Continuous-Wave and Mode-Locking Laser Operation of Yb doped disordered Crystals, $M^{+}T^{3+}(XO_4)_2$

M. Rico, J. Liu, S. Rivier, U. Griebner, and V. Petrov

Max-Born-Institute for Nonlinear Optics and Ultrafast Spectroscopy, 12489 Berlin, Germany

M.D. Serrano, C. Cascales, F. Esteban-Betegón, and C. Zaldo

Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), 28049 Madrid, Spain

MOTIVATION

Femtosecond laser pulses based on Yb-doped double tungstate and molybdates

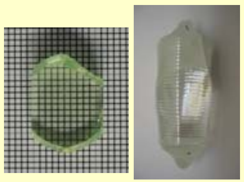
- Introduction of the tetragonal disordered double tungstate and molybdates laser crystal Yb:$M^{+}T^{3+}(XO_4)_2$, where M^{+} = Li or Na, T^{3+} = Gd or La, and X = W or Mo.
- Growth of $M^{+}T^{3+}(WO_4)_2$ or $M^{+}T^{3+}(MoO_4)_2$ single crystals by the Czochralski method.
- High incorporation of Yb-concentrations in all these laser host matrices.
- Disorder causes inhomogeneus broadening of the absorption (suitable for diode-laser pumping) and emission bands (tunable and mode-locked laser operation).

Yb:$M^{+}T^{3+}(XO_4)_2$ hold great promise as new laser materials for diode-pumped high-power lasers, and generation of ultrashort (fs) pulse laser systems.

CRYSTALLINE GROWTH CHARATERIZATION

- Yb-doped $NaT(XO_4)_2$ (T = Gd, La and X = W, Mo) single crystals were grown in air by the Czochralski method and Yb-doped LiGdMo crystal was grown by the Top Seeded Solution Growth method using Li_2MoO_4 as solvent.

$NaGd(WO_4)_2$ (NaGdW) | **$LiGd(MoO_4)_2$ (LiGdMo)** | **$NaLa(WO_4)_2$ (NaLaW)**



- Segregations coefficients K=$[Yb]_{crystal}/[Yb]_{melt}$ where [Yb] denotes the concentration, were about 0.8 for NaGdW, 0.6 for NaLaW, 0.35–0.5 for NaLaMo, and 0.6 for LiGdMo.
- The Yb doping levels in these materials, applied for laser operation, were 7.49×10^{20} cm^{-3} (NaGdW), 1.1×10^{20} cm^{-3} (NaLaW), 3.08×10^{20} cm^{-3} (NaLaMo), and 4.06×10^{20} cm^{-3} (LiGdMo).
- These crystals show structural disorder which causes inhomogeneous broadening of the absorption and emission features in the spectra of the optically active dopants, as a consequence of the presence of a number of local fields acting on them.

REFERENCES Yb^{3+}:$M^{+}T^{3+}(XO_4)_2$

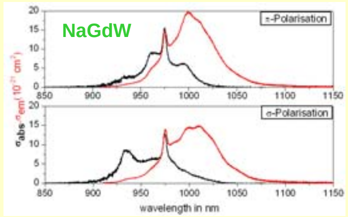
Crystal growth M. D. Serrano et al. *J. Cryst. Growth 275, e819 (2005)*

Spectroscopy M. Rico et al. *Opt. Express* ***12****, 5362 (2004)*

CW laser M. Rico et al. *Appl. Phys. B* ***81****, 621 (2005)*

Mode-locked laser S. Rivier et al. *CLEO/Europe CF4-4-Thu (2005)*

SPECTROSCOPIC CHARACTERIZATION

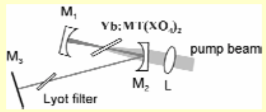


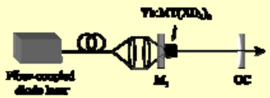
Yb-host	λ_{max} [nm]	$\sigma_{\pi,max}$ [$10^{-20}cm^{-1}$]	$\sigma_{\pi,max}$ [$10^{-20}cm^{-1}$]	τ [µs]
NaGdW	974	1.51	1.21	320
NaLaW	976	1.60	1.15	220
NaLaMo	977	2.5	1.5	280
LiGdMo	975	1.64	1.17	250
KGdW	981	1.31 //g	11.8 //m	375
YAG	968	0.7		1080

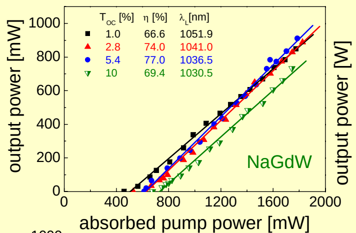
- In general, π-polarization is higher than σ-polarization.
- $\sigma_{abs,emi}$ similar to Yb:YAG and lower than monoclinic double tungstates, Yb:KGW.
- Broadening bands (FHWM >3 times to KGW) could support sub-100 fs pulses.

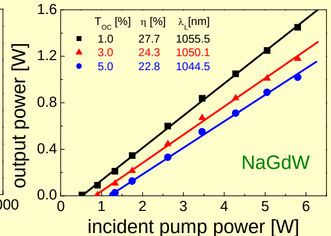
CW LASER OPERATION

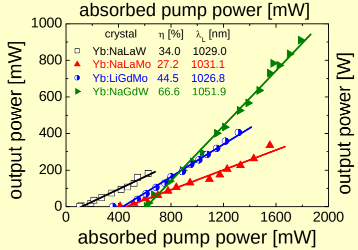
Ti:sapphire-pumped | **Diode-pumped**

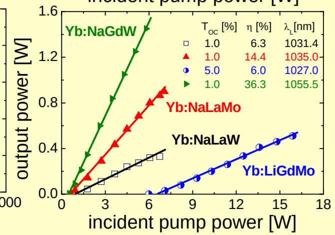








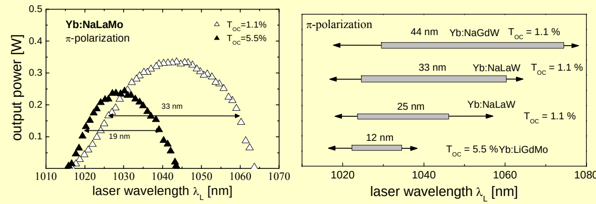




- Currently, Yb:NaGdW crystals show the best performance for both pump sources.
- Crystal thickness: 3.3 mm (NaGdW), 3.4 mm (NaLaW), 2.6 mm (NaLaMo), 2.6 mm (LiGdMo)
- No crystal damage (intracavity intensity >1MW/cm²) and no cooling systems applying (except LiGdMo pumping with diode and water cooling).

TUNABLE LASER OPERATION

- Tuning curves depend on the laser gain and loss mechanisms. Largest tunung range extend from 1016-1064 nm and 1013-1080 nm for Yb:NaLaMo and Yb:NaGdW.
- The FWHM of 33 nm and 44 nm corresponds to $\Delta\nu$ = 9.1×10^{12} Hz and 12×10^{12} Hz, respectively, which means for a $sech^2$ or Gaussian pulse shape, that potentially sub-50 fs pulses could be supported in the mode-locked regime.

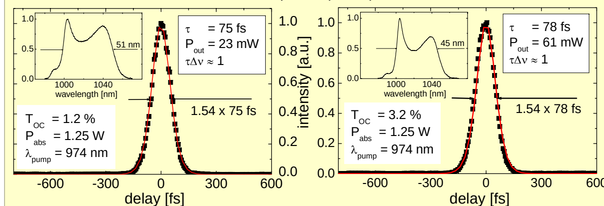


	Ti:sapphire laser pumping				Diode laser pumping			
Yb-host	NaGdW	NaLaW	NaLaMo	LiGdMo	NaGdW	NaLaW	NaLaMo	LiGdMo[a]
λ_P [nm]	976	976.6	976.7	975	≈976	≈976	≈976	980
T_{OC} [%]	5.4	1.1	1.1	10.0	1.0	1.0	1.0	5
P_{max} [mW]	911	205	400	473	1450	330	900	510
λ_L [nm]	1036.5	1034	1039.5	1025.7	1055	1031	1035	1027
$\Delta\lambda$ [nm]	50	40	48	23				

[a] crystal with active cooling

MODE-LOCKED LASER OPERATION of Yb:$NaGd(WO_4)_2$

Autocorrelation traces and spectra (insets) of the Yb:NaGdW laser



First mode-locked disordered tungstate laser

SUMMARY

- High-quality Yb:$M^{+}T^{3+}(XO_4)_2$ single crystals have been grown.
- First lasing of Yb^{3+} in the disordered double tungstate and molybdate (P_{out} = 911 mW, η_c = 77% for NaGdW).
- Efficient tunability of Yb^{3+} ions for all materials, p.e. NaGdW >60 nm.
- First mode-locked laser operation of Yb:NaGdW (P_{out} = 61 mW, $\tau \approx$ 78fs).
- Shortest pulse duration of a SAM mode-locked tungstate laser.
- Improvement in crystal growth, SESAM and cavity designs will allow to reduce the short-pulse generation to sub-50 fs regime.