Picosecond Thin Disk Lasers for Pumping Parametric Amplifiers

2nd Photonic Instruments Workshop

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Zürich
11.09.2013

Agenda

- TRUMPF Scientific Lasers
- Motivation for Short-Pulse Pumping of Optical Parametric Amplifiers
- Current ps Laser Development at TSL
- Available TRUMPF Technology for ps Lasers
- Current OPA Development at TSL
- Summary

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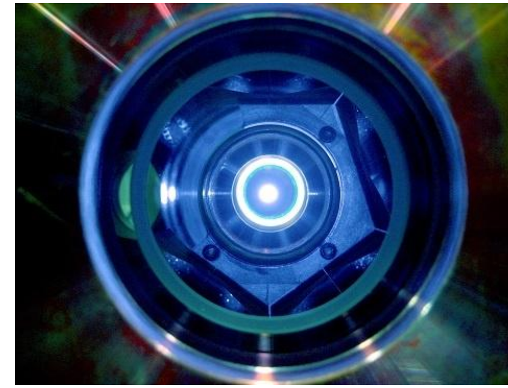
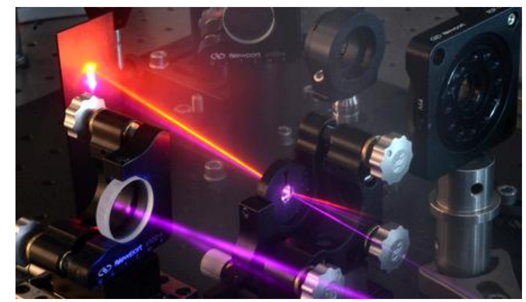
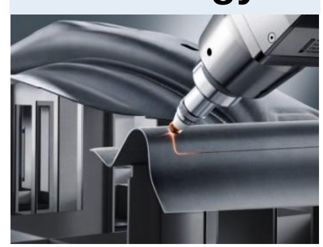
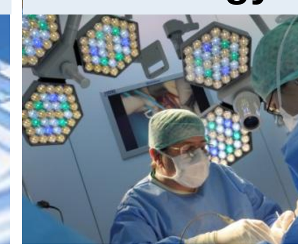
Introduction



- Joint Venture between the TRUMPF Group and Prof. Ferenc Krausz founded in May 2012
- Product portfolio:
  - Picosecond Thin Disk Lasers
  - Optical Parametric Amplifiers (OPA)
  - Jitter-Synchronization
- Currently 6 People in Munich, Germany
- Completely embedded in the TRUMPF-Group



Machine Tools	Laser Technology	Electronics	Medical Technology
 			

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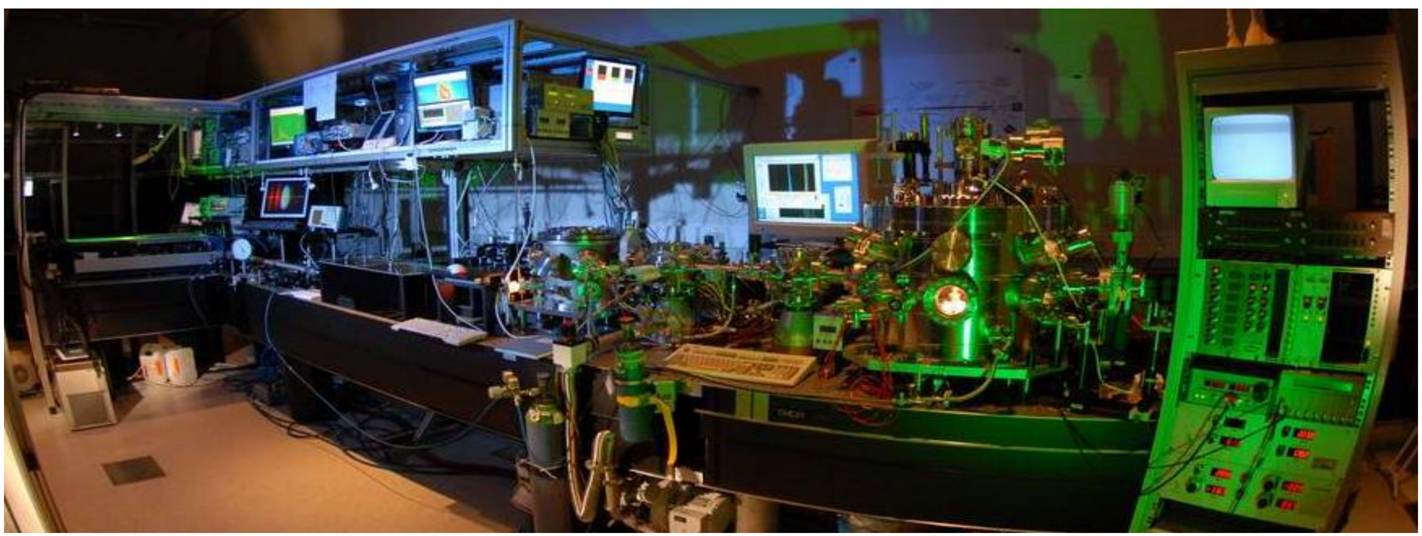
Agenda

- TLM Team & Location
- Motivation for Short-Pulse Pumping of Optical Parametric Amplifiers
- Current ps Laser Development at TSL
- Available TRUMPF Technology for ps Lasers
- Current OPA Development at TSL
- Summary



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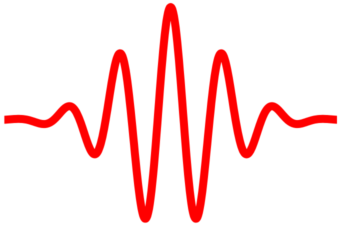
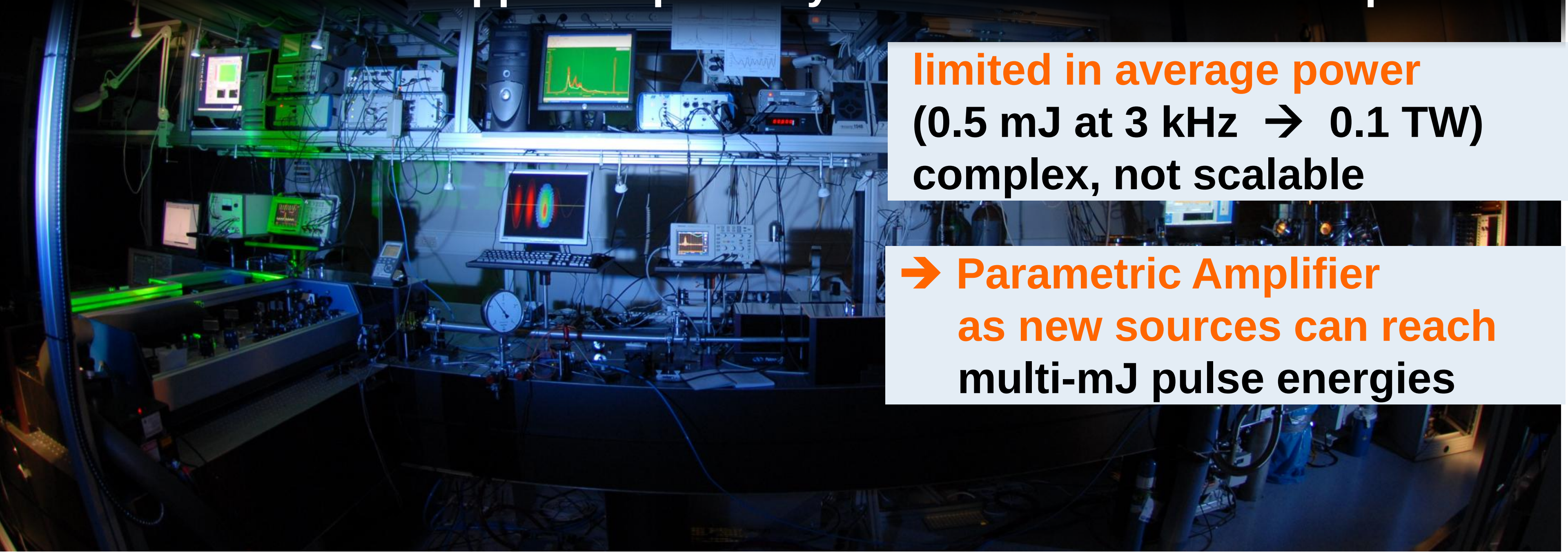
Few-Cycle Laser Systems (5 fs; NIR)

for the generation of isolated attosecond pulses via HHG



State of the art: Ti:Sappire amplifier systems with nonlinear compression



limited in average power
(0.5 mJ at 3 kHz → 0.1 TW)
complex, not scalable

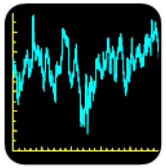
→ Parametric Amplifier as new sources can reach multi-mJ pulse energies

Toolbox for OPCPA

Seed 

Dispersion 

OPA 

Jitter 

Pump 

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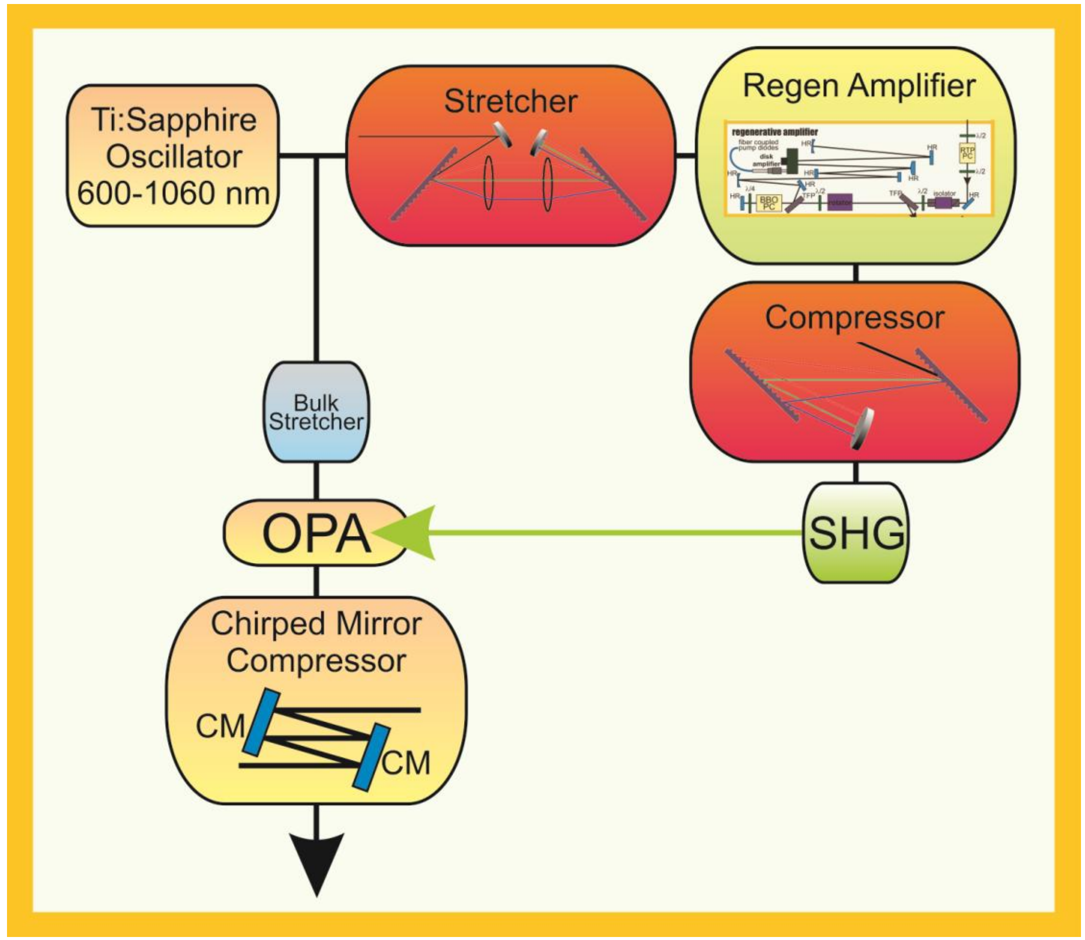
Optical Parametric Amplifiers (OPA/OPCPA)

OPCPA:

- \+ **large amplification (10^7)**
- \+ **no heat deposition**
- \+ **scalable**
- \+ **high pulse energies**
- \+ **compact**
- \+ **high pulse contrast**
- \+ **large bandwidth**
- – **strong ps pump lasers**



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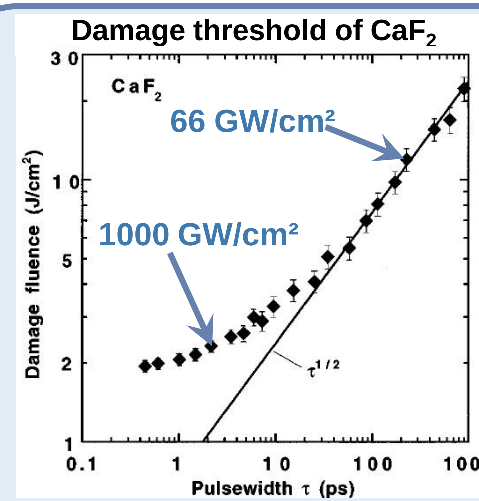
Pumping OPCPA with ps pulses

Amplification: $g \propto I_p^{\,2} \cdot L$

Bandwidth: $\Delta\omega \propto \frac{1}{\sqrt{L}}$

With I_p **: pump intensity**

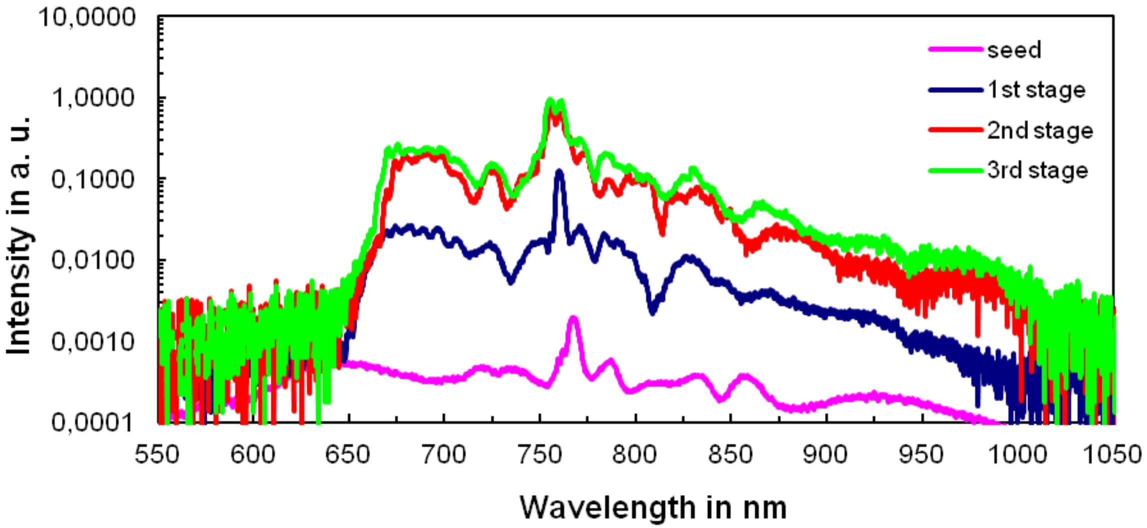
L **: crystal length**



Stuart et al, J. Opt. Soc. Am B, 13, 459 (1996)

- Increased damage threshold of dielectric materials
- OPA can be pumped with large intensities
- High parametric gain **&** large amplification bandwidth
- Simple dispersion management

OPCPA Pumped by a ps Thin-Disk Regen Amplifier



OPA stage	pump energy 515nm	ampl. signal energy	BBO crystal length
1	1.5 mJ	0.2 mJ	1.5 mm
2	7.3 mJ	1.8 mJ	2.0 mm
3	recycle	2.5 mJ	2.0 mm

32 % efficiency pump to signal
5.7 fs TBL pulse duration
Results: Hanieh Fattahi (2011)

H. Fattahi et al. "High efficiency, multi-mJ, sub 10 fs, optical parametric amplifier at 3 kHz," in *Conference on Lasers and Electro-Optics 2012*, OSA Technical Digest (online) (Optical Society of America, 2012), paper CTh1N.6.

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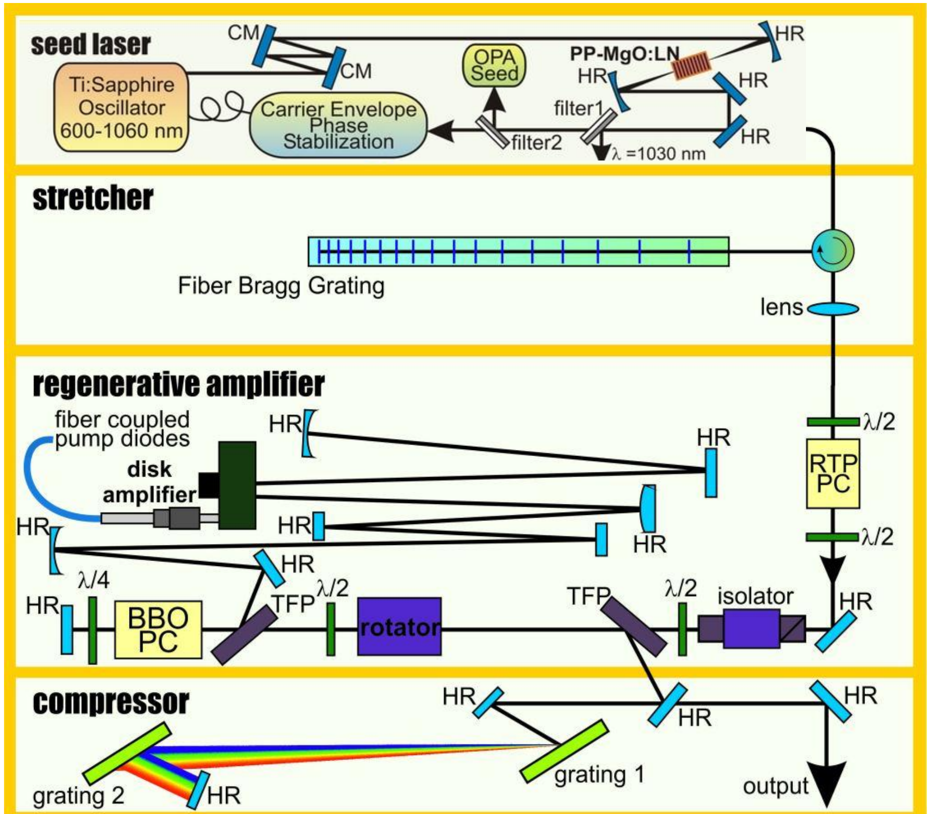
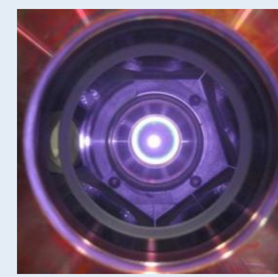
Experimental Setup: 2-5 kHz, 100-150 W



Fiber seed laser
40 MHz, 1.75 nJ; 36 nm bandwidth

FBG = $1.7 \cdot 10^8$ fs² (GDD)
$\Delta\lambda$ = 5 nm @ λ_{signal} = 1030 nm
$\tau_{stretch}$ = 1.5 ns

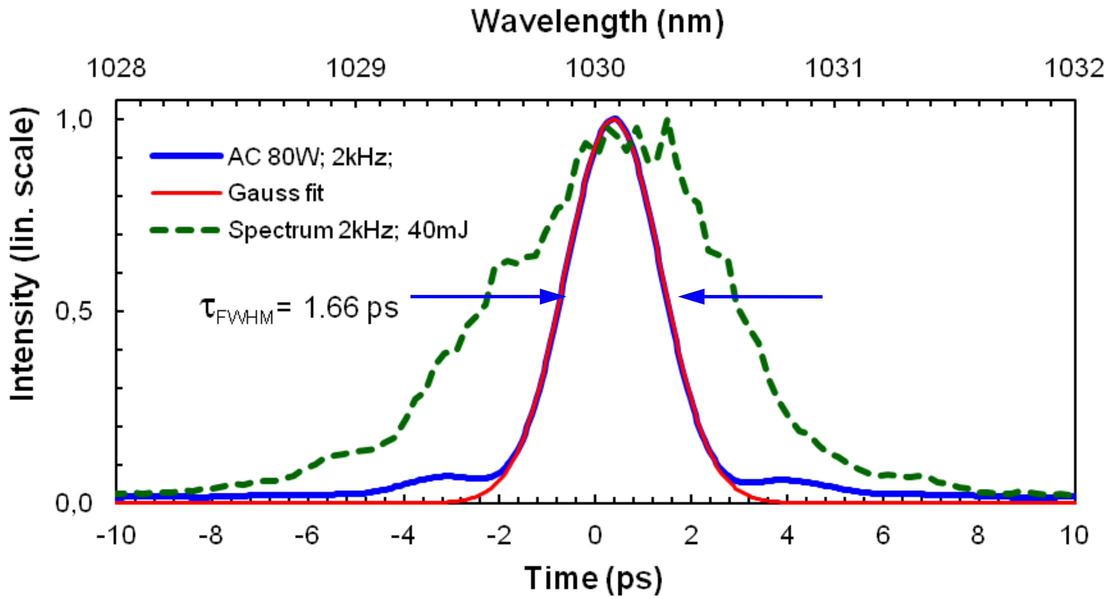
Yb:YAG-disk amplifier
435 W pump power
~150 round trips
35 mJ; 5 kHz; 500 ps
>175 W average power



GDD = $-1.7 \cdot 10^8$ fs²; $\Delta\lambda$ = 1 nm
31 mJ @ 5.0 kHz; 153 W
$\tau_{compressed}$ = 1.7 ps → 18 GW

C. Teisset, et al., *"Picosecond Thin-Disk Regenerative Amplifier with High Average Power for Pumping Optical Parametric Amplifiers,"* in *CLEO: 2013*, OSA Technical Digest (online) (Optical Society of America, 2013), paper CTh5C.6.

Autocorrelation & Spectrum 2 kHz; 80 W

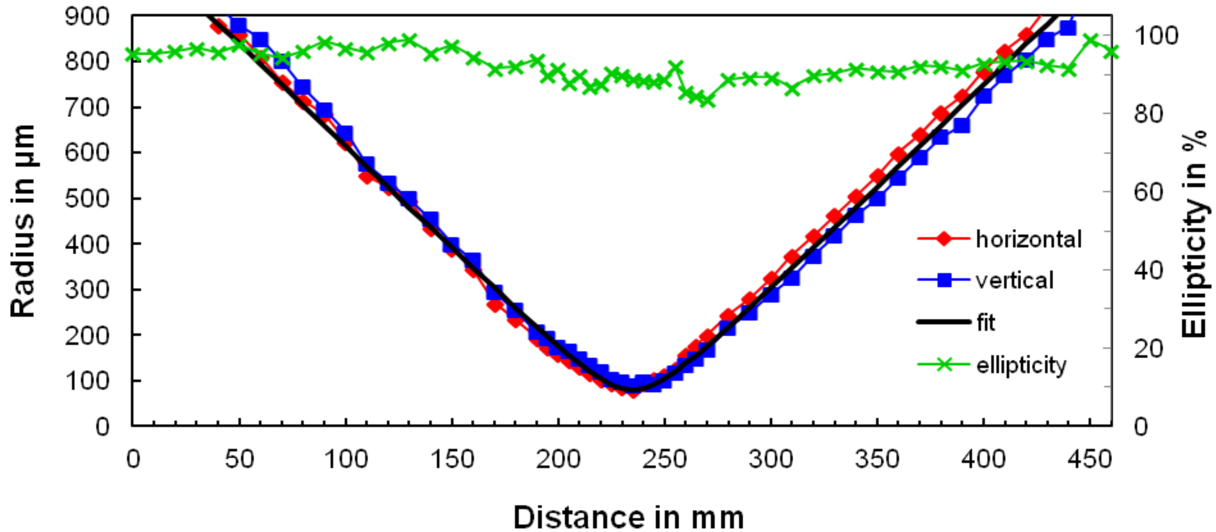


Autocorrelation: 2.4 ps
Pulse Duration: 1.7 ps
Gauss Fit
Bandwidth: 1.1 nm

Side wings due to nonlinear dispersion of a malfunctioning fiber Bragg grating

Beam Quality 5 kHz; 150 W

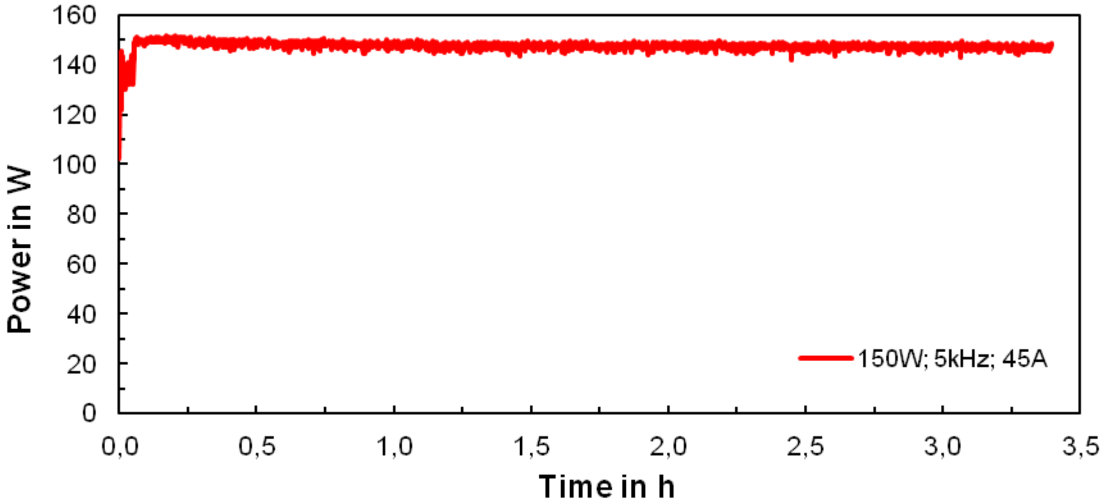
Measured according to ISO 11146



M² = 1.1
Measured at 155W; 5kHz

M² fit function: $$\sigma^2(z)=\sigma_0^2+M^2\left(\frac{\lambda}{\pi\cdot\sigma_0}\right)^2(z-z_0)^2$$

Long Term Measurement 5 kHz; 150 W

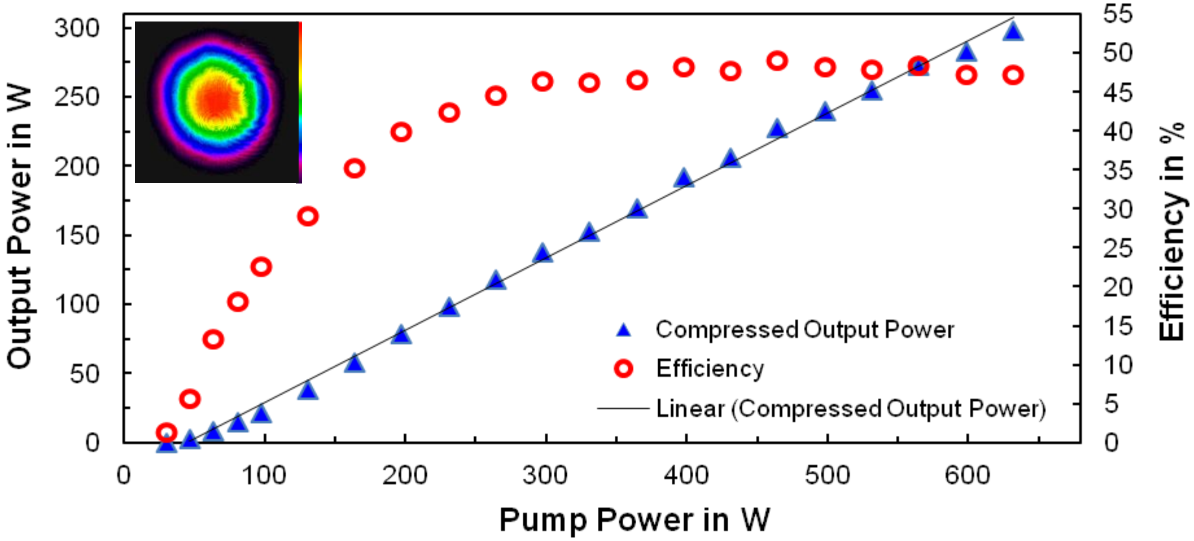


Start: 18:00 pm
Stop: 21:30 pm

Standard Deviation: 0.85%

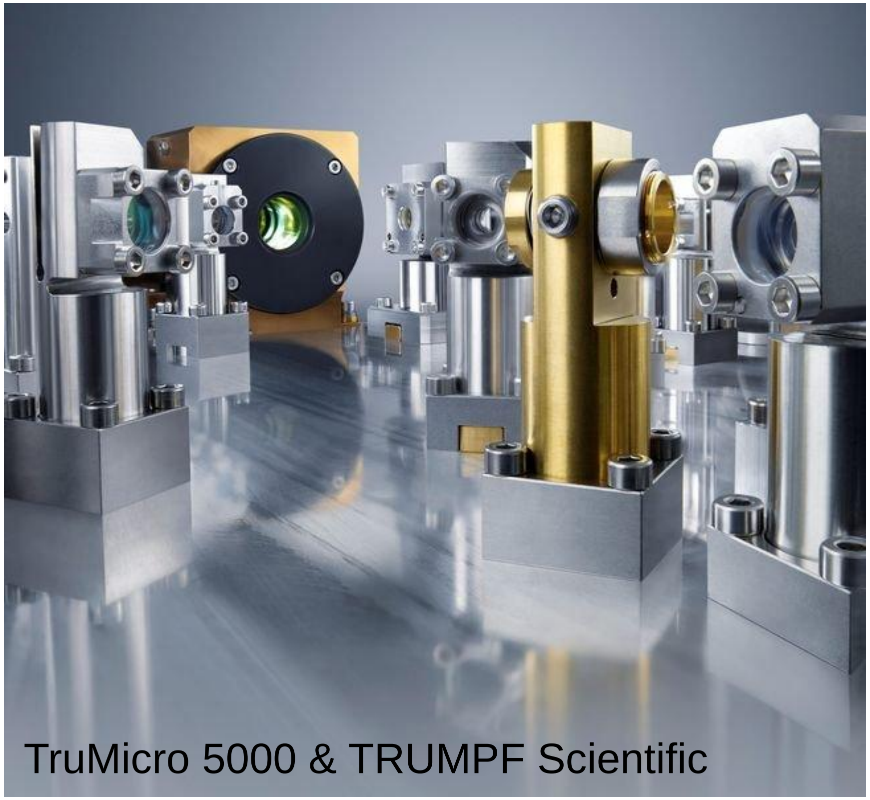
Lab. Temperature: 21.4°C (evening/night)

Latest Results 10 kHz; 300 W; 1.6 ps

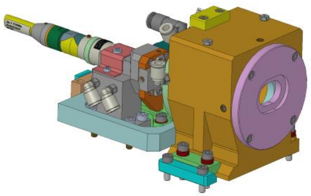
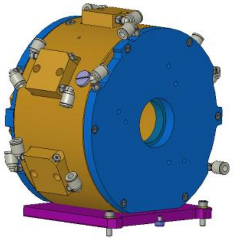
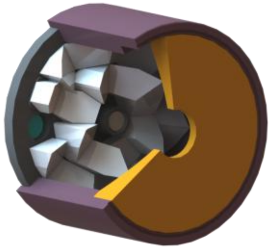


Opt. Efficiency = ~ 50%
- after compression
- 12 % opt. losses in the grating compressor

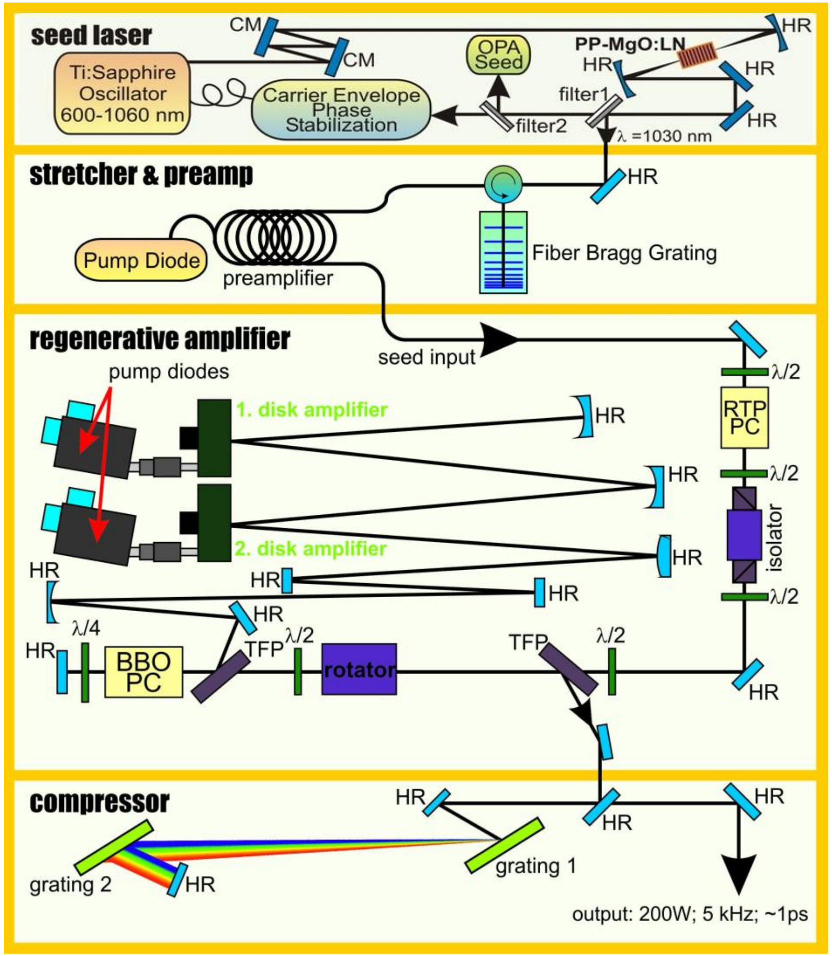
Technology – Yb:YAG Thin-Disk Laser Heads

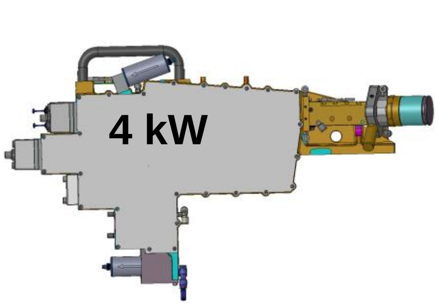


TruMicro 5000 & TRUMPF Scientific

Pump Power:	Laser Head:
~ 1 kW	
~ 10 kW	
~ 16 kW	

200 mJ; 1 – 5 kHz Regen. Amplifier in Development





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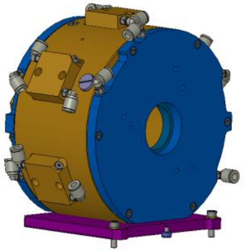

1st phase: single laser head
1 kHz (pulsed pumping)

2nd phase: double laser head
5 kHz (cw pumping)

Goal: **kW class regen**
200 mJ
2 ps

TruDisk 2000: 2 kW, CW

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TLM development: ps disk laser (regen. amplifier)

- > 100 kHz; 1-2 mJ (modified TruMicro 5080)
- < 10 kHz; 20-50 mJ (use of TruMicro 36 laser head)
- ~ 1 kHz; 200 mJ (use of 4C laser head+4 kW PE)

100-800 kHz: Serial PRODUCT

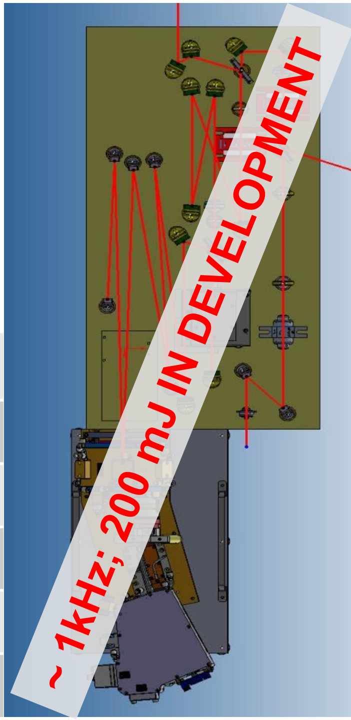
Modified TruMicro 5080: 150 W, 100 - 800 kHz, ~1 ps

Sutter et al, Proc. SPIE 8235 (2012)
Solid State Lasers XXI

~ 10 kHz DEMONSTRATOR

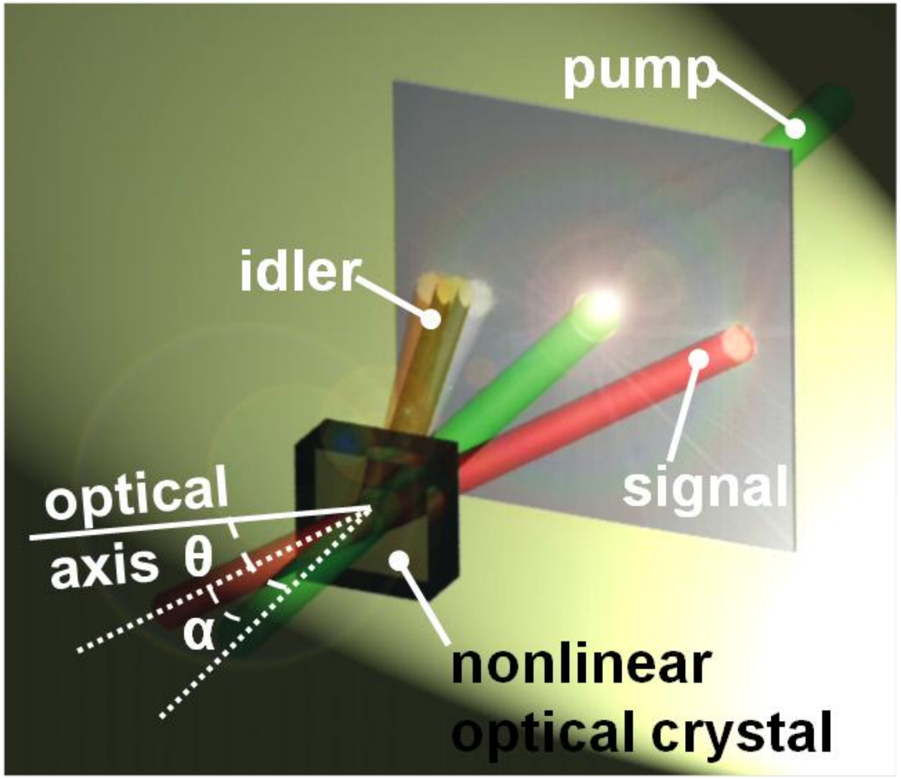
Latest Results < 10 kHz regenerative amplifier

repetition rate	2 kHz	3 kHz	10 kHz
average power	100 W	150 W	300 W
pulse energy	50 mJ	50 mJ	30 mJ
pulse duration	1.7 ps		
beam quality; M^2	< 1.1		



TLM development: OPA

- > 300 kHz; 40 µJ; ~ 7 fs (pumped by: modified TruMicro 5080)
- < 10 kHz; 1.5 – 5.0 mJ; < 7 fs (pumped by: TSL home build ps-laser)

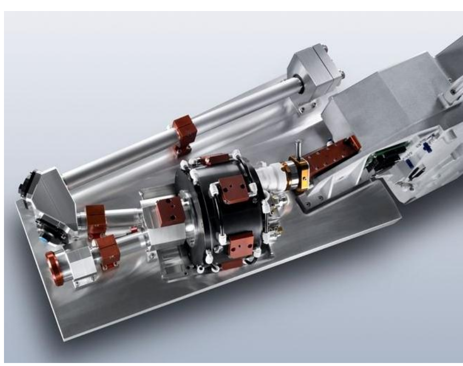


Summary

- Regen. amplifier: **2-10 kHz; 30-50 mJ; 1.7 ps (demonstrated)**
  100-800 kHz; > 120 W; ~1 ps (based on TruMicro 5080)
  1 kHz (5 kHz); 200 mJ; < 2 ps (planned)

- Demonstration of an ultrabroadband proof of principle OPCPA

- OPCPA: **2-10 kHz, ~15 W, < 6 fs** based on TSL pump source
  300 kHz, ~12 W, < 6 fs based on TruMicro 5000

Thank you for your attention

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