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TRAPPING OF PARAMETRICALLY AMPLIFIED LIGHT WAVES IN A KDP CRYSTAL

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We present here the result of observation of trapping of parametrically amplified waves by pump radiation. This phenomenon, theoretically predicted in [1], may turn out to be quite significant in parametric luminescence and in parametric amplification and generation. The structure of the "trapped" fields for a Gaussian pump beam (or pulse), and also the dependence, in this case, of their increments on the radius and power of this beam, were determined in [2]. It is also shown there that a sufficiently rapid phase modulation of the pump radiation can raise the trapping threshold and greatly decrease the gain. In addition, methods for calculating the fields of the amplified waves for given sources, under conditions when the trapping phenomenon is significant, were presented in [3 - 7].

Trapping of parametrically amplified waves is possible only when the energies of these waves flow in opposite directions relative to the pump beam axis [1]. In this case, owing to the interaction with the pump radiation, they become so to speak "rereflected" in the volume in such a way that the pump beam serves, in a certain sense, as a waveguide for the parametrically amplified waves. At a beam pump power exceeding a certain critical value¹⁾ P_0, certain waveguide modes begin to grow exponentially, and their fields are localized mainly inside the wave packet of the pump radiation. Thus, when the trapping conditions are satisfied, the signals are amplified over the entire length of the crystal, even if this length greatly exceeds the static-interaction length $L_c = a_p/\Delta\beta_{max}$ (a_p is the radius of the pump beam and $\Delta\beta_{max}$ is the larger of the angles $\Delta\beta_1$ and $\Delta\beta_2$).

We observed trapping in the amplification of waves with λ = 1.06 μ via interaction of the oe - e type with the second harmonic of a neodymium laser in a KDP crystal (crystal length d = 60 mm, a_p = 0.6 mm). Polarized radiation with wavelength λ = 1.06 μ was focused on the surface of the nonlinear crystal at the center of the pump beam. The synchronizing condition was satisfied in each of the planes passing through the pump beam axis for two pairs of waves: $\vec{k}_3 = \vec{k}_1^o + \vec{k}_1^e = \vec{k}_2^o + \vec{k}_2^e$ (Fig. 1). The synchronism angles could be varied by rotating the crystal.

We registered on the screen of an electron-optical converter either the directivity pattern of the amplified (ordinary wave, $\vec{k}^o$) and converted (extraordinary wave, $\vec{k}^e$) signals, or the field distribution of the converted signal

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[1] For a Gaussian beam $P_0 = \pi^2\Delta\beta_1\Delta\beta_2/8\chi^2$, where $\Delta\beta_1$ and $\Delta\beta_2$ are the angles between the pump-beam axis and the group velocities of the amplified waves, and χ is the coefficinnt of proportionality of the static gain γ_0 to the square root of the maximum pump radiation power flux density S_0 ($\gamma_0 = \chi\sqrt{S_0}$). Trapping can be observed also in parametric interaction with a cubic nonlinearity, for example when Stokes and anti-Stokes radiation components interact in stimulated Raman scattering (SRS) [1]. In this case the trapping can be observed if the radius of a beam with arbitrary finite power is decreased to a sufficient degree.

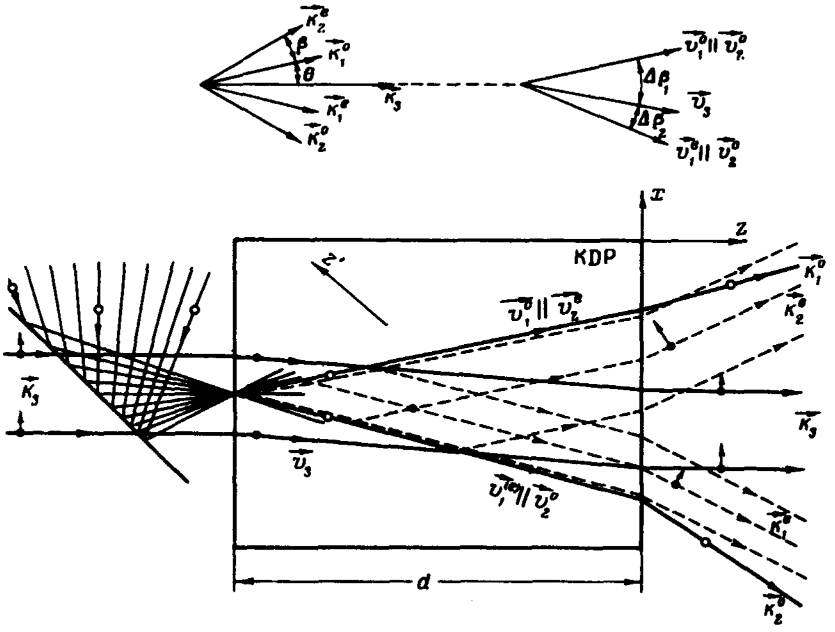

Fig. 1. Diagram of wave interaction. The solid lines in the KDP crystal represent the rays of the amplified waves, while the dashed lines show the paths of the transformed waves at $P < P_0$. z_1 is the direction of the optical axis: $\vec{v}^o$, $\vec{v}^e$, and $\vec{v}_3$ are the group velocities of the amplified, converted, and pump waves, respectively; β is the birefringence angle.

at the far face of the nonlinear crystal and at a distance of 10 cm from the crystal (Fig. 2).

The results obtained in this manner are best compared with the results of a theoretical analysis for sufficiently large values of the angles $\Delta\beta_1$ and $\Delta\beta_2$ ($\Delta\beta_1$, $\Delta\beta_2 > 0.5°$), when the crystal length greatly exceeds L_c and the length $L_0 = (a_p/4\Delta\beta_2)[(\Delta\beta_1 + \Delta\beta_2)/\Delta\beta_1]$ in which the zeroth mode of the parametric waveguide is formed [3, 5]. In this case the gain and the field distribution on leaving the crystal should be close to the gain and field distribution of this mode.

Since the pump radiation power ($P = 6 - 9$ MW) could exceed the critical power by 5 - 10 times up to angles $\Delta\beta_1 \simeq \Delta\beta_2 \simeq 3°$, it follows that the gain ($p_0 d$) and the radius ρ_0 of the zeroth mode, and also the distance a_0 between the intensity maxima of the amplified waves, could be determined from the formulas [2]

$$p_0 = \gamma_{max}\sqrt{1 - a_0/a_p} - \frac{\alpha_1\Delta\beta_2 + \alpha_2\Delta\beta_1}{\Delta\beta_1 + \Delta\beta_2}, \tag{1a}$$

$$\rho_0 = \sqrt{a_0 a_p}; \quad a_0 = \gamma_0^{-1}\sqrt{\Delta\beta_1\Delta\beta_2}. \tag{1b}$$

Here $\gamma_{max} = 2\gamma_0\sqrt{\Delta\beta_1\Delta\beta_2}/(\Delta\beta_1 + \Delta\beta_2)$, α_1 and α_2 are the wave attenuation coefficients. The difference between the absolute values of the shifts Δx_1 and Δx_2 of the amplified-wave intensity maxima from the maximum intensity of the pump radiation, according to estimates (in the case of weak attenuation[2], i.e.,

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[2] It should be noted that since the relations obtained in [2 - 7] are valid for large wave attenuation, they can be readily used to analyze the trapping in such limiting parametric-interaction cases as SRS on polaritons or SRS on picosecond pulses [8]. In the latter case, as can be readily seen from a comparison of the equations, it suffices to introduce the substitutions

$\alpha_{1,2} << p_0$, $\Delta x_{1,2} \simeq \pm(a_0/2) + a_p[(\Delta\beta_1 - \Delta\beta_2)/(\Delta\beta_1 + \Delta\beta_2)]$), should be approximately one-third the pump radius. The error in the measurement of $(|\Delta x_1| - |\Delta x_2|)$ turned out to exceed the expected value of this difference.

When plotting the directivity pattern, we measured only the relative gain. It turned out that, as follows from (1a), at an approximate pump power of 7 MW the gain decreases by not more than a factor of 1.5 when the angle θ (Fig. 1) is increased to 2°30', although the static-interaction length L_c is decreased thereby by a factor of 5.

Trapping of amplified waves was most strongly pronounced in the observation of the change in the distribution of the transformed-wave intensity on leaving the crystal with increasing pump power (Fig. 2). In accordance with the calculation of the conversion process at small pump power ($P < P_0$; Fig. 1) two spots were observed at the far face, with radii approximately equal to the pump beam radius and separated by a distance

$$b = \left[d - \frac{a_p}{2}\,\frac{\Delta\beta_1 + \Delta\beta_2}{\Delta\beta_1\Delta\beta_2}\right](\Delta\beta_1 + \Delta\beta_2)$$

(Fig. 2a). When the pump threshold was exceeded by approximately one order of magnitude, the spots came closer together and their radii decreased (Fig. 2b). The table shows that the experimental values of the spot radii ρ_0^e and the distances between them a_0^e are close to the values of ρ_0 and a_0 obtained from the

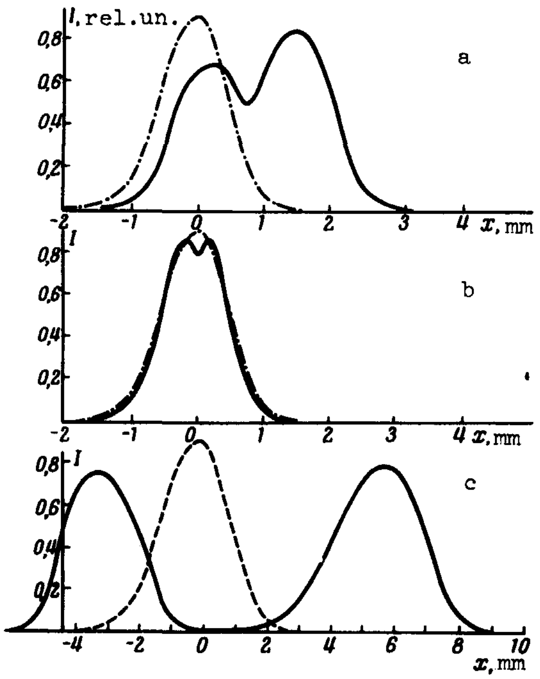

Fig. 2. Distribution of the intensity of the transformed waves at the far face of the crystal for $P < P_0$(a), for $P > P_0$(b), and at a distance 10 cm from the far face of the crystal at $P > P_0$(c). The dashed lines show the distribution of the pump radiation intensity.

$\Delta\beta_1$, rad	$\Delta\beta_2$, rad	γ_0, cm^{-1}	a_p, mm	ρ_0, mm	ρ_0^e, mm	a_0, mm	a_0^e, mm
0,021	0.041	1,4	0.6	0,37	0,42	0.21	0,21
0,021	0,041	1,2	0,6	0,39	0,45	0,24	0,25
0,048	0,080	1,4	0,6	0,49	0,50	0,41	0,43

$\gamma_0 \to A_p\sqrt{\sigma_c\sigma_q/v_q}$, $a_p \to \tau_p$, $\alpha_1 \to (v_qT_2)^{-1}$, $\Delta\beta_2 \to (v_c^{-1} - v_p^{-1}) = \Delta s$, and $\Delta\beta_1 \to v_q^{-1}$ (σ_c and σ_q are the coupling coefficients of the molecular vibration and the Stokes wave, T_2 is the relaxation time of the molecular vibrations and A_p is the amplitude of the pump pulse), and then let the velocity v_q of the molecular vibration tend to zero.

theoretical analysis. After emerging from the crystal, the beams diverge rapidly (Fig. 2c).

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EMISSION OF CHARGED PARTICLES FROM A SOLID SURFACE ON WHICH A CHEMICAL REACTION TAKES PLACE

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It is known that when free atoms or radicals recombine from the gas phase on the surface of a solid, the recombination energy leads to different electronic excitations in the solid and is accompanied by luminescence (radical-recombination luminescence - RRL [1]). Effects of this kind include also the excitation of the luminescence of a solid at the expense of the energy released by chemosorption on the surface of molecules or atoms (adsorption luminescence [2]).

The yield of luminescence of this kind (which we shall call heterogeneous chemoluminescence) is low and amounts to 10^{-3} - 10^{-8} photons per elementary chemical act [1, 2]. It is clear that there are energy-release channels other than luminescence. One of them is excitation of phonons, corresponding to heating of the crystal surface. Another possible way is the transfer of chemical energy, particularly the recombination energy of the atoms, to impurities on the surface or in the region adjacent to the surface. This can lead to desorption of these impurities, to dissociation of the adsorbed molecules, and even to detachment of the crystal-lattice components from the surface. If the impurity is on a charged surface, then desorption of ions can be expected. In other words, ion emission can appear during the course of the chemical reaction in this case. The emitted charged particles can also be produced in the elementary chemical-reaction acts themselves.

Finally, as is clear from the existence of heterogeneous chemoluminescence, the chemical can be transferred to the electrons of the solid, and if the transferred energy exceeds the work function of the electron, the appearance of electron emission can be expected.

The present investigation was aimed at experimentally observing the emission of charged particles from a surface during the course of a heterogeneous chemical reaction of atom recombination.