Nd:GYSGG laser at 1331.6 nm passively Q-switched by a Co:MgAl2O4 crystal

Hong-Yi Lin a, b, *, Dong Sun a, b, Nigel Copner b, c, Wen-Zhang Zhu a, b

a School of Optoelectronic and Communication Engineering, Xiamen University of Technology, Xiamen, 361024, China
b Fujian Key Laboratory of Optoelectronic Technology and Devices, Xiamen University of Technology, Xiamen, 361024, China
c Wireless and Optoelectronics Research and Innovation Centre, University of South Wales, Cardiff, CF371DL, United Kingdom

Article info
Article history:
Received 5 February 2017
Received in revised form 24 March 2017
Accepted 20 April 2017
Available online 27 April 2017

Keywords:
Nd:GYSGG laser
Co:MgAl2O4 crystal
Passively Q-switched
1331.6 nm laser

Abstract
The CW and passively Q-switched operation of a Nd:GYSGG laser is demonstrated. In the CW operation, triple-wavelength lines at 1323.9, 1331.6 and 1336.8 nm are generated simultaneously. The maximum CW output power is 1133 mW under a pump power of 7.85 W. In the passively Q-switched operation, a Co:MgAl2O4 crystal with initial transmission of 82% is employed, only single-wavelength line at 1331.6 nm is realized. The narrowest pulse width of 20.5 ns is achieved with an output power of 225 mW under the same pump power. The highest peak power and pulse energy are 1319 W and 27.2 μJ under a pump power of 7.20 W, respectively.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction
The Nd3+-doped gain crystals, such as YVO4, YAP, YAG, GGG, GdVO4, VLF, etc, are outstanding and efficient laser materials for pulse lasers at 1.3 μm, which have been widely used in nonlinear laser microscopy, medical instrumentation, fiber testing and sensing, fiber communication, and nonlinear optics [1,2]. In our previous work, we obtained a Q-switched a-cut Nd:YVO4 laser at 1342.2 nm passively Q-switched by graphene-oxide [1]. However, the pulse width was very wide and reached to 329 ns, and the peak power of 7.39 W was also too low.

The Nd:GYSGG crystal is a new and efficient radiation-resistant laser medium and it presents very outstanding and excellent laser properties, such as high doping, admirable optical quality, large size, wide absorption and emission spectrum, anti-radiation in outer space, etc. [3–5]. Similar to the Nd:YAG crystal, the energy transition of 4F3/2 → 4I11/2 could also generate laser lines at around 1.3 μm. In 2012, Zhong demonstrated a CW Nd:GYSGG laser at around 1.3 μm firstly [3]. Most recently, Song reported a Nd:GYSGG laser at 1331 nm passively Q-switched by a V:YAG crystal for the first time [4]. The narrowest pulse width and the peak power are 23.9 ns and 954 W, respectively. But there is no report about the passively Q-switched Nd:GYSGG laser based on the Co:MgAl2O4 crystals. While the Co:MgAl2O4 crystals have mostly dealt with pulse lasers at 1.5 μm. In this paper, we propose a Nd:GYSGG laser at 1331.6 nm passively Q-switched by a Co:MgAl2O4 crystal for the first time. The peak power at 1331.6 nm exceeds 1 kW, while the narrow pulse width is only 20.5 ns.

2. Properties of the Co:MgAl2O4 crystal
The Co:MgAl2O4 crystal has a spinel structure with a lattice constant of 0.8085 nm, in which the Mg2+ ions are substituted by tetrahedrally coordinated Co2+ ions [6–9]. The Co:MgAl2O4 crystal has an excellent optical property. In this paper, a Co:MgAl2O4 boules is grown by Verneuil method with 0.6 at.% Co2+ concentration [7], then a polished sample with the length of 1 mm is cut from the grown boules. Fig. 1 represents the absorption spectrum of the Co:MgAl2O4 sample at 1000–1600 nm. The near-infrared absorption band locates 1.3–1.5 μm to the transition of 4A2 → 4T1(F) which is similar to that of other Co2+-doped spinel crystals [9]. Its absorption peak is close to 1520 nm, which is mostly used in the eye-safe lasers [6–8]. The absorption at 1331 nm has gone down to 82% of the maximum rate. While the absorption rate at 1060 nm drops to 3%. The absorption cross-section at 1520 nm is 3.5 × 10−19 cm2 [8]. So we can deduce that the absorption cross-
section ($\sigma_s$) at 1331 nm is $2.8 \times 10^{-19}$ cm$^2$. Therefore, the stimulated emission cross-section ($\sigma_s$) at 1331 nm of the Nd:GYSGG crystal is about $0.78 \times 10^{-19}$ cm$^2$ [5]. The factor $\sigma_a$ is much larger than the factor $\sigma_s$, which makes it easy to achieve efficient Q-switched operation. Given all that, we believe that the Co:MgAl$_2$O$_4$ sample can be used to realize passively Q-switched pulses at 1331 nm in Nd:GYSGG lasers.

Fig. 1 also shows the initial transmittance of the Co:MgAl$_2$O$_4$ sample at 1200–1600 nm. The Co:MgAl$_2$O$_4$ sample with anti-reflection coating at 1.3–1.5 mm has a small-signal transmission of around 82% at 1331 nm.

3. Experimental setup

The Nd:GYSGG laser at 1331.6 nm passively Q-switched by a Co:MgAl$_2$O$_4$ crystal is studied on the experimental setup in Fig. 2. The cavity of length 50 mm consists of the input concave mirror ($M_{in}$) with the radius of curvature 200 mm and the 99.9% reflection at 1331 nm and high transmission at 808.4 nm and of the flat output coupler ($M_{out}$) with 12% transmission at 1331 nm. The Nd:GYSGG active element (1 at.% Nd$^{3+}$ concentration) of thickness 10 mm is mounted on a Cu heat sink. The laser is pumped by an 808.4 nm, 15 W laser diode arrays (LDA). The 808.4 nm light is coupled into the Nd:GYSGG crystal with focusing lens. The Co:MgAl$_2$O$_4$ crystal is placed near to $M_{out}$ in the mode waist.

Because the thermal conductivity of the Nd:GYSGG crystal is only 4.3 W m$^{-1}$ K$^{-1}$, near three times lower compared with the traditional Nd:YAG, the thermal effect is very severe. In order to reduce this thermal effect, we adopt the following methods. a). Nd$^{3+}$ concentration of the Nd:GYSGG crystal is only 1 at.%, the low concentration could reduce the heat density. b). the beam radius of the pump light in the Nd:GYSGG crystal is about 250 µm c). the short cavity with the length of 50 mm is used, which is limited by the Cu heat sink. The laser spots ($r_a$ and $r_s$) at the Co:MgAl$_2$O$_4$ and Nd:GYSGG crystals are 210 and 190 µm. The pump-to-mode size ratio is 1.2, which is good for the Nd:GYSGG laser.

The bleaching of the Co:MgAl$_2$O$_4$ crystal is determined by the parameter $\alpha$, which is given by Ref. [10].

$$\alpha = \frac{\sigma_a A_a}{\sigma_s A_s} = \frac{\sigma_a \pi r_a^2}{\sigma_s \pi r_s^2}$$

where $A_a$ and $A_s$ are the effective areas of the Nd:GYSGG and Co:MgAl$_2$O$_4$ crystal. The larger $\alpha$ is, the more effectively Co:MgAl$_2$O$_4$ crystal could be bleached. In this work, $\alpha$ is about 4.8.

4. Results and discussion

4.1. CW operation at 1.3 µm

At first, we study the CW operation of the Nd:GYSGG laser. The input-output diagram is shown in Fig. 3. The threshold is relatively high, at the pump power of around 0.99 W. This is mainly due to the uncoated anti-reflection at 1.3 µm on both sides of the Nd:GYSGG crystal. The slope efficiency is 17.2%. The output powers linearly depend on the pump powers when the pump powers are lower than 7.20 W, corresponding to output powers of less than 1102 mW. Above this point the thermal effects of the Nd:GYSGG crystal degrade the CW operation. The largest CW output power and the conversion efficiency are 1133 mW and 14.4% under the pump power of 7.85 W.

We also observe the output spectrum of the Nd:GYSGG laser in Fig. 4. At the pump threshold of 0.99 W, dual-wavelength lines at 1331.6 and 1336.8 nm are realized simultaneously. The energy level transition at 1331.6 nm is R$_2$/X$_3$, while the transition at 1336.8 nm is R$_1$/X$_1$. These transitions have different super Stark energy levels. When the pump power reaches to 4.89 W, triple-wavelength lines at 1323.9, 1331.6 and 1336.8 nm are appeared simultaneously. The new line at 1323.9 nm due to the transition of R$_2$/X$_2$ has the same super energy level R$_2$ with that line at 1331.6 nm. The relative intensities of three lines are slight jitters due to gain competition, but the total output power at round 1.3 µm is stable.

4.2. Q-switched operation at 1331.6 nm

The Q-switched operation of the Nd:GYSGG laser is also carried out based on the Co:MgAl$_2$O$_4$ crystal. The pump threshold increases
to 4.89 W, and the average output power and the slope efficiency decrease to 225 mW and 7.9%, respectively. The Q-switched efficiency is 19.9% under the pump power of 7.85 W. Only single-wavelength line is obtained by use of the Co:MgAl2O4 plate as an FP etalon. The wavelength is centered 1331.6 nm with a line width of 0.2 nm in Fig. 4.

The pulse width and repetition rate vary from 22.4 to 20.5 ns and from 2.2 to 9.1 kHz, when the pump increases from 5.28 W to 7.85 W. The increase of the pump power greatly increases the repetition rate and slightly reduces the pulse width due to faster saturation of the Co:MgAl2O4 crystal at larger pump power in Fig. 5. A laser single pulse with width of 20.5 ns and a pulse train with repetition rate of 9.1 kHz are obtained when the pump power is 7.85 W in Fig. 6. It is easy to conclude that the stability of this Nd:GYSGG laser at 1331.6 nm passively Q-switched by the Co:MgAl2O4 crystal is very good.

The pulse energy and peak power increase from 14.4 to 27.2 μJ and from 643 to 1319 W, when the pump increases from 5.28 W to 7.20 W in Fig. 7. While the pulse energy and peak power decrease from 27.2 to 24.7 μJ and from 1319 to 1206 W, when the pump increases from 7.20 W to 7.85 W. The decreases of pulse energy and peak power attribute to the serious thermal effects of the Nd:GYSGG crystal. So the highest peak power and pulse energy are 1319 W and 27.2 μJ under the pump power of 7.20 W, respectively.

Table 1 shows the output performances of passively Q-switched Nd3+-doped lasers at 1.3 μm. We can see that the output performance of this Nd:GYSGG laser at 1331.6 nm passively Q-switched by a Co:MgAl2O4 crystal is very good and admirable.

5. Conclusion

We report a Nd:GYSGG laser at 1331.6 nm passively Q-switched by a Co:MgAl2O4 crystal for the first time. In the Q-switched operation, pulse laser at 1331.6 nm with a pulse width of 20.5 ns and an output power of 225 mW is achieved. The maximum peak power reaches to 1319 W. In the CW operation, triple-wavelength lines at 1323.9, 1331.6 and 1336.8 nm are obtained.
simultaneously, and the maximum CW output power is 1133 mW.

Further an increase in peak power and output power and reduction of pulse width can be achieved by using a microchip configuration with shorter length of the cavity and optimal transmission of output coupler. Moreover, The usage of burst mode of pump source could reduce thermal effect, which can sufficiently improve laser performance of the Nd:GYSGG laser.

Acknowledgments

This paper is partly sponsored by the Fujian Outstanding Youth Scientific Research Program of China, and the Fujian Natural Science Foundation of China (2016J01683).

References


