Designer kit for an affordable and compact 0.1 – 1 TW laser

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We have developed and tested an advanced cost-effective architecture for high peak power lasers based on easily reproducible modules. Possible alternative concepts for producing ultrashort high-energy laser pulses are also discussed.

INTRODUCTION

Since the first Optical Parametrical Chirped Pulse Amplifier (OPCPA) was reported [1], many advanced architectures of high peak power lasers have been developed [2]. Typically, TW-class lasers take up a lot of space, and development and maintenance costs limit their use. Therefore, such systems are shared by many scientists with limited access time. For Europe, access to Extreme Light Infrastructure (ELI) remains difficult outside of the Czech Republic, Hungary and Romania. For widespread use of high peak power lasers, it is vital to reduce size and cost.

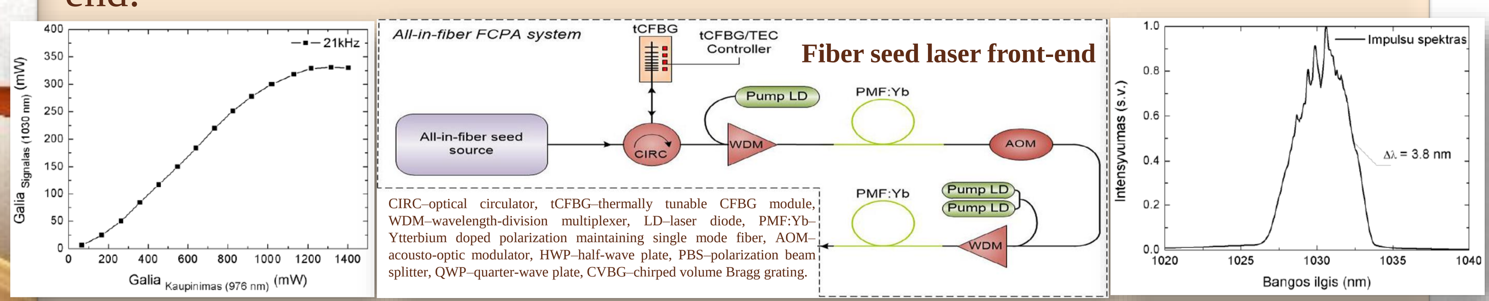
APPLICATIONS

Affordable and compact next-generation lasers with TW level of peak power are in demand for emerging applications in biology, medicine, microelectronics, space technology and materials science.

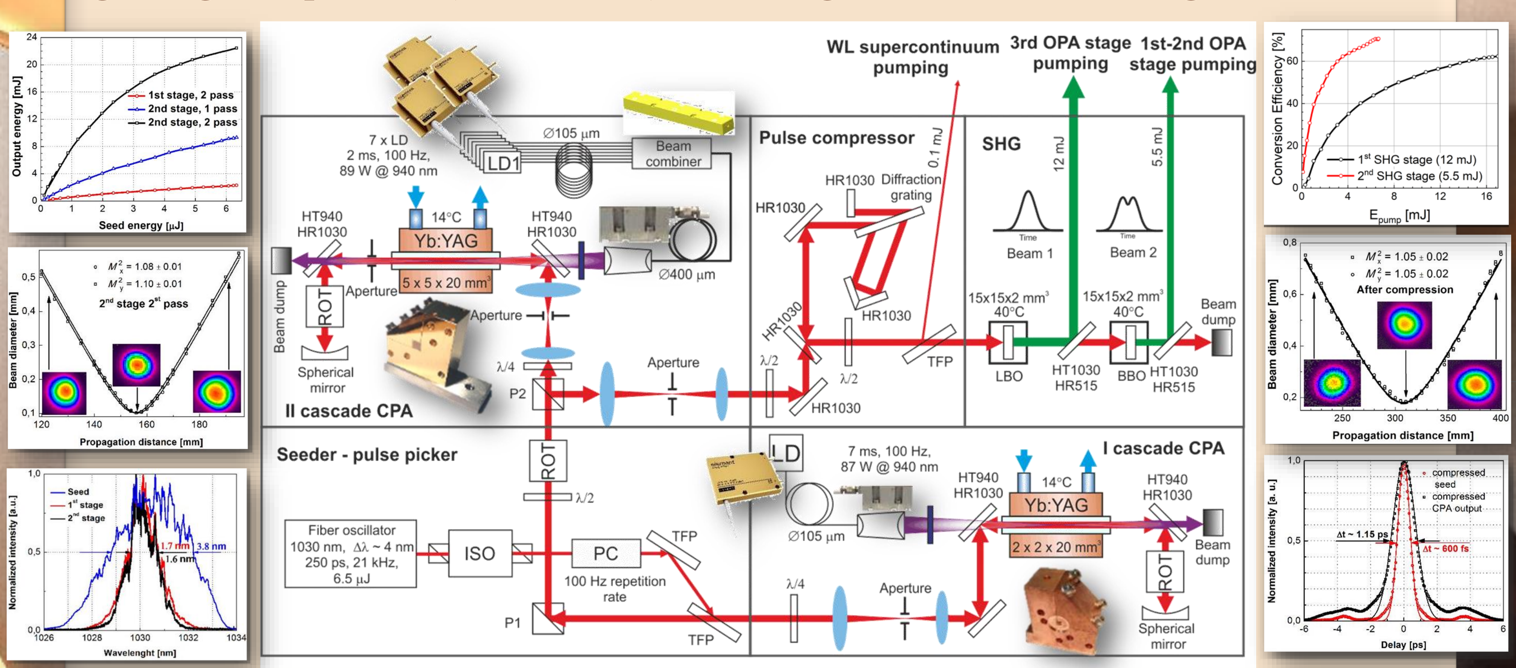
High energy, high repetition rate ultrashort laser pulses allow to create point x-ray sources and, thus, significantly increase the contrast and resolution of medical X-ray tomography. At present, such lasers are usually based on relatively outdated Ti:S with a limited repetition rate or based on OPCPA with limited conversion efficiency.

OPTICAL LAYOUT

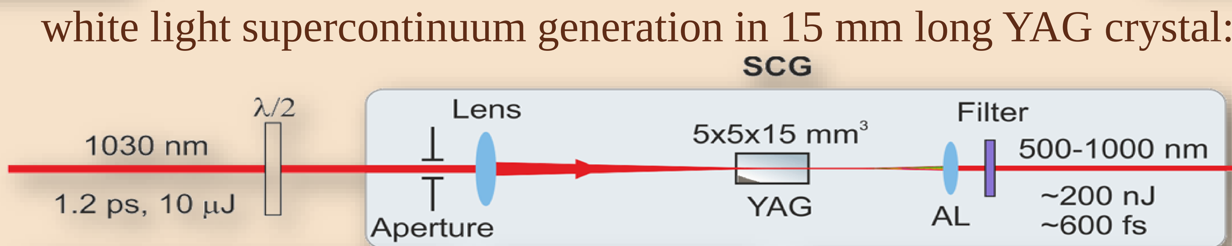
We have developed and tested an advanced architecture for high peak power lasers based on easily reproducible modules: fiber seed laser front-end:

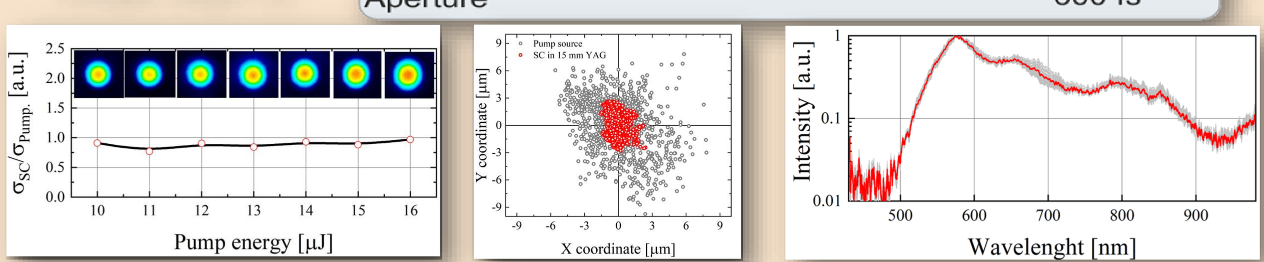


EO pulse picker (running at 100 Hz), two-cascaded double-pass chirped pulse amplifier (CPA) based on Yb:YAG rods with low doping level, grating compressor (1842 mm^{-1}), two-stage second harmonic generation:

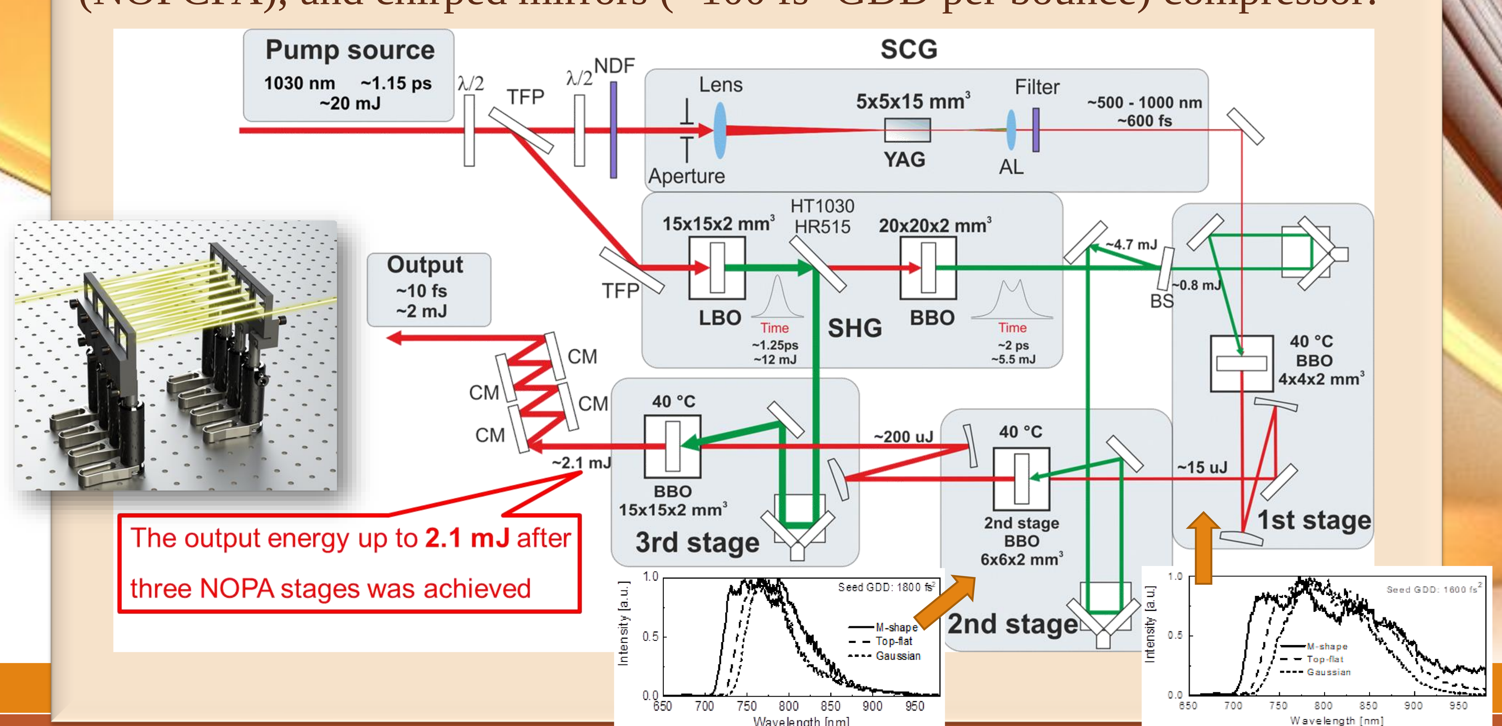


white light supercontinuum generation in 15 mm long YAG crystal:



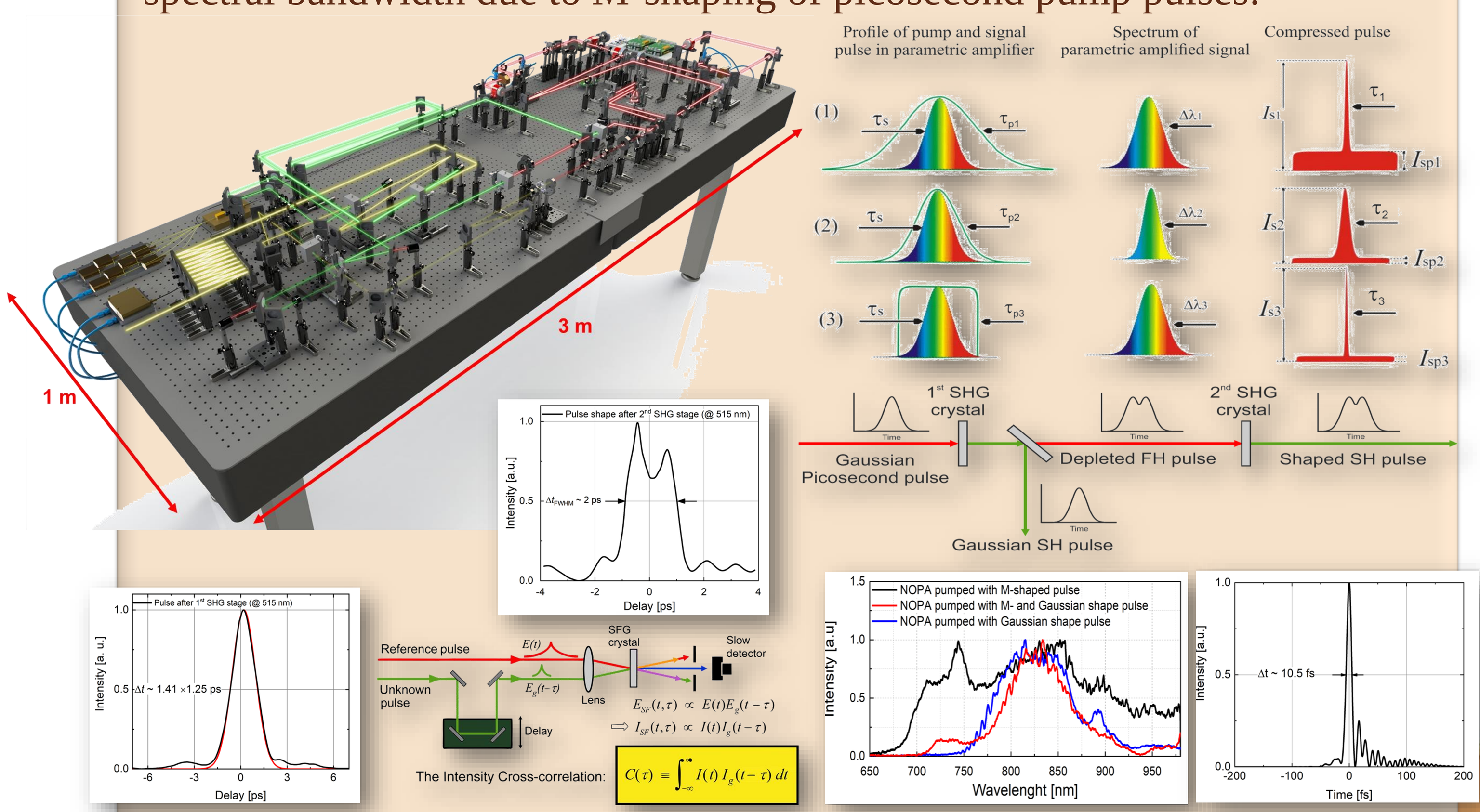


3 or 4 stages of non-collinear optical parametric chirped pulse amplifier (NOPCPA), and chirped mirrors (- 100 fs^2 GDD per bounce) compressor:



ADVANCED DESIGN FEATURES

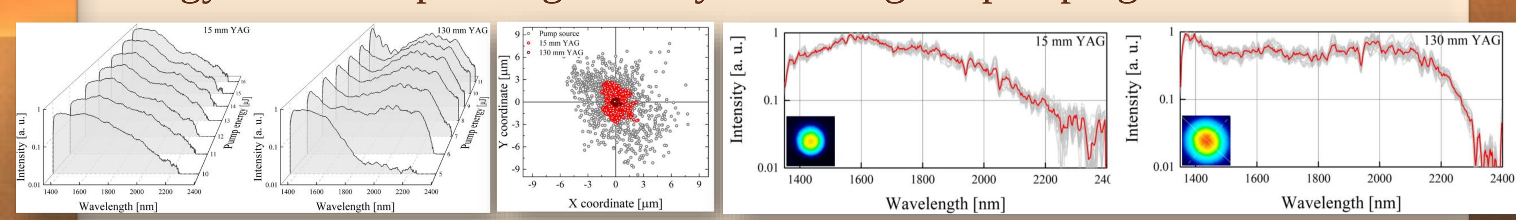
Using the same Yb:YAG DPSS-source with a pulsewidth of 1.1 ps for pumping NOPCPA and supercontinuum generation provides internal synchronization and, thus, greatly simplifies the scheme. Particular attention is paid to improving the energy conversion efficiency by reusing depleted pump in SHG and NOPCPA, as well as maintaining a wide spectral bandwidth due to M-shaping of picosecond pump pulses:

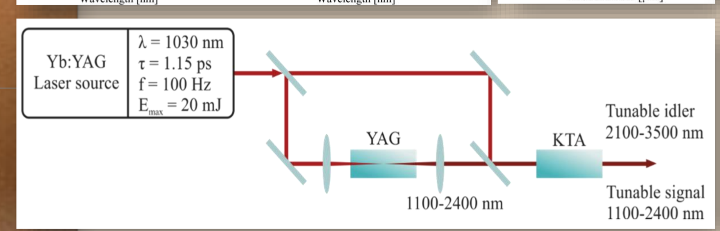


The pulsewidth after compression reaches 12 - 15 fs, and the output energy is mainly limited by the number and power of laser diodes used for pumping, providing the output peak power of the laser system from 0.1 to 1TW. The experimental scheme is assembled on an optical table measuring 1 x 3 m^2, all components used are commercially available, and the repeatability is confirmed by student interns.

IR-WING OF SUPERCONTINUUM

We also demonstrate the generation of a multi-octave white light supercontinuum with a long-wavelength wing up to 2500 nm with an energy and beam pointing stability exceeding the pumping source:

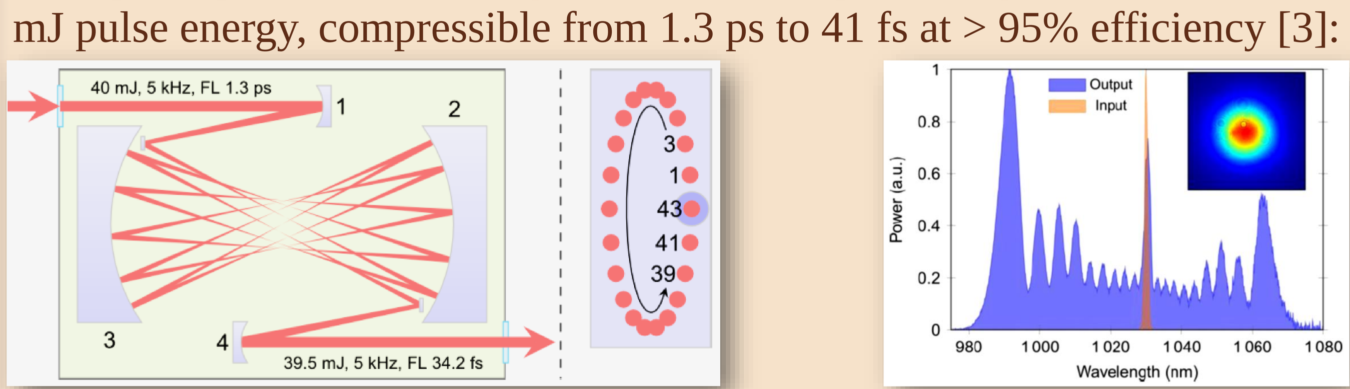




This makes it possible developing a sub-TW laser in the spectral range of 2µm for the high order harmonics generation (HHG).

ALTERNATIVE CONCEPT

Multipass spectral broadening in Herriott low pressure gas cell with tens of mJ pulse energy, compressible from 1.3 ps to 41 fs at > 95% efficiency [3]:



CONCLUSIONS

- ~ 1.2 ps amplified pulses with energy of ~ 23 mJ were obtained after two-cascaded Yb:YAG CPA – compressor with overall gain of > 3.500. In the future, by combining of 19 pumping diodes with a beam combiner, it is possible to scale up the output energy to 60 mJ.
- SC in a YAG shows an energy and beam pointing stability exceeding the pumping source, making it also possible a sub-TW laser about 2 µm.
- We demonstrate the results of ~ 1.2 ps pulse shaping and the overall 90% SHG conversion efficiency. M-shaped pump pulses support a wider amplified spectrum after NOPCPA.
- The output energy up to 2.5 mJ after three NOPCPA stages was achieved with pulsewidth of 12 - 15 fs after compression. For ultimate compression up to ~ 10 fs, dispersion control is required.

[1] A.Dubietis, G.Jonušauskas and A.Piskarskas, Powerful femtosecond pulse generation by chirped and stretched pulse parametric amplification in BBO crystal, Opt. Comm. **88** (1992): 437-440
[2] National Academies of Sciences, Engineering, and Medicine, Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light, (Academies Press, Washington, 2018). https://doi.org/10.17226/24939
[3] M.Kaumanns et al., Multipass spectral broadening of 18 mJ pulses compressible from 1.3ps to 41fs, Opt. Lett.**43** (2018)

Our group invites to scientific and industrial collaboration to develop advanced TW-class lasers