LASER

Light amplification by stimulated emission of radiation.

Q1. Distinguish between laser source and ordinary source.

Light Laser Source	Ordinary source
1.Monochromatic light	1.Wide wavelength range
2.Coherent waves are in phase.	2.Waves have no definite phase relation.
3.Highly focused has low divergence hence very intense.	3.Highly divergent hence diffuse because intensity decreased due to spreading.
4.Laser light is directional emitted in one direction . eg. Nd-YAG laser, He- Ne	4.Emitted in all directions. eg. candle, LED, bulb

Q2. Interactions of radiation with Matter.

Ans. Radiation consists of photons and Matter consists of atoms and molecules. Thus , Interaction of radiation with Matter means interaction of photons with atoms and molecules. There are three processes that coexist at all temperatures whenever radiation interacts with matter . They are absorption , emission and stimulated emission.

Absorption :

The transition of atoms from lower energy ground state E_1 to a higher energy excited state E_2 after acceptance of an incident photon is known as absorption. The incident photon should be of energy $E = hv = E_z$.

Absorption con be expressed as A+ hv = > A*

where

A = atom in ground state
A* =atom in excited state

Spontaneous Emission:

If an excited atom returns to the ground state on its own accord by releasing an energy equivalent to $hv = E_2 – E_1$, then the process is known as spontaneous emission .
It can be expressed as A* => A + hv

Stimulated Emission:

If an atom in the excited state E_2 returns to the ground state E_1 in presence of an external photon of energy $hv = E_2 – E_1$ giving out another photon of same energy the process is called stimulated emission .
It can be written as A* + hv => A + 2hv.

Characteristics of stimulated emission :

- The emitted photon and the incident photon are identical in all respects.
- Both photons travel in the same direction.
- Multiplication of photons takes place in the process.

Q3. Explain the terms population inversion, Active medium , meta stable state , pumping.

Ans. Population inversion : Every system in nature tries to achieve minimum potential energy . Thus naturally majority of atoms in every system lie in the ground state and a very few are present in excited state .

For stimulated emission to occur we require majority of atoms to be present in the excited state and very few in the ground state i.e. just inverse of the natural population. Once this condition is achieved . The state of population inversion is said to be achieved.

Active medium : The medium in which light gets amplified is called active medium . It may be solid , liquid or gases. Out of all atoms present in medium only few are responsible for stimulated emission and consequent light amplification , they are called active centres .

Meta stable state : The state which has energy in between that of ground state and excited state is called meta stable state. This is a partially stable state. The life time of atoms is in between their respective life time is ground state and excited states .

Pumping : To obtain and maintain a state of population inversion atoms have to be raised continuously to excited state. It requires energy to be supplied to the system. The process of supplying energy to the medium with a view to transfer it into the state of pumping.

Techniques for pumping are ,

1. Optical pumping: Light source used for pumping.
2. Electric discharge: Electric field is applied to medium producing ionisation creating excitation .
3. Chemical pumping: When chemical reaction is used for excitation .

Q4. Describe action of resonant cavity.
Ans. When stimulated emission is generated in medium it has to be sustained in the desired direction and suppressed in remaining direction . This goal can be achieved by resonant cavity.

Resonant Cavity consist of two oppositely facing parallel mirrors with active medium placed in between them. The action of such a cavity can be explained as follows :

1. Ground state : Initially active centres are in ground state.
2. Optical pumping: By optical pumping the material is taken to a state of population inversion.
3. Spontaneous and stimulated emission : Spontaneous occur in random direction and they thus produce stimulated emission.
4. Optical feedback : Due to reflecting mirrors photons in favourable direction are feedback.
5. Light amplification : Feedback from mirrors combined with stimulated emissions will lead to light multiplication and then light amplification.
6. Light oscillation : Light beam in the cavity begins to oscillate when the amount of amplified light becomes equal to the total amount of light lost through the sides of the resonator. Then waves propagating in the cavity take the standing wave pattern. If L is the length of the cavity.
   2L = mλ

   $2\square = \frac{\square\square}{\square}$

   $\square = \frac{\square\square}{\square\square}$ ____equation 1

   A resonator may support several standing waves of slightly different wavelength, these are called longitudinal modes. Each mode has distinct frequency as in equation 1.

Q5. Derive expression for Einstein's coefficients.

Ans. In 1917 Einstein predicted that emission could be of two types spontaneous and stimulated. At equilibrium the rate of emission is equal to that of atmosphere.

Consider a two level laser system with ground state $\square_1$and excited state$\square_2$. Let $\square_1$ and $\square_2$ be the numbers of atoms in each state. Let Q(*x*) be the sensity of photons incident on this system. Then probability of $\square_1$ atoms to get excited to $\square_2$ state is $\square_{12}$ and can be written as $\square_{\square\square} = \square_{\square\square}\square_{\square}\square$ - equation 1

where $\square_{12}$ is constant.

The probability of emission will have two terms, one corresponding to stimulated and spontaneous emission each. $\square_{\square\square} = \square_{\square\square\square\square} + \square_{\square\square\square\square}$

Therefore, $\square_{\square\square} = \square_{\square}(\square_{\square\square}\square + \square_{\square})$ - equation 2

Here $\square_{\square\square}, \square$ are constant coefficients.

At Equilibrium, $\square_{\square\square} = \square_{\square\square}$

$$\square_{\square}\square\square_{\square\square} = \square_{\square}(\square_{\square\square}\square + \square_{\square})$$

$$\square = \frac{\square_{\square\square}\square_{\square}}{(\square_{\square}\square_{\square\square})(\frac{\square_{\square\square}\square_{\square\square}}{\square_{\square\square}\square_{\square\square}} - \square)}$$

By Maxwell distribution, $\square_{\square} = \square_{\square}\square^{\frac{\square\square}{\square\square}}$ - equation 3

Comparing Eq 3 with Plank's law $\square = \frac{\square\square\square\square^{\square}}{\square^{\square}}(\frac{\square}{\square^{\frac{\square}{\square\square}}})$

We get $\square_{\square\square} = \square_{\square\square}$

$\frac{\square_{\square\square}}{\square_{\square\square}} = \frac{\square\square\square\square^{\square}}{\square^{\square}}$ - Expression for Einstein's coefficient.

Where $\square_{12}$, $\square_{21}$ and $\square_{21}$ are called Einstein's coefficients.

Q6. Explain the working of He-Ne laser along with Principle.

Ans. Principles :

Gas lasers employ electrical pumping of gas mixtures where electron impact excites A gas . Then A gas molecules transfer their energy in collisions to B Gas molecules that are the actual active centres.

It can be expressed as

$e_1 + A \Rightarrow e_2 + A^*$

$A^* + B \Rightarrow A + B^*$

Note: A* is metastable state and B* is excited state.

Construction :

He- Ne laser consist of long and narrow tube that is filled with He and Ne gas in the ratio 10:1 at a pressure of 1 mm of mercury .

Diagram left

Tube length is 50cm and 1cm in diameter . Electrodes are provided to produce discharge in the gas and they are connected to a high voltage power supply .Tube ends are sealed at ends using silica windows inclined as brewsters angle. This tube is placed in between two minor set one is fully reflecting other is partially reflecting. This forms the resonant cavity of He-Ne laser .

Working :

He-Ne laser employs a four level pumping scheme . When the power (1kv) is switched on , the electric field ionises some of gas atoms and ions move towards oppositely charged electrode . Electron lighter in weight hence gain higher velocity and He atoms excited more readily because they are lighter in weight .

$e_1 + He \Rightarrow e_2 + He^*$

He atoms get excited to F_2 and F_3 from F_1 where F_2 and F_3 are metastable state where atoms remain for a longer time creating population inversion.

Diagram left

Ne energy states E_6 and E_4 are very close to metatable states of F_2 and F_3 of He atom. Thus when He collides Ne atom , resonant transfer of energy takes place .

$He^* + Ne \Rightarrow He + Ne^*$

Population increases rapidly in E_6 and E_4 .Thus population inversion takes place in E_6 and E_4 w. r. t. E_5 and E_3 .

Three main transition that became available at o/p.

1)E_6-E_5 of 3:39 µm in IR region not visible.

2)E_6-E_3 of 6328 A^0red color visible.

3)E_4-E_3 of 1.15µm in IR region not visible.

Atoms in E_3 collected undergo spontaneous emission to reach E_2 . E_2 is a metastable state in Ne . So, there is a chance of accumulation in this state.The atoms in E_2 are de-energized by keeping diameter of the discharge tube small . So that wall collision take away their energy and they rapidly reach ground state to get excited to E_6 and E_4 again .

The discharge is maitained continuously thus this cycle of events continues , giving out a continuous laser o/p.

Q7. Explain Nd-YAG laser , Principle , construction and working.

Ans. Principle:
Optically pumped Nd-YAG rod inside the resonant cavity undergoes stimulated emission and light thus produced gets amplified in the cavity to produce Nd -YAG laser.

Construction:
Nd-YAG assembly consists of an elliptically cylindrical cavity that has Nd-YAG rod along if one focal axis and Xenon flash lamp at the other.

Two Diagrams

The cavity is silvered internally so that light leaving the lamp at one focus meets the rod at other focus after every reflection . Thus, light is focused on the rod.Two ends of the rod are polished and silvered for resonator formation .

Working:

Below figure shows the energy level of Nd. E_1 is the ground state and E_3 is the metastable state .Light in the range 5000-8000 A^0 is used to pump
the Nd^{+3} ions that act as active centres to higher states.

Diagram

E_3 is the metastable state that gets rapidly populated due to downward transitions from higher energy levels as none of them is metastable . Thus population inversion takes place between E_3 and E_2 . Thus by resonant cavity action with help of pumping a Continuous laser of 1.6 µm in IR region is given out between E_3 and E_2.

Applications : welding , hole drilling, surgery , cutting .

Q8. Explain semiconductor diode laser on the basis of principle , construction and working .
Ans. When a current higher than a Threshold value is passed in a forward bias on junction that is basically doped it emits a laser that is called semiconductor diode laser .

Construction:

- junction is the active region.
- diode of size of
orden 1 mm ,
- front and rear
ends are polished perpendicular to the junction to make fabry perot resonant cavity .

Diagram

Working:

A heavily doped pn junction is forward biased. This puts fermi level within conduction band. So , on heavily
doped p side the acceptor levels enter with Efp into the valence band creating holes in valence band.

One diagram

Zero bias condition
is as shown in the
adjoining figures :

One diagram

When a forward bias is applied zero bias changes to the condition shown , electrons injected into depletion region hence it's holes appear in lower region. Low forward bias current causes spontaneous emissions of photons at the junction .
Spontaneous emission light will have Range B-W. When
the current increases **threshold value** carrier concentration
increases to very high
value . The narrow region where this is achieved is called active region . Forward bias current plays the
role of pumping agent in diode lasers.
eg . In GaAs laser light of 9000 A° in IR. GaAsP in visible region red colour 6500 A°. Diode laser are simple, efficient low power
compact , less monochromatic and highly temperature sensitive.

Q9. Write a note on holography .
Ans. A Photograph records a two dimensional record of a three dimensional scene.The emulsion on the photographic plate is
sensitive to intensity variations only. In the process the phase information carried by electromagnetic wave
scattered from the object is lost hence 3D character is lost.

Principle behind holography is during recording process . The wave scattered from project is made

to interfere with a coherent unscattered wave (reference beam) to obtain inteference pattern that becomes the record of phase information i.e. 3rd dimension. Thus hologram is "holos" greek "complete" record.

Recording hologram:

Diagram

The hologram thus obtained is not similar to the image as in case of photograph . On the contrary, it consists of alternate
bright and dark bands (interference pattern).

Reading a hologram:

Diagram

When hologram is illuminated by the reconstruction two waves are produced. One appears to diverge from the object and
provides virtual image of the object and second converges to form real image.

Q10. Distinguish between photograph and hologram.
Ans.

Photograph	Hologram
2D representation of the object.	3D representation of the object.
Looking at the negative we can get to know about the object.	But looking at the hologram , its just alternate dark and bright band interference pattern that does not resemble object.
Ordinary light is used for photography.	Laser light is used for holography.