LASER

3.2 Population Inversion

3

CHAPTER OUTLINE

3.2–1 Population inversion and pumping

3.2–2 Types of LASER

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What is LASER

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. The LASER action was first proposed by Einstein. But, the term LASER is also, used for a device that generates an intense beam of coherent monochromatic electromagnetic light by stimulated emission of photons from excited atoms or molecules.

HISTORY OF LASER

1917: *On the Quantum theory of radiation* – Einstein's paper.

- 1954: MASER by Townes *et al*.
- Means of Acquiring Support for Expensive Research
- 1958: Townes (1964) and Schawlow (1981) conceive basic ideas for a laser.
- 1960: LASER coined by Gould.
- 1960: First laser (Ruby) by Maiman.
- 1961: First HeNe laser, then rapid invention of most lasers …
- 1977: Gordon Gould awarded the patent for the laser.

In 1958, Charles H. Townes and Arthur L. Schawlow showed that the effect of stimulated emission can be amplified to produce a practical source of light, which is coherent and can travel long distances without appreciable spread of the beam width. Such a light source is called LASER, an acronym for Light Amplification by Stimulated Emission of Radiation.

Lasing operation -Population inversion and Pumping

When an atom or molecule in the lasing medium absorbs light it is excited.

The excited molecule then decays to a lower level either through emission of a photon (stimulated or spontaneous) or via a non-radiative loss of energy.

As determined by the Boltzmann factor, the population of the ground state must be greater than the population of the excited state.

Hence, typically absorption dominates.

But, it is found that lasing operation requires obtaining stimulated emission exclusively. For this, the population of the excited state must be larger than the lower state population which is called "**population inversion**", $N_{upper} > N_{lower}$.

The non-equilibrium state in which the population of the upper energy level exceeds to a large extent the population of the lower energy level is known as the state of population inversion.

According to the Boltzmann's distribution the population of the excited state can exceed that of lower state only when the temperature is negative.

How can it be possible to create "population inversion" in a material which will allow for an inversion of population in its electronic states?

It is possible by excitation of the lasing atoms or molecules named '**Pumping**".

For intense pump source, the no of excited atoms or molecules can be large.

However, once excited, the atoms and molecules must stay in the excited state longer enough to create population inversion. It is a non-equilibrium state and is possible to attain at normal temperature.

Pumping

Process by which, atoms are raised from the lower level to the upper level.

Energy is to be supplied somehow to the laser medium to raise atoms from the lower level to the excited level and for maintaining population at the excited level at a value greater than that of the lower energy.

- Usual method – to **heat the material**. Will it do the job?
- Heating the material only, increases the average energy of atoms but does not make N_2 greater than N_1.
- Therefore, only way to do the job is to excite selectively the atoms providing energy through pumping.
- Most common methods of pumping are possible with the use of Light and Electrons of definite energy.
    - Optical Pumping
    - Electrical Pumping
    - Direct Conversion

Optical Pumping

Use of photons to excite the atoms

- A light source used to illuminate the laser medium
- Photons of appropriate frequency excite the atoms of lower level to upper levels.
- Atoms drop to the metastable level to create the state of P.I.

Optical pump sources:

Flash discharge tubes, continuously, operation lamps, Spark gaps or an auxiliary laser. Optical pumping is suitable for laser medium- transparent to pump light. Mostly used for solid state crystalline and liquid tunable dye lasers.

Electrical Pumping

Electrical pumping can be used only in case of laser materials that can conduct electricity without destroying lasing activity. This process is suitable in gases.

•In case of a gas laser, a high voltage pulse initially ionizes the gas so that it conducts electricity.
•An electric current flowing through the gas excites atoms to the excited level from where they drop to the metastable upper laser level leading to **population inversion**.

Direct Conversion

In semiconductor lasers also electrical pumping is used, but here it is not the atoms that are excited. It is the current carriers; {e-h} pairs which are excited and population inversion is achieved in the junction region.

Electrons recombine with holes in the junction regions producing laser light.
A direct conversion of electrical energy into light energy

Active Center and Active Medium

Active medium may be a solid, a liquid, a gas. But all type of atoms are not suitable for laser operation. Only, a small fraction of a particular species is suitable for stimulated emission and laser action.

Those atoms which cause light amplification are called Active Centers. The medium that acts as host and supports active centers is called an Active Medium.

An active medium is thus a medium which, when excited, reaches the state of population inversion, and eventually causes light amplification.

Metastable States

An atom can be excited to an higher energy state by pumping. Normally, excited states have ***short lifetimes*** of the order of *nano-secs* ***(10^{-9}s)*** and return back to the stable state immediately after releasing their excess energy through spontaneous emission. Therefore, population inversion cannot be established.

Many atoms in the excited state rapidly undergo spontaneous transitions to the lower energy level. They do not stay at that excited states long enough to be stimulated though the pumping agent continuously raises the atoms to the excited level.

•For establishing population inversion at comparatively upper than the stable lasing level, the excited atoms are required to **"wait"** till, a large number of atoms accumulate.

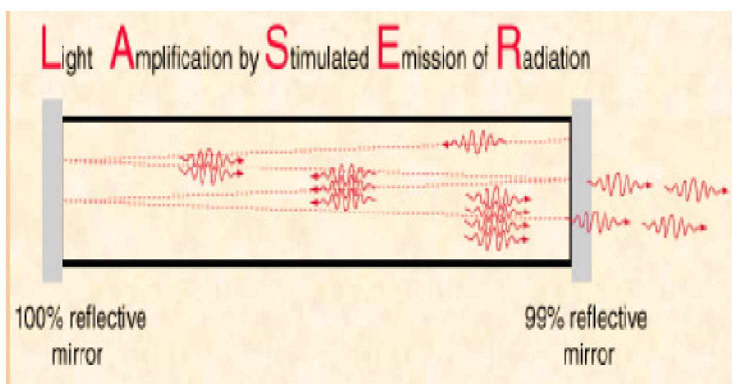
Such longer-lived upper levels from where an excited atom does not return to lower level at once, but remains excited for an appreciable time, are known as ***Metastable States.***

- Atoms can stay in metastable states for about **10^{-6} to 10^{-3}s**. This is **10^3 to 10^6 times longer** than the time of stay at excited levels.

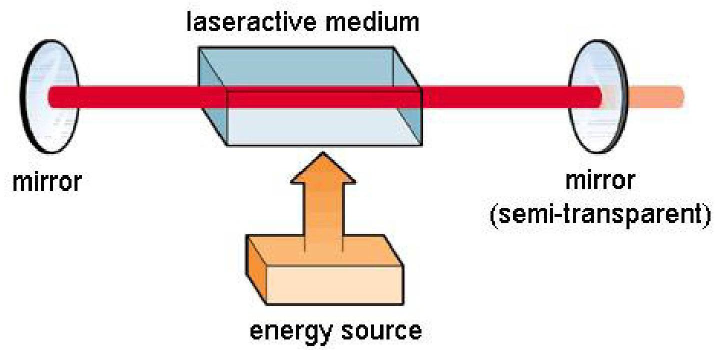
- The population of the metastable state can exceed the population of a lower level that lead to the state of population inversion.

Therefore, **the existence of metastable state is the main basis of laser operation.**

Amplification of Light



The principle behind such amplification is simple. One incident photon strikes the excited atom in the higher energy state under population inversion condition to produce two photons. If those two photons are reflected back from a mirror and simultaneously, strike another two atoms, four photons have been emitted which are coherent in nature and are in same phase. This process continues for a no of repeated reflections that results the amplification of stimulated light intensity constructively.

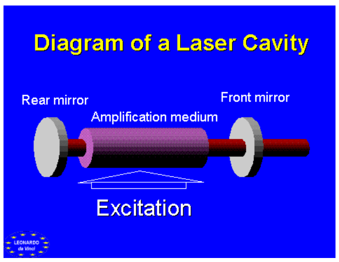


Components of a laser

A laser consists of 3 basic components:

- A lasing medium or "gain medium":
  May be a solid (crystals, glasses), liquid (dyes or organic solvents), gas (helium, CO_2) or semiconductors
- An energy source or "pump":
  May be a high voltage discharge, a chemical reaction, diode, flash lamp or another laser
- An optical resonator or "optical cavity":
  It consists of a cavity containing the lasing medium, with 2 parallel mirrors on either side. One mirror is highly reflective and the other mirror is partially reflective, allowing some of the light to leave the cavity to produce the laser's output beam – this is called the output coupler.

This also determines the type of pump required and the wavelength of the laser light which is produced.



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