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Spatial Hole Burning Multiple Reflection and Squeezed State

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ABSTRACT

The present work reports a possible correlation between the intensity contour of fringes due to multiple reflection, showing how the sharpness depends on reflectance, Spatial hole burning in the plot of normalized population difference versus axial coordinate in the semi classical theory of Laser and the squeezed state of light. There are three pairs of parameters which have been brought into discussion in this case. In the first case it is the intensity versus phase angle at various reflectivity (r = 0.1000 to 0.9999), in the second case it is the normalized population difference versus axial coordinate at various values of dimensionless intensity (.1 to 102) and in the third case it is the plot of the variance of variance of a squeezed state with the squeezed angle. In all the cases there is a worthwhile analogy among the three phenomena.

Keywords: Spatial Hole Burning, Squeezed state, Reflectivity
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INTRODUCTION

In many ways some phenomena of physics appearing in different contents are quite analogous. Sometimes the phenomena appearing in physics show up also in non-physics contexts. In the present work we work out an analogy in three different phenomena appearing in classical optics, laser and quantum optics. These are respectively the phenomena of multiple reflection (1), spatial hole burning [2] and Squeezed State of light [3]. An analogy between spatial hole burning and the intensity contour of the beams in multiple reflection inside a Fabry- Perot Cavity was already established in an earlier work [4]. In this work it was shown that the laser parameter known as the dimensionless intensity is identical to the parameter reflectance (r). In the present work we carry the analogy further and use it to the squeezed state of light.

2. Spatial Hole Burning :

The normalized population difference in terms of the density matrix ρ_{aa} and ρ_{bb} is given by [2]

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

Where the constant R_S is known as saturation parameter and is given by $R_S=\frac{\gamma_a\gamma_b}{2\gamma_{ab}}$

γ_a and γ_b are the decay rates from the upper and lower states respectively and

$$\gamma_{ab}=\frac{1}{2}(\gamma_a+\gamma_b)$$

R is called the rate constant given by

$$R=\frac{1}{2}\left(\frac{\wp E_n}{\hbar}\right)^2|U_n|^2\gamma^{-1}\alpha(\omega-\upsilon_n)$$

Where $\alpha=\frac{\gamma^2}{\gamma^2(\omega-\upsilon_n)^2}$

For a rate constant R with $U_n^2(2)=Sin^2K_nz$ dependence we have

$$\frac{R}{R_S}=I_n\left(\frac{2\gamma_{ab}}{\gamma}\right)\frac{\gamma^2}{\gamma^2+(\omega-\upsilon_n)^2}$$

Where $I_n=\frac{1}{2}\frac{\wp^2E_n^2}{\hbar^2\gamma_a\gamma_b}$ is the so called dimensionless intensity, $K_n=2\pi/\lambda$

For central tuning $\omega-\upsilon_n=0$, and using $\gamma=2\gamma_{ab}$ eqn. (1) becomes

$$\rho_{aa}-\rho_{bb}=\frac{N(z,t)}{1+I_nSin^2K_nz}$$

The normalized population difference versus axial coordinate Z is shown in Fig.1. In this figure spatial hole firmed by the laser field for various values of dimensionless intensity I_n are depicted.

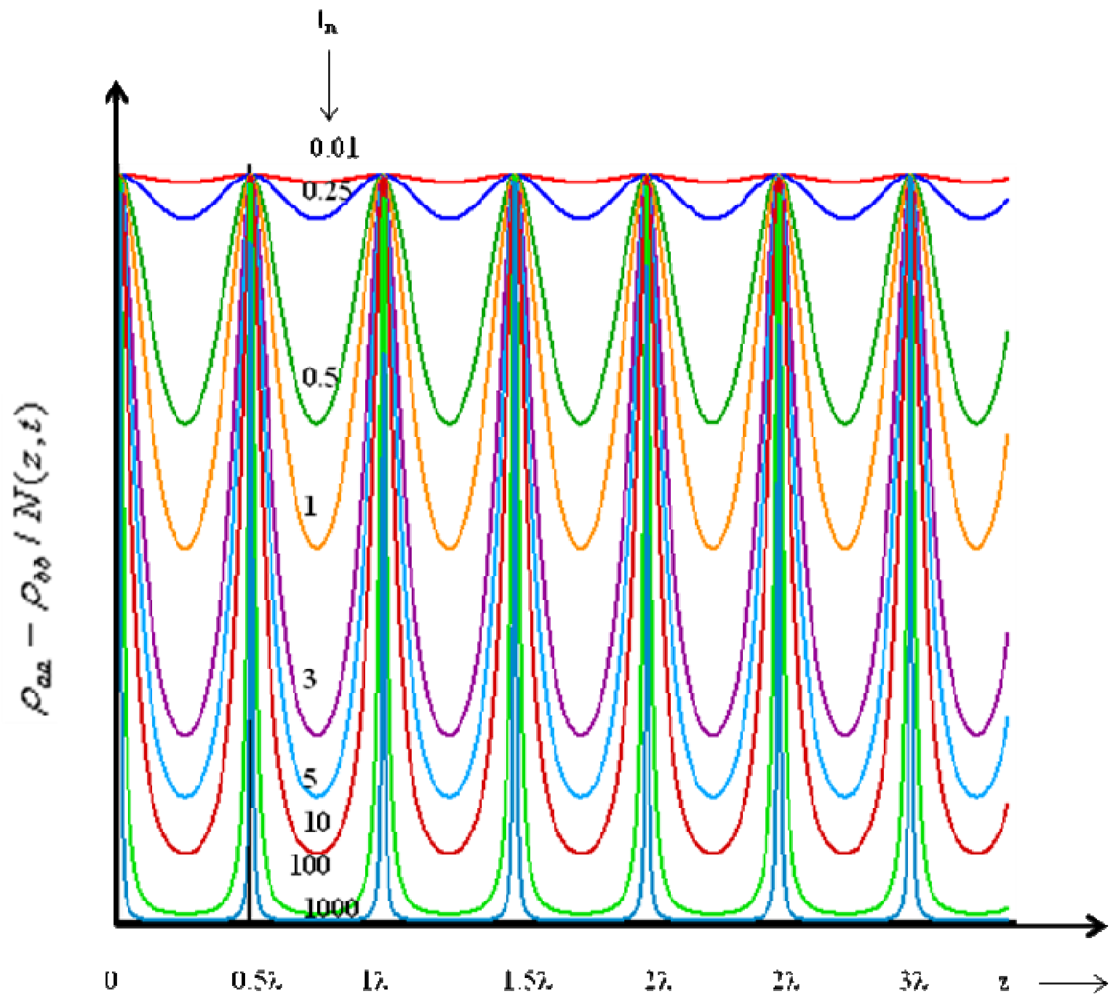

Fig. 1 : Normalized population difference vs axial co-ordinate.

3. Intensity Contour of Fringes Due to Multiple Reflections :

We consider the intensity contour of fringes due to multiple reflections inside a Fabry-Perot cavity. In this case the intensity of the transmitted rays may be worked out as

$$I_T = \frac{I_o}{1+\left[4r^2/(1-r^2)^2\right]Sin^2\,\delta/2} \qquad \text{.........} \ (3)$$

Where $\delta = 2\pi m$; At maxima $Sin^2\frac{\delta}{2} = 0$, $I_T = I_o$. When the reflectance r^2 is large, approaching unity, the quantity $4r^2/(1-r^2)^2$ will also be large and even a small departure of δ from its values for maximum will result in a rapid drop of intensity. Fig.2 shows the intensity contour of fringes due to multiple reflections indicating exact analogy with the case of decrease in the magnitude of the normalized population difference with the increase kin dimensionless intensity. The case of decrease in the magnitude of the normalized population density with the increase in dimensionless intensity has its parallel in the intensity contour of fringes due to multiple reflections where it is shown that the sharpness of fringes or transmitted beam depends on reflectance.

Comparing eqn. (2) and (3) we note that

$$\rho_{aa} - \rho_{bb} \equiv I_T, I \equiv \frac{4r^2}{\left(1-r^2\right)^2}, N(z,t) \equiv I$$

$$2\pi z/\lambda \equiv \delta \equiv 2\pi m$$

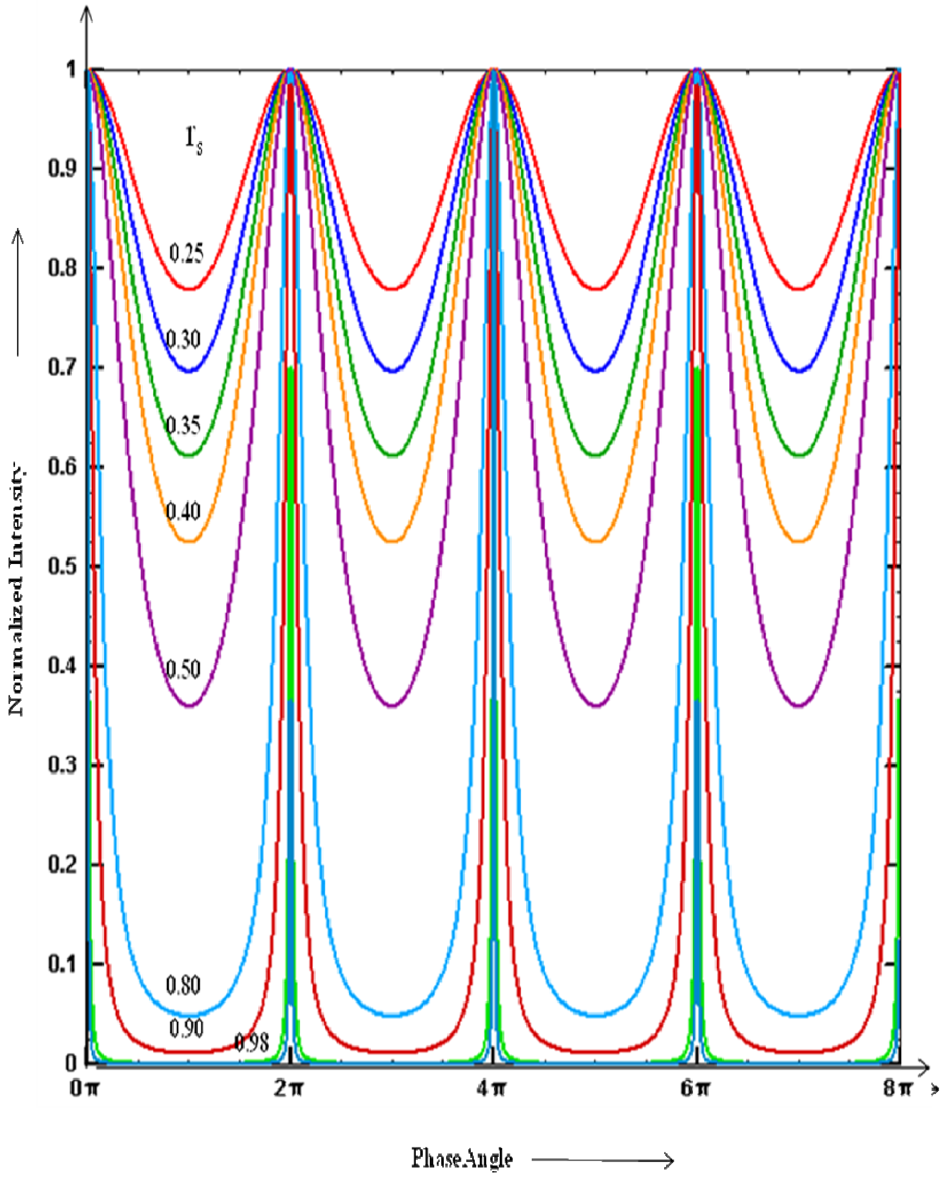

Fig. 2 : Intensity contour of Fringes due to multiple reflections

4. Squeezed States of Light :

We now consider a unique state of light known as squeezed states which have less uncertainty in one quadrature than a coherent state. The electric state for a nearly monochromatic plane wave may be decomposed into two quadrature components with time dependence Cos ωt and Sin ωt respectively. In a coherent state, the closest counterpart of a classical field, the fluctuations in the two quadratures are equal and minimize the uncertainty product given by Heisenberg's uncertainty relation. The quantum fluctuations in a coherent state are equal to the zero-point fluctuations and are randomly distributed in phase. These zero-point fluctuations represent the standard quantum limit to the reduction of noise in a signal. Even an ideal laser operating in a pure coherent state would still possess quantum noise due to zero-point fluctuations. Other minimum uncertainty states are possible which have less fluctuation in one quadrature than the coherent state at the expense of increased fluctuations in the other quadrature phase. Such states, which have been called squeezed states, no longer have their quantum noise randomly distributed in phase.

For the purpose of analogy we consider the specific case of the variance of the generalized quadrature [5]

$$\bar{X}(\theta) = \exp(-i\theta)\bar{a} + \exp(i\theta)\bar{a}^{+}$$

The quadrature would be measured at rotation angle θ. The variance is given by

$$Var\{\bar{X}(\theta)\} + Cosh(2r_S) - Sinh(2r_S)Cos2(\theta - \theta_S)$$

This is quite complex expression. It shows that the variance is a periodic function of the rotation angle as one would expect from the concept of an ellipse being rotation. If has a minimum when $\theta = -\theta_S$ and a maximum in the orthogonal direction $\theta = -\theta_S + \frac{\pi}{2}$. This variance is plotted in Fig. 3 for one fixed squeezing angle $\theta_S = -\frac{\pi}{3}$, and angle of squeezing parameters $\pi_S = 0.25,\ 0.5,\ 0.75$ and 1. It can be seen that as the squeeze variance decreases and maximum variance increases

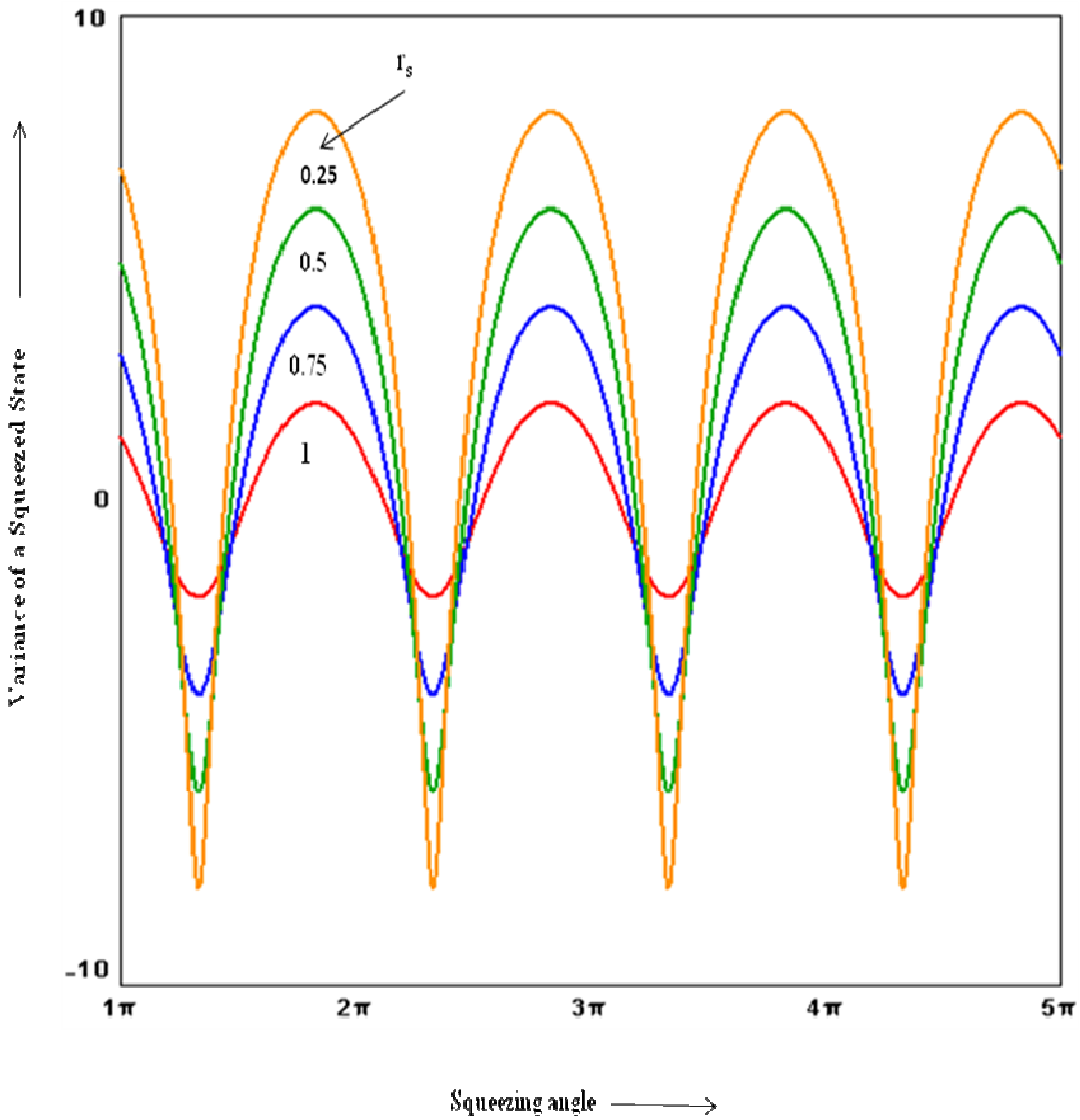

Fig. 3 : A plot on logarithmic scale (dB) above quantum noise limit of the variance of a squeezed state with $\theta_2 = -\pi/3$ as a function of the squeezing angle and different squeezing parameters.

In this work we have attempted to provide an analogy in three domains of physics, that is, classical, semi classical and quantum theoretical. It is worthwhile to note here that squeezed states represent a class of quantum states which have no classical analogy.

CONCLUSION

In the present work we have worked out an analogy comprising three phenomena in different domains of light. These phenomena include the intensity contour of fringes due to multiple reflection, spatial hole burning in semi classical theory of laser and squeezed state of light. It is believe that these may be correlations among these phenomena.

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