Optimally-Output-Coupled, 17.5 W, Yb-Fiber-laser-Pumped Continuous-Wave Optical Parametric Oscillator

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Summary

We report a compact, practical, fiber-laser-pumped, cw optical parametric oscillator based on MgO:PPLN, capable of delivering as much as 17.5 W of infrared output power at 61% extraction efficiency, with a pk-pk idler power stability of 5% over 14 hours and TEM_{00} spatial beam quality with M^2<1.24 (idler), M^2<1.39 (signal).

Introduction

Continuous-wave (cw) mid-infrared optical parametric oscillators (OPOs) are of prime interest for variety of applications including photo-acoustic spectroscopy and trace gas analysis [1]. Generating high mid-infrared output powers in cw OPOs is challenging due to heavy thermal loading of the nonlinear crystal arising from the high intracavity signal power at increased pump powers. To date, the highest output power generated from a cw OPO is 10 W of idler at 3 μm for 50 W of pump at 20% efficiency using a singly resonant oscillator (SRO) [2]. Output coupling of SRO signal has enabled the generation of 8.6 W of total power (5.1 W signal, 3.5 W idler) for 15 W of pump, with improved extraction efficiency up to 59% [3]. Here we report the generation of as much as 17.5 W of total power (9.8 W signal, 7.7 W idler) from an out-coupled cw SRO at 61% extraction efficiency. We also show that high power stability and good spatial beam quality can be maintained at such elevated output powers by careful control of crystal thermal loading effects through optimized signal out-coupling. To our knowledge, this is the highest output power and extraction efficiency reported from a cw OPO.

Experiment

The OPO is pumped by a Yb fiber laser delivering up to 30 W of single-frequency output at 1064 nm with M^2<1.01 and a nominal linewidth of 89 KHz. The nonlinear crystal is 50-mm, 5% MgO:PPLN with five gratings (□□29.5-31.5 μm). The pump beam is focused to a waist radius of 63 μm at the centre of the crystal (ξ~1). The OPO is a compact ring cavity formed by two concave and two plane mirrors. All mirrors have R>99%@1.3-1.9 μm and T>90%@2.2-4 μm for SRO operation. Out-coupled SRO (OC-SRO) operation is achieved by replacing one of the plane high reflectors with a suitable output coupler (OC) at the signal. Careful cavity design ensures accurate overlap of pump and signal waists within the crystal. The total length of the cavity is 862 mm (FSR~348 MHz).

The power scaling results for the SRO and OC-SRO (□=31 μm, 100 °C) are shown in Fig. 1. In the SRO configuration, an idler power of 8.6 W was generated at 3061 nm

ISBN 978-3-00-024191-8

for 28.6 W of pump at 30.1% efficiency. In order to maximize output power and efficiency, we performed signal out-coupling optimization by deploying several OCs of transmission ranging from 3% to 6%. The inset of Fig. 1 shows the variation of signal and idler power with OC transmission. As seen from the plot, with a 3.8% OC, we were able to generate 7.7 W of idler at 3070 nm together with 9.8 W of signal at 1627 nm, resulting in 17.5 W of total power, at an overall extraction efficiency of 61%. The power scaling of the OC-SRO with the 3.8% OC is also shown in Fig. 1, clearly demonstrating >200% output power enhancement over SRO. We also recorded the long-term idler power stability of the OC-SRO at 40 ^{o}C, where a pk-pk stability as high as 5% was obtained over 14 hrs (Fig. 2). Using a CaF_2 lens and a scanning beam profiler, we also measured M^2<1.24 and M^2<1.39 of the idler and signal, respectively, confirming the TEM_{00} spatial mode. The inset of Fig. 2 shows the 3D beam profile of the output idler at 3174 nm. The results in Fig. 2 were obtained at full idler power of >7 W. To our knowledge, these are the first measurements of idler power stability and beam profile at such mid-IR wavelengths.

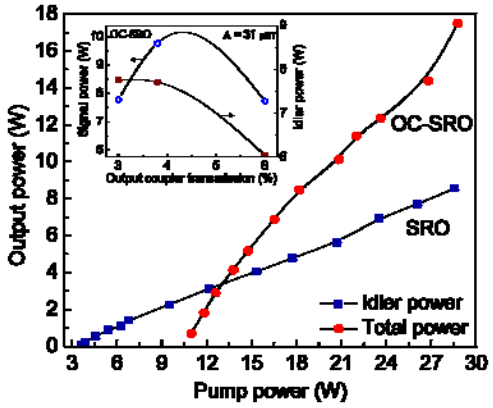

Fig. 1: Extracted output power against pump power in SRO and 3.8% OC-SRO, and (inset) variation of output power with OC transmission.

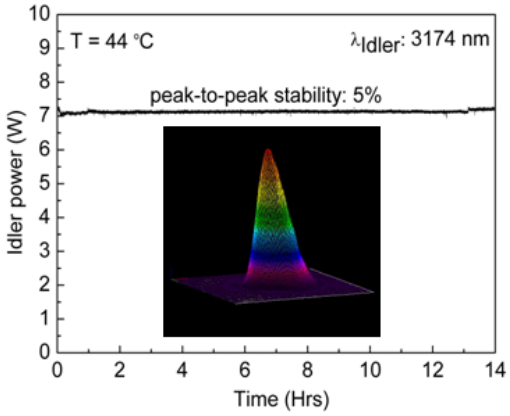

Fig. 2: Idler power stability of OC-SRO over 14 hours, and (inset) 3D beam profile of idler.

Conclusion

We have generated 17.5 W of total infrared power at 61% extraction efficiency from a compact, fiber-pumped cw OPO by using optimized signal output coupling to control thermal loading of the nonlinear crystal. The exceptional power, high long-term stability and excellent beam quality make this cw OPO an attractive mid-infrared source for many applications. Full characterization of this system, including wavelength tuning, thermal issues and frequency stability have been preformed and will be presented.

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