Spatial Hole Burning And Its Analogy With Some Non-Physics Context

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Abstract

The semi classical theory of laser as developed by Willis Lamb and coworkers several decades ago explains a large number of laser phenomena particularly in gaseous phase. In this theory it has been shown that, whenever we plot normalized population difference versus axial coordinates, there appears dips or holes at regular intervals at particular positions along the laser axis. These holes represent the depletion of population inversion thereby meaning the reduction of laser beam intensity. These holes are known as spatial holes. These holes are always present in laser originating from a Fabry-Perot cavity and are not welcome in the operation of high power laser. In the present work, we analyzed the phenomenon of spatial hole burning in the light of some non-physics context.

Keywords: Spatial hole burning, Laser beam intensity, Fabry-Perot cavity, Non-physics context.

1. Introduction

The phenomenon of spatial hole burning is an important topic in semi-classical theory of laser which was developed by Willis Lamb Jr. and co-workers several decades ago (Sargent, *et al.,* 1974; Lamb, 1964). In this theory it has been shown that, whenever its plotted normalized population difference versus axial co-ordinates, there appears holes or dips at regular intervals at particular positions along the laser axis. These holes represent the depletion of population inversion and thereby meaning the reduction of laser beam intensity. These holes are known as "spatial holes". They are always present in laser originating from a Fabry-Perot cavity. Though the hole is burned by the field intensity for a non-moving atom (Lamb, 1963), they are seen to wash out for rapidly moving atom (Stenholm & Lamb, 1969). The phenomenon of spatial hole burning has also been used to explain few characteristics of quantum wells (Borah & Baruah, 1999). In a recent work(Dubey & Baruah, 2010; Dubey ,2010) it has been shown that, the spatial hole burning in semi-classical theory of laser remains unaffected in lasing without inversion. Spatial holes are not welcome in high power laser operation. It is worthwhile to note here that, spatial holes and holes burned in a line profile (popularly known as Lamb dip) are two different phenomena. In the present work, the role of these holes in laser operation were analysed and also few non-physics phenomena which carry analogies with spatial hole burning were discussed.

1.1 Spatial Hole Burning

In this section , the concept of spatial hole burning, the details of which can be formed in the work of Willis Lamb Jr. (Sargent, *et al.,* 1974; Lamb, 1963; Lamb, 1964) were briefly introduced. We have the normalized population difference in terms density matrix in ρ_{aa} and ρ_{bb} a two level atom as,

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

Where the saturation parameter $R_s = \{\gamma_a \gamma_b\}/ \{2 \gamma_{ab}\}$---------------(2)

And unsaturated population difference

$$N(z, t) = \lambda_a \gamma_a^{-1} - \lambda_b \gamma_b^{-1} \text{ -----------------------------(3)}$$

The rate constant $R = ½ (\wp/\hbar)^2 E_n^2 \; |U_n|^2 \gamma^{-1} \mathcal{L} (w - \nu_n)$ -----(4)
Dimensionless Lorentzian $\mathcal{L} (w - \nu_n) = [\gamma^2/\{(w- \nu_n)^2 + \gamma^2\}]$ --(5)
γ_a and γ_b are decay rates from the upper and lower states respectively and $\gamma_{ab} \rightarrow ½(\gamma_a + \gamma_b)$

$U_n(z)$ is the unidirectional (running waves) mode function given by $U_n(z) = \exp(iK_n z)$, P is dipole moment matrix element, λ_a and λ_b are the number of atoms per unit volume per unit time excited to levels a and b respectively. In equation (1) it was observed that, the population difference is given by that in the absence of the field N(z) divided by the factor 1+(R/ R_s), which increases as the intensity of the electric field increases. In particular, when $R = R_s$, then the population difference is $\rho_{aa} - \rho_{bb} = \frac{1}{2} N(z)$, *i.e.*, one half of the zero field value . For a rate constant R with $U_n^2(z) = \sin^2 K_n z$ dependence, the population difference $\rho_{aa} - \rho_{bb}$ also exhibits this dependence. For sinusoidally, varying electric field intensity burns holes into the population difference spaced one half wavelength apart. The depth of the holes will depend on a specific parameter usually known as dimensionless intensity. To see how these spatial holes are actually burned in the population difference it can be noted that,

$U_n(z) = \sin K_n z, \quad K_n = 2\pi/\lambda$

$R/R_s = I_n \{2\gamma_{ab}/\gamma\}[\gamma^2/\{(w-\nu_n)^2 + \gamma^2\}] \sin^2(2\pi/\lambda) z$, ---------------(6)

Where $I_n = \frac{1}{2} (\wp/\hbar)^2 \{1/(\gamma_a \gamma_b)\} E_n^2$ -------------------------------(7)

The parameter I_n is referred to as dimensionless intensity and is an important in the semi-classical theory of laser and not known in any earlier works.

For central debuting $w - \nu_n = 0$, ($w = \nu_n$), $2\gamma_{ab} = \gamma$, equation (6) becomes,

$\rho_{aa} - \rho_{bb} = \{N(z)\} / (1 + I_n \mathrm{Sin}^2 K_n z)$

or ($\rho_{aa} - \rho_{bb}$) / $\{N(z)\} = 1/(1 + I_n \mathrm{Sin}^2 K_n z)$ ------------------------(8)

For different values of I_n the normalized population difference versus axial co-ordinates may be easily plotted (figure 1) and spatial holes are clearly depicted in these graphs. At the nodes the population has the zero field value. It must be emphasized that, spatial hole burning is responsible for gain suppression in a laser cavity. Though the holes burned by the field intensity are seen to wash out for rapidly moving atoms, the effect is inherently present in laser oscillator (Sargent, *et al.,* 1974).

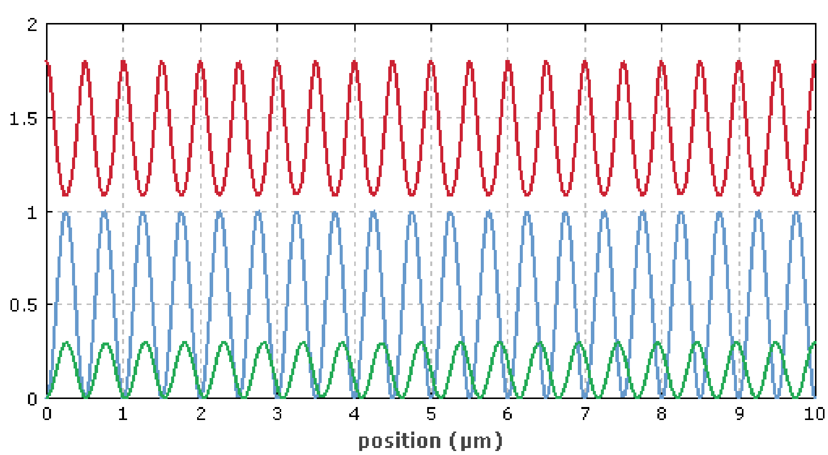

Fig.1. *Illustration of spatial hole burning in a laser. A strong beam with the blue standing-wave intensity pattern saturates the gain (red curve). It experiences a more strongly reduced gain than the green curve, corresponding to a weaker beam with slightly different wavelength.*

1.2 Spatial Hole Burning and Absorption

In this section, the phenomenon of absorption in the light of spatial hole burnings were discussed. This discussion is necessary in the sense that in laser population, inversion is needed to overcome absorption because absorption inhibits laser gain, similarly, in lasing without inversion also absorption inhibits gain and quantum interference leads to the suppression of absorption and subsequently laser gain is achieved. This is shown in figure 2.

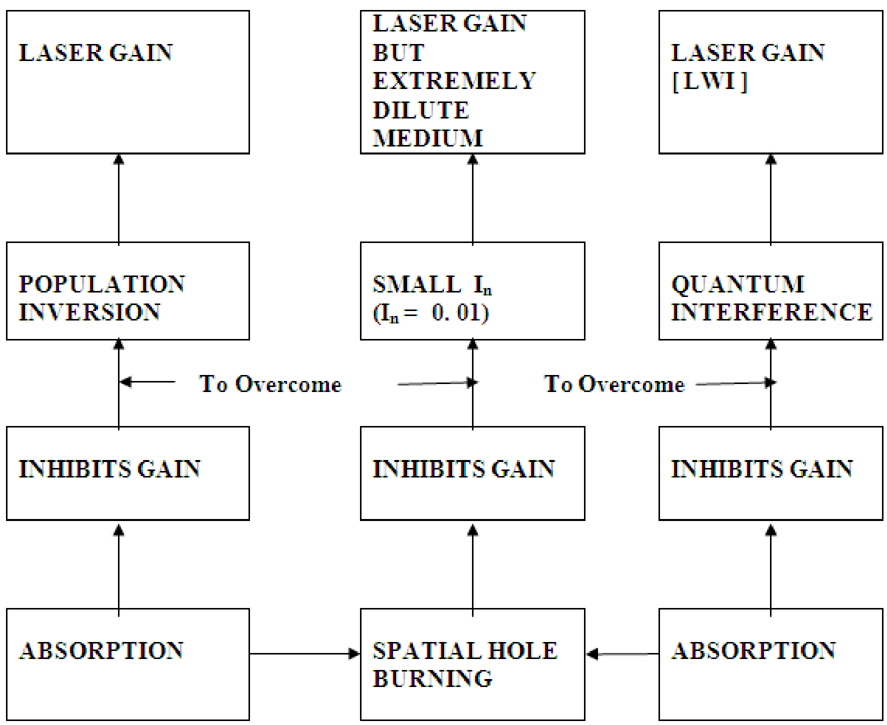

Fig. 2 *The Role of Spatial Hole Burning.*

1.3 Spatial Hole Burning and Analogy in Non-Physics Context

It is now appropriate to discuss some non physics phenomena as analogies to spatial hole burnings in the semi-classical theory of laser . As an example, whenever a river flows, it flows with a particular speed which, depends on various factors like rainfall, direction of flow, *etc.*, When a bridge is constructed on a river it is supported by pillars. As river flows, the flowing river (speed of water) is opposed by the pillars. In the language of spatial hole burning it inhibits the flow of water, (which represents gain in laser). Similarly, to overcome the problem of flood and to avoid erosion of the banks of a river during flood, numerous spurs are constructed. Closure examination shows that, the pattern of water during flow around the spurs is analogous to spatial hole burning patterns. There are several instances to draw these analogies. The following photographic figures (Fig 3 and Fig 4) illustrates these analogies. One of them is the photographic pattern exhibited by the mica white board or front window pans of a car or plain glass of big size or similar objects, when water is splashed on the objects. These patterns are wavy in nature presumably originated from in-homogeneities or dust in the mica white board or window pans.

Fig.3. *The analogy of spatial hole burning presented by river flowing water by the pillars of a bridge.*

Fig.4. *Analogy of spatial hole burning by the photographic pattern of coloured water on the white board.*

2. Summary and Conclusion

Spatial hole burning can have various consequences for the operation of lasers. The phenomenon may be used to control energy which appears in the form of gain in laser.

The effect can make it difficult to achieve single-frequency operation. The optical bandwidth of a free-running laser may be much larger. Spatial hole burning can reduce the laser efficiency. Some man-made non-physics analogy to spatial hole burning have been discussed. There may be many other artificial or natural analogy. The role of spatial hole burning in connection with the phenomenon of absorption have also been indicated.

3. References

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