Efficient, High-Energy, KTP Optical Parametric Oscillators Pumped with 1-micron Nd-lasers

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Abstract

We have recently demonstrated efficient operation of KTP optical parametric oscillators (OPO) pumped by multimode Nd:YLF and Nd:YAG lasers. These experiments have demonstrated what is, to our knowledge, the highest pulse energy (450 mJ) and the highest average-power signal output (7.4 W) obtained to date from an OPO. With a 1.1-J, 10-Hz, Nd:YAG pump laser we obtained 450 mJ (4.5 W) of signal output at 1571 nm from a singly-resonant OPO. In a separate experiment with a 625-mJ, 30-Hz, Nd:YLF pump laser we obtained 7.4 W (245 mJ, 30 Hz) of signal output at 1550 nm. These results provide a clear demonstration that very high pump-to-signal energy conversion (up to 41%) can be obtained from an OPO even with highly multi-transverse-mode pump lasers.

Introduction

The primary motivation of our recent experimental work was to determine whether a KTP OPO, operating in the non-critically phase-matched (NCPM) orientation, could efficiently and reliably provide an eyesafe source when pumped with a multi-transverse-mode pump laser. A further goal was to compare the efficiency of extracavity and intracavity configurations. In "extracavity" operation the pump laser and the OPO are separate oscillators. In "intracavity" operation the OPO resonator is inside the pump-laser resonator. In this case the OPO becomes a nonlinear loss mechanism for the pump laser, which significantly changes the dynamics of the photon field in the pump-laser.

Experimental Set up

The experimental set-up for both the extracavity and intracavity OPO configurations is shown in Fig. 1. Three different pump lasers were employed in the extracavity OPO tests: 1) a Nd:YLF oscillator, 2) a Nd:YLF oscillator/amplifier and 3) a Nd:YAG oscillator/amplifier. The Nd:YLF oscillator was a flashlamp-pumped, Q-switched oscillator employing a 6.4 x 100 mm rod that was operated at up to 240 mJ/pulse from 10 to 50 Hz. For the Nd:YLF oscillator/amplifier set-up a 6.4 x 90 mm rod was used in the oscillator and a 6.4 x 100 mm rod as the amplifier. The oscillator was operated at 320 mJ at 30 Hz. With this input, the amplifier was capable of up to 625 mJ at 30 Hz. The Nd:YAG laser was an oscillator/amplifer system capable of 1.1 J/pulse at 10 Hz.

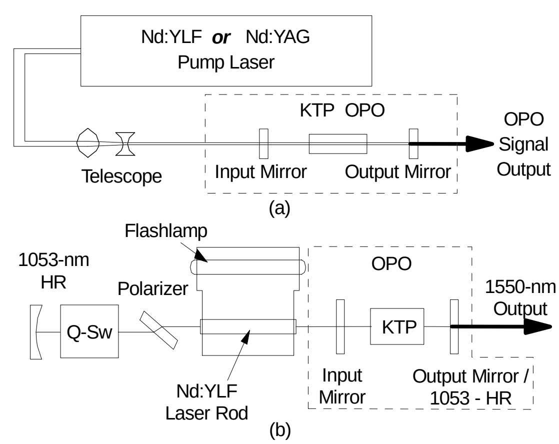

Figure 1. Optical schematic of the experimental set-up for: (a) the three extracavity OPO experiments and (b) the intracavity OPO.

For the intracavity OPO experiments the 240-mJ, Nd:YLF oscillator described above was used with the 20%-R, 1053-nm output coupler replaced with the OPO resonator. In all cases the OPO resonator was comprised of a 1550-nm, high-reflectivity (HR) mirror, an 8 x 8 x 20 mm, x-cut (θ=90, ϕ=0), KTP crystal with an anti-reflection (AR) coating, and a 40%-R, 1550-nm output coupler. The spacing between the resonator mirrors was 3.5 cm. The OPO HR mirror was 98%-T at the 1053-nm pump wavelength and the OPO output coupler was a high reflector at 1053 nm. This coating design allows high transmission of pump radiation into the OPO cavity and retro-reflects the pump for a second pass through the crystal, thereby doubling the effective interaction length.

Nd:YLF was selected for the high pulse-repetition frequency (PRF) experiments because it has excellent thermo-optic properties: low thermal lensing and natural birefringence. The natural birefringence, which dominates over thermally-induced birefringence, maintains highly linear polarization of the output beam, even at high average power operation. This is of particular importance in pumping the Type II KTP OPO where only pump photons with a polarization parallel to the y-axis will be phase-matched.

Experimental Results

The first two experiments discussed below are the extracavity and intracavity OPOs that used the Nd:YLF oscillator as the pump source. These data provide a valid performance comparison for extracavity versus intracavity configurations in terms of conversion efficiency and beam quality since all components and resonator details were the same for the two cases.

The signal wavelength was measured with a 0.25-m, grating spectrometer to be 1550 nm with the 1053-nm Nd:YLF pump. Figure 2 shows the 1550-nm output energy that was obtained with the extracavity Nd:YLF OPO. Data are given for 10, 20, 30, 40 and 50 Hz. We looked carefully for the presence of any idler energy in the output beam, using both prisms and dichroic optics, and found no detectible levels of idler output. (The idler with the Nd:YLF pump is at about 3284 nm, which is absorbed in both the KTP crystal and the OPO mirror substrates). Slope efficiencies for 1053- to 1550-nm energy conversion are about 67% for all five PRFs. 67% is, in fact, the Manley-Rowe quantum limit for these photon energies. Therefore, the data show that the KTP OPO is able to reach quantum-limited energy conversion even with the highly multimode pump laser. The highest average power output in this Nd:YLF-pumped, extracavity OPO was 3.73 W (93.2 mJ at 40 Hz).

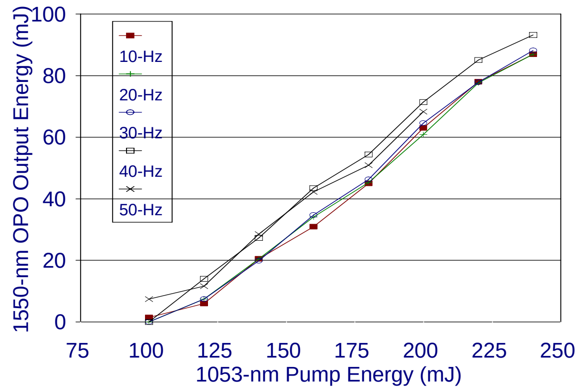

Figure 2. Signal output energy for the Nd:YLF - pumped extracavity OPO at five different pulse-repetition-frequencies.

Fig. 3 shows the signal output energy as a function of flashlamp pump energy for the Nd:YLF intracavity OPO, which was operated at 10, 20, 40 and 60 Hz. The highest lamp-energy point in the intracavity OPO experiment (about 24.5 J) is the level that produces 240 mJ of Q-switched, 1053-nm output when the Nd:YLF system is operated as a conventionally Q-switched laser. The overall efficiency (flashlamp input to OPO signal-wave output) at the maximum output point is 0.36 % for the extracavity OPO of Fig. 2 and 0.57 % for the intracavity OPO of Fig. 3.

The beam quality of the Nd:YLF pump laser, the extracavity OPO and the intracavity OPO were measured as well. The measured M^2 values for the Nd:YLF pump laser (in the 240-mJ, oscillator-only experiment) varied from 14.4 at 10 Hz to 15.7 at 40 Hz. With this pump laser the extracavity OPO had the following output beam quality: M^2 = 8.4 in the plane parallel to the KTP y-axis and an M^2 = 7.8 in the plane parallel to the z-axis. The intracavity OPO constructed with the same Nd:YLF oscillator (as described above and in Figure 1 (b)) was highly divergent with M^2 = 29 in the x-y plane and M^2 = 28 in the x-z plane.

To investigate operation at higher pulse energies we set up the same extracavity OPO with a 1.1-J, 10-Hz, Nd:YAG oscillator/amplifier as the pump source. Fig. 4 shows the extracavity OPO signal output energy as a function of the Nd:YAG oscillator/amplifier pump energy. The overall pump-to-signal energy conversion at the 450-mJ output point is 41% and the average-power output is 4.5 W.

To investigate high-average-power performance of the KTP OPO further we constructed the separate Nd:YLF oscillator/amplifier that was described above. With this 18.8-W (625 mJ, 30 Hz)

1053-nm pump laser we were able to obtain 7.4 W of signal output at 1550 nm. The input/output characteristics, in terms of average power, are shown in Fig. 5. The naturally birefringent YLF host prevents depolariation thus providing the linear polarization needed for the Type II parametric conversion in the KTP crystal even at high thermal loads on the YLF pump laser. This Nd:YLF/OPO data was obtained with no coating damage to any of the pump or OPO resonator components.

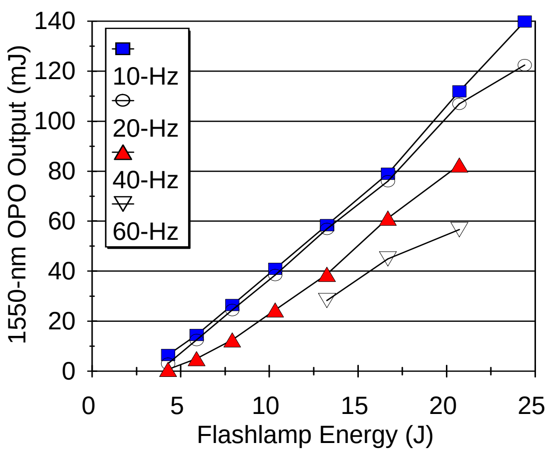

Figure 3. Signal output energy as a function of flashlamp energy for the Nd:YLF, intracavity OPO.

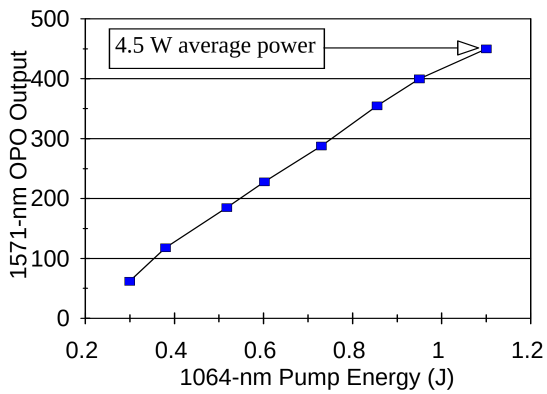

Figure 4. Signal output energy as a function of pump energy for the extracavity OPO pumped by the 1.1-J, 10-Hz, Nd:YAG oscillator/amplifier.

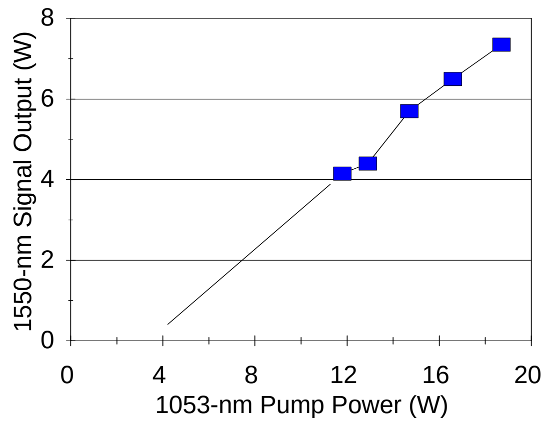

Figure 5. Average-power performance of an extracavity KTP OPO using the Nd:YLF oscillator /amplifier as a pump laser.