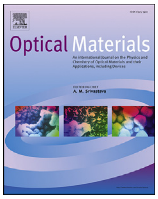
Optical Materials 73 (2017) 330–336

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat



Disordered Nd:LuYSiO$_5$ crystal lasers operating on the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ and $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transitions

Xiaofeng Guan [a], Zhiyong Zhou [a], Xiaoxu Huang [a], Bin Xu [a, *], Huiying Xu [a], Zhiping Cai [a], Xiaodong Xu [b, **], Jun Xu [c]

[a] *Department of Electronic Engineering, Xiamen University, Xiamen 361005, China*
[b] *Jiangsu Key Laboratory of Advanced Laser Materials and Devices, School of Physics and Electronic Engineering, Jiangsu Normal University, Xuzhou 221116, China*
[c] *School of Physics Science and Engineering, Institute for Advanced Study, Tongji University, Shanghai 200092, China*

ARTICLE INFO

Article history:
Received 21 July 2017
Received in revised form
24 August 2017
Accepted 26 August 2017

Keywords:
Diode pumped laser
Disordered Nd:LYSO crystal
CW laser

ABSTRACT

We report on diode-pumped disordered Nd:LuYSiO$_5$ (Nd:LYSO) crystal lasers operating on the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ and $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transitions. Simultaneous laser operation at 1074 and 1078 nm is achieved with maximum output power of 4.46 W and slope efficiency of 39.6%. Single wavelength laser at 1358 nm with maximum output power of 1.15 W and slope efficiency of 11.8% is also obtained. Moreover, four single-wavelength lasers at 1058, 1107, 1330 and 1386 nm with relatively low gains are achieved with maximum output powers of 2.72, 1.22, 0.52 and 0.42 W, respectively, for the first time to our knowledge. Lasing at non-traditional emission lines was obtained by using output couplers with dielectric coatings for specific wavelength ranges.

1. Introduction

During the past decades, owing to wide practical applications, Nd^{3+} laser materials have drawn a lot of attention because they have rich energy structure and set of transition lines from upper level $^4F_{3/2}$ to lower levels $^4I_{9/2}$, $^4I_{11/2}$, and $^4I_{13/2}$, which correspond to laser emissions at 0.9 μm [1,2], 1.06 and 1.1 μm [3,4], as well as 1.3 and 1.4 μm [5,6], respectively. Recently, our group has achieved effective operation at ~1.83 μm Nd^{3+} bulk lasers, i.e. transition to a higher laser lower level of $^4I_{15/2}$ [7,8]. In fact, exploring the lasing potential of various Nd^{3+} laser materials at different wavelengths for potential applications is an important and practical research topic.

Oxyorthosilicate materials have been in use as laser hosts since the 1970's [9]. Since then, such materials have been widely investigated as scintillators due to their good scintillating properties such as high density, short decay time and high output [10,11]. Among oxyorthosilicate materials, Y$_2$SiO$_5$ and Lu$_2$SiO$_5$ single crystals, abbreviated as YSO and LSO, have been mostly studied as laser host materials for various rare-earth dopants [12–14]. Thermal conductivities of YSO and LSO are about 4.4 and 5.3 W/m K, which is quite high, notably owing to the high melting point temperatures of YSO and LSO. Their mixed crystal, LuYSiO$_5$ (LYSO), has the same structure as YSO and LSO and therefore shares the common advantages of YSO and LSO. In fact, in recent years, research on mixed crystals has become hot topic [15–19]. Mixed crystals exhibit enhanced structural disorder owing to different substitutional sites, leading to inhomogeneous crystal field. As a result, mixed crystals, doped with various rare earth elements, exhibit broadened absorption and emission spectra, which are believed to have potential in ultrafast laser generation by mode locking technology.

At present, investigations on Nd^{3+}-doped LYSO disordered crystal lasers have been mainly focused on 1.07 μm spectral region. For example, in 2010, Li et al. [20] reported the growth, spectral properties and laser performance of Nd:LYSO. These authors achieved a maximum output power of 814 mW with slope efficiency of 28.9%. In 2011, Cong et al. [21] improved the output power and efficiency of the Nd:LYSO laser to 3.83 W and 37.5%. Three years later, by selecting crystal orientation, Zhao et al. [22] further promoted the Nd:LYSO laser performance to a maximum output power of 10.3 W and slope efficiency of 46%. Li et al. [23] reported for the first time the laser oscillation at 1359.5 nm with output power of 856 mW and slope efficiency of 19.2%. All these above mentioned

---

* Corresponding author.
** Corresponding author.
E-mail addresses: xubin@xmu.edu.cn (B. Xu), Xdxu79@mail.sic.ac.cn (X. Xu).

http://dx.doi.org/10.1016/j.optmat.2017.08.039

laser results were achieved for traditional emission peaks of $^4F_{3/2} \rightarrow {}^4I_{11/2}$ and $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transitions of Nd:LYSO crystal. Other emission lines with relatively low gains have not yet been studied. At the same time, laser sources operating at these wavelengths may have potential for various applications.

In this paper, we have investigated the laser performance of Nd:LYSO on the $^4F_{3/2} \rightarrow {}^4I_{11/2}$ and $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transitions. Based on operating peak laser emissions at ~1.07 and ~1.36 μm, we have demonstrated laser generation on low-gain transition lines at 1058 nm, 1107 nm, 1330 nm and 1386 nm by using output couplers with dielectric coatings for specific wavelength ranges. This method for direct generation of laser emissions with low gains is more efficient than other methods using additional intracavity optics.

Table 1

Parameters of cavity mirrors used in experiments and achieved laser output parameters for $^4F_{3/2}$-$^4I_{11/2}$ transition (sharing the same IM with transmission of 91.4% at pumping wavelength and reflection of 99.9% at 1.07 μm).

OC	coating (transmission)	laser wavelength	P_{out}(W)	P_{th}(W)	η_a
OC1	10.6%@1074 nm 10.9%@1078 nm	1074 + 1078 nm	3.92	~1.7	35.9%
OC2	2.3%@1074/1078 nm		4.22	~0.76	34.8%
OC3	6.8%@1074 nm 7.2@1078 nm		4.46	~1.3	39.6%
OC4	1.1%@1058 nm 21.8%@1078 nm	1058 nm	2.72	~1.3	22.9%
OC5	87%@1058 nm 68.5%@1074 nm 55.7%@1078 nm 3.4@1107 nm	1107 nm	1.22	~2.72	12.5%

Table 2

Parameters of cavity mirrors used in experiments and achieved laser output parameters for $^4F_{3/2}$-$^4I_{13/2}$ transition (sharing the same IM with transmission of 89.2% at pumping wavelength, reflection of 99.9% at 1.36 μm and transmission of more than 75% at 1.07 μm).

OC	coating (transmission)	laser wavelength	P_{out}(W)	P_{th}(W)	η_a
OC6	4.2%@1358 nm	1358 nm	1.15	~1.65	11.8%
OC7	3.9%@1330 nm 26.6%@1358 nm	1330 nm	0.52	~3.04	5.7%
OC8	30.7%@1330 nm 51.7%@1358 nm 5.7%@1386 nm	1386 nm	0.42	~4.8	7.1%

2. Experimental setup

The laser experimental setup is schematically shown in Fig. 1, which consisted of pump source, coupling optics and laser resonator. The pump source is 808-nm fiber-coupled diode laser with fiber core diameter of 400 μm and numerical aperture of 0.22. The pump beam was collimated and then focused into the laser gain medium by two doublet lenses both with focal lengths of 40 mm. The laser resonators were plane-concave configurations for the two laser emission bands (~1.07 and ~1.36 μm). For obtaining the laser operation at different wavelengths a set of input mirrors (IMs) and output couplers (OCs) (see Tables 1 and 2) were used. These OCs are concave mirrors with curvature radii of 50 mm. All coatings of the cavity mirrors were designed and fabricated according to the appropriate requirements in our lab by using plasma direct-current sputtering technology. During the laser experiments, the physical cavity lengths were maintained to be about 45 mm.

The laser medium was a disordered Nd:LYSO crystal with a doping concentration of 0.5 at% and dimensions of 3 × 3 × 6 mm^3 (6 mm in thickness). To remove thermal loading, the Nd:LYSO crystal was wrapped with indium foil and then mounted inside a copper block, which was connected to a circulating water chiller with temperature set at 16 °C during the laser experiments.

3. Results and discussion

3.1. $^4F_{3/2} \rightarrow {}^4I_{11/2}$ transition lasers

Using IM1 as input mirror and OC1 as output coupler (OC1: transmissions of about 10.6% and 10.9% at 1074 and 1078 nm, respectively), the maximum output power reached 3.92 W with threshold of about 1.7 W of absorbed power. The corresponding slope efficiency was linearly fitted to be about 35.9%. After replacing OC1 by OC2 (OC2: transmissions of about 2.3% at 1074 and 1078 nm), the maximum output power was increased to 4.22 W with slope efficiency of about 34.8% while the threshold was decreased to 0.76 W. The highest output power in this work was achieved by using OC3 (OC3: transmissions of about 6.8% and 7.2% at 1074 and 1078 nm) with output power of 4.46 W, threshold of 1.3 W and slope efficiency of about 39.6%. Taking the similar pumping level into account, our results are better than that reported in Ref. [20] with maximum output power and efficiency 3.83 W and 37.5%. The output powers and laser spectrum are shown in Fig. 2. Using the infrared camera, the laser beam quality was measured to be close to about 4.3 at maximum output powers for all the cases of three OCs. The inset in Fig. 2(a) shows the output beam spot measured at maximum output power of 4.46 W.

It should be pointed out that the output power dependence on pump power exhibited good linearities and therefore power scaling could be expected by using a pump source with higher power. Peak wavelength was measured to be at 1074.84 and 1078.22 nm, indicating simultaneous operation at two laser lines, which could be useful for difference wavelengths generating applications with a difference frequency at 0.87 THz. The dual-wavelength lasing behavior has also been reported in previous studies [20,21]. This suggests that the two emission lines have the same or very close thresholds. In fact, according to Ref. [20], the 1074 and 1078 nm lines have close emission cross sections as 7.17 and 7.84 × 10^{-20} cm^2. At the same time, the emission cross section of Nd:YAG at peak wavelength of 1064 nm is 27 × 10^{-20} cm^2 [24], i.e. about 2.5 times

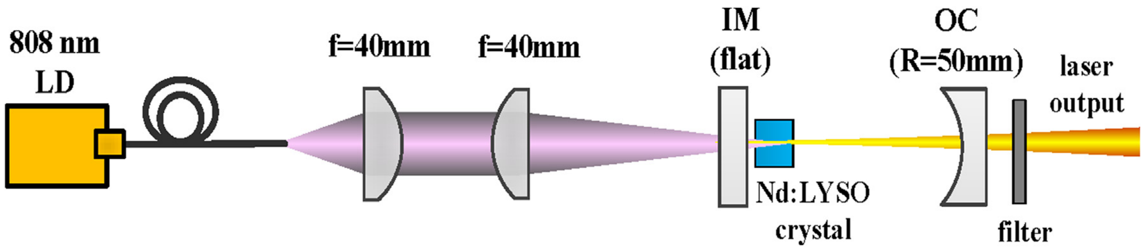


Fig. 1. The schematically experimental setup of diode-pumped Nd:LYSO lasers.