UNIVERSITY OF LUCKNOW

LIGHT AND LEARNING

Lasers Lecture 3 Light Amplification Process

100 Years 1920-2020

University of Lucknow | Centenary Year

लखनऊ विश्वविद्यालय | शताब्दी वर्ष

Light Amplification

The stimulated emission requires the presence of a photon. An incident photon stimulates a molecule or an atom in the excited state to decay to the ground state by emitting a photon. The stimulated photons travel in the same direction as the incoming photon and is in the same phase and state of polarization as that of the incoming photon.

Spontaneous emission does not require the presence of a photon. Instead a molecule in the excited state can relax to the ground state by spontaneously emitting a photon. Spontaneously emitted photons are emitted in all directions and they are not related to each other in phase in any manner.

When light travels through an absorbing medium, the medium absorbs the light and the molecules or atoms are excited

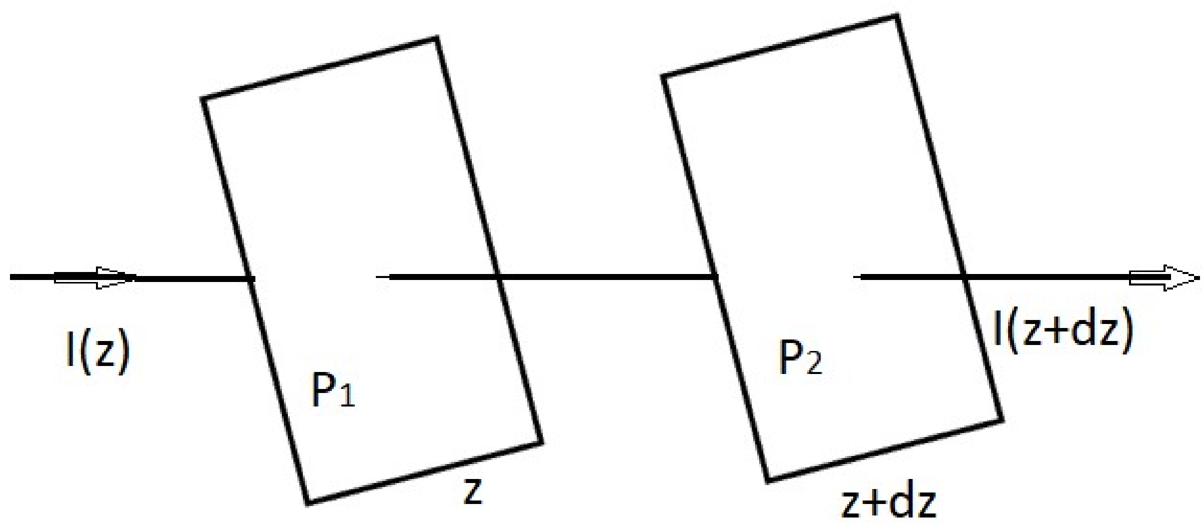
If the excited molecules or atoms then decay to a lower energy level through stimulated emission of photons it leads to light amplification, or they may also decay via spontaneous emission or through a non-radiative loss of the energy.

For lasing action, the stimulated emission must dominate

For stimulated emission to be the dominant the lasing process, the excited state population must be larger than the lower state population.

Consider a collection of atoms. Let a nearly monochromatic radiation of energy density u at frequency ω' pass through it. P_1 and P_2 are two planes of area of cross section S each situated at z and z+dz. Z is the direction of propagation of the radiation.

I(z) and I(z+dz) are intensity of radiation at z and z+dz, respectively



Net amount of energy per sec entering the volume [SdZ] between P_1 and P_2

$$[I(z) – I(z+dz)] S= [I(z) - I(z) - (dI/dz) dz] S = -(dI/dz) Sdz$$

This must be equal to the net energy absorbed per sec by the atoms in the volume [Sdz]

Energy absorbed per sec by atoms in transition 1 → 2 will be Γ_{12} Sdz ħω'

Energy released per sec through stimulated emission Γ_{21} Sdz ħω'

Energy radiating out per sec by spontaneous emission is spread over a broad range of frequency and emitted in all directions, having different states of polarization.

The fraction of the spontaneous emission travelling in z direction at radiation frequency ω' is very small. This may be neglected.

Net energy absorbed per sec in volume [Sdz]

$$[\Gamma_{12} - \Gamma_{21}]\, \hbar\omega'\, Sdz = \frac{\pi^2 c^3}{\hbar\, n_o^3 \omega'^3} \frac{1}{t_{sp}}\, g(\omega')u\,(N_1 - N_2)\, \hbar\omega'\, Sdz$$

$$\frac{dI}{dz} S\, dz = \frac{\pi^2 c^3}{n_o^3 \omega'^2} \frac{1}{t_{sp}} g(\omega')u(N_1 - N_2)\, \hbar\omega'\, S\, dz$$

The energy density u and intensity of radiation I are related as following

$$I = vu = (c/n_o)\, u$$

$$dI/dz = -\alpha I = -\alpha\, (c/n_o)\, u$$

$$-\alpha \frac{c}{n_o} u = N_2 \frac{\pi^2 c^3}{n_o^3\, \omega'^2} \frac{1}{t_{sp}} g(\omega')\, u\, (N_1 - N_2)$$

$$\alpha = \frac{\pi^2 c^2}{n_o^2 \omega'^2} \frac{1}{t_{sp}} g(\omega')\, (N_1 - N_2)$$

$$\alpha = \frac{\pi^2 c^2}{n_o^2 \omega^2} \frac{1}{t_{sp}} g(\omega)\, (N_1 - N_2)$$ The prime has been dropped

$$dI/dz = -\alpha I \quad \Longrightarrow \quad I = I(0)e^{-\alpha z}$$

If $N_1 > N_2$, α is positive and hence intensity decreases with z leading to attenuation of the beam.

If $N_2 > N_1$, α is negative and the beam is amplified with z.

The exponential decrease or increase of intensity is obtained for lower intensities. For large intensities saturation sets in and $(N_1 - N_2)$ is no longer independent of I.

YouTube Channel Link:
https://www.youtube.com/channel/UC3rdRYA605bdDdsJdEf0oJw/featured

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