OBSERVATION OF TWO-DIMENSIONAL PARAMETRIC INTERACTION OF LIGHT WAVES

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Parametric interaction of light waves (the theory of which was considered in [1-4]) is of special interest in connection with the construction of tunable-frequency light generators. It is shown in the cited papers that under certain conditions the energy of powerful oscillations (pump) of frequency ω_p is transferred effectively to oscillations at frequencies ω_1 and ω_2 satisfying the relation

$$\omega_1 + \omega_2 = \omega_p \ . \tag{1}$$

The frequencies ω_1 and ω_2 can be tuned continuously at a fixed frequency ω_p if the following relation is satisfied between the wave vectors:

$$\vec{k}_1 + \vec{k}_2 = \vec{k}_p \ . \tag{2}$$

Two variants of frequency tuning are possible in principle:

1. The use of so-called one-dimensional interaction, in which the vectors $\vec{k}_1$, $\vec{k}_2$, and $\vec{k}_p$ are collinear. In this case the tuning of the frequencies $\omega_{1,2}$ at fixed position of $\vec{k}_p$ in space can be realized either by changing the orientation of the nonlinear crystal in the Fabry-Perot resonator, or by changing the refractive indices of the crystal (in [2] it is proposed to do this, for example, with the aid of an external electric field, while variation of the nonlinear-crystal temperature was used for this purpose in [7]).

2. The use of two-dimensional interaction: the vectors $\vec{k}_1$, $\vec{k}_2$, and $\vec{k}_p$ are not collinear. The frequency is tuned by changing the mutual orientation of these vectors. Such a scheme can have definite advantages if the frequencies ω_1 and ω_2 differ greatly.

One-dimensional parametric interactions were observed in [5-7]. The object of the present communication is to report the results of an experiment in which two-dimensional parametric interaction was realized in the optical band. The nonlinear crystal used in our experiment was ADP, the pump was the second harmonic of ruby-laser emission ($\lambda_p = 0.3471\ \mu$), and the signal was the laser emission itself ($\lambda_s = 0.6943\ \mu$). A degenerate interaction mode was thus realized ($\omega_s = \omega_1 = \omega_2 = \omega_p/2$). The two-dimensional interaction of the signal wave with the pump in the ADP crystal gives rise to still another wave at frequency ω_s (called the supplementary wave), the wave vector of which $\vec{k}_{sup}$ has a direction determined by relation (2) and by the dispersion characteristics of the crystal. As follows from the tuning curves of

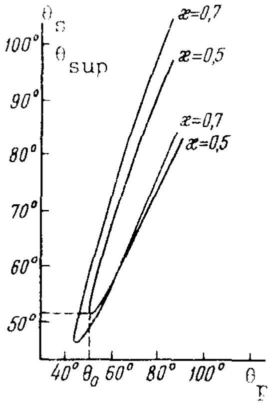

Fig. 1. Tuning curves of the parametric amplifier (generator); $\kappa = \omega_1/\omega_p$; $\theta_p = \vec{k}_p \hat{} \vec{z}$, $\theta_s = \vec{k}_s \hat{} \vec{z}$, $\theta_{sup} = \vec{k}_{sup} \hat{} \vec{z}$, $\vec{z}$ - optical axis of the ADP crystal.

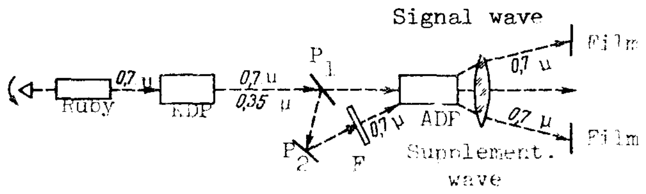

Fig. 2. Block diagram of experimental setup. P_1 and P_2 - plane-parallel plates, F - filter absorbing the pump radiation (λ_p = 0.3471).

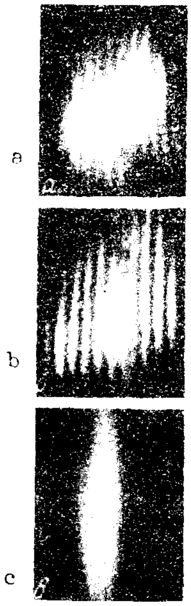

Fig. 3. Image of signal (a, b) and supplementary (c) beams. Image (a) was obtained without the ADP crystal, b - through a 1000x attenuator.

the parametric amplifier (generator), shown in Fig. 1, in the degenerate mode ($\kappa = \omega_1/\omega_p = 0.5$) the angle $\Delta\theta$ between the wave vectors of the signal and supplementary waves varies from 0 to $\Delta\theta_{max} = 18°$ $^{1)}$ when the angle $\theta_p = \vec{k}_p \hat{} \vec{z}$ ($\vec{z}$ - vector in the direction of the crystal optical axis) changes from $\theta_p = \theta_0$ to $\theta_p = 90°$ (θ_0 - angle of one-dimensional synchronism). The powers P_s and P_{sup} of the signal and supplementary waves at the crystal output are:

$$P_s = P_s(0)(\cosh^2\Gamma_0 l_{int})\exp(-2\delta l_s); \quad P_{sup} = P_s(0)(\sinh^2\Gamma_0 l_{int})\exp(-2\delta l_{sup}), \tag{3}$$

where Γ_0 is the growth coefficient, equal in our case to

$$\Gamma_0 = \frac{2\pi\chi\, k_s \sin\theta_p}{(n_s^0)^2 \cos(\theta_p - \theta_s)}, \tag{4}$$

$\chi = 2d_{36}$ (cf. [9]) is the coefficient of quadratic polarizability, n_s^0 the refractive index of the crystal for the ordinary wave at frequency ω_s, l_{int} the interaction length of the waves in the crystal, l_s and l_{sup} the paths traversed by the signal and supplementary waves in the crystal; in the case of two-dimensional interaction $l_{int} \neq l_s \neq l_{sup}$; δ is the damping decrement at the frequency ω_s.

It is interesting to note that whereas the process of degenerate parametric amplification in one-dimensional interaction is determined essentially by the phase shift between the pump and the signal, the phase dependence disappears for the two-dimensional degenerate interaction.

A block diagram of the experimental setup is shown in Fig. 2. The Q-switched ruby laser excites an optical frequency doubler (with a KDP crystal 2 cm long) and is simultaneously the generator of the amplified signal. The unfocused pump and signal waves interact in the ADP crystal (3 cm long); the way the two-dimensional interaction is realized is clear from the figure. The efficiency of the optical frequency doubler was approximately 5%; the pump-power density in the ADP crystal was $S_p \approx 5 - 6$ MW/cm. The signal and pump power ratio at the input of the amplifying crystal was $P_s(0)/P_p = 10^{-2}$. The angles in our experiments were $\theta_p = \vec{k}_p{}^\wedge\vec{z} = 90^\circ$, $\theta_s = \vec{k}_s{}^\wedge\vec{z} = 81^\circ10'$, and $\theta_{sup} = \vec{k}_{sup}{}^\wedge\vec{z} = 89^\circ50'$. The signal and supplementary waves were recorded photographically.

Figure 3 shows photographic images of the signal (3a,b) and supplementary (3c) beams (the ADP crystal was removed when photograph 3a was taken). The images are distorted by fringes due to interference in plates P_1 and P_2 (see Fig. 2). The parametric-interaction effect was manifest both in the appearance of the supplementary beam (Fig. 3c) and in the change of the signal-beam image: owing to the loss in the crystal, the brightness of the image decreases over the entire corss section, except in the central band, where the loss is compensated for by the parametric interaction. All these attributes of the parametric interaction vanish when the angle of incidence of the signal wave on the crystal decreases by ±9' from the optimal value; this agrees with the divergence of the ruby-laser beam.

The experiment yielded $P_{sup}/P_s(0) = 0.02$ and $P_s/P_s(0) = 0.8$, as against the theoretical $P_{sup}/P_s(0) = 0.2$ and $P_s/P_s(0) = 1.0$. For the theoretical estimate we used the following values of the parameters in (3) and (4): $l_{int} = 2$ cm, $l_s = 3$ cm, $l_{sup} = 2$ cm, $\delta = 0.05$ cm^{-1}, $S_p = 5$ MW/cm, $\chi = 2 \times 10^{-11}$ cm/V, $n_s^0 = 1.5$. The values of l_{int}, l_s, and l_{sup} change strongly over the beam cross section. The value $l_{int} = 2$ cm used for the estimate is in our case the maximum possible; optimization of the spatial arrangement of the pump and signal rays was not carried out in our experiment.

We must emphasize that the angular aperture $\Delta\theta_y$ of the two-dimensional parametric interaction exceeds the corresponding value for the one-dimensional amplification, and is equal to the angular aperture of the pump beam. In our experiment the divergence of the pump was 2', equal to the divergence of the supplementary wave. We note that the theoretical value of the capture angle calculated for the conditions of our experiment is 10".

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ELECTRIC EXPLOSION OF A MERCURY JET

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Electrically exploded wires are used extensively for various purposes - to obtain intense molecular beams [1], shock waves [2], powerful radio pulses [3,4], as laser pumps [5], to initiate chemical reactions [6], etc. The difficulty of replacing the wire limits the application of this method. We have therefore deemed it desirable to investigate the possibility of replacing the wire with a jet of liquid metal, so as to produce repeated electric explosions in a simple manner. The working medium used was mercury, but other liquid metals can also be employed. The mercury jet was made to explode both under atmospheric pressure and in vacuum.

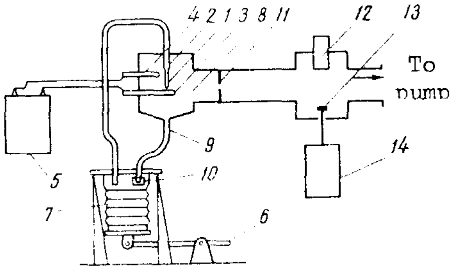

Fig. 1. Schematic diagram of setup.

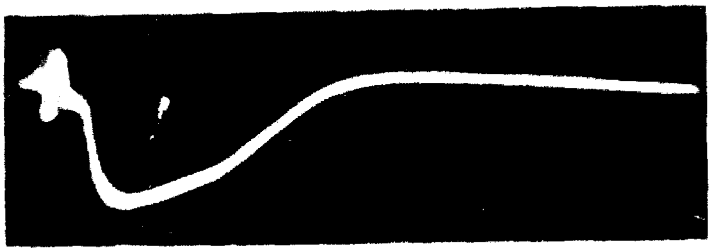

Fig 2. Oscillogram of collector current.

The setup (Fig. 1) consisted of a system simulating a mercury jet ("mercury wire"), electrodes with which to apply voltage from a capacitor to the jet, and measuring apparatus. The mercury jet (1) escaped under pressure from a glass capillary (2) and struck an electrode (3). The diameter of the mercury jet was determined by the capillary. In our case the capillary diameter was 0.15 - 0.30 mm. The jet length was 25 mm. The "mercury wire" was grounded, and neither electrode was connected directly to the ground. Voltage (3 - 4 kV) was applied to these electrodes from a capacitor (5) rated 18 μF. The mercury pressure in the