High-Efficiency Mini-Slab Laser Based on Tm-doped Double Tungstate Crystal

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High-Efficiency Mini-Slab Laser Based on Tm-doped Double Tungstate Crystal

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Abstract. We report on highly-efficient room-temperature lasing in 5at.%Tm:KLu(WO$_4$)$_2$ mini-slabs side-pumped by a 35W diode bar. QCW (duty cycle $\sim$ 14%) output power of 1.47 W at 1908 nm has been demonstrated with optical and slope efficiencies being of 33 and 43% respectively. In our experiments, we used samples of active elements produced in the slabs form with Brewster's angle cut faces and original laser cavity design.

1. Introduction

Lasers emitting in the spectral range of 2 μm are of particular interest for many scientific and technical applications, including remote sensing, medicine, and optical pumped mid-infrared OPO [1-4]. Crystals of double rare-earth potassium tungstate's doped with trivalent thulium ions are promising laser materials for compact highly efficient sources of coherent two-micron (1.8–2.0 μm) radiation and well known for excellent laser properties. They have rather high gain cross-sections and would allow an efficient diode pumping by widely available laser diodes and bars emitting at 800–810 nm [5-7]. It should be noted that they have about low thermal conductivity (3 W/m·K) and microhardness ($\sim$5), but in our previous works it was demonstrated the possibility of increasing the output power of thulium lasers by using active elements of a special shapes including thin disks, epitaxial and composite structures [8,9]

In previous works, we have experimentally achieved efficient multi-watt lasing in N_m-cut and *AT*-cut slab-shaped laser crystals [10]. For example, a 16.7 W maximum CW output at 1910 nm was achieved for N_m-cut slab-shaped laser crystal with a slope efficiency of 41 % and an optical-to-optical conversion efficiency of 31 %. Key past results are summarized in Table 1.

Table 1. Slope efficiency, optical efficiency and maximum output power of the different types slab active elements in the CW mode for *T*=10 %. AT is the "athermal" direction.

Type of mini-slab active element		Slope Efficiency, %	Optical Efficiency, %	Output power, W
AT-cut	[12]	40	23	~9.7
N_m-cut	[12]	41	31	~16.7
N_m-cut	**this work**	**43**	**33**	**~10.0**

In this paper, we present the first results of investigation of the oscillation performance of laser based on the 5at.%Tm:KLu(WO$_4$)$_2$ mini-slabs. In our experiments, we used samples of active elements produced in the slabs form with Brewster's angle cut faces and original laser cavity design. QCW (duty cycle ~14 %) output power of 1.47 W at 1908 nm has been demonstrated with optical and slope efficiencies being of 33 and 43 % respectively.

2. Experiment and results

The potassium lutetium double tungstate crystal, 5at.%Tm:KLu(WO$_4$)$_2$ was grown in the Institute of Inorganic Chemistry SB RAS, by the modified Czochralski technique (from the flux) using potassium ditungstate, K$_2$W$_2$O$_7$, as a solvent, under low temperature gradients, ~ 1 K/cm. The seed was oriented along the **b** crystallographic axis. A platinum crucible with a diameter of 70 mm and a length of 120 mm was used, and the pulling rate was as low as 0.1-0.2 mm/h [11].

After that, the piece of 5at.%Tm:KLu(WO$_4$)$_2$ crystal boule was processed into a mini-slabs with Brewster's angle cut faces having 6.2 mm in length along N_m axis by 0.7 mm along N_p (b-) axis and by 0.36 mm along N_g axis, all facets are flat and polished, see Fig. 1a. The bottom (upper) 0.36×6.2 mm^2 facet was HR (AR) coated for pump wavelengths centred at 808 nm, Brewster's angle cut end-faces were not AR coated for lasing wavelengths. At the final stage the coated slab was clamped between two copper heatsinks with an indium solder, see inset to figure 2a.

The active element was pumped by the collimated radiation of commercial CS-type diode bar with the total optical power up to 35 W at a wavelength of 808 nm. The total optical loss related to delivery of pump light to the upper slab facet was estimated to be ~5 %, the rectangular pump spot was of 6.0 mm in length by 0.1 mm in width allowing efficient side pumping. In our case, a ten-pass diode pumping scheme was used, quite similar that of [10]. The residual pump power was not measured, because we established that all pumping was absorbed in the active element in ten passes, see [10] for more details.

The temperature of the copper base, on which all the elements of the optical circuit and the radiator of the active element were attached, was maintained constant (T = 25±0.5 °C) using modules of the thermal stabilization system based on Peltier elements.

The laser cavity was formed by a spherical rear mirror with a radius of curvature equal to -40 mm, AR-coated YAG crystal lens with a focal length of 20.0 mm and flat output coupler. The distance between the rear mirror and output coupler was approximately 80 mm, see Fig. 1b. The transmission output coupler was 10 % in the spectral range 1850–1950 nm.
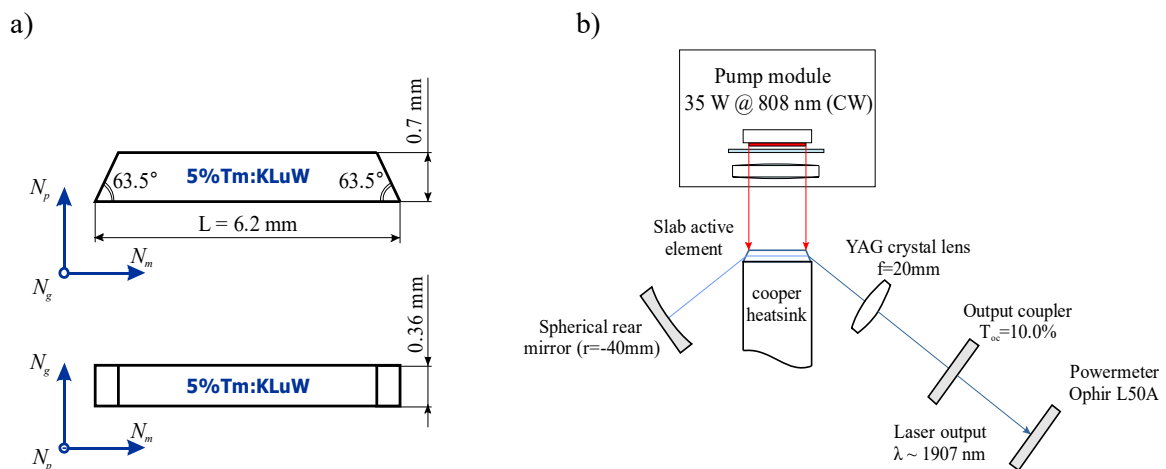

Figure 1. The form with final dimensions (a) of the two mini-slabs active elements and the cavity design (b) of a transversely diode pumped 5at.%Tm:KLu(WO$_4$)$_2$ laser.
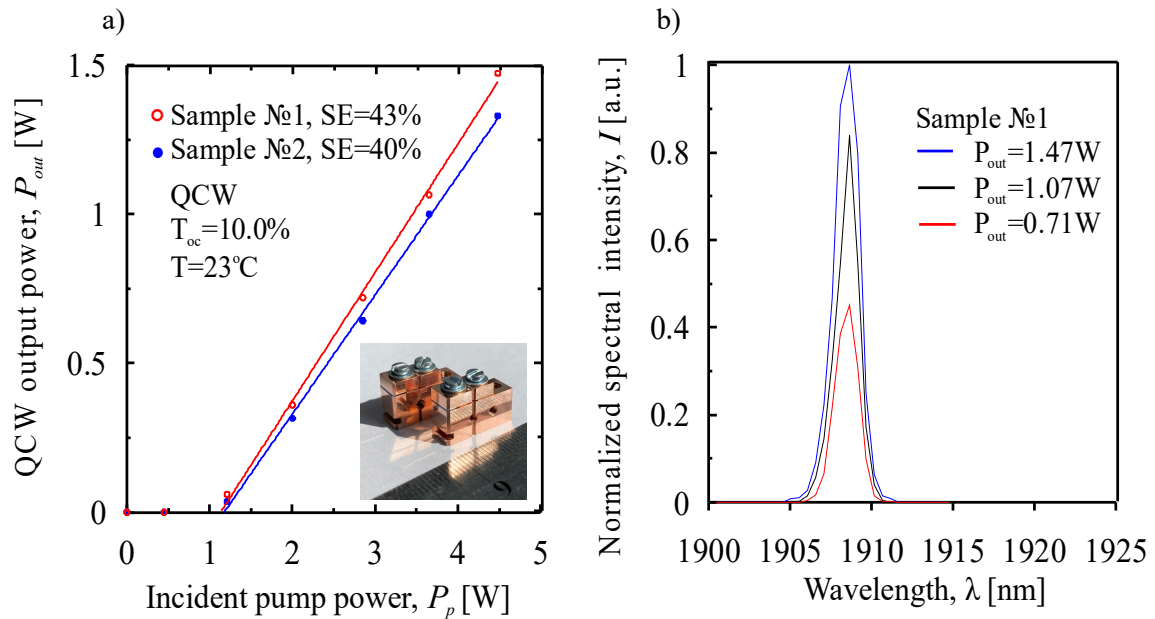
Figure 2. Input-output dependences of N_m-cut 5at.%Tm:KLu(WO$_4$)$_2$ slabs in QCW mode (a) and typical normalized output spectrum for different output power (b). The inset shows the active elements. SE is the slope efficiency.

Figure 1a shows the dependences of the output laser power on the QCW diode pump power (pump pulse duration 7 ms, pulse repetition rate 20 Hz, duty cycle 14%) for two identical samples of mini-slabs. The optical powers of the light beams (pumping and lasing) were measured with powermeter Ophir L50A. All output spectrum emission patterns (see figure 1b) were recorded by MDR-204 monochromator equipped with a photoresistor FR-185 and a Unipan-233 selective nanovoltmeter as a preamplifier. The spectral resolution was ~ 0.5 nm. Similarly to [10], the emission of the N_m-cut slabs with Brewster's angle cut end-faces was centered at 1908 nm with a spectral bandwidth (full width at half maximum, FWHM, of ~ 2 nm).The average output power over 1.4 W at 1908 nm has been demonstrated for all samples with slope efficiencies being of over 40 % with respect to the incident pump power and an optical-to-optical conversion efficiency of 33 %. At this stage, CW mode testing has not been carried out but these results are consistent with calculated output power about ~10 W on the CW mode accounting duty cycle 0.14 (7 ms to 50 ms).

3. Summary

In summary, a high-efficiency QCW laser performance of Brewser-cut N_m 5at.%Tm:KLu(WO$_4$)$_2$ slab seems to be very similar to other Tm^{3+}-doped double tungstate gain elements including thin disks and epitaxial structures that have been studied previously. The further work will be focused on the increasing laser output power up to 10…20 W in CW mode by combining two active elements into a single resonator. The further optimization of laser cavity parameters should improve laser beam quality up to M^2<1.5, and active Q-switching regime with KTP/RTP electooptics is also under intensive study.

References

[1]   Fischer C, Sorokin E, Sorokina I, Sigrist M 2005 Photoacoustic monitoring of gases using a novel laser source tunable around 2.5μm *Opt. Lasers Eng.* **43** 573

[2]   Henriksson M, Tiihonen M, Pasiskevicius V, Laurell F 2006 ZnGeP$_2$ parametric oscillator pumped by a linewidth-narrowed parametric 2 μm source *Opt. Lett.* **31** 1878

[3]   Scholle K, Lamrini S, Koopmann P, Fuhrberg P 2010 2 µm Laser Sources and Their Possible Applications, *Source: Frontiers in Guided Wave Optics and Optoelectronics* 21 471

[4]   John D, Craig S 1992 2-µm laser applications *Proc. SPIE* **1627** 1

[5]   Demidovich A, Kuzmin A, Nikeenko N, Titov A, Mond M, Kueck S 2002 Optical characterization of Yb,Tm:KYW crystal concerning laser application *Journal of Alloys and Compounds* **341** 124

[6]   Mateos X, Petrov V, Liu J, Pujol M, Griebner U, Aguilo M, Diaz F, Galan M, Viera G 2006 Efficient 2-µm continuous-wave laser oscillation of Tm^{3+}:$KLu(WO_4)_2$ *IEEE J. Quantum Electron.* **42** 1008

[7]   Petrov V, Pujol M, Mateos X, Silvestre O, Rivier S, Aguilo M, Sole R, Liu J, Griebner U, Diaz F 2007 Growth and properties of $KLu(WO_4)_2$, and novel ytterbium and thulium lasers based on this monoclinic crystalline host *Laser & Photon. Rev.* **1** 179

[8]   Vatnik S, Vedin I, Kurbatov P, Pavlyuk A 2014 Efficient 2-mm laser oscillation of 5%Tm^{3+}:$KLu(WO_4)_2$ disks and 5%Tm^{3+}:$KLu(WO_4)_2$/$KLu(WO_4)_2$ composite structures *Quantum Electronics* **44** 989

[9]   Vatnik S, Vedin I, Segura M, Mateos X, Pujol M, Carvajal J, Aguiló M, Díaz F, Petrov V, Griebner U 2012 Efficient thin-disk Tm-laser operation based on Tm:$KLu(WO_4)_2$/$KLu(WO_4)_2$ epitaxies *Opt. Lett.* **37** 356

[10] Bagayev S, Vatnik S, Vedin I, Orlovich V, Kuleshov N, Pavlyuk A, Gusakova N, Kurilchik S, Yasukevich A, Kisel V, Yumashev K, Loiko P, Dashkevich V 2019 Efficient Tm-laser operation based on 5at.%Tm:$KLu(WO_4)_2$ with N_m and at orientations *AIP Conference Proc.,* **2098**, 020003

[11] Vatnik S, Pujol M, Carvajal J, Mateos X, Aguiló M, Díaz F, Petrov V 2009 Thermo-optic coefficients of monoclinic $KLu(WO_4)_2$ *Appl. Phys.* **B95**, 653

[12] Pavlyuk A, Vasiliev Y, Kharchenko L, Kuznetsov F 1993 Low thermal gradient technique and method for large oxide crystals growth from melt and flux *Proc. of APSAM-92* **1** 164