Efficient intracavity optical parametric oscillator with diode side-pumped electro-optic Q-switched laser

Xu Liu (刘 旭)[1,2], Changyong Lu (卢常勇)[1], Xiaobing Wang (王小兵)[1],
Bin Sun (孙 斌)[1], Yong Cheng (程 勇)[1], and Jianwen Chen (陈建文)[2]

[1]*Institute Opto-Electronics Technology, Wuhan Ordnance Non-Commissioned Officers Academy, Wuhan 430075*
[2]*Key Research Laboratory, Air Force Radar Academy, Wuhan 430019*

Received July 7, 2006

An efficient intracavity single-resonant optical parametric oscillator (OPO) at 1.571-μm eye-safe range using a non-critically phase-matched KTP crystal is reported. The OPO is excited by a diode side-pumped electro-optic Q-switched Nd:YAG laser at 1.064 μm. Signal pulse of 97 mJ and 3.56 ns is obtained under the input electric energy of 2.3 J, corresponding to a slope efficiency of 4.2%, and a repetition rate range of 1—30 Hz.

OCIS codes: 190.2620, 140.3480, 140.3540, 140.0140.

The radiation at around 1.5 μm has been extensively investigated for eye-safe applications. The optical parametric oscillator (OPO) using KTP crystal can be used as the basis for frequency conversion of Nd-doped lasers to longer wavelength. The resonator of the intracavity OPO and the nonlinear crystal for parametric interaction are placed inside a high-finesse Q-switched laser cavity[1−4], 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[1]. It takes advantage of the high fundamental field inside the pump laser cavity to increase parametric conversion efficiency. The parametric threshold is lower for the intracavity OPO compared with the extracavity OPO. The OPO experiments over the last few years were almost carried out by flash-lamp-pumped Q-switched Nd:YAG laser[2−4]. Radiation sources based on diode pumped solid-state lasers are developed as an alternative to the flash-lamp-pumped lasers for the high efficiency and high repetition rate can be obtained. It is difficult to combine high energy (hundred millijoules), high efficiency, and high repetition rate in OPO, because that the pump photon density must be increased to scale an OPO to higher energy without exceeding the damage threshold of nonlinear crystals and other optics. On account of the higher intensities in OPO cavity, the frequency generation of signal and idler may transfer energy back to the pump wavelength, which can reduce both efficiency and beam quality. The control of the laser medium pumping, the optimization of the output coupler reflectivity and the well-design of the OPO cavity length are essential for the laser.

Here we analyze the operating conditions of an eye-safe pulsed KTP OPO, singly resonant at 1.57 μm, intracavity excited by a diode side-pumped electro-optically Q-switched multi-transverse-mode Nd:YAG laser at a fundamental wavelength of 1.064 μm. A simple model of a non-critically phase-matched KTP OPO is described.

The experimental setup is shown in Fig. 1. The active medium of the laser oscillator is a Nd:YAG rod, 80-mm-long, 5 mm in diameter, antireflection coated on both ends at 1.064 μm. The pumping laser diode of 5400 W consists of six QCW laser diode cylinder arrays, with the pump wavelength of 808 nm coinciding with Nd:YAG absorption band. By the both sides of the rod, three laser diodes are alternately aligned, and each diode is mounted on thermal energy converter (TEC) and copper heat sink in order to achieve a high repetition rate, the rod is cooled from the unexcited side surface by copper heat sink. The experiments are carried out using a KD_2PO_4 (KD^*P) crystal for electro-optic Q-switching. The plane-parallel optical resonator of the pump wave oscillator is 200 mm long, having two mirrors, M1 and M3. M1 rear mirror is highly reflective ($R = 99.7\%$) at 1.064 μm, whereas M3 mirror is partly reflective at the signal parametric wavelength of 1.57 μm. The OPO 30-mm-length cavity is formed by a pair of plano-parallel mirrors, M2 and M3. One face of M2 flat mirror is highly reflective ($R = 99.8\%$) at 1.57 μm and transparent at 1.064 μm, whereas the other face is coated antireflection at 1.064 μm. The KTP crystal, $7\times7\times20$ (mm), pumped with the fundamental frequency of the Nd:YAG laser, is cut for type II non-critical phase-matching interaction along the x crystallographic axis ($\theta = 90°$, $\varphi = 0°$). The polarization of the pump wave is along the y axis of the crystal which is the ordinary wave, as is that of the signal wave, whereas the idler is polarized along the z axis. The OPO produces a signal wavelength of 1.57 μm, whereas the idler wavelength is 3.2 μm. Because of the high absorption of the idler radiation in the KTP crystal, the OPO is resonant on the signal frequency only.

We perform several experiments with various output coupler transmissions of 25%, 40%, 50%, 60%, and 75% at 1.57 μm. The temperature of the heat sink is held at a constant 295 K with a thermoelectric cooler. Figure 2

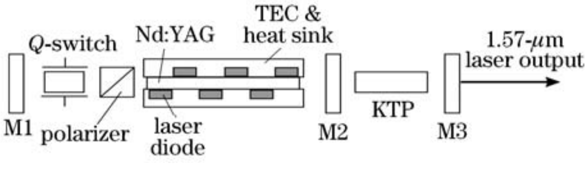

Fig. 1. Schematic diagram of the intracavity OPO with diode side-pumped electro-optic Q-switched laser.

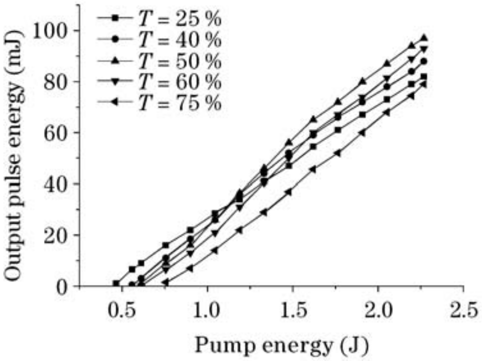

Fig. 2. Output energy at 1.57 μm as a function of the input electric energy with different output coupler transmissions.

shows the output energy at the signal wavelength of 1.57 μm as a function of input electric energy for different values of the output coupler. The best performance is achieved with the output coupler transmission of 50%, and the highest output energy of 97 mJ is obtained under the input electric energy of 2.3 J and pump pulse width of 240 μs, which corresponds to a slope efficiency of 4.2%. As can be seen from these curves, the lowest threshold of OPO is 0.465 J with the transmission of 25%, the threshold increases when the transmission of the output coupler rises. After the laser threshold is reached, the signal pulse energy depends on the number of available pump photons that exist in the OPO cavity. The parametric conversion will grow when the pump energy increases, whereas a delayed sub-pulse of Q-switched laser reached the threshold of OPO again, a second signal pulse will develop. The multiple signal pulses generation was not reached in our experiments because of the capability of Q-switched pump laser.

Signal pulse shape and width are measured with a fast response Ge detector connected with a TDS3052 500-MHz digital oscilloscope. Figure 3 shows the pulse width of signal laser as a function of corresponding energy. The pulse width of 3.56 ns is obtained when the energy is 97 mJ and the Q-switched pump laser width of 16 ns is detected by a Si detector, and signal pulse shape is observed in Fig. 4. For the intracavity OPO, the buildup time of the signal pulse is determined by the parametric gain and signal photon lifetime. Unlike the extracavity pumped OPO in which the signal pulse width is only slightly shorter than the pump pulse, the intracavity OPO signal pulse width is much shorter than that of the pump pulse. High-energy conversion efficiency from the laser pump energy to the signal and idler pulse energy can be obtained when the pump photon lifetime in the laser cavity is much longer than the signal photon lifetime in the OPO cavity. In this case, it is possible to store the energy for a long time in the pump laser cavity and still have a short signal pulse. Figure 5 shows the spectrum of the output signal pulse, in which the peak of the wavelength is 1571 nm.

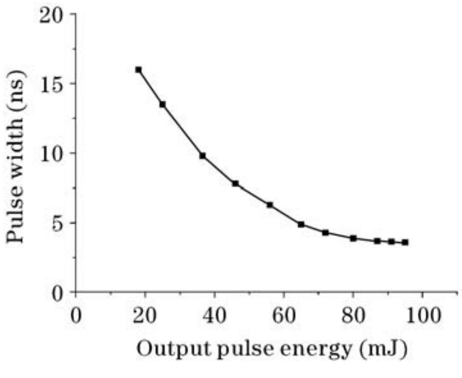

Fig. 3. Output signal pulse width as a function of its corresponding energy.

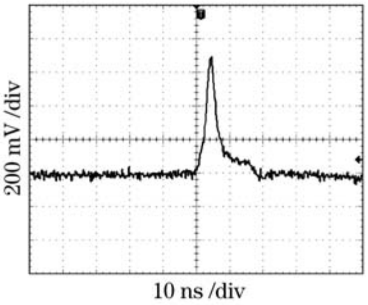

Fig. 4. Waveform of the signal pulse when the output energy is 97 mJ.

The original design of the pump module arrangement makes an attractive feature be less sensitive to laser rod thermal wedge, for the half-circular laser-diode arrays are alternately and oppositely arranged with the heat-sink, resulting in the thermal gradient and thermal effect, the deflection of optical beam can be compensated automatically. The pulse repetition rate of the OPO can be varied over a wide range, Fig. 6 shows the slight change of the

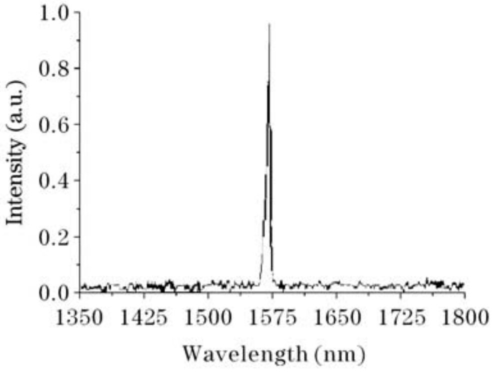

Fig. 5. Spectrum of the output signal pulse.

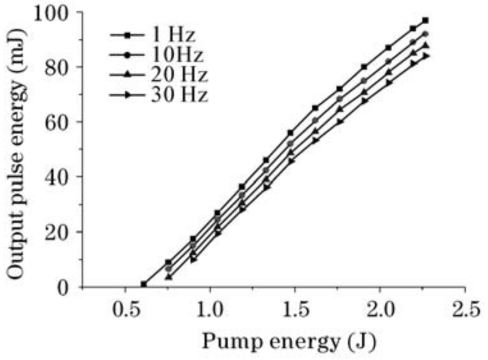

Fig. 6. Output energy at 1.57 μm as a function of the input electric energy with different pulse repetition rates.

output signal energy within the repetition range of 1—30 Hz. Figure 7 shows the stability of output energy under the input electric energy of 2.3 J in different the pulse repetition rates. Some decreases of the output energy at high repetition rate are attributed to the thermal lens fluctuation and the thermally-induced birefringence effects in the pump laser.

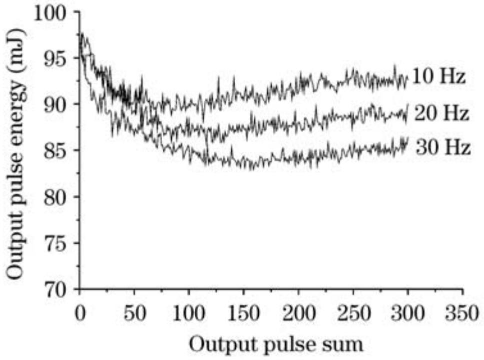

Fig. 7. Stability of output energy under the input electric energy of 2.3 J with different pulse repetition rates.

In conclusion, an efficient intracavity OPO with diode side-pumped electro-optic Q-switched laser has been demonstrated. Signal pulse energy at 1.57 μm is 97 mJ and pulse width is 3.56 ns, when the input electric energy is 2.3 J, which corresponds to a slope efficiency of 4.2% and high repetition rate range of 1—30 Hz. It may be used in number of applications such as ranging and target indicating.

This work was supported by the National Defense Foundation (No. 51438060404). X. Liu's e-mail address is gdyjs@263.net.

References

1. E. O. Ammann, J. M. Yarborough, M. K. Oshman, and P. C. Montgomery, Appl. Phys. Lett. **16,** 309 (1970).
2. T. Debuisschert, J. Raffy, J. P. Pocholle, and M. Papuchon, J. Opt. Soc. Am. B **13,** 1569 (1996).
3. R. Dabu, C. Fenic, and A. Stratan, Appl. Opt. **40,** 4334 (2001).
4. Q. Liu, Y. Wang, B. Yao, and Q. Wang, Acta Opt. Sin. (in Chinese) **21,** 1228 (2001).