Passive mode-locking of novel Yb-doped tungstate crystals

S. Rivier, A. Schmidt, V. Petrov, U. Griebner

Max-Born-Institut, Berlin, Germany

D. Rytz

FEE GmbH, Idar-Oberstein, Germany

A. García-Cortés, J. M. Cano-Torres, M. D. Serrano, B. C. Cascales, C. Zaldo

Instituto de Ciencia de Materiales, Madrid, Spain

Outline

Motivation

Characterization of Yb-doped monoclinic and tetragonal double tungstate crystals

Mode-locked laser operation of novel Yb-doped monoclinic and tetragonal double tungstate and borate crystals

Summary

Motivation

Goal: Sub-50 fs diode-pumped ultrashort-pulse lasers

=> highly-efficient mode-locked lasers @1 µm

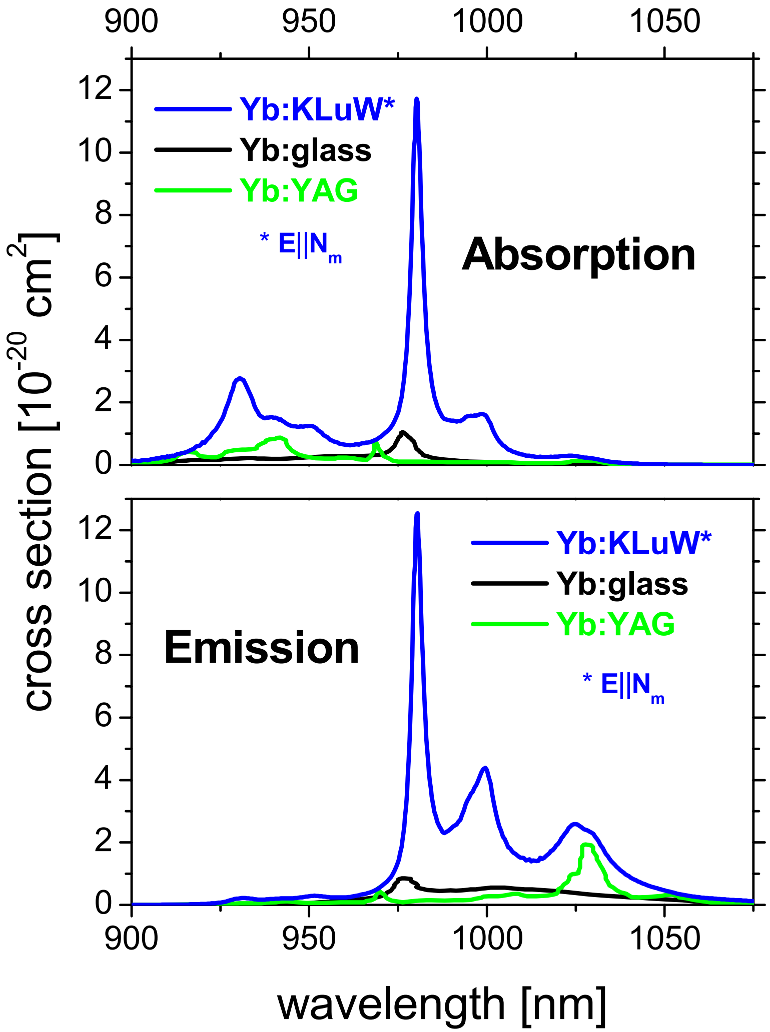
Choice: active ion: Yb^{3+} => low heat generation

- absence of:
    * excited-state absorption
    * up-conversion, cross-relaxation
    * concentration quenching

laser host: double tungstate crystals

Absorption and emission cross sections

- Yb-doped laser materials comparison -



Advantages of Yb-doped monoclinic double tungstates

- compared to Yb:YAG -

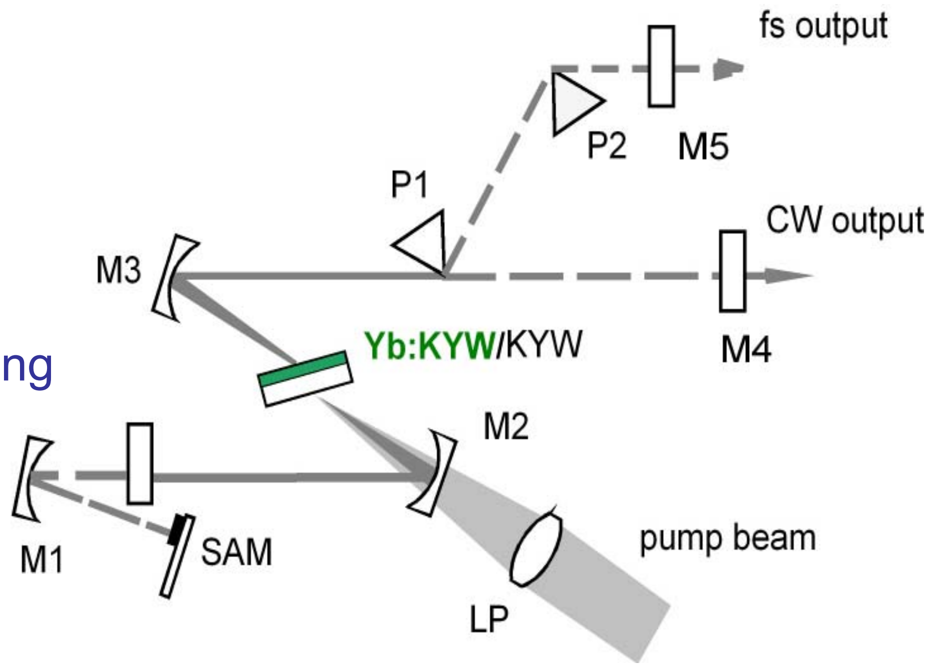
- **Larger emission cross section**
- **Broader amplification bandwidth**
- **Absorption cross section @980nm**
  15 times larger than Yb:YAG

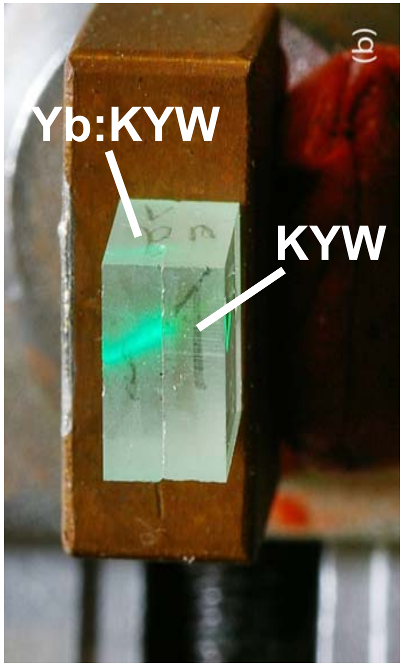
Yb:KYW, Yb:KGdW, Yb:KLuW and KYbW are almost identical

Laser operation of diffusion bonded Yb:KYW/KYW structures

Laser setup

without active cooling





Yb:KYW structure: 5% Yb-doped KYW (1.5mm) on KYW (1.5mm), 4.8x5.2 mm^2

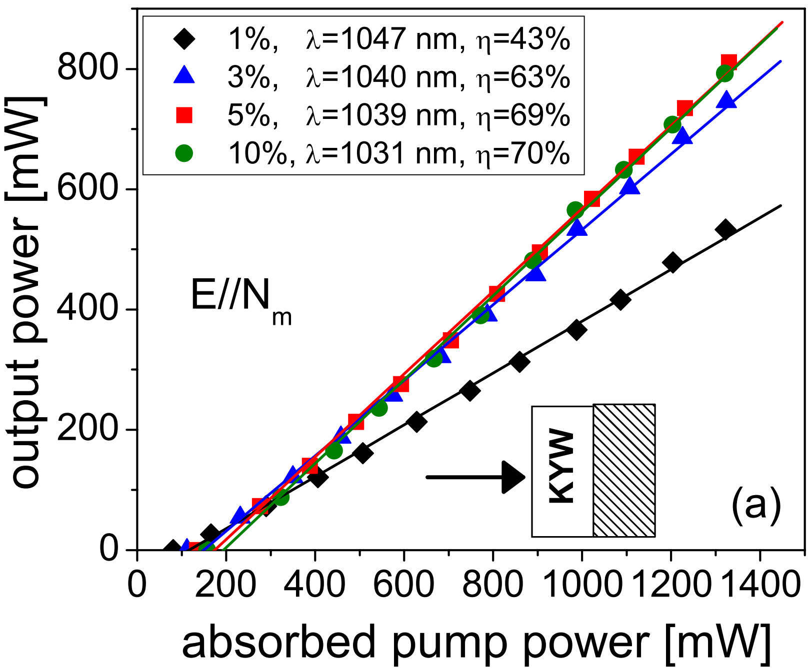
Orientation: polarization || N_m principal optical axis

Pump: Ti:sapphire or diode laser, 4 W @980 nm

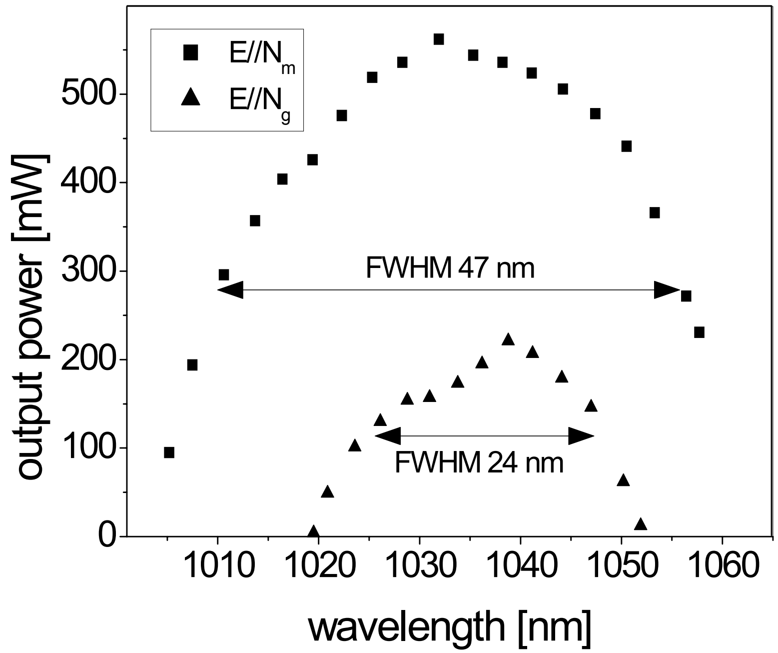
Output coupler (OC): M4, M5; transmission: 1% - 10%

CW laser operation of diffusion bonded Yb:KYW/KYW crystals

Ti:Sa pumping at 981nm



Wavelength tuning
- with Lyot-filter -

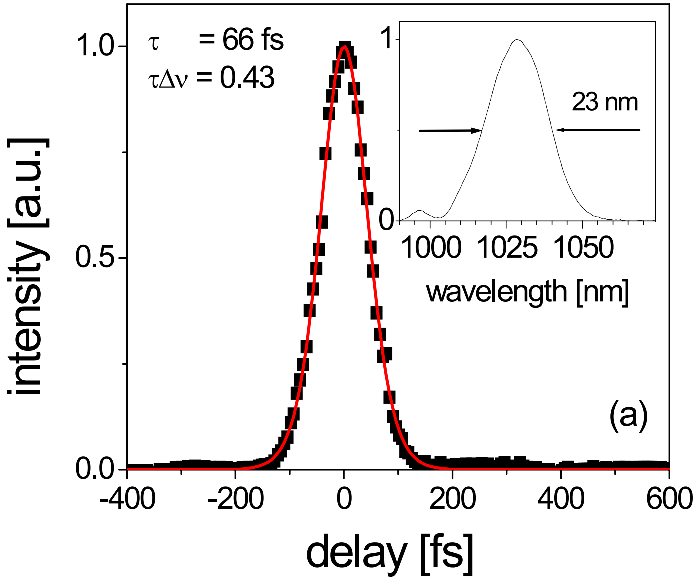


- highly efficient CW laser operation with slope efficiencies up to 70% (P_{out} >800 mW)

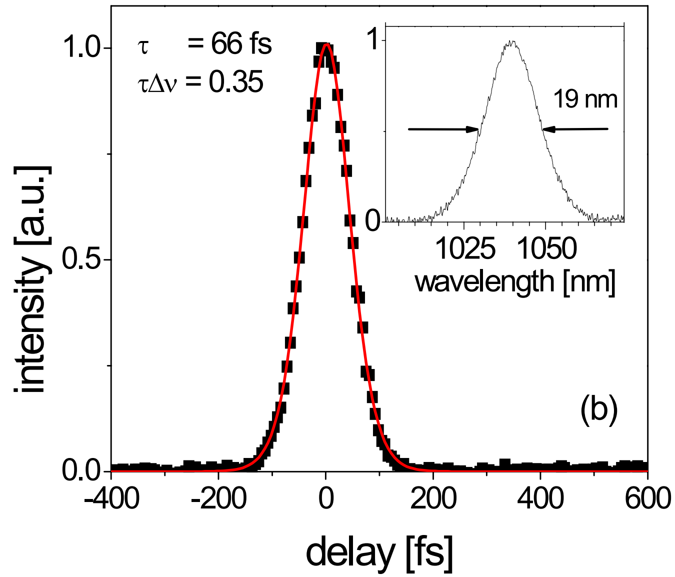
⇒ Successful implementation of diffusion bonding of double tungstate crystals

Mode-locked operation of diffusion bonded Yb:KYW/KYW structures

Autocorrelation and spectrum
- Ti:sapphire pumped -



Autocorrelation and spectrum
- Diode pumped -



=> shortest pulse duration of a monoclinic tungstate laser

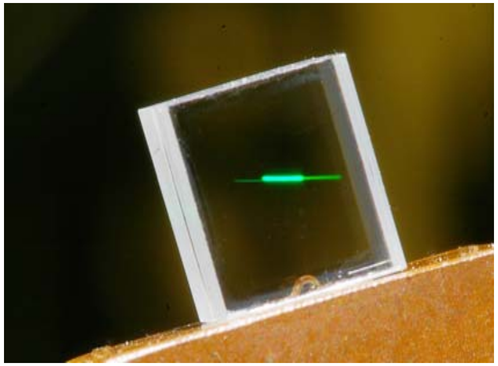
- so far Yb:KYW: 71 fs, [H. Liu et al., Opt. Lett. **26** (2001) 1723] – Kerr-lens mode-locked

First mode-locked laser based on a diffusion bonded double tungstate crystal

Mode-locked operation of diffusion bonded Yb:KYW/KYW structures

Summary

- **Shortest pulse: 62 fs with additional external compression ($\tau\Delta\nu = 0.40$)**
- **Output power: 182 mW (62 fs); 264 mW (69 fs)**
- Repetition frequency: 93 MHz; Output coupling: 5%
- Central wavelength of 1027 nm => population inversion >0.2
- Composite structure with same crystal host: no parasitic reflection and birefringence effects.
- Strongly reduced reabsorption (shorter wavelength) and higher population inversion compared to non-composite => shorter pulse duration possible



Yb-doped tetragonal double tungstates

Yb-doped monoclinic and tetragonal double tungstates as laser host materials at 1 µm

Monoclinic potassium double tungstates

KGdW KYW KLuW

Already very popular Yb-hosts for various types of oscillators/amplifiers

Limitations:

- strong anisotropy: thermo - mechanical properties
- low thermal conductivity
- bandwidths with Yb^{3+} – still yet comparable to Ti:sapphire
- difficult to grow = small size

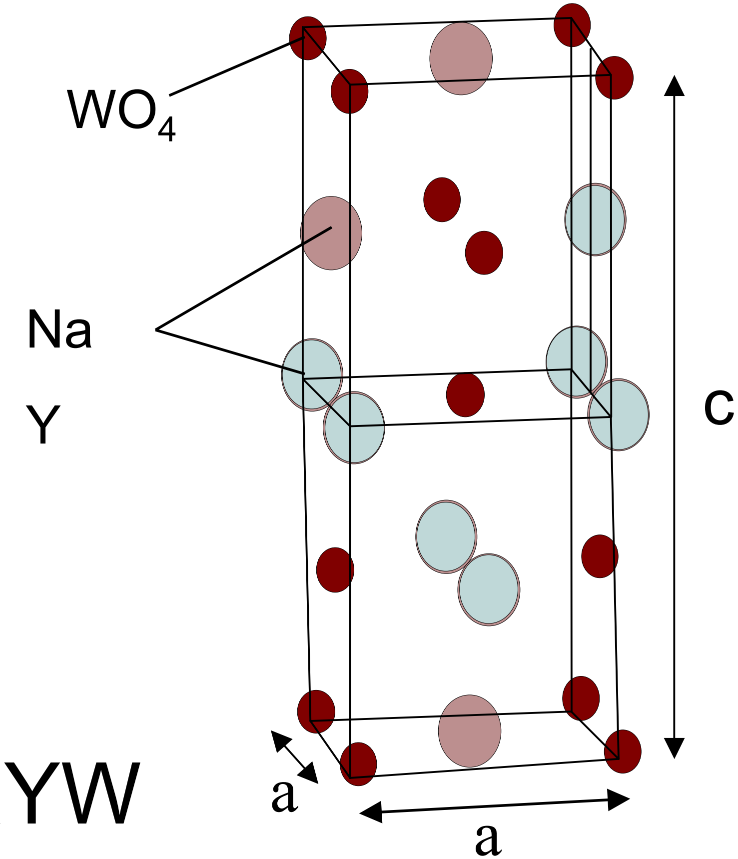
Tetragonal double tungstates

$NaY(WO_4)_2$ – NaYW

Novel Yb-doped disordered crystal hosts

Interesting for:
- **broad tunability**
- **sub-100 fs pulse generation**

Ordered and disordered crystals



NaYW

Disorder 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.

Advantages in disordered crystals

- broad absorption bands
⇒ suitable for diode-pumping

- broad emission bands
⇒ tunable and mode-locked lasers

*I*4 space group, two different sites each with multiple environments

Double tungstate laser materials

Ordered crystals

CaW
KYW
KGdW
KLuW

⇓

Pulsed and cw laser operation with Nd^{3+}, Pr^{3+}, Dy^{3+}, Ho^{3+}, Er^{3+}, Tm^{3+}, and Yb^{3+} doping

⇓

Ultrashort pulse lasers for Nd^{3+} and Yb^{3+}

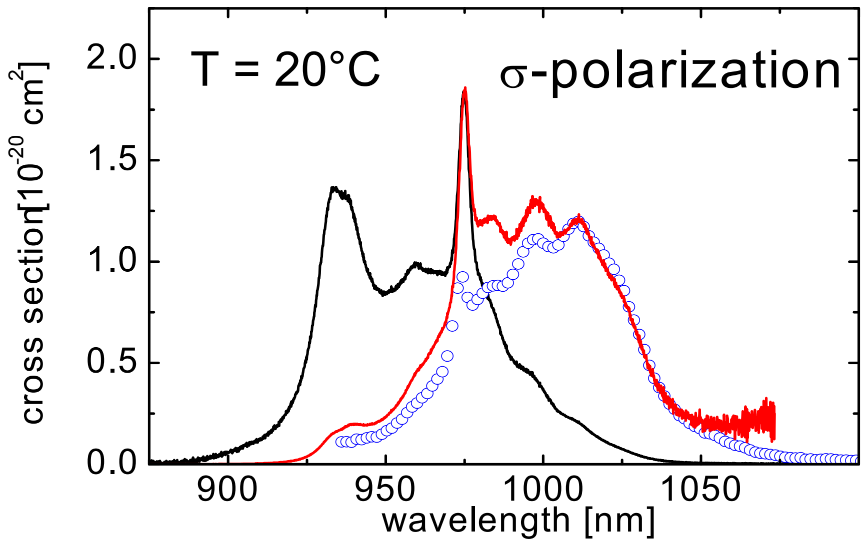
Disordered crystals

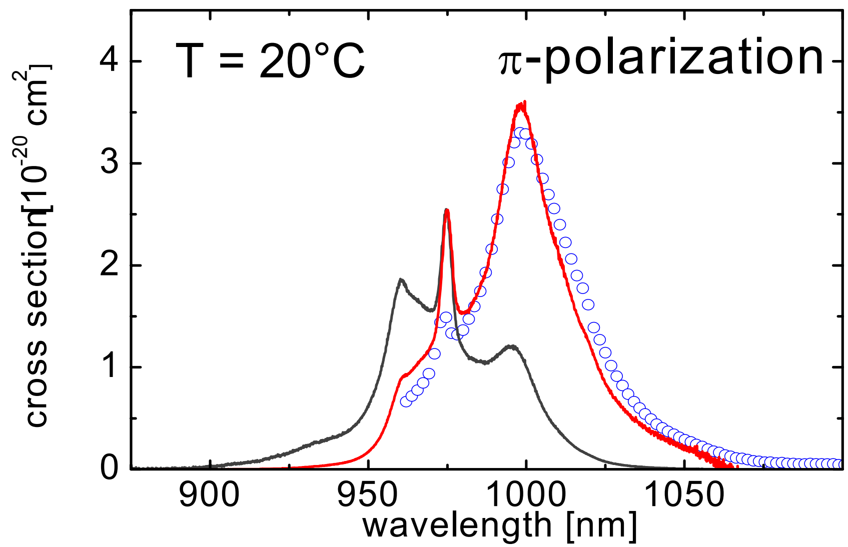
Host	**Pulsed**	**CW**
LiGdMo	Nd^{3+}	Nd^{3+}, Yb^{3+}
NaGdMo	Nd^{3+}	
NaYMo	Nd^{3+}	
KLaMo	Ho^{3+}, Er^{3+}	Nd^{3+}
NaLaW	Nd^{3+}	Yb^{3+}
NaLuW		Yb^{3+}
NaGdW	Nd^{3+}	Nd^{3+}, Yb^{3+}
NaYW	Nd^{3+}	Nd^{3+}, **Yb^{3+}**

first laser with disordered tungstate host: Nd:NaGdW
G. E. Peterson et al. Appl. Phys. Lett. ***4*** *(1964) 173*

Spectroscopy of Yb:NaYW

Absorption and emission cross sections



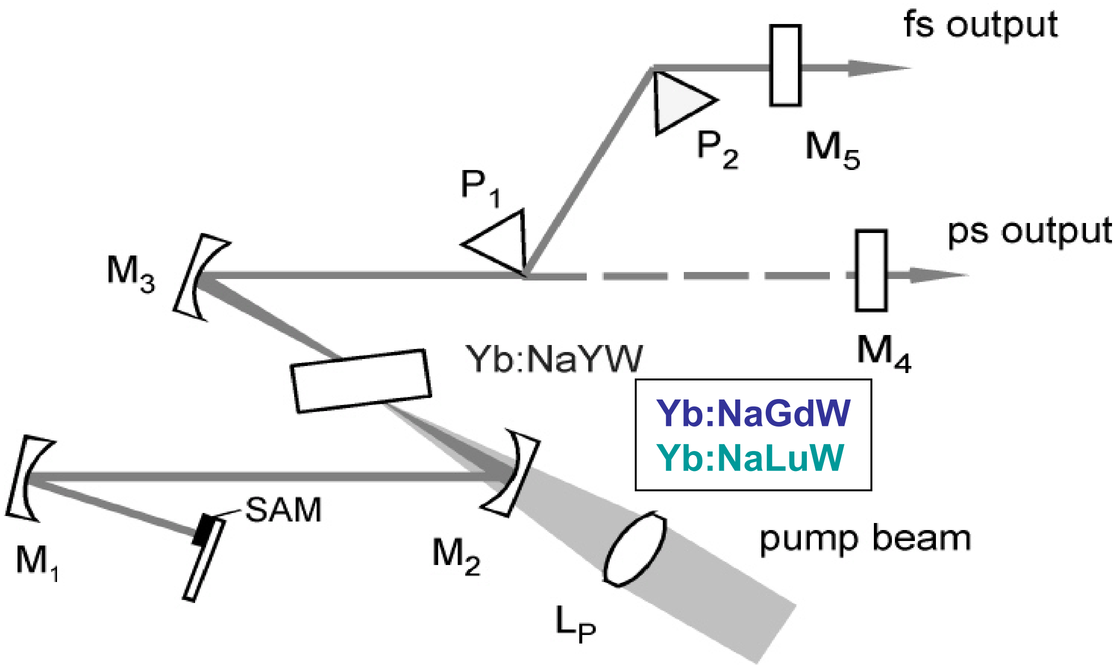


fluorescence lifetime: 392 µs

- Largest σ_{abs} and σ_{em} among the Yb-doped disordered tungstates

Mode-locked Yb:NaYW laser - setup

- Ti:sapphire pumped -



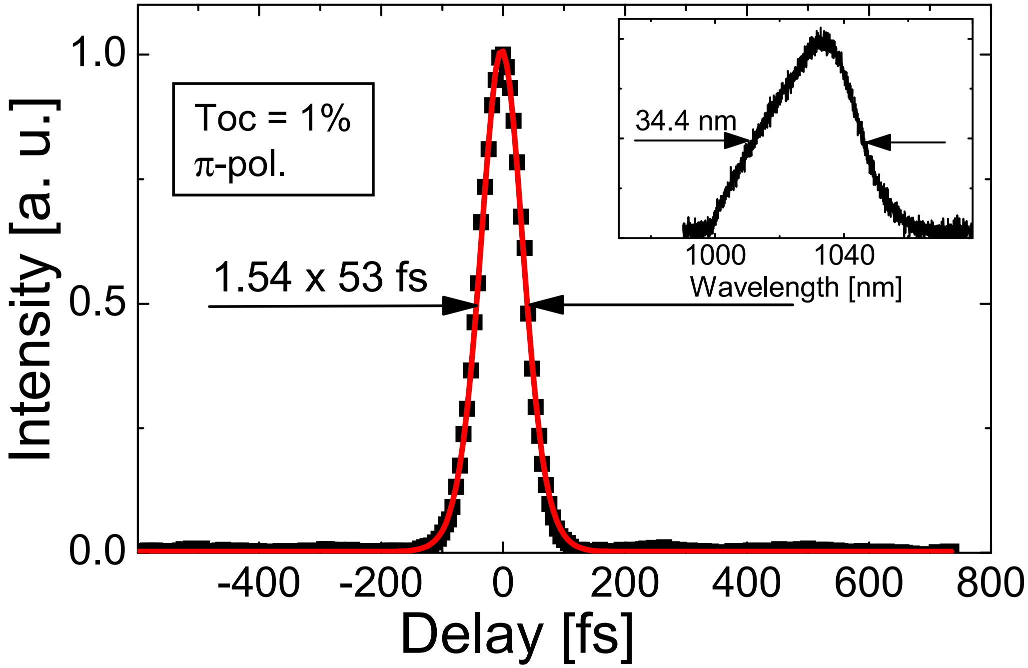
- pump wavelength: 975 nm
- no cooling
- P_{inc} = 1.3 W (max)

Yb:NaYW crystal

- Czochalski grown
- Yb-concentration: 4.52×10^{20} ions cm^{-3}
- uncoated 1.5-mm thick Yb:NaYW plate

Passively mode-locked Yb:NaYW

Autocorrelation trace and optical spectrum



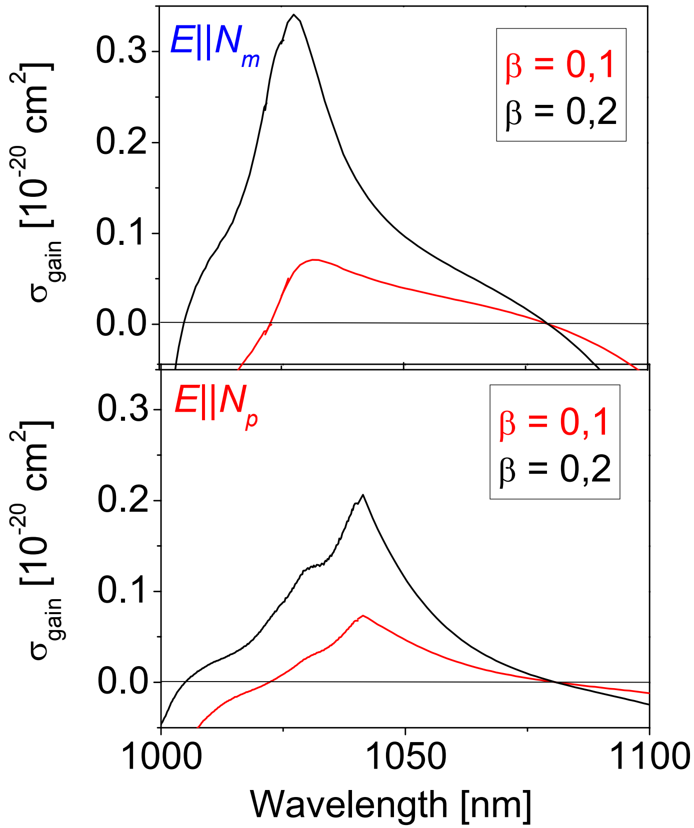
P = 91 mW
f = 96 MHz
$\Delta\nu\Delta\tau = 0.513$
$\tau = 53$ fs

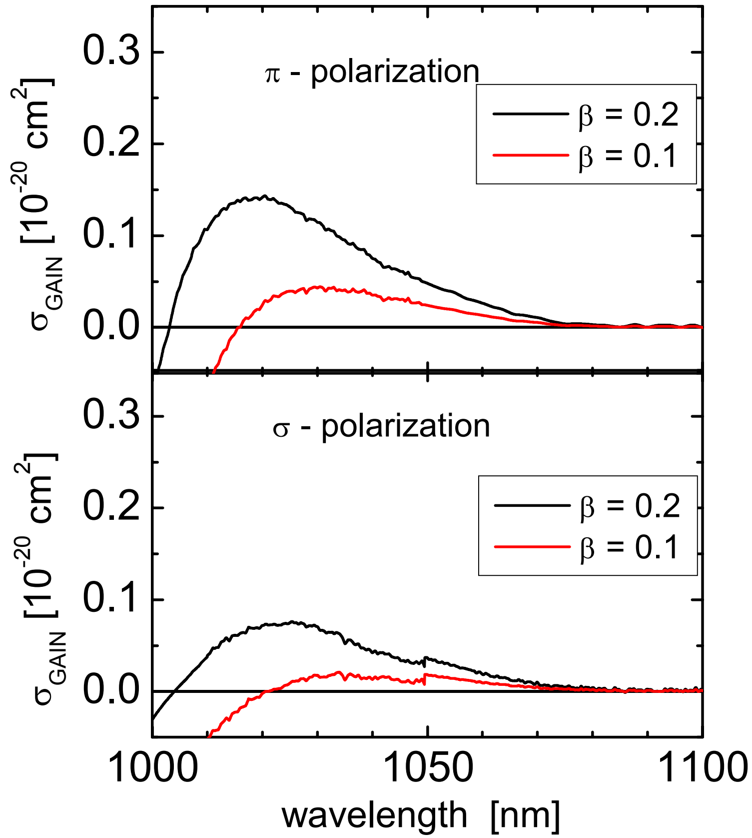
Additional external pulse compression using prism sequences

=> Generation of extremely short pulses using disordered tungstates

Comparison gain cross section Yb:KYW and Yb:NaYW

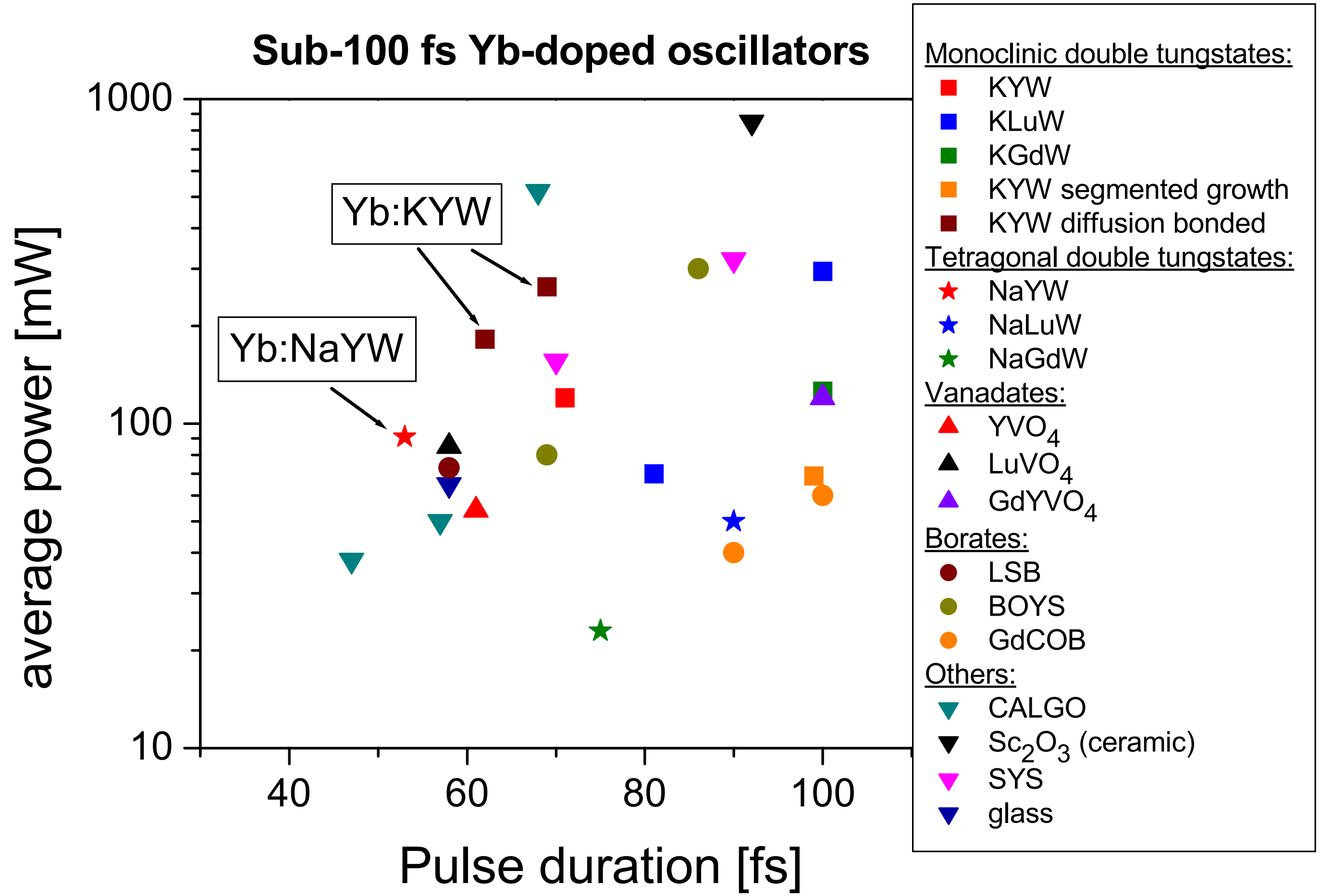
$\sigma_{gain} = \beta\sigma_{em} - (1 - \beta)\sigma_{abs}$ β : population inversion





⇒ smoother and larger gain bandwidth (FWHM) for Yb:NaYW

Yb-doped materials for sub-100 fs pulses



Summary

High quality diffusion bonded Yb-doped monoclinic double tungstates
– very efficient continuous-wave laser (η = 70%)

Passively mode-locked diffusion-bonded Yb:KYW laser

- **τ = 62 fs, $\tau\Delta\nu$ = 0.40, P = 182 mW** (Ti:Sa-pumped)
- **τ = 66 fs, $\tau\Delta\nu$ = 0.35, P = 80 mW** (diode-pumped)

Introduction of novel tetragonal double tungstates – Yb:NaYW
– local disorder causes inhomogeneous broadening

Passively mode-locked laser based on the disordered host: Yb:NaYW

- **τ = 53 fs, $\tau\Delta\nu$ = 0.51, P = 91 mW @1040 nm** (external compress.)

=> among the shortest pulses achieved with Yb-doped lasers

- Yb:$CaGdAlO_4$: 47 fs *(CNRS)*
- Yb:glass: 58 fs *(ETH)*
- Yb:LSB: 58 fs *(MBI)*
- Yb:$LuVO_4$: 58 fs *(MBI)*
- Yb:YVO_4: 61 fs *(BNTU)*