UNIT-3(LASERS)

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LASERS

25. CHARACTERISTICS OF LASERS

What is a Laser?

Laser stands for **Light Amplification by Stimulated Emission of Radiation**.

It is a device that produces a **narrow, intense, and coherent beam of light**.

Key Characteristics of Laser Light:

1. **Monochromatic**

- Laser light has a **single wavelength (color)**.

2. **Coherent**

- The light waves are **in phase** both in space and time.

3. **Highly Directional**

- Laser beams are very **narrow and focused** with little spreading.

4. **High Intensity**

- Laser light is very **bright and powerful** due to concentration of energy.

5. **Polarized**

- Laser light waves vibrate in a particular direction (polarization).

26. SPONTANEOUS AND STIMULATED EMISSION OF RADIATION

1. Spontaneous Emission

- An excited atom or molecule **randomly** emits a photon when it returns to a lower energy state.
- The emitted photon has a **random phase and direction**.
- This process is **natural and random**.

2. Stimulated Emission

- An incoming photon of a specific energy **causes** an excited atom to emit a second photon.

- The emitted photon is **identical in phase, frequency, direction, and polarization** to the incoming photon.
- This process **amplifies light** and is the basis of laser operation.

27. EINSTEIN COEFFICIENTS

What are Einstein Coefficients?

Einstein introduced **three coefficients** to describe how atoms interact with radiation (light). These coefficients explain the probabilities of **absorption**, **spontaneous emission**, and **stimulated emission** of photons in a two-level atomic system.

Let's say an atom has two energy levels:

- **E_1** (lower energy level)
- **E_2** (higher energy level)

1. Einstein Coefficient A_{21} – Spontaneous Emission

- Describes the **probability per unit time** that an atom in the excited state **E_2** will spontaneously emit a photon and fall to **E_1**.
- Emission is **random** in direction and phase.

Rate of spontaneous emission

$$= A_{21}N_2$$

Where:

- **A_{21}** = Einstein coefficient for spontaneous emission
- **N_2** = Number of atoms in the excited state

2. Einstein Coefficient B_{21} – Stimulated Emission

- Describes the **probability per unit time** that an atom in excited state **E_2** emits a photon when exposed to radiation and goes to **E_1**.
- Emitted photon is **coherent** with the incident one.

Rate of stimulated emission=B21N2ρ(ν)\text{Rate of stimulated emission} = B_{21} N_2 \rho(\nu)

Where:

- **B_{21}** = Einstein coefficient for stimulated emission
- **ρ(ν)** = Radiation energy density at frequency **ν**

3. Einstein Coefficient B_{12} – Absorption

- Describes the **probability per unit time** that an atom in lower state **E_1** will **absorb a photon** and jump to **E_2**.

Rate of absorption

$$= B_{12}\,\rho(\nu)\,N_1$$

Where:

- **B_{12}** = Einstein coefficient for absorption
- **N_1** = Number of atoms in ground state

Relation Between Einstein Coefficients:

At thermal equilibrium, using Planck's law of blackbody radiation, Einstein showed:

Where:

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

- **h** = Planck's constant
- **ν** = frequency of radiation
- **c** = speed of light

29. PRODUCTION OF LASER

What is Laser Production?

Laser production is the process of **generating a focused and coherent beam of light** using the principles of **stimulated emission**, **population inversion**, and **optical amplification**.

Steps in Laser Production:

1. Energy Pumping (Excitation)

- Energy is supplied to the laser material (called the **active medium**) to excite electrons to **higher**

energy levels.

- This is done using **electric current**, **flash lamps**, or **other lasers**.

2. Population Inversion

- Normally, more atoms are in lower energy levels.
- In laser production, energy is used to achieve **population inversion**, i.e., **more atoms in excited state than in ground state**.
- This is necessary for **stimulated emission** to dominate over absorption.

3. Stimulated Emission

- When an excited atom is hit by a photon of the right energy, it **releases a second photon** that is **identical** (same direction, frequency, phase).
- This process **amplifies light**.

4. Optical Resonator (Cavity)

- The laser medium is placed between **two mirrors**:
  - One is **fully reflective**, the other is **partially transparent**.
- Light bounces back and forth, **amplifying with each pass** through the medium.
- Some light **escapes through the partially reflective mirror** as the laser beam.

31. POPULATION INVERSION

What is Population Inversion?

Population inversion is a condition where **more atoms or electrons are in an excited energy state** than in the ground (lower) energy state.

- This condition is **necessary for laser action** to occur.
- It allows **stimulated emission** to dominate over absorption.

Why is it Important?

- In normal conditions, most atoms are in the **ground state**, and they **absorb** light.

- To create a laser, we need atoms to **emit** light when stimulated.
- **Population inversion** makes this possible by creating a **non-natural condition** where excited atoms are **more than** ground-state atoms.

How is Population Inversion Achieved?

It is done by supplying **external energy** to atoms using methods like:

- **Optical pumping** (using flash lamps or lasers)
- **Electrical pumping** (in gas lasers and semiconductor lasers)
- **Chemical reactions** or **collisions**

Energy Level System:

➤ **Two-Level System**

- Not efficient, hard to achieve population inversion.

➤ **Three-Level System**

- Atoms are excited from level 1 → level 3
- They fall quickly to **metastable level 2**
- Population builds up in level 2 (inversion occurs between level 2 and 1)

➤ **Four-Level System (Better)**

- Even easier to maintain population inversion
- Laser action occurs between two excited states

30. SOLID STATE LASER – RUBY LASER (CONSTRUCTION AND WORKING)

What is a Solid-State Laser?

A **solid-state laser** uses a **solid crystal** as its **active medium**, with doped atoms to generate laser light.

Ruby Laser is the **first successful laser** developed, and it's a **type of solid-state laser**.

What is a Ruby Laser?

- A **ruby laser** uses a **synthetic ruby crystal** (Al_2O_3 doped with chromium ions Cr^{3+}) as the active medium.

- It emits **red laser light** with a wavelength of **694.3 nm**.

Construction of Ruby Laser:

1. **Active Medium**:
    - A **ruby rod** (crystal of aluminum oxide with 0.05% chromium ions).
    - Chromium ions (Cr^{3+}) are responsible for laser action.
2. **Optical Pumping Source**:
    - A **helical flash lamp** (like a camera flash) wraps around the ruby rod.
    - Provides energy to excite electrons in Cr^{3+} ions.
3. **Optical Resonator (Mirrors)**:
    - **Two mirrors** are placed on the ends of the ruby rod:
        - One is **fully reflective** (100%)
        - The other is **partially reflective** (~95%)
    - They reflect light back and forth to stimulate emission and amplify it.

Working of Ruby Laser:

1. **Pumping**:
    - Flash lamp excites the Cr^{3+} ions to higher energy levels.
2. **Population Inversion**:
    - A **metastable state** (long-lived excited state) allows more ions to stay excited, achieving **population inversion**.
3. **Stimulated Emission**:
    - Excited Cr^{3+} ions emit photons. These photons trigger more stimulated emission.
4. **Amplification and Laser Output**:
    - Light bounces between mirrors, getting amplified.
    - A portion escapes through the partially reflective mirror as a **red laser beam**.

32. HELIUM-NEON LASER – CONSTRUCTION AND WORKING

What is a Helium-Neon Laser?

The Helium-Neon (He-Ne) laser is a **gas laser** that produces a **continuous, coherent, red light beam** at **632.8 nm**. It is widely used in labs, laser pointers, and barcode scanners.

Construction of He-Ne Laser:

1. **Laser Tube**:
   - A **long glass discharge tube** (about 80 cm to 1 meter in length).
   - Filled with a **mixture of helium and neon gases** (ratio 10:1).
2. **Electrodes**:
   - Electrodes are placed at both ends of the tube to provide **electrical discharge**.
3. **Power Supply**:
   - A **high voltage DC supply** (5,000–10,000 volts) excites the gas atoms.
4. **Optical Resonator**:
   - Two **mirrors** are fixed at the ends of the tube:
     - One is **fully reflective**, the other is **partially reflective** to let laser light out.

Working of He-Ne Laser:

1. **Electrical Excitation**:
   - When voltage is applied, it creates an electric discharge inside the tube.
   - The **helium atoms** get excited to higher energy levels.
2. **Energy Transfer to Neon**:
   - Excited helium atoms collide with **neon atoms** and transfer energy to them.
   - Neon atoms get excited to **metastable states** (long-lived excited states).
3. **Population Inversion**:
   - More neon atoms collect in the excited state than in the lower energy state.

    - This creates **population inversion**, which is essential for laser action.
4. **Stimulated Emission**:
    - A photon emitted by one neon atom stimulates others to emit **identical photons**.
    - These photons bounce back and forth between mirrors, getting amplified.
5. **Laser Output**:
    - A part of this coherent, amplified red light escapes through the **partially reflective mirror** as the **laser beam**.

Key Points (for clarity):

- **Active medium**: Neon atoms (Helium is used for energy transfer).
- **Laser transition**: Occurs in neon at 632.8 nm (red light).
- **Pumping method**: Electrical discharge excites helium.
- **Type of emission**: Continuous wave (CW) laser.

33. SEMICONDUCTOR LASER – PRINCIPLE AND WORKING

What is a Semiconductor Laser?

A **semiconductor laser**, also called a **laser diode**, is a type of laser where **light is generated by a p-n junction** made of semiconductor material.

- It is compact, energy-efficient, and used in **CD/DVD players, laser printers, fiber optics, and barcode scanners**.
- Emits **coherent, monochromatic light** through **electrical pumping**.

Principle of Semiconductor Laser:

The semiconductor laser works on the principle of **spontaneous and stimulated emission** of radiation due to **electron-hole recombination** in a **forward-biased p-n junction**.

- When **forward bias** is applied, **electrons** from the n-side and **holes** from the p-side are injected into the junction.
- When these recombine, they release **photons (light energy)**.

- Under the right conditions, **stimulated emission** occurs and a **laser beam** is formed.

Working of Semiconductor Laser:

1. **Construction**:
    - Made of a **highly doped p-n junction** of semiconductor material like **GaAs (Gallium Arsenide)**.
    - Ends of the crystal are **cleaved or polished** to act as **mirrors** (for optical feedback).
    - **One end** is partially reflective to allow **laser light** to exit.
2. **Forward Biasing**:
    - When forward voltage is applied, electrons from the n-region move toward the junction, and holes from the p-region do the same.
    - This creates a **high concentration** of electrons and holes at the junction.
3. **Recombination and Photon Emission**:
    - Electrons and holes recombine at the junction, releasing **photons**.
    - These photons stimulate other electrons and holes to recombine and emit **more photons** (stimulated emission).
4. **Optical Feedback**:
    - The cleaved mirrors at both ends **reflect photons back and forth**, amplifying the light.
    - A **coherent and intense beam of light** is emitted through the partially transparent mirror.

34. APPLICATIONS OF LASER

What are Laser Applications?

Lasers are used in a wide range of fields due to their **high precision**, **intensity**, **coherence**, and **focusability.** They are widely used in **science, industry, medicine, communication**, and **entertainment.**

Applications of Lasers:

1. Medical Field

• Used in **eye surgeries** (LASIK – to correct vision).

• **Laser scalpel** for bloodless surgery.

• **Cancer treatment** and tissue removal.

• **Dental procedures** – tooth whitening, gum reshaping.

2. Communication

• **Fiber-optic communication** uses laser light for fast data transfer.

• Lasers transmit signals over long distances with **minimum loss**.

• Used in **undersea internet cables**.

3. Industry

• **Cutting, welding, drilling**, and **engraving** hard materials.

• Used in **precision manufacturing** (automobile, electronics).

• **Barcode scanners** use laser beams in retail shops.

4. Scientific Research

• Used in **spectroscopy** and **holography**.

• Helps in **measuring distances** with great accuracy (laser ranging).

• Used in **nuclear fusion** research.

5. Military and Defense

• **Laser-guided missiles** and weapons.

• **Range-finding** and **target detection** systems.

• Used in **military communication** and **night vision**.

6. Consumer Electronics

• Used in **CD/DVD/Blu-ray players** to read/write data.

• Present in **laser printers** and **computer mice**.

• Used in **projectors** and **laser light shows**.

7. Construction and Surveying

• **Laser levels** for accurate alignment.

• **Laser rangefinders** to measure distances.

• Used in **3D scanning** and **mapping**.

NOTES CREDIT: "MOHD ASIM SAAD "