volume an estimated upper limit

$$W = W_0 N \lesssim W_{max} = \epsilon E^2,$$

where ϵ is the dielectric constant of the medium. The per-unit radiation power, apart from a numerical factor of the order of unity, is equal to

$$P_{\sim} \simeq \frac{1}{\pi} \gamma W \lesssim 10^{-2} \omega \epsilon E^2.$$

A direct current of density $I = evN$ flows in this case through the crystal, and the dissipated per-unit power is $P_0 = IE$. If $\omega\tau \gg 1$, then the particle velocity coincides in order of magnitude with the drift velocity $v \simeq E/B$ of a free particle in crossed fields, so that

$$P_0 \lesssim \frac{e N_{max} E^2}{B} = \omega \epsilon E^2; \qquad \frac{P_{\sim}}{P_0} \lesssim \gamma/\pi.$$

For $E = 10^2$ V/cm, $\epsilon = 10\epsilon_0$ (ϵ_0 is the dielectric constant of vacuum), and $\omega = 2\pi \times 10^{12}$ we obtain

$$P_0 \lesssim 10^4 \text{ W/cm}^3, \qquad P_{\sim} \lesssim 10^2 \text{ W/cm}^3.$$

The foregoing estimates allow us to assume that the mechanism considered for the instability of an electron plasma in a crystal can be used to develop sources of coherent radiation in the submillimeter and infrared bands.

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TUNABLE PARAMETRIC LIGHT GENERATOR WITH KDP CRYSTAL

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We present in this communication the results of an experimental investigation that has led to the construction of a continuously tunable parametric generator of coherent light waves in the region of $\lambda \simeq 1\ \mu$, using a KDP crystal. Continuous tuning of the wavelength was effected mechanically in a band from 9575 to 11,775 Å, and the oscillation power reached several kilowatts.

Effective parametric action of light waves (the feasibility of which was theoretically discussed back in 1962 [1-3]) were first observed in 1965 in ADP [4,7], KDP [5,11], and $LiNbO_3$ crystals [6]. In the last two references the reported gain was sufficient to actuate parametric light generators. The generator described in [6] made use of an $LiNbO_3$ crystal and the tuning was by varying the crystal temperature. With an aim at broadening the frequency band

and the tuning range of parametric generators, it is of interest to use other crystals and more effective frequency-variation schemes.

In the parametric light generator which we developed, in which a KDP crystal is used [1)], the frequency is tuned by rotating a nonlinear crystal in an optical resonator. Such a scheme has made it possible not only to construct a generator with larger bandwidth than that described in [6], but also to attain better reproducibility of the generated frequencies. The latter is of importance from the point of view of the stabilization of the parametric-generator frequency. We recall that the frequencies excited in a parametric generator are determined primarily by the dispersion characteristics of the nonlinear crystal. If the waves at the pump frequency (ω_p) and at the generated frequencies (ω_1, ω_2) propagate in the same direction, then the values of the generated frequencies satisfy, with high degree of accuracy, the relations

$$\omega_p = \omega_1 + \omega_2, \quad k_p = k_1 + k_2, \tag{1}$$

where k_i are the moduli of the wave vectors. An analysis of the dispersion properties of the KDP crystal shows that when $\lambda_p \simeq 0.53\ \mu$ it is possible to excite parametric oscillations with tunable frequency by using either an interaction of the type

$$\gamma_o(\omega_1) + \gamma_o(\omega_2) = \gamma_e(\omega_p) \tag{2a}$$

(ordinary waves at frequencies ω_1 and ω_2 interact with an extraordinary pump wave), or interactions such as

$$\gamma_o(\omega_1) + \gamma_e(\omega_2) = \gamma_e(\omega_p); \quad \gamma_e(\omega_1) + \gamma_o(\omega_2) = \gamma_e(\omega_p). \tag{2b}$$

For correctness we assume henceforth that $\omega_1 < \omega_p/2 < \omega_2$.

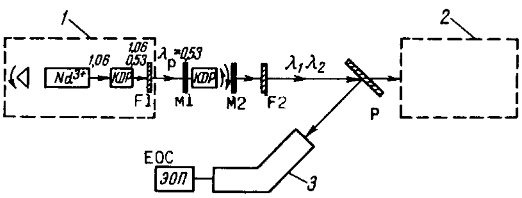

Fig. 1. Block diagram of experimental setup.

A block diagram of the experimental setup is shown in Fig. 1: M_1 and M_2 are the mirrors of the parametric generators, F_1 and F_2 are filters, P is a plane-parallel plate that diverts part of the parametric-oscillation energy to a spectrograph, 1 -- pump generator, 2 -- meter for the energy or for the spatial structure of the radiation, 3 -- ISP-51 spectrograph.

The pump produced coherent oscillations at $\lambda_p = 0.53\ \mu$ (second harmonic of laser with Nd^{3+}), the maximum pump power in the unfocused beam reached $P_p \simeq 30 - 35$ MW/cm^2, the pump pulse duration was $\tau_p = 25 \times 10^{-9}$ sec, and the beam divergence was ~7' - 8'. The pump wave excited an optical resonator containing a KDP crystal of length $\ell = 3$ cm. The mirrors M_1 and M_2 were maintained parallel to within 6"; the power reflection coefficients at the pump wavelength were $R_1(\lambda_p) \simeq R_2(\lambda_p) \simeq 15\%$. In the band from 1 to 1.12 μ the values were $R_1 \simeq R_2 \geq 95\%$ (see also the plot in Fig. 3). The KDP crystal was cut in such a manner that its faces were perpendicular to a direction corresponding to satisfaction of the synchronism condition for the interaction (2b) at $\lambda_p = 0.53\ \mu$ and $\omega_1 = \omega_2 = \omega_p/2$ (degenerate mode; angle between pump ray and optical axis of the crystal $\theta_0 = 57°$). Rotation of the crystal in the resonator in the plane of the optical axis through an angle $\Delta\theta$ relative to θ_0 causes the synchronism condition to be satisfied for a certain pair of unequal frequencies ω_1 and ω_2, satisfying the conditions

$$\omega_1 + \omega_2 = \omega_p; \qquad \begin{array}{ll} n_1^o\omega_1 + n_2^e\omega_2 = n_p^e\omega_p; & \Delta\theta = \theta - \theta_0 > 0, \\ n_1^e\omega_1 + n_2^o\omega_2 = n_p^e\omega_p; & \Delta\theta = \theta - \theta_0 < 0. \end{array} \tag{3}$$

Of course, satisfaction of condition (3) alone is not sufficient for self-excitation of parametric oscillations. It is necessary also that the pump power and the Q's of the optical resonator at the frequencies ω_1 and ω_2 be sufficiently large (the closer ω_1 and ω_2 to the resonator natural frequencies Ω_1 and Ω_2, the easier is the latter to satisfy). In our setup the degenerate parametric oscillations ($\lambda_1 = \lambda_2 = 1.06\ \mu$) were registered at a power $P_p \geq 8 - 10$ MW/cm^2 (inside the resonator). With increasing deviation from the degenerate mode, the threshold pump power increased. Self-excitation was manifested by the appearance of an intense signal which exceeded the indicator background by a factor of at least 10^5; the produced radiation had good directivity and its divergence angle did not exceed 1.5'. At $P_p \simeq 30 - 35$ MW/cm^2 the power of the parametric oscillations reached I = 5 kW. Figure 2 shows spectrograms of the

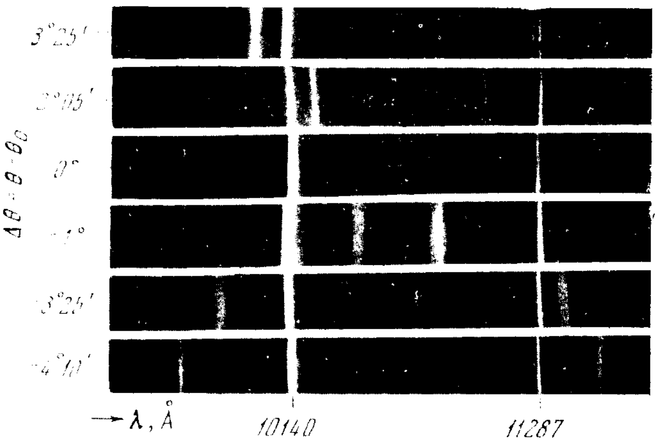

Fig. 2

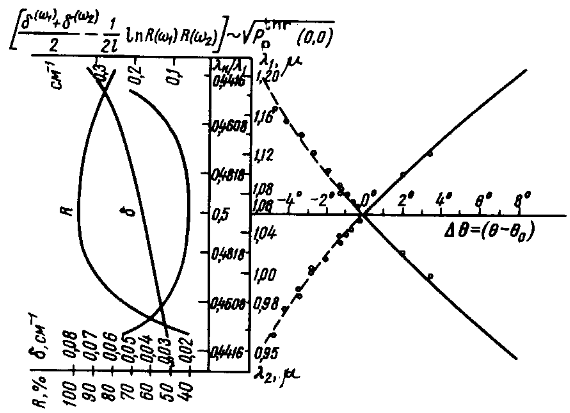

Fig. 3. Tuning curves of parametric light generator with KDP crystal.

oscillations obtained at the output of the parametric generator at different orientations of the KDP crystal relative to the pump ray [2]; the interaction used was (2b). The ordinates represent the values of $\Delta\theta = \theta - \theta_0$ where θ is the angle between the pump ray in the crystal and the optical axis, and θ_0 corresponds to the degenerate case ($\lambda_1 = \lambda_2 = 2\lambda_p$). All the spectrograms show, besides the doublet of the parametric oscillations, also a mercury-line doublet. The tuning curves of the parametric generator, $\lambda_{1,2} = \lambda_{1,2}(\Delta\theta)$, obtained by reduction of the spectrograms, are shown in Fig. 3. The theoretical curves are as follows: solid -- for the interaction $\gamma_o(\omega_1) + \gamma_e(\omega_2) = \gamma_e(\omega_p)$; dashed -- for the interaction $\gamma_e(\omega_1) + \gamma_o(\omega_2) = \gamma_e(\omega_p)$; it is assumed in both cases that $\lambda_1 > 2\lambda_p > \lambda_2$. The experimental points are marked by circles. On the left are experimental plots of the mirror power reflection coefficients R, the KDP crystal damping decrement δ, and the quantity

$$\frac{\delta_1 + \delta_2}{2} - \frac{1}{2l} \ln R(\omega_1)R(\omega_2),$$

which characterizes the threshold, against the wavelength. In the nondegenerate mode the oscillation powers decreased somewhat (to 1 - 0.5 kW for tuning by 1000 Å).

The results agree essentially with the presently accepted theory (see [6,8-10]). The minimum pump power $P_p^{thr}(0,0)$ corresponds to exact satisfaction of the synchronism conditions (3) and to exact tuning of the resonator system ($\omega_p = \Omega_1 + \Omega_2$). According to [8-10], for one-dimensional interaction and for our values of the damping decrement δ of the KDP and of the mirror power reflection coefficient R (see Fig. 3) the threshold pump power $P_p^{thr}(0,0)$ is ~4 MW/cm^2 in the degenerate case. Estimates show that the extent of the tuning range attained in our setup was determined by the frequency characteristics of the mirrors (see Fig. 3). The value of $P_p^{thr}(0,0)$ at the edge of the range attained by us increases four-fold. On the other hand, the limiting tuning range of a generator with a KDP crystal at $\lambda_p = 0.53\ \mu$ is determined only by the position of the absorption bands; estimates show that it should be not smaller than 4000 Å. It is preferable here to use angles $\theta > \theta_0$, for then the role of the aperture effect decreases.

The theoretical curves of Fig. 3 were plotted in accordance with formulas (3) and the data of [12]. It is important to emphasize that for the interaction in question we have $\Delta\theta \sim \Delta\lambda$ (unlike the interaction (2a) used in [6], for which $\Delta\theta \sim (\Delta\lambda)^2$); the latter has made it possible to obtain reproducible frequencies also near the degenerate mode (we recall that in [6] the generation was registered only when the departure from the degenerate mode exceeded 200 Å). The efficiency of the generator consturcted by us, $\eta \sim P_g/P_p \simeq 3 \times 10^{-4}$ is much lower than the theoretical limit (cf. [9]). Estimates show that in our scheme the value of η is determined essentially by the properties of the parametric resonator, and not by the finite duration of the pump pulse.

In conclusion, the authors thank N. K. Podsotskaya who took part in the measurements, and I. V. Nizhegorodova for help with the data reduction.

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1) We note that the use of this crystal makes possible the construction of parametric light generators in the 0.4 - 0.8 μ band.

2) The lines at frequencies $\omega_{1,2}$ split in turn into doublets spaced by ~ 70 Å, owing to the excitation of several modes.

INDUCED MANDEL'SHTAM-BRILLOUIN SCATTERING IN SINGLE-CRYSTAL QUARTZ AT TEMPERATURES 2.1 - 300°K

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The following effects were observed in induced Mandel'shtam-Brillouin scattering (IMBS) in single-crystal quartz: a strong increase in the shift of the Stokes component, due to the quasilongitudinal hypersonic wave, as the temperature was lowered from 80 to 2.1°K; occurrence of a Stokes component of IMBS due to the quasitransverse wave at 80°K and a difference in the character of the damage to the single crystal in the focused laser beam at different temperatures and for practically constant light-pulse power. The investigations was made with a previously-described installation [1].

The giant light pulse from a ruby laser, of ~250 MW power, was focused with a lens (f = 5 cm) onto the interior of the crystal sample, which was either at room temperature or placed in a cryostat filled with liquid helium or liquid nitrogen. All crystal samples were cut from a single block of Brazilian quartz. The exciting light was guided along the optical axis of the crystal (Z axis) 1), and the scattered light was observed at a scattering angle 180°. The dispersion region of the Fabry-Perot etalon was 2.5 cm. Reproductions of the IMBS spectrum are shown in Fig. 1. The table lists the frequency shifts $\Delta\nu$ of the Stokes component. $\Delta\nu$ doubles in the temperature interval 80 - 4°K 2) and continues to increase with decreasing temperature.

Temperature dependence of $\Delta\nu_E$ in single-crystal quartz

T, °K	2.1	2.4	4.3	80	293
$\Delta\nu_{long}$, cm^{-1}	2.30 ± 0.02	1.97 ± 0.02	1.88 ± 0.02	0.93 ± 0.01	0.93 ± 0.01
$\Delta\nu_{transv}$, cm^{-1}	-	-	-	0.65 ± 0.01	-

Ganapol'skii and Chernets [2] and Bomel and Dransfeld [3] have established that no essential change in sound velocity occurs in a quartz crystal in the temperature interval 300 - 4.2°K.