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Laser Diode and Pumped Cr:Yag Passively Q-Switched Yellow-Green Laser at 543 nm[1]

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Abstract—Efficient and compact yellow green pulsed laser output at 543 nm is generated by frequency doubling of a passively Q-switched end diode-pumped $Nd:YVO_4$ laser at 1086 nm under the condition of suppressing the higher gain transition near 1064 nm. With 15 W of diode pump power and the frequency doubling crystal LBO, as high as 1.58 W output power at 543 nm is achieved. The optical to optical conversion efficiency from the corresponding Q-switched fundamental output to the yellow green output is 49%. The peak power of the Q-switched yellow green pulse laser is up to 30 kW with 5 ns pulse duration. The output power stability over 8 hours is better than 2.56% at the maximum output power. To the best of our knowledge, this is the highest watt-level laser at 543 nm generated by frequency doubling of a passively Q-switched end diode pumped $Nd:YVO_4$ laser at 1086 nm.

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INTRODUCTION

Diode-pumped all-solid-state lasers have facilitated considerable advances in various fields of science and technology. $Nd:YVO_4$ has proved to be an excellent gain medium because of its high pump absorption coefficient and high gain character. The output wavelengths in research involving $Nd:YVO_4$ crystals were focused mostly at 1064, 1342, and 914 nm. However, a spectroscopic study with crystal-field analysis has demonstrated that there are five or six emission bands with the ${}^4F_{3/2}$–${}^4I_{11/2}$ transition of an $Nd:YVO_4$ crystal. The room temperature fluorescence spectrum shows that one of the Stark components has a central emission wavelength at 1086 nm. The diode end-pumped configuration can provide much stronger pump power density than the transverse pump structure. Therefore it is possible for the operation to be achieved at some weak transitions such as 1086 nm in the diode end-pumped configuration [1–3].

After Zhang et al. demonstrated an efficient intracavity second-harmonic generation (SHG) at 1084 nm in a nonlinear optical crystal of BiB_3O_6 (BIBO) where 19 mW laser output at 542 nm is obtained [4], the output power was enhanced up to 105 mW in 2009 by using type I LiB_3O_5 (LBO) as the frequency doubling crystal by Q. Zheng [5]. The output power at 543 nm has been enhanced to 2.35 W with $Nd:YVO_4$ crystal [6].

In this letter, an efficient and compact yellow green pulsed laser output at 543 nm is generated by frequency doubling of a passively Q-switched end diode-pumped $Nd:YVO_4$ laser at 1086 nm under the condition of suppressing the higher gain transition near 1064 nm. With 15 W of diode pump power and the frequency doubling crystal LBO, as high as 1.58 W output power at 543 nm is achieved. The optical to optical conversion efficiency from the corresponding Q-switched fundamental output to the yellow green output is 49%. The peak power of the Q-switched yellow green pulse laser is up to 30 kW with 5 ns pulse duration. The output power stability over 8 hours is better than 2.56% at the maximum output power. To the best of our knowledge, this is the highest watt-level laser at 543 nm generated by frequency doubling of a passively Q-switched end diode pumped $Nd:YVO_4$ laser at 1086 nm.

THEORETICAL ANALYSIS

Considering the performance of the main laser lines of $Nd:YVO_4$ crystal as a laser gain medium, since the stimulated emission cross section for the 1086 nm transition is approximately five times smaller than that for the 1064 nm line and about three times smaller than that for the 1342 nm line, operation of the $Nd:YVO_4$ laser at 1086 nm requires suppression of the competing transitions at 1064 and 1342 nm. In our experiment, the stronger transitions near 1064 and

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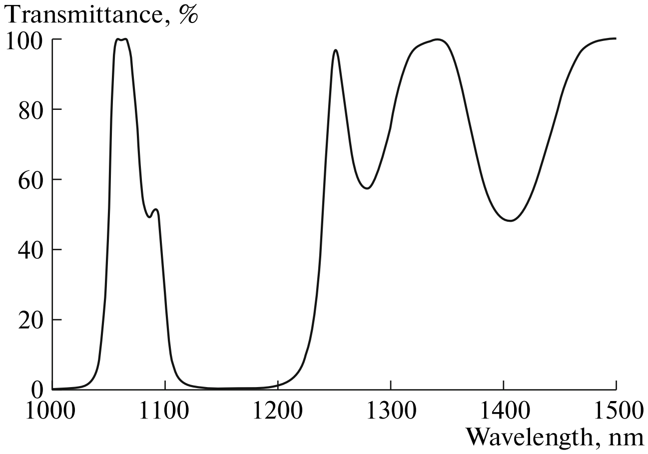

Fig. 1. Transmittance spectrum of the output coupling mirror M1 of the 543 nm laser.

1342 nm are suppressed by use of specifically coated mirrors, especially the output coupling mirror M1, which is convenient for the coating process and commercial utility. Therefore, the output coupling mirror is partially reflective coated at 1086 nm and AR coated at 1064 and 1342 nm, which can suppress the oscillation at 1064 nm. Figure 1 shows the coating curves of the concave surface of the output coupling mirror M1. The left side of the Nd:YVO_4 is coated at 808 nm AR and at 1064 and 1086 nm HR. The other facet of the Nd:YVO_4 is AR coated at 1064, 1086 nm. The left facet of M1 is AR coated at 1064 nm and PR coated at 1086 nm. The right facet of M1 is AR coated at 1086 nm.

The LBO is a $2 \times 2 \times 15$ mm^3 nonlinear crystal ($\theta = 90°$, $\varphi = 9.9°$). Though BIBO has a high nonlinearity of 2.26 pm/V in frequency doubling of the 1086 nm laser, the large walk-off angle of 84.35 mrad, which yields a beam spot with low beam quality, makes BIBO not suitable for this application. LBO is selected as the frequency-doubling material for its small walk-off angle of 6.05 mrad. Although the nonlinear coefficient of LBO is 0.834 pm/V, the length of the LBO could be extended to compensate for the relatively smaller nonlinear coefficient. Both facets of the LBO crystal are AR coated at 543 and 1086 nm to reduce the reflection losses in the cavity. The LBO is mounted in a copper block, which is also fixed on a thermoelectric controller for active temperature control.

EXPERIMENTAL SETUP

The experimental setup is shown in Fig. 2. In this configuration, the pump source is a 10 W 808 nm fiber coupled LD with a core diameter of 400 μm and a numerical aperture of 0.22 for CW pumping. Its emission central wavelength is 808.2 nm at room temperature and can be tuned by changing the temperature of the heat sink to match the best absorption of the laser crystal. The spectral width (FWHM) of the pump source is about 1.5 nm.

The coupling optics consists of two identical plano-convex lenses with focal lengths of 20 mm used to reimage the pump beam into the laser crystal at a ratio of 1 : 1. The coupling efficiency is 97%. Because the pump intensity is high enough in the pump spot regions, the first lens must be well adjusted to collimate the pump beam, since it will strongly affect the focal spot. However, the distance between the two lenses can be freely adjusted by experiment. For the aberration, the average pump spot radius is about 220 μm. The laser crystal was a 0.5% at% Nd^{3+}–doped, $3 \times 3 \times 7$ mm^3 c–cut Nd:YVO_4 crystal which is wrapped with indium foil and mounted at a thermal electronic cooled cooper block to keep the temperature at 23 centigrade. The doping level and length was enough to ensure almost 90% of the pump light were absorbed. The cavity configuration was consisting by the laser crystal and the output coupling mirror, and the Cr^{4+}:YAG was used to obtain the passively Q-switched operation. The LBO crystal was used to generate the 543 nm yellow green laser. The dimension of the Cr^{4+}:YAG was about $10 \times 10 \times 3$ mm^3 like a thin plate with the thickness of 3 mm, and the initial transmission at 1086 nm was about 72%. The both side of the Cr^{4+}:YAG was antireflection coated at 1086 nm. The LD, the whole cavity, and the crystal are cooled by a thermoelectric controller for active temperature control with a stability of ±0.1°C.

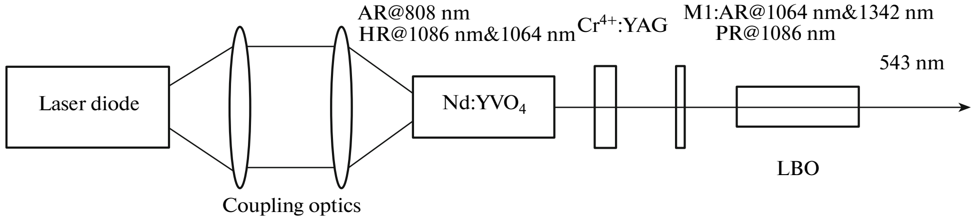

Fig. 2. Schematic for the frequency-doubled passively Q-switched 543 nm yellow green laser.

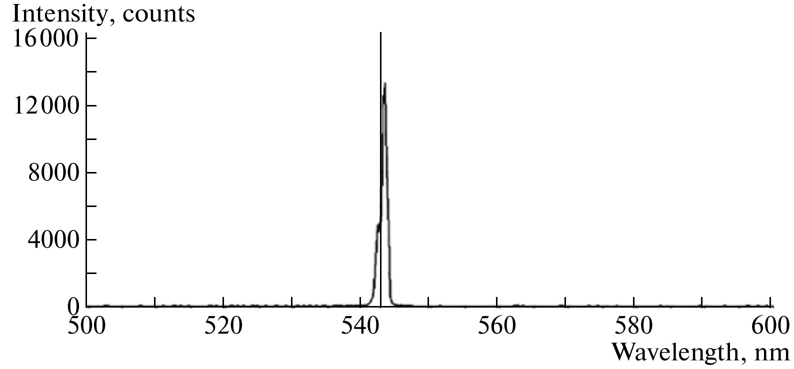

Fig. 3. Spectrum of the 543 nm green-yellow laser.

RESULTS AND DISCUSSION

Using the LABRAM–UV spectrum analyzer to scan yellow green laser and dealing with the data by software, the spectrum of the SHG laser is shown in Fig. 3. When using the 1086 nm output coupling mirror and the corresponding nonlinear crystal LBO, the laser output at 543 nm was obtained. The average output power at 1086 nm and 543 nm versus the incident pump power are demonstrated in Fig. 4 and Fig. 5.

It is obvious that the fundamental wave at 1086 nm is increased with the incident pump power almost linearly. The SHG output power also increases with the incident pump power at 808 nm. The maximum output power at 1086 nm and 543 nm were 3.2 and 1.58 W, respectively. The pulse width and the repetition rates of the yellow green at 543 nm versus the incident pump power are shown in Fig. 6 and Fig. 7.

In Fig. 6, it is shown that the pulse repetition rates increase with the incident pump power up to about 11 kHz, and the corresponding pulse energy at this rate is about 143.6 μJ. The pulse width is keep almost constant, varying between 4.4 and 5.2 ns as shown in Fig. 7, but it changes gradually when the incident pump power increased further. These phenomena are most likely affected by the cavity mode change, resulting in change of the ratios of the mode size in laser crystal to that in the saturable absorber. Usually, in this cavity configuration, the larger the incidents pump power, the shorter the thermal focal length, there is a characteristic that the mode size in the crystal will decrease gradually, and at the same time the mode size in the Cr^{4+}:YAG will also increase slowly. The typical pulse shape and sequence of the pulsed yellow green light were measured by the high speed Si photodiode (Thorlabs DET 10A) and the oscilloscopes (Tektronix TDS1002B) are shown in Fig. 8 and Fig. 9.

In the experiments, we have found that when the incident pump power is less than 12 W, the symmetry of pulse shape is good, the pulse repetition rates are stable, but at higher incident pump power, the pulse to pulse stability of repetition rate and pulse shape worsens. In summary, at the total incident pump power of 15 W we obtain the pulsed yellow green laser at 543 nm with the pulse repetition rates of 11 KHz, with peak

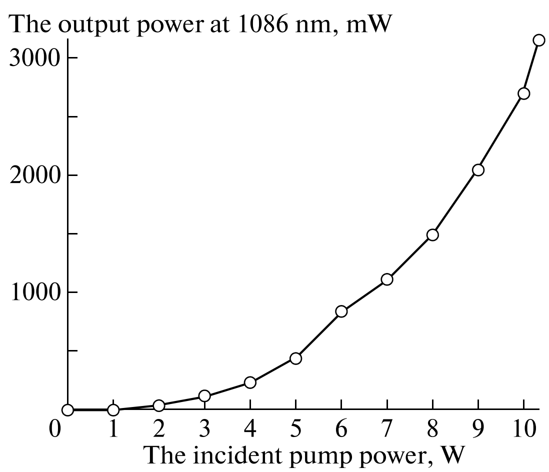

Fig. 4. The output power at pulsed 1086 nm versus incident pump power.

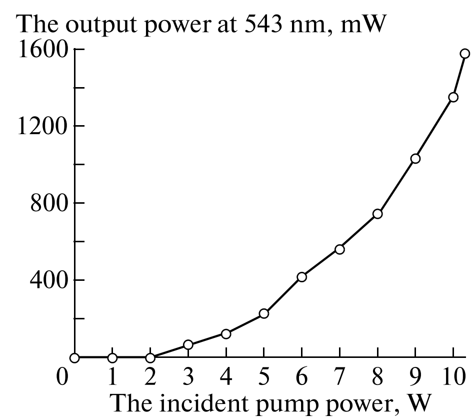

Fig. 5. The output power at pulsed 543 nm versus incident pump power.

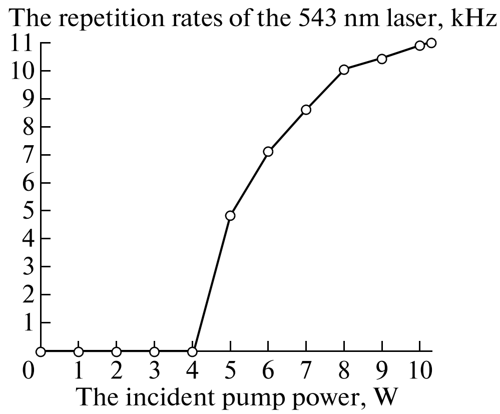

Fig. 6. The repetition rates at 543 nm versus incident pump power.

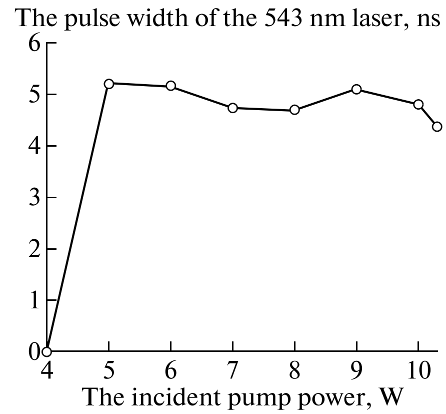

Fig. 7. The pulse width at 543 nm versus incident pump power.

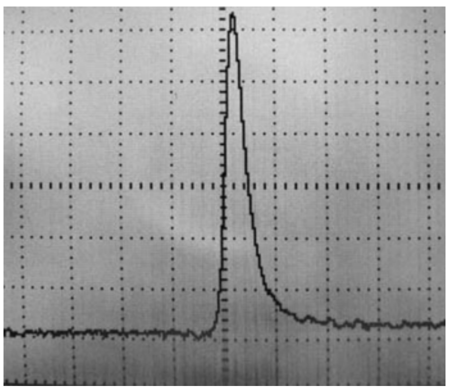

Fig. 8. The pulse shape of single pulse at 543 nm.

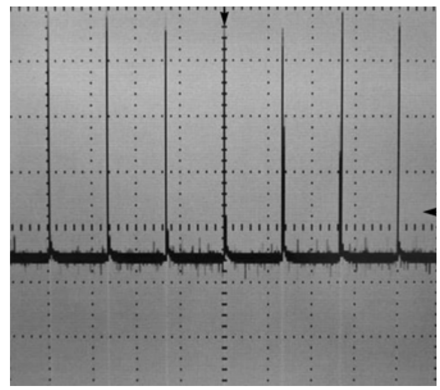

Fig. 9. The pulse sequence at 543 nm.

power of 30 kW and pulse width of 5ns. The output power at 543 nm is very stable, with peak-peak fluctuation less than 3% in 4 hours investigation. The optical to optical conversion efficiency is up to 10.5%.

CONCLUSIONS

In conclusion, an efficient and compact yellow green pulsed laser output at 543 nm is generated by frequency doubling of a passively Q-switched end diode-pumped Nd:YVO_4 laser at 1086 nm under the condition of suppressing the higher gain transition near 1064 nm. With 15 W of diode pump power and the frequency doubling crystal LBO, as high as 1.58 W output power at 543 nm is achieved. The optical to optical conversion efficiency from the corresponding Q-switched fundamental output to the yellow green output is 49%. The peak power of the Q-switched yellow green pulse laser is up to 30 kW with 5 ns pulse duration. The output power stability over 8 hours is better than 2.56% at the maximum output power. To the best of our knowledge, this is the highest watt-level laser at 543 nm generated by frequency doubling of a passively Q-switched end diode pumped Nd:YVO_4 laser at 1086 nm.

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