Stable, high-power, continuous-wave, single-frequency source at 532 nm using MgO:sPPLT crystal

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Abstract: We describe a compact, high-power, cw green source based on single-pass SHG of a Yb-fiber laser in MgO:sPPLT, providing 7.58W, single-frequency output at 532nm in TEM_{oo} profile(M^2<1.29) with peak-to-peak power stability of 9% over 13h.

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High-power, continuous-wave (cw), single-frequency green sources are of interest for variety of scientific and technological applications, including pumping of Ti:sapphire lasers and cw singly-resonant optical parametric oscillators (SROs) pumped in the visible [1]. To date, such sources have been based almost exclusively on internal second-harmonic-generation (SHG) of cw Nd:YAG and Nd:YVO_4 solid-state lasers, where the attainment of stable, high-power, and single-frequency performance necessitates elaborate system designs involving intricate cavity configurations, thermal management, and active stabilization, resulting in complexity and high cost. It would, thus, be desirable to devise alternative approaches for the development of such sources using more simplified and cost-effective techniques. An attractive approach is external SHG of high power infrared lasers in quasi-phase-matched (QPM) ferroelectric materials such as MgO:PPLN [2], MgO:sPPLT [2,3], and PPKTP [2,4], of which MgO:sPPLT has demonstrated the most promise due to its high photorefractive damage threshold and large thermal conductivity to handle high optical powers. Earlier reports on green generation in MgO:sPPLT include external single-pass SHG of a 91.5-W cw Nd:YAG laser, providing a maximum power of 16.1 W at 17.1% conversion efficiency [3]. However, the development of high-power, cw, single-frequency sources in the green based on cw fiber laser technology and offering high output power stability, spatial beam quality, mandatory requirements for the above applications, has not been extensively explored. Here we describe such a source using a simple, compact, and cost-effective design based on external single-pass SHG of a cw Yb fiber laser in MgO:sPPLT. The source can deliver 7.58 W of cw, single-frequency green power at 532 nm with a conversion efficiency as high as 25.6%, peak-to-peak power stability of 9% over 13 hours, and TEM_{oo} spatial profile.

The configuration of the experimental setup is identical to our previous work [4]. The nonlinear crystal is MgO:sPPLT (d_{eff}~10 pm/V). It is 30-mm long, with a single grating period of Λ=7.97 µm, and is housed in an oven with a temperature stability of ±0.1 °C. The crystal faces are antireflection (AR) coated (R<0.5%) for the fundamental (1064 nm), and high transmission (T>99%) at second harmonic (532 nm) wavelength. The pump

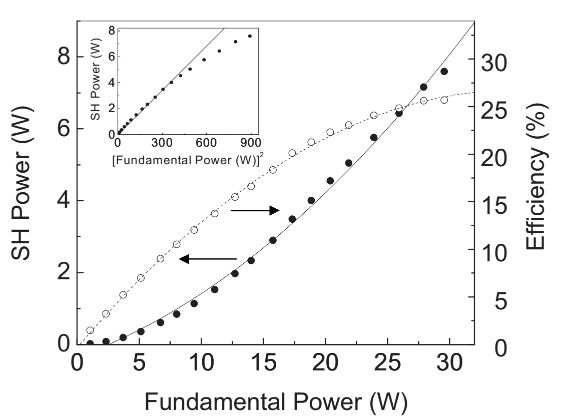

Fig. 1. Dependence of the measured cw SHG power and the corresponding conversion efficiency on the incident fundamental power. Inset: Variation of SH power as a function of square of the fundamental power.

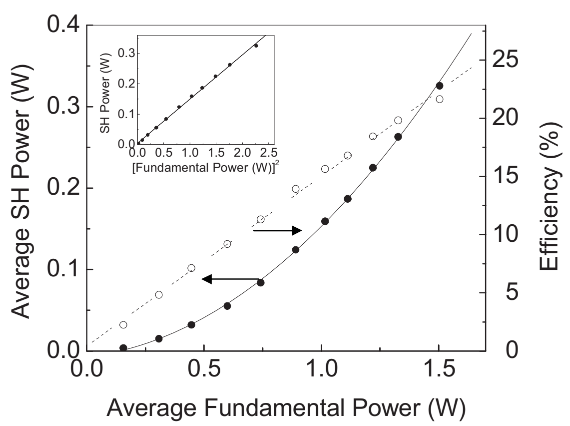

Fig. 2. Dependence of the measured quasi-cw SH power and the corresponding conversion efficiency on the incident fundamental power. Inset: Variation of SH power as a function of square of the fundamental power.

source is a 30-W cw Yb fiber laser at 1064 nm (IPG Photonics, YLR-30-1064-LP-SF), which delivers single-frequency output in a linearly polarized beam with a M^2 factor <1.01, and a linewidth of 12.5 MHz [4]. The fundamental beam was focused to a beam waist radius of w_0~37 µm (1/e^2-intensity) in the crystal (ξ=1.74).

The SHG power and efficiency up to the maximum available fiber laser power of 30 W, are shown in Fig. 1. We obtained 7.58 W of green power at the full fundamental power of 29.58 W, representing a single-pass conversion efficiency of 25.6 %. The quadratic increase in SH power and the corresponding linear variation in efficiency are maintained up to a fundamental power of 21 W (Fig. 1), after which saturation sets in. The saturation effect is also evident from the deviation of the linearity of SHG power with the square of the fundamental power, in the inset of Fig.1, and is attributed to pump depletion, back-conversion and thermal phase-mismatch effects in the MgO:sPPLT crystal. To verify the contribution of pump depletion and back conversion to saturation effect, we chopped the fundamental beam at a frequency of 530 Hz, with 5.5% duty cycle, in order to characterize the SH output without thermal effects. Fig. 2 shows the quadratic variation of the generated average green power and corresponding linear variation of conversion efficiency up to the highest fundamental power, showing no sign of saturation. The inset of the Fig. 2 also confirms the linear variation of SHG power with the square of fundamental power, as expected, implying that the saturation effect is only due to the thermal phase-mismatch effects in the MgO:sPPLT crystal resulting from the absorption of fundamental and the generated green power.

The power stability and spectral output near the maximum green power of 7.58 W are shown in Fig. 3. Under free-running conditions and in the absence of thermal isolation, the green power exhibits a peak-to-peak fluctuation of 7.6% over the first 8 h and 9% over 13 h. This power fluctuation is attributed mainly to the change in the laboratory environment. The transmission spectrum of generated green output at the highest power, monitored through a confocal scanning interferometer (FSR=1GHz, finesse=400), is shown in the inset of Fig. 3, confirming reliable single-frequency operation with an instantaneous linewidth of ~6.5 MHz. Similar behavior was observed

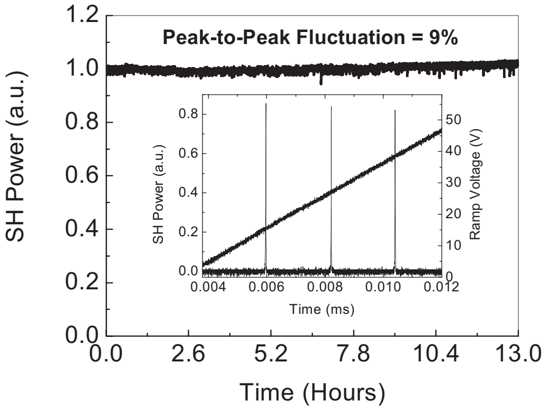

Fig. 3. Green output power stability at 7.58 W over 13 h and the corresponding single-frequency spectrum (inset).

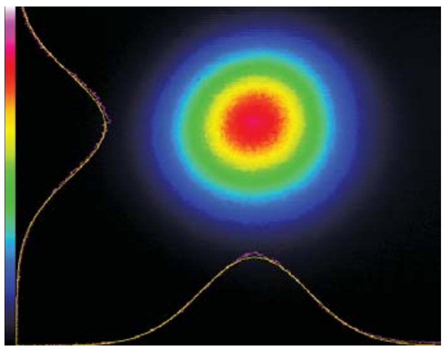

Fig. 4. TEM_{00} energy distribution, beam profiles (pink curves), and Gaussian fits (yellow curves) of the generated green beam at 7.58 W in the far-field.

throughout the pumping range with the same instantaneous linewidth, confirming robust single-mode operation at all pump powers. Further improvements in green power stability, below 3%, are expected through improved thermal isolation and better temperature control.

The far-field energy distribution of the green radiation at 7.58 W, together with the intensity profile and corresponding Gaussian fits in the two orthogonal axes, recorded at 29.58 W of fundamental power, are shown in Fig. 4. Using a focusing lens of 25-cm focal length and scanning beam profiler, we measured M^2 values of the green beam to be M_x^2 ~1.29 and M_y^2 ~1.23, confirming TEM_{00} spatial mode, useful to pump SROs.

In conclusion, we have demonstrated a cw, high-power, stable, single-frequency green source at 532 nm, providing green power as much as 7.58 W with a natural peak-to-peak power-stability better than 9% over 13 h. Power-stability can further be improved by proper thermal management, making it an alternative source for pumping of cw and mode-locked Ti:sapphire lasers and cw single-frequency SROs.

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