kW-class picosecond thin-disk pre-pulse laser Perla for efficient EUV generation

Akira Endo

2017 EUVL Workshop June 12-15, 2017, Berkley

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 664482

Outline

- Prepulse for Sn LPP sources
- Seed laser for wavelength stabilization of EUV FEL
- Thin disk platform for high average power picosecond generation
- Key technologies for thin disk laser development
- PERLA C – 100 kHz regenerative amplifier
- High average power pulse compression – CVBG
- Deep UV & mid-IR frequency conversion
- Summary

Scaling 13.5 nm LPP source to kW

Table 1. Typical operational parameters are shown in a present 110 W source and upgraded 1 kW source. Data are from reference 5 for the present one* and from reference 13 for the 1 kW case**.

Source main parameters	Present HVM source*	Upgrade to kW range
EUV IF power	110W (13.5 nm)	1kW (13.5 nm)
CO2 laser power	20 kW	50 kW
Conversion efficiency	2.5%	5%**
Collection efficiency	22%	40%

Journal of Modern Physics, 2014, 5, **-**
Published Online March 2014 in SciRes. http://www.scirp.org/journal/jmp
http://dx.doi.org/10.4236/***.2014.*****

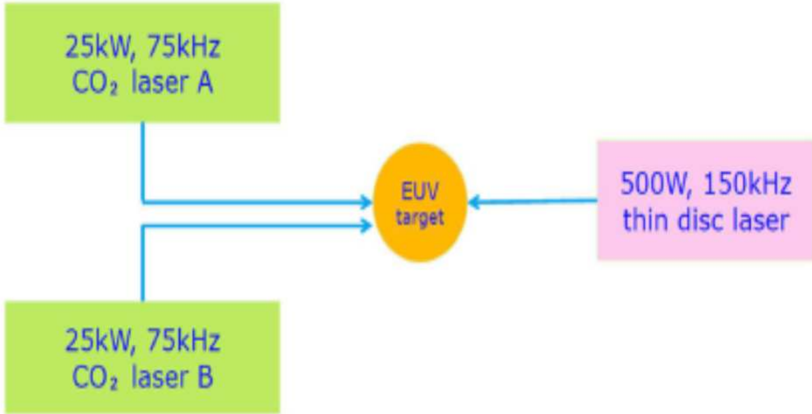


Figure 8. Concept of LPP EUV source at 1 kW IF power. Two laser beams (75 kHz) are combined to irradiate Sn droplet at 150 kHz repetition rate.

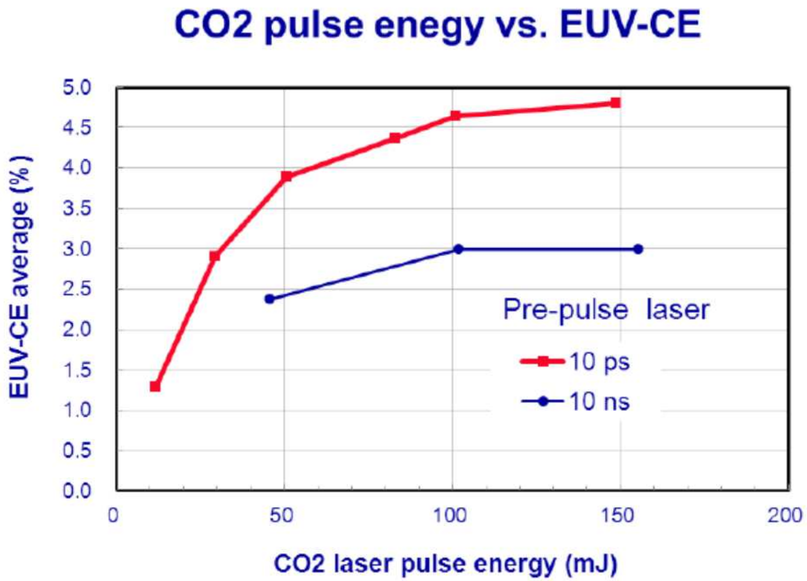
Scientific Research

Extendibility Evaluation of Industrial EUV Source Technologies for kW Average Power and 6.x nm Wavelength Operation

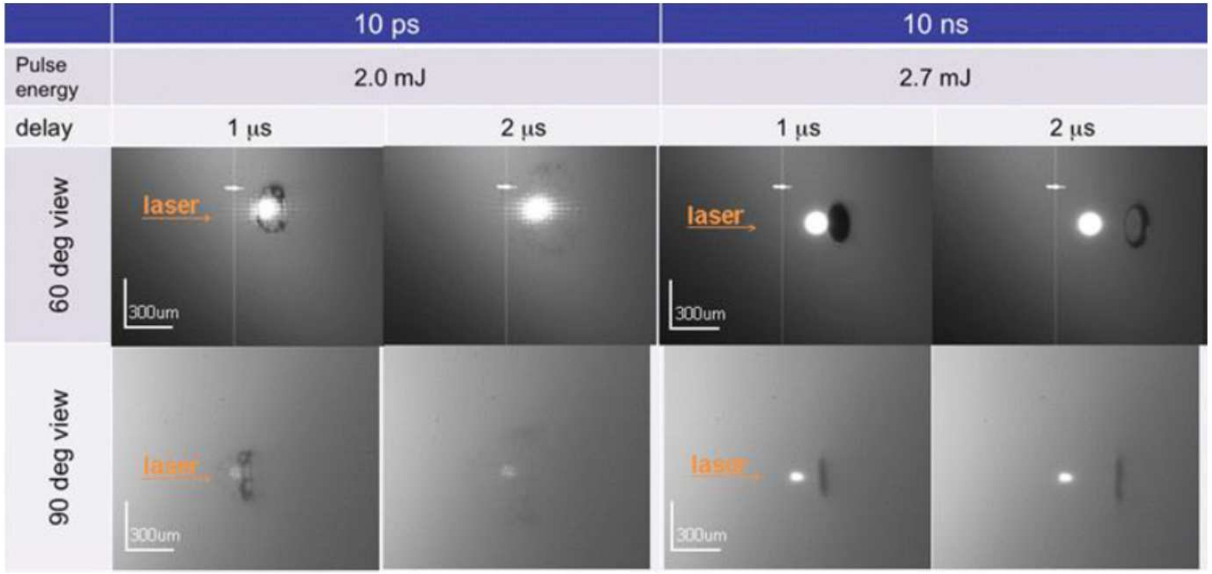
Akira Endo[1,2]

[1]Research Institute for Science and Engineering, Waseda University, Tokyo, Japan
[2]HiLASE Project, Institute of Physics AS, Prague, Czech Republic

Mist tin bunch formation

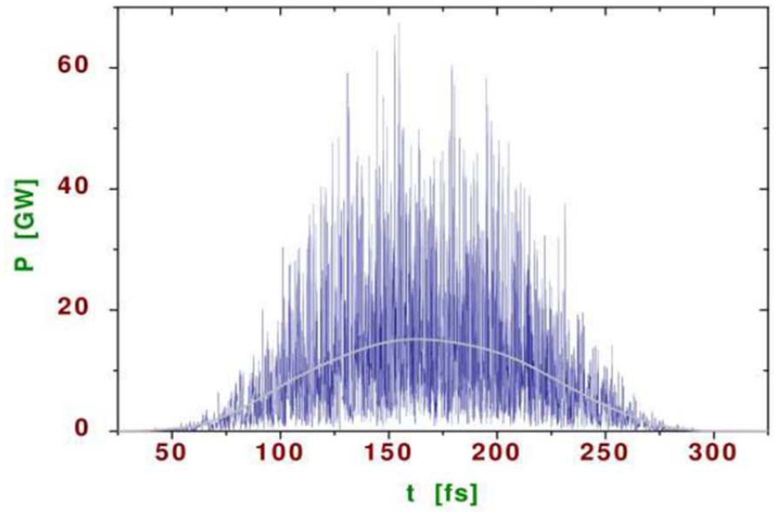


- Mist shape of a picosecond pre-pulse is different from nanosecond prepulse
- Nanocluster distribution is key for higher conversion efficiency and full exhaust of Sn

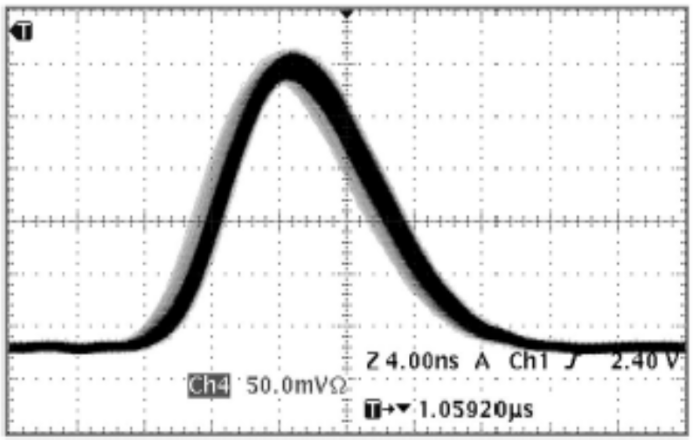


Temporal pulse structure of EUV FEL

SASE FEL (FLASH)



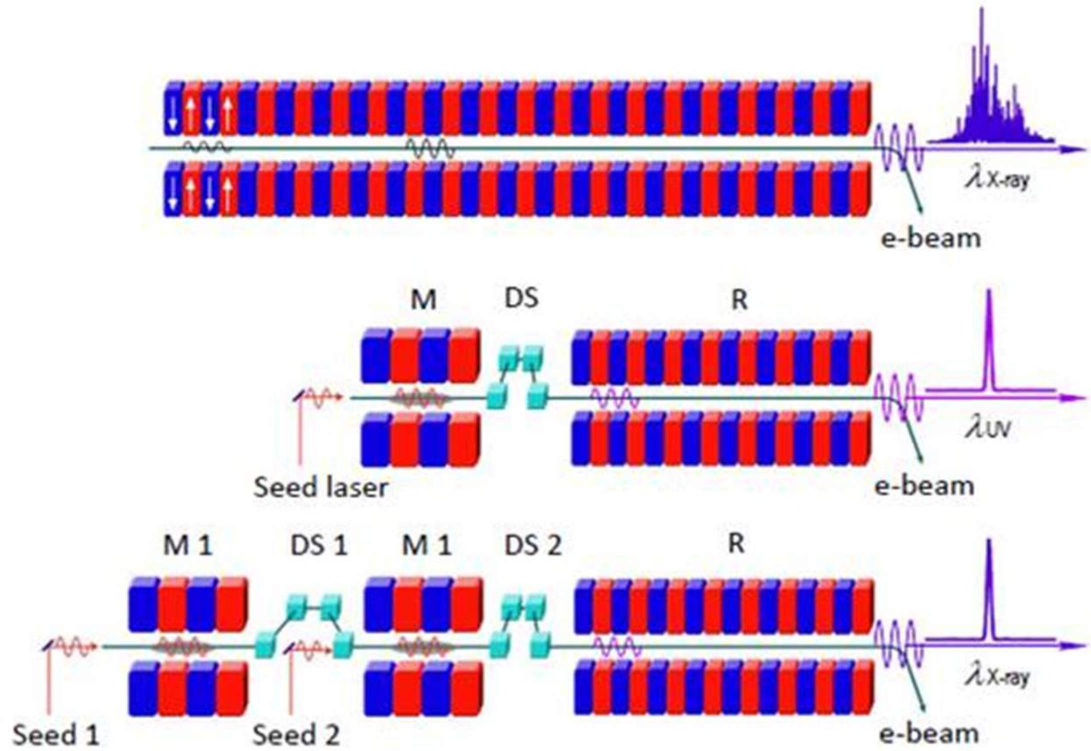
Sn laser plasma



4ns/div

E.A. Schneidmiller and M.V. Yurkov, Coherence properties
of the radiation FLASH, FLASH Seminar, September 17, 2013

Seeding for 13.5nm FEL



13.5nm

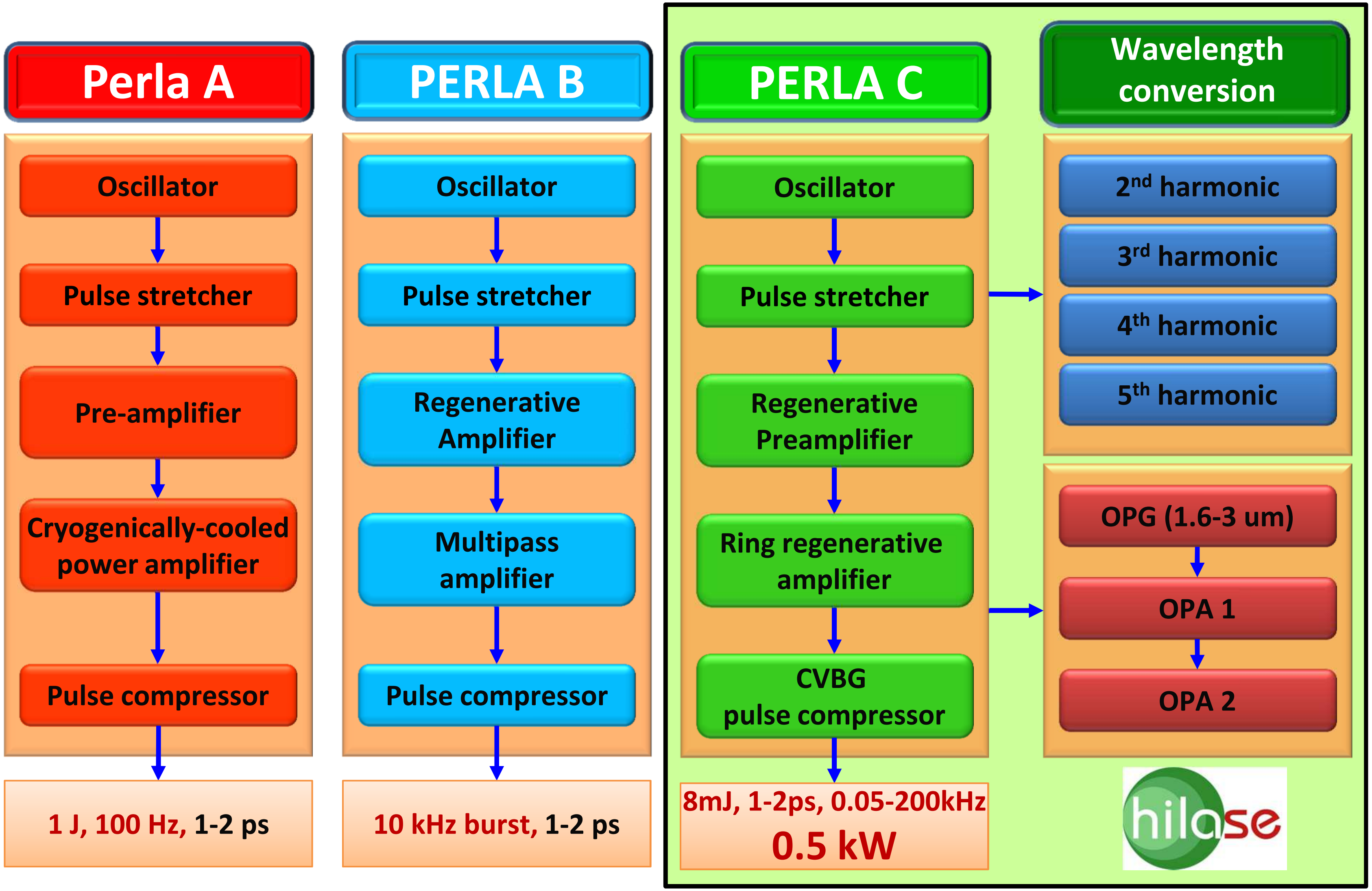
324nm, 100fs, 20μJ

40.5nm

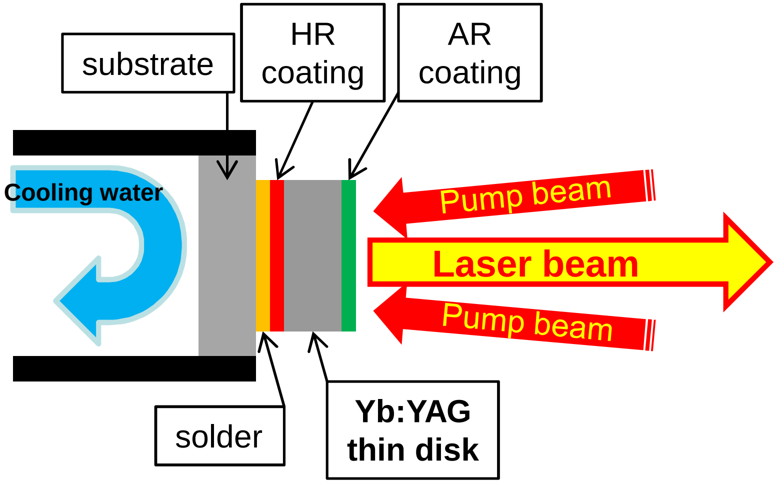
Fresh bunch injection HGHG

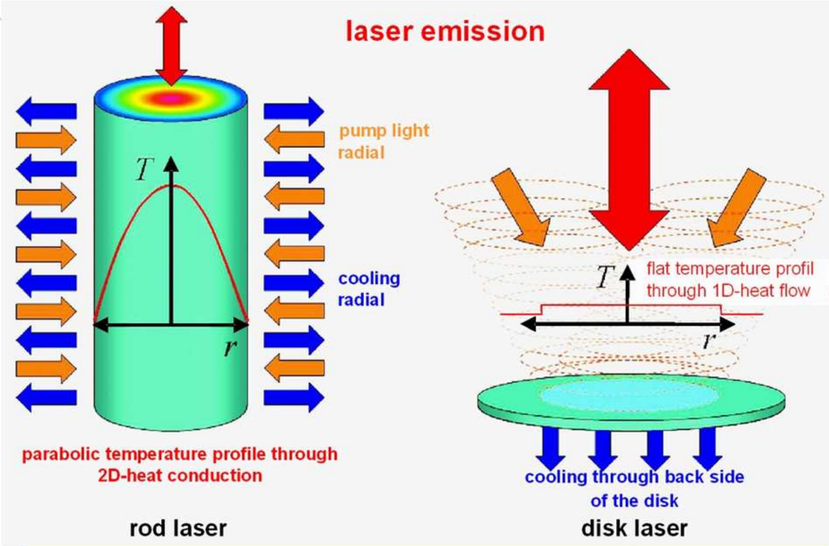
Example : 20 μJ x MHz = 20 W

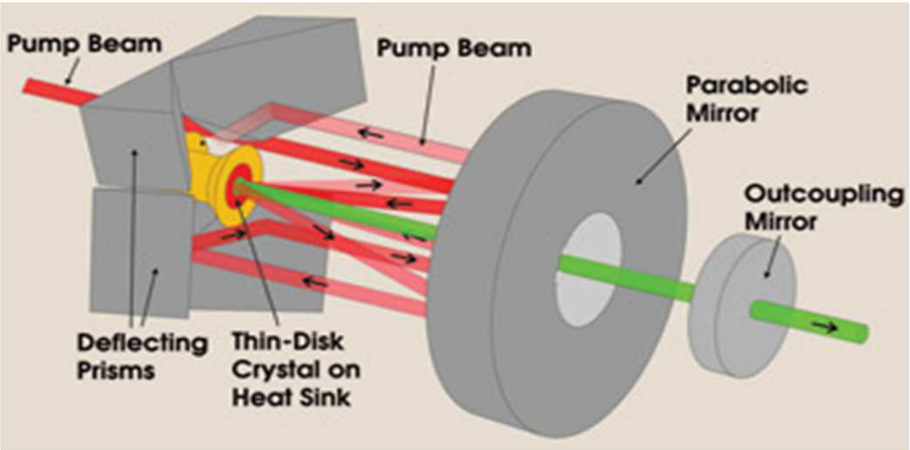
Thin disk laser beamlines at HiLASE



Thin disk geometry for high power lasers







Thin disk pros and cons:

+ Efficient cooling
+ Low thermal lensing
+ Axial heat flow
+ Low nonlinearities (B-integral,SPM)
+ High gain saturation
- Low single pass gain

Amplification technology - Yb:YAG Thin disk

Thin disk parameters:

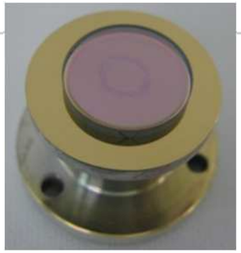
•220 µm thickness

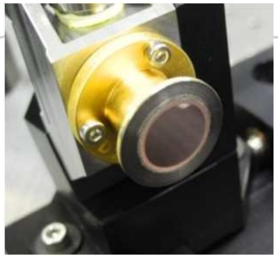
• 10 mm diameter

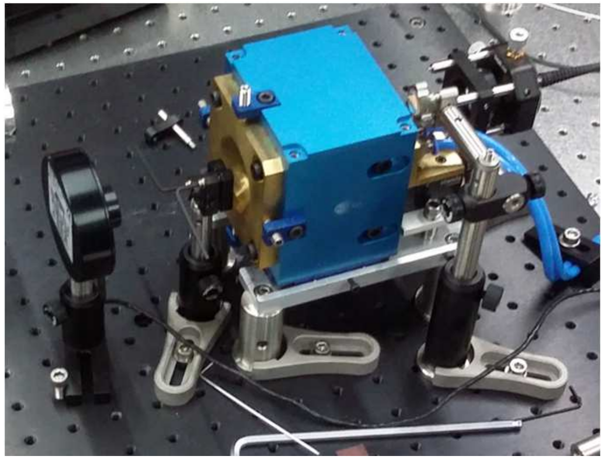
• 0.1° wedged

• radius of curvature 4 m

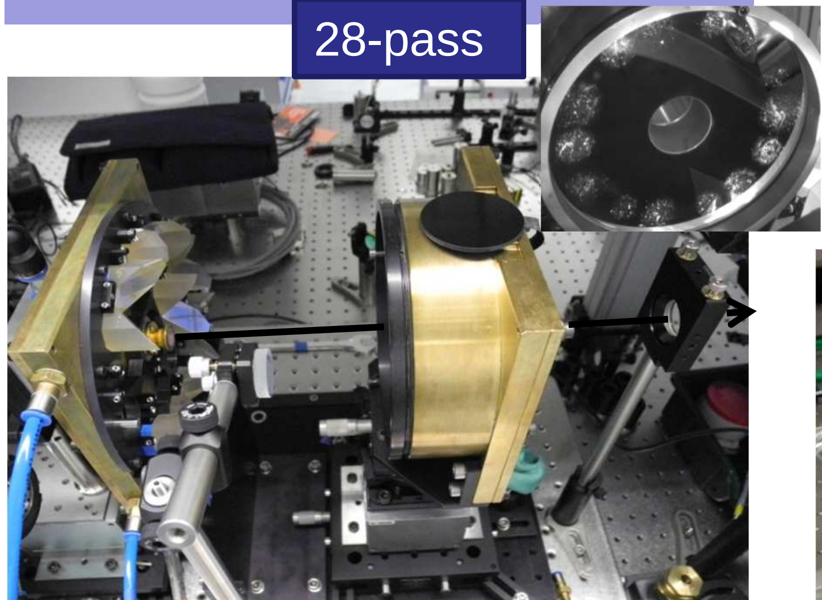
• water cooled

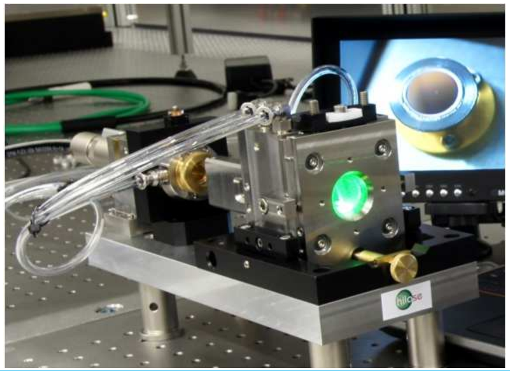


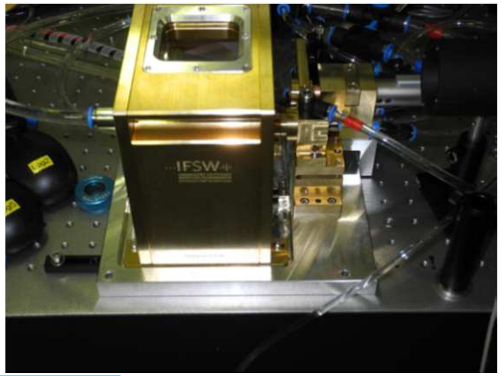




28-pass

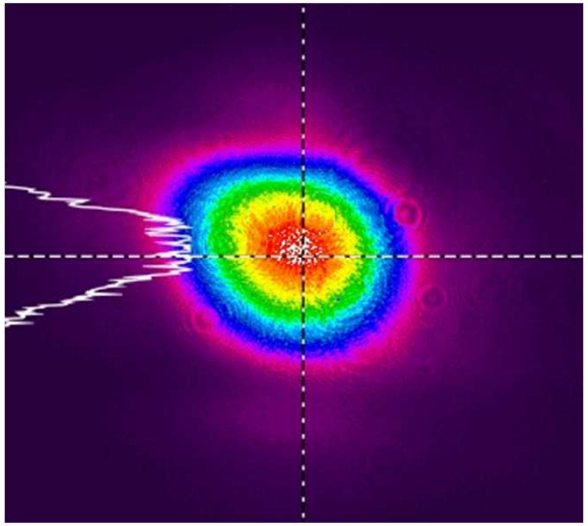


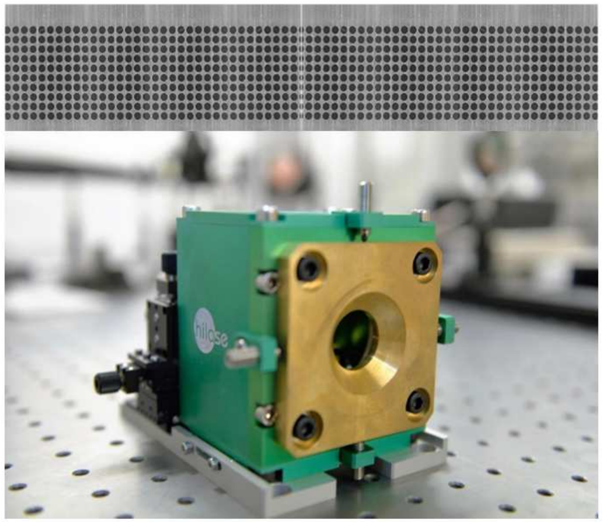




K. Macúchová, et al. "Innovative opto-mechanical design of a laser head for compact thin-disk laser", Proceedings SPIE Optics and Measurement 2016, 11-14 October, Liberec, Czech republic.

Picosecond kW-class laser “PERLA” (PERfect LAser)





„Teaming for Success“

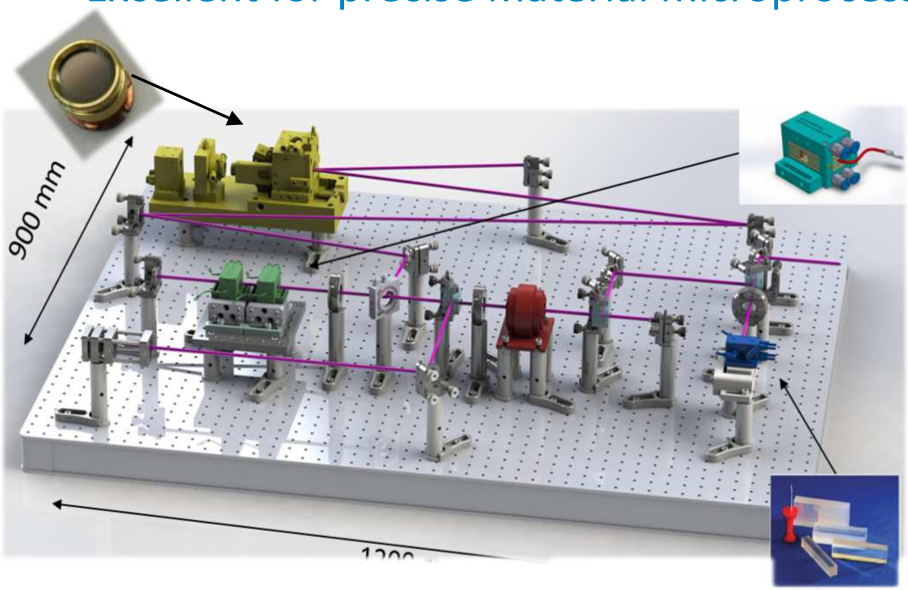
High repetition rate thin disk lasers

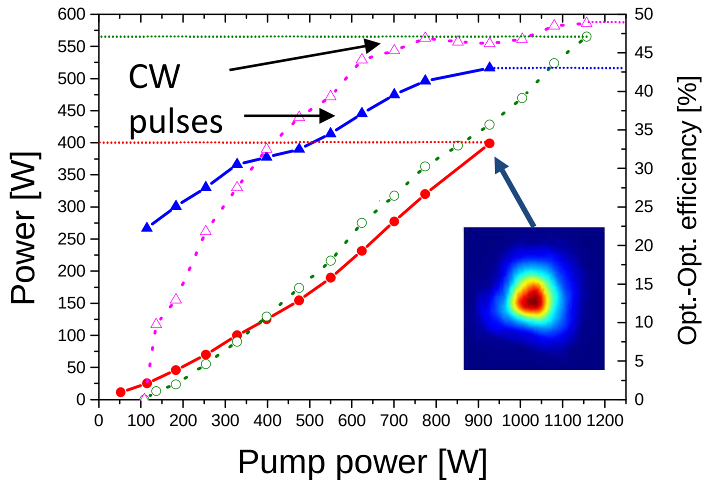
PERLA C-100

PERLA C-500

High repetition rate platform PERLA C

- High repetition rate – 50 – 100 kHz (plan to 1 MHz)
- Pulse energy up to 8 mJ (average power < 0.5 kW)
- Picosecond pulses – pulse length <2 ps
- Wavelength 1030 nm
- Nearly Gaussian beam – M^2 1.4 – 1.8
- Excellent for precise material microprocessing

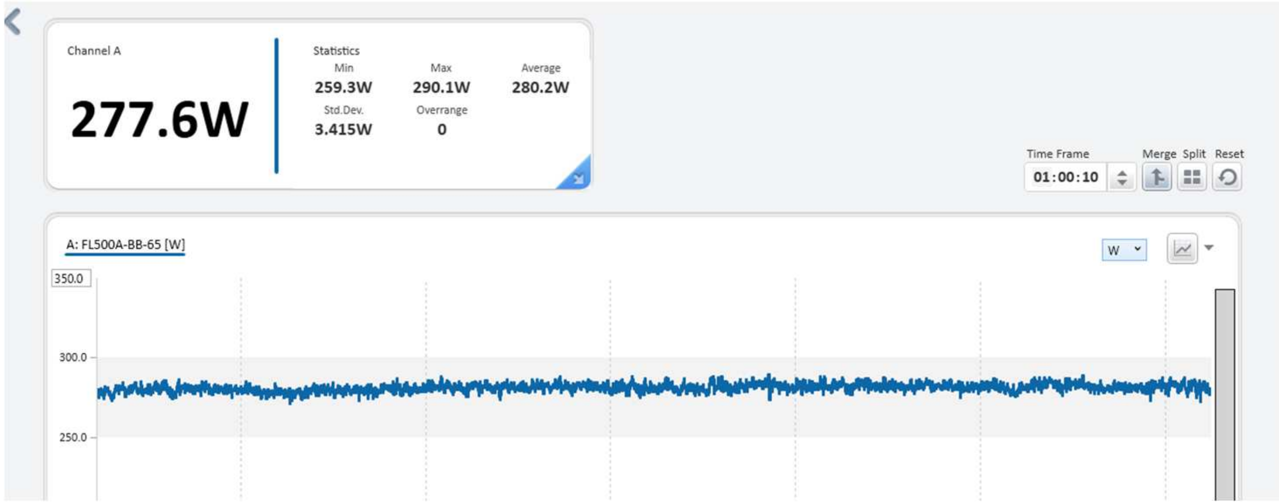


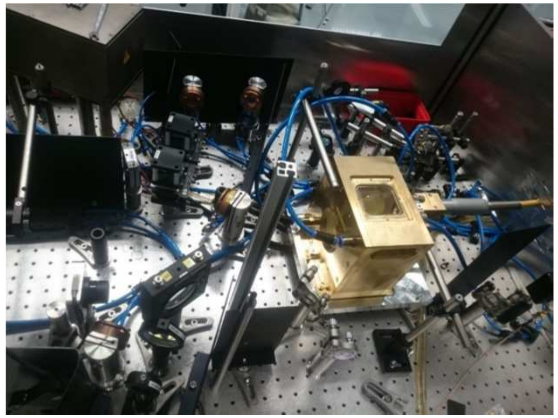


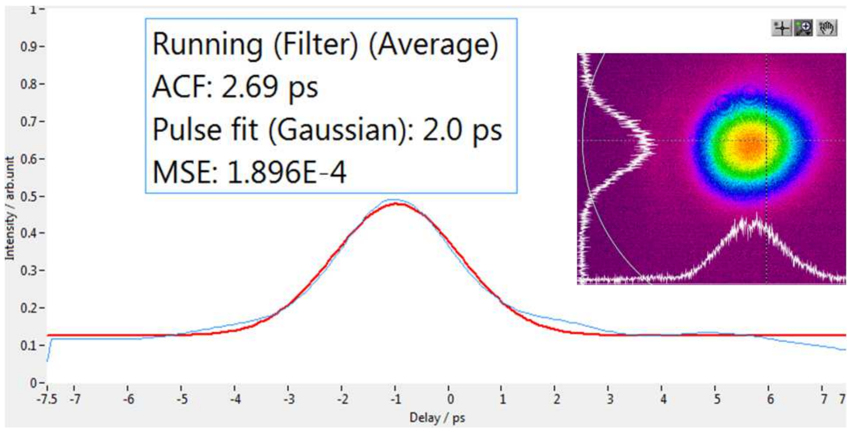
„Teaming for Success“

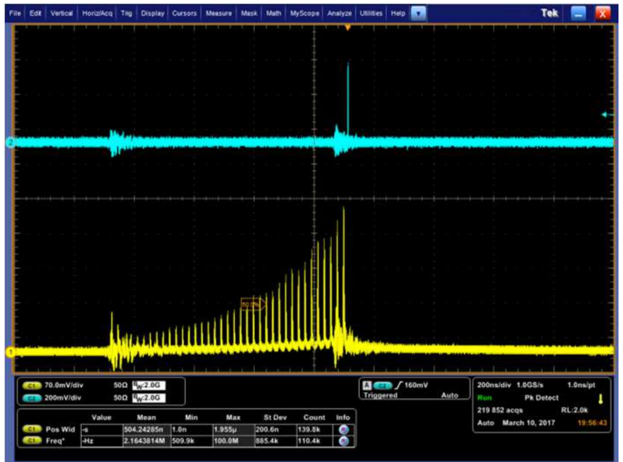
PERLA C - 500 stability and pulse length

- Tested at 280 W, for experiment increased to 330 W
- Longest operation for 10 hours at 330 W, power RMS 1.2% over 2 hours

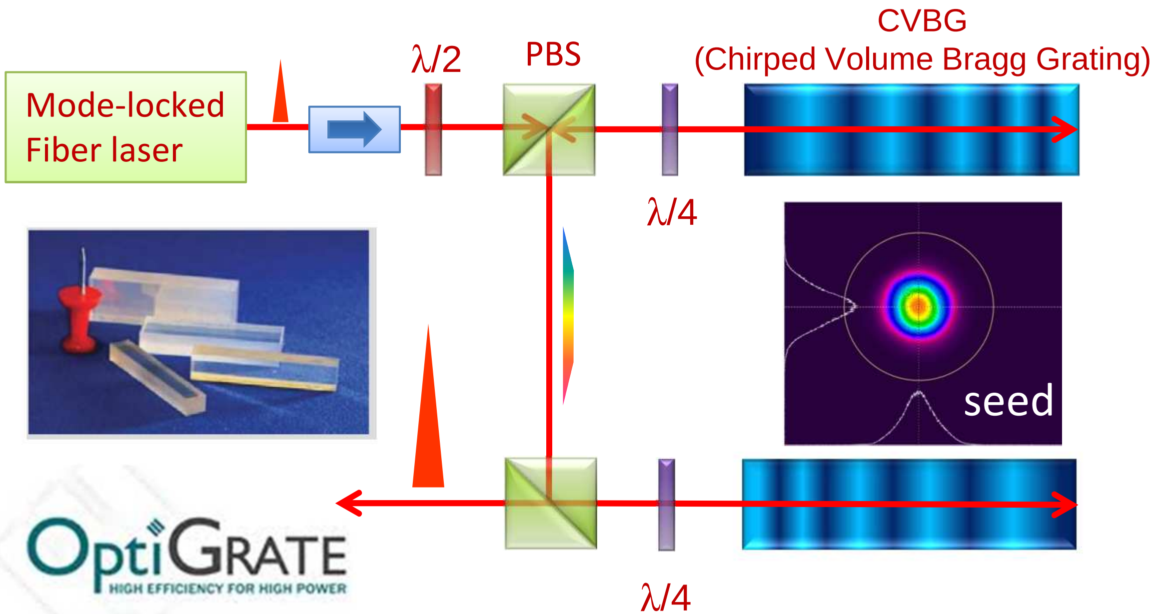


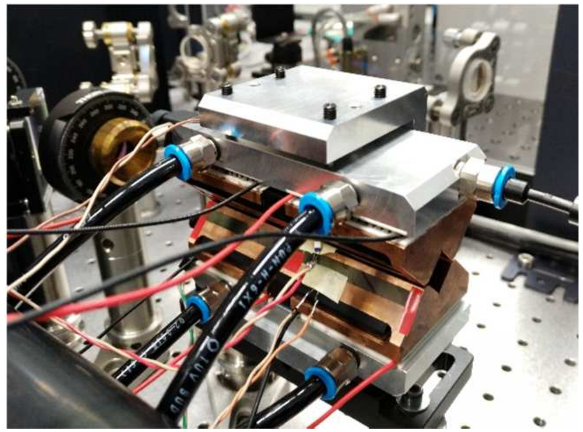




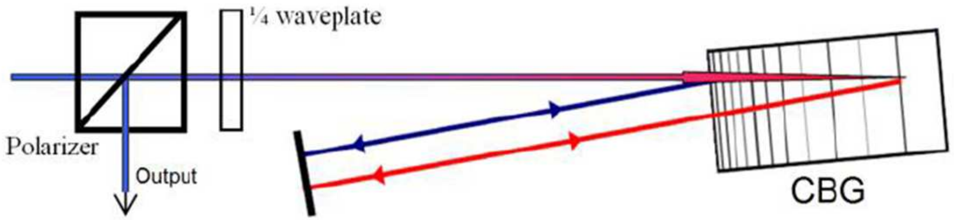


CVBG compressor

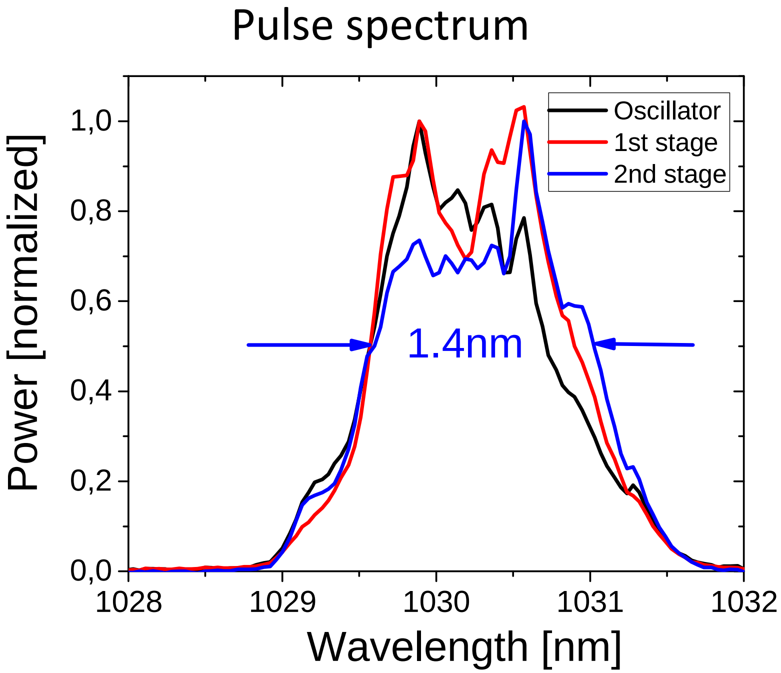


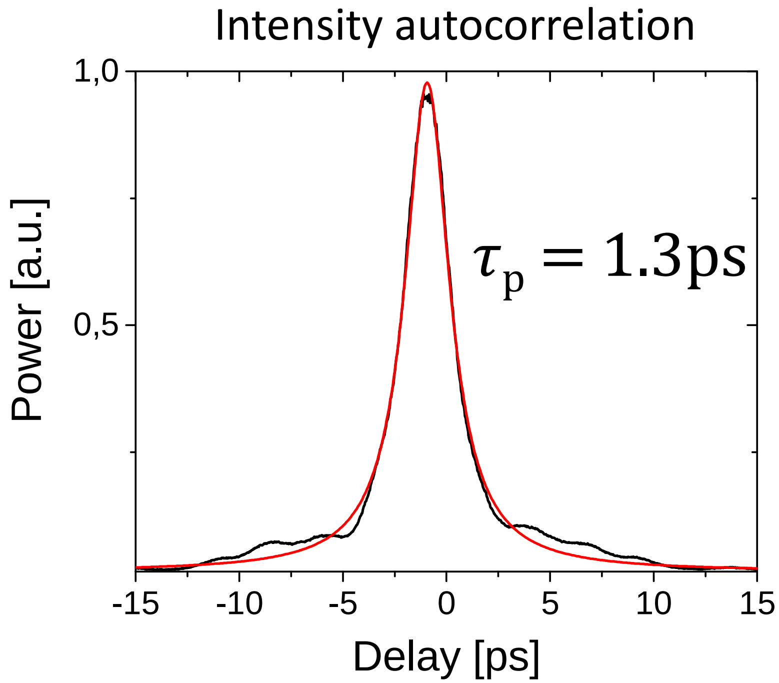


- CVBGs designed for
  3 nm +- 0.5nm bandwidth (FWHM)
- Paired with a CFBG stretcher
- Aperture 8x8mm, 10x10mm
- 220 ps/nm
- Fine temperature tunning of dispersion
- Compressor (grating) efficiency 85 %, 92% new generation



Spectral bandwidth and compressed pulse



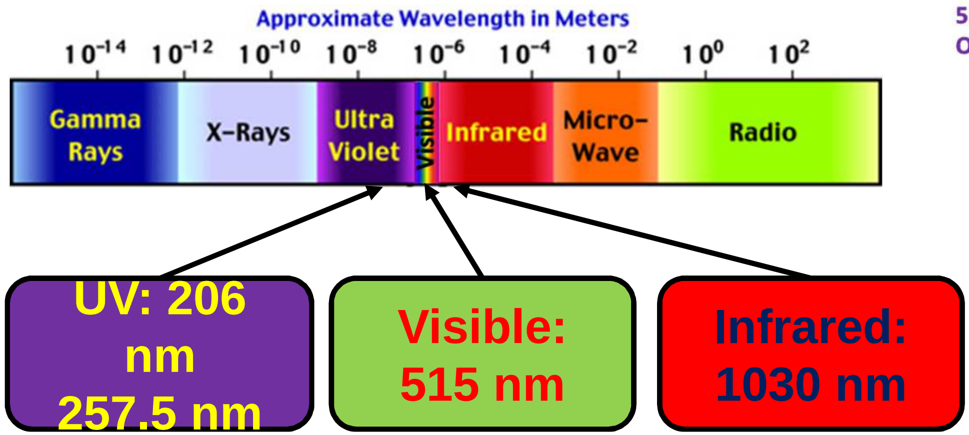


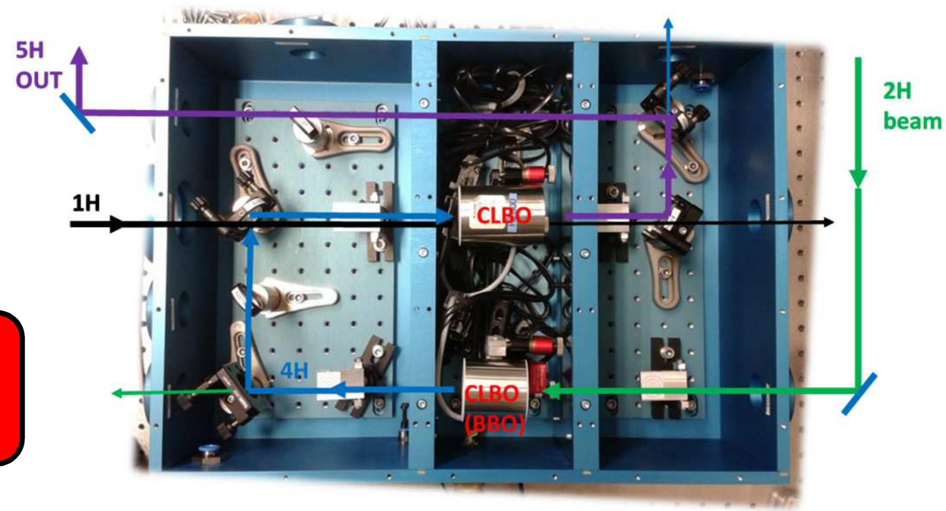
- Intensity autocorrelation sech^2 fit 1.3 ps (FWHM recalculated)
- Bandwidth after compression 1.4 nm (FWHM)
- Pulse bandwidth limit 0.8 ps (sech^2)
- AC wings – third order dispersion must be compensated

VIS-UV-DUV frequency conversion

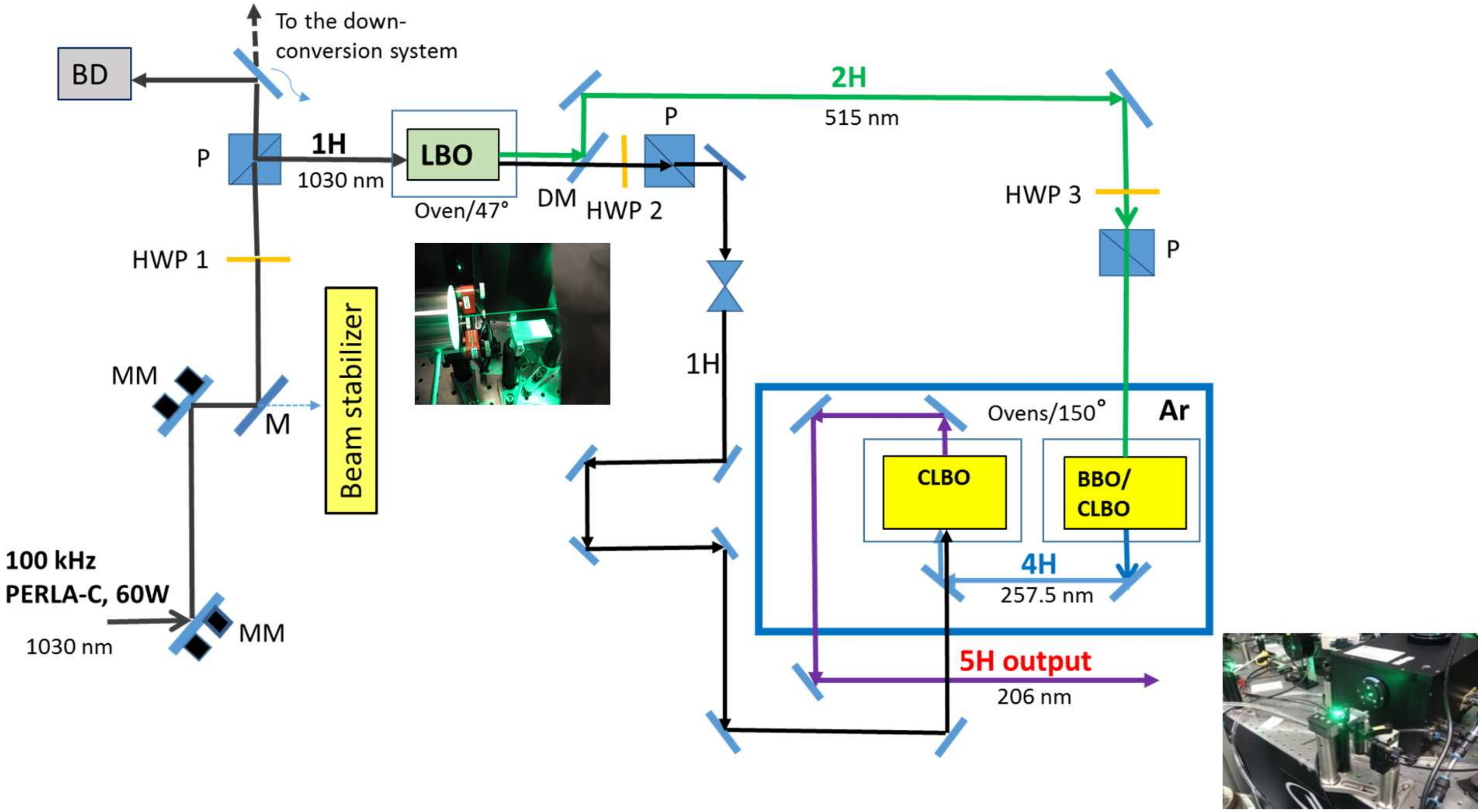
Short wavelength PERLA C extension

- Fundamental wavelength 1030 nm
- Picosecond pulses <1 ps
- UV-B laser – glass cutting (solar cells, electronics)
  - 257.5 nm >6 W (world record)
  - 205 nm >0.8 W
- Visible laser – Cu welding (automotive), etc.
  - 515 nm >35 W



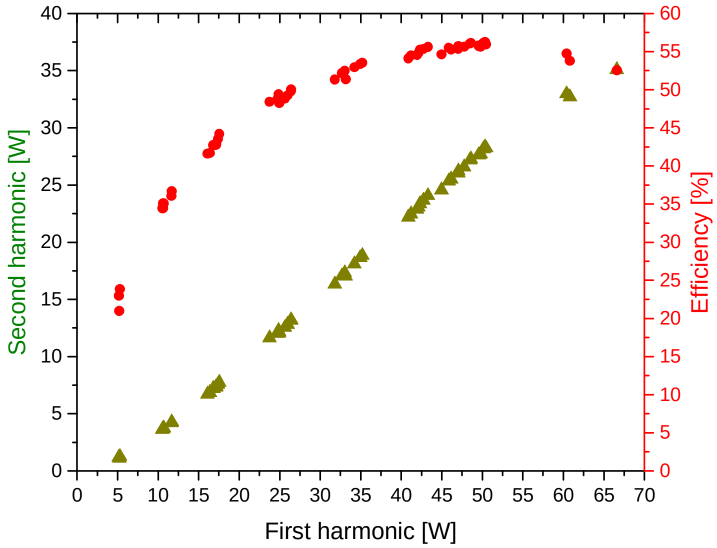


Layout of the up-conversion system (515 nm, 257.5 nm, 206 nm)



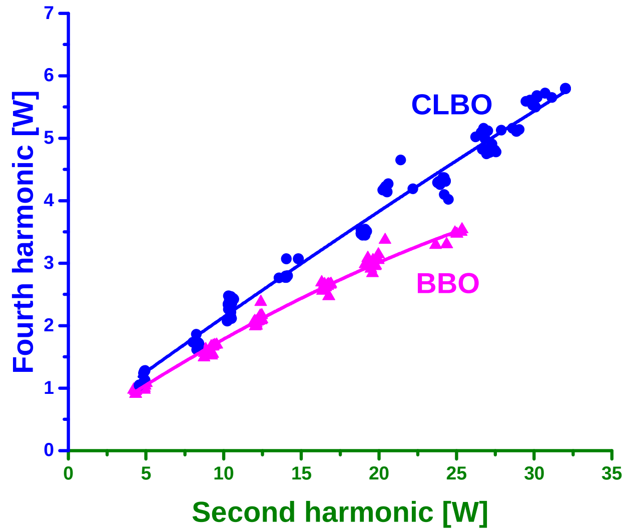
2H&4H generation

2HG (515 nm)



- **LBO** – 8x8x10 mm in an oven, T = 47°C
- Best result η = 63%, 35 W

4HG (257.5.nm)



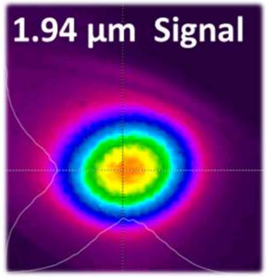
- **BBO** – 8x8x3 mm
- **CLBO** – 6x6x6 mm in an oven, T = 150°C
- Best result 6 W (CLBO)

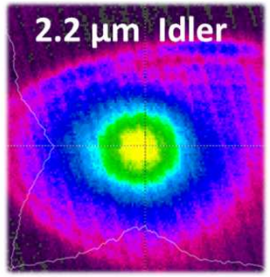
O.Novak et.al. "Picosecond green and deep ultraviolet pulses generated by a high-power 100 kHz thin-disk laser" Opt. Lett. Vol.41, No.22, 5210-5213,(2016).

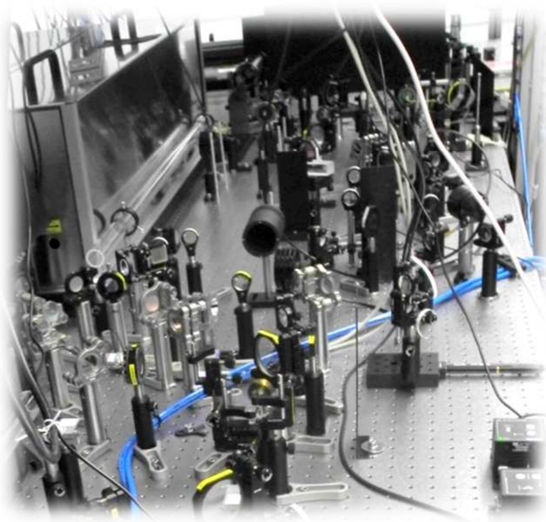
Mid-IR conversion

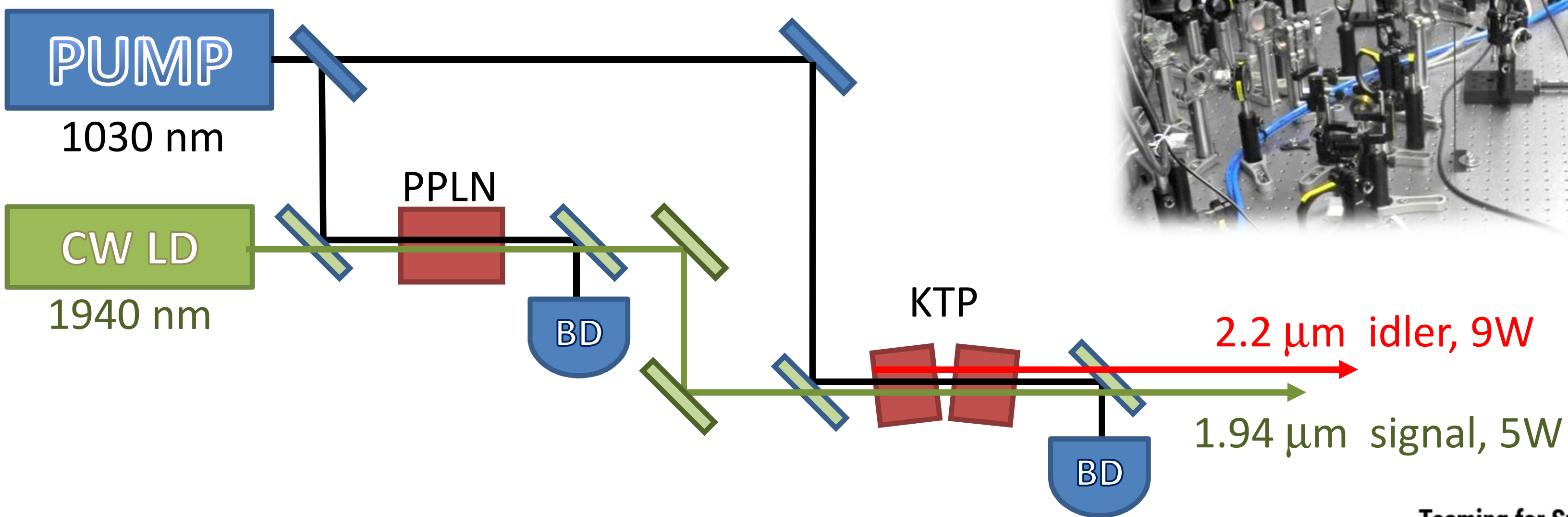
Long wavelength PERLA C extension

- Wavelength range – tunable from 1.4 to 2.6 um
- Picosecond pulses
- Average power up to 9 W (comparable commercial systems up to 1 W)
- High beam quality
- Environmental applications, medicine, semiconductor modifications









Future schedules

- Increase in average power beyond **1 kW**
- Pulse shape optimization **0.5 ps – 5 ps**
- Wavelength shift to mid-IR (**2-10 um**) and UV (**205 nm, 257 nm**)
- Combination with fiber technology – **compact disk lasers**
- Cryogenic technology for **J class pulse laser**
- Continuation in **advanced technology development**
  - disk bonding, isolators, Pockels cells, hollow core fiber pulse delivery, etc.

hilase
Power of light

Summary

Ready for >kW LPP & FEL EUV sources

- Technology platform of kW class picosecond thin disc laser established
- Extendibility to DUV and mid-IR for 100W class average power