High repetition rate, low noise and wavelength stable OPCPA laser system with highly efficient broadly tunable UV conversion for FEL seeding

Tino Lang[1], Mehdi M. Kazemi[1], Jiaan Zheng[1], Samuel Hartwell[1], Nhat-Phi Hoang[1], Eugenio Ferrari[1], Enrico Allaria[1], Lucas Schaper[1] and Ingmar Hartl[1]

1. Deutsches Electron Synchrotron DESY, Hamburg, Germany

High energy tunable ultrafast UV pulses are of great interest for a variety of applications. Within the FLASH2020+ project the FLASH VUV/XUV FEL facility at DESY (Hamburg, Germany) is currently undergoing a major upgrade to become the first high repetition rate, fully coherent FEL light source worldwide [1]. To reach this goal, one of the two in parallel operated FEL branches will be seeded at a fixed wavelength at 343 nm in a first step (SEED 1) and tunable between 297 nm to 317 nm in a second step (SEED 2) following the two-color Echo-Enhanced Harmonic Generation (EEHG) scheme [2]. The seed laser system is designed to deliver UV pulse energies > 100 µJ and > 50 µJ for SEED 1 and SEED 2, respectively, and with 6000 pulses in one second (1 MHz pulse train in 600 µs - 10 Hz bursts). In order to exploit the full capabilities of the narrow-band fully coherent FEL pulses for 24/7 scientific user experiments, the seed laser needs to provide broadly tunable, high power UV laser pulses with pulse durations of 50 fs, excellent beam quality and exceptional high short and long-term stability in respect to the seeding wavelength (< 2e-4), pulse – pulse energy (< 2%) and pointing jitter (< 20 µrad). Altogether, the requirements on the laser system are beyond state-of-the-art.

We will present the concept as well as the first experimental results of our novel high-power seed laser system based on a 5 kW Inno-Slab CPA pump laser system, optical parametric chirped pulse amplification (OPCPA) and a highly efficient UV conversion scheme. An extensive numerical study based on a 3+1 dimensional start-to-end simulation code (chi3D) allows for predictions of system performance in terms of output power, tunability, beam quality and stability in respect to the measured input parameters and respective statistical fluctuations and systematic in-burst sweeps. Fig. 1 shows both, the schematic setup of all sub-sequent nonlinear conversion stages within the laser system and at the same time the numerical simulation blocks. The model includes all nonlinear second order direct and cascaded conversion processes as well as self-phase modulation and self-focusing. The performance of the pump laser system and the super-continuum generation via filamentation in a YAG-crystal are input parameters for the simulation. The theoretical results are confirmed by first experimental studies showing an out-standing high broadband (50 fs transform limit) OPCPA-Signal to UV conversion efficiency of up to 68 % and excellent beam quality. Furthermore, the numerical predicated improvement of the pulse-to-pulse stability compared to the OPCPA output stability could be experimentally reproduced.

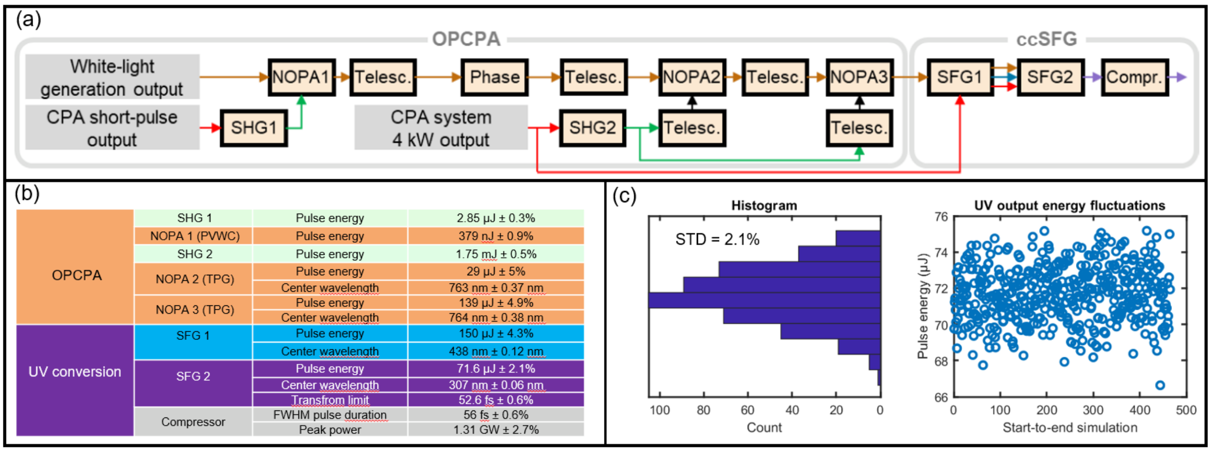

Fig. 1 (a) Simulation building blocks including all second order nonlinear conversion stages as well as SPM, self-focusing and propagation and imaging effects; (b) Simulations results showing the rms value and its corresponding standard deviation of each sub-sequent conversion stage; (c) Exemplary, all start-to-end simulation results and the corresponding histogram in case of UV output pulse energy

The insides of this study had major impact on the conceptual design of the laser system, especially the dispersion concept and the best implementation of remote controls, such as power attenuation and fast wavelength control, etc.

References

[1] M. Beye, Ed., FLASH2020+ : Making FLASH brighter, faster and more flexible : Conceptual Design Report. Deutsches Elektronen-Synchrotron, DESY, Hamburg, 2020. DOI: 10.3204/PUBDB-2020-00465

[2] L. Schaper, ed.al, "Flexible and Coherent Soft X-ray Pulses at High Repetition Rate: Current Research and Perspectivesal" Appl. Sci. 2021, 11, 9729. https://doi.org/10.3390/app11209729