PACS numbers: 42.55.Rz; 42.60.Lh; 42.70.Hj
DOI: 10.1070/QE2010v040n02ABEH014242

Two-micron lasing in $NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystals doped with Tm^{3+} ions

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***Abstract*. Lasing on the $^3F_4 \rightarrow {}^3H_6$ transition of Tm^{3+} ions in $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystals pumped by a diode laser is obtained for the first time. The π- and σ-polarised laser radiation at wavelengths of 1908 and 1918 nm was generated with a slope efficiency of 28 % and 25 %, respectively.**

Keywords: *two-micron lasing, Tm^{3+} ions, $NaLa_{0.5}Gd_{0.5}(WO_4)_2$ crystals.*

The use of two-micron laser radiation in medicine, as well as in monitoring of various gases (for example, NO_2, CO_2, NH_3) in the atmosphere, stimulates the search for new active media emitting at this wavelength. Two-micron lasing can be obtained in solid matrices doped with Ho^{3+} ($^5I_7 \rightarrow {}^5I_8$ transition) or Tm^{3+} ($^3F_4 \rightarrow {}^3H_6$ transition). According to the energy level diagram of Tm^{3+} ions in crystalline matrices, the upper laser level $^3F_4$ of this ion is populated due to the cross-relaxation ($^3H_4 \rightarrow {}^3F_4$, $^3H_6 \rightarrow {}^3F_4$) under pumping of the $^3H_4$ level. This scheme of population of the $^3F_4$ level is used to obtain two-micron lasing under both lamp pumping [1 – 3] and pumping by commercial laser diodes ($\lambda_p \approx 800$ nm) [4, 5].

At present, in order to create compact mid-power two-micron lasers, one studies the crystals of scheelite-like double tungstates doped with Tm^{3+} ions [6 – 12]. The absorption and fluorescence lines of Tm^{3+} in these laser hosts are strongly inhomogeneously broadened due to the disordered crystal structure. The broad absorption bands of the active ions make them low-sensitive to variations in the pump source spectrum, while the broad luminescence bands allow one to obtain frequency-tunable laser radiation, including fine tuning to the absorption lines of particular gases.

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Received 30 October 2009
Kvantovaya Elektronika **40** (2) 101 – 102 (2010)
Translated by M.N. Basieva

Lasing in $Tm^{3+}:NaLaGd(WO_4)_2$ crystals was reported for the first time in [8], and somewhat later the authors of paper [6] achieved tunable lasing in this crystal in the region of $\sim$ 200 nm under pumping by a $Ti^{3+}:Al_2O_3$ laser, as well as lasing at 1997 nm under diode laser pumping. The authors of [7] reported two-micron lasing in $Tm^{3+}:NaLa(WO_4)_2$ crystals pumped by a $Ti^{3+}:Al_2O_3$ laser.

In this paper, we present the results of the first, to our knowledge, experiment on lasing in $Tm^{3+}:NaLa_xGd_{1-x}(WO_4)_2$ crystals. The crystals of mixed scheelite-like tungstates $Tm^{3+}:NaLa_xGd_{1-x}(WO_4)_2$ with a variable La – Gd composition occupy an intermediate position between the lanthanum and gadolinium tungstates. Our estimates show that the absorption cross section for the $^3H_6 \rightarrow {}^3H_4$ transition and the stimulated emission cross section for the $^3F_4 \rightarrow {}^3H_6$ transition of Tm^{3+} ions in mixed scheelite crystals are comparable with the corresponding characteristics for $Tm^{3+}:NaGd(WO_4)_2$ [6, 9, 12] and $Tm^{3+}:NaLa(WO_4)_2$ [7] crystals.

The $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystals were grown by the Czochralski method from a melt of the composition $NaLa_{0.46}Gd_{0.46}Tm_{0.07}(WO_4)_2$. To optimise the pump radiation absorption, the cylindrical active elements (AEs) were cut from a crystal oriented with a DRON-4 X-ray diffractometer so that the optical axis of the crystal was perpendicular to the axis of the cylindrical AE. The AE dimensions (diameter 3 mm, length 5 mm) satisfied the condition of efficient longitudinal diode laser pumping at $\lambda_p \sim 794$ nm.

The AE faces were AR-coated for the pump and laser wavelengths. The residual reflectance at the pump (R_{794}) and laser (R_{1910}) wavelengths was 0.67% and 0.21%, respectively.

The scheme used to obtain lasing in the $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystal is shown in Fig. 1.

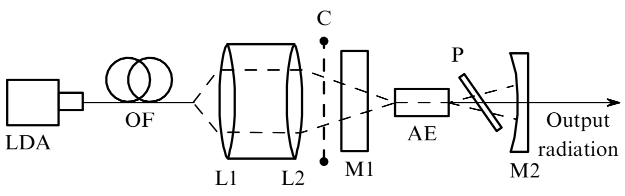

Figure 1. Laser scheme: (LDA) laser diode array, (OF) optical fibre, (L1) and (L2) telescope lenses, (C) chopper, (M1) dichroic mirror, (AE) active element, (P) glass plate, (M2) plano-concave mirror.

As a pump source, we used a 40-W laser diode array (LDA), whose temperature was kept constant at $\sim 26.5\,^{\circ}$C, which corresponded to the radiation wavelength of $\sim$ 794 nm (the diode radiation linewidth was $\sim$ 2 nm). To decrease the heat load on the AE, the average pump power was attenuated using a chopper, which formed radiation pulses with a duration of 10 ms and a repetition rate of 5 Hz. The radiation of the fibre-coupled LDA (fibre diameter 800 μm, numerical aperture 0.14) was focused into the AE by a two-lens telescope. For efficient cooling, the AE wrapped with indium foil was mounted in a copper heatsink, whose temperature was kept constant at $\sim 18\,^{\circ}$C with the help of a Peltier element. The cavity used in the experiment was formed by a plane dichroic mirror M1 ($T_p \approx 90\,\%$, $T_{las} \approx 0.5\,\%$) and a plano-concave mirror M2 ($T_{las} \approx 11\,\%$) with a 200-mm radius of curvature of the spherical face. To separate laser radiation with the π or σ polarisation, we placed a glass plate inside the cavity at Brewster angle to the system axis.

During the experiment with the $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystal, we obtained laser radiation with the π and σ polarisations according to the spectral dependences of the stimulated emission cross section for the $^3F_4 \rightarrow {}^3H_6$ transition of Tm^{3+} in the $Tm^{3+}:NaGd(WO_4)_2$ [6], $Tm^{3+}:NaLa(WO_4)_2$ [7], and $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystals for the π and σ-polarisations. The lasing characteristics of the $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystal for these polarisations are given in Table 1.

Table 1. Lasing parameters of the $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystal.

Polarisation	Slope efficiency (%)	Total efficiency (%)	Laser wavelength/nm
π	28	11	1908
σ	25	9	1918

Figure 2 shows the dependences of the output laser power on the pump power for the π and σ polarisations. The slope efficiency was 25 % for the σ polarisation and 28 % for the π polarisation.

Our estimates of the spectroscopic characteristics of Tm^{3+} ions in scheelite crystals with a varying La – Gd composition together with the results of the reported experiment allow us to conclude that, using AEs of a better optical quality and optimising the output mirror transmittance and the cavity scheme, it is possible to achieve higher output laser characteristics for the $Tm^{3+}:NaLa_{1/2}Gd_{1/2}(WO_4)_2$ crystal. In addition, the broad gain bands in the region of 2 μm for the π- and σ-polarised radiation in this crystal allow one to obtain wavelength-tunable laser radiation.

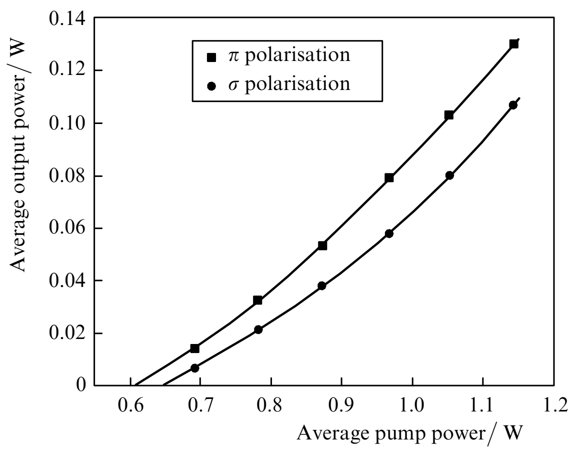

Figure 2. Dependences of the average laser output power on the average pump power.

Acknowledgements. This work was supported by the Russian Foundation for Basic Research (Grant No. 07-02-0055a).

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