Tunable Laser Operation of Yb:NaY(WO$_4$)$_2$

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Abstract: CW laser operation of Yb^{3+} in a Czochralski-grown disordered NaY(WO$_4$)$_2$ crystal is demonstrated. The tunability extends from 1003.7 to 1073 nm. The maximum slope efficiency and output power are 74.6% and 463 mW, respectively.

OCIS Codes: (140.5680) Rare earth and transition metal solid-state lasers; (140.3070) Infrared and far-infrared lasers; (160.5690) Rare earth doped materials

1. Introduction

The tetragonal double tungstate (DT) and double molybdate (DM) compounds with nominal formula MT(XO$_4$)$_2$ (shortly MTX), where M and T are monovalent and trivalent cations respectively and X=W or Mo, are locally disordered crystals due to the random distribution of M and T cations on the same lattice sites. Yb^{3+} dopant ions replacing T cations of the host experience a crystal field distribution, and the optical absorption and photoluminescence bands are broadened in comparison to ordered crystals, such as the monoclinic KT(WO$_4$)$_2$, T=Y, Gd, Lu. Continuously tunable and mode-locked femtosecond laser operation of Yb^{3+} has been previously shown in three tetragonal DT crystals, NaLaW, NaGdW and NaLuW, as well as in two tetragonal DM crystals, NaLaMo and LiGdMo, all of them being isostructural [1-3].

The largest Yb^{3+} cross sections in DT hosts were found in NaLuW but its incongruent melting requires the use of the Top Seeded Solution Growth (TSSG) method to prepare single crystals of this compound. Although some DM hosts are also characterized by relatively high cross sections, the molybdates are in general less transparent and more susceptible to optical damage. The ionic radius of Y is very close to that of Lu and similar spectroscopic properties can be expected for NaYW and NaLuW, with the NaYW advantage of congruent melting which permits to grow it by the more efficient Czochralski (Cz) method. In this work we present the spectroscopic characteristics of Yb:NaYW and demonstrate efficient laser operation at room temperature.

2. Crystal growth and spectroscopy

NaYW crystals doped with 10 mol % of Yb in the melt were grown by the Cz method using a procedure similar to those described in our previous work on other Na-based DT crystals [1-4]. NaYW melts at 1483 K. To protect the Pt crucible used and to facilitate the seeding process we reduced the melting temperature by addition of 2.3 mol % of $Na_2W_2O_7$. Undoped ***c***-cut NaYW was used as a seed. The Yb concentration in the grown crystal determined by X-ray fluorescence spectroscopy was 6.9 mol %. Taking into account the NaYW lattice cell volume, V= 305.00(5) Å^3, the Yb-density in the crystal is [Yb]=4.52×10^{20} cm^{-3}.

Table 1. Absorption (σ_{ABS}) and emission (σ_{EMI}) cross sections of Yb^{3+} in tetragonal DT and DM crystals.

Crystal	NaLuW	NaYW	NaGdW	NaLaW	LiGdMo	NaLaMo
Growth method	TSSG	Cz	Cz	Cz	TSSG	Cz
σ_{ABS} (σ/π) [10^{-20} cm^2] λ [nm]	1.65 / 2.22 973.8	1.83 / 2.55 975	1.36 / 1.78 975	1.15 / 1.60 976	1.17 / 1.64 975	1.5 / 2.5 977
σ_{EMI} (σ/π) [10^{-20} cm^2] λ [nm]	1.4 / 2.1 1000	1.3 / 3.55 1000	0.75 / 1.89 1000	0.94 / 2.28 1000	1.2 / 3.5 1000	1.3 / 3.5 1000

Low temperature (5 K) spectroscopic studies of the absorption, $^2F_{7/2}(0)\rightarrow{}^2F_{5/2}(0',1',2')$, and photoluminescence, $^2F_{5/2}(0')\rightarrow{}^2F_{7/2}(0,1,2,3)$, transitions allowed to determine the energy levels for an average Yb^{3+} center in NaYW: E($^2F_{7/2}$)=0, 230, 374, 487 cm^{-1} and E($^2F_{5/2}$)=10273, 10397 and 10656 cm^{-1}. These levels were used to calculate by the reciprocity method the emission cross sections of Yb:NaYW for the two polarizations from the measured room temperature absorption cross sections. Both are shown in Fig. 1. together with the measured photoluminescence, which is affected at short wavelengths by reabsorption. Table 1 shows a comparison with other isostructural DT and DM crystals. The $^2F_{5/2}$ Yb^{3+} lifetime measured by the pinhole method was τ_f=392 (±15) µs.

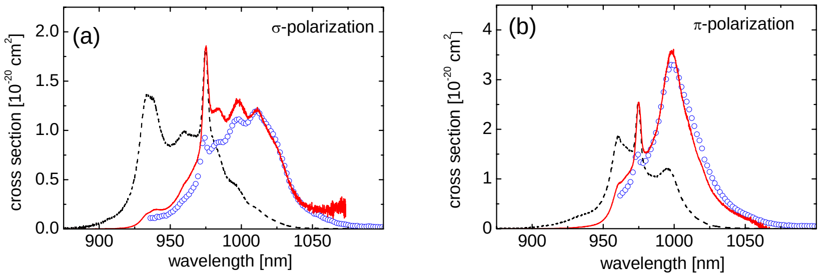

Fig. 1. Room temperature absorption (black dashed curves) and emission (red curves) cross sections, and fluorescence profiles (blue symbols) of Yb:NaYW for σ (a) and π (b) polarization. The photoluminescence was excited at 959 nm.

3. Laser experiments

Continuous wave (CW) laser operation was studied at 300 K in an astigmatically compensated four mirror (Z-shaped) cavity, Fig. 2a. Three uncoated ***a***-cut Yb:NaYW samples with thickness ranging from ≈0.7 to ≈1.5 mm were studied for both polarizations. They were positioned under Brewster angle and were only passively cooled. The pumping was in a single pass at 974.7 nm, by a Ti:sapphire laser; the maximum power applied was 1.35 W. In all cases the thresholds were lower and the efficiency and maximum output powers were higher for the π-polarization, Fig. 2b. The maximum slope efficiency and output power achieved with the ≈1.5 mm thick sample were 74.6% (T_{OC}=5%) and 463 mW (T_{OC}=3%), respectively. The laser wavelength depended on the output coupler and decreased for the π-polarization from 1045 nm (T_{OC}=1%) to 1021 nm (T_{OC}=10%). The laser tunability with a birefringent filter inside the cavity, Fig. 2a, was also broader for the π-polarization, extending from 1003.7 to 1073 nm, Fig. 2c.

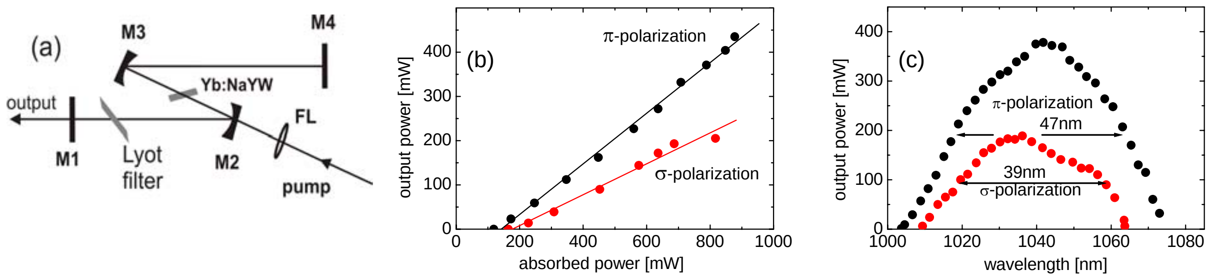

Fig. 2. Laser performance of ≈1.5-mm thick Yb:NaYW for T_{OC}=1% output coupler. (a) Cavity, M2 and M3 have RC=-10 cm. (b) Output power versus absorbed pump power (symbols) and fitted slopes (lines). (c) Tunability at maximum pump power.

Although laser performance depends critically on the crystal quality, these first CW results obtained with Yb:NaYW are very promising because in terms of efficiency they are very similar to the best values demonstrated with the technologically mature Yb:NaGdW [2]. Thus, having in mind the broad tunability achieved, we are confident that Yb:NaYW has great potential also as a passively mode-locked laser.

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