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High Repetition Rate, Low Noise and Wavelength Stable OPCPA Laser System with Highly Efficient Broadly Tunable UV Conversion for FEL Seeding

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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 > 50 µJ and > 100 µJ for SEED 1 and SEED 2, respectively, and with 6000 pulses in one second (1 MHz pulse trains in 600 µs - 10 Hz bursts). In combination with the EEHG seeding principle, this will allow for the generation of high harmonics corresponding to XUV FEL pulses with photon energies of more than 300 eV (down to 4 nm in wavelength). 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 a precise predictions of system performance in terms of output power, tunability, beam quality and stability in respect to the measured input parameters and respective statistical and systematic fluctuations. The theoretical results are confirmed by first experimental studies being in excellent agreement in terms of UV conversion efficiency, beam quality and the predicated improvement of the pulse-to-pulse stability compared to the OPCPA stability. 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 user controls, such as power attenuation and fast wavelength control, etc.
[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

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Primary authors: LANG, Tino (Deutsches Elektronen-Synchrotron DESY at Zeuthen); HARTWELL, Samuel (Deutsches Elektronen-Synchrotron DESY at Zeuthen); ZHENG, Jiaan (Deutsches Elektronen-Synchrotron DESY at Zeuthen); HARTL, Ingmar (Deutsches Elektronen-Synchrotron DESY at Zeuthen); SCHAPER, Lucas (Deutsches Elektronen-Synchrotron DESY at Zeuthen); MOHAMMAD KAZEMI, Mehdi (Deutsches Elektronen-Synchrotron DESY at Zeuthen); Mr HOANG, Nhat-Phi (Deutsches Elektronen-Synchrotron DESY at Zeuthen); FERRARI, Eugenio (Deutsches Elektronen-Synchrotron DESY at Zeuthen); ALLARIA, Enrico (Elettra-Sincrotrone Trieste S.C.p.A.)

Presenters: LANG, Tino (Deutsches Elektronen-Synchrotron DESY at Zeuthen); HARTWELL, Samuel (Deutsches Elektronen-Synchrotron DESY at Zeuthen); ZHENG, Jiaan (Deutsches Elektronen-Synchrotron DESY at Zeuthen); HARTL, Ingmar (Deutsches Elektronen-Synchrotron DESY at Zeuthen); SCHAPER, Lucas (Deutsches Elektronen-Synchrotron DESY at Zeuthen); MOHAMMAD KAZEMI, Mehdi (Deutsches Elektronen-Synchrotron DESY at Zeuthen); Mr HOANG, Nhat-Phi (Deutsches Elektronen-Synchrotron DESY at Zeuthen); FERRARI, Eugenio (Deutsches Elektronen-Synchrotron DESY at Zeuthen); ALLARIA, Enrico (Elettra-Sincrotrone Trieste S.C.p.A.)

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