Ultrafast Pump-Probe Laser for the European X-ray Free-Electron Laser Facility

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***Abstract*—We present a versatile and flexible ultrafast optical laser setup, developed for future experiments at the European XFEL. Like the XFEL, the laser operates in burst-mode, emitting milli-Joule class few-cycle pulses at MHz repetition rates. At its core is an optical parametric amplifier optimized for 800nm emission. We present the design, capabilities, scope of operation and installation schedule.**

Keywords—ultrafast optics; free-electron lasers; x-ray lasers.

I. Introduction

The European X-ray Free Electron Laser (European XFEL) is a multi-national user facility, currently under construction in Hamburg, Germany. Once fully operative, it will deliver up to 27000 soft and hard x-ray femtosecond pulses per second to a total of six instrument end stations. This high number of pulses is emitted in burst-mode at a burst rate of 10Hz [1]. The bursts are up to 600µs long and contain up to 2700 pulses, corresponding to an intra-burst repetition rate of up to 4.5MHz. Driven by the experimental requirements of a diverse range of science fields, the target pulse duration of the European XFEL lies in the range of sub-10fs to 100fs. Numerous experimenters aim to use an optical laser to excite or probe samples during experiments with x-rays, referring to this type of laser as pump-probe laser (PP-laser). Naturally, the PP-laser must be adapted to the lasing-mode of the XFEL. Here, we report on the results of the final R&D campaign, capabilities and installation schedule of the European XFEL PP-laser.

II. Laser Design and Principle

The PP-laser should provide 10Hz bursts of mJ-level synchronized femtosecond pulses with intra-burst repetition rates up to 4.5MHz and with a close to diffraction limited beam. We have shown previously how this is achieved, reaching burst-powers in excess of 30W and pulse energies up to 180µJ at 15fs from a 2-stage noncollinear parametric amplifier (NOPA) [2]. Following an upgrade of the 1030nm pump laser power from 400W to 4kW, the NOPA output power and energy could be raised accordingly using a 3-stage NOPA design. Fig. 1 shows the schematic of the laser design including all major subsystems. An all-fiber front-end amplifier is seeded by a synchronized soliton seed-oscillator. The front-end has two synchronized outputs, one seeding a chain of power amplifiers, the other generating supercontinuum to seed the first NOPA amplifier. The three NOPA stages are pumped by the frequency doubled 800fs pulses from the power amplifiers. All amplifiers operate in 10Hz burst-mode. There are four frequency settings

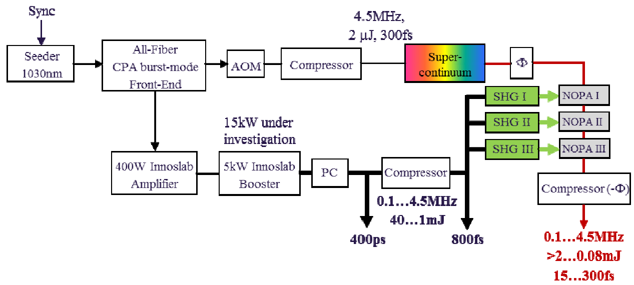

Fig. 1: Schematic of the PP-laser for experimental station at the European XFEL. Pockels-cell, PC, acousto-optic modulator, AOM, chirped pulse amplifier, CPA and second-harmonic generation, SHG.

corresponding to the intra-burst repetition rates (100kHz, 200kHz, 1MHz and 4.5MHz). The energies of the pump pulses scale inversely with frequency, since the burst average power of the amplifiers remain constant. The laser can be configured to work at above repetition rates with outputs at 800nm and 1030nm.

III. Summary of Results

At 800nm, depending on the intra-burst repetition rate and setpoint of the NOPA, the single pulse energy ranges from 0.08 to >2mJ with compressed pulse duration between <15fs and >300fs depending on the implemented dispersion management. In all cases the pulses are nearly transform limited and the beam quality is close to the diffraction limit.

At 1030nm, using the pulses from the pump laser, the user has a choice of 400ps (chirped) and 800fs (compressed) pulses with up to 40mJ single pulse energy. Mixed operation, with both 1030nm and 800nm outputs is feasible.

IV. Conclusion

The concept and performance of the PP-laser for the European XFEL is presented. In alignment with facility time plans, installation of three systems will start in July 2016.

References

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