An Introduction to Laser Safety
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What are Lasers?

"Now you know the difference between a moon beam and a laser beam!"
What are Lasers?

- Light Amplification by Stimulated Emission of Radiation (LASER)
- Light emitted at very narrow wavelength bands (monochromatic)
- Light emitted in a directed beam
- Light is coherent (in phase)
- Light often polarized

[Diagram of a laser setup showing components like pump, active medium, mirrors, and laser beam]
Why Study Lasers: Laser Applications

- Market $4.3 billion (2002) (just lasers)

**Major areas:**
- Market Divided in laser Diodes (56%) & Non diode lasers (44%)
- Materials Processing (28%)
- Medicine (10%)
- Entertainment/CD/DVD/Printers (~50%)
- Communications
History of the Laser

- 1917: Einstein's paper showing "Stimulated Emission"
- 1957: MASER discovered: Townes & Schawlow
- 1960: First laser using Ruby rods: Maiman
  first solid state laser
- 1961: gas laser
- 1962: GaAs semiconductor laser
- 1964: CO₂ laser
- 1972: Fiber optics really take off
- 1983: Laser CD introduced
- 1997: DVD laser video disks

![Diagram of an ammonia-beam maser](image)

**Fig. 3.4** Schematic of the ammonia-beam maser. Because the energy separation of the two states (• and ○) is small compared to the thermal energy of the system \((E_+ - E_- \ll kT)\), the energy levels are nearly equally populated (top insert). By passing the atoms through an electric field gradient (quadrupole focuser), the higher-energy-state atoms (•) are directed into a microwave cavity resonant at \(v = (E_+ - E_-)/h\). This physical separation creates a population inversion in this two-level system (bottom insert).
World’s First Laser: Ruby Laser

Dr. Maiman: Inventor of the World’s First Laser (on left)
Fig. 1-6 Electromagnetic spectrum.
Spontaneous and Stimulated Emission

- Consider 2 energy levels $E_0$ (ground state) and $E_1$ (excited state)
- Photon can cause **Stimulated Absorption** $E_0$ to $E_1$
- Excited state has some finite lifetime, $\tau_{10}$
  
  \[ \text{(average time to change from state 1 to state 0)} \]
- **Spontaneous Emission** of photon when transition occurs
- Randomly emitted photons when change back to level 0
- Passing photon of same $\lambda$ can cause "**Stimulated Emission**"
- Stimulated photon is emitted in phase with causal photon
- Stimulated emission the foundation of laser operation

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**Fig. 3.1** Energy-state-transition diagram differentiating between stimulated absorption, spontaneous emission, and stimulated emission. A black dot indicates the state of the atom before and after the transition takes place. In the stimulated emission process, energy is added to the stimulating wave during the transition; in the absorption process, energy is extracted from the wave.
Main Requirements of the Laser

- Optical Resonator Cavity
- Laser Gain Medium in the Cavity
- Sufficient means of Excitation (called pumping) eg. light, current, chemical reaction
- Population Inversion in the Gain Medium due to pumping

Laser Types

- Two main types depending on time operation
- Continuous Wave (CW)
  - Power measured in Watts
- Pulsed operation
  - Power measured in Jules/pulse
  - Repeatition rate important for pulsed systems
  - Ranges from ~ sub Hz to ~10 kHz
  - Pulsed is easier, CW more useful

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**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.
Laser Threshold

- With good Gain Medium in optical cavity can get lasing but only if gain medium is excited enough
- Low pumping levels: mostly spontaneous emission
- At some pumping get population inversion in gain medium
- Beyond inversion get **Threshold** pumping for lasing set by the losses in cavity
- Very sensitive to laser cavity condition
  eg slight misalignment of mirrors threshold rises significantly
- At threshold gain in one pass = losses in cavity

**Figure 3.5** Laser threshold phenomenon—a laser does not generate significant optical output until the pump energy passes a threshold. At higher pump energies, the output power increases rapidly. In practice, each laser has limits on output, and eventually the output-input curve bends over.
General Laser Types

- Solid State Laser (solid rods): eg ruby
- Gas laser: eg He-Ne
- Dye Lasers
- Semiconductor Laser: GaAs laser diode
- Chemical Lasers
- Free Electron Lasers

Fig. 2. Range of wavelengths for current commercial lasers. First date is date of discovery, the second is of commercialisation (4).
Gas Lasers

- Gas sealed within a tube with brewster windows
- Electric arc in tube causes glowing of gas
- Glow indication of pumping
- Commonest type He-Ne.

![Diagram of Gas Laser](image)

**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.

![Diagram of Gas Laser Structure](image)

**Fig. 2.27** Typical structure of a sealed mirror HeNe laser.
**Gas Lasers**

- Gas sealed within a tube with brewster windows
- electric arc in tube causes glowing of gas
- glow indication of pumping

**Most Common Types**

- Atomic (atoms not ionized) eg He-Ne 632 nm (deep Red)
  - Power ~1-40 mW
- Nobel Gas Ion Lasers eg. Argon 514/488 nm (Green) to UV
  - Power 10mW – 100 W
- Molecular Lasers: CO$_2$ 10.6 micorns (Far IR)
  - pulsed 50 nsec >100J/pulse
- Excimer Lasers (UV range XeF 350 nm to F2 (157 nm)

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**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.
Argon & Krypton Laser
Solid State Lasers

- Was first type of laser (Ruby 1960)
- Uses a solid matrix or crystal carrier
  - e.g., Glass or Sapphire
- Doped with transition metal or rare earth ions
  - e.g., Chromium (Cr) or Neodymium (Nd)
- Mirrors at cavity ends
- Typically pumped with light
- Most common a Flash lamp
- Light adsorbed by doped ion, emitted as laser light
- Mostly operates in pulsed mode

Figure 8-4  Schematic of solid laser—for example, ruby
Most Commn Nd: YAG Lasers

- Dope Neodymium (Nd) into material most common
- Most common Yttrium Aluminum Garnet - YAG: \( \text{Y}_3\text{Al}_5\text{O}_{12} \)
- Hard brittle but good heat flow for cooling
- 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
- Generally pulsed lasers: pulses from 2 nsec – 10’s msec
- Powers from microJ/pulse to \( > 10^4 \text{ J/pulse} \)
- Can be run in CW mode also (less efficient)
- Power from mW to \( \sim 10\text{W} \)
- Can change to different wavelengths with non-linear crystals
- Get 2\textsuperscript{nd} Harmonic (533 nm) (green common)
- 3\textsuperscript{rd} Harmonic (544 nm), 4\textsuperscript{th} harmonic (266 nm) and 5\textsuperscript{th} (213 nm)

<table>
<thead>
<tr>
<th>Material</th>
<th>Wavelength, nm</th>
<th>Cross section, ( \times 10^{-20} \text{ cm}^2 )</th>
<th>Linewidth, nm</th>
<th>Lifetime, ( \mu\text{s} )</th>
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<tr>
<td>YLF*</td>
<td>1047</td>
<td>37</td>
<td>—</td>
<td>480</td>
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<tr>
<td></td>
<td>1053</td>
<td>26</td>
<td></td>
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<tr>
<td>Phosphate</td>
<td>1054</td>
<td>4.0–4.2</td>
<td>28</td>
<td>290–330</td>
</tr>
<tr>
<td>glass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSGG</td>
<td>1061</td>
<td>11</td>
<td>—</td>
<td>222</td>
</tr>
<tr>
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<td>1061–1062</td>
<td>2.7–2.9</td>
<td>19–22</td>
<td>340</td>
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<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.
Semiconductor Lasers

- Semiconductors were pumped by lasers or e-beams
- First diode types developed in 1962:
  - Modified form of Light Emitting Diodes
- Must use Direct Bandgap Materials:
  - eg III-V or II-VI compounds
- Most common are GaAs, AlAs, InP, InAs combinations
- Si is an indirect bandgap material (except spongy Si)
- Indirect materials must emit an acoustic package (phonon) during transition
- Very inefficient
- Direct band: highly efficient
Simple Diode Laser

- Abrupt junction of P doped and N doped regions
- Emission confined to junction area
- Mirrors created by cleaving rods
- Uses crystal planes to create smooth mirrors (change in n mirrors)
- Highly Elliptical emission: 1x50 microns
- Homojunction where first type of laser diodes
- Homojunction: materials the same on both sides of the Junction
- Hetrojunction better: P and N materials different
- Typical powers 1mW-40 mW
- Typical wavelengths 830 nm (GaAs), 670 nm (Red)
- Many now in Green and into Violet/UV

Figure 11.11 The radiation field of a semiconductor laser.
Monolithic Array Lasers

- Single strip lasers limited to 200 mW
- Many Laser strips edge emitters
- Bars with up to 200 strips produced
- 50 W power achieved
- 20: 10 micron wide strips on 200 micron centers

Figure 18.9  Monolithic array of diode laser stripes. (Courtesy of Spectra Diode Laboratories.)
**Human Eye**

- Human eye is a simple single lens system
- Crystalline lens provide focus
- Cornea: outer surface protection
- Iris: control light
- Retina: where image is focused
- Note images are inverted

*FIGURE 10A*
A cross-sectional diagram of a human eye, showing the principal optical components and the retina.