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High-efficiency parametric converter based on KTP crystals

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Abstract. A high-efficiency extracavity parametric oscillator based on KTP crystals for converting radiation of Nd^{3+} : YAG lasers at 1.064 μm to radiation at 1.573 μm is made and its oscillation characteristics are studied. A differential efficiency of 56.5% and a threshold energy density of 0.06 J cm^{-2} were obtained. The angular divergence of parametric emission did not exceed four diffraction limits in a wide range of pump energies. The feasibility of stable operation for a more than 30-fold excess of pump energy over the threshold value was obtained.

In recent years, the feasibility of obtaining laser emission in the wavelength range that is safe for human eyes, in particular, in the 1.5-μm region, was extensively studied. This range is also convenient for instrument making because of the well-developed photodetection technique in this spectral region. Direct lasing in this range is commonly obtained using crystals or glasses doped with Er^{3+} ions. However, the efficiency of such lasers, as a rule, is noticeably lower than the efficiency of lasers on Nd^{3+}-doped crystals and glasses.

An alternative method of obtaining coherent emission in this range is based on the use of optical parametric oscillators (OPOs) [1]. Using widely accepted lasers on crystals doped with Nd^{3+} ions ($\lambda = 1.06$ μm) for pumping parametric converters, one can make an OPO emitting in the 1.5-μm region. Present-day nonlinear-crystal growth technology is able to produce $LiNbO_3$, KTiOPO4 (KTP), $KTiOAsO_4$ (KTA), $RbTiOPO_4$ (RTP), β-BaB_2O_4 (BBO) and other nonlinear crystals of high optical quality, which are used in OPOs.

In this work, we studied the possibility of high-efficiency oscillation in an OPO based on KTP crystals pumped by a Nd^{3+} : YAG laser at 1.064 μm for estimating the suitability of this approach for designing ecologically safe solid-state lasers. The choice of KTP crystals was determined by high nonlinear coefficients and a high resistance to laser radiation damage typical of these crystals and by the possibility of using noncritical phase matching for parametric conversion of radiation emitted by lasers on Nd^{3+}-doped crystals [2].

The studies of the simplest linear OPO schemes [3] showed that such oscillators had satisfactory energy parameters, but their angular divergence was rather high and strongly increased with increasing pump energy. Because of this, in the cases where a small divergence is desired, one should use pump radiation providing small excess over the oscillation threshold, which limits the OPO efficiency.

The aim of this work was to develop a high-efficiency OPO based on KTP crystals, with a low divergence at high excess over the threshold pump energy, a low oscillation threshold, and a high conversion efficiency. The KTP crystals chosen for the experiments were 4 × 4 × 20 mm in size along the *y*-, *z*-, and *x*-axes, respectively. Pump and laser radiation travelled along the *x*-axis, and the pump and signal waves were polarised perpendicular to the *z*-axis. For this orientation, pump radiation at 1.064 μm is parametrically converted to the signal and idler waves at 1.573 and 3.288 μm, respectively, under noncritical phase-matching conditions [2].

We chose a three-mirror ring cavity shown in Fig. 1. This cavity has some advantages over the linear one because it can be used for obtaining parametric oscillation only on the running wave. This cavity has no standing waves, and it is characterised by a considerably higher spatial uniformity of intracavity radiation compared to linear cavities. This is of particular importance because of a high absorption coefficient of KTP crystals (of the order of 1 cm^{-1} [4]) in the region of the idler wave. The three-mirror configuration was chosen because of the simplicity of cavity alignment, which should be made only in the plane perpendicular to the cavity plane. Moreover, the outer beams (*1, 2*) in the three-mirror cavity change upon each round trip to the inner

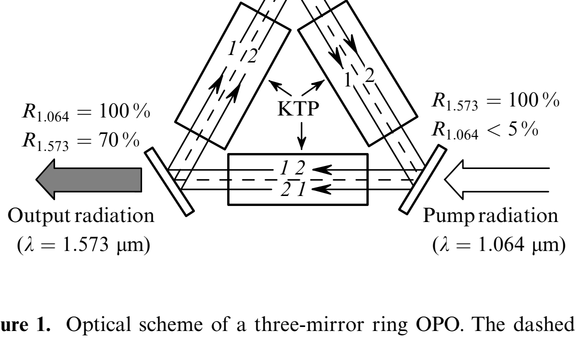

Figure 1. Optical scheme of a three-mirror ring OPO. The dashed line represents the optical axis of the oscillator beam.

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beams and vice versa (Fig. 1). This noticeably compensates for the nonuniformity of the transverse structure of the oscillation field and substantially weakens the effect of optical inhomogeneities and the pump beam quality on the transverse structure of the oscillation field.

A view of the parametric oscillator and its size are shown in Fig. 2. When measuring oscillation characteristics of the OPO, we pumped it by single- and multimode radiation of *Q*-switched Nd:YAG lasers. The output mirror of the OPO had reflectivity of ~ 70% at 1.57 μm.

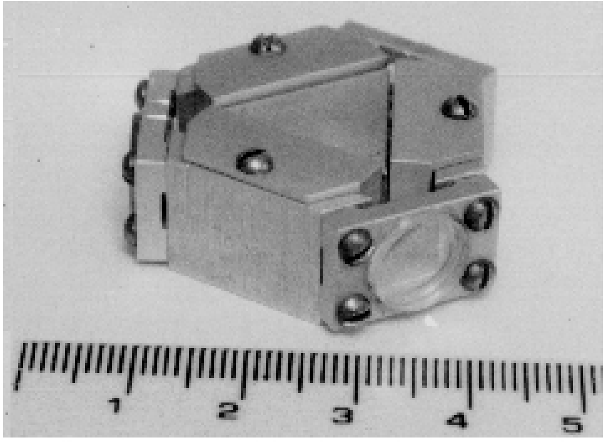

Figure 2. External view of the OPO.

The dependence of the output radiation energy on the pump energy in the case of multimode pumping is presented in Fig. 3a. The pump beam diameter (at an energy level of 0.86) was 1.6 mm, the pulse repetition rate was 5 Hz, and the pump pulse duration was 10 ns. We obtained a differential conversion efficiency of 46%, and the oscillation threshold was 2.5 mJ (0.12 J cm^{-2}). The divergence of parametric radiation (at an energy level of 0.86) in the range of pump energies used by us did not exceed 3.5 mrad, which is less than four diffraction limits. Output pulses of the OPO were no longer than 10 ns.

The energy dependence upon single-mode laser pumping is shown in Fig. 3b. The pump beam diameter (at an energy level of 0.86) was 2 mm, the pulse repetition rate was 12.5 Hz, the pump pulse duration was 8 ns, and the output OPO pulse duration was also 8 ns. In this case, we obtained a differential efficiency of 56.5%, and the oscillation threshold was 2 mJ (0.06 J cm^{-2}). The divergence of parametric radiation (at an energy level of 0.86) in the range of pump energies did not exceed 4 mrad, i.e., it was also lower than four diffraction limits. Thus, a low threshold, a high efficiency, and a low divergence make this OPO scheme attractive for the use in small-size instruments with a limited pump energy.

We also studied the feasibility of operation of this parametric converter upon pumping it by laser radiation with increased energy. It was pumped by a multimode laser, which produced 15-ns pulses with a repetition rate of 2.5 Hz and the energy up to 180 mJ. The pump beam diameter at the input of the OPO was 3 mm (at an energy level of 0.86). The dependence of the output OPO energy on the pump energy is presented in Fig. 3c. At a maximum pump energy, the OPO produced stable 70-mJ pulses. The oscillation threshold was 5 ± 1 mJ, i.e., we obtained stable oscillation at pump energies exceeding the threshold value by a factor of more than 30. The OPO pulse duration was 15 ns. The radiation divergence at the maximum pump energy was about 7 mrad, which is equal to ten diffraction limits. An increase in the pulse repetition rate and the output energy of the OPO is limited by high absorption of the idler wave in the KTP crystal. To increase these parameters in the given design, one should use large-aperture nonlinear elements.

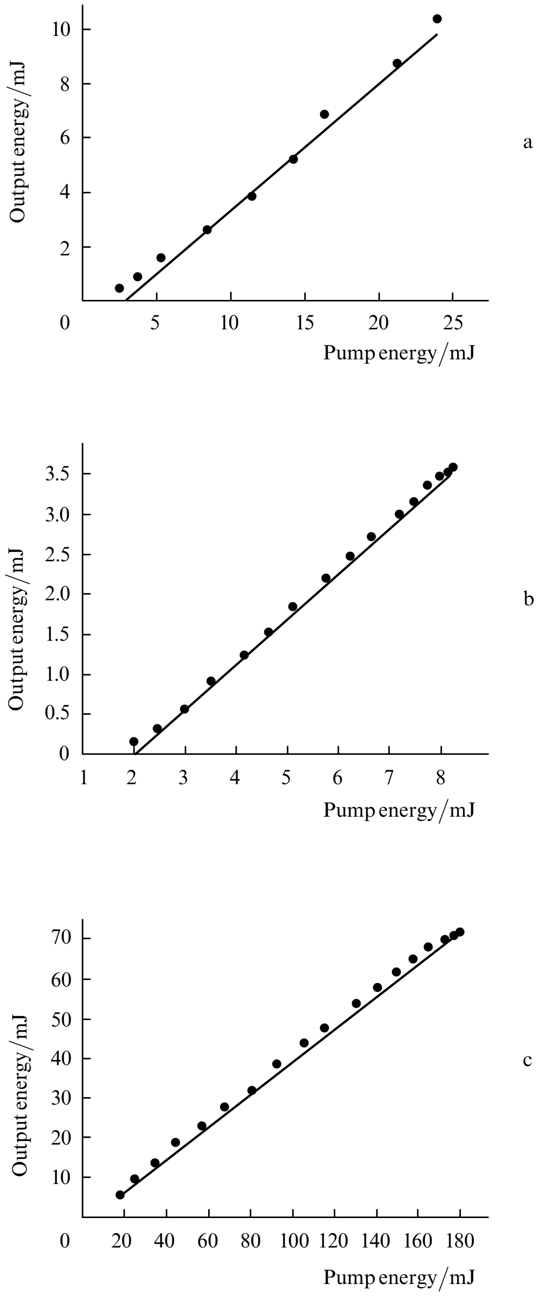

Figure 3. Dependence of the output energy of pulsed parametric radiation at 1.573 μm on the pump pulse energy for the oscillator pumped by multimode laser radiation (a), single-mode laser radiation (b), and multimode laser radiation with increased pulse energy (c).

Thus, we made an OPO with a low radiation divergence and high energy characteristics. These output parameters and small size of the converter make it attractive for the use in various devices, including small-size devices.

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