Generation of 30 mW CW ultraviolet by a two-path geometry for cascaded $\chi^{(2)}$ processes with periodically poled lithium niobate crystals

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Abstract: 30 mW continuous wave ultraviolet radiation is generated via a two-path geometry for cascaded frequency doubling and sun-frequency generation (SFG) at 18.9 W pump, where SFG is enabled by a third-order periodically poled MgO:LiNbO$_3$.

I. INTRODUCTION

Continuous-wave (CW) ultraviolet (UV) lasers are useful in photolithography, holography, flow cytometry, and spectroscopy [1-4]. CW UV can be obtained by gas lasers [5], however, they are typically bulky, inefficient, and of limited output power. Frequency tripling by using a Nd:YAG laser and two nonlinear crystals for cascaded second-harmonic generation (SHG) and sum-frequency generation (SFG) can be an alternative method. For example, CW powers of 68 mW, 7 mW, and ~100 mW at 355 nm were demonstrated by using a single-path geometry (the same fundamental beam pumped the SHG and SFG crystals located along a line), where a BIBO [6], third-order periodically poled MgO-doped congruent LiTaO$_3$ (PPMgCLT) [7] and MgO-doped stochastic LiTaO$_3$ (PPMgSLT) [8] were used for SFG, respectively. In practice, BIBO and SLT crystals suffer from lower nonlinear coefficient (d_{33}~3.9 pm/V), poorer beam quality (due to the spatial walk-off), higher cost, and supply chain trouble, respectively. The single-path geometry is further subject to lower conversion efficiency for the lack of optimization of (1) the fundamental power budget for the two processes, and (2) the waist locations and beam diameters of the fundamental and second-harmonic beams in the SFG crystal. In this work, we used a two-path geometry to independently control the pump powers for the two processes and the focusing conditions of the two pump beams in the SFG crystal. Up to 30 mW CW UV power was produced by 18.9 W pump, a first-order periodically poled MgO-doped congruent LiNbO$_3$ (PPMgCLN) for SHG and a third-order PPMgCLN for SFG, respectively.

II. THEORY AND EXPERIMENTAL RESULTS

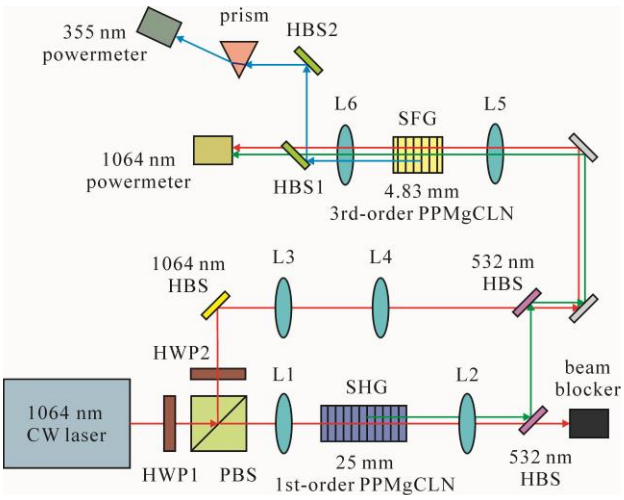

Fig. 1. Experimental setup. HWP, half-wave plate; PBS, polarization beamsplitter; HBS, harmonic beamsplitter.

Figure 1 shows the experimental setup. The fundamental pump source was a 27-W Nd:YAG CW laser at 1064 nm. The first half-wave plate (HWP1) and the polarization beamsplitter (PBS) controlled the ratio between the fundamental powers used in SHG and SFG, respectively. The p-wave component was focused by a lens L1 into a 25-mm-long first-order PPMgCLN for SHG, then re-collimated by another lens L2. The s-wave component was brought to p-wave by HWP2. The lens pairs L1, L2 and L3, L4 are designed for beam expansion. By properly choosing the locations and focal lengths of L1-L5, we were able to optimize the diameters of fundamental (1064 nm) and second-harmonic (532 nm) beams and made the two waists coincide with each other inside the 4.83-mm-long third-order PPMgCLN for SFG. To accurately measure the UV power at 355 nm, two harmonic beam splitters (HBS1-2, with <0.5 % reflectance at 1064 nm and 532 nm) and a prism were introduced to separate the UV beam from the rest two colors.

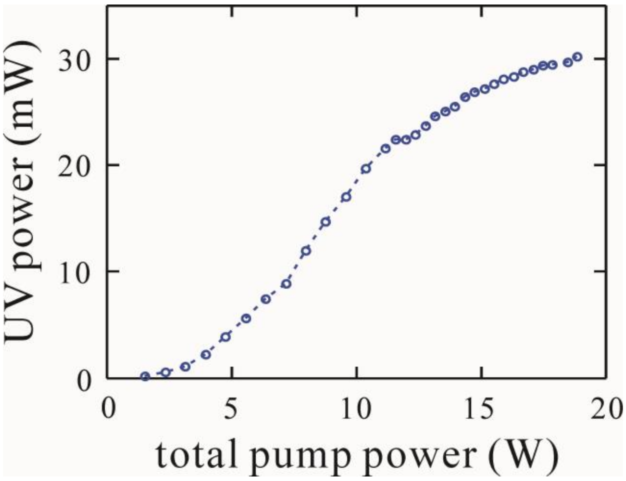

Fig. 2. The UV output power versus the total pump power.

Figure 2 shows the relation between the total pump power (1064 nm) and the output UV power (355 nm) of our system under the experimentally optimized conditions (focal lengths are f_1=17.5 cm, f_2=30 cm, f_3=5 cm, f_4=15 cm, f_5=10 cm). Each data point represents a result of 2-min average. The maximum UV power of 30.2 mW was obtained when the total pump power, the fundamental and second-harmonic input powers for SFG were 18.9 W, 7.72 W, and 0.42 W, respectively. The input/output relation exhibits evident saturation at pump powers higher than 11 W. This is mainly attributed to the longitudinal crystal temperature gradient caused by UV absorption, where only a fraction of the crystal length is at the perfect phase-matching temperature.

The UV absorption effect was further evidenced by the distortion of the measured phase-matching tuning curves at high pump powers.

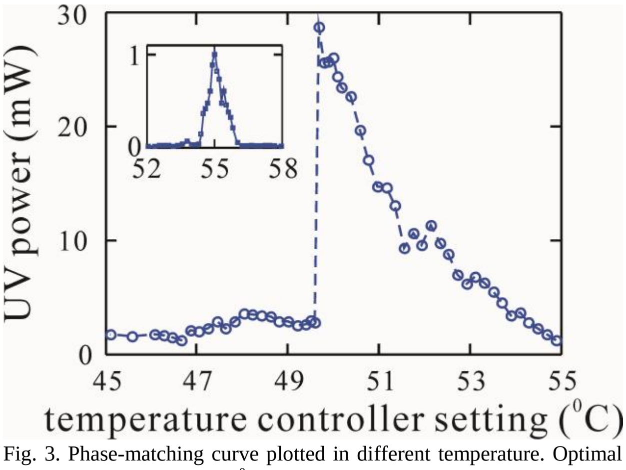

Fig. 3. Phase-matching curve plotted in different temperature. Optimal PPLN condition is at 49.7^{0}C. The slope edge is sharp between 49.6-49.7^{0}C in high power condition. Subplot: phase-matching curve at low input power.

Figure 3 shows the phase-matching curves of SFG at total pump powers of 18.9 W and 3.2 W (inset), respectively. The curve exhibits a strong asymmetry at high pump powers, significantly different from the ideal sinc^2 function. This abnormal feature comes from the UV absorption-induced transversal gradient of crystal temperature. Since the temperature sensor is placed between the crystal bottom and the heater, the light-matter interaction area is actually hotter than the temperature controller setting (supposed equal to the sensor temperature). When the temperature controller setting is reduced from the optimal value by ΔT, the UV power will decrease due to the increased phase mismatch. The lower UV power absorption further cools down the light-matter interaction area, causing a temperature drop even more than ΔT. The extra phase mismatch results in an even lower UV power accordingly. On the contrary, the cooling effect in the light-matter interaction area can partially compensate the temperature increasing instructed by the controller and produce an UV power higher than expectation. As a result, the phase-matching tuning curve could exhibit a steeper rising edge and a smoother falling edge if the temperature controller setting is used as the independent variable. The curve is expected more symmetric if the actual crystal temperature is used or at lower UV powers (inset, Fig. 3).

III. CONCLUSIONS

We demonstrated a two-path frequency tripling system, where a 4.83-mm-long third-order PPMgCLN is used for the SFG process. This new geometry permits optimization of the pump power budget and focusing conditions, realizing a four-fold enhancement of CW UV power (30 mW) compared with the single-path geometry with third-order PPCLT crystal. We would like to thank HC Photonics Corp. for providing the PPMgCLNs.

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