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LD-pumped Nd:YAG/LBO 556 nm yellow laser

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Abstract

A new laser transition at 1112 nm was obtained after analyzing the parameters of the main laser transitions in Nd:YAG and calculating the transmission loss of the cavity at 1064, 1319, and 946 nm. The maximum output power of the fundamental wavelength was 610 mW, the fundamental wavelength light-to-light conversion efficiency was 38.1%, the maximum output at 556 nm was 109 mW intra-cavity frequency doubled by LBO, the SHG conversion efficiency was 17.8%, and the overall light-to-light efficiency was 6.8% for the pump power of 1.6 W.

Keywords: LD pump; 556 nm; Yellow laser; LBO; Intracavity frequency-doubling

1. Introduction

Yellow laser is a new hotspot due to its advantages in entertainment and medical applications. It has better penetration through nuclear sclerotic cataracts, excellent penetration through fluid and pageantry disturbances, less dispersion of energy in the neurosensory retina, causes less discomfort to the patient, and greater margin of safety. Up to now, the yellow lasers were obtained mainly by intracavity sum-frequency mixing (ISFM) [1,2], which was based on the dual-wavelength oscillation theory [3] and scarcely on frequency-doubling due to the lack of ideal fundamental laser transitions [4]. The ISFM was characterized by inversion population competition among the different laser transitions, which had shortcomings such as difficulty in thin film designing, low conversion efficiency, undesirable beam quality and power stability. Consequently, the application of special technologies like second harmonic generation (SHG) and the appropriate fundamental laser oscillation were vital to obtain a stable, low cost, and compactness yellow laser.

To our knowledge, the most popular transition in Nd:YAG is 1064 nm, which is superior to the 1319 and 946 nm laser transitions. In fact, there are about 30 transition lines in Nd:YAG including the main transitions [5]. The performance of 1112 nm laser transition is similar to 1123 nm and better than the other transition lines except for the familiar laser lines of Nd:YAG. The research reports on lasers at 1123 nm were popular due to their special applications [6,7] and mainly focused on the fundamental wavelength operation [8–10]; unfortunately, to our knowledge, the reports on the fundamentals and SHG of 1112 nm have not been presented. Because the SHG of 1112 nm is a light at 556 nm, which was an alternative to the currently used He–Ne 543 nm and Kr 568 nm lasers, its applications in various field is hopeful. In this paper, we obtained the yellow laser at 556 nm by SHG of Nd:YAG laser through thin film designing. The 1112 nm continuous wave (CW) lasing was obtained firstly, then the LBO frequency doubler was inserted into the cavity; the yellow laser at 556 nm was achieved and the maximum output power at the 556 nm was about 109 mW.

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2. Theory analysis

Nd^{3+} ion replaced Y^{3+} ion in YAG and the energy levels of the Nd^{3+} were split by the field of the crystal lattice. The energy levels are shown in Fig. 1. The 1064, 1112, 1116, and 1123 nm laser transitions come from $^4F_{3/2}$–$^4I_{11/2}$, but they are different in the upper and lower energy levels. Particularly, 1064 nm laser transition comes from R_2–Y_3 transition, 1112 nm from R_2–Y_6, 1116 nm from R_2–Y_5, and 1123 nm from R_1–Y_6. The comparison of the laser performance [5,11] of the main laser transitions and 1112 nm transition in Nd:YAG is shown in Table 1. σ is the stimulated emission cross-section, $\Delta\upsilon$ is the width of transition frequency, and β is the branching ratio which represents the relative intensity of the spontaneous emission. According to Table 1, we can see that the relative performance of the 1112 nm is about half of 1064 nm; the stimulated emission cross-section of the 1112 nm is as much as $\frac{1}{13}$ of 1064 nm, $\frac{4}{9}$ of 1319 nm, and $\frac{5}{9}$ of 946 nm. In order to obtain the laser oscillation at 1112 nm, which has a lower gain cross-section than the other main laser lines, not only 1064 nm oscillation, but also the 1319 and the 946 nm must be restrained at the same time. Through calculations, the lasing condition at 1112 nm is that the transmission of the cavity at the 1064, 1319 and 946 nm must be larger than 90%, 60%, and 60%, respectively.

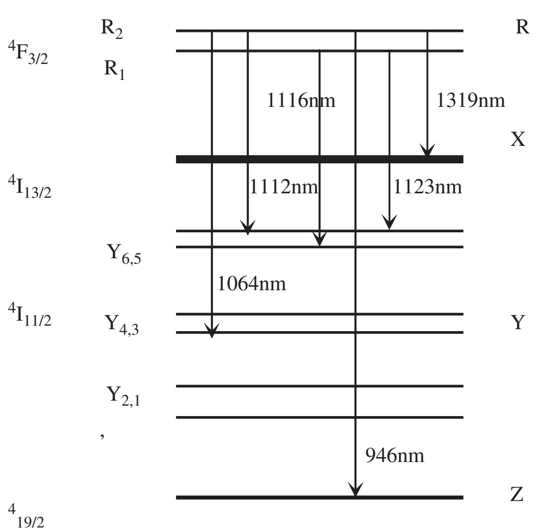

Fig. 1. The energy levels of Nd^{3+} in Nd:YAG.

Table 1
The comparison of the performance among the main laser transitions of Nd:YAG

λ (nm)	Transition	σ (10^{-20} cm^2)	$\Delta\upsilon$ (cm^{-1})	β (Branching ratios)	Relative performance
1064	R_2–Y_3	45.8	5	0.135	100
946	R_1–Z_5	5.1	9	0.040	46
1319	R_1–X_1	8.9	6	0.018	34
1112	R_2–Y_6	3.6	14	0.025	49
1123	R_1–Y_6	3.0	13	0.030	40

3. Experimental setup

The experiment setup of the 556 nm Nd:YAG/LBO yellow laser is shown in Fig. 2. A quantum well (QW) 1000 laser diode (LD) made by the Institute of Semiconductor, CAS, was used as the pump source, which was a continuous GaAlAs LD with an emission wavelength of 808 nm, maximum power of 2 W, emission light cross-section of $100 \times 1\,\mu m^2$, and divergent angle of $68.8^\circ \times 28.6^\circ$. The left facet of Nd:YAG (3.0 mm thickness, 1 at%-doped) was coated with high reflection (HR) coatings at 1112 nm and anti-reflection (AR) coatings at 808 nm; the right facet of Nd:YAG was AR coated at the fundamental wavelength. LBO ($2 \times 2 \times 10\,mm^3$) was a frequency doubler at 1112 nm (I type phase-matching cut, $\theta = 90^\circ$, $\Phi = 8.3^\circ$). CO was the couple optics system and OC was the output coupler; the output coupler was a plane-concave mirror, and the radius of the left-concave side was 50 mm. The OC was coated as follows: at the left facet, $T = 1\%$ at the fundamental wavelength, high transmission (HT) at 1064, 1319 and 946 nm; AR coated the right facet of the OC at 556 nm. TEC_1 and TEC_2 were the thermoelectric coolers. By TEC_1, the emission wavelength of LD was tuned to the absorption peak of Nd:YAG to utilize the pump energy as much as possible. Measurements show that the pump radius in Nd:YAG was about 100 μm. The cavity was composed by the left side of the Nd:YAG and the left side of the output coupler and the length of the cavity was about 24 mm. F was an infrared light filter and PM was a power meter.

After tuning the TEC_1, TEC_2, and the output coupler, the laser was oscillated at a good state and the color of the fluorescence was blue due to the excited state absorption (ESA). The Field Master-GS was used to measure the output power. The dependence of the fundamental output power on the pump power is shown in Fig. 3; the threshold was about 400 mW, the maximum output power was 610 mW for the pump power of 1.6 W. The spectrum of the fundamental wavelength was measured by the infrared spectral meter with a resolution of 0.2 nm and is shown in Fig. 4. It was

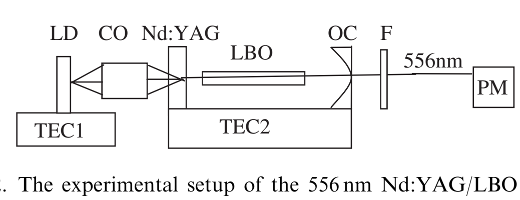

Fig. 2. The experimental setup of the 556 nm Nd:YAG/LBO yellow laser.