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REPETITION OPERATION OF A 447.3 nm BLUE–VIOLET LASER BY INTRACAVITY FREQUENCY DOUBLING OF AN LD-PUMPED CESIUM VAPOR LASER

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Abstract

We investigate experimentally the repetition operation of a 447.3 nm blue–violet lasers pumped by intracavity frequency doubling of an LD-pumped cesium vapor laser. We study the output performance of the 447.3 nm laser using am LBO crystal as an intracavity frequency doubler. We obtain maximum power in the repetition operation of 0.36 mW, and the slope efficiency does not decrease in the range of pump powers from 2 to 16 W. Our results show that the thermal effect can be reduced in the repetition operation. The optimized working temperature of the LBO is ∼25°C, with a full width at half maximum (FWHM) of 4.1°C.

Keywords: blue–violet laser, cesium vapor laser, frequency doubling, repetition operation.

1. Introduction

In recent years, an increasing number of applications of blue–violet laser sources with high power and high efficiency have emerged in high-density optical data storage, medical diagnostics, laser displays, precision meteorology, spectroscopy, and underwater communication.

The blue–violet lasers are commonly produced by frequency conversion of all-solid-state lasers [1–5]. In comparison, the diode-pumped alkali vapor lasers (DPALs) have many preferred properties, such as higher quantum efficiency, narrower emission linewidth, larger stimulation absorption/emission cross

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section, and smaller refractive index perturbation. So there exists a potential to develop more efficient repetition operation of 447.3 nm blue–violet lasers by intracavity frequency doubling of LD-pumped cesium vapor laser.

Much effort toward the development of blue–violet lasers have been aimed at frequency doubling of DPALs. In 2008, frequency doubling of a diode-pumped rubidium vapor laser (Rb-DPAL) by a BIBO crystal with a SH power of 40 mW at 398 nm was reported by Petersen et al. [6]. Later, the same authors increased the second harmonics (SH) power to 250 mW [7]. In 2008, a SH power of 300 mW at 447.3 nm was obtained by Zhdanov et al.; they used a single-pass frequency doubling of a pulsed Cs-DPAL with a PPKTP crystal [8]. Then the SH power was increased to 2.1 W by intracavity frequency doubling of a pulsed Cs-DPAL, using a PPKTP crystal [9]. In 2010, a comparative study of the performance of nonlinear crystals (PPKTP, BIBO, and LBO) for frequency doubling of a Cs-DPAL was reported. For the Cs-DPAL operating in the pulse mode, the maximum SH powers were 2.5, 1.12, and 0.277 W using PPKTP, BIBO, and LBO, respectively [10]. In 2016, employing external-cavity frequency doubling of a tapered amplified diode laser at the cesium D1 line, a continuous single-frequency blue laser at 447.3 nm was reported, and a maximum blue power of 178 mW with 50.8% conversion efficiency was obtained [11]. In 2016, we obtained a SH power of 11.2 μW at 447.3 nm employing extracavity frequency doubling of a Cs-DPAL and using a LBO crystal; the theoretical study of the characteristics of intracavity frequency doubling of a Cs-DPAL was also demonstrated [12, 13].

In this paper, we carry out experiments on the repetition operation of 447.3 nm blue–violet lasers by intracavity frequency doubling of a cesium vapor laser. We analyze the SH power and slope efficiency in the repetition operation through comparison with the CW operation. In addition, we investigate the temperature performance and measure the full width at half maximum of the temperature curve.

2. Experimental Setup

In Fig. 1, we show the experimental setup of intracavity frequency doubling of an LD-pumped cesium vapor laser. A fiber-coupled LD is employed as the pump source, which provides a maximum output power of 16 W. The central wavelength of the LD is 852.3 nm with a linewidth of 0.17 nm. The numerical aperture of the fiber is 0.22 with a diameter of 400 μm. The pump beam is coupled to a cesium vapor cell by a coupling system consisting of two aspheric plano-convex lenses. To optimize the mode-matching efficiency between the pump beam and the oscillating beam and reduce the thermal-lensing effect in the cesium vapor cell, the focal lengths of the plano-convex lens are chosen as 20 and 50 mm, respectively. The radius of the pump beam waist is $\sim$500 μm. The resonator consists of a spherical dichroic mirror and a flat bandpass filter as the output coupler. The spherical dichroic mirror has a reflectivity of 99.9% at 894.6 nm and a transmission of 97.5% at 852.3 nm, with the radius of curvature of the spherical dichroic mirror being 500 mm. The flat bandpass filter has a reflectivity of 99.99% at 894.6 nm and a transmission of 98% at 447.3 nm. The resonator length is $\sim$160 mm. The cesium vapor cell in the oven is placed near the spherical dichroic mirror, and the cavity TEM_{00} mode in the cesium vapor cell has a radius of $\sim$300 μm. The LBO crystal (3×3×15 mm) is placed in a copper oven near the bandpass filter, which is working at a phase matching of I type. The temperature of the LBO is controlled with 0.1°C accuracy. An indium foil is used between the copper oven and the crystal surface to ensure a fairly good thermal contact. Both sides of the LBO crystal are antireflection coated at 447.3 and 894.6 nm.

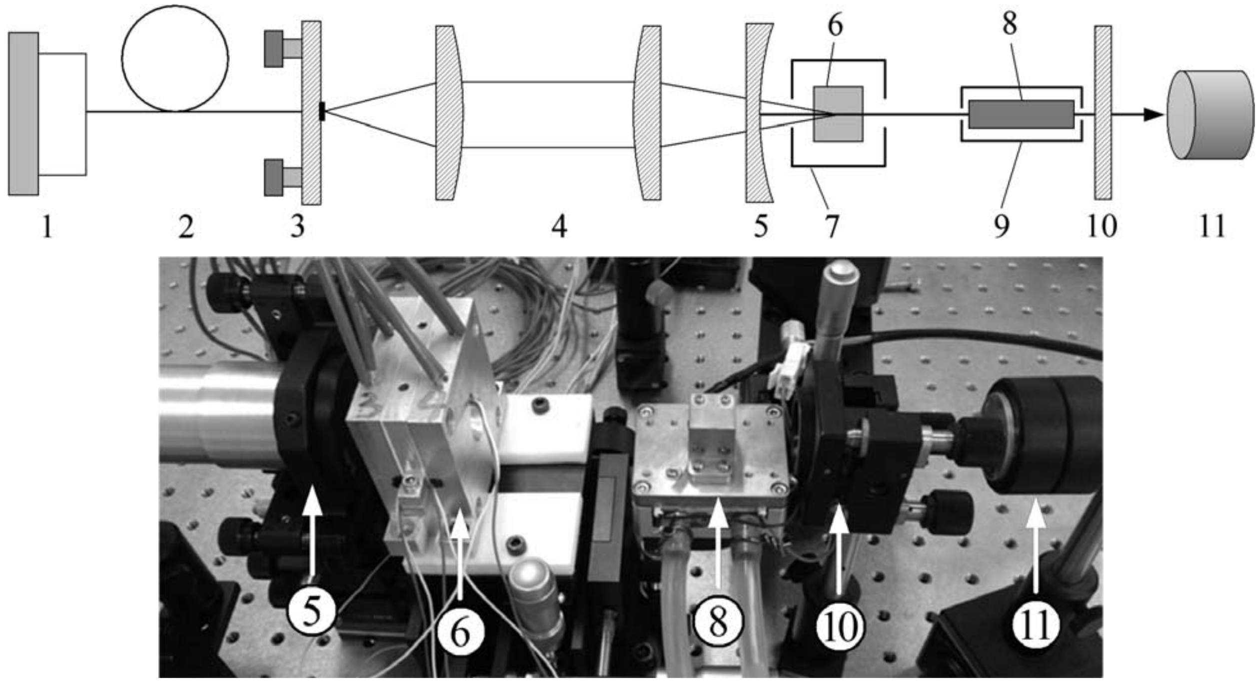

Fig. 1. Experimental setup of intracavity frequency doubling of an LD-pumped cesium vapor laser. Here, laser diode 1, optical fiber 2, fiber clip 3, coupling system 4, dichroic mirror 5, Cs vapor cell 6, oven 7, LBO 8, heat sink 9, output coupler 10, and power meter 11.

3. Results and Discussions

We carry out our experiment of the repetition operation of intracavity frequency doubling of the LD-pumped cesium vapor laser using the LBO crystal. We analyze the repetition operation performance of the blue–violet laser and compare it with the CW performance. In Fig. 2, we show the change in the pump power up to 16 W, which provides the SH powers in the CW and repetition operations up to 0.22 and 0.36 mW, respectively. When the pump power is below 10 W, the SH power in the repetition operation is slightly lower than that in the CW operation. In contrast, when the pump power is higher than 10 W, the SH power in the repetition operation is higher than that in the CW operation. In Fig. 2, we also show the cubic and quadratic fittings of the experimental data at the CW and repetition operations. We see that the SH slope efficiency in the CW operation first increases and then decreases with increase in the pump power. However, the SH slope efficiency in the repetition operation decreases at all values of the pump power from 2 to 16 W. This phenomenon is due to the thermal effect in the cesium vapor cell. Thus, the thermal effect of intracavity frequency doubling of LD-pumped cesium vapor lasers can be reduced in the repetition operation, providing a better performance.

In Fig. 3, we present the experimental data and Gaussian fitted curve of the SH power on the LBO-crystal temperature in the repetition operation with a pump power of 10 W. We see that the maximum SH power close to 0.14 mW corresponds to a temperature of $\sim$25°C. Moreover, the full-width at half maximum of the temperature curve is $\sim$4.1°C.

The spectrum of the blue–violet laser elaborated is shown in Fig. 4, using a fiber spectral analyzer (Ocean Optics, HR4000); a wavelength of 447.3 nm was registered.

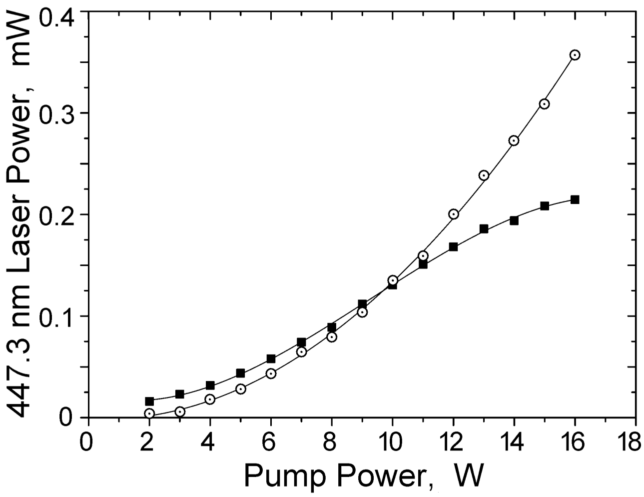

Fig. 2. Experiment data and fitted curves of the SH power in the CW operation (■) with cubic fit and in the repetition operation (⊙) with quadratic fit versus the LD pump power.

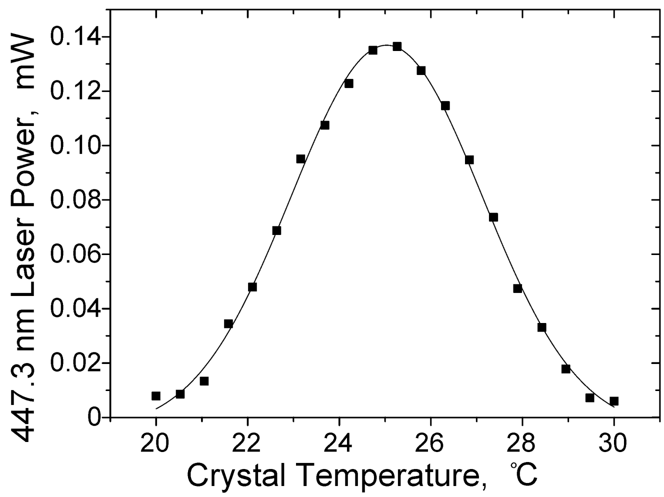

Fig. 3. Experimental data and Gaussian fitted curve of the 447.3 nm laser power as a function of the LBO-crystal temperature in the repetition operation.

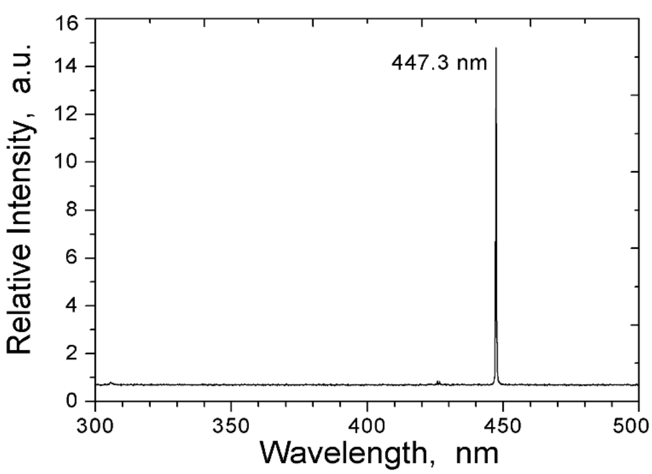

Fig. 4. Spectrum of the 447.3 nm laser.

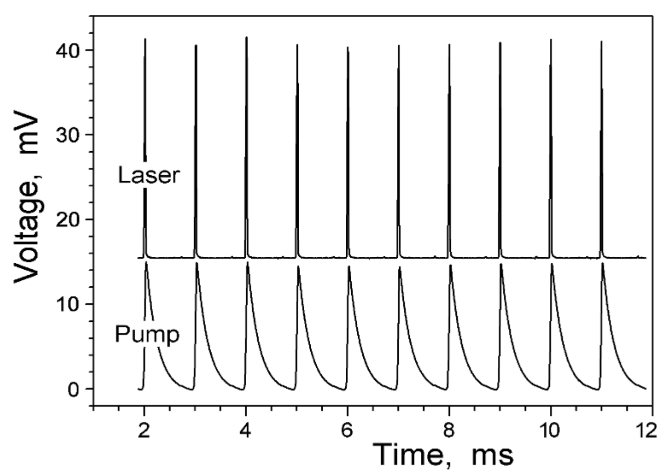

Fig. 5. Repetition operation of the 447.3 nm laser.

Figure 5 demonstrates the repetition operation of the blue–violet laser at a pulse repetition frequency of 1 kHz.

We measure a typical beam profile of the blue–violet laser using a beam quality analyzer (LBA-712PC-D, Spiricon Inc.), and the near field intensity distribution of the 447.3 nm laser is shown in Fig. 6.

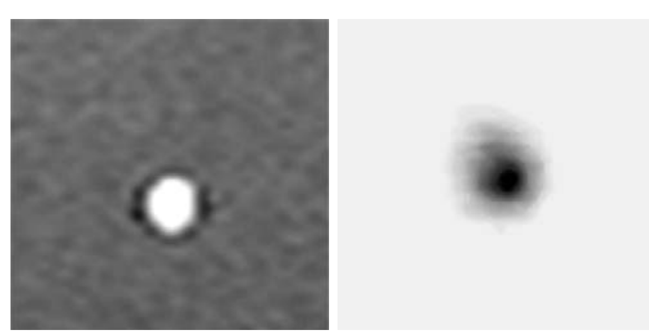

Fig. 6. Beam profile of the 447.3 nm laser recorded by camera and CCD.

4. Conclusions

We elaborated an experiment setup for the repetition operation of intracavity frequency doubling of an LD-pumped cesium vapor laser using an LBO crystal. We investigated the performance of this blue–violet laser source and obtained SH powers in the CW and repetition operations of 0.22 and 0.36 mW, respectively, at a pump power of 16 W. Due to reducing the thermal effect, the repetition operation demonstrates a better performance than the CW operation, which provides higher SH power and slope efficiency. We measured the SH powers at different LBO temperatures and showed that the FWHM of the temperature curve is ∼4.1°C. The optimized temperature of the LBO crystal is ∼25°.

Acknowledgments

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