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RESONATORLESS PARAMETRIC LIGHT GENERATOR USING AN α-HIO₃ CRYSTAL

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We obtained generation in a resonatorless parametric light generator. The coefficient of conversion of the pump radiation energy into parametric waves that are smoothly adjustable in frequency in the range 1 - 1.10 μ was 57%. We measured the dynamics of the generation development. The width of the output radiation spectrum was 0.2 cm^{-1}.

Until recently, parametric generation of light was realized in schemes using a resonator for at least one of the parametric waves. In [1], an attempt was made to observe parametric generation in accordance with the traveling-wave scheme, but the gain turned out to be insufficient to obtain generation in the strictly-traveling-wave regime. Interest in resonatorless schemes of parametric light generation (PLG) is due mainly to the fact that in such generators the frequency variation is smooth, whereas in parametric generation of light with resonators it occurs jumpwise, owing to the mode character of the resonator radiation. Besides the traveling-wave PLG considered in [1], a resonatorless scheme of PLG can be realized by using feedback [2], and also by means of the scheme proposed in [3]. In resonatorless PLG the parametric frequencies are determined only by the resonant properties of the parametric gain lines. This makes it possible to obtain narrow emission lines coupled to the center of the gain line, regardless of the stability of the geometric dimensions of the system. The latter is of interest in connection with the fact that the frequency stability of PLG can be higher than the stability of the pump frequency [4].

A distinguishing feature of resonatorless PLG is the high threshold pump power, so that experimental realization calls for the use of highly efficient nonlinear crystals [5]. In our experiment we used an α-HIO₃ crystal with length $\ell = 2.3$ cm, cut for an $e_p - e_s o_i$ interaction (the subscripts p, s, and i pertain to the pump, signal, and idle waves, respectively). Such an interaction has enabled us to use collinear propagation of the parametrically coupled waves, for which the threshold pump powers are minimal, unlike the vector interaction considered in [3]. The experimental setup is shown in Fig. 1. The resonator-

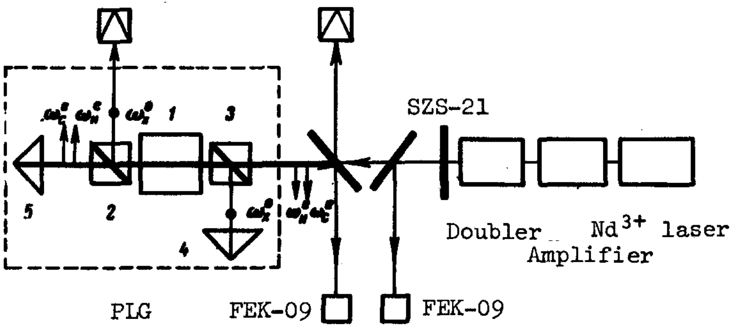

Fig. 1. Block diagram of resonatorless PLG: 1 - α-HIO₃ crystal 2.3 cm long; 2, 3 - Glan prism; 4, 5 - glass prisms.

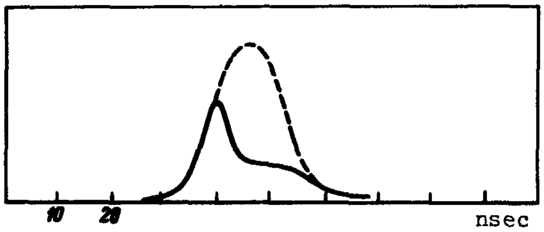

Fig. 2. Distortion of pulse pump passing through a resonatorless PLG (solid curve). The dashed curve characterizes the pulse pump incident on the PLG. The case corresponds to a 55% efficiency of energy conversion.

less PLG consists of a nonlinear crystal 1, two modified Glan prisms 2 and 3, and two glass total-internal-reflection prisms 4 and 5.

The operating principle of such a generator is as follows: During propagation in the forward direction, the extraordinary pump wave e_p (the polarization pertains to the nonlinear crystal 1) passes through Glan prism 3 and interacts in a nonlinear crystal with the ordinary wave ω_i^o, reflected from prism 4, and the ordinary wave ω_s^o increases thereby. After passage through the nonlinear crystal, the wave ω_i^o is reflected from the Glan prism and leaves the generator 2 completely, whereas the extraordinary pump and signal waves ω_p^e and ω_s^e are reflected from prism 5 and propagate in the crystal 1 in the backward direction, forming the ordinary wave ω_i^o, etc. The self-excitation threshold of such a PLG, in the plane-wave approximation, is determined by the expression

$$P_{\mathrm{thr}}^{\mathrm{theor}} = \frac{4.2\cdot 10^{-9}}{d_{\mathrm{eff}}^2\, \ell^2} \operatorname{Ar\,sh}^2 \frac{1}{(1-\epsilon_c)}, \tag{1}$$

where ε_s and ε_i are the losses for the signal and idle waves in one direction, d_{eff} is the effective nonlinear coefficient. For our setup $\varepsilon_s = \varepsilon_i = 0.5$, $P_{\mathrm{thr}}^{\mathrm{theor}}$ was 3.5 MW/cm². The experimental value of the generation threshold, determined from the appearance of the parametric signal in the recording system, was $P_{\mathrm{thr}}^{\mathrm{exp}} = 12$ MW/cm². The difference between the experimental and theoretical threshold is determined mainly by the pulsed character of the pump.

The efficiency was measured by comparing the pump power with the idling-wave power ω_i^o, and also by comparing the pump pulses at the input and output of the PLG. As seen from Fig. 2, there is an appreciable distortion of the pump pulse. At $P_p = 20$ MW/cm², the energy efficiency reached 57%. At higher power densities, the α-HIO₃ crystal was destroyed. The time for establishment of generation τ_{est}, determined from the oscillogram of Fig. 2, was 5×10^{-9} sec. The output power of the parametric signal could be estimated from the formula

$$P_s^{(N)} = R_s^{2(N)} P_{so} \operatorname{sh}^{4(N)} s\ell, \tag{2}$$

where N is the number of passes; P_{so} is the noise power at the signal frequency; $R_s \simeq (1 - \varepsilon_s)$, and

$$s = \left[\left(\frac{1.28\,\pi^4\, 4 d_{\mathrm{eff}}^2}{c n_p n_s n_i \lambda_s \lambda_i}\, \frac{P_H}{w_0^2}\right) - \frac{(\Delta k)^2}{4}\right]^{1/2}.$$

Calculations by means of this formula show that the pump-pulse distortion should occur after 8 - 9 passes, which at the given generator length is in good agreement with the measured time $\tau_{est} = 5 \times 10^{-9}$ sec.

An investigation of the spectral structure was carried out with the aid of a Fabry-Perot interferometer with bases 2 and 6 mm. The interference patterns (Fig. 3a) show that the spectrum consists of only one component with width $\Delta\nu_i = 0.2$ cm^{-1} in the case of an idle wave with $\lambda_i = 1.09$ μ. This spectral width agrees with estimates of the narrowing of the spectrum, calculated by means of formula (2). The additional narrowing of the spectrum should occur as a result of saturation of the gain [6], which takes place in our generator. Experiments have shown that the output radiation of a resonatorless PLG has good directivity, ∿4 min.

The investigated resonatorless PLG scheme could be easily transformed into a PLG with a resonator at one frequency. By rotating the Glan prism 2 90° about the beam axis, a resonator was produced for the idling frequency ω_i^0. In this case the output spectrum consisted of several components, usually two or three, corresponding to the resonator modes (Fig. 3b). The experimental threshold of this PLG was 7.5 MW/cm^2, and theoretical threshold was 1 MW/cm^2. The output frequencies of the resonatorless PLG could be smoothly tuned in the range 1 - 1.10 μ by rotating the α-HIO_3 crystal. As expected, the characteristic of the generator did not change noticeably in this case.

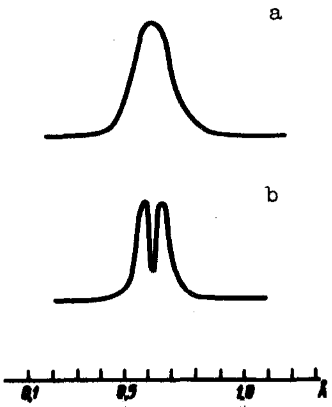

Fig. 3. Typical spectrum of output radiation of resonatorless PLG. The spectrum consists of only one component of width $\Delta\nu_i = 0.2$ cm^{-1}. The distance between the spectral components corresponds to the intermode distance of the lower resonator. The resonator lengths in a and b are the same. The interference patterns were obtained with the aid of a Fabry-Perot interferometer with base 6 mm.

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