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PHASE EFFECTS AT PARAMETRIC INTERACTION IN INTENSE LIGHT FIELDS IN NONCENTROSYMMETRICAL MEDIA

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The theory of parametric amplification in the intense laser fields in noncentrosymmetrical media in the presence of both quadratic and cubic polarization in the constant-intensity approximation has been developed. This approximation takes into account the reverse effect of an excited wave on exciting one and at the same time permits to take into account the phase mismatch and damping of all the interacting waves. It is shown that the changes of pump intensity through effects of self-phase and cross-phase influence upon optimal phase relation between interacting waves. The conditions of compensation of undesirable phase shifts between interacting waves have been determined, the analytical expressions for calculation of optimal values of linear phase mismatch, lengths of noncentrosymmetrical medium and threshold values of pump intensity are given. It is shown that with increase of pump intensity the spatial beating period increases. Besides, at growth of linear mismatch from zero there occurs an increase of spatial beating period first, and then decay comes. The numerical analysis has been made of efficiency of parametric process for KDP crystal.

Key words: parametric conversion, constant-intensity approximation, noncentrosymmetrical medium, intensintense fields

Parametric amplifiers and generators of light provide discovery and amplification of weak optical signals. They are powerful devices for generation of wave length tuneable of ultrashort pulses of high peak power in a wide range. Presently, realization of this task in IR and visible ranges is absolutely actual [1, 2]. Therefore the investigations of parametric process accompanied by the interaction of intense laser fields present an interest. In recent years the methods of generation and formation of light pulses of intensities in the range of 10^{18}–10^{20} W/cm^2 have been elaborated what permits to have a fresh look at the processes of interaction of laser radiation with a substance. In particular, at spreading light waves in noncentrosymmetrical medium at comparatively high values of pump radiation field, (beginning from the values $10^9 - 10^{11}$ W/cm^2) effects connected with cubic nonlinearity $\chi^{(3)}$

become essential. Some authors experimentally observed an effect of cubic nonlinearity on three frequency optical processes in noncentrosymmetrical media [3, 4].

The principle of action of parametric transformers is based on the regulated splitting pump frequency. With this, the condition of synchronism being followed, pump wave energy transfers to two weak light waves which intensify in nonlinear medium. The basic requirement for the efficient conversion of pump frequency is fulfilment of an optimal phase relation between waves interacting in nonlinear medium. The intensity of converted radiation reaches maximum at coherent length of nonlinear interaction. Therefore, for the purpose of increasing the efficiency of frequency conversion, it is necessary to increase a coherent length. It is carried out by compensation of undesirable phase shifts of interacting waves generated at parametric interaction.

As it is known, the parametric processes are of threshold nature determined by losses in a transformer. For this reason, it is expedient to proceed such a process with account of dumping of all interacting waves in dispersing medium. In connection with the mentioned, the task of obtaining maximum conversion in nonlinear-optical converters of frequency and clearing out the causes influencing its restriction, is actual [5].

The analysis of the case of phase mismatching between interacting waves and at the same time of linear absorption existing in real optical media can be made in the constant-intensity approximation [6]. In this approximation, taking into account the reverse effect of excited wave on the exciting one there are no restrictions to phases of interacting waves.

The present work developed a theory of parametric interaction of intense pump wave with signal and idler waves in dissipative noncentrosymmetrical media in the constant-intensity approximation. The investigation was carried out at the different values of losses in media, phase mismatch, pump intensity and nonlinear medium length. The threshold conditions for parametric generation have been obtained. A comparison of the results received in the constant-intensity approximation with the results of accurate calculation has been carried out. The conditions of compensation of undesirable phase shifts between interacting waves have been determined, in general case of arbitrary noncentrosymmetrical medium there are given the analytical expressions for the calculation of optimal values of linear phase mismatch and non-linear medium length at which conversion efficiency in a medium with cubic nonlinearity is maximum.

Thus, the effect of cubic polarization of medium on the efficiency of parametric interaction of intense light waves with account for phase effects in a medium has been considered. By the choice of optimal parameters of the task it is possible to increase conversion efficiency. There has been carried out the numerical calculation of nonlinear process for crystals with diverse cubic nonlinearity, in particular for KDP crystal and comparison of the obtained results.

Let's consider parametric process with high frequency pump at frequency ω_3 ($\omega_3 = \omega_1 + \omega_2$) in a medium with quadratic and cubic polarization where $\omega_{1,2}$ are the frequencies of signal and idler waves ($\omega_1 > \omega_2$). We consider that interacting waves are spreading in a positive direction of axis z. In this case the reduced equations of nondegenerated three -frequency interaction of waves in dissipative dispersing medium look as [3]:

$$\begin{aligned}
&\frac{dA_1}{dz} + \delta_1 A_1 = -i\gamma_1 A_3 A_2^* \exp(-i\Delta z) - iA_1\left(\gamma_{11}|A_1|^2 + \gamma_{12}|A_2|^2 + \gamma_{13}|A_3|^2\right),\\
&\frac{dA_2}{dz} + \delta_2 A_2 = -i\gamma_2 A_3 A_1^* \exp(-i\Delta z) - iA_2\left(\gamma_{21}|A_1|^2 + \gamma_{22}|A_2|^2 + \gamma_{23}|A_3|^2\right), \qquad (1)\\
&\frac{dA_3}{dz} + \delta_3 A_3 = -i\gamma_3 A_1 A_2 \exp(-i\Delta z) - iA_3\left(\gamma_{31}|A_1|^2 + \gamma_{32}|A_2|^2 + \gamma_{33}|A_3|^2\right),
\end{aligned}$$

where A_1, A_2, A_3 are complex amplitudes of waves at the corresponding frequencies, $\gamma_{1,2,3}$ are nonlinear coefficients connected with quadratic nonlinearity of medium, $\delta_{1,2,3}$ are the absorption coefficients for the waves at the frequencies $\omega_{1,2,3}$ respectively, $\Delta = k_3 - k_2 - k_1$ is phase mismatch, γ_{jj}, γ_{mj} are the coefficients connected with cubic nonlinearity of the medium. The members with $\gamma_{11}, \gamma_{22}, \gamma_{33}$ are responsible for self-phase modulations, and those with $\gamma_{12}, \gamma_{21}, \gamma_{13}, \gamma_{31}, \gamma_{23}, \gamma_{32}$ for cross-phase modulations.

From (1) it is seen that in the presence of cubic nonlinearity of medium side by side with coherent interactions, there also take place noncoherent nonlinear interactions. The latter lead to nonlinear corrections to dielectric constant. The change of phase velocities of interacting waves and absorption on the account of these correction can essentially influence on the process of amplification.

We decide the task in a general case, supposing that at the entrance to nonlinear medium (z=0) there exist pump wave, signal and idler waves

$$A_1(z) = A_{10}, \quad A_2(z) = A_{20}, \quad A_3(z) = A_{30} \qquad (2)$$

Carrying out the standard procedure of solution of the system (1) in the constant-intensity approximation [6] $I_2(z) = I_2(z=0) = I_{20}$, $I_3(z) = I_3(z=0) = I_{30}$, for complex amplitude of signal wave with regard to boundary conditions (2) we obtain

$$\begin{aligned}
&A_1(z) = A_{10}\left(\cosh q_1 z - \frac{B_1 + P_1}{q_1}\sinh q_1 z\right)\exp\left(-\frac{p}{2}z\right) \qquad \text{at} \quad p^2 > 4q,\\
&A_1(z) = A_{10}\left(\cos q_2 z - \frac{B_1 + P_1}{q_2}\sin q_2 z\right)\exp\left(-\frac{p}{2}z\right) \qquad \text{at} \quad p^2 \le 4q, \qquad (3)
\end{aligned}$$

where

$$q_1^2=\left(p^2/4-q\right),\quad q_2^2=\left(q-p^2/4\right),\quad p=\delta_1+\delta_2+\delta_3+i\left[aI_{10}+bI_{20}+cI_{30}+\Delta\right],$$
$$a=\gamma_{11}+\gamma_{21}+\gamma_{31},\quad b=\gamma_{12}+\gamma_{22}+\gamma_{32},\quad c=\gamma_{13}+\gamma_{23}+\gamma_{33},$$
$$q=\Gamma_2^2-\Gamma_3^2+\left(\delta_1+id\right)\left[\delta_2+\delta_3+i\left(e+f+\Delta\right)\right],\quad \Gamma_2^2=\gamma_1\gamma_3I_{20},\quad \Gamma_3^2=\gamma_1\gamma_2I_{30},$$
$$d=\gamma_{11}I_{10}+\gamma_{12}I_{20}+\gamma_{13}I_{30},\quad e=\gamma_{21}I_{10}+\gamma_{22}I_{20}+\gamma_{23}I_{30},\quad f=\gamma_{31}I_{10}+\gamma_{32}I_{20}+\gamma_{33}I_{30},$$
$$I_j=A_jA_j^*,\quad B_1=i\gamma_1A_{30}A_{20}^*/A_{10},\quad P_1=\left[\delta_1-\delta_2-\delta_3+i\left(d-e-f-\Delta\right)\right]/2.$$

From the equation (3) it follows that the phase of intensified wave depends on the intensities of interacting waves. In case of powerful pump ($\Gamma>\delta,\ \Delta$) and long lengths of interaction ($q_1z>1$) we'll determine threshold amplitude of pump ($\delta_1=\delta_2+\delta_3$)

$$I_{30}^{thresh}=\frac{2}{g_3^2}\times$$
$$\times\left\{\gamma_1\gamma_2-\frac{\Delta+g_1I_{10}+g_2I_{20}}{2}g_3-\sqrt{(\gamma_1\gamma_2)^2-\gamma_1\gamma_2g_3(\Delta+g_1I_{10}+g_2I_{20})-(\Gamma_2^2+\delta_1^2)g_3^2}\right\} \tag{4}$$

where $g_1=\gamma_{31}+\gamma_{21}-\gamma_{11},\quad g_2=\gamma_{32}+\gamma_{22}-\gamma_{12},\quad g_3=\gamma_{33}+\gamma_{23}-\gamma_{13}$.

In case of pump intensity less than I_{30}^{thresh}, parametric increase is not possible. From expressions for I_{30}^{thresh} it follows that threshold intensity of pump increases with growth of phase mismatch and losses in the medium, it also changes due to the members cubic by field.

The presence of the member Γ_2^2 in the expression (4) reflects the fact that in the given approximation the reverse influence of the excited wave on exciting pump wave is considered ($\gamma_3\neq 0$). The more parameter of Γ_2^2, the higher is the threshold intensity of pump.

From (3) we determine the amplification of signal wave $\eta_1=I_1/I_{10}$ ($\delta_1=\delta_2+\delta_3$)

$$\eta_1=\left(\cosh^2 q_1'z+\left|B_1+P_2\right|^2\sinh^2 q_1'z/q_1'^2\right)\exp(-2\delta_1z), \tag{5}$$

where $q_1'^2=\Gamma_3^2-\Gamma_2^2-\frac{\left(\Delta+\Delta^{NL}\right)^2}{4}$, $\Delta^{NL}=g_1I_{10}+g_2I_{20}+g_3I_{30}$, $P_2=\frac{-i\left(\Delta+\Delta^{NL}\right)}{2}$.

Here Δ^{NL} is a nonlinear phase mismatch depending on intensities of interacting waves.

Phase shifts caused by nonlinear phase mismatch Δ^{NL} depend, as it is seen from its expression, on the levels of intensity I_{10}, I_{20} and I_{30} whereas the linear phase mismatch Δ does not depend on intensities of interacting waves, its value is constant along the whole length of nonlinear medium. At initial moment of parametric interaction when the amplitudes of idler and signal waves are small, their contribution to nonlinear mismatch is not great. With increase of the amplitudes of these waves the value of nonlinear mismatch grows what exerts an influence on optimum phase relation.

Thus, the changes of pump intensity through the effects of self-phase and crossphase modulations influence on optimal phase relation between interacting waves. Changing pump intensity and nonlinear medium length as well as the linear phase mismatch it is possible to compensate undesirable phase shifts of interacting waves and reach the high efficiencies of parametric conversion in the media with cubic nonlinearity.

At $\delta_3 = 0$, $\gamma_3 = 0$, $\gamma_{3j} = 0$, ($j = 1 \div 3$) from (5) the expression for the coefficient of amplification η_1 in the constant-field approximation is received.

From (5) we can determine the optimal value of the linear phase mismatch. For this, differentiating the expression for η_1 with respect to Δ and equating the received expression to zero it is necessary numerically to solve the next equation:

$$\frac{\tanh q_1' z}{q_1' z} = \frac{|B_1 + P_2|^2 + q_1'^2}{\left[|B_1 + P_2|\left(\Delta + \Delta^{NL}\right) - 2q_1'^2\right]} \frac{\left(\Delta + \Delta^{NL}\right)}{|B_1 + P_2|} . \tag{6}$$

As it is seen from the obtained equation, the value of linear mismatch at which the conversion efficiency of pump wave energy into energy of signal wave is maximum, depends on such parameters of the task as I_{30}, I_{20}, Δ^{NL} and z. The received value Δ_{opt} compensates nonlinear mismatch Δ^{NL}. Deviations from full compensation are connected with the expression $|B_1 + P_2|^2$, being before parameter $\sinh^2 q_1' z / (q_1' z)^2$ in the equation (5). The numerical analysis (5) displays that this deviation is 0.01.

Now, let’s determine the optimal value of nonlinear medium length. According to (5) z_{opt}, at which the efficiency of the process of conversion is maximum it is determined from condition $q_1' z_{opt} = \pi p / 2$, $p = 1, 2, 3, \ldots$. Hence, we have for optimal length

$$z_{opt} = \pi p / 2\sqrt{\Gamma_3^2 - \Gamma_2^2 - (\Delta + \Delta^{NL})^2 / 4} . \tag{7}$$

For the spatial beating period of signal wave intensity $(\Delta z)_{per} = z_p - z_{p-1}$ we have

$$(\Delta z)_{per} = \pi / 2\sqrt{\Gamma_3^2 - \Gamma_2^2 - (\Delta + \Delta^{NL})^2 / 4} . \tag{8}$$

As it is seen from the obtained expressions, the optimal values z_{opt} and $(\Delta z)_{per}$ depend on pump intensity on the account of the parameters Γ_3^2 and Δ^{NL}, on intensity of signal and idler waves on the account of the parameters Γ_2^2 and Δ^{NL}. With an increase in pump intensity the spatial beating period decreases as contribution of pump intensity I_{30} in Γ_3^2 is more than in Δ^{NL}

($\gamma_{1,2} \sim 10^{-4}$ esu, $\gamma_{mj}, \gamma_{jj} \sim 10^{-10}$ esu). With growth of linear mismatch from zero there first takes place an increase of spatial beating period, then decay comes.

The boundaries of applicability of the constant-intensity approximation at parametric interaction of waves in quadratic medium were determined in the work [7] what are briefly in Appendix. A similar approach was used in [6] for the case of the second harmonic generation.

From (3) and (5) it follows that in the noncentrosymmetrical media the cubic nonlinearity of the medium effects the nonlinear parametric interaction. Effects of self-phase and cross-phase modulations lead to the change of relationship, determining the conditions of the efficient transfer of pump wave energy to the energy of signal and idler waves. The analysis of the given expressions showed that due to nonlinear phase mismatch Δ^{NL}, the efficiency of conversion process is of oscillating nature. From the expression for $q_1'^2$ it is seen that a period of oscillations of dependence η_1 on parameters of the task (length, linear mismatch) depends on pump intensity (through the expression for Γ_3^2 and through parameter $g_3 I_{30}$ in the expression for Δ^{NL}) and on intensities of signal and idler waves (through the expression for Γ_2^2 and on the account of the parameters $g_1 I_{10}$, $g_2 I_{20}$ in the expression for Δ^{NL}).

Further, there are cited the results of the numerical account of the analytical expression (5) obtained in the constant-intensity approximation for the coefficient of amplification η_1 in a general case of arbitrary noncentrosymmetrical medium with and without the account of cubic nonlinearity. The influence of cubic nonlinearity on maximum efficiency of conversion rises a great practical interest. Therefore, the curves were calculated according to (5) at optimal parameters of the task.

The case of e-oe interaction is considered. An analysis of the parametric process for crystal KDP in the constant-intensity approximation and comparison of the obtained results with corresponding results of the accurate calculation obtained at the same conditions for the given crystals [3] have been conducted. Below, at numerical calculation of pump intensity in the absolute electrostatic units there was taken into account the coefficient of recounting $8\pi / cn_3$ $(n_3 = n(\omega_3))$

In Fig. 1 there is shown one period of oscillations for dependences of relative value of the coefficient of amplification $\eta_1 / \eta_{1\max}$ on length z of KDP crystal calculated according (5), for the various values of pump intensity I_{30} (for 10^{13}W/cm^2 solid and dotted curves 1 are, for $2 \cdot 10^{13}$W/cm^2 solid and dotted curves 2 are). The data on KDP crystal for the coefficients $\gamma_{1,2,3}$, γ_{jj}, γ_{mj} are taken from the work [3]. Hence $g_1^{KDP} = 2.657 \cdot 10^{-10}$ esu, $g_2^{KDP} = 28.604 \cdot 10^{10}$ esu, $g_3^{KDP} = -26.074 \cdot 10^{-10}$ esu. The obtained curves have marked maximum that testifies to the existence of optimal length of nonlinear medium z_{opt}. The latter can be determined according to analytical formula (7) got in the constant-intensity approximation, substituting the respective parameters of the task. The optimal values of linear phase mismatch at the given parameters correspond to all the curves. From comparison of solid curves 1 and 2 we observe that z_{opt} decreases with an increase in pump intensity that agrees with formula (7). As it was expected [3], the existence of cubic nonlinear medium leading to the nonlinear phase mismatch influences on optimal conditions, providing the maximum efficiency of conversion. From comparison of solid and dotted curves 1 and 2 we observe the following: In the absence of Δ^{NL} the optimal value of linear phase mismatch compensates the expression $\Gamma_3^2 - \Gamma_2^2$. For the dotted curves 1 and 2 $\Delta/\Gamma_3 = 2.002$. In the presence of Δ^{NL} the optimal value of linear mismatch increases as it is necessary to compensate emerged undesirable phase shift. For solid curve 1 the value $\Delta/\Gamma_3 = 3.904$, but for the solid curve 2 the value $\Delta/\Gamma_3 = 4.692$. This increase in the value of optimal linear mismatch is connected with a growth of pump intensity at transfer from curve 1 to curve 2. Thus, by changing a value of linear mismatch it is possible to choose its optimal value that will compensate Δ^{NL}. It will allow to obtain the high amplification of the same value what was in absence of cubic nonlinearity.

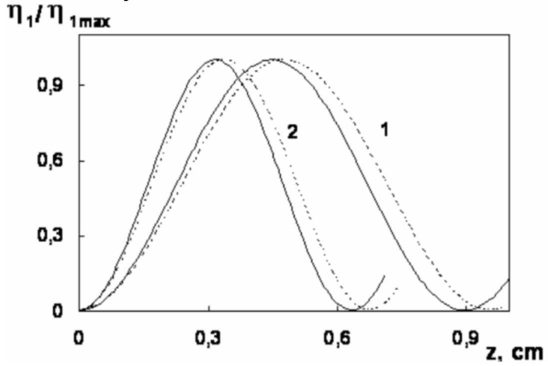

Fig. 1. Dependencies of amplifying coefficient $\eta_1/\eta_{1\max}$ (in relative units) on length z of KDP crystal calculated in the constant-intensity approximation (curves 1-4) at $g_1^{KDP} = 2.657\cdot10^{-10}$ esu, $g_2^{KDP} = 28.604\cdot10^{10}$ esu, $g_3^{KDP} = -26.074\cdot10^{-10}$ esu, $I_{30} = 10^{13}$ W/cm^2 and $\delta_1/\Gamma_3 = 0$, calculated with taking into account(solid curves 1 and 2) and without taking into account (dotted curves 1 and 2) cubic nonlinearity of medium for $I_{20}/I_{30} = 10^{-5}$, $I_{20}/I_{30} = 10^{-9}$, $\Delta/\Gamma_3 = 3.904$ (solid curve 1), 2.002 (dotted curves 1 and 2) and 4.692 (solid curve 2).

Such dependences for KDP crystal were obtained by the authors in the work [3] from a numerical account of the system of the reduced equations (1) for parametric interaction in a medium with quadratic and cubic nonlinearities.

The dependences of amplification (in relative units) $\eta_1 / \eta_{1\max}$ from the given linear phase mismatch Δ / Γ_3 are offered in Fig. 2.

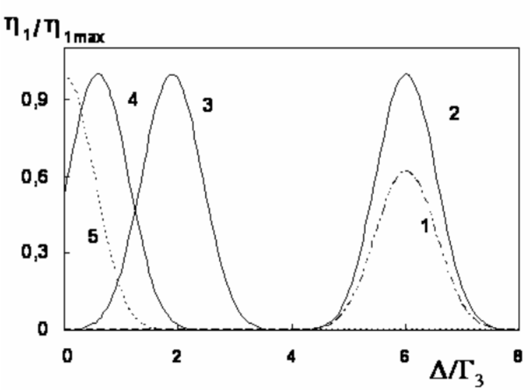

Fig. 2. Dependencies of $\eta_1 / \eta_{1\max}$ on a given linear mismatch for KDP crystal calculated in the constant-intensity approximation taking into account (curves 1-4) and without taking into account (curve 5) cubic nonlinearity of medium at $g_1^{KDP} = 2.657 \cdot 10^{-10}$ esu, $g_2^{KDP} = 28.604 \cdot 10^{10}$ esu, $g_3^{KDP} = -26.074 \cdot 10^{-10}$ esu, $I_{10} / I_{30} = 10^{-6}$, $I_{20} / I_{30} = 10^{-10}$, $I_{30} = 10^{12}$ W/cm^2 (curve 4), 10^{13}W/cm^2 (curves 3 and 5), 10^{14}W/cm^2 (curves 1 and 2), $\delta_1 / \Gamma_3 = 0$ (curves 2-4) and 0.03 (curve 1).

The dependences are plotted for KDP crystal in the presence and absence of cubic nonlinearity for the various pump intensities. The analysis of behaviour of the curves at the various intensities I30 showed that at parametric interaction the effect of cubic nonlinearity is revealed, beginning at $I_{30} \geq$ 1012W/cm^2 (curves 1-4). This fact was earlier noted in the work [3] as well, where the authors made the numerical account of the system (1). With growth of pump intensity the optimal value of linear mismatch increases. It is connected with the fact that increasing I_{30} leads to an increase in contribution of cubic nonlinearity, i.e. Δ^{NL}. Hence, the value of linear mismatch Δ, required for compensation of undesirable phase shifts Δ^{NL} increases. From comparison of the curves 3 and 5 it is seen that in the absence of cubic nonlinearity (curve 5) optimal phase mismatch $\Delta_{opt} = 0$, as Δ^{NL} in this case is equal to zero. For each value of pump intensity it is possible to find out the corresponding value Δ_{opt} by substituting in (6) the parameters of the task and deciding numerically this equation.

Curve 1 in comparison with Curve 2 shows that the efficiency of conversion process decreases with an increase in the given losses in the medium from 0 to 0.03.

The case of the different noncentrosymmetrical crystals at constant quadratic but diverse cubic nonlinearities in the medium is considered in Fig. 3.

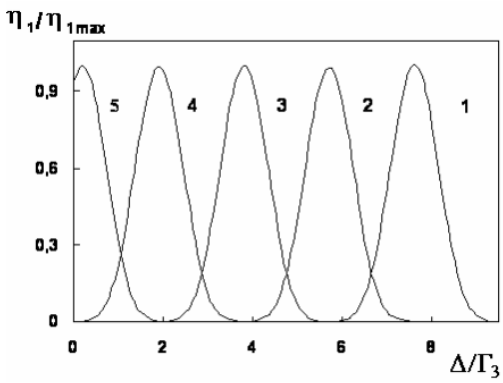

Fig. 3. Dependencies of $\eta_1 / \eta_{1\max}$ on a given linear phase mismatch δ_1 / Γ_3 for diverse noncentrosymmetrical crystals at $I_{30} = 10^{11}$ W/cm^2, $I_{10} / I_{30} = 10^{-6}$, $I_{20} / I_{30} = 10^{-10}$, $g_1^{KDP} = 2.657 \cdot 10^{-10}$ esu, $g_2^{KDP} = 28.604 \cdot 10^{10}$ esu, $g_3^{KDP} = -26.074 \cdot 10^{-10}$ esu, in case $g_i / g_i^{KDP} = 1$ (curve 5), 10 (curve 4), 20 (curve 3), 30 (curve 2) and 40 (curve 1).

The increase of cubic nonlinearity (from curve 5 to curve 1) on the account of pump intensity leads to the growth of optimal value of linear mismatch Δ_{opt}, required for compensation of increasing Δ^{NL}.

The further analysis showed that a marked maximum is observed also at investigation of conversion efficiency on the given pump intensity. This permits to considerably increase conversion efficiency by the choice of optimal value of pump intensity I_{30opt}.

The threshold character of parametric interaction is clearly seen in Fig. 4.

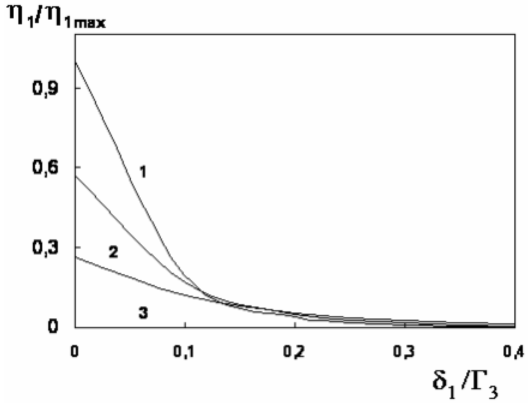

Fig. 4. Dependencies of $\eta_1 / \eta_{1\max}$ on a given losses δ_1 / Γ_3 for KDP crystal calculated in the constant-intensity approximation at $g_1^{KDP} = 2.657 \cdot 10^{-10}$ esu, $g_2^{KDP} = 28.604 \cdot 10^{10}$ esu, $g_3^{KDP} = -26.074 \cdot 10^{-10}$ esu, $I_{30} = 10^{13}$ W/cm^2, $I_{10} / I_{30} = 10^{-6}$, $I_{20} / I_{30} = 10^{-10}$, $\Delta / \Gamma_3 = 3{,}904$, $\Gamma_3 z = 8$ (curve 1), 6 (curve 2) and 4 (curve 3).

Here, the dependences of amplification $\eta_1 / \eta_{1\max}$ (in relative units) on given losses in the medium δ_1 / Γ_3 are provided. It is seen from behaviour of the curves 1-3 that with an increase in the losses the efficiency of amplifier decreases. At the values more than some critical value amplifying does not occur, i.e. threshold regime of amplifying comes.

From comparison of the curves obtained in the present work in the constant intensity approximation with the results of a numerical account, [3] it follows that by choice of optimal values of the length of nonlinear medium (see equation (7)), pump intensity, linear mismatch (see equation (6)) and with the account of the an influence of linear losses in a medium, it is possible to reach increasing conversion efficiency at parametric interaction in noncentrosymmetrical media.

Thus, under nonlinear optical parametric interaction in the intensive light waves it is necessary to take into consideration self-phase and cross-phase modulations directly effecting phase relationship between interacting waves. Investigation of parametric process in the noncentrosymmetrical media in the constant-intensity approximation enables one to obtain the analytical expressions of optimal parameters of the task. The threshold conditions of amplifier have been analysed and the analytical expressions for threshold pump intensity have been obtained.

Appendix

To determine the conditions of applicability of the constant-intensity approximation at parametric interaction in the quadratic medium [7] the differential equation for complex amplitude of signal wave $A_1(z)$ should be solved with more accuracy then it was in used constant-intensity approximation. If in the given approximation there are no any restrictions to the phases of interacting waves, then intensities of idler and pump waves are considered to be constant ($I_2(z) = I_2(z=0) = I_{20}$, $I_3(z) = I_3(z=0) = I_{30}$). To take into account the reverse reaction of excited wave to exiting one at strong consideration, one has to pay attention to the changes of intensities $I_{2,3}$ from z. For this purpose, it is necessary to take into account the following member differing from zero in expanding intensities $I_{2,3}$ in a Taylor's series in the area $z = 0$. By solving the differential equation for $A_1(z)$ with an account of the subsequent members in expanding, it is possible to obtain the solution corresponding to the second, third etc. approximations.

The solution obtained in the second approximation is expressed by the Whittaker's function. Using the relation between the Whittaker's function and degenerated hypergeometrical function it is possible to receive the final expression for complex amplitude $A_1(z)$ in the second approximation. The boundaries of applicability of the constant-intensity approximation are determined by the comparison of the obtained solution with a solution got in the constantintensity approximation.

Thus, at parametric amplification of waves in the quadratic nonlinearity [4], the following applicability conditions of the constant-intensity approximation were obtained

$$\Gamma_3^2 > 4 \cdot 2^{1/2} \cdot \Gamma_1 \Gamma_3 + \Delta^2 / 4 . \quad (9)$$

Where, $\Gamma_1^2 = \gamma_2 \gamma_3 I_{10}$. It should be noted that this condition is just at any lengths of nonlinear medium.

In (9) by substituting Δ for $(\Delta + \Delta^{NL})$ one can roughly estimate the boundaries of applicability of the constant-intensity approximation in the case considered in the present work.

In conclusion we'll note that the developed approach can be applied also for the other category of the nonlinear optical tasks, in particular, nonstationary processes of spreading ultrashort light pulses [6].

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MƏRKƏZİSİMMETRİK OLMAYAN MÜHİTLƏRDƏKİ İNTENSİV İŞIQ SAHƏLƏRİNDƏ PARAMETRİK QARŞILIQLI TƏSİR ZAMANI FAZA EFFEKTLƏRİ

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XÜLASƏ

İntensiv lazer sahələrində mərkəzisimmetrik olmayan mühitlərdə, verilmiş intensivlik yaxınlaşmasında, mühitdə kvadratik və kubik polyarizasiyanı nəzərə almaqla parametrik gücləndirmənin nəzəriyyəsi inkişaf etdirilmişdir. Verilmiş intensivlik yaxınlaşması həyəcanlanan dalğanın həyəcanlandıran dalğaya əks təsirini nəzərə alır, faza pozulmasını və bütün qarşılıqlı təsirdə olan dalğaların sönməsini eyni zamanda nəzərə almağa imkan verir. Göstərilmişdir ki, öz-özünə təsir və çarpaz qarşılıqlı təsir hesabına nakaçka intensivliyinin dəyişməsi qarşılıqlı təsirdə olan dalğalar arasında olan optimal faza münasibətlərinə təsir edir. Qarşılıqlı təsirdə olan dalğalar arasında arzuolunmaz faza sürüşmələrinin kompensasiya şərtləri müəyyən olunmuş xətti faza pozulmasının, mərkəzisimmetrik olmayan mühitin uzunluğunun, nakaçka intensivliyinin astana qiymətinin optimal qiymətlərini hesablamaq üçün analitik ifadələr verilmişdir. Göstərilmişdir ki, nakaçka intensivliyinin artması ilə faza döyünmələrinin periodu artır. Xətti pozuntunun sıfırdan artması ilə əvvəlcə fəza döyünmələrinin periodu artır, sonra isə

azalır. KDP kristalı üçün parametrik prosesin effektivliyi ədədi təhlil edilmişdir.

Açar sözlər: parametrik çevrilmə, sabit intensivlik yaxınlaşması, mərkəzi simmetrik olmayan maddələr, güclü sahələr.

ФАЗОВЫЕ ЭФФЕКТЫ ПРИ ПАРАМЕТРИЧЕСКОМ ВЗАИМОДЕЙСТВИИ В ИНТЕНСИВНЫХ СВЕТОВЫХ ПОЛЯХ В НЕЦЕНТРОСИММЕТРИЧНЫХ СРЕДАХ

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РЕЗЮМЕ

Развита теория параметрического усиления в интенсивных лазерных полях в нецентросимметричных средых при наличии в среде как квадратичной, так и кубичной поляризации в приближении заданной интенсивности. Данное приближение учитывает обратное влияние возбуждаемой волны на возбуждающую и позволяет одновременно учесть фазовую расстройку и затухание всех взаимодействующих волн. Показано, что изменения интенсивности накачки через эффекты самовоздействия и перекрестного взаимодействия влияют на оптимальное фазовое соотношение между взаимодействующими волнами. Определены условия компенсации нежелательных фазовых сдвигов между взаимодействующими волнами, даны аналитические выражения для расчета оптимальных значений линейной фазовой расстройки, длины нецентросимметричной среды, порогового значения интенсивности накачки. Показано, что с ростом интенсивности накачки период пространственных биений увеличивается. Также с ростом линейной расстройки от нуля сперва происходит рост периода пространственных биений, а затем спад. Проведен численный анализ эффективности параметрического процесса для кристалла KDP.

Ключевые слова: параметрическое преобразование, приближение заданной интенсивности, нецентросимметричные среды, интенсивные поля.

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