Nd: YAG Lasers

- Dope Neodymium (Nd) into material (~1%)
- Most common Yttrium Aluminum Garnet - YAG: Y₃Al₅O₁₂
- Hard brittle but good heat flow for cooling
- Reason: only 5% efficient so lots of waste heat.
- Next common is Yttrium Lithium Fluoride: YLF: YLiF₄
- Stores more energy, good thermal characteristics
- Nd in Glass stores less energy but easy to make

<table>
<thead>
<tr>
<th>Material</th>
<th>Wavelength, nm</th>
<th>Cross section, × 10⁻²⁹ cm</th>
<th>Linewidth, nm</th>
<th>Lifetime, μs</th>
</tr>
</thead>
<tbody>
<tr>
<td>YLF*</td>
<td>1047</td>
<td>37</td>
<td>—</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td>1053</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphate glass</td>
<td>1054</td>
<td>4.0–4.2</td>
<td>28</td>
<td>290–330</td>
</tr>
<tr>
<td>GSGG</td>
<td>1061</td>
<td>11</td>
<td>—</td>
<td>222</td>
</tr>
<tr>
<td>Silicate glass</td>
<td>1061–1062</td>
<td>2.7–2.9</td>
<td>19–22</td>
<td>340</td>
</tr>
<tr>
<td>YAG</td>
<td>1064</td>
<td>34</td>
<td>0.45</td>
<td>244</td>
</tr>
</tbody>
</table>

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

![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.](image-url)
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 $\mu$m is converted to 0.53 $\mu$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.
**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

\[ P = \varepsilon_0 \left( \chi_1 E + \chi_2 E^2 + \chi_3 E^3 + \ldots \right) \]

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

\[ E = E_0 \sin(\omega t) \]

\[ P = \varepsilon_0 \left( \chi_1 E_0 \sin(\omega t) + \chi_2 E_0^2 \sin^2(\omega t) + \chi_3 E_0^3 \sin^3(\omega t) + \ldots \right) \]

\[ P = \varepsilon_0 \left( \chi_1 E_0 \sin(\omega t) + \frac{1}{2} \chi_2 E_0^2 [1 - \cos(2\omega t)] + \ldots \right) \]

- Thus get both fundamental and 2\textsuperscript{nd} harmonic light out

---

**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 (ii) as the wave inducing it, (iii) 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\textsuperscript{nd} 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\textsuperscript{nd} harmonic laser out in green
- Get $\sim 70\%$ efficiency of conversion for green
- 3\textsuperscript{rd} harmonic 354 nm in UV much lower $\sim 30\%-40\%$
- 4\textsuperscript{th} harmonic use two doubling crystals 266 nm $\sim 15\%$ efficient
- 5\textsuperscript{th} harmonic use 2\textsuperscript{nd} & 3\textsuperscript{rd} type crystals get 213 nm at $\sim 6\%$
- Typical crystals KTP, Lithium Niobate
- Crystals have finite lifetime $\sim$ few years depending on usage
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

![Image of diode pumped Nd:YAG laser](image)

**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-µm beam emerges from the output coupler.
### Typical Nd: Yag laser parameters

**TABLE 22.2** Typical Output Powers for Neodymium Lasers Derived from Specifications

<table>
<thead>
<tr>
<th>Type</th>
<th>Pump source</th>
<th>Wavelength, nm</th>
<th>Output powers (average or CW), W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsed quadrupled Nd-glass</td>
<td>Flashlamp</td>
<td>263–266</td>
<td>≤0.04</td>
</tr>
<tr>
<td>Pulsed quadrupled Nd-YAG</td>
<td>Flashlamp</td>
<td>266</td>
<td>0.001–2</td>
</tr>
<tr>
<td>Pulsed tripled Nd-glass</td>
<td>Flashlamp</td>
<td>351–355</td>
<td>≤0.07</td>
</tr>
<tr>
<td>Pulsed tripled Nd-YAG</td>
<td>Flashlamp</td>
<td>355</td>
<td>0.001–20</td>
</tr>
<tr>
<td>Pulsed doubled Nd- YLF</td>
<td>Diode</td>
<td>532</td>
<td>0.00002–0.01</td>
</tr>
<tr>
<td>Pulsed doubled Nd-YLF</td>
<td>Flashlamp</td>
<td>523–527</td>
<td>1–3</td>
</tr>
<tr>
<td>CW Doubled Nd-YAG</td>
<td>Diode</td>
<td>532</td>
<td>0.001–0.8</td>
</tr>
<tr>
<td>Pulsed doubled Nd-YAG</td>
<td>Diode</td>
<td>532</td>
<td>0.00001–0.0004</td>
</tr>
<tr>
<td>Pulsed doubled Nd-YAG</td>
<td>Flashlamp</td>
<td>532</td>
<td>0.01–50</td>
</tr>
<tr>
<td>CW doubled Nd-YAG</td>
<td>Arc lamp</td>
<td>532</td>
<td>3–4*</td>
</tr>
<tr>
<td>Pulsed doubled Nd-glass</td>
<td>Flashlamp</td>
<td>532</td>
<td>≤0.15</td>
</tr>
<tr>
<td>CW Nd–YLF</td>
<td>Diode</td>
<td>1047</td>
<td>0.035–0.25</td>
</tr>
<tr>
<td>CW Nd–YLF</td>
<td>Diode</td>
<td>1053</td>
<td>0.015–0.1</td>
</tr>
<tr>
<td>CW Nd–YLF</td>
<td>Arc lamp</td>
<td>1053</td>
<td>≤20</td>
</tr>
<tr>
<td>Pulsed Nd–YLF</td>
<td>Flashlamp</td>
<td>1053</td>
<td>≥20</td>
</tr>
<tr>
<td>Pulsed Nd-phosphate glass</td>
<td>Flashlamp</td>
<td>1054</td>
<td>0.01–1</td>
</tr>
<tr>
<td>CW Nd,Cr–GSGG</td>
<td>Diode</td>
<td>1061</td>
<td>≤0.1</td>
</tr>
<tr>
<td>Pulsed Nd,Cr–GSGG</td>
<td>Flashlamp</td>
<td>1061</td>
<td>≤1</td>
</tr>
<tr>
<td>CW Nd–YAG</td>
<td>Diode</td>
<td>1064</td>
<td>0.002–3</td>
</tr>
<tr>
<td>Pulsed Nd-silicate glass</td>
<td>Flashlamp</td>
<td>1064</td>
<td>0.1–100</td>
</tr>
<tr>
<td>CW Nd–YAG</td>
<td>Arc lamp</td>
<td>1064</td>
<td>0.5–1800</td>
</tr>
<tr>
<td>Pulsed Nd–YAG</td>
<td>Flashlamp</td>
<td>1064</td>
<td>≤1500 W</td>
</tr>
<tr>
<td>CW Nd–YLF</td>
<td>Diode</td>
<td>1313</td>
<td>≤0.1</td>
</tr>
<tr>
<td>CW Nd–YLF</td>
<td>Lamp</td>
<td>1313</td>
<td>≤3</td>
</tr>
<tr>
<td>CW Nd–YAG</td>
<td>Diode</td>
<td>1319</td>
<td>≤0.25</td>
</tr>
<tr>
<td>Pulsed Nd–YAG</td>
<td>Flashlamp</td>
<td>1319</td>
<td>≤20</td>
</tr>
<tr>
<td>CW Nd–YAG</td>
<td>Arc lamp</td>
<td>1319</td>
<td>0.05–40</td>
</tr>
<tr>
<td>CW Nd–YLF</td>
<td>Diode</td>
<td>1321</td>
<td>0.015–0.1</td>
</tr>
<tr>
<td>CW Nd–YAG</td>
<td>Diode</td>
<td>1335</td>
<td>0.012–0.1</td>
</tr>
<tr>
<td>Pulsed Nd,Cr–GSGG</td>
<td>Flashlamp</td>
<td>1335</td>
<td>&gt;1</td>
</tr>
</tbody>
</table>

*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 µm (Not All Available Commercially)

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

*Series of 20–200 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 (Juhaez et al., 1990).
Alexandrite Lasers

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

![Energy-level diagram of Alexandrite laser](image-url)

**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 $^4T_2$ 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

![Diagram of cavity wavelength tuning](image)

**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 ($\lambda_2$ say) is reflected out of the laser cavity.
**Ti: Sapphire Lasers**

- Uses Sapphire (Al$_2$O$_3$) rods doped with Titanium
- Ti$^{3+}$ ion is very long lived with wide gain bandwidth
- Typically pumped with green light Argon or 2$^{nd}$ 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
**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

![Diagram of F Centre Laser](image)

*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
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 $\mu$m, 1.15 $\mu$m (IR) & 543.5 nm (green)
- Choose wavelength by dielectric mirror reflectivity
- Fast decay to Ne $^3S$

![Energy levels relevant to the operation of the HeNe laser. M indicates a metastable state (see p. 19).](image)

- HeNe (main red)
  - 632.8 nm
- HeNe (green)
  - 543.5 nm
Typical He-Ne

- Small ballest 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.)
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

![Energy level diagram](image)

**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) 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

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>ARGON</th>
<th>KRYPTON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INNOVA 304</td>
<td>INNOVA 305</td>
</tr>
<tr>
<td>Multiline Visible</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Multimode Visible</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>1090</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>793.1–799.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>752.5</td>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>676.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>647.1</td>
<td></td>
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<tr>
<td>568.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>530.9</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>526.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>520.8</td>
<td></td>
<td>1.70</td>
</tr>
<tr>
<td>514.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>501.7</td>
<td>0.30</td>
<td>0.40</td>
</tr>
<tr>
<td>496.5</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>488.0</td>
<td>1.30</td>
<td>1.50</td>
</tr>
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<td>482.5</td>
<td></td>
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</tr>
<tr>
<td>476.5</td>
<td>0.50</td>
<td>0.60</td>
</tr>
<tr>
<td>476.2</td>
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<tr>
<td>472.7</td>
<td>0.12</td>
<td>0.20</td>
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<tr>
<td>466.8</td>
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<td>0.15</td>
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<td>457.9</td>
<td>0.25</td>
<td>0.35</td>
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<tr>
<td>454.5</td>
<td>0.05</td>
<td>0.12</td>
</tr>
<tr>
<td>350.1–356.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>333.6–363.8</td>
<td>0.20</td>
<td>0.40</td>
</tr>
</tbody>
</table>
### Beam Specifications

<table>
<thead>
<tr>
<th></th>
<th>Argon</th>
<th>Krypton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Diameter (@ 1/e² points)</td>
<td>1.5 mm</td>
<td>1.5 mm</td>
</tr>
<tr>
<td>Beam Divergence (full angle)</td>
<td>0.5 mrad</td>
<td>0.8 mrad</td>
</tr>
<tr>
<td>Beam Waist Diameter</td>
<td>1.4 mm</td>
<td>1.1 mm</td>
</tr>
<tr>
<td>Beam Waist Location</td>
<td>1.50 m</td>
<td>1.27 m</td>
</tr>
<tr>
<td>Cavity Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-line</td>
<td>1.16 m</td>
<td>1.16 m</td>
</tr>
<tr>
<td>Multiplex</td>
<td>1.14 m</td>
<td>1.14 m</td>
</tr>
<tr>
<td>Long-Term Power Stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Regulation</td>
<td>±0.5%</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Current Regulation</td>
<td>±3.0%</td>
<td>±3.0%</td>
</tr>
<tr>
<td>Optical Noise (rms)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Regulation</td>
<td>±0.2%</td>
<td>±0.2%</td>
</tr>
<tr>
<td>Current Regulation</td>
<td>±0.2%</td>
<td>±0.2%</td>
</tr>
</tbody>
</table>
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 CO$_2$
- Power from 10's - 1000's Watts
- High efficiency: up to 30%

![Diagram](image)

$v_1 = 4 \times 10^{13}$ Hz  
(a) Symmetric stretch

$v_2 = 2 \times 10^{13}$ Hz  
(b) Bend

$v_3 = 7 \times 10^{13}$ Hz  
(c) Asymmetric stretch

**Fig. 6.8** Vibrational modes of the CO$_2$ molecule.
Carbon Dioxide Lasers

- N-CO$_2$:He mixture 1:1:1
- N$_2$ (001) vibration level close to CO$_2$ (001)
- N$_2$ excited collisions with CO$_2$
- Emissions at 10.6 $\mu$m (most important) and 9.6 $\mu$m
- 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

![Energy Level Diagram](image.png)

**Fig. 2.32** Simplified energy level diagram for the carbon dioxide laser. Each vibrational level has many rotational levels associated with it. $J = 1, 2$, etc. The letters P and R represent transitions where $J$ 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

![Diagram of TEA CO₂ laser](image)

Fig. 2.33 Schematic diagram of a TEA CO₂ 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)

![Diagram of Carbon Dioxide Lasers](Image)

Figure 10.2 Major types of CO₂ 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/gasdynamnic.html

Figure 10.4 Basic structure of a gas-dynamic laser.
Nitrogen Gas Lasers

- UV laser first built in 1963 by Heard: commercial 1972
- N₂ at 20 Torr or 1 atm
- Electrical discharge like TEA lasers
- Very fast current pulse ~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 μJ 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.)