



Part 2: Operation of Practical Lasers

Physics 435: Laser Physics

Dr. Abdulaziz Alqasem

Physics and Astronomy Department
King Saud University

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1. Doped Insulator Lasers

2. Semiconductor Lasers

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1.1 Impurity ion energy levels in solids

What is the difference between host medium and doped ions in a gain medium?

host has certain important properties such as high thermal conductivity, good mechanical strength, and low optical absorption at the lasing wavelength. The doped ions are responsible for providing the necessary energy levels for lasing action, while the host medium provides a stable environment for the ions to function effectively.

1.2 Pumping methods

What are the common pumping methods?

The common pumping methods include **optical** pumping, **electrical** pumping, and **chemical** pumping. Optical pumping is light that excite the gain medium, while electrical pumping uses an electric current to excite the medium. Chemical pumping relies on chemical reactions to provide the necessary energy for lasing action.

What are the common pumping sources for doped insulator lasers?

Optical pumping sources include **flashlamps**, arc lamps, and other lasers. Electrical pumping is commonly used in semiconductor and gas lasers, while chemical pumping is often employed in chemical lasers.

How does a Flashlamp work (in general)?

(see your book around page 40 for more details)

1.3 Fresnel losses

How to reduce Fresnel losses?

1. Using anti-reflective coatings on the surfaces of the gain medium to minimize reflection losses.
2. Using Brewster's angle to minimize reflection losses for one polarization of light.

1.4 The Nd: YAG laser

What is the host medium and the doped ions in the Nd:YAG laser?

The host is Yttrium Aluminum Garnet (YAG) and the doped ions are Neodymium (Nd^{3+}).

What is the doping level?

1.5%

How many energy levels are involved in the lasing process of the Nd:YAG laser?

Four energy levels are involved in the lasing process of the Nd:YAG laser.

What is the lasing wavelength of the Nd:YAG laser?

1064 nm

1.5 Nd: glass lasers

What is the host medium and the doped ions in the Nd:glass laser?

The host is glass and the doped ions are Neodymium (Nd^{3+}).

What is the doping level?

up to 6%

What are the advantages of using glass compared to YAG as a host medium?

1. It is Isotropic, meaning that it has the same properties in all directions, which can lead to more uniform lasing action.
2. It is easier to fabricate and shape compared to crystalline materials like YAG, allowing for more flexible laser designs.
3. It is cheaper than YAG, making it more cost-effective for certain applications.

1.5 Nd: glass lasers

4. It can be doped with higher concentrations of active ions compared to YAG.

What are the disadvantages of using glass compared to YAG as a host medium?

1. It has lower thermal conductivity than YAG, which limit the operating power of the laser.
2. It is more susceptible to mechanical damage and has lower mechanical strength compared to crystalline materials.

1.6 The ruby laser

First successful laser was the ruby laser, which was developed in 1960 by Theodore Maiman.

What is the active ions used in the ruby laser?

The active ions used in the ruby laser are chromium ions (Cr^{3+}) doped into a synthetic ruby crystal, which is a form of aluminum oxide (Al_2O_3).

What is the lasing wavelength of the ruby laser?

The lasing wavelength of the ruby laser is 694 nm, which is in the red region of the visible spectrum.

1.7 The alexandrite laser

Can the gain medium of the alexandrite laser operate in three-level and four-level configurations?

Yes, it can do both.

What is the lasing wavelength of the alexandrite laser?

- At three-level configuration, the lasing wavelength is around 680nm.
- At four-level configuration, the lasing wavelength is tunable between 700 nm and 820 nm, which is in the near-infrared region of the spectrum.

1.7 The alexandrite laser

For the tunable lasing wavelength of the alexandrite laser, how to choose the lasing wavelength?

The lasing wavelength can be selected by adjusting a prism or diffraction grating, which only allows certain wavelengths to be reflected back into the cavity to achieve lasing action at the desired wavelength.

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2. Semiconductor Lasers

3. Gas Lasers

4. Liquid Dye Lasers

5. The Free Electron Laser

2.1 Semiconductor lasers

What is the pumping mechanism for a semiconductor laser?

Semiconductor lasers are typically pumped electrically, where an electric current is passed through a p-n junction to achieve lasing action.

What is the lasing wavelength of a semiconductor laser and how can it be tuned?

The lasing wavelength of a semiconductor laser equals the band gap energy of the semiconductor material, which can be tuned by changing the composition of the semiconductor material.

2.1 Semiconductor lasers

What are some common semiconductor materials used in semiconductor lasers?

Some common semiconductor materials used in semiconductor lasers include gallium arsenide (GaAs), indium phosphide (InP), and aluminum gallium arsenide (AlGaAs).

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3.1 Atomic lasers: The HeNe laser

What is the ratio of helium to neon atoms in the HeNe laser?

The ratio of helium to neon atoms in the HeNe laser is typically around 10:1.

What is the lasing wavelength of the HeNe laser?

The most common lasing wavelength of the HeNe laser is 632.8 nm, which is in the red region of the visible spectrum. However, other lasing wavelengths can be achieved at: 543.5 nm (green), 1.15 microns (infrared), and 3.39 microns (infrared).

What is the pumping mechanism for the HeNe laser?

The pumping mechanism for the HeNe laser is electrical discharge, where an electric current is passed through a gas mixture of helium and neon to excite the atoms and achieve lasing action.

3.1 Atomic lasers: The HeNe laser

At what atom the laser transitions occur in the HeNe laser?

The laser transitions in the HeNe laser occur at the neon atoms, where the excited helium atoms transfer energy to the neon atoms through collisions, leading to population inversion and lasing action at the neon transition wavelengths.

How many energy levels are involved in the lasing process of the HeNe laser?

Four energy levels are involved in the lasing process of the HeNe laser.

Why does the HeNe laser tube is kept as narrow as possible?

The HeNe laser tube is kept as narrow in diameter as possible to increase the gain of the laser. This is because a narrower tube increases the probability of collisions between the excited neon atoms and the walls of the tube, which increase the

3.1 Atomic lasers: The HeNe laser

efficiency of pumping and population inversion (look at Fig. 2.26 in your book for more details).

Some advantages of the HeNe laser include:

1. It produces a stable and **high-quality beam profile** with low divergence, making it suitable for many applications.
2. It has an exceptionally **narrow linewidth**.

3.2 Ion lasers: The argon ion laser

What is the lasing wavelength of the argon ion laser?

The argon ion laser can produce lasing action at several wavelengths in the visible spectrum, including 488 nm (blue), 514.5 nm (green).

What is the pumping mechanism for the argon ion laser?

The pumping mechanism for the argon ion laser is **electrical discharge**, where an electric current is passed through the argon gas for ionization and excitation of the argon ions to achieve lasing action.

3.3 Molecular lasers: The carbon dioxide laser

What is the lasing wavelength of the carbon dioxide laser?

The carbon dioxide laser typically emits light at a wavelength of **10.6 microns** in the infrared region of the spectrum.

How does the carbon dioxide laser achieve population inversion?

The carbon dioxide laser get to population inversion through a process known as **vibrational excitation**. In this process, the carbon dioxide molecules are excited to higher vibrational energy levels through collisions with excited nitrogen molecules in the gas discharge. Helium is also added to the gas mixture to help with thermal management and to increase the efficiency of energy transfer and overall laser performance.

3.3 Molecular lasers: The carbon dioxide laser

What are some applications of the carbon dioxide laser?

The carbon dioxide laser is widely used in industrial cutting and welding applications, as well as in scientific research and medical procedures.

What are some advantages of the carbon dioxide laser?

1. It can produce high power output that can reach to several hundreds of kilowatts, making it suitable for cutting and welding applications.
2. Its wavelength is in the mid-infrared region and is strongly absorbed by many materials, and can penetrate deeply into biological tissues and other media.
3. It is relatively efficient compared to other types of lasers, with typical efficiencies of up to 30%.

3.4 Molecular lasers: The nitrogen laser

What is the lasing wavelength of the nitrogen laser?

The nitrogen laser typically emits light at a wavelength of 337 nm in the ultraviolet region of the spectrum.

3.5 Molecular lasers: The excimer laser

- The excimer laser is a type of molecular laser that uses a combination of a noble gas (such as argon, krypton, or xenon) and a halogen gas (such as fluorine or chlorine) to create an excited state known as an **excimer** (short for “excited dimer”).
- The excimer laser typically emits light in the ultraviolet region of the spectrum (120 - 500 nm)
- It can produce relatively high power output such as average power of 200 W at energy of 1 J.

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4.1 Liquid dye lasers

- Liquid dye lasers use organic dye molecules dissolved in a liquid solvent as the gain medium.
- The dye molecules are typically excited using **optical pumping** from another laser.
- The lasing wavelength of a liquid dye laser can be tuned over a wide range by changing the type of dye used and the solvent, making them versatile for various applications.
- Some common dyes used in liquid dye lasers include rhodamine 6G, coumarin, and fluorescein, which can produce lasing action in the visible and near-infrared regions of the spectrum.
- Liquid dye lasers are an example of a 4-level system.

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5. The Free Electron Laser

5.1 The free electron laser

- The free electron laser (FEL) is a type of laser that uses a beam of high-energy electrons moving through a magnetic structure called an undulator or wiggler to produce coherent electromagnetic radiation.
- The lasing wavelength of a free electron laser can be tuned over a wide range, from the microwave to the X-ray region of the spectrum, by adjusting the energy of the electron beam and the magnetic field strength of the undulator.
- Free electron lasers are used in scientific research.
- One of the disadvantages of free electron lasers is that they require large and complex facilities to generate the high-energy electron beams, making them less practical for many applications compared to other types of lasers.