$KY(WO_4)_2:Tm^{3+}$ planar waveguide laser

Simon Rivier, Xavier Mateos, Valentin Petrov, and Uwe Griebner
Max-Born-Institute for Nonlinear Optics and Ultrafast Spectroscopy, 2A Max-Born-Str., D-12489 Berlin, Germany,
griebner@mbi-berlin.de

Yaroslav E. Romanyuk,[1] Camelia N. Borca,[2] Florent Gardillou,[3] and Markus Pollnau[4]
Advanced Photonics Laboratory, Institute of Imaging and Applied Optics,
Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland,

[1] Present address: Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[2] Present address: Paul-Scherrer-Institut, CH-5232 Villigen, Switzerland
[3] Present address: Teem Photonics S.A., F-38240 Meylan, France
[4] Visiting researcher; permanent address: University of Twente, NL-7500 AE Enschede, The Netherlands

Abstract: Waveguide lasing of monoclinic $KY(WO_4)_2:Tm^{3+}$ grown by liquid-phase epitaxy is demonstrated in the 2 µm spectral range. The maximum continuous-wave output power achieved was 32 mW in the fundamental mode.

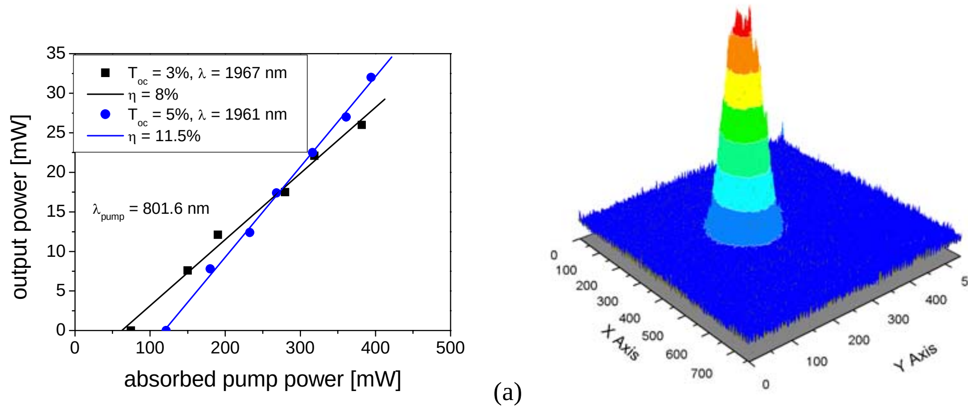
OCIS codes: (140.5680) Rare earth and transition metal solid-state lasers; (230.7390) Waveguides, planar

The monoclinic double tungstates, $KY(WO_4)_2$ (KYW), $KGd(WO_4)_2$ (KGdW) and $KLu(WO_4)_2$ (KLuW), which are strongly anisotropic biaxial crystals, doped with different rare-earth ions are recognized as very promising materials for solid-state lasers operating at room temperature [1]. In particular, they are intensively studied when doped with Tm^{3+}-ions in the 2 µm spectral range [2,3]. In crystalline hosts, planar Tm-waveguide lasing was demonstrated so far only based on YAG. The first reported YAG:Tm waveguide, grown by liquid phase epitaxy (LPE), delivered 180 mW of continuous-wave (CW) output power at a laser wavelength of 2012 nm using a longitudinal pump geometry [4]. High-power side-pumped planar YAG:Tm waveguide lasers were also studied. For this purpose, diffusion-bonded structures were applied and laser operation at 2020 nm with a CW output power of up to 15 W was achieved [5]. Recently, the first planar waveguide laser based on a monoclinic double tungstate host was demonstrated [6]. CW laser emission near 1 µm was achieved with excellent performance using an end-pumped Yb-doped KYW layer on a KYW substrate. An output power of 290 mW in the fundamental mode and a very high slope efficiency above 80% was obtained at room temperature. The combination of high doping levels and large cross-sections, which is one feature of the monoclinic double tungstate hosts, permits the use of relatively thin active layers. Very recently, the growth of a 130-µm-thick KLuW:Tm layer on a KLuW substrate and its CW laser operation under longitudinal Ti:sapphire laser pumping normal to the layer have been reported [7].

The $^3F_4 \rightarrow ^3H_6$ transition of Tm^{3+} acts as a quasi-three-level laser which is connected with a pronounced reabsorption and a rather high laser threshold. One way of decreasing the threshold is the use of a waveguiding structure, in which high pump-power densities and excellent overlap of pump and resonator modes can be achieved. This approach requires fabrication of high-quality KYW:Tm layers on suitable substrates with close-to-perfect interfaces to ensure low-loss propagation. On the other hand, in a waveguiding configuration with end-face pump coupling, the Tm^{3+} concentration can be much smaller than would be required for transversal pumping. Thus, stress due to lattice mismatch between layer and substrate is minimized and large-area, defect-free thin layers can be grown.

LPE is a well-known technique for the production of high-quality oxide films for laser applications, in which a single-crystal layer can be flux grown on a flat, oriented single-crystal substrate. 1-mm thick undoped KYW crystals with laser-grade polished (010) faces were used as substrates. The vertical dipping technique with partial immersion of the substrate was applied. Out of the two solvents employed recently for the fabrication of rare-earth ion-doped KYW waveguides, a low-temperature chloride solvent or $K_2W_2O_7$, we chose the latter because of the much better interface and layer quality obtained with $K_2W_2O_7$ [6]. Single-crystalline layers with thickness up to 40 µm and different Tm^{3+} concentrations ranging from 0.7 to 1.2 at. % were obtained at a growth rate of 18 µm/h. The surface of each layer was polished to remove flux residuals and growth steps. Special alignment precautions were taken to keep the layer surface parallel to the interface. The end-faces of each layer were polished to laser-grade quality.

The planar waveguide used for the laser experiments consisted of a 35-µm thick layer of 1.0 at. % Tm^{3+}-doped KYW. Due to the geometrical dimension of the structure a large number of transversal modes can be guided. The 6-mm long waveguide was polished on all sides and placed in an external resonator. To match the resonator waist size with the waist of the transverse fundamental mode of the waveguide, a X-shaped four-mirror laser resonator was constructed. The KYW:Tm waveguide was positioned at Brewster angle between two 10-cm folding mirrors so that the resonator waist is located at both end-faces of the waveguide. This corresponded to propagation approximately along the N_g-principal optical axis and polarization along the N_m-axis. The sample was mounted on a copper plate but no special care was taken for cooling. The KYW:Tm layer was pumped in single pass absorption by a tunable CW Ti:sapphire laser. The measured single-pass low-signal absorption of the 1.0 at. % Tm-doped KYW layer at 800 nm amounted to about 60%.



(a) (b)

Fig. 1. Continuous-wave lasing of the Tm-doped KYW planar waveguide. (a) Output power versus absorbed pump power for two output couplers (T_{OC}: output coupler transmission, η: slope efficiency). (b) 3D far-field intensity distribution at maximum output power. The numbers on the space axes are pixels and 1 mm corresponds to 75 pixels.

CW laser operation was obtained for output coupler transmissions (T_{OC}) between 1 and 5%. The laser performance of the Tm-doped waveguides is presented in Fig. 1a. Depending on the output coupler transmission, the laser emission was between 1960 and 1970 nm. Best laser performance was achieved when pumping in the absorption peak at 801.6 nm. The laser threshold of the 35-µm-thick KYW:Tm layer was reached at an absorbed pump power of 80 mW. The maximum output power was measured to be 32 mW with T_{OC} = 5%, resulting in a slope efficiency versus absorbed pump power of 11.5%. The maximum optical-to-optical conversion efficiency achieved is only about 8%, which is mainly due to the two times larger pump spot-size compared to the active layer thickness. The observed far-field intensity distribution of the KYW:Tm waveguide laser is shown in Fig. 1b. It indicates, despite the highly multimode waveguide structure, that the laser output is close to the diffraction-limit, also when aligned for maximum output power. The x- and y-cuts can be well fitted with a Gaussian function and a beam ellipticity of only ~25% is deduced. The larger waist is always located in the plane without guiding.

References

[1] N. V. Kuleshov, A. A. Lagatsky, V. G. Shcherbitsky, V. P. Mikhailov, E. Heumann, T. Jensen, A. Diening, and G. Huber, "CW laser performance of Yb and Er, Yb doped tungstates," Appl. Phys. B **64**, 409-413 (1997).

[2] A. A. Kaminskii, L. Li, A. V. Butashin, V. S. Mironov, A. A. Pavlyuk, S. N. Bagaev, and K. Ueda, "New stimulated emission channels of Pr^{3+} and Tm^{3+} ions in monoclinic $KR(WO_4)_2$ type crystals with ordered structure (R=Y and Gd)," Jpn. J. Appl. Phys. **36**, L107-L109 (1997).

[3] X. Mateos, V. Petrov, J. Liu, M. C. Pujol, U. Griebner, M. Aguiló, F. Díaz, M. Galan, and G. Viera, "Efficient 2-µm continuous-wave laser oscillation of $Tm^{3+}:KLu(WO_4)_2$," IEEE J. Quantum Electron. **42**, 1008-1015 (2006).

[4] A. Rameix, C. Borel, B. Chambaz, B. Ferrand, D. P. Shepherd, T. J. Warburton, D. C. Hanna, and A. C. Tropper, "An efficient, diode-pumped, 2 µm Tm:YAG waveguide laser," Opt. Commun. **142**, 239-243 (1997).

[5] J. I. Mackenzie, S. C. Mitchell, R. J. Beach, H. E. Meissner, and D. P. Shepherd, "15 W diode-side-pumped Tm:YAG waveguide laser at 2 µm," Electron. Lett. **37**, 898-899 (2001).

[6] Y. E. Romanyuk, C. N. Borca, M. Pollnau, S. Rivier, V. Petrov, and U. Griebner, "Yb-doped $KY(WO_4)_2$ planar waveguide laser," Opt. Lett. **31**, 53-55 (2006).

[7] O. Silvestre, M. C. Pujol, M. Aguiló, F. Díaz, X. Mateos, V. Petrov, and U. Griebner, "CW laser operation of $KLu_{0.945}Tm_{0.055}(WO_4)_2$/ $KLu(WO_4)_2$ epilayers near 2-µm," IEEE J. Quantum Electron., in press.