Basic Principles of Lasers

Presentation for an Honors Contract
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Summary

• Classification of light-atom interaction.
• Necessary conditions for a lasing transition.
• Standard lasing systems:
  - three-level atom system,
  - four-level atom system.
• Properties of a laser.
• Types and uses of lasers.
Classification of Light-atom Interaction

- **Stimulated absorption**
  \[ A + h\nu \rightarrow A^* \]

- **Spontaneous emission**
  \[ A^* \rightarrow A + h\nu \]

- **Stimulated emission**
  \[ A^* + h\nu \rightarrow A + 2h\nu \]
The Cascade of Photons
Energy Distribution

- For \( N_o \) atoms in thermal equilibrium at temperature \( T \), the population of atoms \( N_j \) on the \( j \)-state is
  \[ N_j = N_o \exp(-E_j/kT) \]  (Boltzmann distribution)
  where \( kT \) represents the mean energy of the atoms.
Understanding the Lasing Process

• **LASER** – Light Amplification by Stimulated Emission of Radiation

• Necessary conditions for a lasing transition:
  - population inversion,
  - metastable states.
Population Inversion

Metastable States

Long-lived state (~1 ms)

(N₂; E₂)  ——— Laser beam  ——— (N₁; E₁)

Short-lived state (~1 ns)

Spontaneous

Ground state
Three-level Atom

Example: Ruby laser (uses Cr^{++} ions)

- Deficiency – Photons may be re-absorbed during the lasing process → it makes the laser beam weaker.
The build-up of a Laser

1) Pumping (excitation of atoms)

2) Stimulated emission of atoms

3) The lasing process is enriched by multiple reflections between mirrors

4) A laser beam exits.
Ruby Laser

- Developed by Theodore H. Maiman in 1960
- Creates a beam at $\lambda = 694$ nm (deep red).
- Metastable state of $\sim 3$ms
- Has efficiency of less than 1% but creates a diameter ranging from 1 mm to about 25 mm, so a large energy density is achieved in the laser beam.
Four-level Atom

- Example: HeNe laser

[Diagram showing energy levels and transitions]
Properties of a Laser

- Monochromaticity – same $\lambda$ or frequency
- Directivity
- Highly correlated photons for long distances.
- High energy-density
- Polarization
- Modes
Resonant Cavity

Nd:YAG solid-state laser

Optical resonator

HeNe
Modes of Lasers

- **Mono-mode laser** – Gaussian profile

- **Multimode lasers**
Types of Lasers

- Gaseous laser:
  - atomic gaseous lasers (e.g. HeNe)
  - molecular laser (e.g. CO₂)
- Dye laser (e.g. N₂ - rhodamine)
- Electronic laser (uses the acceleration of electrons)
- Solid laser – semiconductor (YAG-Nd laser)
- Atomic laser – Bose-Einstein condensate.
HeNe Laser
A Look at Laser Sizes

Dye Laser Wavelengths
YAG-Nd Laser

Electronic Laser
## Comparisons of a Few Lasers

<table>
<thead>
<tr>
<th>Laser</th>
<th>Typical $\lambda$</th>
<th>Range</th>
<th>Pulse or CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>HeNe</td>
<td>1.15(\mu\text{m})-633nm</td>
<td>IR-Visible</td>
<td>CW</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>9.4-10.6(\mu\text{m})</td>
<td>IR</td>
<td>CW</td>
</tr>
<tr>
<td>Dye</td>
<td>360-720nm</td>
<td>IR-UV</td>
<td>Usually Pulse</td>
</tr>
<tr>
<td>Electronic</td>
<td>1mm-1nm</td>
<td>Microwaves-X-rays</td>
<td>CW</td>
</tr>
<tr>
<td>YAG:Nd</td>
<td>940-1440nm</td>
<td>IR</td>
<td>Both</td>
</tr>
</tbody>
</table>
The use of Lasers

- Science – precise measurements, spectroscopy
- Medicine – laser scalpel, eye surgery
- Industry – cutting and welding, guidance systems
- Arts – etching
- Telecommunications (fiber optics)
- Radars
- Precise measurement of long distances (e.g. Moon)
- Consumer – CDs, DVDs, laser lights
Resources