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On the nature of spatial hole burning and lasing without inversion

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Abstract

In the present work it has been shown that the phenomenon of spatial hole burning in semi classical theory remains unaffected in Lasing without inversion. The notion of stimulated decay is introduced for Lasing without inversion.

Key words: spatial hole burning, Lasing without inversion and stimulated decay.

Introduction

The semi classical theory of laser noise considers the spontaneous emission fluctuations as the major noise sources, and they have influences on gain in a number of ways .The phenomenon like spatial hole burning [1-3], heating are mainly responsible for gain suppression in laser cavity. The phenomenon of spatial hole burning appears naturally in semi classical theory of laser [4]. This appears in the graph of normalized population difference versus axial co ordinate along laser axis. Though the hole is burned by the field intensity for a non moving atom [5] the effect is inherently present as noise in laser oscillators and amplifiers. The basic principles of spectral hole burning was indeed applied by Arnand[6] in the case of complicated structures like quantum wells. It was shown that the constant voltage driven laser diodes generate amplitude squeezed light. The phenomenon of spatial hole burning has also been used to explain few characteristics of quantum wells [7] In the last decade lasing without inversion (LWI)[8-14], has attracted tremendous attention. LWI gives the production of light with greatly reduced noise which could be useful in X ray laser and new type semiconductor laser [13-14].In the present work we show that the phenomenon of spatial hole burning in semi classical theory remains unaffected in Lasing without inversion. This fact has not been discussed in earlier works.

Spatial hole burning:

Spatial hole burning is responsible in gain suppression in a laser cavity. This phenomenon appears naturally in the semiclasical 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.

The normalized population difference in terms of density matrix ρ_{aa} and ρ_{bb} is given by

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

Where the term in the left hand side is the population difference,

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

Saturation parameter $R_S = \frac{\gamma_a \gamma_b}{2\gamma_{ab}}$

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 sinusoid ally varying electric field holes are burned in the population difference one half wavelengths apart.

Lasing without inversion:

One of the central issues in laser techniques is the generation of laser in x ray domain. However since 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 [15-18].Mean while as it does not need a large population in the upper lasing level, the spontaneous emission phase noise is quite small and then laser generated in this way will have a very narrow natural line width[16,19].

Varieties of LWI schemes have been proposed and number of experiment are now under way, and few experimental demonstrations have been successful [21-23]. Bloembergen's three level schemes, which worked out five decades ago, carry the essential features of LWI. We have seen that in this system two fields are allowed to be incident on an assembly, a strong field at resonance with frequency ν_{31} (frequency separating the ground level and highest excited level) and the weak signal field at frequency ν_{32} .In LWI also two fields are allowed to be incident on this assembly; one strong field and another weak field and coupling take place between the two fields. We have seen that because of the closeness of two levels there is uncertainty in making transitions to the upper level or lower level, depending on whether the system is Λ type or V type resulting in destructive interference [9].

To present the basic physics of LWI it is best to consider the theory of this effect in three level Λ configuration and then to demonstrate how the concept of lasing without inversion can be realized. Theoretical analysis predicts that lasing without inversion can be achieved in simple three level V scheme configuration [20], it requires more population in the ground state than in the excited state i.e. the lasing without inversion requires $\rho_{aa} < \rho_{bb}$.(ρ_{aa} excited state and ρ_{bb} ground state, population is in the density matrix notation).A three level diagram of the Λ and V schemes of lasing without in version is given below in the figure I and II.

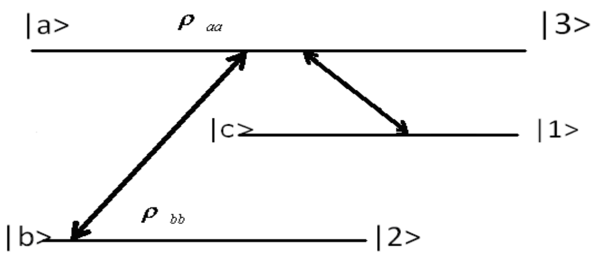

Figure I Three level atom in the Λ -configuration

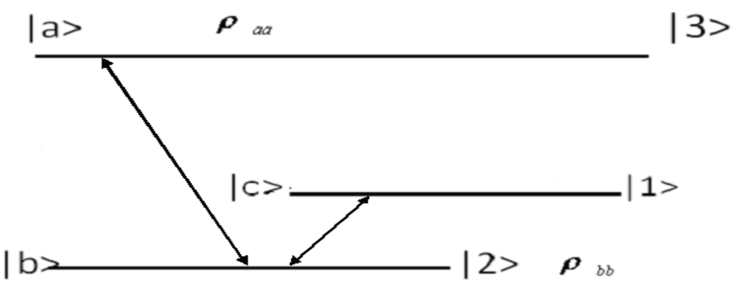

Figure II: Three level atom in the V-configuration

If we consider $\rho_{aa} < \rho_{bb}$ and apply in to equation (1) we obtain the left hand side of the equation (1) to be negative, the population difference will be negative, and this expression can be reframed as

$$\frac{\rho_{bb} - \rho_{aa}}{N(z,t)} = \frac{1}{1 + R/R_S} \qquad (2)$$

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

$$\text{Here} \quad -N(z) = \frac{1}{2}(\lambda_a \gamma_a^{-1} - \lambda_b \gamma_b^{-1})$$

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

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 .Though the LWI has been demonstrated experimentally, a practical device has not yet been made. Thus any high power device dealing with LWI should also consider the effect of spatial hole burning.

It is worthwhile to note that the presence of spatial hole burning inhibits the gain or amplification of a laser medium and proper mechanism should be provided so that the effect is overcome. In this connection it is worthwhile to connect the phenomenon of spatial hole burning with the processes of LWI. We have seen that population is needed for lasing and primary reason for this population inversion is to overcome absorption which is inherently present in the process of interaction of radiation with matter. We have discussed this matter in the case of LWI. Absorption inhibits gain in the process of lasing and in spatial burning encountered in the semi classical theory of lasers gain or amplification is suppressed sinusoidally along the laser axis. In LWI absorption is cancelled via the process of quantum interference, which leads to amplification or lasing even in the absence of the population in the excited states. Spatial hole burning inhibits gain, like wise absorption inhibits population inversion and gain (lasing). Absorption is cancelled via quantum interference leading in LWI. Spatial hole burning if suppressed will lead to increase and in gain. In this way we observed that both process as are analogous. Further behind every radiation there must be some decay. In LWI though less amount of decay is present but it is not completely responsible for lasing.

Without loss of generality we may infer that in this case the decay is stimulated or stimulated decay is responsible for lasing without inversion.

Conclusion

In the present work it has been shown that spatial hole burning also effects lasing without inversion like lasing with inversion. The concept of stimulated decay is introduced for Lasing without inversion.

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References

[1.] G.P.Agrawal and N.K.Dutta, Long wavelength semi classical laser, Van No strand Reinhold, New York,**1986** pp-132-134.
[2] X Plan II Olsen,B Tromborg and H.E.Lassen, *Proc IEEE J* **1992**, 139,189.
[3] T.Takahashi and Y Arkawa, *IEEE photon Jechnot Lett* **1991**, 3, 106.
[4] M .Sargent III, M O Scully and W E Lamb Jr Laser Physics Addison –Wiesley, Publishing Company,Massachustts **1974** pp 261-265.
[5] S Stenhalm and W E Lamb, *J Phy Rev* **1969**, 181, 115.
[6] J Arnand, Phys *Rev A* **1993**, 48, 2235.
[7] R Borah and G D Boruah, *Asian J Chem.* **1999**, 3, 63.
[8] M O Scully and M S Jubairy, Quantum Optics 1st edition Cambridge University Press, **1997** pp-251-256.
[9] Kocharovskaya, *Phys Rep***1992**, 219, 175.
[10] M O Scully, *Phys Rep* **1992**, 219,191.
[11] P Mandel, *Contem Phys* **1993**, 34, 235.
[12] G G Padmanaandu etal, *Phys Rev Lett* **1996**, 76 2053.
[13] M O Scully, *Phys Rev Lett* **1985**,55,2820.
[14] M.P.Winters, J.L.Hall and P E Toschek, *Phys Rev Lett* **1990** 65, 3116.
[15] S E Harris, Phys Rev Lett **1989**, 62.1033.
[16] M O Scully S Y Zhu and A Gaverilides, Phy *Rev Lett* **1989**, 62, 2813.
[17] A Imamoglu,J E Field and S E Harris, *Phys Rev Lett* **1991**,66,1154.
[18] Fie Zhen Lou and Zhon Zhi Xu, *Phys Lett A* **1992** 169,389.
[19] Fie Zhen Lou and Zhon Zhi Xu, *Phys Rev A* **1993**, 47, 1.
[20] G S Agrawal, *Phys Rev Lett* **1992**, 67,980.
[21] M Fleischhour, T Mechllrath and M O Scully, *Appl phys B* **1995**, 60 5123.
[22] A.S.Zebrov, *Phys Rev Lett*. **1999**,75,1499.
[23] W.E.Veer and J.J.Diest *Phys Rev Lett* **1999**,70,3243.