High-average power THG of a diode-pumped Nd:YAG laser at 355 nm generated by LiB_3O_5 crystal

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More than 6 W average power ultraviolet radiation at 355 nm was generated in LiB_3O_5 (LBO) crystal through the frequency mixing of the fundamental and second harmonic radiation of a Nd:YAG laser. This performance was achieved with 38% optical-to-optical conversion efficiency (532 nm to 355 nm).

OCIS codes: 140.3610, 140.3480, 140.3580.

High-average power diode-pumped Q-switched solid-state laser at 355 nm has potential applications in the fields of printed circuit board manufacturing and precise material processing with the advantages of high reliability and low maintenance cost compared with other UV lasers. The printed circuit board manufacturing demands UV lasers to provide more than 300 μJ per pulse at high repetition and industrial precise processing applications, such as drilling on printed circuit board or cutting the printed circuit, generally requires the UV average power range from 5 to 10 W at kHz repetition. High efficient third-harmonic generation (THG) of laser radiation of Nd^{3+} doped crystals through sum-frequency generation of fundamental and second-harmonic in nonlinear crystal is one of the most promising methods to generate high power UV laser[1-4] and more than 10 W 355 nm radiation at high repetition were reported. Here we report that more than 17 W 532 nm average power output is obtained at 4 kHz repetition rate by non-critically phase matching SHG with LiB_3O_5 (LBO) and more than 6 W 355 nm by critically phase matching THG with LBO.

Figure 1 shows schematic drawing of the experimental setup. A 90° quartz rotator is inserted between two identical laser modules (CEO: RB30-1C2) to compensate the thermal birefringence, which makes the stable regions of different polarization overlapping each other to increase the output power. The dimensions of Nd:YAG rod is $\Phi 3 \times 64$ mm^2. Plane-plane cavity is used in experiment and the total cavity length is 71 cm. The calculated dependence of TEM_{00} mode radius on thermal lens is shown in Fig. 2. As the current of the pump increases from 5 to 26 A, the thermal lens decreases from 1000 to about 310 mm and develops from the bottom of the stability zone to the hemispherical edge of the stability zone. At the maximum diode pump power this configuration results in a calculated fundamental mode radius of 0.8 mm in stability zone. This mode size allows only a few lowest modes to oscillate without the loss of laser power.

An acousto-optic Modulator (NEOS Model: N33027-50-51-M3) with high diffraction loss is used for Q-switching to generate the repetition range from 1 to 50 kHz. The maximum average output power of 1064 nm is greater than 60 W with 18% slope efficiency. Second harmonic generation (SHG) is realized with a non-critically phase-matched LBO of 20 mm length. The M^2 factor of 532 nm radiation is measured to be about 3.9. A critically phase matched LBO crystal ($\theta = 42.6°$, $\phi = 90°$) with the size of $4 \times 4 \times 15.6$ mm^3 is used for external UV generation. Because the refractive index of LBO is sensitive to temperature and the thermal conductivity of LBO is 0.035 W/(cm ·° C), which is about 1/4 of that of Nd:YAG, and the permitted temperature range for THG is as small as 3.47 (cm ·° C), accurate temperature control is very important for high efficient THG with high stability. The polarization of 355nm is arranged in horizontal polarization and a pair of quartz Brewster prisms are used to separate 355 nm from 1064 and 532 nm for measurement. Figure 3 presents measured output power at the wavelength of 532 and 355 nm as a function of diode drive current at the repetition rate of 4 kHz.

Initially, the laser operates in high beam quality and the efficiency of frequency conversion is higher. However, as the pump increases, the efficiency of frequency conversion is decreasing, because the beam quality of the fundamental light becomes worse for the reason that the thermal lens is in the bottom of stability zone of resonance cavity and the TEM_{00} mode radius is almost the same as that in lower pump. Increasing the pump further, the thermal lens moves into the edge of stability zone and the TEM_{00} radius becomes larger, therefore, the beam quality becomes better and the efficiency of SHG is the highest. The maximum average output power

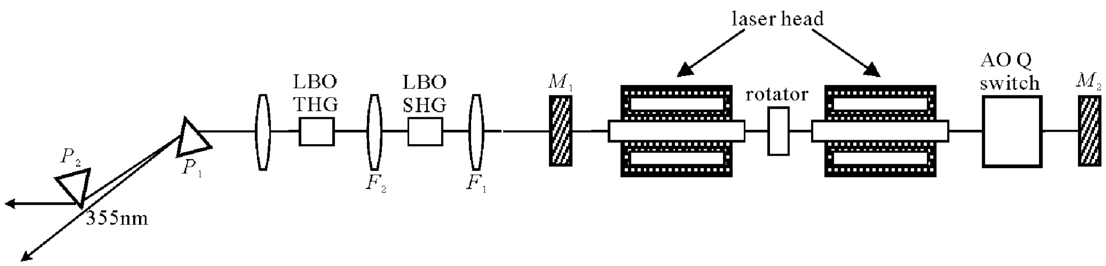

Fig. 1. Experimental setup. M_1: output coupler; M_2: HR mirror; F_1, F_2: lenses; P_1, P_2: Brewster prisms.

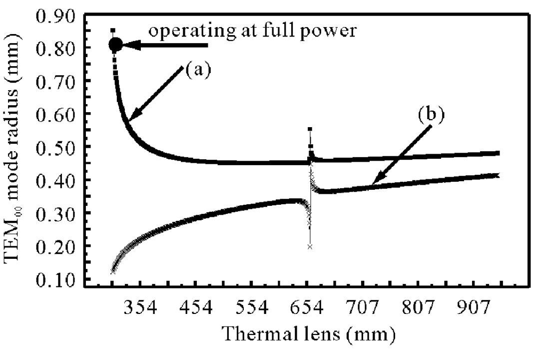

Fig. 2. The calculated dependence of TEM_{00} mode radius on the thermal lens. The dependence of spot sizes on Nd:YAG rod and mirror are given by curve (a) and (b), respectively.

at 532 and 355 nm are 17.6 and 6.72 W, respectively, at the diode drive current of 26 A, and the optical-to-optical efficiency (532 nm to 355 nm) is up to 38%. With the accurate temperature control, the output stability of 532 and 355nm is better than 10% and 8%, respectively.

In conclusion, we have reported an ultraviolet 355 nm radiation source with average output power of more than 6 W at the repetition rate of 4 kHz. We believe that it is possible to enhance the output of 355 nm radiation up to 10 W by enhancing the output power of 532 nm and improving the beam quality. Because the permitted temperature range for THG is very small, a key problem for obtaining more 355nm output is to design high efficient heat sink to decrease the temperature gradient in THG LBO crystal. Further work on enhancement of output power is now under way.

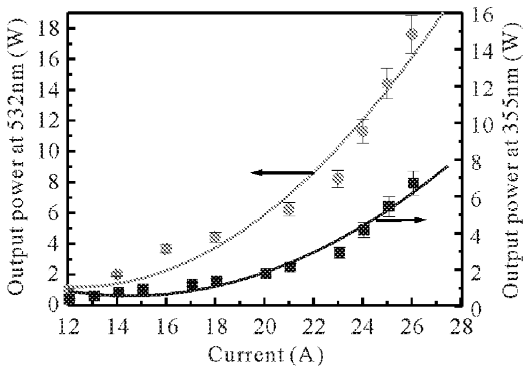

Fig. 3. Output power at the wavelength of 532 (circle) and 355 nm (square) as a function of diode drive current at the repetition rate of 4 kHz.

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