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High-Power, Fiber-Laser-Pumped Picosecond Optical Parametric Oscillator for the Near- to Mid-Infrared

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Abstract: We report a high-power picosecond optical parametric oscillator synchronously pumped by a Yb fiber laser. The oscillator provides a total average power of 9.58 W at 60% extraction efficiency in a TEM_{00} spatial beam profile.
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Synchronously pumped optical parametric oscillators (SPOPOs) are attractive sources of high-repetition-rate, wavelength tunable picosecond and femtosecond pulses from the UV to mid-IR. Picosecond SPOPOs are of particular interest for applications where pulses of narrow bandwidth and high average power are required. A key factor in achieving this goal is the exploitation of suitable nonlinear materials capable of withstanding the large average powers while at the same time fulfilling the requirements of long interaction length, phase-matching for the wavelength range of interest, high nonlinear gain, and noncritical phase-matching to achieve the high focused intensities. Quasi-phase-matched (QPM) ferroelectric crystals can fulfill such simultaneous requirements, although the attainment of high average powers requires control of crystal heating effects to minimize thermal lensing and thermal phase-mismatching, which can lead to output instabilities. Among the QPM nonlinear crystals, periodically-poled $LiNbO_3$ (PPLN) has been established as the most effective material for the generation tunable picosecond pulses at high average powers in the infrared [1]. However, PPLN is susceptible to photorefractive effect when exposed to increasing levels of visible light, generated through higher-order phase matching or non-phase-matched processes, which can deteriorate the temporal, spatial and power stability of SPOPO output, limiting efficient and practical operation. Doping with MgO, however, can greatly reduces the photorefractive damage, permitting stable high-power generation, even at low operating temperatures close to the room temperature.

Another important factor is the development of new mode-locked pump sources in improved architectures to reduce system complexity and cost, while maintaining or enhancing the SPOPO performance with regard to all important operating parameters. A major step in this direction is the deployment of more simplified, compact, portable and cost-effective pump sources based on fiber laser technology to replace the more complex mode-locked picosecond lasers predominantly deployed to date. Recently, the operation of a picosecond SPOPO at a low repetition rate of 15.3 MHz providing an average power of 1.09 W was reported [2]. Here we report the generation of high-repetition-rate picosecond pulses at multiwatt average powers in the near- to mid-infrared using a SPOPO based on MgO:PPLN and synchronously pumped by a cw mode-locked Yb fiber laser 81 MHz repetition rate. We extract total average powers of up to 9.58 W in the near- to mid-IR for 16 W of pump power at 60% external efficiency.

A schematic of the experimental setup is shown in Fig. 1. The 20-ps (FWHM) pulses from the Yb fiber laser (Fianium, FP1060-20) at a wavelength of 1064 nm are focused into a 50-mm-long, 8.2-mm-wide, 1-mm-thick MgO:PPLN crystal, which contains seven grating, equally spaced in period from 28.5 μm to 31.5 μm, and kept in an

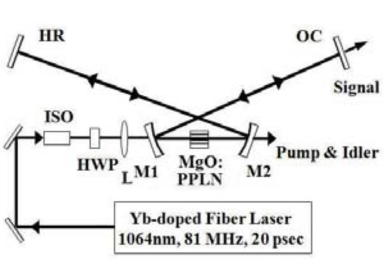

Fig. 1. Experimental setup of picosecond optical parametric oscillator. OC: Output Coupler, HR: High-Reflector, M1 and M2: curved mirrors, ISO: optical isolator, HWP: a half-wave plate, L: focusing lens.

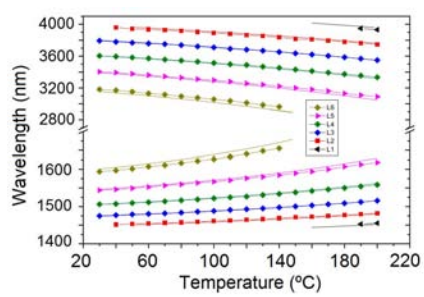

Fig. 2. Temperature tuning of SPOPO with changing MgO:PPLN crystal grating and temperature. L1 to L6 are 28.5, 29, 29.5, 30, 30.5, 31 μm. Points are the experimental data and lines are calculated theoretical curves.

oven with a temperature stability of ±0.1°C. The SPOPO is formed in a four-mirror standing-wave cavity configuration, comprising two curved mirrors (M1 and M2, *r*= 20 cm, CaF_2 substrate), which are highly reflecting for the signal (*R*>99.9%) and highly transmitting for the idler (*T*>87%) and pump (*T*~92%). The plane output coupler (OC) has 20-25% transmission over the signal wavelength range, while the other plane mirror (HR) is highly reflecting for signal (*R*>99.9%) and highly transmitting for the pump (*T*~92%). The signal output is extracted from the OC and the idler radiation is measured after M2. We tuned the signal and corresponding idler wavelength by changing the temperature of the crystal for different grating periods. Tuning data for six of the seven available grating periods (28.5-31 µm) are shown in Fig. 2, along with the corresponding theoretical curves based on the appropriate Sellmeier equations [3]. The last grating period was not accessible due to the physical limitation imposed by the oven design.

Figure 3 shows the average output signal power as a function of pump power at the input to the MgO:PPLN crystal. The measurement was performed at signal wavelength of 1.55 µm (idler at 3.393 µm) and at crystal temperature of 53 ºC. The SPOPO exhibits a threshold of 830 mW (with ~25% output coupling at 1.55 µm) and SPOPO output increases with increased pump power. We measured the signal output power, shown at Fig. 3, for an output coupling of 20-25% for three different pump powers of 5 W, 9.37 W and 16 W. The SPOPO signal power extraction efficiency remains relatively constant, decreasing only slightly from 43.4% to 41%. With the highest available pump power of 16 W at the input to the crystal, we were able to extract 6.53 W of signal power from the SPOPO. This level of output power is in itself useful for additional frequency conversion processes external to the SPOPO cavity such as cascaded down-conversion into deeper mid-IR. In addition, the large circulating signal intensities can be harnessed for efficient frequency up-conversion internal to the SPOPO using a secondary focus in a modified cavity design to reach other wavelengths in the visible [4].

Figure 4 depicts the corresponding average output idler and total power for pump powers of 5 W, 9.37 W and 16 W. At the highest pump power, we generated 9.58 W of total power (6.53 W signal, 3.05 W idler) from 16 W of pump with ~60% extraction efficiency in excellent TEM_{00} spatial beam quality. At all three pump powers, depletion was ~85% and the pulse spectrum exhibited a clean single peak with a bandwidth of ~0.47 nm, as shown in Fig. 5.

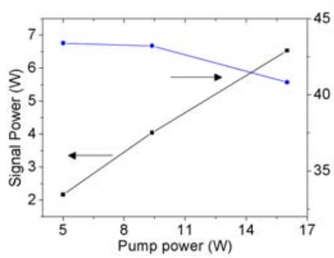

Fig. 3. SPOPO signal output power and efficiency at 1.55 µm versus pump power at the input to the crystal.

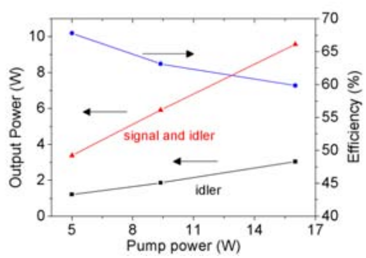

Fig. 4. SPOPO idler (at 3.393 µm), total average power, and total power efficiency versus pump power.

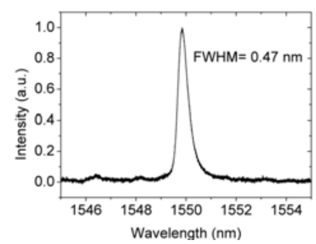

Fig. 5. Spectrum of the out-coupled 6.53 W signal power at 16 W of pump power.

In conclusion, we have demonstrated successful operation of a picosecond SPOPO based on MgO:PPLN and capable of delivering 9.58 W of output power in the near- and mid-infrared at an external efficiency as high as 60%. The SPOPO is synchronously pumped by a high-power picosecond Yb fiber laser at 1.064 µm and is continuously tunable from 1.45 to 1.75 µm. We have been able to obtain in a TEM_{00} spatial profile with high power and spectral stability by avoiding crystal heating effects. The high-power, wide tunability, and excellent spatial and spectral quality of the SPOPO, combined with the use of a fiber pump laser, make it a practical source of high-repetition-rate picosecond pulses for many applications.

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