1.27 W, tunable, continuous-wave, single-frequency, solid-state blue source

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Abstract: We describe a tunable, cw, single-frequency blue source based on internal SHG of a cw singly-resonant OPO, providing up to 1.27 W across 425-489 nm with a passive frequency stability <280 MHz over >5 minutes.

OCIS codes: 190.4970, 190.4360, 190.4400, 1902620, 190.7220, 140.7300.

Continuous-wave (cw) solid-state blue sources are of interest for optical data storage, laser displays, spectroscopy, and medical diagnostics. While cw GaN diodes or frequency-doubling of AlGaAs diodes and short-wavelength Nd:YAG and Nd:YVO_4 lasers can provide practical powers in the blue, they offer little or no tunability. Frequency doubling of Ti:sapphire can provide coverage in the 400-500 nm range, but at increased cost and complexity. Similar approaches based on diode-pumped Cr:LiSAF have achieved limited power in confined blue tuning range.

Recently, we reported a new technique for the generation of cw blue radiation, which offers wide tuning range across 425-489 nm, practical output power up to 448 mW, and single-frequency performance, in a simple, compact, all-solid-state design [1]. The approach is based on intracavity SHG of a cw singly-resonant OPO (SRO) based on MgO:sPPLT [2,3]. Here, we report high-power, single-frequency and mode-hop-free operation of this device with frequency stability better than 280 MHz over 340 seconds and blue power in excess of 1.27 W across 425-489 nm.

Figure 1 shows the schematic of the experimental setup. The ring cavity comprises two concave reflectors, M_1 and M_2 (r=100 mm), and two plane mirrors, M_3 and M_4. The mirrors are all reflecting (R>99.9%) for the resonant signal (840-1000 nm) and highly transmitting (T=85-90%) for the idler (1100-1400 nm), thus ensuring SRO operation. M_4 also has high transmission (T=85-90%) over 425-500 nm. The nonlinear crystal is MgO:sPPLT (d_{eff}~10 pm/V). It is 30-mm long and contains a single grating (Λ=7.97 µm). The pump is a frequency-doubled, cw, single-frequency Nd:YVO_4 laser[2,3]. For internal SHG and frequency selection, a BiB_3O_6 (BIBO) as the nonlinear crystal and a 500-µm-thick uncoated fused silica etalon (free spectral range (FSR) =206 GHz, finesse ~0.6) are used respectively at the second cavity waist between M3 and M4. The BIBO crystal is 5 mm in length and cut for type I interaction ($ee \rightarrow o$) in the yz-plane (φ=90°) at an internal angle θ=160° at normal incidence (d_{eff}~3.4 pm/V). The crystal end faces are AR-coated for the resonant signal (R<0.5%) and for the SHG wavelengths (R<0.8%). The total optical length of the cavity including the crystals and etalon is 690 mm, corresponding to a FSR~434 MHz.

By varying the MgO:sPPLT crystal temperature from 71 °C to 240 °C, the signal could be tuned from 978 to 850 nm [3]. The corresponding SHG wavelengths from 489 to 425 nm are generated by varying the BIBO crystal angle from 163.8° to 155.2°. Figure 2 (a) shows the extracted SH blue power across the tuning range. The measured power varies from 145 mW at 425 nm to 360 mW at 489 nm, with as much 1.27 W available at 459 nm with a green to blue conversion efficiency in excess of 14% at crystal temperature 128°C. We extracted >500 mW of blue power over 58% of the tuning range and >250 mW over 84% of the tuning range. The sudden fall in the blue power near 450 nm is due to the rise in signal coupling loss through mirror M_4, which results in reduced intracavity signal power and thus lower SHG conversion efficiency. As such, the use of a more optimized coating for M_4 with minimum transmission loss across the signal tuning range will readily overcome the dip in SHG power. The overall decline in blue power towards the shorter wavelengths is, however, attributed to the reduction in intracavity signal power due to the increased effects of thermal lensing near the extremes of the SRO tuning range (higher temperatures), higher MgO:sPPLT crystal coating losses, and parametric gain reduction away from degeneracy, as observed previously [3]. As evident in Fig. 2(b), there is also >100 mW of useful signal output available over 850-

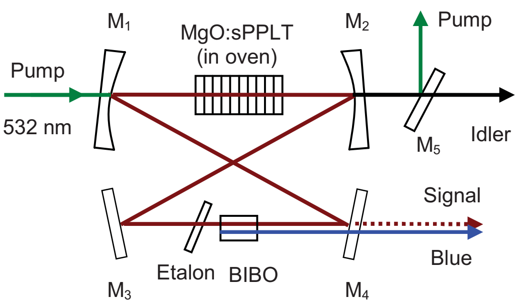

Fig. 1. Schematic of the intracavity frequency-doubled MgO:sPPLT cw SRO for blue generation, with BIBO as the SHG crystal.

915 nm (50% of total signal tuning range), with 970 mW at 900 nm. In addition to the blue and signal radiations, the SRO simultaneously generates substantial levels of non-resonant idler radiation with powers of more than 780 mW, with as much as 2.6 W across the 1167-1422 nm tuning range.

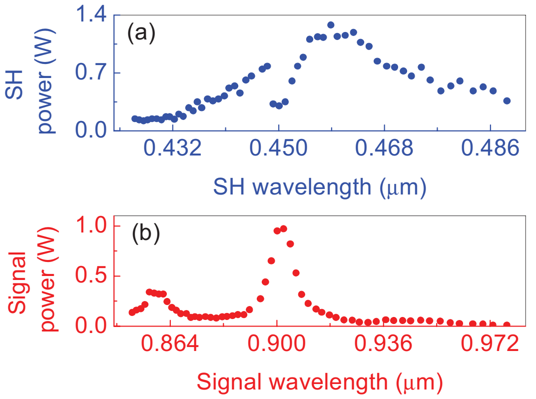

Fig. 2. (a) Generated blue power versus wavelength, and (b) Coupled-out signal power across the tuning range.

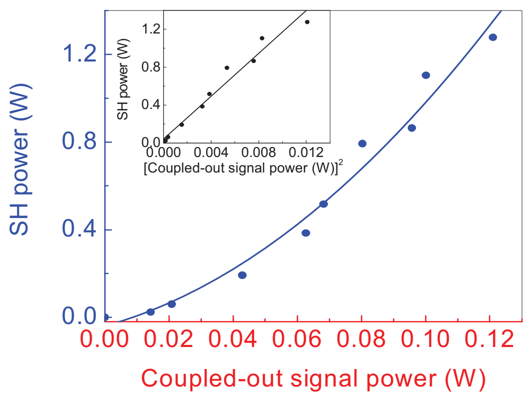

Fig. 3. Quadratic dependence of SHG power on coupled-out signal power. Inset, linear dependence of SHG power on the square of the coupled-out signal power.

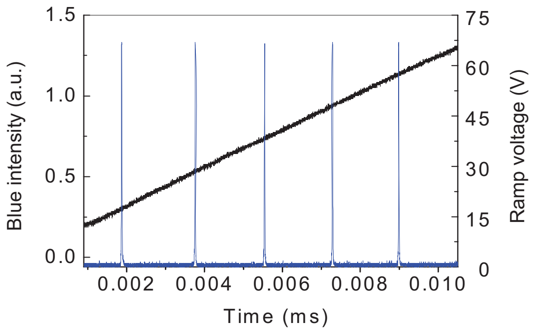

Fig. 4. Single-frequency spectrum of the generated blue light recorded by a scanning Fabry-Perot interferometer.

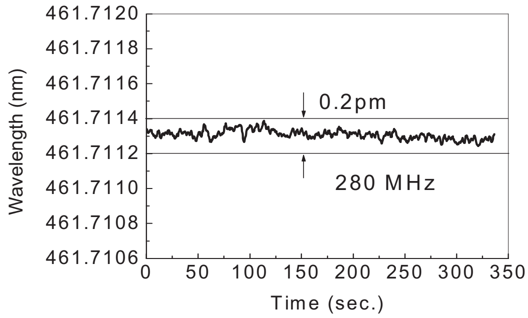

Fig. 5. Wavelength variation of the blue radiation over time.

Figure 3 shows the blue power at 459 nm as the function of the out-coupled signal power by varying the input pump power. As expected, the increase in SHG power with out-coupled signal power is seen to be quadratic, also implying quadratic variation with the intracavity signal power. The inset of the Fig. 3 also confirms the linear variation in SHG power with the square of the out-coupled signal power, as expected.

We analyzed the spectrum of the generated blue light using a confocal scanning Fabry-Perot interferometer (FSR=1 GHz, finesse=400). A typical transmission fringe pattern at maximum blue power at 459 nm is shown in Fig. 4, confirming single-frequency operation with an instantaneous linewidth of ~8.5 MHz. Similar behaviour was observed throughout the tuning range in the blue. In the absence of active frequency control, we recorded mode-hope-free, single-mode behavior of the blue output using a wavemeter (BRISTOL 612A, resolution 0.2 pm). As evident in Fig. 5, passive frequency-stability of the system is better than 280 MHz (limited by the wavemeter resolution) over a time-scale of 340 seconds, implying the possibility of stable single-frequency operation over longer time with active stabilization and improved thermal isolation of the system from the laboratory environment.

In conclusion, we have demonstrated a high-power, cw, stable single-frequency blue source tunable in the 425-489 nm spectral range and providing as much as 1.27 W of output power. The device exhibits free-running frequency stability better than 280 MHz over 340 seconds without active stabilization.

References

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