ISSN 1054-660X, Laser Physics, 2009, Vol. 19, No. 5, pp. 919–922.

Laser Diode End-Pumped Yb:YAG/LBO Green Laser[1]

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Received October 27, 2008; in final form, November 14, 2008

Abstract—With a type-I critical phase-matching LBO crystal, an intracavity frequency doubled solid-stated Yb:YAG green laser is reported. Using a plano-concave resonator, with pump power of 1.37 W, 24.5 mW TEM_{00} continuous wave laser at 525 nm was obtained. The optical conversion efficiency is 1.8%. By adjusting the placed angle of LBO, several lasers wavelength from 525.0 to 537.8 nm could be extracted. The maximum output power at 537.8 nm is 3.1 mW.

PACS numbers: 42.55.Xi, 42.70.Hj, 42.65.Ky

DOI: 10.1134/S1054660X0905003X

1. INTRODUCTION

Yb:YAG laser crystal has been invented for many years, but only after the appearance of the InGaAs laser diode whose laser wavelength is 940 nm, researchers began to notice its immense potential. Yb:YAG laser crystal has many advantages compared to Nd^{3+}-doped crystals [l], for example, a much longer upper laser level state lifetime (0.95 ms), higher quantum efficiency (91.4%) and very broad absorption band (18 nm). So it is more suitable for high power laser and Q-switched laser. An edge-pumped composite CW Yb:YAG thin disc laser has achieved over 100 W power [2]. Both the long-pulse and the short-pulse were all obtained in Q-switched Yb:YAG lasers [3–5].

Yb:YAG is quasi-three-level laser crystal, whose energy level diagram is shown in Fig. 1 [6]. Yb^{3+} ion has only two Stark splitted manifolds: the ground $^2F_{7/2}$ state with four sub-levels, and the excited $^2F_{5/2}$ with three sub-levels [7]. They form running mechanism of a quasi-three-level laser. At room temperature, the Boltzmann occupation factor of the terminal level of 1030 nm emission is 0.046. Because there are many ions at this terminal level, serious reabsorption is caused at the point of 1030 nm and population inversion is difficult to obtain. Under low pump power, laser operation at 1030 nm can not be easily realized. The Boltzmann occupation factor of the terminal level of 1050 nm emission is only 0.02, so the reabsorption is lower at this emission.

Figure 2 [8] shows the absorption and emission spectral properties of Yb:YAG crystal. The absorption band around 940 nm is very broad, so Yb:YAG crystal is more proper for laser diode pumping. There are also two main emission peaks in Yb:YAG crystal: one is at 1030 nm, and another is at 1050 nm. The emission cross-section of 1030 nm is much higher than that of 1050 nm, but there is also an apparent absorption peak at 1030 nm. So the threshold at 1030 nm should be much higher [9], and researches of low power pumped Yb:YAG lasers are mainly at 1050 nm. Tinghua University of China has reported a continuous 1049 nm Yb:YAG microchip laser and its Q-switched output research [10, 11]. A thin chip Yb:YAG laser with CW output of 1053 nm pumped by Ti:sapphire was also realized by Shanghai Institute of Optics and Fine Mechanics [12]. In this paper, with a type-I critical phase-matching LBO crystal, a 24.5 mW 525 nm laser is reported. By adjusting the placed angle of LBO, 3.1 mW of 537.8 nm CW output power has also been obtained.

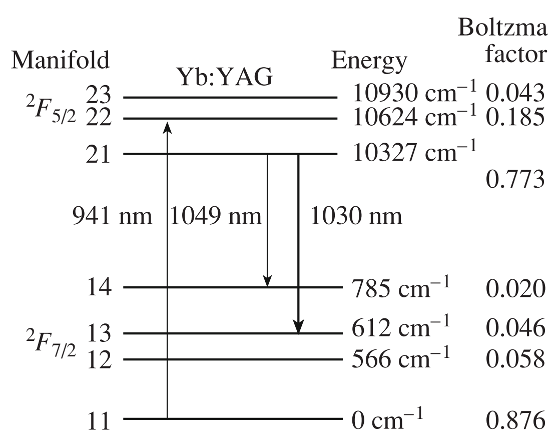

Fig. 1. Energy level diagram of Yb^{3+} ion in YAG crystal.

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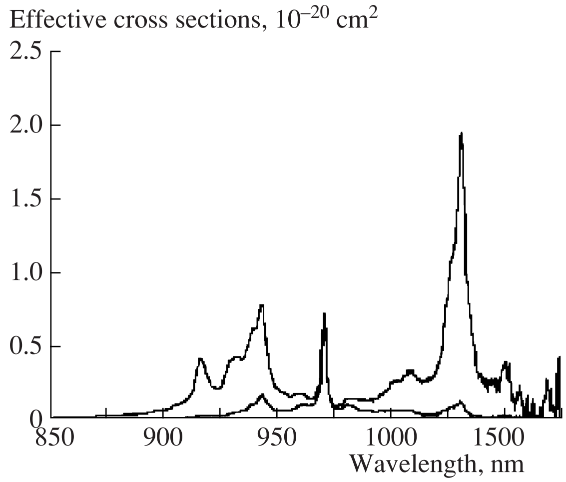

Fig. 2. Absorption and emission spectra of Yb:YAG crystal at 300 K.

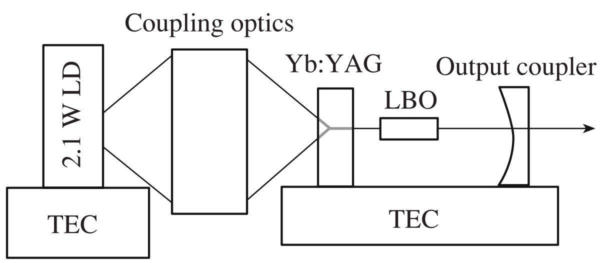

Fig. 3. Experimental setup of diode end-pumped Yb:YAG/LBO laser.

2. EXPERIMENTAL SETUP

Figure 3 shows the schematic diagram of the LD pumped Yb:YAG/LBO green laser. The pump source is a 2.1 W 940 nm laser diode from Spectra-Physics Company. In our experiment, the maximum pump power is 1.37 W. The Yb:YAG laser crystal is 10 at % doped with dimension of $\varnothing 4 \times 1$ mm^3. Its front face has high transmission at 940 nm (>88.9%) and high reflectivity at the wavelength of 1050 nm (>99.9%) and 525 nm (>99.2%), and another face has an anti-reflective coating for 1050 nm (>99.7%) and 525 nm (>99.8%). The front face and the output coupler mirror composite of a plano-concave resonator with the length of 19.1mm. The output coupler has an anti-reflective coating for 525 nm (>94%) and a high reflective coating for 1050 nm (>99.9%). The mirror radius is 100 mm. In the cavity, a $2 \times 2 \times 10$ mm^3 critical phase-matching LBO crystal, which was antireflection coated for fundamental and second harmonic wavelength on its both sides, was used to generate green laser.

For quasi-three-level Yb:YAG laser crystal, efficiently cooling can reduce the population of the terminal laser level and the threshold, so it was fixed on copper holder and its temperature was controlled at 19.8°C with a thermo-electric cooler (TEC) in our experiment. The temperature control accuracy was 0.1°C.

3. RESULTS AND DISCUSSIONS

With an input power of 1.37 W, 24.5 mW output power at 525 nm was obtained, and the optical conversion efficiency was 1.8%. The output power as a function of input power is shown in Fig. 4, and the threshold is 417 mW. Figure 5 is the spectrum of the 525 nm laser. By adjusting the placed angle of LBO crystal, a green laser at 537.8 nm can be obtained, and the output power

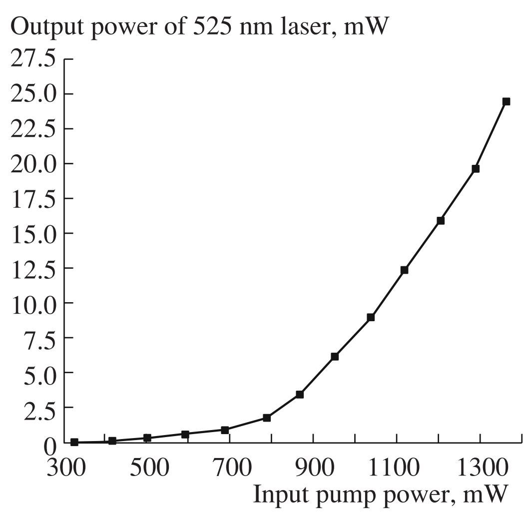

Fig. 4. Output power of 525 nm laser as n function of input pump power.

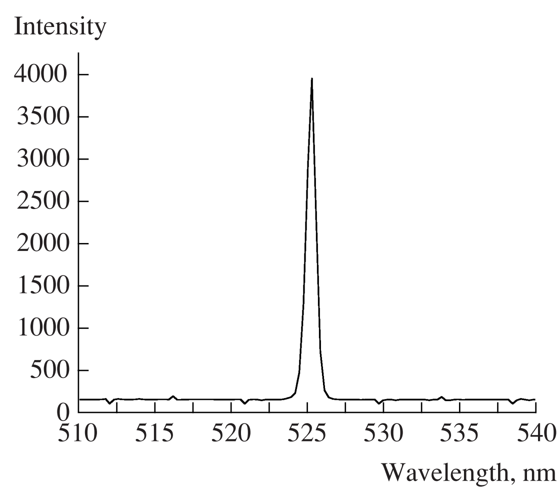

Fig. 5. The spectrum of 525 nm laser.

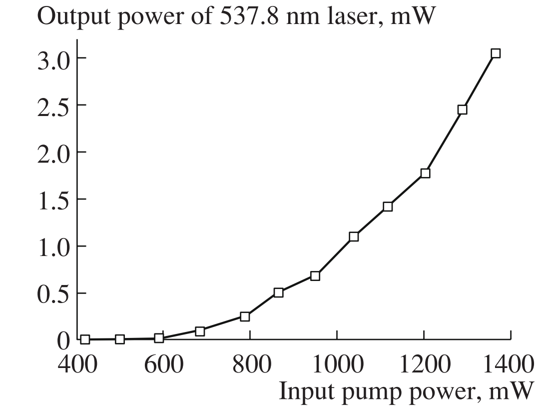

Fig. 6. The output power of 537.8 nm laser as a function of input pumped power.

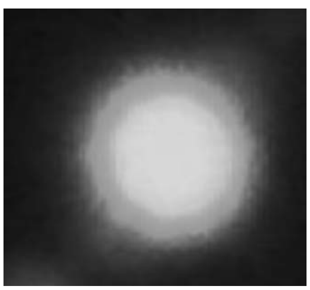

Fig. 7. The output beam of 537.8 nm laser.

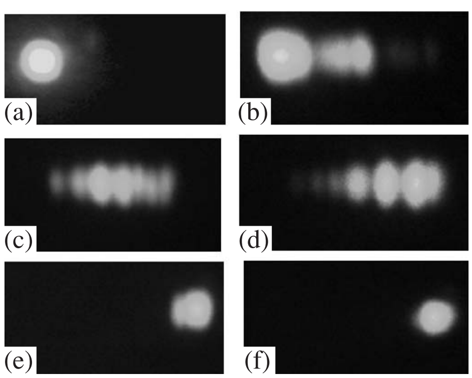

Fig. 8. The transformation process of the divergence spots with LBO's angle adjusted.

can reach 3.1 mW. Figure 6 presents its output characteristics, and its beam shape is shown in Fig. 7.

During our experiment the placed angle of the LBO was adjusted slowly and a grating was employed to disperse the output beam. At the beginning, there was only one output beam spot on the diffractive screen (Fig. 8a). With the changing of angle, several beam spots of much longer wavelengths appeared, and the shorter wavelength beam spots became to disappear one by one (Figs. 8b–8e). At last, there was only 537.8 nm laser beam spot (Fig. 8f). So the wavelength of the output laser got longer at this process.

As shown in the Fig. 2, the emission bandwidth of Yb:YAG is very broad. There are also apparent emission cross-sections beyond 1050 nm, but the absorption cross-sections are close to zero. In our experiment, the output coupler has a high reflective coating (>99.9%) for wavelengths between 1020 and 1100 nm. All of them make the longer wavelength oscillation possible and contribute to the fundamental laser shifting to longer wavelength. It can be found in many reports of tunable Yb:YAG lasers [13, 14].

In this experiment, the LBO is type-I critical phase-matching ($\theta = 90°$, $\varphi = 12.2°$) for frequency doubling of 1050 nm laser. So when it is placed into the cavity, laser at 525 nm can be easily obtained with higher output power. But when we adjust the angle of LBO and the laser wavelength satisfying critical phase-matching get longer, the frequency doubling output power of 1050 nm laser will decrease to zero. The longer wavelength satisfying critical phase-matching will be extracted by frequency doubled. We calculated the critical phase-matching angle of frequency doubling 1075.6 nm laser by SNLO software, and they are $\theta = 90°$, $\varphi = 10.6°$. So when critical phase-matching angles are satisfied. 537.8 nm laser will be extracted.

We also figure out the mixed accepting bandwidth of our LBO, and they are between 8.37 and 9.30 nm from 1050.0 to 1075.6 nm, so several green lasers were obtained at the same time. But the distance between 1050.0 and 1075.6 nm is 25.6 nm, their second harmonic waves can not exist simultaneously.

4. CONCLUSIONS

In summary, an end-pumped Yb:YAG laser with LBO intracavity frequency doubled has been investigated. The maximum output power of 525 nm laser was 24.5 mW. With the changing of LBO's angle, several other lasers wavelength between 525 nm and 537.8 nm were also observed, and the power of 537.8 nm laser could reach 3.1 mW.

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