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 2.7 W of average power at 2.1 µm with high spectral and power stability in good spatial beam quality.

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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-wavelength optical parametric oscillators (OPOs) covering the 3–10 µm wavelength range. Such OPOs require nonlinear materials such as ZnGeP₂ (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 w₀=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 °C. The OPO is configured in a three-mirror cavity, with mirror, M₁, 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, M₂, 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-off 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).

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 $M_x^2 \approx 3.83$ in the horizontal direction and $M_y^2 \approx 2.48$ 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.](image)

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.](image)

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