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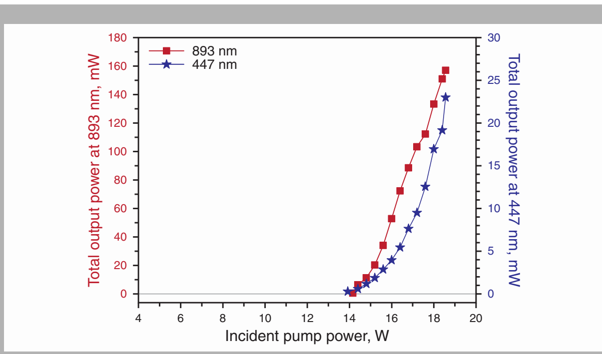
Abstract: We report for the first time a $Nd:GdVO_4$ laser operating in a continuous wave (CW) on the quasi-three-level laser at 893 nm, based on the ${}^4F_{3/2}-{}^4I_{9/2}$ transition, generally used for a 912 nm emission. The use of a pump module with 16 passes through the crystal allowed the realization of a $Nd:GdVO_4$ thin-disk laser with 157 mW of CW output power at 893 nm. Moreover, intracavity second-harmonic generation (SHG) has also been achieved with a power of 23 mW at 447 nm by using a BiB_3O_6 (BiBO) nonlinear crystal.



Output powers at 893 and 447 nm *versus* pump power at 808 nm

Diode-pumped thin-disk $Nd:GdVO_4$ laser at 893 nm

Y.L. Li, [1,*] *A.G. Wang,* [2] *and X.H. Fu* [1]

[1] School of OptoElectronic Engineering, Changchun University of Science and Technology, Changchun 130022, China
[2] Science Park, Changchun University of Science and Technology, Changchun 130022, China

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Key words: diode-pumped; solid-state laser; thin-disk laser; $Nd:GdVO_4$ crystal

1. Introduction

Since T. Fan and R. Byer introduced the first diode laser pumped 946 nm Nd:YAG laser at room temperature in 1987 [1], lasers operating around 0.9 μm have attracted much attention in the past few years [2–13]. This is because the laser around 0.9 μm has some unique applications such as water vapor lidars and differential absorption lidars for ozone measurements, and it also can be used as the pump source for the Yb-doped crystals and Yb-doped fibers. In past few years, the quasi-three-level 912 nm continuous wave (CW) laser emission was investigated for $Nd:GdVO_4$ [14–26] crystal. The ${}^4F_{3/2}-{}^4I_{9/2}$ transition usually used in $Nd:GdVO_4$ for 912 nm emission can offer other possibilities at lower wavelengths (Fig. 1). The lower wavelengths ever reported with diode-pumped solid-state lasers based on Nd^{3+} ions are 899 nm with Nd:YAG [27]. Recently, the pure three-level laser reported based on Nd^{3+} ions, for example, 880 nm [28] with $Nd:YVO_4$, 879 nm [29] with $Nd:GdVO_4$, and 869 nm [30] with Nd:YAG. To the best of our knowledge, the quasi-three-level $Nd:GdVO_4$ laser at 893 nm has not been reported. In this letter, we report on a quasi-three-level $Nd:GdVO_4$ laser at 893 nm by a laser diode for what we believe to be the first time. Moreover, we will also examine intracavity second-harmonic generation (SHG) to reach the blue light at 447 nm.

2. Experimental setup

The experimental setup used is described in Fig. 2a. The optical pumping at 808 nm was realized with a fiber coupled diode laser of DILAS Co., Germany. The maximum CW output power delivered by this prototype diode was 20 W and the width of the emission spectrum was $\sim$2.5 nm. The optical fiber of diode had a diameter of 400 μm and a numerical aperture of NA = 0.22. The laser crystals used in the experiments were 0.5 at.% $Nd:GdVO_4$. The crystals' thickness was 0.2 mm. The thin-disk crystal

* Corresponding author: e-mail: liyongliang1973@163.com

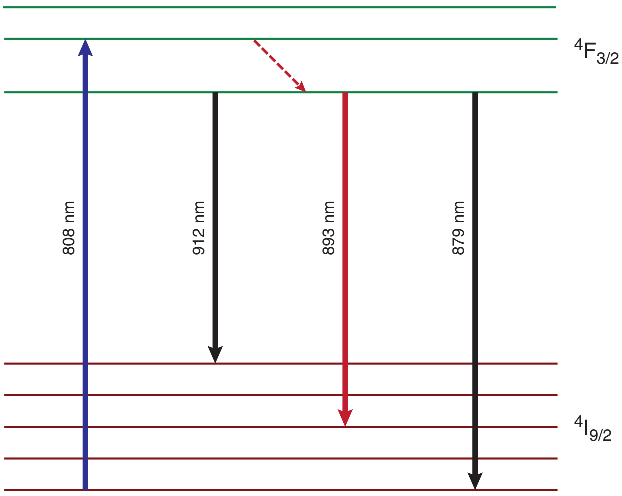

Figure 1 (online color at www.lphys.org) Energy level diagram of Nd^{3+} ion in Nd:GdVO$_4$ crystal

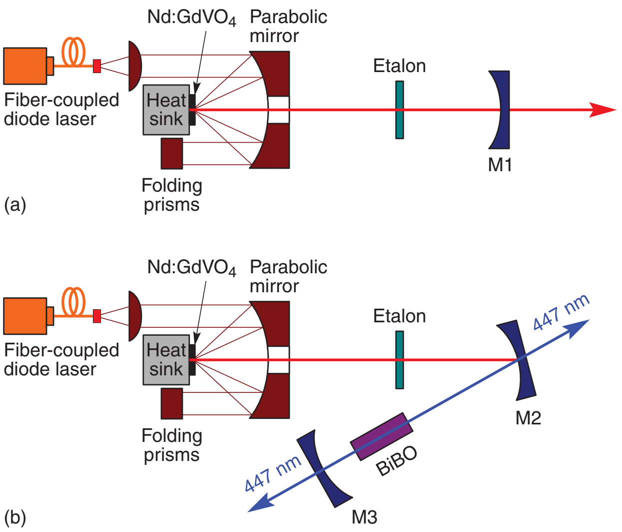

Figure 2 (online color at www.lphys.org) Experimental setup of (a) – the ground state and (b) – the frequency-doubled laser

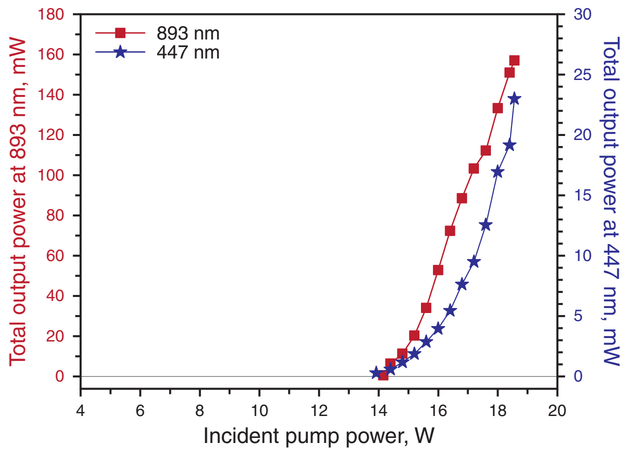

Figure 3 (online color at www.lphys.org) Output powers at 893 and 447 nm *versus* pump power at 808 nm

was anti-reflection (AR)-coated at the front side (S1) and high-reflection (HR)-coated at the rear side (S2) for pump and laser wavelengths. The rear side was soldered onto a water-cooled heat sink with a coolant temperature maintained at 15°C. The parabolic mirror (32 mm focal length) and the folding prisms lead to a 16-pass pump scheme. The radii of curvature of mirror M1 was 200 mm. M1 is an output coupler, which was coated with a transmission of 1.2% at 893 nm and AR from 912 to 1340 nm to suppress the strong parasitical oscillation at these transitions. To select the lasing wavelength, we inserted a 25 μm Fabry-Perot etalon into the cavity.

3. Experimental results

The output power at 893 nm versus the incident pump power is shown in Fig. 3. When the incident pump power is 18.2 W, the laser yielded 157 mW of CW output power at 893 nm. With this configuration, we recorded an oscillation threshold at 12.7 W. This high threshold is because of the energy of the lower level of the laser transition: the closer to the ground state, the lower the laser level, and the harder to reach the population inversion, and the higher the reabsorption at this lasing wavelength. The M^2 factor is 1.17 measured by knife-edge technique which shows that the laser output at 893 nm is operating at TEM_{00} mode. The power stability was investigated by a Field-Master-GS powermeter and the fluctuation was about 2.5% at the maximum output power of 157 mW in 30 min.

The generation of blue light at 447 nm was realized with a V-type resonator, as shown in Fig. 2b. The radii of curvature of mirror M2 was 50 mm. M2 is an output coupler, which was AR coated at 447 nm and AR from 912 to 1340 nm and HR at 893 nm. The radius of curvature of mirror M3 was 200 mm. M3 was AR coated at 447 nm and HR 893 nm. The distances S1 – M1, S1 – M2, and M2 – M3 were 56, 65, and 31 mm, respectively. The generation of blue light was achieved by using a 10 mm long BiB_3O_6 (BiBO) nonlinear crystal, which was cut for type I phase matching ($\theta = 90°$, $\Phi = 23.4°$) at room temperature. The LiB_3O_5 crystal, which had both surfaces AR coated for 893 and 447 nm, was inserted into the M2 – M3 arm of the V-type resonator.

The laser performance is also presented in Fig. 3. With an incident pump power of 18.2 W, a CW SHG total output power of 23 mW at 447 nm blue emission on two output beams has been obtained. The M^2 factors are 1.21 and 1.34 in X and Y directions respectively. The asymmetry of the M^2 factor in two directions is result of the walk-off between the fundamental wave and the second in the

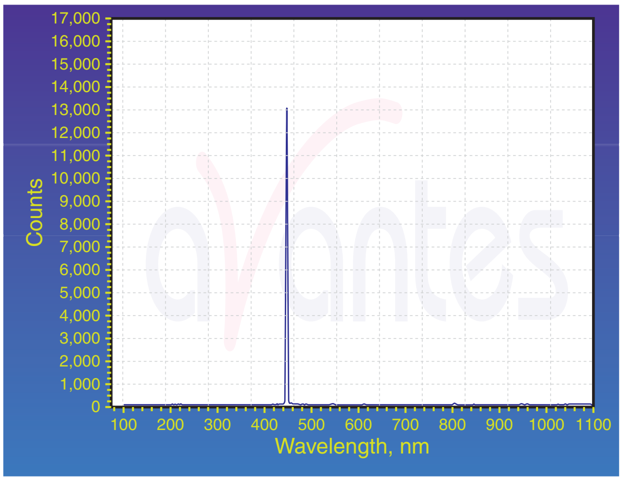

Figure 4 (online color at www.lphys.org) The laser spectrum line of 447 nm blue laser

direction of the BiBO. The fluctuation of the blue output power is about 3.4% in 30 min. Fig. 4 shows the spectra of 447 nm laser, which was detected using the high resolution spectrometer.

4. Conclusion

In conclusion, we succeeded in the realization of what we believe to be the first diode-pumped CW quasi-three level $Nd:GdVO_4$ laser at 893 nm. For the 893 nm emission, a CW output power of 157 mW was achieved. After the SHG, a total power of 23 mW at 447 nm was obtained on two output beams. Thus, this demonstration opens a new way to reach deep wavelengths. More efficient nonlinear conversion could also be obtained by using more efficient nonlinear crystals.

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