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Archives of Physics Research, 2012, 3 (2):84-87
(http://scholarsresearchlibrary.com/archive.html)

ISSN : 0976-0970
CODEN (USA): APRRC7

A study of Absorption and Spatial Hole Burning in Laser action

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ABSTRACT

The population inversion is required to overcome absorption and to achieve lasing with inversion but in case of lasing without inversion absorption is cancelled via the processes of quantum interference. In this work an analysis of the two process has been made using the phenomenon of spatial hole burning of semiclassical theory of laser.

Key Words: lasing with inversion, lasing without inversion, spatial hole burning and stimulated decay.

INTRODUCTION

The population inversion is a necessary condition for laser action. When light incident on a material medium causes absorption, spontaneous emission and stimulated emission of photons. Stimulated emission is much less than the spontaneous emission and the absorption. The population inversion is required to overcome absorption to achieve lasing with inversion [1] but in case of lasing without inversion [2-7] absorption is cancelled via the processes of quantum interference [].The phenomenon spatial hole burning appeared in semiclassical theory of laser is responsible for gain suppression in laser cavity. The phenomenon of spatial hole burning [8-12]remains un affected in lasing without inversion as appeared in semiclassical theory of laser[].In this work an analysis of the two process has been made using the phenomenon of spatial hole burning of semiclassical theory of laser and provide a schematic representation of spatial hole burning, Lasing with inversion and Lasing without inversion. This fact has not been discussed in earlier work.

LASER ACTION:

"LASER" is an acronym for "Light Amplification by Stimulated Emission of Radiation."The laser is a light source that exhibits unique properties such as directionality, monochromaticity and coherence. These properties easily distinguish the laser from any other source of light hence has found a wide variety of applications in modern technology. In order for a laser to produce an output, more light must be produced by stimulated emission than is lost through absorption. For this process to occur, more atoms must be in upper energy level than in lower level which does not occur under normal circumstances, this process is called "population inversion."

However the population inversion between states connecting in ultra short wavelength laser, in general is hard to realize. Moreover even if a population inversion is reached between two states ,the strong spontaneous emission yield a large phase noise, as spontaneous emission rate relates to laser wavelength in a cubic inversion ratio. Consequently, it is impossible for an output ultra short wavelength laser to have narrow line width. Recently it is theoretically recognized that under proper conditions a buildup of coherent radiation is achievable in some multilevel systems, even if population is absent. This new kind of the mechanism is termed as lasing without inversion. Under special conditions coherent atomic transitions can cancel absorption. The main idea of LWI is that absorption cancellation provides the possibilities to obtain light amplification even if the population of the upper level is less than the population of the lower level.

SPATIAL HOLE BURNING:

Spatial hole burning is responsible in gain suppression in a laser cavity. This phenomenon appears naturally in the semiclassical theory of laser. This hole burning appears in the graph representing the normalized population difference versus axial co-ordinate along z axis. Though the hole burned by the field intensity for non moving atoms are seen to wash out for rapidly moving atoms the effect is inherently present in laser oscillator. Spatial hole burning can be defined as distortion of the gain shape in a laser medium caused by saturation effects of a standing wave.

We consider a semiclassical model of laser homogeneous medium. This model illustrates simply some basic laser principle. An atom excited to state a at time t_0,and place z,is described by the density matrix $\rho(a,z,t_0,t)$. Atoms are excited to the state a at the rate $\lambda_a(z,t_0)$ atoms per second per unit volume. The level probabilities decay with constants γ_a and γ_b. The polarization matrix element decays with constant.

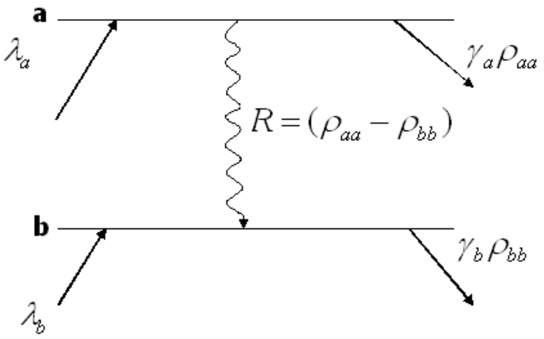

Fig 1: Energy level diagram for atom comprising laser active medium.

The response frequency of the transition from the lower level (b) to the upper level (a) is ω the no of atoms per volume per unit time excited to the a and b levels are λ_a and λ_b respectively. The number decaying are $\gamma_a\rho_{aa}$ and $\gamma_b\rho_{bb}$ respectively and the number making transitions from the level a to b is $R(\rho_{aa}-\rho_{bb})$. According to the rate equations normalized population difference in terms of density matrix ρ_{aa} and ρ_{bb} is given by

$$\frac{\rho_{aa}-\rho_{bb}}{N(z,t)}=\frac{1}{1+\frac{R}{R_s}} \qquad (1)$$

Where the term in the left hand side is the population difference, R_S saturation parameter $R_S=\frac{\gamma_a\gamma_b}{2\gamma_{ab}}$

R rate constant given by $R=\frac{1}{2}\left(\frac{\wp E_n}{\hbar}\right)|U_n|\gamma^{-1}L(\omega-\nu_n)$

Where $L=\frac{\gamma^2}{\gamma^2+(\omega-\nu_A)^2}$ γ_a,γ_b are decay rates from the upper and lower states respectively and $\gamma_{ab}=\frac{1}{2}(\gamma_a+\gamma_b)$. In equation (1) we see that the population difference is given by *N(z)* divided by

$(1+\frac{R}{R_S})$. When $R = R_S$ the population difference is $\rho_{aa} - \rho_{bb} = \frac{1}{2}N(z)$ i.e. the population difference becomes one half of its value. It may be noted that the factor $(1+\frac{R}{R_S})$ increases as intensity of the electric field increases. For sinusoidal varying electric field holes are burned in the population difference one half wavelengths apart. To see how spatial holes are actually burned in the population difference we note that for central detuning we use the equation

$$\frac{(\rho_{aa}-\rho_{bb})}{N(z)} = \frac{1}{1+I_n \sin^2 \frac{2\pi}{\lambda} z} \tag{2}$$

For different value of I_n the normalized population difference versus axial coordinate z are plotted and they are shown in Fig 2. The spatial holes are clearly depicted in the diagram.

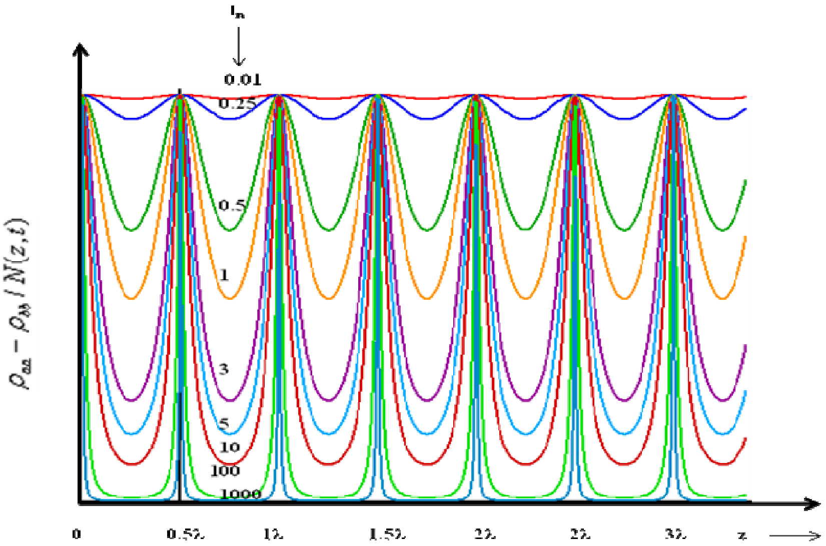

Fig 2: Normalized population difference vs axial co-ordinate

RESULTS AND DISCUSSION

In case of lasing without population inversion it is considered thatwe consider $\rho_{aa} < \rho_{bb}$ and apply it in to equation (1) we obtain the left hand side of the equation to be negative, the population difference will be negative, and this expression can be reframed as

$$\frac{\rho_{bb} - \rho_{aa}}{N(z,t)} = \frac{1}{1+ R/R_S} \tag{3}$$

In equation (1) we see that the population difference is given by N (z) divided by a factor $1+\frac{R}{R_S}$ and we observe the LHS's equation (1) and (3) are equal in magnitude. When $R = R_S$ the population difference is

$$\rho_{aa} - \rho_{bb} = \frac{1}{2}N(z)$$

i.e. the population difference becomes one half of its value but here when $\rho_{aa} < \rho_{bb}$ $\rho_{aa} - \rho_{bb} = -\frac{1}{2}N(z)$

which can be modified as $\rho_{bb} - \rho_{aa} = \frac{1}{2}N(z)$

Here $-N(z) = \lambda_a \gamma_a^{-1} - \lambda_b \gamma_b^{-1}$

and $\rho_{aa} - \rho_{bb} = \lambda_b \gamma_b^{-1} - \lambda_a \gamma_a^{-1}$

When the life time in the upper level "a" relatively shorter than the life time in the lower level "b" ($\frac{1}{\gamma_a} << \frac{1}{\gamma_b}$,), means $\gamma_a >> \gamma_b$ which causes decrease in inversion and net gain. This indicates that the spatial hole burning also affects the gain in lasing without inversion, and it is interesting to note that this point has not been discussed in various schemes dealing with lasing without inversion.

CONCLUSION

It is worthwhile to note that the presence of spatial hole burning inhibits the gain or amplification of a laser medium. In this connection it is worthwhile to connect the phenomenon of spatial hole burning with the processes of LWI. We have seen that population inversion is needed for lasing and primary reason for this population inversion is to overcome absorption. Absorption inhibits gain in the process of lasing and in spatial hole burning encountered in the semi classical theory of lasers gain or amplification is suppressed sinusoid ally along the laser axis. Further we note that absorption inhibits gain and to overcome it we need population inversion. Similarly spatial hole burning inhibits gain, to overcome it we need dimensionless intensity of the laser medium I_n to be extremely small that is 0.001, which indicate extremely dilute medium. In LWI absorption is cancelled via the process of quantum interference, which leads to amplification or lasing even in the absence of the population inversion. We can conclude that spatial hole burning is a similar process as absorption and its presence in laser with population inversion and laser without population inversion is noted.

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