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Continuous-wave and passively Q-switched laser performance of a disordered Nd:GYSGG crystal

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ABSTRACT

The performance of continuous wave (CW) and passively Q-switched Nd:GYSGG lasers was investigated for the first time. The CW output powers of 4.2 W with dual wavelength of 1058.4 nm and 1061.5 nm were obtained under the diode pump power of 17 W with slope efficiencies of 26%. By using Cr^{4+}:YAG wafer as saturable absorber, Q-switching operation was performed and the short pulse with pulse width of 6.6 ns was obtained with the peak power of 9.97 kW.

1. Introduction

Laser crystals with the disordered structure were found to be of great interest because they possess both advantages of glass media and ordered crystals in spectral and thermal properties [1–5]. Besides, owing to the random distribution of cationic ions in some lattice sites, multiple structural centers exist in the disordered crystal. The presence of multiple structural centers causes the considerable inhomogeneous broadening and splitting of the spectral lines in the disordered crystals, and their potential applications in the generation of terahertz (THz) radiation have been proposed [4,7]. Recently, continuous wave, passively Q-switched and mode-locked operation of the disordered crystals, such as Nd:CNGG, Nd:CLNGG, Nd:CTGG and Nd:$CaYAlO_4$ have been investigated due to their optimal laser performance [5–9]. So far new disordered crystalline structure, Nd-doped gadolinium yttrium scandium gallium garnet (Nd:GYSGG) was obtained at Anhui Institute of Optics and Fine Mechanics (Chinese Academy of Sciences, China). It was grown by substitution of the 31 at % of Y^{3+} ions to Gd^{3+} with respect to already known disordered crystal Nd:YSGG. In this paper, CW and passively Q-switching laser performance of the disordered Nd:GYSGG crystal were investigated. In case of CW operation, it has been found that the laser emits simultaneously two wavelengths at 1058.4 nm and 1061.5 nm, and, therefore, can be considered as a new candidate source for the generation of THz radiation. By using Cr^{4+}:YAG wafer as saturable absorber Q-switching operation was performed; the pulse width and the peak power were found to be 6.6 ns and 9.97 kW, respectively.

2. Experimental setup

The schematic of experimental setup is shown in Fig. 1. The length of the cavity was designed to be about 27 mm. The pump source used in the experiments was a commercially available fiber-coupled diode-laser with a maximum output power of 17 W at 808 nm. The pump beam was focused into the laser crystal through the focusing optics (N.A. = 0.22) with a spot diameter of 200 μm. The Nd(1at%):GYSGG crystal with the dimensions of $3 \times 3 \times 5\ mm^3$, was employed in the experiment. Both sides of the crystal were HT-coated at 1.06 μm and 808 nm. The input concave mirror M_1 with a curvature radius of 500 mm has AR coatings at 808 nm on the flat face, HR coatings at 1.06 μm and HT coatings at 808 nm on the concave surface. The laser crystal was wrapped in an indium foil then mounted in a water-cooled copper block. The cooling temperature was maintained at

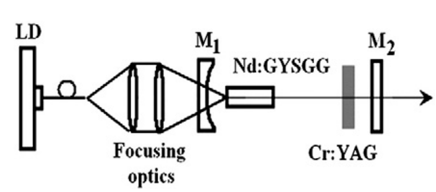

Fig. 1. Schematic diagram of the experimental setup.

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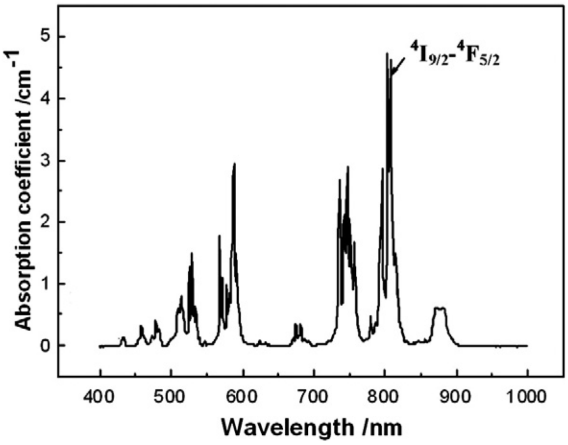

Fig. 2. Room temperature absorption spectrum of the crystal Nd:GYSGG.

20 °C. The output coupler (OC) M_2 was a flat mirror with 5% transmission at 1.06 μm laser wavelength. The Cr^{4+}:YAG was employed as the saturable absorber for the Q-switching operation.

3. Experimental results and discussions

3.1. Crystal growth and spectroscopic analysis

A disordered crystal with the nominal composition $Nd_{3x}Gd_{3y}Y_{3(1-x-y)}Sc_2Ga_3O_{12}$ was grown by the conventional Czochralski method. The powders of Nd_2O_3, Gd_2O_3, Y_2O_3, Sc_2O_3 and Ga_2O_3 were mixed adequately by a planetary mixer, and pressed into tablets. Then the polycrystalline material was obtained after sintering the tablets at about 1250 °C for 48 h. Good optical quality crystal was obtained and then processed for the further optical measurements. The measurement of the room temperature absorption spectra was carried out by using of a Lamda 900 UV/VIS/NIR spectrophotometer with a resolution of 0.3 nm (see Fig. 2). The absorption cross-section maximum and the absorption line bandwidth at 808 nm (${}^4I_{9/2}$–${}^4F_{5/2}$ transition) were found to be about 5.844×10^{-20} cm^2 and 7 nm, respectively, which are in good accordance for laser diode pumping. The effective distribution coefficient is about 0.59, which is larger than that of Nd:YAG and Nd:GGG. At room temperature, the emission cross section at 1.061 μm was calculated to be 1.58×10^{-19} cm^2. With respect to Nd:YAG(3.3×10^{-19} cm^2) [10], and Nd:GGG(2.1×10^{-19} cm^2) [11], the Nd:GYSGG crystal has lower emission cross sections which characterize this crystal as more perspective for Q-switching applications.

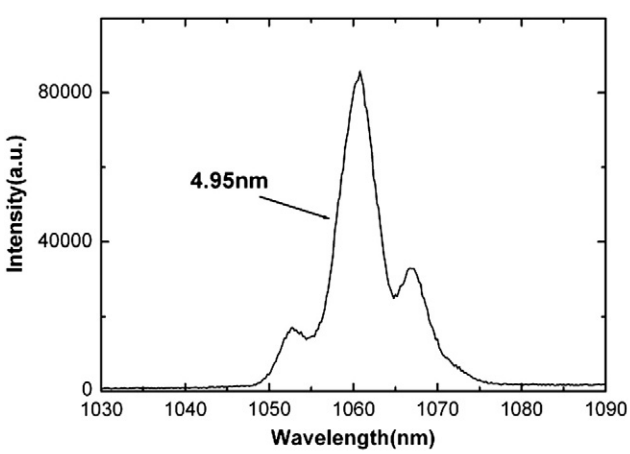

Fig. 3. Room temperature fluorescence spectrum in the 1.06 μm laser transition region.

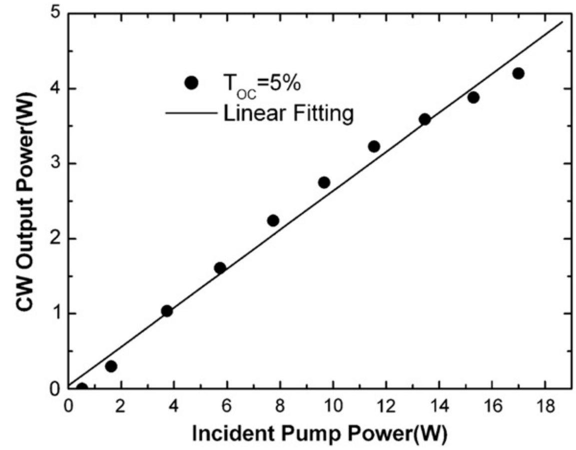

Fig. 4. Output power versus pump power in continuous wave operation.

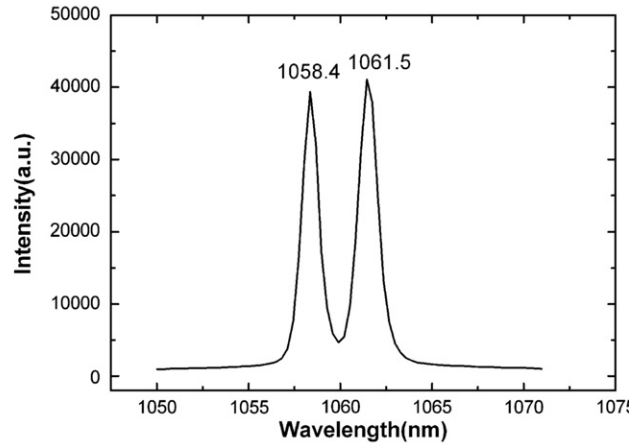

Fig. 5. The spectra of continuous wave Nd:GYSGG laser.

The emission spectrum was measured for wavelength range around 1 μm using a Jobin Yvon Fluorolog 3 Tau fluorescence spectrophotometer (see Fig. 3).

3.2. Continuous-wave laser operation

The CW laser operation of the crystal was experimentally investigated using the cavity length of about 27 mm. Fig. 4 shows the CW output performances of Nd:GYSGG crystal using the output

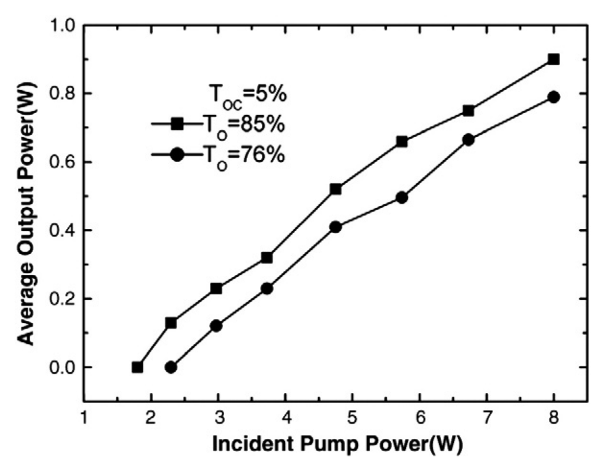

Fig. 6. Average output power versus incident power in Q-switching operation.

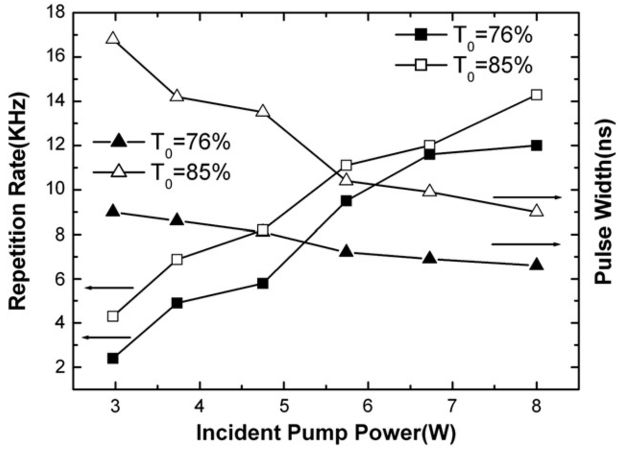

Fig. 7. Repetition rate and pulse width versus incident pump power.

coupler with transmission of 5%. The highest output powers of 4.2 W were obtained under the pump power of 17 W, the thresholds were measured to be 0.527 W, and the slope efficiency was linearly fitted to be 26%. Within the available pump power range there was not observed visual saturation of laser emission, which indicates that the output power could be further scaled with the pump power increase. Therefore, the Nd:GYSGG crystal could be considered as a good Nd-doped laser medium for diode pumping. A fiber-coupled spectrometer (HR4000CG-UV-NTR Ocean Optics) was used for the measurements of emission spectra at the laser threshold. We found that under this condition the laser emits at 1058.4 and 1061.5 nm wavelengths simultaneously, the separation between wavelengths is quite stable, and the intensities for different wavelength lines were nearly equal (Fig. 5, spectral resolution is ~0.75 nm). Recently, Creeden et al. have demonstrated the generation of THz radiation by using two pulsed diodes centered at 1064.2 and 1059 nm as laser sources [12,13]. Considering that the line separation for dual wavelength oscillation regime is optimal for difference frequency generation, this laser material might be employed to generate THz-wave at 0.83 THz with a suitable nonlinear crystal.

3.3. Q-switching operation

With the Cr^{4+}:YAG absorber inserted into the cavity, stable passively Q-switching operation was achieved. For all experiments to investigate passive Q-switching regime, the output coupler with transmission of 5% was used. To avoid damages of active crystal and saturable absorber, the pump power has been limited to 8 W. Fig. 6 shows the variation of average output power with increasing the pump power. It indicates that the maximum output power raises with the increase of Cr^{4+}:YAG's initial transmission. Under the pump power of 8 W, the maximum output powers of 0.79 W and 0.9 W were obtained with the thresholds of 2.3 W and 1.8 W, and the optical conversion efficiencies were 9.9% and 11.2% for $T_0 = 76\%$ and 85%, respectively. Further optimization of the Q-switching performance is possible by balancing the pulse width and output power [14]. For example, the optical conversion efficiency can be increased by using the Cr^{4+}:YAG with higher initial transmission, but at the same time it can result in the increasing the half-width of the output pulse. The repetition rate and pulse width versus the incident pump power are shown in Fig. 7. It can be seen that the repetition rate increases and the pulse width decreases with the increase of the incident pump power. It could be explained by higher speed of Cr^{4+}:YAG saturation under higher laser irradiance. Applying the Cr^{4+}:YAG absorbers with lower transmission results in the lower repetition rate and shorter pulse width. By using the Cr^{4+}:YAG with $T_0 = 76\%$ and 85%, the highest pulse repetition rate was measured to be 12 and 14.3 kHz; the shortest pulse widths were 6.6 ns and 9 ns, respectively. Using the values for the pulse repetition rate, the average output power and the pulse width, the pulse energy and the peak power can be calculated. For two different passive absorbers ($T_0 = 76\%$ and 85%), the maximum pulse energies were 65.8 and 62.9 μJ, and the maximum peak powers were estimated to be 9.97 and 6.99 kW, respectively (Fig. 8).

4. Conclusions

The continuous-wave and passively Q-switching laser performance of the disordered Nd:GYSGG crystal were investigated for the first time. The CW output powers of 4.2 W and dual wavelength of 1058.4 nm and 1061.5 nm were obtained under the pump power of

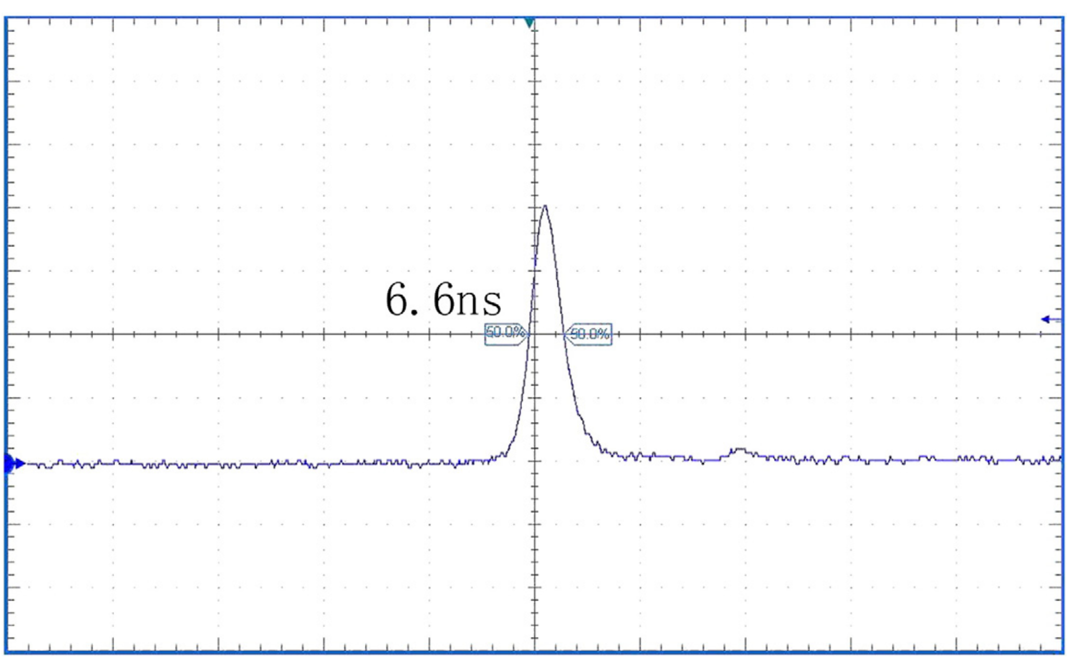

Fig. 8. Typical pulse profile of the Q-switched Nd:GYSGG laser (20 ns/div).

17 W with slope efficiencies of 26%. Q-switching operation was performed with the Cr^{4+}:YAG wafer and the short pulse with pulse width of 6.6 ns was obtained with the peak power of 9.97 kW and pulse energies of 65.8 μJ. These results show that the disordered Nd:GYSGG crystal is a promising laser material for Q-switched operation and applications where the synchronized dual-wavelength laser emission is required.

Acknowledgements

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