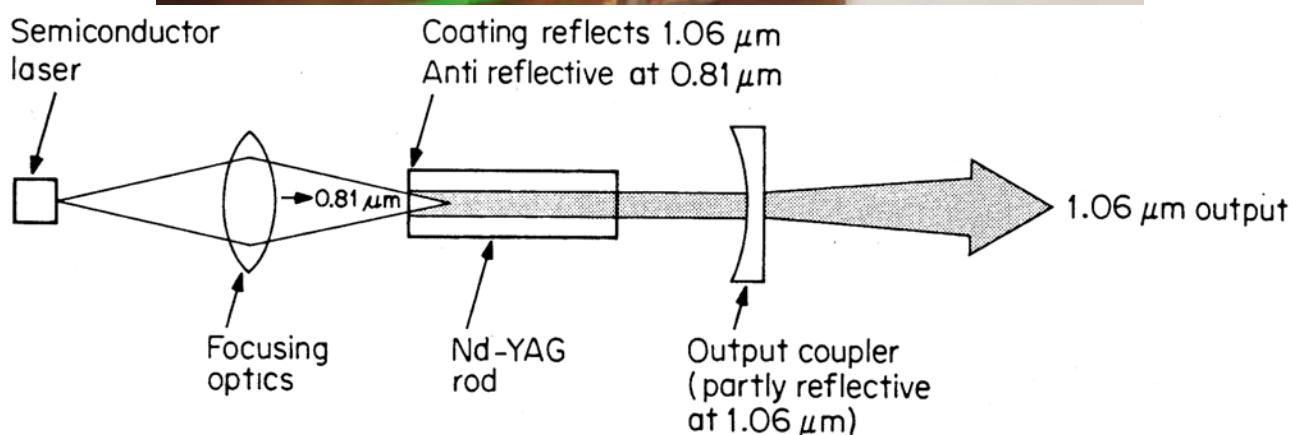
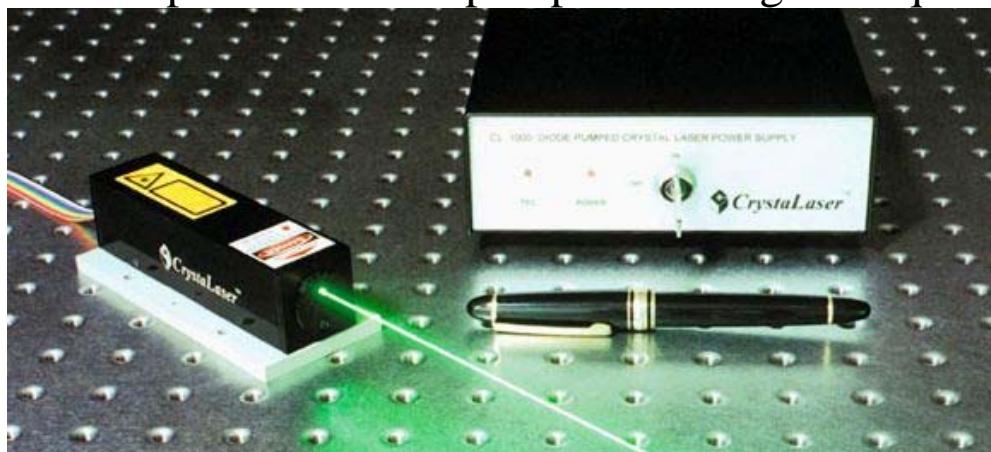


Figure 22.3 End pumping of an Nd-YAG rod with an 810-nm diode laser. Virtually all of the pump light is absorbed in the laser rod, so only the 1.06- $\mu\text{m}$  beam emerges from the output coupler.

## Typical Nd: Yag laser parameters

TABLE 22.2 Typical Output Powers for Neodymium Lasers Derived from Specifications

Type	Pump source	Wavelength, nm	Output powers (average or CW), W
Pulsed quadrupled Nd-glass	Flashlamp	263–266	≤0.04
Pulsed quadrupled Nd-YAG	Flashlamp	266	0.001–2
Pulsed tripled Nd-glass	Flashlamp	351–355	≤0.07
Pulsed tripled Nd-YAG	Flashlamp	355	0.001–20
Pulsed doubled Nd-YLF	Diode	523	0.00002–0.01
Pulsed doubled Nd-YLF	Flashlamp	523–527	1–3
CW Doubled Nd-YAG	Diode	532	0.001–0.08
Pulsed doubled Nd-YAG	Diode	532	0.000001–0.0004
Pulsed doubled Nd-YAG	Flashlamp	532	0.01–50
CW doubled Nd-YAG	Arc lamp	532	0.3–4*
Pulsed doubled Nd-glass	Flashlamp	532	≤0.15
CW Nd-YLF	Diode	1047	0.035–0.25
CW Nd-YLF	Diode	1053	0.015–0.1
CW Nd-YLF	Arc lamp	1053	≤20
Pulsed Nd-YLF	Flashlamp	1053	≤20
Pulsed Nd-phosphate glass	Flashlamp	1054	0.01–1
CW Nd,Cr-GSGG	Diode	1061	≤0.1
Pulsed Nd,Cr-GSGG	Flashlamp	1061	≤1
CW Nd-YAG	Diode	1064	0.002–3
Pulsed Nd-silicate glass	Flashlamp	1064	0.1–100
CW Nd-YAG	Arc lamp	1064	0.5–1800
Pulsed Nd-YAG	Flashlamp	1064	≤1500 W
CW Nd-YLF	Diode	1313	≤0.1
CW Nd-YLF	Lamp	1313	≤3
CW Nd-YAG	Diode	1319	≤0.25
Pulsed Nd-YAG	Flashlamp	1319	≤20
CW Nd-YAG	Arc lamp	1319	0.05–40
CW Nd-YLF	Diode	1321	0.015–0.1
CW Nd-YAG	Diode	1335	0.012–0.1
Pulsed Nd,Cr-GSGG	Flashlamp	1335	>1

\*Average power for modelocked second-harmonic output; continuous-wave (CW) power would be lower.

TABLE 22.3 Duration and Repetition Rates Available from Pulsed Neodymium Lasers Operating at 1.06  $\mu\text{m}$  (Not All Available Commercially)

Type	Modulation	Excitation source	Typical repetition rate	Typical pulse length
Nd-glass	Lamp only	Flashlamp	0–3 Hz	0.1–10 ms
Nd-glass	Q switched	Flashlamp	0–3 Hz	3–30 ns
Nd-glass	Modelocked	Flashlamp	Pulse trains*	5–20 ps
Nd-YAG	Lamp only	Flashlamp	0–200 Hz†	0.1–10 ms
Nd-YAG	Q switched	Flashlamp	0–200 Hz†	3–30 ns
Nd-YAG	Cavity dump	Flashlamp	0–200 Hz†	1–3 ns
Nd-YAG	Modelocked	Flashlamp	Pulse trains*	20–200 ps
Nd-YAG	Q switch	Arc lamp	0–100 kHz	40–700 ns
Nd-YAG	Q switch	Diode	0–15 kHz	20–30 ns
Nd-YAG	Modelocked	Arc lamp	50–500 MHz	20–200 ps
Nd-YAG	Modelocked and Q-switched	Arc lamp	Varies‡	20–200 ps§
Nd-YLF	Modelocked	Arc lamp	Same as YAG	About half YAG
Nd-YLF¶	Modelocked	Diode	160 MHz	7 ps
Nd-YLF/ glass	Modelocked and chirped pulse amplification	Lamp	0–2 Hz	1–5 ps

\*Series of 30–200 ps pulses, separated by 2–10 ns, lasting duration of flashlamp pulse, on the order of a millisecond.

†Depends on flashlamp pulse rate.

‡Depends on Q-switch rate; modelocked pulses.

§In pulse trains lasting duration of Q-switched pulses (100–700 ns).

¶Laboratory results (Juhasz et al., 1990).

## Alexandrite Lasers

- Alexandrite: dopant  $\text{Cr}^{3+}$  in  $\text{BeAl}_2\text{O}_4$
- Similar to ruby: developed 1973
- 4 level system
- Transition to wide range of bands: 700-820 nm
- Creates a tunable laser

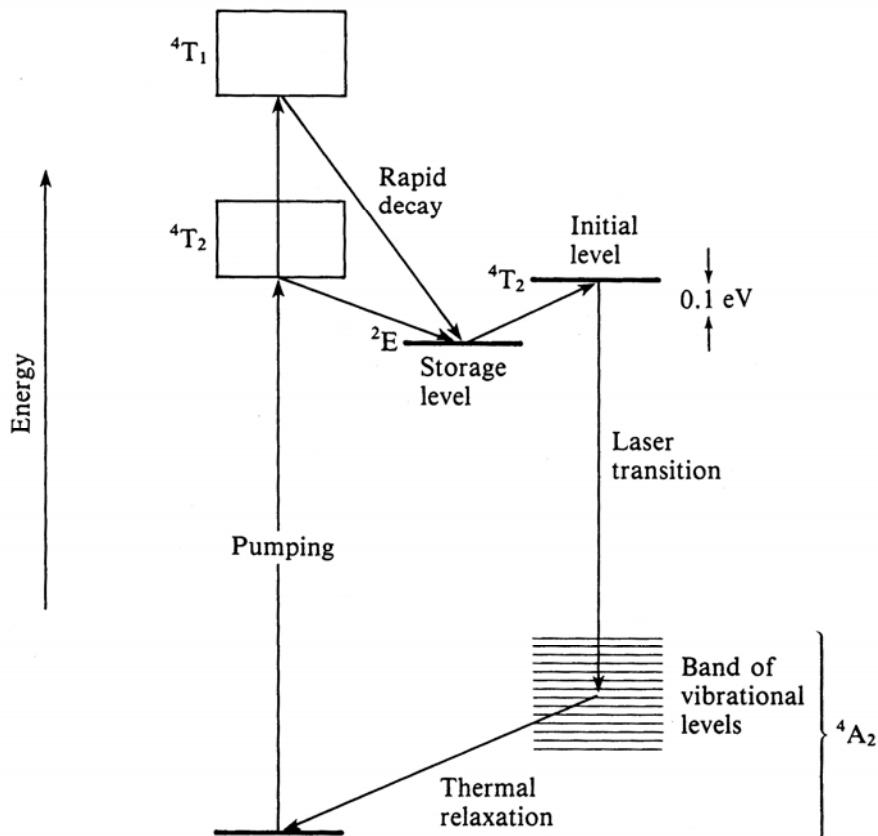
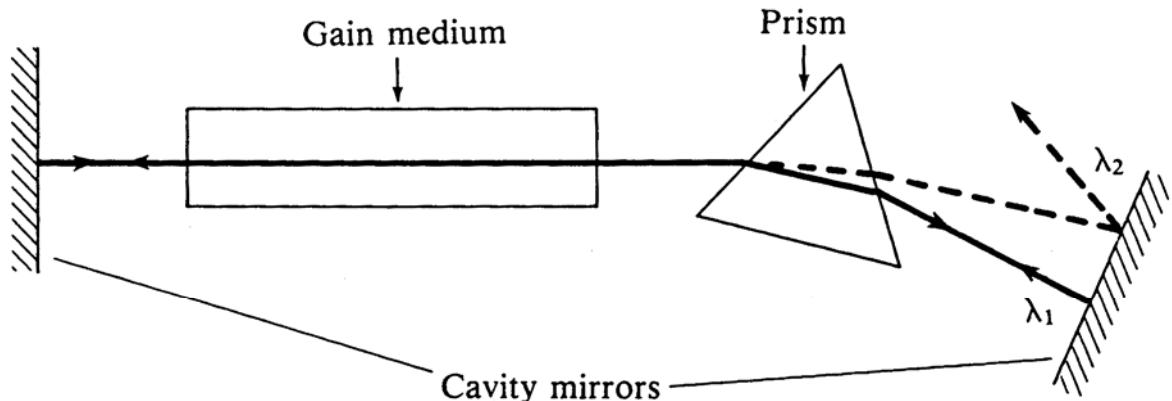


Fig. 2.11 Schematic energy-level diagram for active levels in the Alexandrite laser. The laser is effectively a four-level system. The laser transition terminates on one of a band of closely-spaced vibronic levels associated with the ground state thus allowing the laser to be tuned over the range 700–815 nm. Note that the ‘initial level’ is in fact the bottom of the  ${}^4\text{T}_2$  band, the two have been drawn as if they were separate for pictorial convenience.

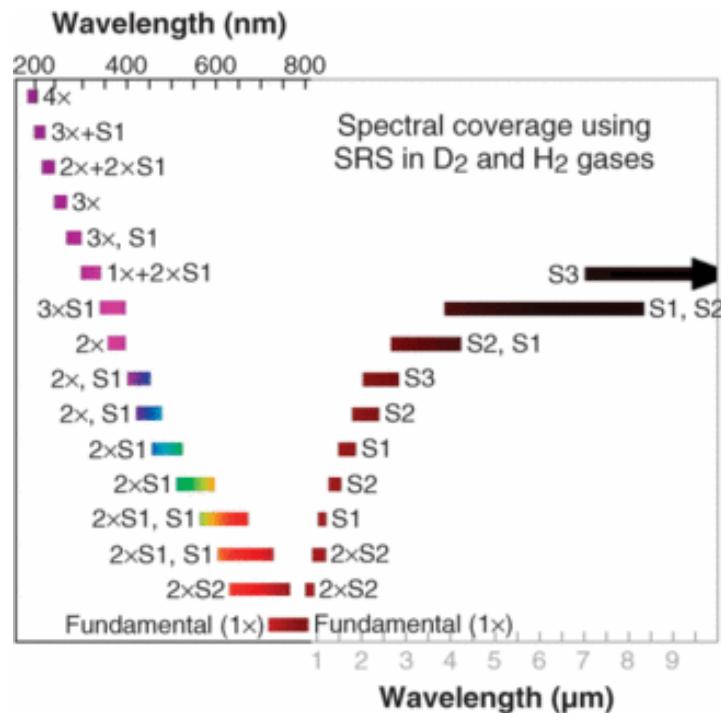


## Tuneable Alexandrite Laser

- Place frequency tuneable device in cavity at rear
- Typically prism or diffraction grating with tuneable angle
- Also acousto-optical shutter (controllable diffraction grating)
- Only wavelength set by prism is for proper for cavity
- Set to specific wavelength for chemical or spectroscope usage



**Fig. 2.12** Cavity wavelength tuning using a prism as the dispersive element. Light of wavelength  $\lambda_1$  meets the cavity mirror at normal incidence and is reflected back through the laser medium. Light at other wavelengths (say  $\lambda_2$ ) is reflected out of the laser cavity.



## Ti: Sapphire Lasers

- Uses Sapphire ( $\text{Al}_2\text{O}_3$ ) rods doped with Titanium
- $\text{Ti}^{3+}$  ion is very long lived with wide gain bandwidth
- Typically pumped with green light Argon or 2<sup>nd</sup> Harmonic Nd:Yag
- Generates very short pulse: typically 100 femtosec.
- Tuneable using acousto-optic modulator from 650-1100 nm
- Also usually mode lock the laser
- Most popular tuneable laser in that wavelength band
- Replaced dye lasers in most applications

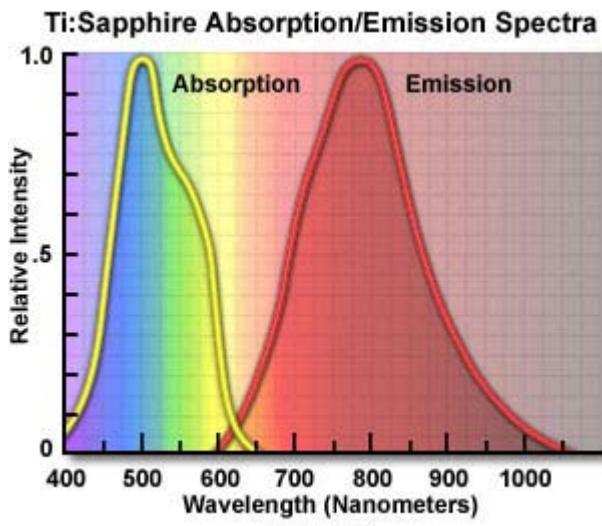
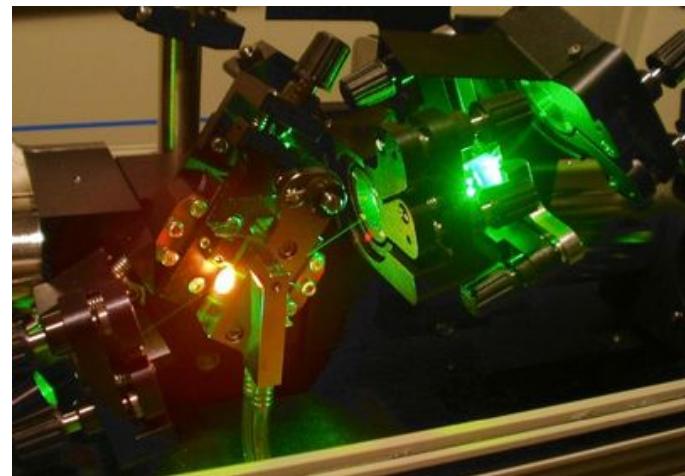
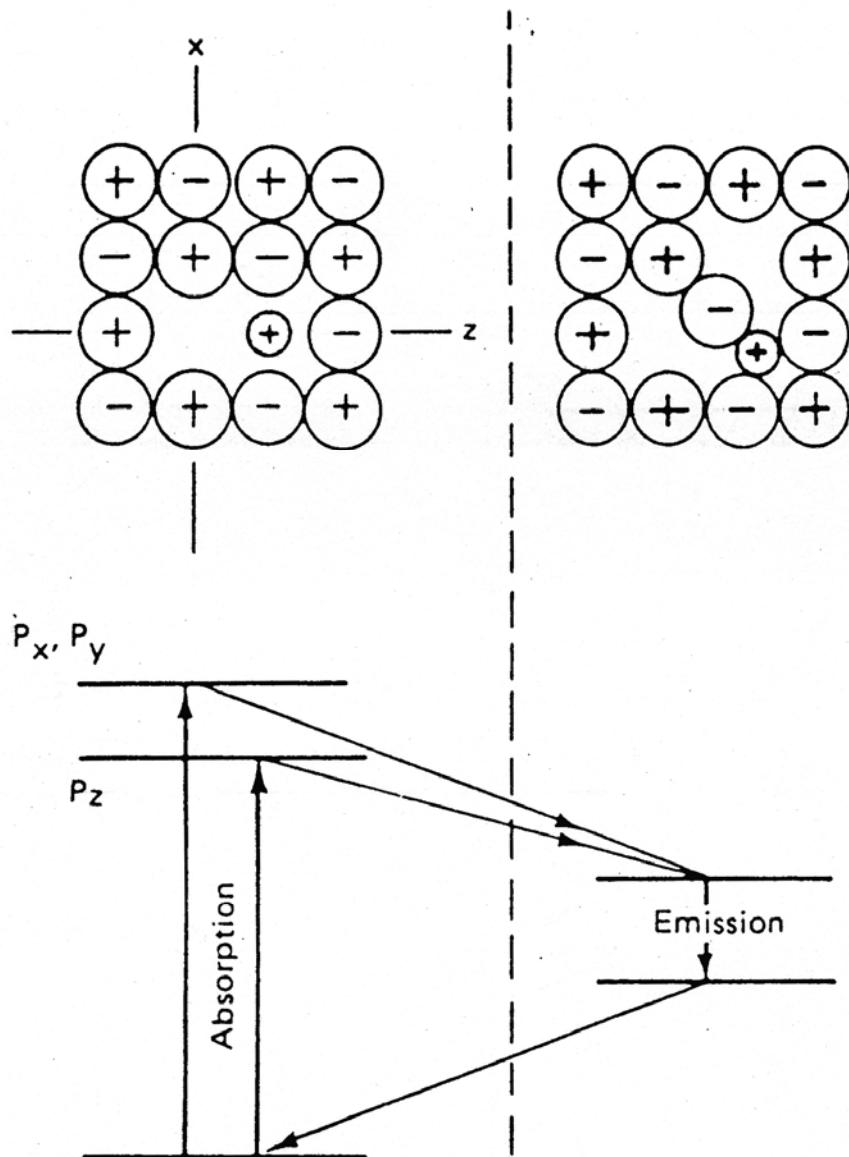


Figure 1



## Color or F Centre Laser

- Clear material (eg glass) develops damage points
- Damaged when high power (eg light)
- Alkali Halids form point defects from X-rays, e-beams
- Clear material becomes coloured
- Defect a cation vacancy: net positive charge
- Electron orbits this: broad absorption band



**Figure 25.1** Structure of a  $F_A$ (II) color center showing (a) normal (vacancy) configuration and (b) configuration in upper laser level. The energy-level structure is shown at bottom. (From Mollenauer, 1982, with permission.)

## Color Centre Laser

- Optically pumped, usually by another laser
- Broad band of states so laser tuned
- eg Thallium doped KBr pumped by Nd:Yag
- Emits at 1.4 - 1.6 microns, 20% efficiency

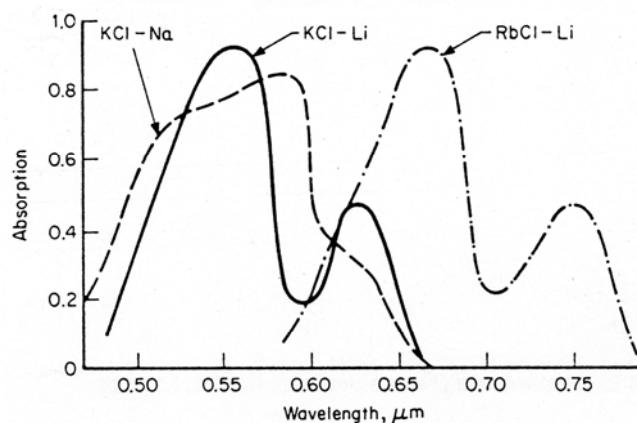


Figure 25.3 Absorption bands of three color-center crystals used in commercial lasers. (Courtesy of Burleigh Instruments Inc.)

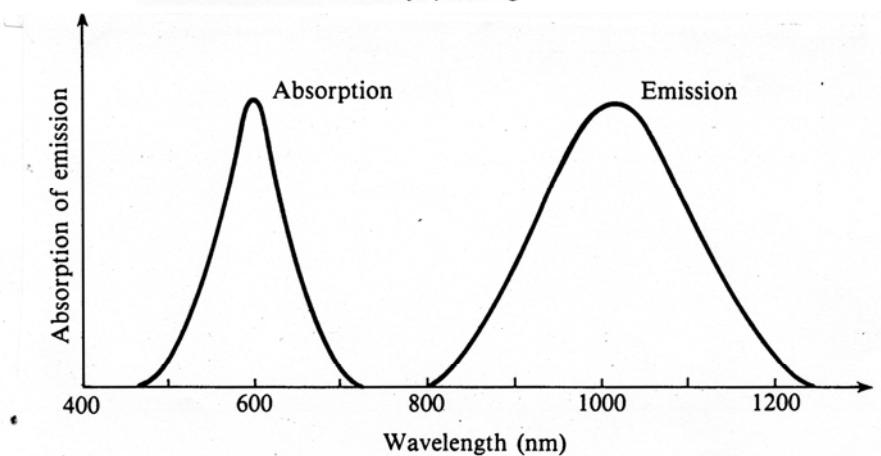


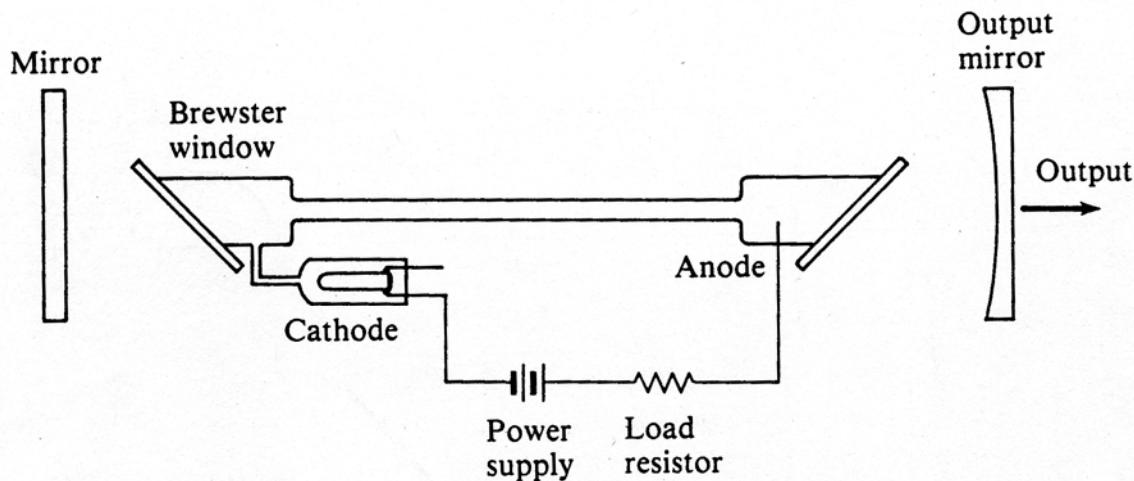
Fig. 2.13 The absorption and emission spectra of F color centers in KCl. The separation between the peaks is an example of the Stokes shift.



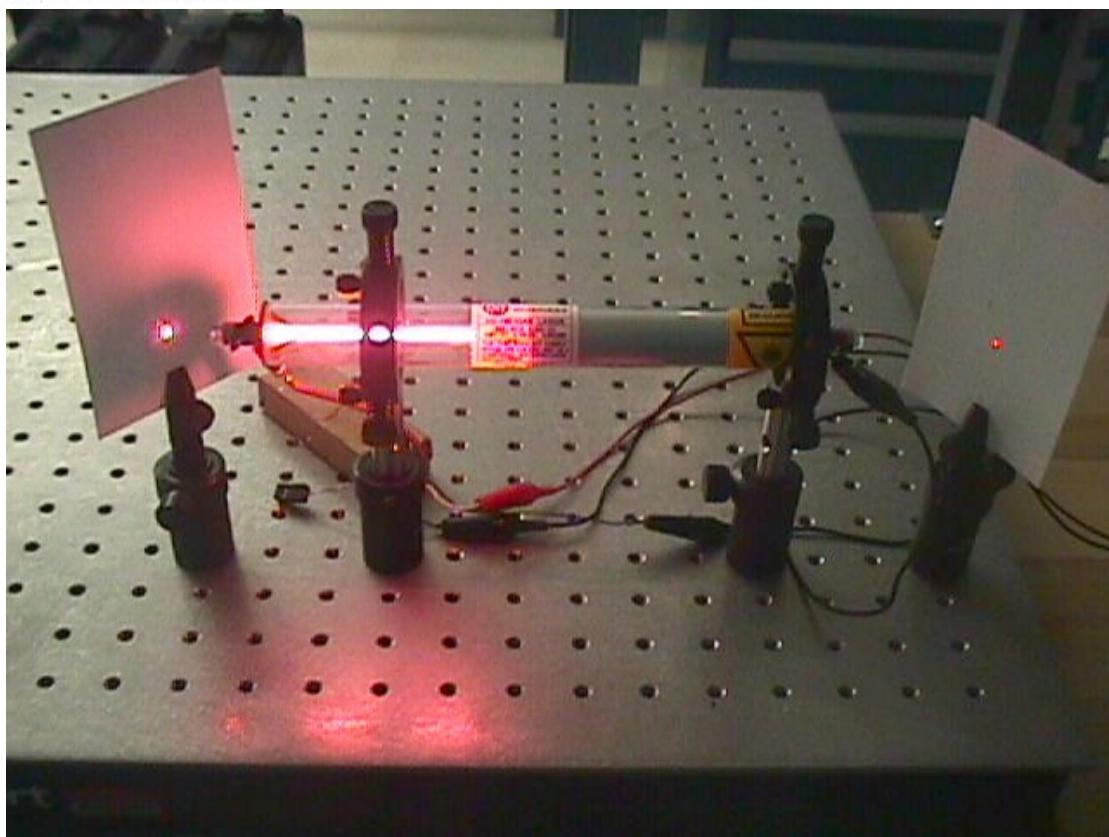
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## Gas Lasers

- Lasers that use gases as the gain medium – 4 main types
- Atomic (atoms not ionized)
- Nobel Gas Ion Lasers
- Molecular Lasers
- Excimer Lasers



**Fig. 2.25** Schematic construction of a low-power gas laser such as the helium–neon laser. The load resistor serves to limit the current once the discharge has been initiated.



## He-Ne Atomic laser

- Transitions between levels non ionized atoms
- He-Ne first: 1960 by Javan at Bell Labs
- He:Ne 10:1 ratio, at 10 torr
- Wall collision needed for ground: narrow tubes
- Very narrow line width, cheap
- Power 0.5 - 10 mW typically



## He-Ne Atomic laser

- He-Ne most common: uses DC arc current to pump
- Current excites He
- He  $2^1S$  at Ne  $3S$  level & metastable
- Transfer by atomic collision
- Strongest (most common) 632.8 nm in red
- Also transitions at  $3.39 \mu\text{m}$ ,  $1.15 \mu\text{m}$  (IR) & 543.5 nm (green)
- Choose wavelength by dielectric mirror reflectivity
- Fast decay to Ne  $3S$

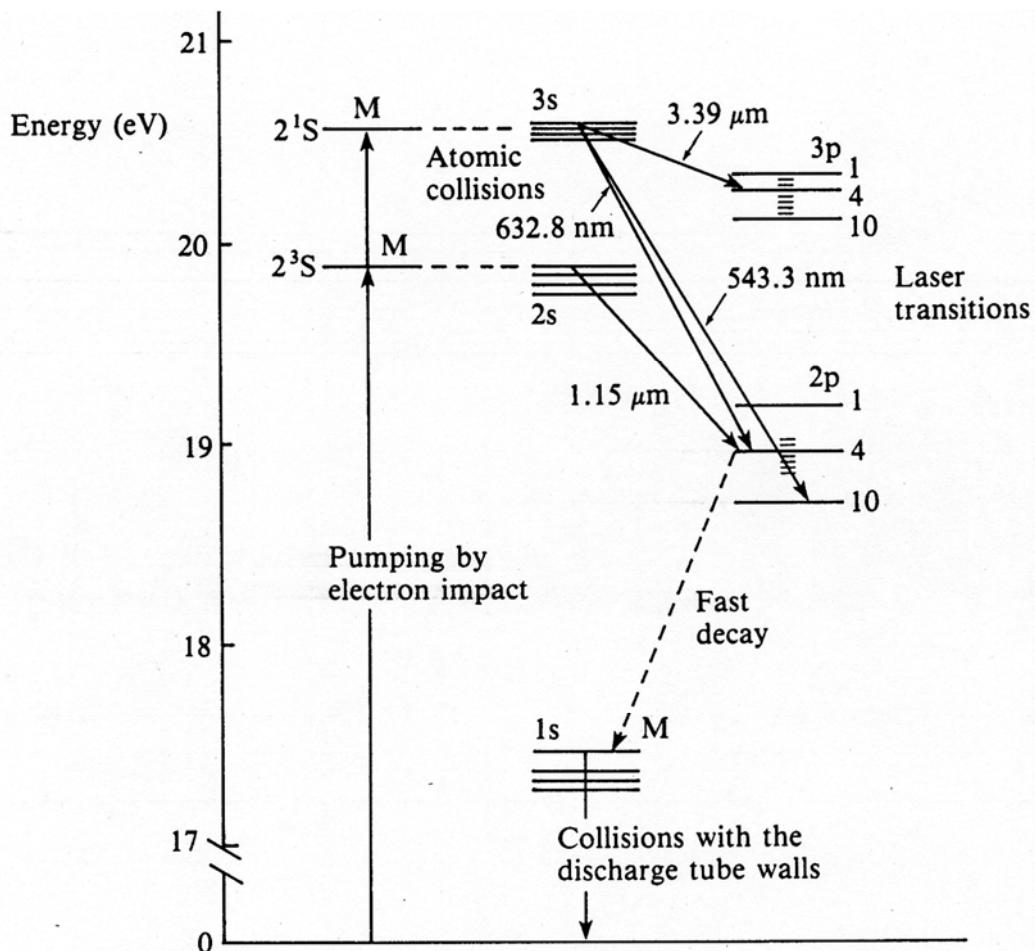


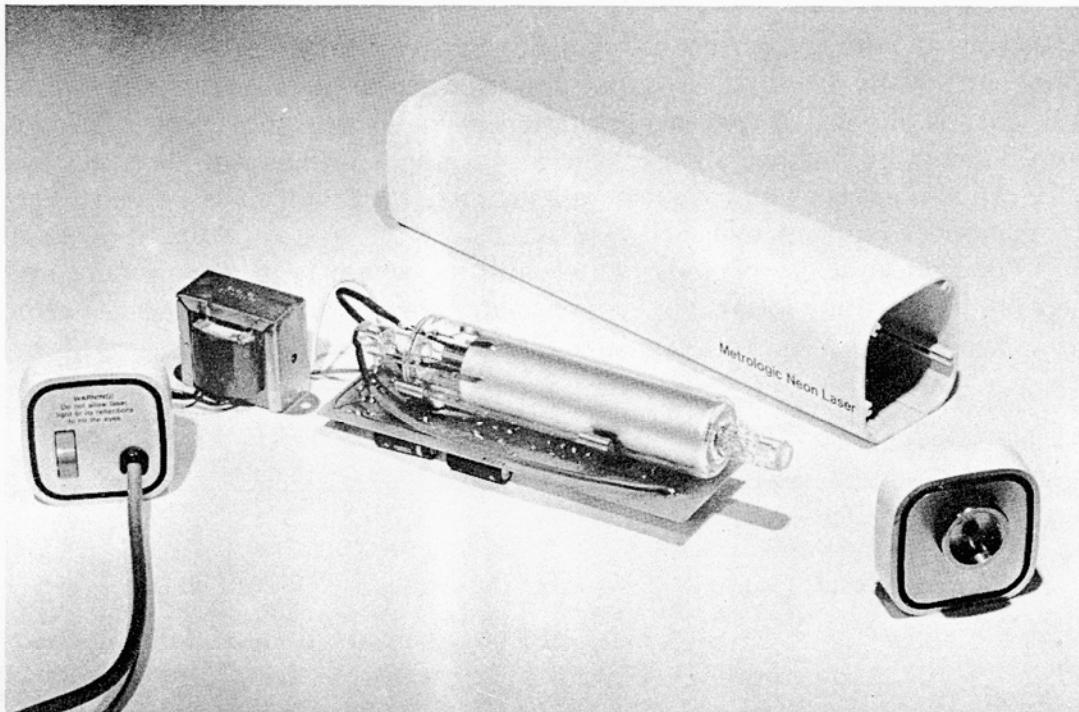
Fig. 2.26 Energy levels relevant to the operation of the HeNe laser. M indicates a metastable state (see p. 19).

HeNe (main red)  
632.8

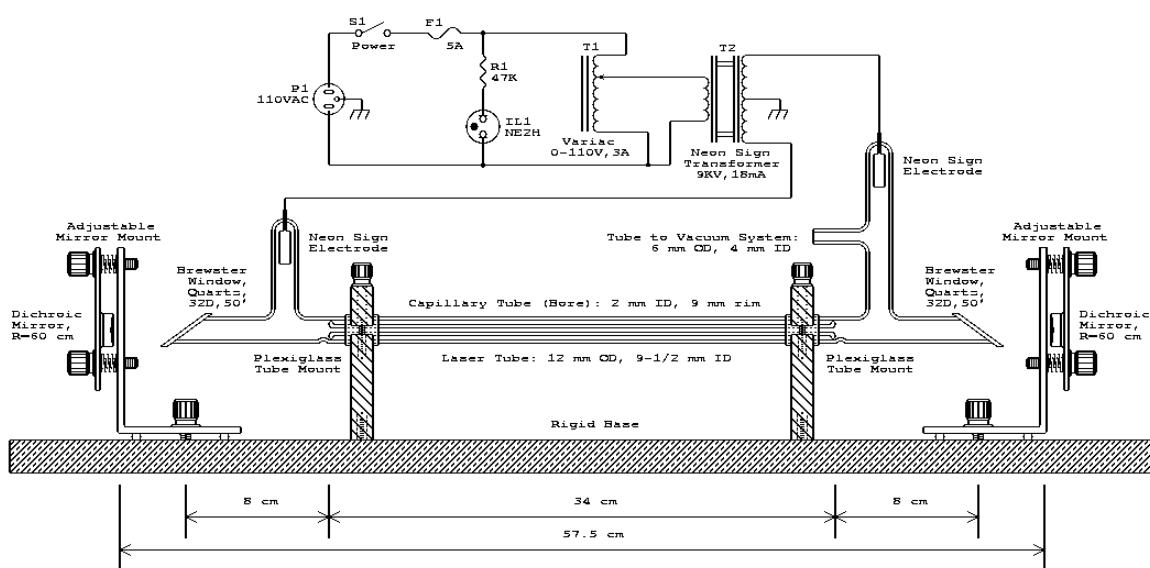
HeNe (green)  
543.5 nm

## Typical He-Ne

- Small ballast like ignitor (like fluorescent lamps/)
- Tube just like Neon tubes
- Can be extremely stable.
- Note: possibly no Brewster windows



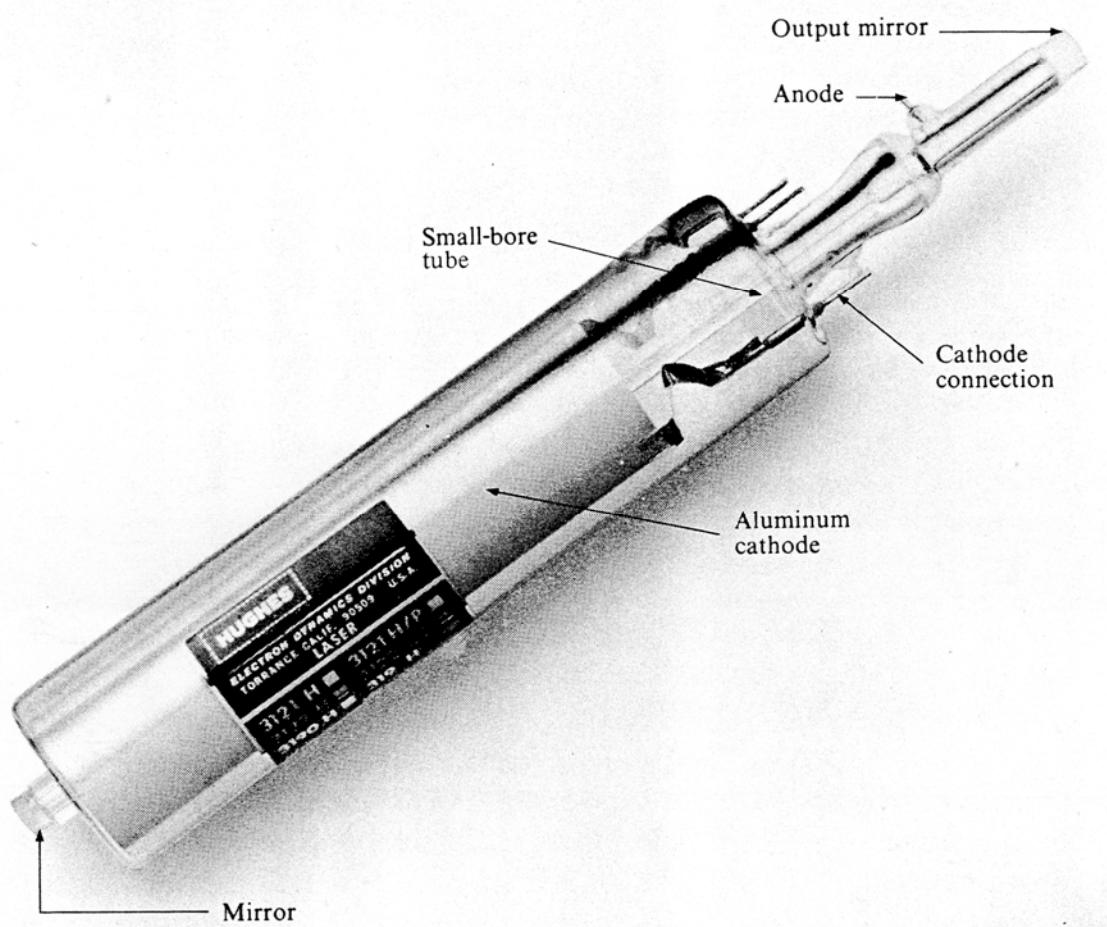
**Fig. 6.2** Mass-produced helium-neon laser, consisting of an extruded aluminum case, a voltage transformer, a voltage multiplier and rectifying circuit on a printed circuit board, and a laser tube. (Courtesy of Metrologic Instruments, Inc.)



Typical Home-Built Helium-Neon Laser Assembly  
(Not to Scale)

## Sealed End He-Ne

- Seal mirror onto tube to fix alignment
- Very narrow line width & cheap
- Power 0.5 - 10 mW typically
- Note: no Brewster windows here so not polarized



**Fig. 6.4** Laser tube with internal mirrors. The large tube is fitted internally with a small-bore tube (about 3 mm inside diameter). The bore confines the discharge to the region between the mirrors and provides the surface for wall collisions needed to maintain the population inversion in the HeNe system. (Courtesy of Hughes Aircraft Company, Electron Dynamics Division.)

## Nobel Gas Ion Lasers

- Most powerfully visible light lasers - up to 10's of Watts
- Must ionize the gas
- Heater heats the gas initially
- Starting current: 10-50 Amp
- Running current few Amp - 100 amp
- longer laser, more power (0.5 - several m)
- Magnetic field keeps ions away from walls
- Most water cooled
- Efficiency about 5% when running all lines
- Select wavelength using prism: only one  $\lambda$  path to mirror

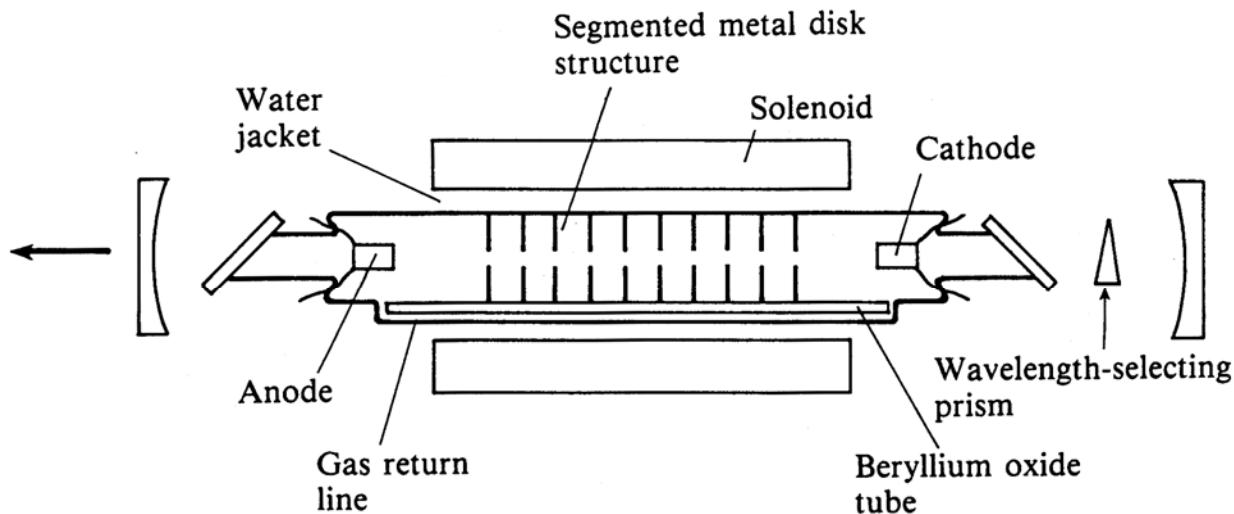
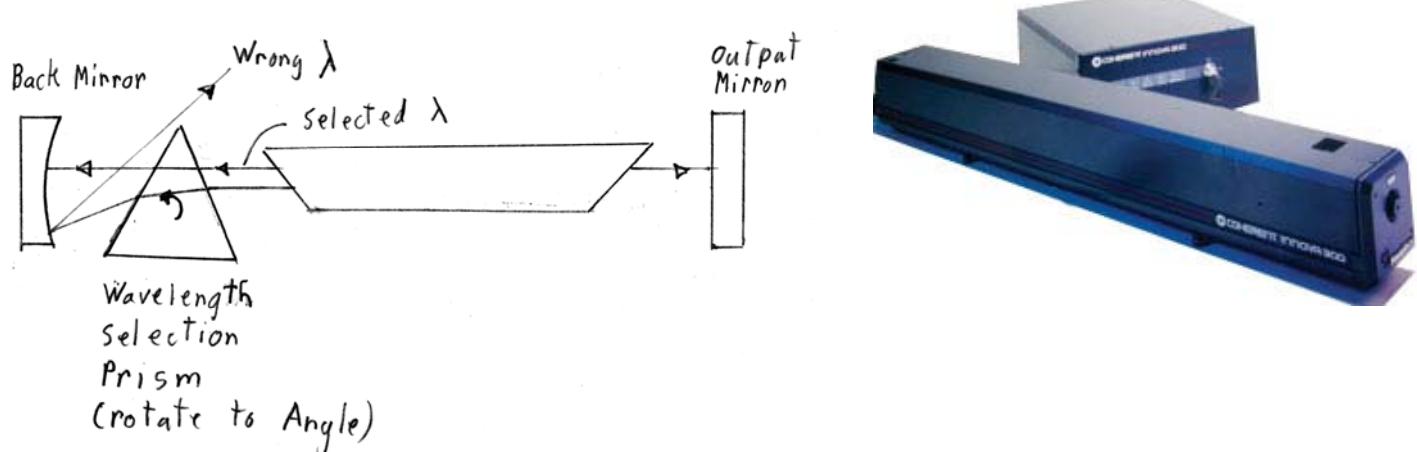
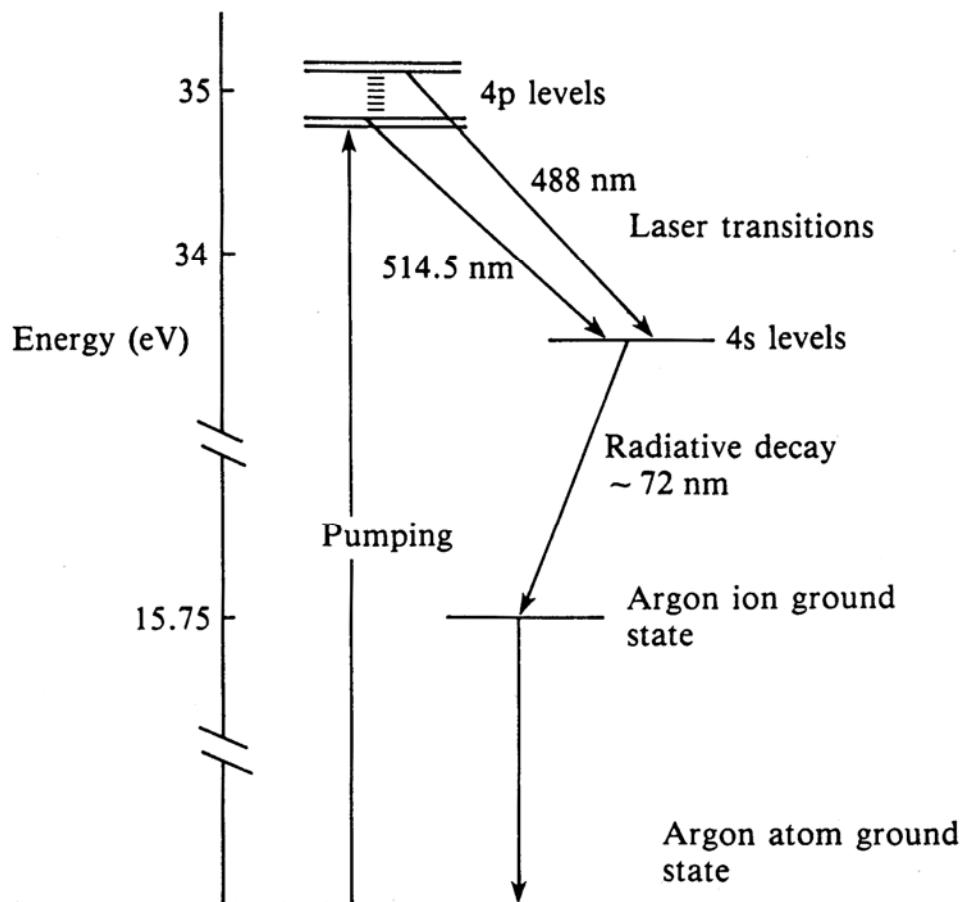


Fig. 2.29 Construction of a typical argon ion laser.



## Argon & Krypton Laser

- Most common
- Argon: current pumping to 4p levels
- 4s transition for 514.5 nm & 488 nm



**Fig. 2.28** Simplified energy level diagram for the argon laser. Ten or more laser lines are produced but the two shown are by far the most intense.

Argon (main green) 514 nm	Krypton (deep red) 676 nm
Argon (main blue/green) 488 nm	Krypton (main red) 647 nm
Argon (main blue) 476 nm	Krypton (yellow/green) 569 nm
Argon (deep blue) 458 nm	Krypton (green) 530 nm
Argon (UV/violet) 364 nm	

## Argon & Krypton Laser

- Actually many transitions
- Most power runs all lines
- Select wavelength with prism
- Widely used in laser light shows
- Argons for Greens - Blues also UV
- Krypton for Red - Yellow

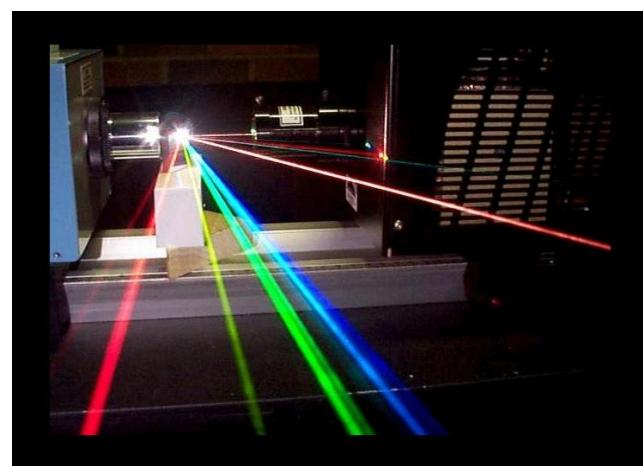
### POWER SPECIFICATIONS<sup>1</sup>

Wavelength (nm)	ARGON			KRYPTON
	INNOVA 304	INNOVA 305	INNOVA 306	INNOVA 301
Multiline Visible	4.0	5.0	6.0	SEE NOTE 2
Multimode Visible	5.0	6.0	7.2	—
1090	0.04	0.05	0.07	—
793.1-799.3	—	—	—	0.03
752.5	—	—	—	0.10
676.4	—	—	—	0.12
647.1	—	—	—	0.60
568.2	—	—	—	0.15
530.9	—	—	—	0.20
528.7	0.20	0.35	0.42	—
520.8	—	—	—	0.07
514.5	1.70	2.00	2.40	—
501.7	0.30	0.40	0.48	—
496.5	0.50	0.60	0.72	—
488.0	1.30	1.50	1.80	—
482.5	—	—	—	0.03
476.5	0.50	0.60	0.72	—
476.2	—	—	—	0.05
472.7	0.12	0.20	0.24	—
465.8	0.10	0.15	0.18	—
457.9	0.25	0.35	0.42	—
454.5	0.05	0.12	0.14	—
350.1-356.4	—	—	—	0.15
336.3-363.8	0.20	0.40	0.50	—



Coherent Innova-90 Argon/Ion Laser

M. Csele, Niagara College, Canada



Whitelight Ar/Kr Ion Laser Spectral Lines

# Argon & Krypton Laser

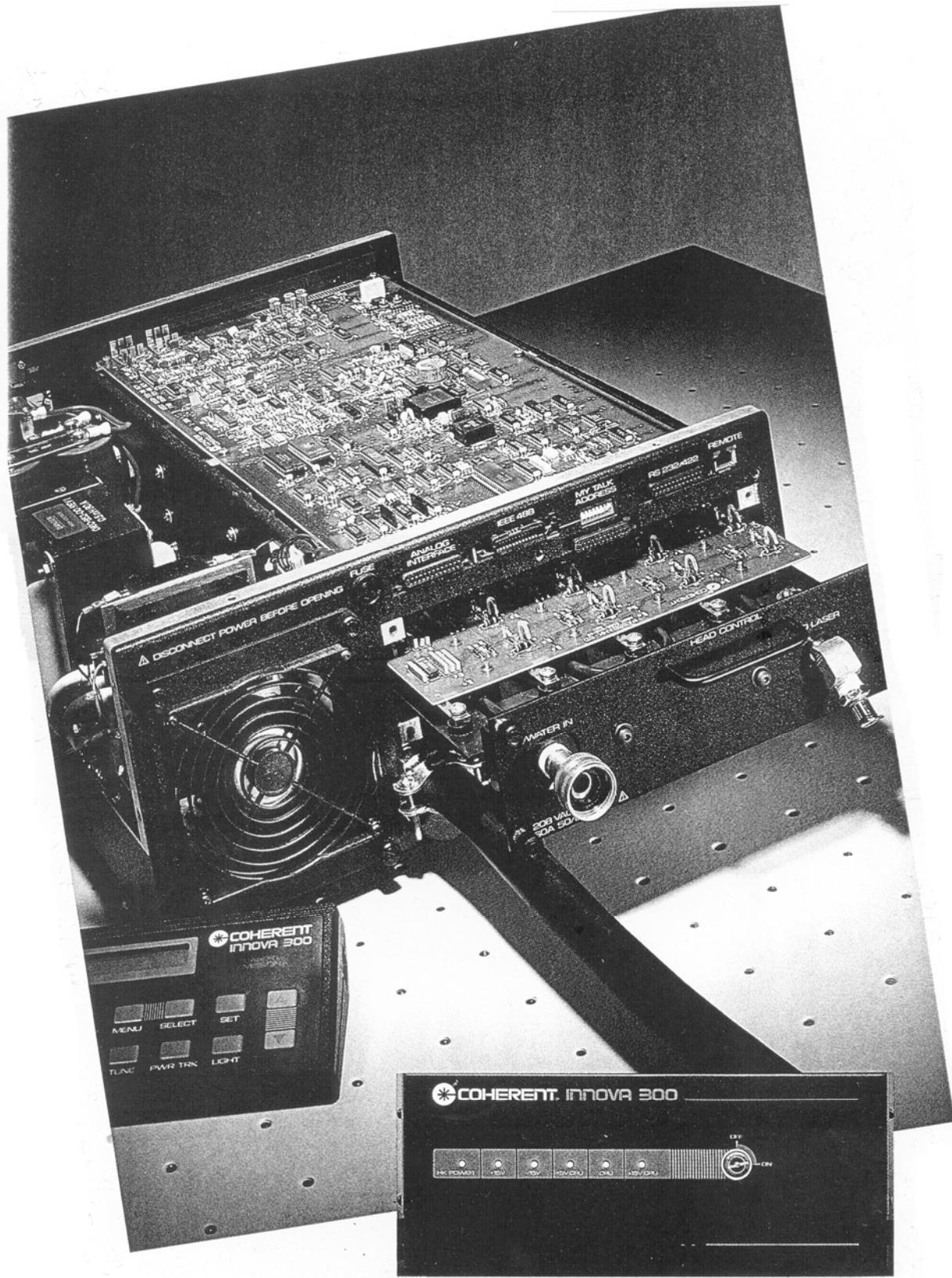


## Beam Specifications<sup>2</sup>

	Argon	Krypton
Beam Diameter (@ 1/e <sup>2</sup> points) <sup>3</sup>	1.5 mm	1.5 mm
Beam Divergence (full angle)	0.5 mrad	0.8 mrad
Beam Waist Diameter <sup>4</sup>	1.4 mm	1.1 mm
Beam Waist Location <sup>4</sup>	1.50 m	1.27 m
Cavity Length		
Single-line	1.16 m	1.16 m
Multiline	1.14 m	1.14 m
Long-Term Power Stability <sup>5</sup>		
Light Regulation	±0.5%	±0.5%
Current Regulation	±3.0%	±3.0%
Optical Noise (rms) <sup>6</sup>		
Light Regulation	±0.2%	±0.2%
Current Regulation	±0.2%	±0.2%

## Argon & Krypton Laser Power Supply

- Very high power - water cooled, 3 phase, 240 V supply



## Molecular Lasers

- Operate by molecular vibration transitions
- Generally Infrared
- Most important  $\text{CO}_2$
- Power from 10's - 1000's Watts
- High efficiency: up to 30%

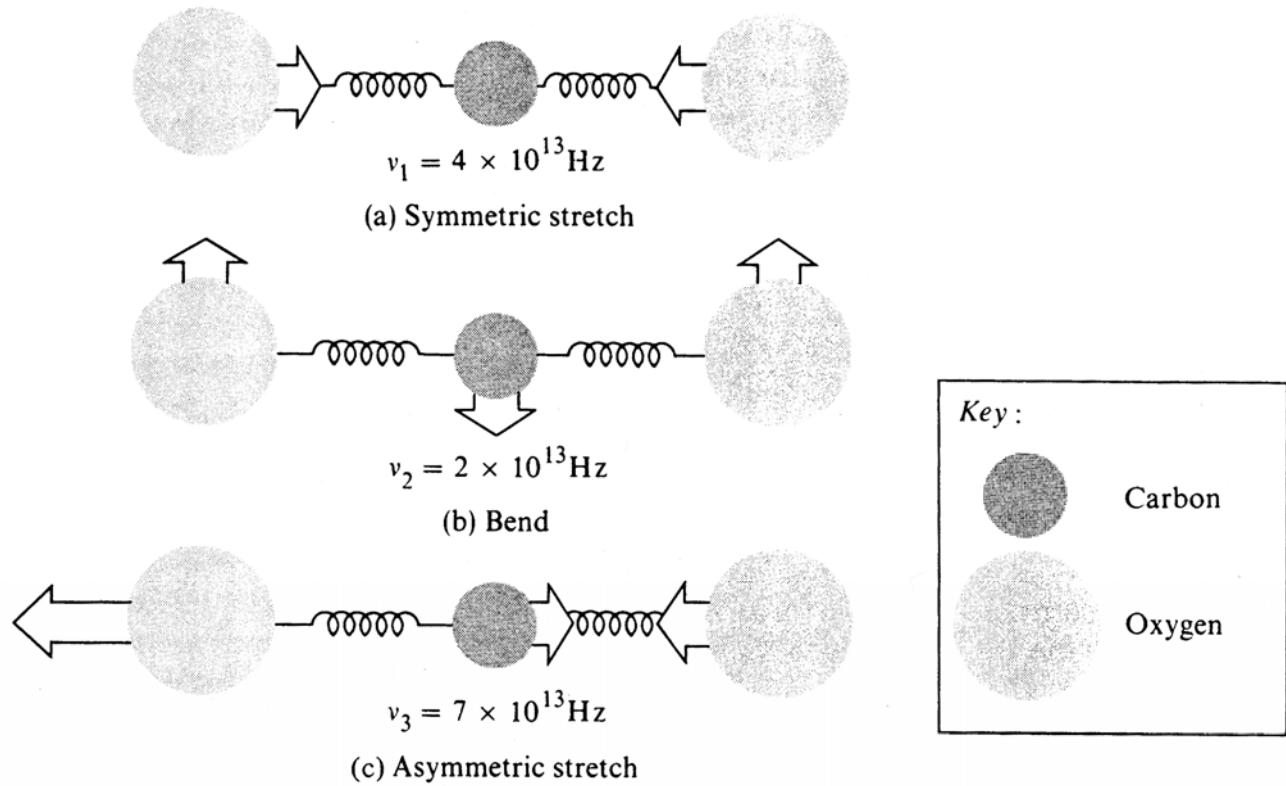
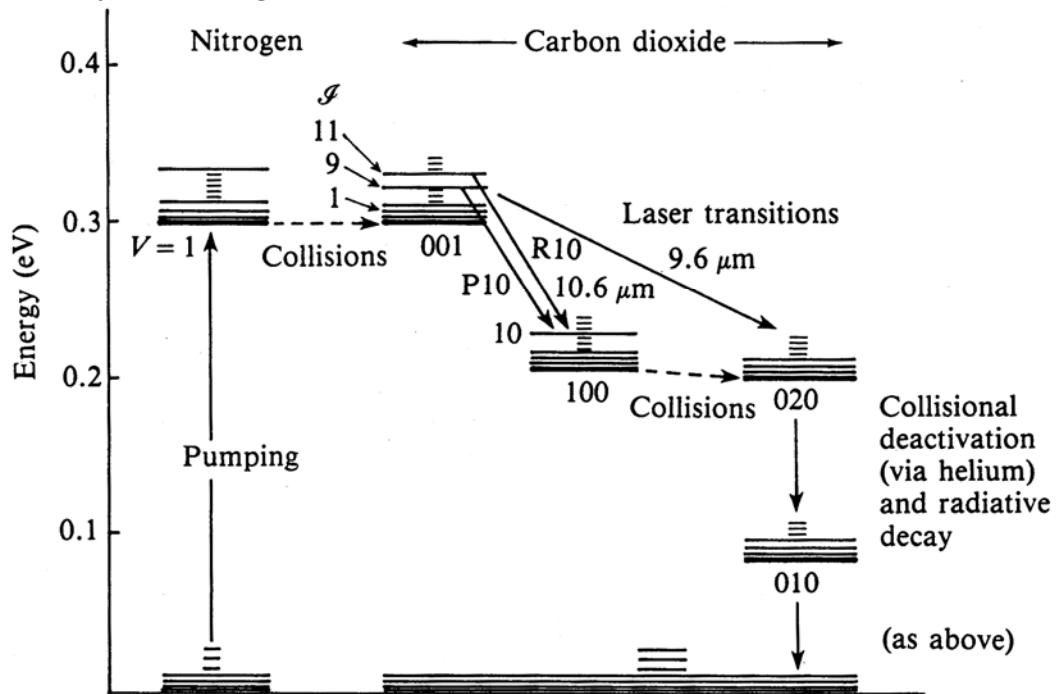


Fig. 6.8 Vibrational modes of the  $\text{CO}_2$  molecule.



## Carbon Dioxide Lasers

- N-CO<sub>2</sub>:He mixture 1:1:1
- N<sub>2</sub> (001) vibration level close to CO<sub>2</sub> (001)
- N<sub>2</sub> excited collisions with CO<sub>2</sub>
- Emissions at 10.6 μm (most important) and 9.6 μm
- Both Far IR – absorbed by glass & plastics (cuts glass)
- Needs to use Geranium Lenses
- 10 torr for CW, high pressure for pulsed
- Sealed tube lasers: like He-Ne: <100 W
- Limited by cooling



**Fig. 2.32** Simplified energy level diagram for the carbon dioxide laser. Each vibrational level has many rotational levels associated with it.  $\mathcal{J} = 1, 2, \text{ etc.}$  The letters P and R represent transitions where  $\mathcal{J}$  changes by +1 and -1 respectively.



## Carbon Dioxide Lasers

- Transversely Excited Atmospheric TEA
- High voltage due to high pressure
- Excite across tube width
- Pulsed: 50 nsec, up to 100 J
- GasDynamic Laser
- Gas heated and compressed then expanded
- Creates the vibration levels & high power
- Mostly of military interest

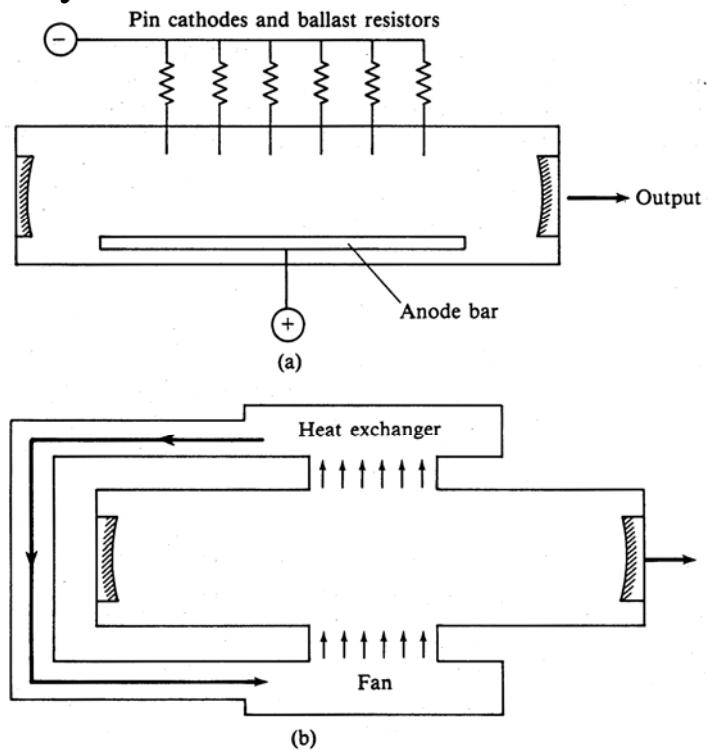


Fig. 2.33 Schematic diagram of a TEA CO<sub>2</sub> laser; the discharge is perpendicular to the axis of the laser cavity ('side' view (a)). A high gas flow is required which can also take place perpendicular to the axis ('top' view (b)).



## Carbon Dioxide Lasers Major types

- Waveguide with few mm wide tube
- Uses radio frequency field stimulation
- Low power (50W) low price (\$1000)

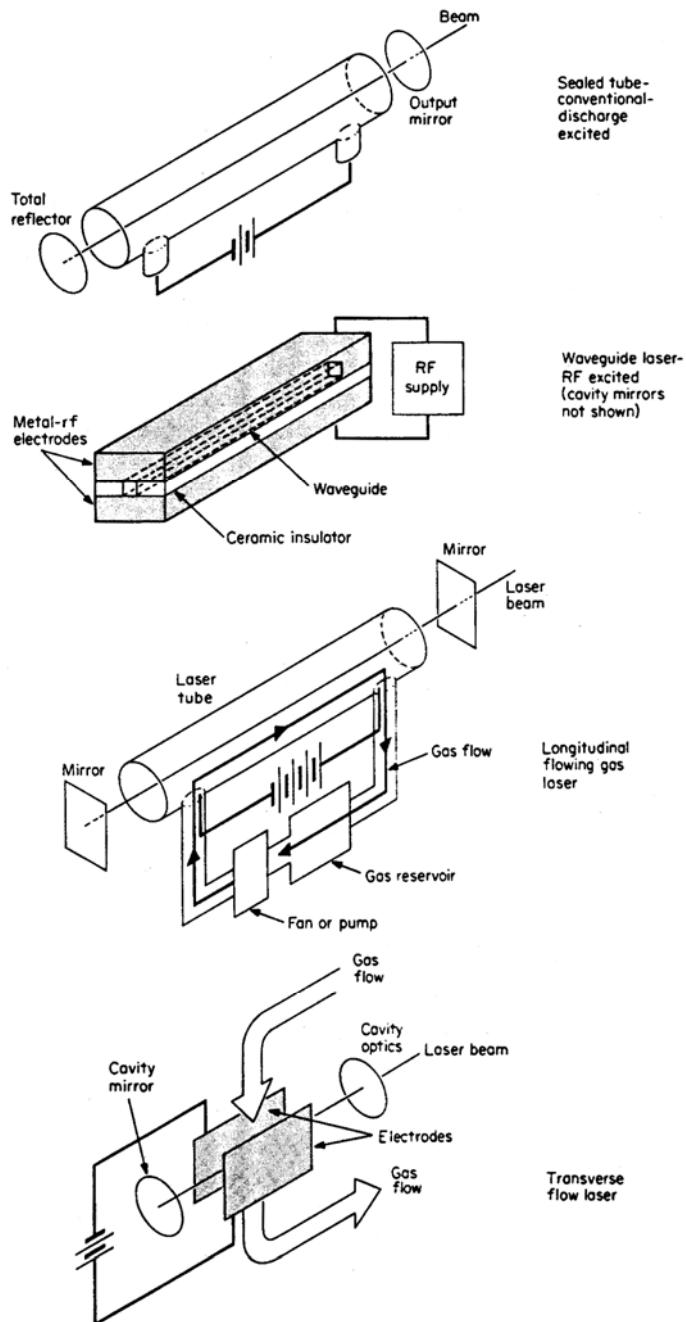


Figure 10.2 Major types of CO<sub>2</sub> lasers are (top to bottom) sealed-tube conventional laser with longitudinal dc discharge excitation, waveguide laser with radio-frequency excitation, longitudinal flowing-gas laser, and axial-flow laser. Slow and fast axial-flow lasers differ in gas speed through the tube; in the latter the laser runs cooler and more efficiently and thus can generate more power.

## Gas Dynamic Carbon Dioxide Lasers

- Gas heated and compressed then expanded (1100°K, 17 Atm)
- Obtained from combustion of Hydrocarbon fuels
- Expanded through a nozzle
- Rapid cooling creates population inversion
- Creates the vibration levels & high power
- US air force air borne laser laboratory (1997)
- Advantage carries own power source – important for aircraft

<http://laserstars.org/biglasers/continuous/gasdynamic.html>

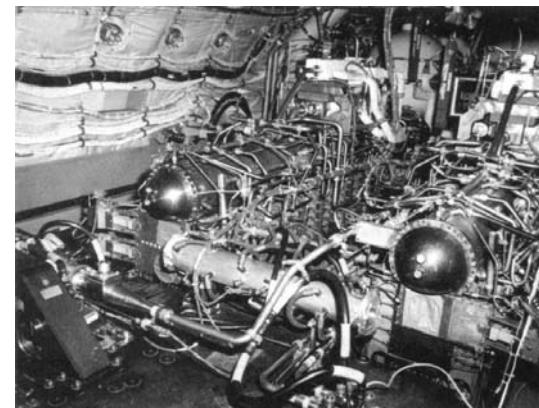
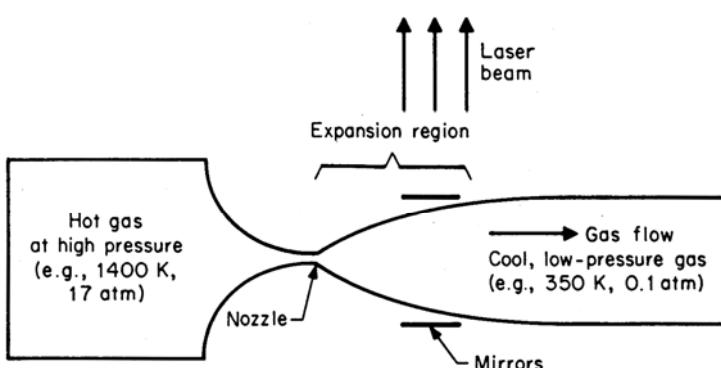
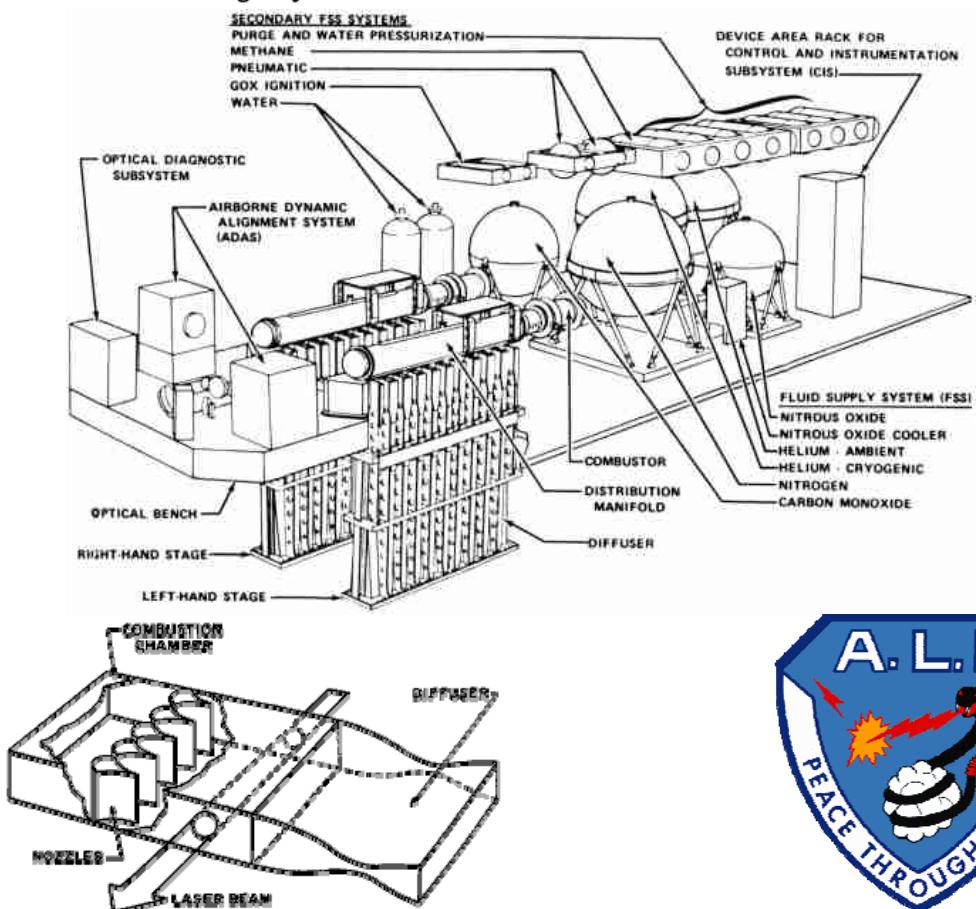


Figure 10.4 Basic structure of a gas-dynamic laser.



## Nitrogen Gas Lasers

- UV laser first built in 1963 by Heard: commercial 1972
- $N_2$  at 20 Torr or 1 atm
- Electrical discharge like TEA lasers
- Very fast current pulse  $\sim 20$  KV
- Top level only 40 nsec lifetime
- Short pulse output 337.1 nm – first powerful UV source
- Very high gain: 50 db/m
- Does not need cavity to lase: Superradiant
- Often used gas flow, though some sealed tubes
- Easy to build: Scientific America Amateur column 1973
- One of few strong early UV sources

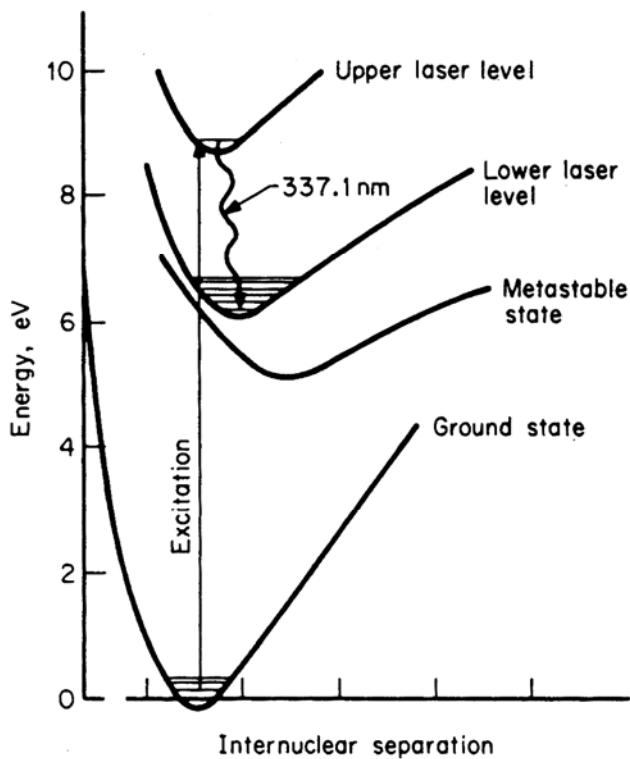
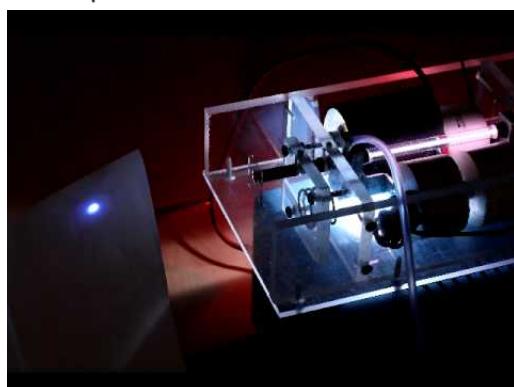


Figure 14.1 Energy levels in neutral nitrogen molecules involved in the 337.1-nm laser transition. The broad curves represent electronic energy levels, with the lines in the potential wells representing vibrational energy sublevels. The laser transition is a vibronic one with changes in both electronic and vibrational energy levels.



## Nitrogen Gas Lasers

- Typical system 100% rear mirror, 5% front
- Doubles power with cavity
- Pulse 20 nsec at 20 torr to 300 psec at atm
- Repetition rate: 10 - 100 Hz
- 10  $\mu$ J to 9 mJ energy
- Peak power 10 KW to 2.5 MegW
- Efficiency low: 0.11%
- Very poor beam quality: cannot be Q switched
- Price: \$1000 to \$20K
- Typically used to pump other lasers (mostly dye lasers)

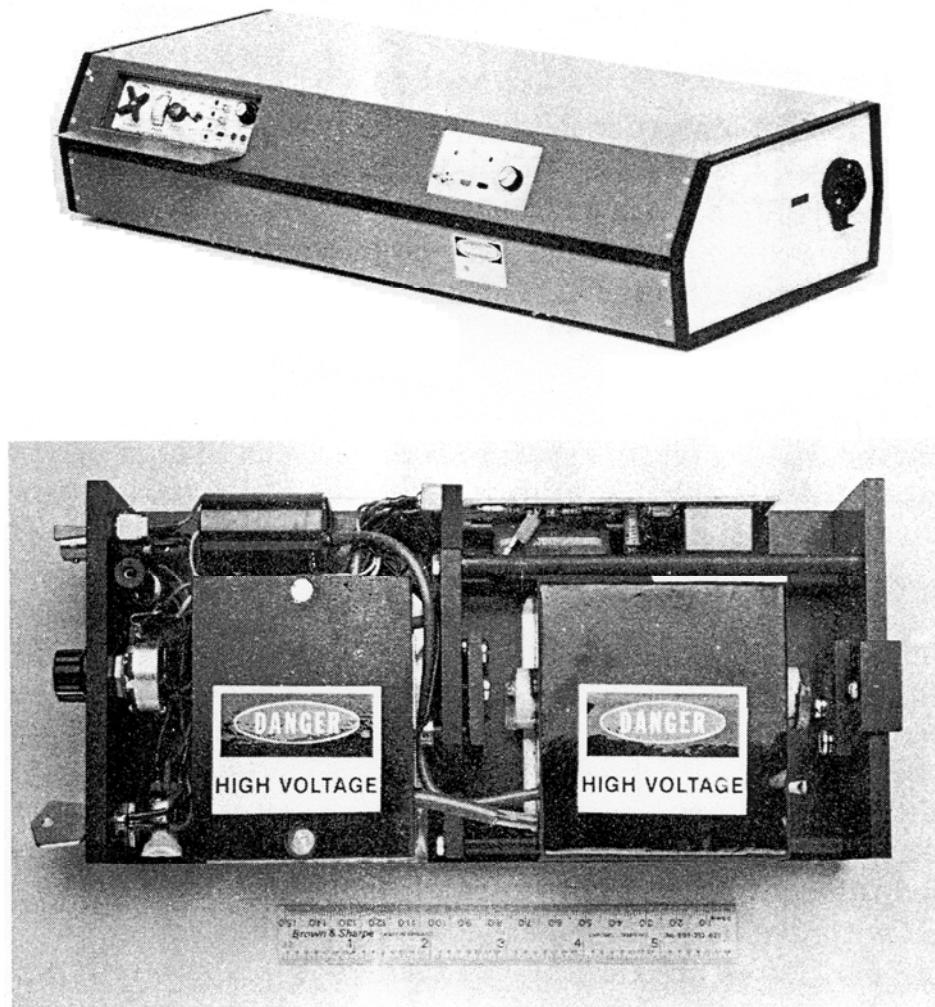


Figure 14.2 A pair of commercial nitrogen lasers. Top: A 1.2-m-long version delivers several-millijoule pulses. (Courtesy of Laser Photonics.) Bottom: A modular sealed laser about 25 cm long produces 0.1-mJ pulses. (Courtesy of Laser Science Inc.)