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Optimization of the temporal quality of ultrafast pulses using dispersion scan based on tunable chirped fiber Bragg gratings

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The XUV Free-Electron Laser (FEL) facility FLASH at DESY provides ultrashort pulses of high-intensity radiation in the extreme ultraviolet and soft X-ray range, which is used as a tool for ultrafast dynamics in molecular physics, chemistry, biology, material science. Vast majority of applications, seeding, and driving electrons from RF photocathode guns of FELs require high power ultrashort laser pulses. Recently, within the upgrade program FLASH2020+, an improved Yb:fiber picosecond front end was developed for seeding high power Yb:YAG gain blocks. Using chirped pulse amplification technology, the pulses are stretched first to 650 ps duration and compressed after amplification to achieve high power transform-limited sub-picosecond pulses for OPCPA pumping or multi-pass cell compression.

In our upgraded system design, we plan for improved stability in 24/7 operation to fix the grating compressor components after initial alignment and optimize the pulse quality as well as correct for any residual day-to-day dispersion drifts (caused by for example environmental factors) via tunable chirped fiber Bragg gratings (CFBG) used for stretching the oscillator pulses. As we know, the dispersion scan (d-scan) technique [1] can be employed to characterization and optimization of the temporal pulse quality. The transform-limited pulse duration in our system is ~550 fs, which means that glass wedges which are typically used in the d-scan technique can't introduce sufficient dispersion for suitable d-scan traces. One option would be to scan the grating compressor dispersion [2,3], which is however not compatible with our goal of a fixed compressor set-up.

Here we present a different option which does not require to use any movable parts for d-scan but utilizes the tunability of our CFBGs (Teraxion) via distributed heaters. The laser schematic is shown in Fig. 1(a). The output pulses from the oscillator are stretched by a tunable CFBG 1. After a pre-amplifier, the repetition rate is down counted to 1 MHz. Then, the pulses are split into two branches. The main branch will be further stretched by tunable CFBG 2, amplified and down-counted to 100 kHz. Note that in our demonstration set-up the last amplifier is a Yb:YAG bulk amplifier, where the output pulse duration is ~650 ps and average power is ~2.5 W. In the final set-up we will further amplify this output to 400 W power. By coarse alignment of the compressor, a pulse duration of ~750 fs could be achieved. D-scan traces are generated by tuning the CFBGs and recording second harmonic spectra using a thin BBO crystal. Figures 1(b) and 1(c) depict two d-scan traces, where the 2nd order dispersion is scanned with fixed but different amounts of 3rd order dispersion. The corresponding reconstructed autocorrelation traces at the GDD value corresponding to the shortest pulse are shown with red and blue curves in Figs. 1(d) and 1(e), respectively. The black curves show the measured autocorrelation traces at these points. The close to perfect consistency between measured and reconstructed autocorrelation traces prove the validity of our method. We also validated this novel d-scan technique by comparing the results to more traditional a grating compressor scan.

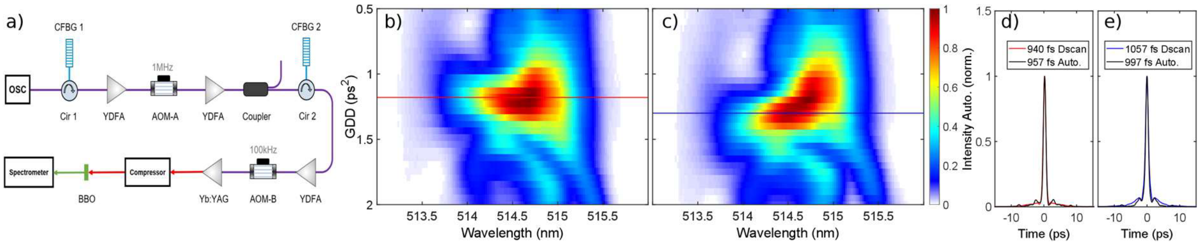

Fig. 1 Schematic layout of laser system together with d-scan and autocorrelation measurements of optimally and non-optimally compressed pulses after a grating compressor. (b) and (c) measured d-scan traces with different amount of introduced residual TODs by CFBG. (d) and (e) comparison of autocorrelation measurements (black curves) and reconstructed autocorrelations traces from d-scan measurements at optimum compression points (b) and (c), respectively. The values correspond to the width of the autocorrelation trace. The retrieved pulse durations from d-scan method are 665 fs and 747 fs for d) and e), respectively.

In conclusion, we demonstrated sub-picosecond pulse optimization using a d-scan technique based on tunable CFBGs. We used this technique to compress 650 ps pulses to ~650 fs with optimized pedestals. This method allows reliable pulse-characterization and optimization without movable parts and therefore no risk of mis-alignment of a laser system used in 24/7 operation at a large scale FEL facility.

References

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