Stable, High-Average-Power, Degenerate Optical Parametric Oscillator at 2.1 µm

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Abstract: We describe a degenerate 1.064-µm-pumped pulsed optical parametric oscillator based on MgO:PPLN in compact Littrow-grating cavity configuration, providing 2.7W of average power at 2.1µm with high spectral and power stability in good spatial beam quality.

OCIS codes: (190.4970) Parametric oscillators and amplifiers; (190.4410) Nonlinear optics, parametric processes; (140.3070) Infrared and far-infrared lasers.

Coherent laser sources operating at ~2 µm are of interest for various applications including LIDAR and remote sensing [1]. The favorable water absorption in this region also enables several biomedical applications [2,3]. In addition, such sources can be used to drive nonlinear processes for mid-infrared or terahertz generation, in particular for pumping long-wave optical parametric oscillators (OPOs) covering the 3-10 µm wavelength range. Such OPOs require nonlinear materials such as $ZnGeP_2$ (ZGP) and orientation-patterned GaAs (OP-GaAs), which necessitate pumping beyond ~2 µm to avoid two-photon absorption. As such, high-power laser sources with linear polarization and high beam quality, operating slightly beyond 2 µm, are of great demand for pumping such mid-IR OPOs. To date, laser sources at ~2 µm have been based predominantly on relatively specialist Tm- or Ho-based solid-state and fiber laser technology. In this report, we present an alternative approach to the development of high-power laser sources at ~2 µm using OPOs pumped by widely available, low-cost Nd-based solid-state lasers at ~1 µm. We achieve this goal by spectral control of a pulsed near-degenerate OPO using a diffraction grating, circumventing the intrinsic spectral and power instabilities associated with doubly-resonant oscillation near degeneracy, also restricting the inherently broad OPO bandwidth for subsequent frequency conversion into the deep-IR using further nonlinear processes.

The schematic of the experimental setup of the MgO:PPLN OPO is shown in Fig. 1(a). The pump laser is a linearly polarized, Q-switched Nd:YAG laser at 1.064 µm with variable repetition rate from 20 kHz to 100 kHz. The pump beam is focused to beam waist radius of w_0~150 µm inside the MgO:PPLN crystal, which is 50-mm-long, 2-mm-wide, and 1-mm-thick, with a single grating period of Λ=32.16 µm, corresponding to a degenerate phase-matching temperature of 72 ºC. The OPO is configured in a three-mirror cavity, with mirror, M_1, highly transmitting (T>90%) for the pump at 1.064 µm and highly reflecting (R>99%) over 1.800-2.150 µm. The output coupler, M_2, is highly reflecting (R>90%) for the pump and partially transmitting (T~60%) at the degenerate wavelength, ensuring a double-pass-pump doubly-resonant configuration for the OPO. A filter with a cut-on wavelength of 1.65 µm is used to extract the degenerate OPO output from the undepleted pump. A diffraction grating with a blazing wavelength of 2.16 µm and 600 grooves/mm is used in Littrow configuration as the third cavity mirror for spectral narrowing the OPO output. The total optical length of the OPO cavity, including the crystal was 126 mm. A laboratory photograph of the grating-cavity OPO is shown in Fig. 1(b).

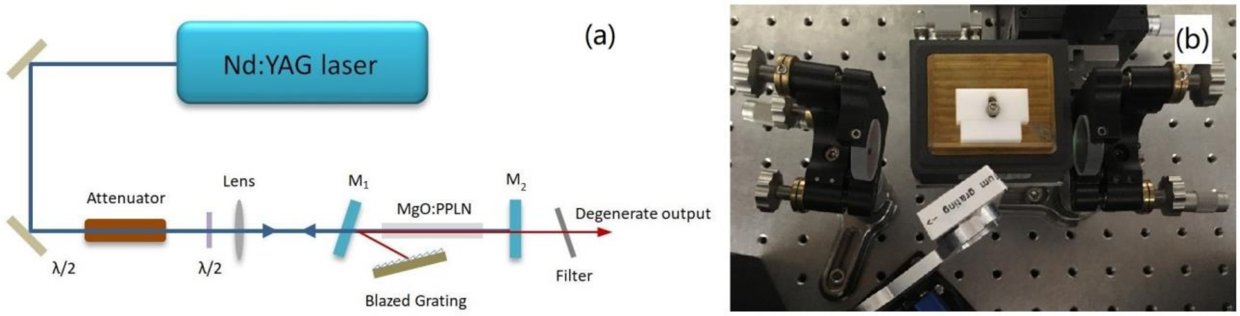

Fig. 1. (a) Schematic of the degenerate OPO setup. λ/2, half-wave plate. (b) Laboratory photograph of the grating-cavity OPO.

In order to characterize the OPO, we first performed power scaling measurements at three different repetition rates, while operating at a near-degenerate wavelength of 2126.5 nm. The results are shown in Fig. 2(a), where slope efficiencies of 28.4%, 23.9% and 18.5% are obtained for 65 kHz, 80 kHz and 90 kHz, respectively. The OPO generated a maximum average output power of 2.7 W for a pump power of 13.7 W at 80 kHz, corresponding to an extraction efficiency of 19.7%. Given the double-pass pumping configuration, the average pump power was not increased beyond 14 W at the three repetition rates to avoid crystal damage. The passive stability of the degenerate OPO at the highest power level was also measured over 1 hour, resulting in 1.05% rms, as shown in Fig. 2(b). The inset of Fig. 2(b) shows the spatial beam profile of the degenerate output at highest power, indicating single-peak intensity distribution. Furthermore, we used a scanning-slit beam profiler and a linear translation stage to measure the beam quality of this output beam. The M^2 values were determined to be M_x^2~3.83 in the horizontal direction and M_y^2~2.48 in the vertical direction.

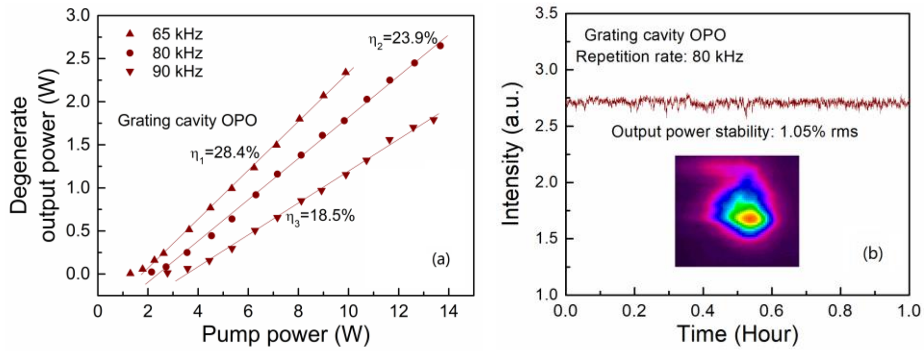

Fig. 2. (a) Power scaling of the grating cavity OPO at different repetition rates.
(b) Power stability of the grating cavity OPO. Inset: the beam profile of the degenerate output.

We further investigated the temporal characteristics of the grating-cavity OPO at the highest output power using a fast infrared detector. A typical single pulse shape of the degenerate wave with duration of 20.5 ns at 80 kHz is shown in Fig. 3(a), with the corresponding the pulse-to-pulse stability shown in Fig. 3(b), measured to be 3.18% rms over 100 ms, after intensity normalization. The effectiveness of the grating cavity in Littrow configuration was also tested at 80 kHz repetition rate using a home-made spectrometer, where we were able to scan the spectrum of the degenerate wave with a resolution of ~0.68 nm. We first measured the single-pass OPG spectrum at the highest pump power, resulting in a broad FWHM bandwidth of 73 nm at degeneracy, as shown in Fig. 3(c). On the other hand, with the grating-cavity OPO, the output spectrum at the same pump power was dramatically reduced to a FWHM bandwidth of 3.9 nm at degeneracy, as shown in Fig. 3(d).

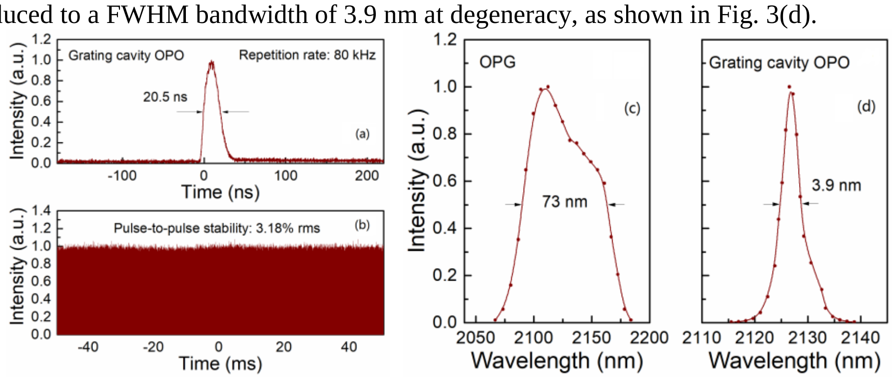

Fig. 3. (a) The measured single pulse profile, and (b) pulse train over 100 ms of the OPO output.
The measured output spectrum of the (c) OPG, and (d) grating-cavity OPO at degeneracy.

In conclusion, we have demonstrated a pulsed near-degenerate OPO based on MgO:PPLN in a grating-cavity configuration pumped at 1.064 μm, and providing up to 2.7 W of average power at 80 kHz repetition rate with high passive stability, good spatial quality, and narrow bandwidth at ~2.1 μm. This OPO offers a viable alternative to Tm- and Ho-doped solid-state and fiber lasers at ~2.1 μm for a variety of applications, including pumping of long-wave parametric sources in the 3-10 μm spectral range in the deep-IR.

References

[1] J. P. Carious, B. Augere, and M. Valla, "Laser source requirements for coherent lidars based on fiber technology," C. R. Phys. **7**, 213-223 (2006).

[2] C. R. Wilson, L. A. Hardy, P. B. Irby, and N. M. Fried, “Collateral damage to the ureter and Nitinol stone baskets during thulium fiber laser lithotripsy,” Lasers Surg. Med. **47**, 403–410 (2015).

[3] N. V. Alexeeva, and M. A. Arnold, “Near-infrared microspectroscopic analysis of rat skin tissue heterogeneity in relation to noninvasive glucose sensing” J Diabetes Sci Technol. **3**, 219–232 (2009).