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Efficient CW Diode-Pumped Er,Yb:$GdAl_3(BO_3)_4$ Laser

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Abstract: We report efficient continuous-wave diode-pumped laser operation of Er,Yb:$GdAl_3(BO_3)_4$ crystal. A maximal output power of 780 mW was obtained at 1531 nm at absorbed pump power of 4 W with slope efficiency of 26 %.

OCIS codes: (140.3480) Lasers, diode-pumped; (140.3500) Lasers, erbium; (160.5690) Rare-earth-doped materials.

1. Introduction

Solid-state lasers emitting in the 1.5-1.6 μm spectral range are very promising for eye-safe laser range finding, ophthalmology, fiber-optic communication systems, and optical location. Phosphate glasses currently are the leading Er^{3+},Yb^{3+} co-doped laser materials, because they combine very efficient energy transfer from Yb^{3+} to Er^{3+} ions (η≈90 %) with a long lifetime of erbium upper laser level $^4I_{13/2}$ (7-8 ms) and short lifetime of the $^4I_{11/2}$ energy level (2-3 μs), which prevents the depopulation of this level by means of excited-state absorption and up-conversion processes [1]. However, phosphate glass has poor thermo-mechanical properties (a thermal conductivity of 0.85 $W\times m^{-1}\times K^{-1}$), that limits the average output power of Er,Yb:glass lasers due to the thermal effects. A maximal CW output power didn't exceed 353 mW with slope efficiency of 26 % [2]. For this reason, the search of new crystalline host for Er,Yb-codoping is actual.

The Er,Yb-codoped oxoborate crystals possess abovementioned spectroscopic characteristics and high thermo-mechanical properties for efficient laser operation, that determines high interest in investigation spectroscopic and laser properties of this hosts. CW room-temperature laser operation was demonstrated for following Er,Yb-codoped crystals: $GdCa_4O(BO_3)_3$ [3], $LaSc_3(BO_3)_4$ [4], $YCa_4O(BO_3)_3$ [5]; while for $Li_6Y(BO_3)_3$ [6], $Sr_3Y_2(BO_3)_4$ [7], $Sr_3Gd_2(BO_3)_4$ [8], $GdAl_3(BO_3)_4$ [9], and $LuAl_3(BO_3)_4$ [10] quasi-continuous-wave regime of operation was realized. However, a maximal CW output power didn't exceed 250 mW with slope efficiency of 27 % [5].

Comparatively recently, excellent laser performance of Er,Yb:$YAl_3(BO_3)_4$ (YAB) crystal has been demonstrated. Diode-pumped Er,Yb:YAB laser exhibited a slope efficiency as high as 35 % and output power of 0.8-1 W at several wavelengths between 1531 and 1602 nm [11].

In this work we present the spectroscopy and, for the first time to our knowledge, a high efficient diode-pumped CW laser operation of Er,Yb:$GdAl_3(BO_3)_4$ (GdAB) crystal.

2. Spectroscopy

Er,Yb:GdAB single crystals were grown by dipping seeded high-temperature solution growth. Concentration of $Er_xYb_yGd_{1-x-y}Al_3(BO_3)_4$ with x = 0.015 and y = 0.11 in the initial load corresponded to 17 wt.%. As a result, Er,Yb:GdAB single crystals with high optical quality and the size up to 20x10x10 mm^3 have been grown. The concentrations of the dopants were measured by microprobe analysis to be 1 at. % for Er^{3+} and 8 at. % for Yb^{3+}.

The polarized absorption spectra of Er,Yb:GdAB crystal around 980 nm at room-temperature recorded with a spectrophotometer Cary-5000 are shown in Fig. 1. A strong absorption band corresponding to transition $^2F_{7/2}\rightarrow{}^2F_{5/2}$ of Yb^{3+} ions is centered at 976 nm with a maximum absorption cross-section of about 3.6×10^{-20} cm^2 and bandwidth of 18 nm (FWHM) in σ polarization. Due to a comparatively broad absorption band thermal control of the pump laser diode is not necessary.

Figure 2 shows room-temperature polarized absorption spectra of Er,Yb:GdAB in the 1450-1650 nm spectral range (transition $^4I_{15/2}\rightarrow{}^4I_{13/2}$ of erbium ions). A number of local maxima are observed in both σ and π polarizations.

For lifetime measurements optical parametric oscillator LOTIS LT-2214OPO pumped by Nd:YAG laser with pulse duration of 20 ns was used as an excitation source. The fluorescence decay was registered by InGaAs photodiode and a 500 MHz digital oscilloscope.

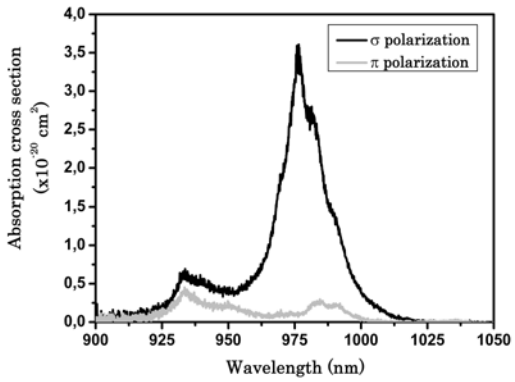

Fig. 1. Room-temperature polarized absorption spectra of Er,Yb:GdAB crystal at 1 μm

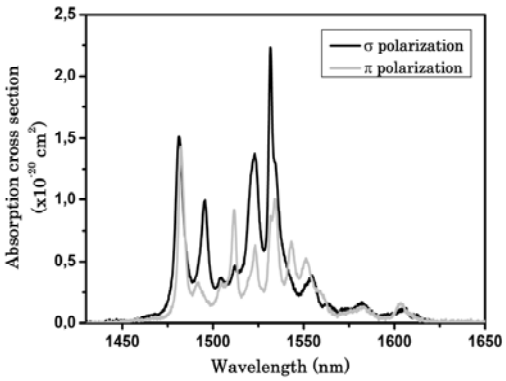

Fig. 2. Room-temperature polarized absorption spectra of Er,Yb:GdAB crystal at 1.45-1.65 μm

The decay curve of 1.5 μm emission was single exponential and luminescence decay time of $^4I_{13/2}$ level was measured to be of about 350 μs. The measured lifetime is significantly shorter than radiative lifetime calculated from the Judd–Offelt analysis (3.72 ms [9]). Thus the luminescence quantum efficiency for the $^4I_{13/2}$ level of Er,Yb:GdAB was estimated to be of about 10%. Such low quantum efficiency is similar to Er,Yb:YAB (8 % [11]) and explained by the large phonon energy in oxoborate crystals.

The lifetime of $^4I_{11/2}$ level was estimated by measuring the rise time of luminescence from $^4I_{13/2}$ in Er,Yb:codoped crystal pumped at 976 nm. The measured time was 2.4 μs, but it is considerably longer, than that obtained in Er single doped YAB (80 ns [11]). It is explained by the fact, that the presence of ytterbium ions leads to increase of measured time due to energy back transfer. Unfortunately, it was impossible to measure the luminescence decay of $^4I_{11/2}$ level of erbium directly because of the absence of Er single-doped GdAB.

The $^2F_{5/2}$ level lifetimes of Yb^{3+} were measured both in Yb-single doped crystal and in Er,Yb:codoped GdAB. To prevent reabsorption caused by significant overlap of the absorption and emission bands all measurements were performed with fine powder of the crystals immersed in glycerin. The lifetime of ytterbium ion in Yb(0.8 at.%):GdAB was measured to be 450 μs. For the search of the optimal concentrations that correspond to maximal energy transfer efficiency the $^2F_{5/2}$ level lifetimes were measured in Er,Yb-codoped GdAB with different concentrations of the dopants. The energy transfer efficiency was measured by the estimation of shortening the $^2F_{5/2}$ level lifetime in Er,Yb-codoped crystals and Yb-single doped crystal according to the formula:

$$\eta = k / \tau^{-1} = \tau (1/\tau - 1/\tau_0) \quad (1)$$

where k is the energy transfer rate, τ is the ytterbium $^2F_{5/2}$ level lifetime in Er,Yb-codoped crystal, and τ_0 is the ytterbium $^2F_{5/2}$ level lifetime in Yb single-doped crystal. The values of energy transfer efficiencies for Er,Yb:GdAB in comparison with Er,Yb:YAB are shown in Table 1.The energy transfer efficiencies in GdAB are similar to those in Er,Yb:YAB and Er,Yb:glass and higher than in vanadates and tungstates.

The stimulated emission cross-section spectra calculated by the integral reciprocity method [12] using the radiative lifetime obtained from Judd-Offelt analysis [9] are shown in Fig.3. The highest stimulated emission cross section of about 2.1×10^{-20} cm^2 is located at 1531 nm.

Table 1. Lifetimes of the $^2F_{5/2}$ level of Yb^{3+} and energy transfer efficiencies in Er,Yb:GdAB in comparison with Er,Yb:YAB

Crystal	Er^{3+} ions, at. %	Yb^{3+} ions, at. %	$^2F_{5/2}$,μs (Yb single-doped)	$^2F_{5/2}$,μs (Yb,Er co-doped)	Energy transfer efficiency, %
GdAB	1.0	8.0	450	75	83
	0.2	12		120	73
	1.2	22		38	92
YAB	1.5	8.4	480	47	90
	1.5	12		31	94

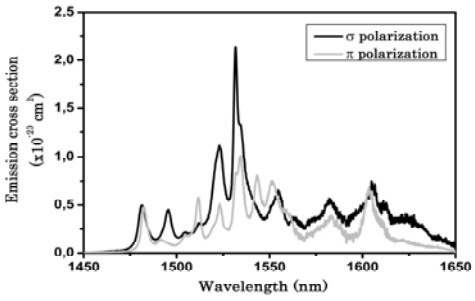

Fig. 3. Emission spectra of Er,Yb:GdAB crystal at 1.45-1.65 μm

3. Laser experiments

The laser experiments were performed in Z-shaped cavity. The plane-plane a-cut Er(1 at. %),Yb(8 at. %):GdAB crystal 1.5 mm long antireflection coated for both pump and lasing wavelengths was mounted on the copper thermoelectrically cooled heatsink. The temperature of the active element was kept at 17°C. As a pump source a 7 W fiber-coupled (Ø 105 μm, NA=0.22) laser diode emitting near 976 nm was used. A combination of two lenses (f_1=100 mm, f_2=80 mm) was used to focus pump beam into the gain medium, and pump beam spot radius was measured to be 45 μm ($1/e^2$ intensity). The cavity setup for laser experiments is presented in Fig. 4.

Input-output characteristics CW Er,Yb:GdAB diode-pumped laser are plotted in Fig. 5. For the output coupler transmittance of 1 % at 1602 nm (2% at 1531nm) the CW π-polarized output at 1602 nm with slope efficiency near 15 % was obtained at absorbed pump power up to 3.4 W and after further increasing of pump power the emission wavelength switched to 1531 nm (σ polarization) with similar slope efficiency. For the output coupler transmittance of 2 % at 1602 nm (4% at 1531nm) the CW π-polarized laser emission with slope efficiency near 19 % was observed at 1602 nm, however at absorbed pump power more than 3 W the emission wavelength again switched to 1531 nm (σ polarization) and slope efficiency was increased drastically to 35 %. The maximal output power of 745 mW was obtained in that case at absorbed pump power of 4W. The maximal output powers of 780 mW with slope efficiency 26 % and 670 mW with slope efficiency 23 % at 1531 nm (σ polarization) were obtained for output coupler transmittance of 5.5 % and 8 %, respectively, without switching between polarizations and wavelengths. The laser threshold was measured to be about 1 W for 5.5% output coupling. The spatial profile of the output beam was TEM_{00} mode with M^2 <1.2 during all laser experiments.

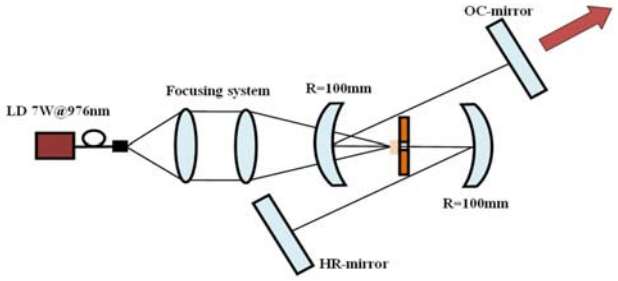

Fig. 4. Cavity setup for laser experiments

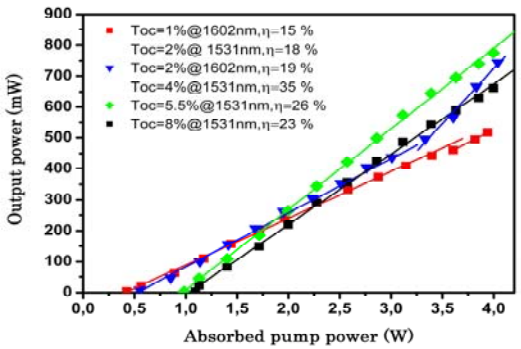

Fig. 5. Input-output characteristics of CW Er,Yb:GdAB diode-pumped laser

In conclusion, a CW diode-pumped Er,Yb:GdAB laser with output power of about 780 mW and slope efficiency as high as 26 % at 1531 nm was realized for the first time to our knowledge.

4. References

1. G. Karlsson, F. Laurell, J.Tellefsen, B. Denker, B. Galagan, V. Osiko, and S. Sverchkov , "Development and characterization of Yb-Er laser glass for high average power laser diode pumping," Appl. Phys. B. **75**, 41-46 (2002).
2. T. Danger, G. Huber, B.I. Denker, B.I. Galagan, S.E. Sverchkov, "Diode-pumped continious-wave laser around 1.54 μm using Yb,Er - doped silico-boro-phosphate glass," CLEO 98 Conference Technical Digest 1998, (San Francisco, USA), CTuM71 (1998).
3. B. Denker, B. Galagan, L. Ivleva, V. Osiko, S. Sverchkov, I. Voronina, J.E. Hellstrom, G. Karlsson, and F. Laurell, "Luminescent and laser properties of Yb,Er-activated $GdCa_4O(BO_3)_3$ - a new crystal for eyesafe 1.5 micrometer lasers," Appl. Phys. B. **79**, 577-581 (2004).
4. A. Diening, E. Heumann, G. Huber, and O. Kuzmin, "High-power diode-pumped Yb,Er:LSB laser at 1.56 μm," in Conference on Lasers and Electro-Optics (CLEO), Vol. 6 of 1998 OSA Technical Digest Series, 299-300 (1998).
5. P. Burns, J. Dawes, P. Dekker, J. Pipper, H. Jiang, and J. Wang, "Optimization of Er,Yb:YCOB for cw laser operation," IEEE J. Quantum Electron. **40**, 1575-1582 (2004).
6. Y.W. Zhao, Y.F. Lin, Y.J. Chen, X.H. Gong, Z.D. Luo, and Y.D. Huang, "Spectroscopic properties and diode-pumped 1594nm laser performance of Er,Yb:$Li_6Y(BO_3)_3$ crystal," Appl. Phys. B. **90**, 461-464 (2008).
7. J. Huang, Y. Chen, Y. Lin, X. Gong, Z. Luo, and Y. Huang, "High efficient 1.56 μm laser operation of Czochralski grown Er,Yb:$Sr_3Y_2(BO_3)_4$ crystal," Optics Express **16**, 17243-17248 (2008).
8. J.H. Huang, Y.J. Chen, X.H. Gong, Y.F. Lin, Z.D. Luo, and Y.D. Huang, "Growth, polarized spectral properties, and 1.5–1.6 μm laser operation of Er,Yb:$Sr_3Gd_2(BO_3)_4$ crystal," Appl. Phys. B. **97**, 431-437 (2009).
9. Y. Chen. Y. Lin, X. Gong, Z. Luo, and Y. Huang, "Spectroscopic properties and laser performance of Er^{3+} and Yb^{3+} co-doped $GdAl_3(BO_3)_4$ crystal," IEEE J. Quantum Electron. **43**, 950-956 (2007).
10. Y. Chen, Y. Lin, J. Huang, X. Gong, Z. Luo, and Y. Huang, "Spectroscopic and laser properties of Er^{3+},Yb^{3+}:$LuAl_3(BO_3)_4$ crystal at 1.5-1.6 μm," Optics Express **18**, 13700-13707 (2010).
11. N.A. Tolstik, S.V. Kurilchik, V.E. Kisel, N.V. Kuleshov, V.V. Maltsev, O.V. Pilipenko, E.V. Koporulina, and N.I. Leonyuk, "Efficient 1 W continuous-wave diode-pumped Er,Yb:$YAl_3(BO_3)_4$ laser" Opt. Lett. **32**, 3233-3235 (2007).
12. A.S. Yasyukevich, V.G. Shcherbitskii, V.E. Kisel, A.V. Mandrik, and N.V. Kuleshov, "Integral method of reciprocity in the spectroscopy of laser crystals with impurity centers," **71**, 202-208 (2004).