Spectroscopy and CW laser operation of monoclinic Tm:KGd(WO$_4$)$_2$ crystals

F. Güell, J. Massons, Jna. Gavaldà, R. Solé, M. Aguiló and F. Díaz.
Dept. Química Física i Inorgànica, Física i Cristal·lografia de Materials (FiCMA), Universitat Rovira i Virgili
Pça. Imperial Tàrraco 1, E-43005 Tarragona, Catalunya, Spain

V. Petrov and U. Griebner.
Max-Born-Institute for Nonlinear Optics and Ultrafast Spectroscopy, 2A Max-Born-Str., D-12489 Berlin, Germany

INTRODUCTION

▶ Tm-doped laser materials are emerging as very interesting active media for the 2 µm spectral region due to the possibility for diode pumping near 800 nm and their broad tunability. Potential applications lie in the fields of medicine, laser radar and atmosphere monitoring.

▶ The monoclinic double tungstates are strongly anisotropic biaxial crystals with weak concentration quenching effects and large cross sections. The advantages of these crystals for highly efficient, low threshold laser operation with diode pumping are well known in the case of Nd and Yb doping but so far only few laser studies were devoted to Tm-doped double tungstates.

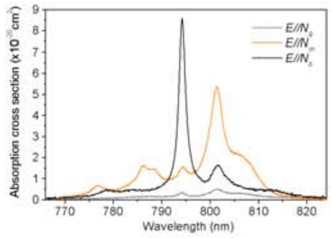
▶ Recently, the successful growth of Tm:KGd(WO$_4$)$_2$ (Tm:KGW) was demonstrated and the spectroscopic properties relevant to laser operation were studied in the orthogonal frame of the optical indicatrix [1].

▶ Here we study the continuous-wave laser characteristics of Tm:KGW at room-temperature using a tunable Ti:sapphire laser in order to compare both polarizations $E//N_m$ and $E//N_p$ with special emphasis on the tuning behaviour for future passive mode-locking experiments. The advantages of the monoclinic double tungstates over other Tm-hosts are outlined.

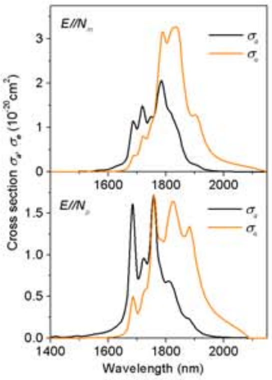
SPECTROSCOPY

▶ We grew good-optical-quality KGW crystals doped with thulium ions by the Top-Seeded-Solution-Growth (TSSG) method.

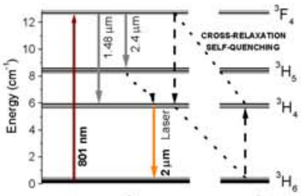
▶ The $^3H_6 \rightarrow ^3F_4$ absorption line of Tm:KGW is broader and shifted to longer wavelengths (more suitable for GaAlAs laser diodes) than in $Y_3Al_5O_{12}$ (YAG) or $LiYF_4$ (YLF).



▶ A maximum emission cross section of σ_e=3.27×10^{-20} cm² at 1834 nm was calculated for polarization $E//N_m$ by the reciprocity method from the absorption spectra σ_a corresponding to the $^3H_6 \rightarrow ^3H_4$ transition.



▶ Partial energy level diagram of Tm:KGW crystals.

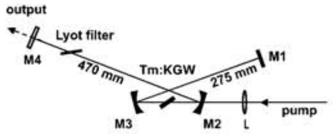


▶ Properties of Tm-doped laser crystals relevant to 2-µm operation, τ_r: calculated radiative lifetime using the Judd-Ofelt (J-O) or the cross section comparison (C-S) methods, τ: measured fluorescence decay time.

Tm-host, κ: thermal conductivity, ΔE: ground state splitting	σ_e: emission cross section [10^{-20}cm^2]	λ_e: emission wavelength [nm]	τ_r [ms]	τ [ms]	$\sigma_e\times\tau$ [10^{-20}cm^{2}ms]	Tm-doping
$Y_3Al_5O_{12}$ (YAG) κ=10.3-13 Wm^{-1}K^{-1} ΔE=580 cm^{-1}	0.22	2011	12.3 (C-S)	10.5	2.31	1%
$LiYF_4$ (YLF) κ=4.3-7.2 Wm^{-1}K^{-1} ΔE=360 cm^{-1}	0.33 (E⊥c)	1902 (E⊥c)	11.9 (C-S)	15.6	5.15	1%
	0.35 (E//c)	1880 (E//c)			5.46	
	0.24 (E⊥c)	1910 (E⊥c)	15.0 (C-S)	15.6	3.74	0.5%
	0.38 (E//c)	1880 (E//c)			5.93	
YVO_4 κ=5.1-9.4 Wm^{-1}K^{-1} ΔE=332-367 cm^{-1}	2.7 (E⊥c)	1800	0.695 (J-O)	0.75-0.8	2.03-2.16	5%
	1.6 (E//c)				1.2-1.28	
	-	-	1.29 (J-O)	1.03	-	1%
	2.60 (E//c)	1805	1.165 (J-O)	-	-	0.5%
	1.73 (E⊥c)	1804			-	
$GdVO_4$ κ=9.7-12.3 Wm^{-1}K^{-1}	-	1830	-	0.93	-	2.5%
$KY(WO_4)_2$ (KYW)	1.9 (E in N_m-N_g)	1850	-	1.47	2.79	15%
κ≈3 Wm^{-1}K^{-1}	2.8-3.8 (E//a')	1820	0.99 (C-S)	1.25	3.5-4.75	3%
$KGd(WO_4)_2$ (KGW) κ=2.6-3.8 Wm^{-1}K^{-1} ΔE=460 cm^{-1}	3.27 (E//N_m)	1834	1.31 (C-S)	1.76	5.76	3%
	1.64 (E//N_p)	1824			2.89	
	1.56 (unpol)	1825	0.8 (J-O)	-	-	3.5%

LASER SETUP

▶ We used an astigmatically compensated X-type cavity without special cooling for laser operation.
L: f=70 mm AR-coated lens,
M1: plane total reflector,
M2-M3: RC=-100 mm mirrors,
M4: plane output coupler (T_{OC}).

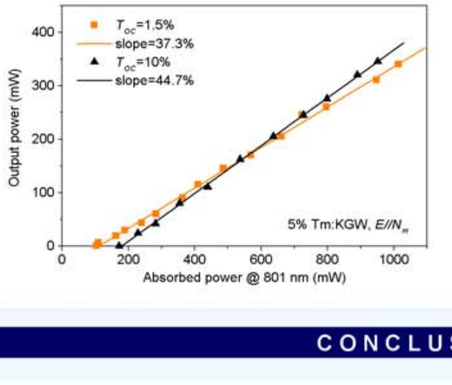


LASER RESULTS

▶ The maximum output power (400 mW) for $E//N_m$ and absorbed power (P_{abs}) 1 W was obtained with T_{OC}=3% and the corresponding pump efficiency amounts to 40%.

▶ The laser threshold for $E//N_m$ and 5% Tm-doped KGW was P_{abs}=70 mW (T_{OC}=1.5%) and P_{abs}=130 mW (T_{OC}=10%).

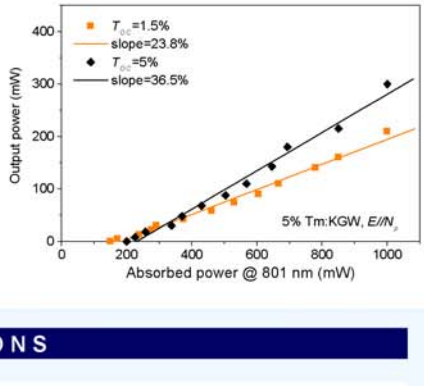
▶ No essential differences in the laser performance could be observed for pumping at 806 nm, better suited for laser diodes, the basic dependence being again on P_{abs}.



▶ The output powers for $E//N_p$ were in general lower but for this polarization lower pump power can be used at 794 nm as compared to 801 nm to achieve the same slope efficiencies.

▶ The laser threshold for $E//N_p$ was P_{abs}=120 mW (T_{OC}=1.5%) and P_{abs}=180 mW (T_{OC}=5%).

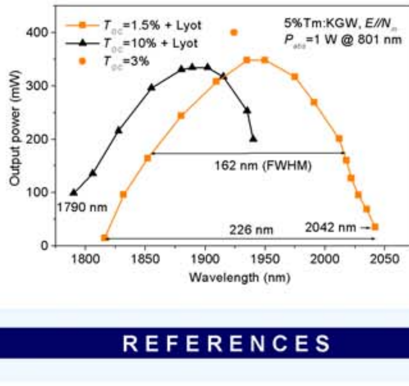
▶ It is the first time Tm-generation is obtained for $E//N_p$ in a monoclinic double tungstate.



▶ An overall tunability extending from 1790 to 2042 nm is achieved with maximum output powers of 400 mW for an absorbed pump power of 1 W.

▶ The FWHM of 162 nm obtained for the tunability curve for T_{OC}=1.5% is in principle capable of supporting sub-50-fs pulses near 1950 nm if this laser could be mode-locked.

▶ The present results represent an improvement of ?100 nm in the tuning range and an 8-fold increase in the output power in comparison to previous results with the isostructural Tm:KYW [2].



CONCLUSIONS

▶ Tm-doped monoclinic tungstates turn out to possess the largest emission cross sections of all crystals included in the table and, as can be seen for Tm:KGW, exhibit larger ground state splitting than Tm:YVO$_4$ or Tm:YLF which is an important advantage in the three-level laser operation scheme.

▶ We note that the combination of broad fluorescence line, large emission cross section and relatively low upper level lifetime is an unique advantage for future experiments on passive mode-locking with such lasers and the generation of femtosecond pulses by an all-solid state laser system tunable in the 2-µm spectral range.

REFERENCES

[1] F. Güell, Jna. Gavaldà, R. Solé, M. Aguiló, F. Díaz, M. Galan and J. Massons. Journal of Applied Physics **95** (2004) 919.

[2] L. E. Batay, A. A. Demidovich, A. N. Kuzmin, A. N. Titov, M. Mond and S. Kück. Applied Physics B **75** (2002) 457.