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Feedback method of the noise suppression in wave-mixing amplifiers based on non-linear materials with photorefractive response in a reflection grating configuration

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ABSTRACT

In the photorefractive wave-mixing system, fluctuation in the signal beam intensity of the photorefractive output with a reflection grating has been analyzed by employing pump feedback method. In this method, fluctuations of the photorefractive wave-mixing process not only induce the intensity fluctuation of the mixing waves but also induce phase fluctuation of the mixing waves. Thus, the phase of the pump and signal beams at the output surface fluctuates in time around a mean value. Using such a positive feedback method of a pump beams, the relative fluctuation in the photorefractive output signal beam intensity with respect to its mean intensity can be minimized significantly without reducing its mean intensity. The factors that control the fluctuation in the signal beam intensity, such as the phase fluctuation of the output pump beam, absorption strength of the material and the feedback reflectivity of the cavity mirrors, on the relative fluctuation of the output signal intensity in the photorefractive wave-mixing systems have been studied in detail. It has been found that the fluctuation of the output signal intensity relative to its mean intensity in the photorefractive wave-mixing system can be suppressed to larger extent by taking lower value of feedback reflectivity of the cavity mirrors which could exist at a higher value of absorption strength of the photorefractive materials.

1. Introduction

Mixing of two coherent light beams in a photorefractive medium for amplifying the weak signal beam has received considerable attention over the last four decade. Photorefractive wave-mixing is one of the fields of non-linear optics that show promise for useful applications. Forward diffusion driven two-beam coupling, leading to energy exchange between a pump and a signal beam, is perhaps the most basic application of the photorefractive effect. It is used for a number of devices such as optical amplifiers [1], self-aligning beam combiners [2], associative memories [3], novelty filters [4], optical interconnects [5], and ring resonators [6]. The two-beam coupling process is commonly described by coupled wave theory [7], using the band transport model to describe build-up of the refractive index grating [8]. Far the largest part of the research on beam coupling is undertaken in the steady state regime where analytical solutions are readily available [7].

As we know that in non-linear optical wave-mixing systems, the output by use of the photorefractive effect, such as in two waves mixing and four-wave mixing, usually shows a large fluctuation in time, which greatly degrades the applications [9–12]. There are several possible sources of fluctuation (noise) in photorefractive systems [10–18]. Randomly distributed charge particles, which arise from ionized dopants and defects, produce inhomogeneities in the refractive index that scatter light [19]. Thermally induced fluctuations in the space-charge field can produce noise through the Pockels effect, the Kerr effect, or a combination of the two, depending on the type of crystal [20–23]. Fluctuations in the pump beam are also contributed to the signal beam noise. In addition, extraneous effects, such as random mirror vibrations and thermally induced changes in the active medium, can produce random cavity detuning and loss fluctuations [20–25]. All of these noise sources must be considered in a thorough examination of signal beam quality when photorefractive materials are used in resonator-based optical processing systems [26–30]. Due to the noise-induced fluctuation of the wave-mixing process, the output signal usually shows large temporal fluctuations, particularly in photorefractive wave-mixing systems [19–34]. In order to improve the performance and application of these non-linear optical phenomena, it is desirable to have the output signal as stable as possible by suppressing this fluctuation. Several approaches have been used by the prior art to reduce the effects of relative intensity noise [12–17,35–39].

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In this paper, the relative fluctuations in the output signal beam intensity of the photorefractive wave-mixing systems with respect to its mean intensity has been analyzed in the photorefractive material by employing positive feedback method of the pump beams i.e., feedback of the output pump beam in appropriate phase with the feedback reflectivity of the cavity mirrors. This method can be applicable to any physical system where the pump beam is available at the output terminal and the total energy of the pump beam and the signal beam is conserved. The advantage of this pump feedback method over the other suppression methods [10–23,37–42] is that it can suppress the fluctuation of the output signal beam intensity efficiently without a suppression of its mean intensity. In addition, because the pump feedback method uses positive feedback, it will not induce any change of the intensity and the spatial fidelity of the output signal in photorefractive wave-mixing. Thus, improves the performance and applications of non-linear optical phenomenon, such as two wave-mixing systems in which two laser beams enter a non-linear medium from opposite directions [31], degenerate four-wave mixing [43,44] and stimulated Brillouin scattering [45,46] where only reflection grating is responsible for photorefractive optical wave-mixing system to have stable output i.e., without any fluctuation in the output signal beam. In the earlier published literatures the effects of various controlling parameters of the non-linear optical medium such as absorption strength of the photorefractive materials, the feedback reflectivity of the cavity mirrors and the phase fluctuation of the output pump beam on the relative fluctuation of the output signal beam intensity of the optical wave-mixing system in a photorefractive materials have not been explored in detail. In this article the above effects have been considered in detail.

2. Theoretical description

2.1. Analysis of fluctuation in the photorefractive wave-mixing systems

Consider the non-linear photorefractive wave-mixing systems with a reflection grating configuration, as shown in Fig. 1.

This scheme consist of a photorefractive crystal of thickness l is aligned along the z-axis with origin of the co-ordinate system at the center of the left crystal plane $z = 0$ and the right crystal plane is the plane $z = l$.

In this configuration, the pump beam and signal beam are taken to be propagate in $+z$ direction and in $-z$ direction, respectively. Let the intensities of the signal and pump beams be I_{s0} and I_{p0} at input surface $z = 0$; I_{sl} and I_{pl} at output surface $z = l$, respectively, in the absence of fluctuation of the wave-mixing process (i.e., the energy transfer efficiency being a constant) and I^t_{s0} and I^t_{p0} at input surface

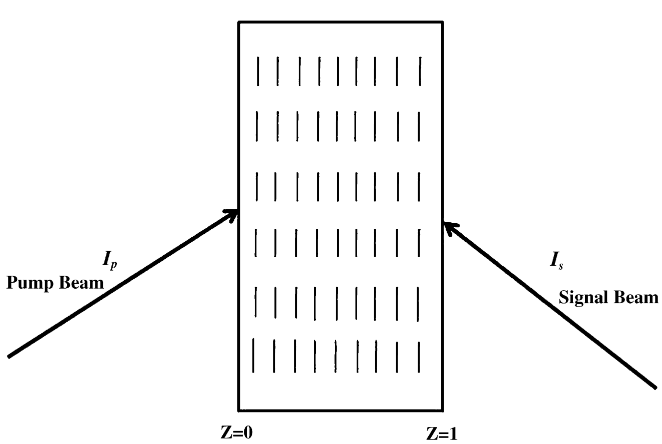

Fig. 1. Photorefractive wave-mixing system with a reflection grating.

$z = 0$ and I^t_{sl} and I^t_{pl} at output surface $z = l$, respectively, in the presence of fluctuation of the wave-mixing process (i.e., the energy transfer efficiency fluctuating in time). The energy is transmitted from the pump beam to the signal beam by the index reflecting grating. In the absence of fluctuation of the wave-mixing process the sum of the input signal and pump intensities I_{s0} and I_{p0} decays exponentially due to material absorption and scattering as,

$$I_{s0} + I_{pl} \approx (I_{p0} + I_{sl})e^{-\alpha l} \tag{1}$$

This means that the total output intensity of the signal and the pump beams is approximately equal to their total input intensity multiplied by a linear absorption factor. Where α is the absorption coefficient and it includes the effect of the absorption and scattering both. This is similar to the case with a transmission grating in which the total output intensity of the signal and the pump beams is equal to their total input intensity multiplied by a linear absorption factor [15,18,24,28]. Therefore, the pump feedback method for the case with a transmission grating as [15,18,24,28] can be applicable to the case with a reflection grating.

Let the fractional energy transfer (energy transfer efficiency) from the pump beam p to the signal beam s be η_0. For the ideal case (without fluctuation) of wave-mixing process (i.e., the energy transfer efficiency being a constant) the energy transfer efficiency η_0 is given by,

$$\eta_0 = \frac{I'_{s0}}{I_{p0}} \tag{2}$$

where, I'_{s0} is the difference of the signal beam intensities with and without wave-mixing process at input surface $z = 0$, i.e.,

$$I'_{s0} = I_{s0} - I_{sl}e^{-\alpha l} \tag{3}$$

Using the Eq. (1) the Eq. (3) becomes,

$$I'_{s0} + I_{pl} \approx I_{p0}e^{-\alpha l} \tag{4}$$

The fractional intensity transfer η which is independent of time in the absence of fluctuation ($\eta = \eta_0$), becomes time dependent in the presence of fluctuation of the wave-mixing process (i.e., the energy transfer efficiency fluctuating in time) and is given by,

$$\eta = \eta_0 + \eta_t \tag{5}$$

where η_t is fluctuating part of the fractional intensity transfer and is very small as compared to η_0. Now, the energy transfer from the pump beam to the signal beam can be written as,

$$\eta I_{p0} = I'_{s0} + \varepsilon_t \tag{6}$$

where, ε_t is fluctuating part of the transferred intensity to the output signal. The value of ε_t is negligibly small compared to the value of I'_{s0}. Eqs. (2) and (6) leads the following expression for ε_t,

$$\varepsilon_t = \eta_t I_{p0} \tag{7}$$

If we take the fluctuating pump beam intensity (I^t_{p0}) at input surface $z = 0$ as,

$$I^t_{p0} = I_{p0} - \sigma_t \tag{8}$$

To make

$$\eta I^t_{p0} = I'_{s0} \tag{9}$$

Multiplying Eq. (8) by η one obtains the following relation:

$$\eta I^t_{p0} = \eta I_{p0} - \eta\sigma_t \tag{10}$$

Using the Eqs. (6) and (9) one may write the Eq. (10) in the form,

$$\eta\sigma_t = \varepsilon_t \tag{11}$$

From Eqs. (5) and (9) one gets,

$$\eta_0\sigma_t + \eta_t\sigma_t = \varepsilon_t \tag{12}$$

As the fluctuating part of the fractional intensity transfer (η_t) is very small as compared to the value of η_0 (i.e., $\eta_t \ll \eta_0$), the second term on the LHS of the Eq. (12) can be neglected and therefore, Eq. (12) can be written as,

$$\eta_0 \sigma_t = \varepsilon_t \tag{13}$$

Substituting the value of η_0 from Eq. (2) into the Eq. (13) leads to the following expression for σ_t,

$$\sigma_t \approx \frac{I_{p0}}{I'_{s0}} \varepsilon_t \tag{14}$$

Eq. (14) represents the optical signal beam intensity without fluctuation. Now, the fluctuating analogue of Eq. (1) can be obtained by replacing I_{pl} by I^t_{pl} in Eq. (1) and using Eqs. (3) and (8) as,

$$I'_{s0} + I^t_{pl} \approx I_{p0} e^{-\alpha l} - \sigma_t e^{-\alpha l} \tag{15}$$

Using Eqs. (4) and (15) the fluctuating pump beam intensity (I^t_{pl}) at output surface $z = l$ can be written as,

$$I^t_{pl} \approx I_{pl} - \sigma_t e^{-\alpha l} \tag{16}$$

In order to achieve condition required by Eq. (8), a fraction of the output pump beam amplitude (a^t_{pl}) can be fed back to the input pump beam amplitude (a_{p0}). If we assume that the intensity reflectivity of all the feedback mirrors is R, the fluctuating pump wave amplitude (a^t_{p0}) at the input surface $z = 0$ of the non-linear materials is given by,

$$a^t_{p0} = a_{\text{in}} + \sqrt{R}\, e^{j\delta} a^{t-\Delta t}_{pl} \tag{17}$$

where a_{in} is the input pump beam amplitude and δ is a phase introduced by the feedback cavity, Δt is the time taken by the light to propagate from the mirror at output surface $z = l$ to the mirror at input surface $z = 0$.

2.2. Effect of phase coupling of the mixing waves on the fluctuation of the signal beam intensity in the photorefractive materials

2.2.1. In the absence of phase coupling between the mixing waves

In this section we will discuss the case when the phase of the mixing waves is not influenced by the wave-mixing process, such as in photorefractive wave mixing with a real coupling coefficient (i.e., no applied electric field exists in the photorefractive medium with a diffusion of charge carriers) [15,18,24,28,37]. For this case the fluctuation of the wave-mixing process induces only the fluctuation of the intensity of the mixing waves, while the phase of the mixing waves remains constant in time. For constructive interference to take place between the input pump wave and the feedback fraction of the output pump beam δ must be an integral multiple of 2π. Assuming Δt to be negligibly small ($\Delta t \to 0$) compared to the response time of the non-linear medium the Eq. (17) assumes the form,

$$a^t_{p0} \approx a_{\text{in}} + \sqrt{R}(a^t_{pl}) e^{j(2n\pi)} \tag{18}$$

where $j = \sqrt{-1}$ and $n = 0, 1, 2, 3, \ldots$. Since $a^t_{pl} = \sqrt{I^t_{pl}}$, Eqs. (18) and (16) give us,

$$a^t_{p0} = a_{\text{in}} + \sqrt{R}\left(\sqrt{I_{pl} - \sigma_t e^{-\alpha l}}\right) e^{j(2n\pi)} \tag{19}$$

For sake of simplicity, we assume input pump amplitude a_{in} to be real and positive. From Eq. (19) one obtains the expression for the input pump beam intensity (I^t_{p0}) as,

$$(a^t_{p0})^2 = a^2_{\text{in}} + R(I_{pl} - \sigma_t e^{-\alpha l}) + 2a_{\text{in}}\sqrt{R}(\sqrt{I_{pl} - \sigma_t e^{-\alpha l}})$$

$$\text{or} \quad I^t_{p0} = \left(a_{\text{in}} + \sqrt{R}\sqrt{I_{pl}}\right)^2 - 2a_{\text{in}}\sqrt{R}\left(\sqrt{I_{pl}} - \sqrt{I_{pl} - \sigma_t e^{-\alpha l}}\right) - R\sigma_t e^{-\alpha l} \tag{20}$$

Taking

$$I_{p0} = (a_{\text{in}} + \sqrt{R}\sqrt{I_{pl}})^2 \tag{21}$$

Using Eqs. (8) and (20) the fluctuating input pump beam intensity (I^t_{p0}) can be written as,

$$I^t_{p0} = (a_{\text{in}} + \sqrt{R}\sqrt{I_{pl}})^2 - \sigma_t \tag{22}$$

Comparing Eqs. (20) and (22) give us,

$$(1 - \text{Re}^{-\alpha l})\sigma_t = 2a_{\text{in}}\sqrt{R}\left(\sqrt{I_{pl}} - \sqrt{I_{pl} - \sigma_t e^{-\alpha l}}\right) \tag{23}$$

From Eq. (21) one gets the expression for the input pump amplitude (a_{in}) as,

$$a_{\text{in}} = \sqrt{I_{p0}} - \sqrt{R}\sqrt{I_{pl}} \tag{24}$$

Substituting the value of a_{in} from Eq. (24) into the Eq. (23) yields the following relation,

$$(1 - \text{Re}^{-\alpha l})\sigma_t = 2\sqrt{I_{pl}}\left(\sqrt{R}\sqrt{I_{p0}} - R\sqrt{I_{pl}}\right)\left(1 - \sqrt{1 - e^{-\alpha l}\left(\frac{\sigma_t}{I_{pl}}\right)}\right) \tag{25}$$

Expanding the second term of the second bracket of the RHS of Eq. (25) and keeping terms up to the first order only, one gets,

$$R = \frac{I_{pl}}{I_{p0}} e^{2\alpha l} \tag{26}$$

Eq. (14) can be written as,

$$I_{p0} \approx \frac{\sigma_t I'_{s0}}{\varepsilon_t} \tag{27}$$

Substituting the value of I_{p0} from Eq. (27) into the Eq. (26) yielding the relation,

$$R = \frac{I_{pl}\varepsilon_t}{\sigma_t I'_{s0}} e^{2\alpha l} \tag{28}$$

From Eq. (28) it can be seen that the feedback reflectivity (R) of the cavity mirrors is depends on the optical signal beam intensity (σ_t) without fluctuation. If we take R as Eq. (26), we can suppress the fluctuation of the output signal intensity greatly, the output signals intensity fluctuation with an order of magnitude less than that without the feedback [15,28]. For a feedback reflectivity smaller than that given in the Eq. (26), the feedback pump intensity is not large enough to compensate for the fluctuation of the signal, but it can still reduce the fluctuation of the signal [15,24,28]. Now, we analyze the reduction efficiency by using this method (taking feedback reflectivity as Eq. (26)). For this purpose, substituting Eq. (26) into Eq. (20) making use of Eq. (21), keeping terms up to the second order of $\frac{\sigma_t e^{-\alpha l}}{I_{pl}}$ one gets the pump wave intensity (I^t_{p0}) at the input surface $z = 0$ of the non-linear media as,

$$I^t_{p0} = I_{p0} - \sigma_t - \frac{1}{4}\frac{I_{s0}}{I_{pl}I_{p0}}\sigma_t^2 \tag{29}$$

Using the relation $\eta = \frac{I'^t_{s0}}{I^t_{p0}}$ and Eq. (29) one obtains the expression for the fluctuating output signal intensity (I'^t_{s0}) as,

$$I'^t_{s0} = \eta \cdot I^t_{p0} = \eta\left(I_{p0} - \sigma_t - \frac{1}{4}\frac{I_{s0}}{I_{pl}I_{p0}}\sigma_t^2\right) \tag{30}$$

From Eqs. (5)–(9), Eq. (30) yields,

$$I'^t_{s0} = I'_{s0} - \eta_t\sigma_t - \frac{(I'^t_s + \varepsilon_t)I'_{s0}}{4I_{pl}I^2_{p0}}\sigma_t^2 \tag{31}$$

Neglecting the third order term into Eq. (31) one gets the fluctuating output signal beam intensity (I'^t_{s0}) as,

$$I'^t_{s0} = I'_{s0} - \left(\frac{1}{I'_{s0}} + \frac{1}{4I_{pl}}\right)\varepsilon_t^2 \quad (32)$$

Comparing Eqs. (6) and (32) it one can be seen that the fluctuation is reduced from ε_t (without feedback) to $(\frac{1}{I'_{s0}} + \frac{1}{4I_{pl}})\varepsilon_t^2$ (with feedback). In other words, with feedback the output signal intensity fluctuates an order of magnitude less that without feedback [15,28].

2.2.2. In the presence of phase coupling between the mixing waves

In this section we will discuss the case when the phase of the mixing waves is influenced by the wave-mixing process, such as in photorefractive wave mixing with a complex coupling coefficient [15,18,24,28,37]. For this case fluctuations of the wave-mixing process not only induce the intensity fluctuation of the mixing waves but also induce phase fluctuation of the mixing waves. Thus, the phase of the pump and signal beams at the output surface fluctuates in time around a mean value. Now, adjusting the cavity phase δ to create the mean phase of $e^{j\delta}a^t_{pl}$ and that of a_{in} in phase. The feedback reflectivity is still taken as, $R = \frac{I_{pl}}{I_{p0}}e^{2\alpha l}$. Assuming Δt to be negligibly small ($\Delta t \to 0$) compared to the response time of the non-linear medium. Using Eq. (16) the Eq. (17) becomes,

$$a^t_{p0} = a_{\text{in}} + \sqrt{R}(\sqrt{I_{pl} - \sigma_t e^{-\alpha l}})e^{j(2n\pi+\phi_t)} \quad (n = 0, 1\ldots) \quad (33)$$

where ϕ_t is the small fluctuating phase of a^t_{pl} relative to its mean phase. The input pump amplitude (a_{in}) is taken as,

$$a_{\text{in}} = \sqrt{I_{p0}} - \sqrt{R}\sqrt{I_{pl}}e^{j(2n\pi+\phi_t)} \quad (34)$$

Here as before, a_{in} is assumed to be real and positive. Keeping terms up to the second order of $\frac{\sigma_t e^{-\alpha l}}{I_{pl}}$ one obtains the expression for the fluctuating output signal intensity (I'^t_{s0}) as,

$$I'^t_{s0} \approx I'_{s0}\left\{1 - 4\frac{I_{pl}}{I_{p0}}e^{\alpha l}\left[1 - \frac{I_{pl}}{I_{p0}}e^{\alpha l}\right]\left(\sin^2\frac{\phi_t}{2}\right)\right\} + 2\left[1 - \frac{I_{pl}}{I_{p0}}e^{\alpha l}\right]\left[1 - 2\frac{I_{pl}}{I_{p0}}e^{\alpha l}\right]\sin^2\frac{\phi_t}{2}\varepsilon_t \quad (35)$$

or

$$I'^t_{s0} \approx I'_{s0}\left\{1 - \frac{I_{pl}}{I_{p0}}e^{\alpha l}\left[1 - \frac{I_{pl}}{I_{p0}}e^{\alpha l}\right]\phi_t^2\right\} + \left[1 - \frac{I_{pl}}{I_{p0}}e^{\alpha l}\right]\left[1 - 2\frac{I_{pl}}{I_{p0}}e^{\alpha l}\right]\frac{\phi_t 2}{2}\varepsilon_t \quad (36)$$

From Eq. (36) it can be can be seen that the fluctuation in the output signal beam intensity (I'^t_{s0}) is mainly depends on the term

$$\frac{I_{pl}}{I_{p0}}e^{\alpha l}\left(1 - \frac{I_{pl}}{I_{p0}}e^{\alpha l}\right)\phi_t^2 \quad (37)$$

Now, in order to provide an explicit discussion of the solution in approximation (Eq. (36)), we define two functions as,

$$U(x) = x(1 - x) \quad (38)$$
$$V(x) = (1 - x)(1 - 2x) \quad (39)$$

where $0 < x = \frac{I_{pl}}{I_{p0}}e^{\alpha l} < 1$. Then Eq. (33) can be written as,

$$I'^t_{s0} \approx I'_{s0}(1 - U(x)\phi_t^2) + V(x)\frac{\phi_t^2}{2}\varepsilon_t \quad (40)$$

It can be seen from Eq. (38) that $U(x)$ has a maximum value of 0.25 at $x = 0.50$ which is understandable. Only when external input pump amplitude (a_{in}) has the same amplitude as the feedback pump amplitude has total intensity I_{p0} of the two interfering beams with a given phase difference ϕ_t, is the maximum deviation from the two beams totally in phase. Therefore, $V(x) = 0$ at $x = 0.50$, $V(x) < 1$ when $0 < x < 0.50$ and $V(x) \leqslant 0.125$ when $0.50 \leqslant x < 1$. From approximation (Eq. (40)), it can be seen that for a small fluctuation ϕ_t, the fluctuation of the output signal intensity is very small. Therefore, the relative fluctuation of the output signal intensity in the optical photorefractive wave-mixing system is given by relation as,

$$\frac{\Delta I'^t_{s0}}{\Delta I_{s0}} = U(x)\frac{\phi_t^2}{2} \quad (41)$$

From Eqs. (26) and (41) one gets,

$$\frac{\Delta I'^t_{s0}}{\Delta I_{s0}} = Re^{-\alpha l}(1 - Re^{-\alpha l})\frac{\phi_t^2}{2} \quad (42)$$

Eq. (42) represents the fluctuation in the intensity of the output signal beam relative to its mean intensity in the non-linear photorefractive wave-mixing medium in terms of feedback reflectivity (R) of the cavity mirrors.

3. Results and discussion

The relative fluctuation in the intensity of the output signal beam ($\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}$) depends on the phase fluctuation in the output pump beam (ϕ_t), absorption strength (αl) of the photorefractive material and feedback reflectivity R $\left(= \frac{I_{pl}}{I_{p0}}e^{2\alpha l}\right)$ of the cavity mirrors (Eq. (42)). The variations of relative fluctuation of the output signal intensity ($\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}$) with absorption strength αl for different values of ϕ_t (fixed $R = 50\%$) and R (fixed $\phi_t = 5^0$) are shown in Figs. 2a and b, respectively. It is obvious (Figs. 2a) that for fixed value $R = 50\%$ the fluctuation in the intensity of the output signal beam relative to its mean intensity decreases exponentially with increasing the value of absorption strength (αl) which arises due to the absorption and scattering of the light beam. However, it can be seen that for a given value of αl the relative fluctuation of the output signal beam intensity is quite small for a very small fluctuation in the phase of the pump beam at the output surface of the optical wave-mixing system. This means that the relative fluctuation in the intensity of the output signal beam of the non-linear photorefractive crystal with respect to its mean intensity can be suppressed to larger extent by decreasing the fluctuation in the phase of the output pump beam to the lowest order. From Fig. 1b it is obvious that the relative fluctuation of the output signal beam intensity $\left(\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}\right)$ increases with increasing the value of αl initially, reaches a maximum value at a certain value of absorption strength (αl) and decreases exponentially afterwards. As R increases, the peak height of the relative fluctuation of the output signal beam intensity with same height shifted towards the higher value of αl.

From Fig. 1b one may conclude that the fluctuation in the intensity of the output signal beam at the output surface of the optical wave-mixing system can be reduced greatly to quite low level by taking lower value of feedback reflectivity of the cavity mirrors which could exist at a higher value of absorption strength. This greatly improves the performance and application of the optical wave-mixing system such as stimulated Brillouin scattering [45,46], degenerate two-wave mixing [31] and degenerate optical four-wave mixing [43,44].

Fig. 3a and b, respectively show the variation of relative fluctuation of the output signal beam intensity $\left(\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}\right)$ with phase fluctuation of the output pump beam (ϕ_t) for different values of αl (fixed $R = 50\%$) and R (fixed $\alpha l = 1$). From Fig. 3a it is clear that for a given value of αl, the fluctuation in intensity of the output signal beam

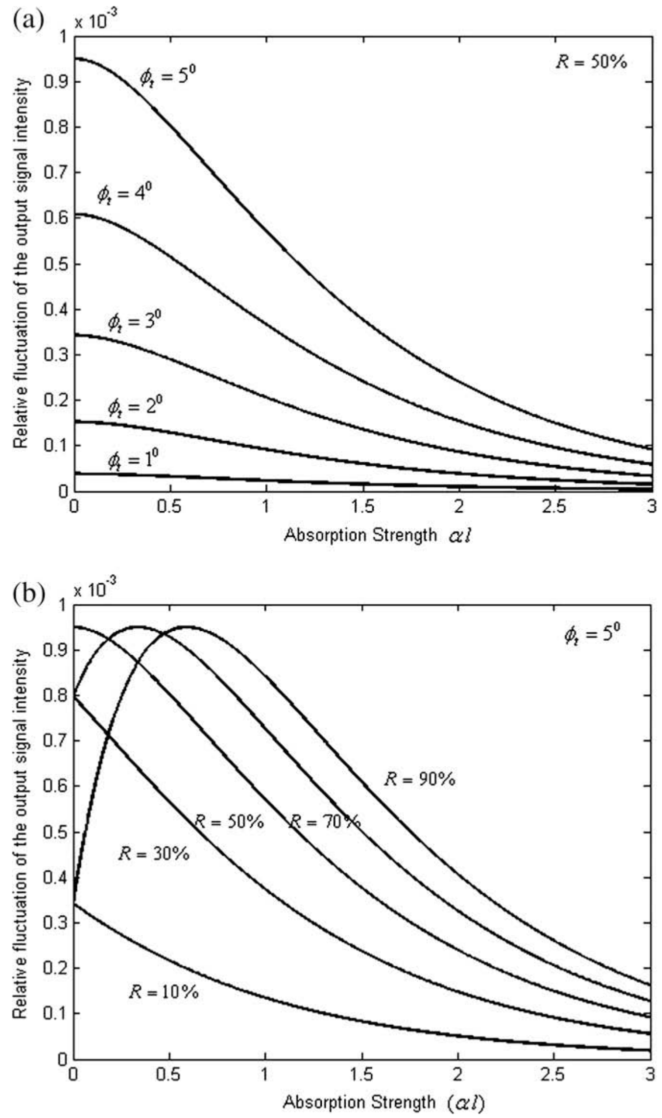

Fig. 2. Relative fluctuation of the output signal beam intensity '$\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}$' with the absorption strength 'αl' for different values of (a) ϕ_t (fixed R = 50%) and (b) R (fixed $\phi_t = 5^0$).

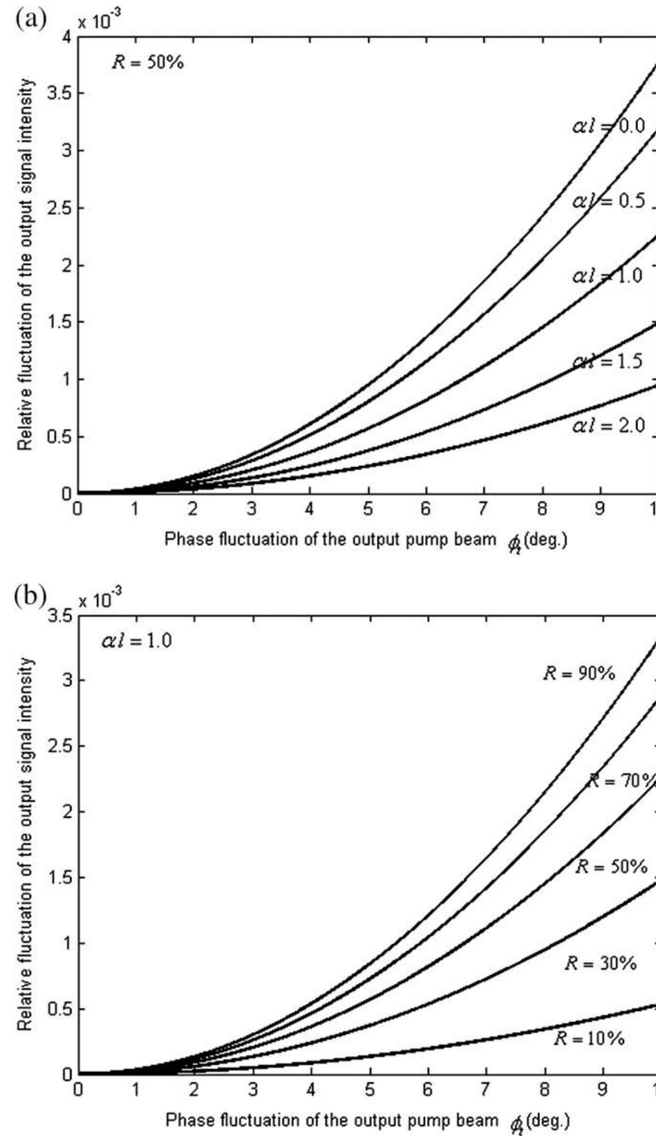

Fig. 3. Relative fluctuation of the output signal beam intensity '$\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}$' with the phase fluctuation of the output pump beam 'ϕ_t' for different values of (a) αl (fixed R = 50%) and (b) R (fixed αl = 1.0).

relative to its mean intensity increases with increasing value of ϕ_t. However, for a given value of ϕ_t, the relative fluctuation in the intensity of the output signal beam of the optical wave-mixing system can be reduced to the minimum level by increasing the value of absorption strength of the photorefractive materials. Similar variations of $\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}$ with R can be seen from Fig. 3b. In this case also, as the feedback reflectivity (R) of the cavity mirrors decreases, the fluctuation in the intensity of the output signal beam decreases from ~0.00335 for R = 90% to ~0.00055 for R = 10%. This means that the fluctuation in the intensity of the output signal beam relative to its mean intensity can be greatly suppressed by decreasing the value of feedback reflectivity (R < 10%) of the cavity mirrors in the optical wave-mixing system. On the basis of above results one may conclude that in the optical wave-mixing system, the relative fluctuation in the output signal beam intensity of the photorefractive crystal can be greatly suppressed by implementing the lowest value of feedback reflectivity (R < 10%) of the cavity mirrors and higher value of absorption strength (α > 2.0) of the photorefractive material.

Fig. 4a and b, respectively depict the variations of relative fluctuation in the intensity of the output signal beam $\left(\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}\right)$ with R for different values of αl (fixed $\phi_t = 5^0$) and ϕ_t (fixed αl = 1). It can be seen (Fig. 4a) that for fixed $\phi_t = 5^0$, the relative fluctuation of the output signal beam intensity $\left(\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}\right)$ increases parabolically with increasing the value of R initially, reaches a maximum value at a certain value of feedback reflectivity (R) and decreases afterwards. However, the relative fluctuation in the output signal beam intensity of the optical wave-mixing system with respect to its mean intensity can be reduced significantly by increasing the absorption strength of the photorefractive material. Similar variations of $\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}$ verses R for different values of ϕ_t can be seen from Fig. 4b. It is evident from Fig. 4b that the relative fluctuation of the output signal beam intensity $\left(\frac{\Delta I'^t_{s0}}{\Delta I_{s0}}\right)$ increases with increasing the value of the feedback reflectivity and the fluctuation in the intensity of the output signal beam is minimum for a very small phase fluctuation in the output pump beam. From the above Fig. 4a and b, one may conclude that for a given value of R, the relative fluctuation of the output signal beam intensity in the optical wave-mixing system is found to be lowest for a very small phase fluctuation of the output

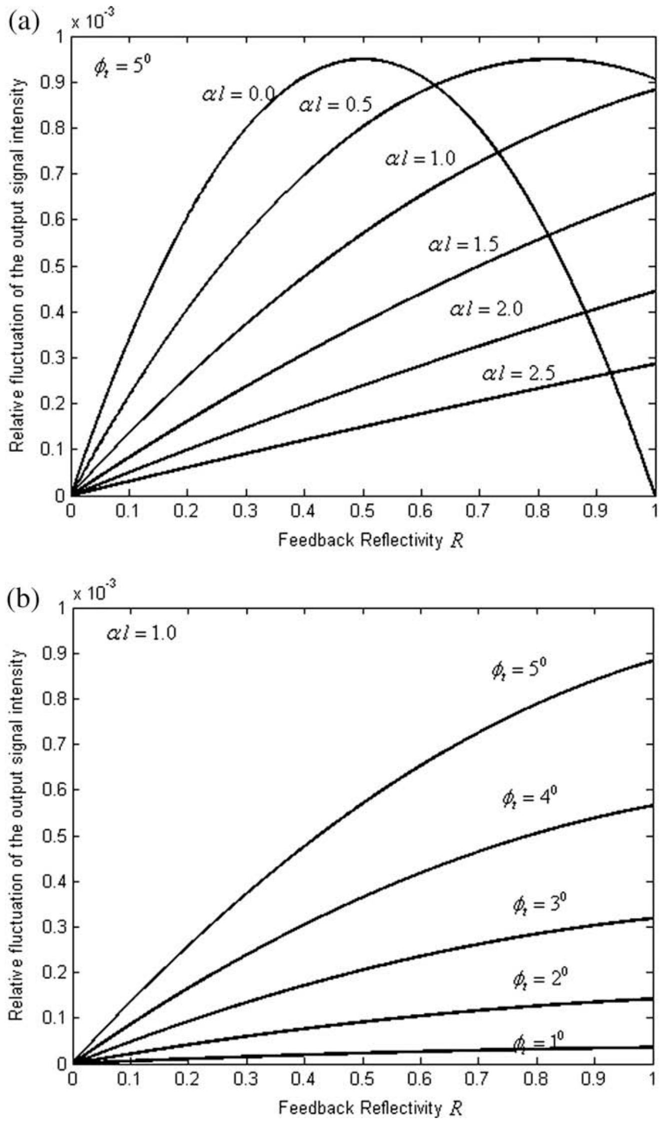

Fig. 4. Relative fluctuation of the output signal beam intensity '$\frac{\Delta I'^{t}_{s0}}{\Delta I_{s0}}$' with the feedback reflectivity 'R' of the cavity mirrors for different values of (a) αl (fixed $\phi_t = 5^0$) and (b) ϕ_t (fixed $\alpha l = 1.0$).

pump beam ($\phi_t < 1^0$). This means that the temporal fluctuation of the output signal beam intensity relative to its mean intensity can be reduced appreciably at the optimum value of feedback reflectivity which greatly improves the performance and application of the non-linear optical wave-mixing systems.

5. Conclusion

Fluctuation in the intensity of the output signal beam of the photorefractive output with a reflection grating has been analyzed in a non-linear photorefractive wave-mixing medium by employing positive feedback method of the pump beams. The advantage of this pump beam feedback method [15] is its simplicity and the fact that the intensity of the output signal beam is not reduced due to the positively feedback. In addition, because the pump feedback method uses positive feedback, small input pump intensity is needed as compared to that without feedback. Thus, improves the performance and applications of non-linear optical phenomenon, such as two-wave-mixing systems in which two laser beams enter a non-linear medium from opposite directions [31], degenerate four-wave mixing [43,44] and stimulated Brillouin scattering [45,46] where only reflection grating is responsible for photorefractive optical wave-mixing system to have stable output i.e., without any fluctuation in the output signal beam. The curves $\frac{\Delta I'^{t}_{s0}}{\Delta I_{s0}}$ versus αl for the different values of ϕ_t suggest that for a given value of αl, the relative fluctuation of the output signal beam intensity is quite small for a very small fluctuation in the phase of the pump beam at the output surface of the optical wave-mixing system. This means that the relative fluctuation in the intensity of the output signal beam of the non-linear photorefractive crystal with respect to its mean intensity can be suppressed to larger extent by decreasing the fluctuation in the phase of the output pump beam to the lowest order. It is also found that the maximum in the dependence of the intensity fluctuation $\left(\frac{\Delta I'^{t}_{s0}}{\Delta I_{s0}}\right)$ versus absorption strength (αl) is valid only for $R > 50\%$. From Figs. 2b and 4a, it can be seen that the fluctuation of the output signal intensity relative to its mean intensity in the optical wave-mixing system can be reduced greatly to quite low level by taking lower value of feedback reflectivity of the cavity mirrors which could exist at a higher value of absorption strength. However, for a given value of ϕ_t, the relative fluctuation in the intensity of the output signal beam of the optical wave-mixing system can be reduced to the minimum level by increasing the value of absorption strength of the photorefractive materials. The disadvantage of this pump feedback method is that it can not reduce the fluctuation of the signal phase.

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