World Academy of Science, Engineering and Technology
International Journal of Physical and Mathematical Sciences
Vol:5, No:5, 2011

High Energy Dual-Wavelength Mid-Infrared Extracavity KTA Optical Parametric Oscillator

Hongjun Liu*, Qibing Sun, Nan Huang, Shaolan Zhu, Wei Zhao

Open Science Index, Physical and Mathematical Sciences Vol:5, No:5, 2011 publications.waset.org/5576.pdf

***Abstract*—**A high energy dual-wavelength extracavity KTA optical parametric oscillator (OPO) with excellent stability and beam quality, which is pumped by a Q-switched single-longitudinal-mode Nd:YAG laser, has been demonstrated based on a type II noncritical phase matching (NCPM) KTA crystal. The maximum pulse energy of 10.2 mJ with the output stability of better than 4.1% rms at 3.467 μm is obtained at the repetition rate of 10 Hz and pulse width of 2 ns, and the 11.9 mJ of 1.535 μm radiation is obtained simultaneously. This extracavity NCPM KTA OPO is very useful when high energy, high beam quality and smooth time domain are needed.

***Keywords*—**mid-infrared laser, OPO, dual-wavelength laser

I. INTRODUCTION

MID-infrared spectral region, which has the minimum atmosphere attenuation on the infrared window and a high penetration capability of the smog, has been obtaining increasing attentions for a variety of applications [1-3]. It has been widespread application value and prospect in spectroscopy, medical treatment, remote sensing, environmental monitoring, military, especially in laser countermeasure, laser jamming, laser guidance, and so on. OPO has the advantage of tunability, all solid state, miniaturization, high power and narrow linewidth. Therefore, mid-infrared OPO pumped by commercially available Neodymium based lasers is well suited for such applications [1-3]. The single-longitudinal-mode laser is an ideal pump laser for OPO due to its high frequency stability, narrow linewidth, and smooth time domain [4]. In recent years, extensive research has been carried out on the intracavity optical parametric oscillators (IOPOs) [5]. However, the extracavity OPOs, the cavity mirror coatings of which are designed accurately, have the advantages of the IOPOs and are convenient to operate and maintain [2, 3, 6-8]. The resonant cavities of the pump laser and parametric light are independent of each other in the extracavity OPOs. Therefore commercial lasers can be used as the pump laser and the resonant cavity of the parametric light can be adjusted separately, which lead to high stability of the extracavity OPOs. M. Henriksson et al. have demonstrated 250 μJ and 10 Hz mid-infrared output in an extracavity ZGP OPO, corresponding to an optical to optical conversion efficiency of 7% from 1.064 μm to the mid-infrared output [3]. Philip Schlup et al. have reported 52 uJ, 5 ns, and 10 Hz mid-infrared output and 170 uJ 1.48-1.80 μm output in an extracavity PPLN OPO pumped by a injection-seeded Nd:YAG laser, corresponding to a slop efficiency of 10% [7]. Markus Henriksson et al. have reported 170 uJ and 20 Hz mid-infrared output in an extracavity ZGP OPO with the conversion efficiency of 4% from 1.064 μm to the mid-infrared output [8]. Xiao-Long Dong et al. have reported 3 W, 18 kHz and 5.46 ns mid-infrared output and 13.6 W 1534 nm output in an intracavity KTA OPO [9].

Here, we report a high energy dual-wavelength mid-infrared extracavity KTA OPO with excellent stability and beam quality pumped by a Q-switched single-longitudinal-mode Nd:YAG laser. With the pump energy of 71 mJ, pulse width of 8 ns and repetition rate of 10 Hz, the highest energy of 10.2 mJ and pulse width of 2 ns at 3.467 μm are obtained, corresponding to a conversion efficiency of 14% from 1.064 μm to 3.467 μm. The energy of 11.9 mJ at 1.535 μm is obtained simultaneously. To our knowledge, this is the highest energy in an extracavity KTA OPO for generating the mid-infrared radiation with excellent stability and beam quality.

II. EXPERIMENTAL SETUP

A schematic of the experimental setup is shown in Fig. 1. A Q-switched single-longitudinal-mode Nd:YAG laser (Precision Π 8010, Continuum) with the pulse width of 8 ns and repetition rate of 10 Hz is used as the pump laser. The pump beam is reimaged into the laser crystal through the coupling lens to improve the beam quality. A KTA crystal of size 5×5×25 mm^3 is cut along X-axis (θ=90°, φ=0°) to satisfy the type II NCPM condition for the optical parametric conversion and not cooled, which is wrapped with the indium foil and mounted on a copper block. The crystal is antireflection coated at 1.064 μm, 1.5-1.6 μm and 3.4-3.5 μm on both faces. The single resonant OPO is formed by two mirrors, M1 and M2, and a KTA crystal. The cavity is carefully designed and its length is optimized to be 34 mm to maximize the output energy of the generated light from the KTA OPO. As an input mirror, M1 (plano-plano, quartz) is coated for antireflection at 1064 nm and high- reflection (HR) at 1.5-1.6 μm and 3.4-3.5 μm. In order to investigate the lasing behavior of the idler, a CaF_2 mirror (plano-plano, M2) is used

---

Hongjun Liu is with the State Key Laboratory of Transient Optics and Photonics Technology, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China. (phone:862988887601 e-mail: liuhongjun@opt.ac.cn).

Qibing Sun is with the State Key Laboratory of Transient Optics and Photonics Technology, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China. (e-mail: qbsun@opt.ac.cn).

Nan Huang is with the State Key Laboratory of Transient Optics and Photonics Technology, Xi'an Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, Xi'an 710119, China. (e-mail: huangnan@opt.ac.cn)

*Corresponding author: liuhongjun@opt.ac.cn

as the output coupler and highly reflective at 1064 nm, antireflective at 3.4-3.5 μm and partially reflective (PR) at 1.5-1.6 μm (R=90%). The signal wave is not totally reflected by M2 to avoid the extreme intracavity fluence of the oscillating light that could damage the crystal. The singly resonant OPO cavity is comprised by the HR coating of M1 and PR coating of M2. The cavity configuration is neither a pure extracavity nor a pure intracavity after employing the 1.064 μm highly reflective mirror M2, which forms another low loss 1.064 μm laser cavity with M1 when it is compared with a general extracavity OPO. It not only increases the utilization of the pump laser to improve the conversion efficiency, but also avoids optical damage to the crystal. The mirror M3 (plano-plano, quartz), which is coated to have high transmission at 1.5-1.6 μm and high reflection at 3.4-3.5 μm, is used as a beam splitter mirror.

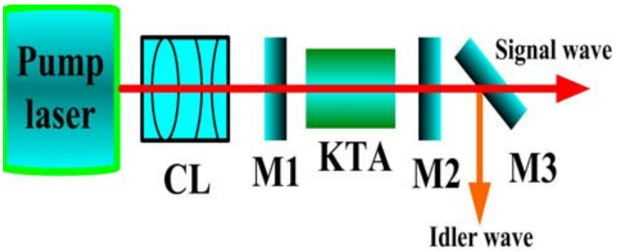


Fig. 1 Experimental setup of the extracavity KTA OPO: M1, rear mirror; M2, output coupler; M3, beam splitter mirror; CL: coupling lens;

III. RESULTS AND DISCUSSION

The wavelengths of 1.535 μm and 3.467 μm are measured by using an ANDO spectrum analyzer (AQ-6315A) and a BRUKER spectrometer (VERTEX 70), respectively. Typical optical spectra of 1.535 μm and 3.467 μm are shown in Fig. 2. The linewidth of the output light is about 0.2 nm. The signal wavelength and idler wavelength are in accordance with the case of the type II NCPM KTA pumped by a 1064 nm laser. The pulse temporal behavior is monitored by a digital phosphor oscilloscope and a fast p-i-n photodiode, which pulse width is about 2 ns and shown in Fig. 3.The energy of the 1.535 μm and 3.467 μm output versus the pump energy are shown in Fig. 4, respectively. When the output coupler transmission is T=10% at 1.5-1.6 μm, the maximum output energy of 10.2 mJ at 3.467 μm and 11.9 mJ at 1.535 μm are achieved under the pump energy of 71 mJ, corresponding to an optical-optical conversion efficiency of 14% from 1.064 μm to 3.467 μm, which is the highest energy in an extracavity KTA OPO for the mid-infrared light to our knowledge. The relative low energy of 1.535 μm is due to the low transmission of the output coupler at 1.535 μm. The energy of 1.535 μm and 3.467 μm could not be increased further because of the low damage threshold of the coating of the mirrors. The high conversion efficiency and high mid-infrared energy obtained in this OPO could be attributed to several factors: 1) the good pump beam quality and high pump power density are improved by choosing a Q-switched single-longitudinal-mode Nd:YAG laser as the pump laser and a output coupler with high reflection at 1.064 μm; 2) the CaF_2 output coupler with high transmission at 3.4-3.5 μm has a very low absorption coefficient at 3-5 μm; 3) the relatively long KTA crystal increases the gain at 3.467 μm; 4) the short OPO cavity decreases the cavity loss of the mid-infrared laser.

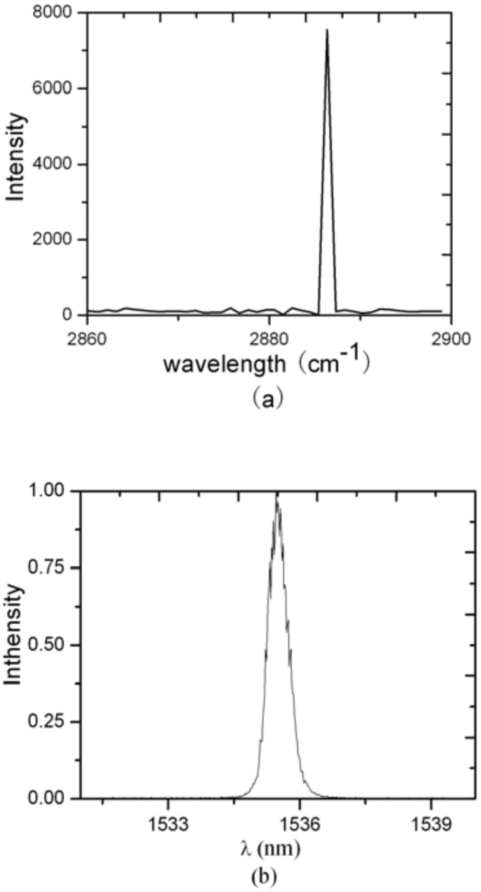


Fig. 2 The spectra of (a) 3.467 μm and (b) 1.535 μm

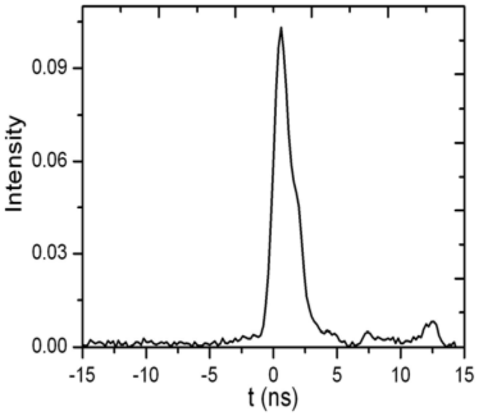


Fig. 3 Typical pulse shape of the output light

The beam spatial profile for 3.467 μm is near TEM_{00} mode as shown in Fig. 5 (a). The beam diameter is about 3.5 mm. The output stability of the KTA OPO is shown in Fig. 5 (b). The output energy of 3.467 μm is measured in one hour with the step size of one minute. Since a single-longitudinal-mode laser is used as the pump laser, the mid-infrared output of the KTA OPO is relatively stable with a less fluctuation of the single pulse energy. The output energy of the idler wave exhibits a less fluctuation due to the temperature changes of the OPO crystal, which is not cooled in our experiment.

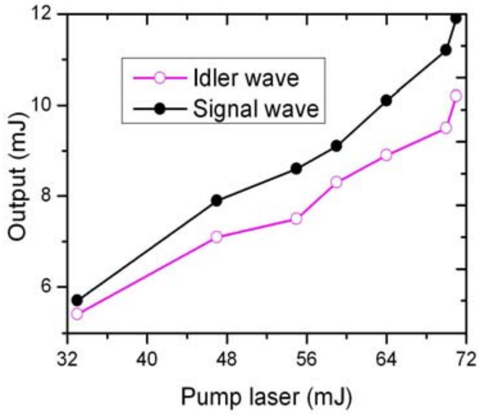
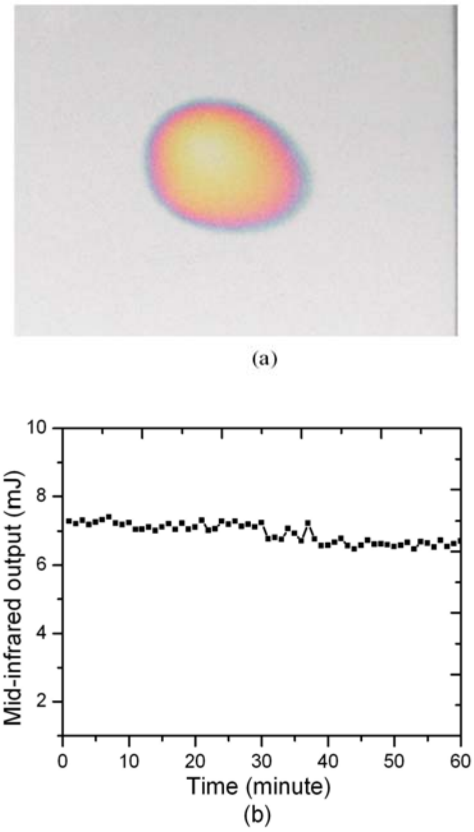


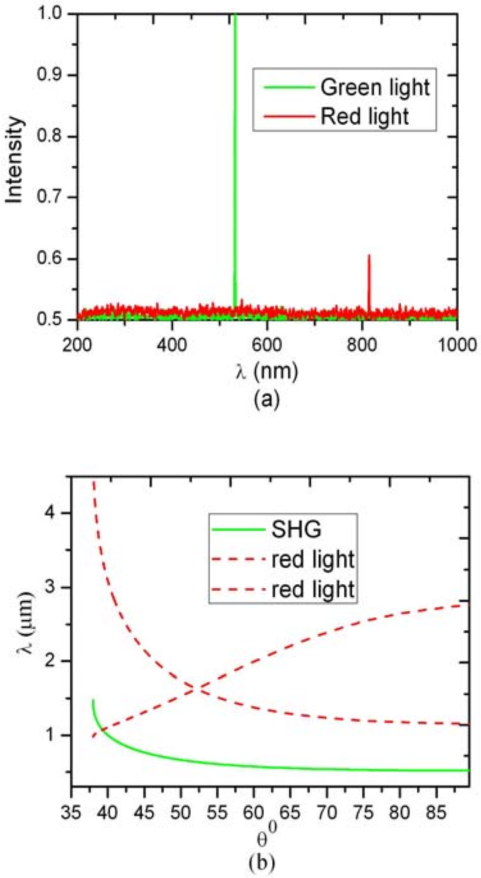
Fig. 4 The energy of the 1.535 μm and 3.467 μm output versus the pump energy


(a)

(b)

Fig. 5 (a) The beam spatial profile for 3.467 μm; (b) The output stability of 3.467 μm

The green light and red light are observed at the end face of the crystal, which wavelengths are about 532 nm and 814 nm, respectively. The optical spectra of the red light and green light are measured by a HR 2000 spectrometer and shown in Fig. 6 (a). The phase matching curves of the red light and green light are calculated and shown in Fig. 6 (b) according to the best fit equations of the refractive index for KTA are given by [10]. The red light is generated by the sum frequency of the idler wave and the pump laser and the green light is the SHG of the 1064 nm laser.



(a)

(b)

Fig. 6 (a) The spectra of the green light and red light; (b) Phase matching curves of KTA for the red light and SHG

IV. CONCLUSION

In conclusion, a high energy dual-wavelength KTA OPO with high stability and excellent beam quality is demonstrated. The pulse energy of 10.2 mJ at 3.467 μm and 11.9 mJ at 1.535 μm is achieved, which is the highest energy of the mid-infrared output in an extracavity KTA OPO for the mid-infrared laser to our knowledge. The conversion efficiency from 1.064 μm to 3.467 μm is as high as 14%. Moreover, the output of the KTA OPO is very stable due to the single-longitudinal-mode pump laser. Due to the efficient and highly stable operation, this simple and compact extracavity KTA OPO is a powerful source with high energy, well suited for many applications.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China under Grant 60878060 and 61078129.

REFERENCES

[1] S. T. Yang and S. P. Velsko, “Frequency-agile kilohertz repetition-rate optical parametric oscillator based on periodically poled lithium niobate,” Opt. Lett. 24, 133-135 (1999).

[2] K. L. Vodopyanov and P. G. Schunemann, “Broadly tunable noncritically phase-matched $ZnGeP_2$ optical parametric oscillator with a 2-μJ pump threshold,” Opt. Lett. 28, 441-443 (2003) .

[3] M. Henriksson, M. Tiihonen, V. Pasiskevicius and F. Laurell, “Mid-infrared ZGP OPO pumped by near-degenerate narrowband type-I PPKTP parametric oscillator,” Appl. Phys. B 88, 37-41 (2007).

[4] X. J. Wang and Z. Y. Xu, “Single-longitudinal-mode operation of a 1 W combined actively and passively Q-switched Cr, Nd:YAG laser,” Opt. Express 13, 6693-6698 (2005).

[5] R. F. Wu, K. S. Lai, H. F. Wong, W. J. Xie, Y. L. Lim, E. Lau, “Multiwatt mid-IR output from a Nd:YALO laser pumped intracavity KTA OPO,” Opt. Express 8, 694-698 (2001).

[6] A. Dergachev, D. Armstrong, A. Smith, T. Drake, M. Dubois, “3.4-μm ZGP RISTRA nanosecond optical parametric oscillator pumped by a 2.05-μm Ho:YLF MOPA system,” Opt. Express 15, 14404-14413 (2007).

[7] P. Schlup, G. W. Baxter and I. T. McKinnie, “Single-mode near mid-infrared periodically poled lithium niobate optical parametric oscillator,” Opt. Commun. 176, 267-271 (2000).

[8] M. Henriksson, M. Tiihonen, V. Pasiskevicius, F. Laurell, “$ZnGeP_2$ parametric oscillator pumped by a linewidth-narrowed parametric 2 μm source,” Opt. Lett. 31, 1878-1880 (2006).

[9] X. L. Dong, B. T. Zhang, J. L. He, H. T. Huang, K. J. Yang, J. L. Xu, C. H. Zuo, S. Zhao, G. Qiu, Z. K. Liu, “High-power 1.5 and 3.4 μm intracavity KTA OPO driven by a diode-pumped Q-switched Nd:YAG laser,” Opt. Commun. 282,1668-1670 (2009).

[10] D. L. Fenimore, K. L. Schepler, U. B. Ramabadran and S. R. McPherson, “Infrared corrected Sellmeier coefficients for potassium titanyl arsenate,” J. Opt. Soc. Am. B 12, 794-796 (1995).