LASERLAB-EUROPE

The Integrated Initiative of European Laser Research Infrastructures III

Grant Agreement number: 284464

Work package 33 - European Research Objectives on Lasers for Industry, Technology and Energy (EURO-LITE)

Deliverable 33.2

OPA system with 12 cm aperture frequency doubling

Report on the test set-up for the full OPA system with 12 cm aperture frequency doubling

Lead Beneficiary: GSI

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Due date: 31/05/2014

Date of delivery: 27/05/2014

Deliverable Nature	
R = Report, P = Prototype, D = Demonstrator, O = Other	R
Dissemination Level	
PU = Public PP = Restricted to other programme participants (incl. the Commission Services) RE = Restricted to a group specified by the consortium (incl. the Commission Services) CO = Confidential, only for members of the consortium (incl. the Commission Services)	PU

A. Abstract

The deliverables under 33.2 concern improvements in the contrast ratio of ultra-intense high-energy lasers. The goal of these improvements was to reach a contrast ratio of the order of 10^{-12}. This means that the pre-pulse power level in the case of a target irradiation with an intensity of 10^{21} W/cm^2 would not exceed 10^9 W/cm^2. In the formulation of the task it seemed obvious, that such a large ratio would not be achievable by only an active improvement of the level of unwanted pre-pulses and the unavoidable amplified spontaneous emission (ASE). Therefore it was planned to combine two different measures, namely the active improvement of the contrast by the addition of an ultra-fast optical parametric amplifier (uOPA) in combination with a passive method, e.g. frequency doubling of the full energy, fully compressed pulse. The preliminary results with the uOPA system demonstrated that with some additional effort in this direction a contrast level well beyond 10^{-10} seemed feasible even for the full 250 kJ Nd:glass amplified laser system PHELIX. At the same time, frequency doubling at the full aperture still does not seem to be an economic solution. The effectiveness of the active pre-pulse suppression was demonstrated down to the limit of diagnostic instruments. With this achievement we believe the milestone is fulfilled with the improved purely active approach.

B. Deliverable Report

We report on the implementation and characterization for temporal contrast enhancement and control at petawatt-class lasers by an active preamplifier module. The module is based on an ultrafast optical parametric amplifier (uOPA), which produces temporally clean pulses at the 60 µJ level for seeding a chirped pulse amplification (CPA) system, namely the petawatt facility PHELIX. The amplifier module allows for gain reduction in the following amplifiers, resulting in an attenuation of amplified spontaneous emission (ASE) by more than 4 orders of magnitude. Since the ASE of a CPA system linearly depends on the seeding energy, we were able to demonstrate a continuous variation of the temporal contrast by tuning the gain of the uOPA.

The enhancement of the pulse contrast is based on direct amplification of the pulses before the pulse-stretcher unit of the CPA laser. Because of the instantaneous nature of the parametric process, the signal-to-noise ratio of the laser oscillator is not degraded outside of the amplification time window, which can be very short. Ideally, the pump pulse used for the uOPA should be shorter than 1 picosecond to avoid plasma expansion on the picosecond scale. The pump pulse used for the uOPA was generated using a diode-pumped Yb-doped amplifier that has enough bandwidth to support sub-picosecond laser pulses as dictated by solid target interaction experiments. In addition, the requirement on the temporal quality of the pump laser in the uOPA is not as high as for the double CPA scheme, which allows for using a compact and cost-effective stretcher/compressor setup based on a single chirped volume Bragg grating (VBG). Finally, with VBGs available at larger sizes and laser diode-pumped Ytterbium amplifiers nowadays reaching the 1 J level, the scheme is fully scalable to higher contrast levels. This paves the way to achieve pedestal-free pulses at even higher intensities in a purely active way.

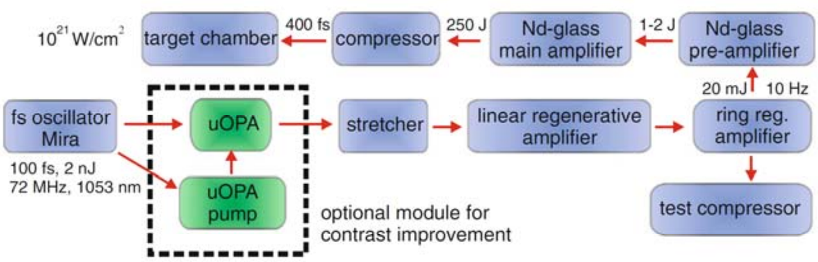


Fig. 1

The PHELIX short-pulse laser system

The uOPA was developed, optimized and demonstrated as a pulse cleaner at the PHELIX short-pulse laser system. The system uses the technique of CPA to deliver pulses with minimum duration of 400 fs, maximum energy of up to 250 J at a repetition rate of one shot every 90 min. With a F2-parabolic mirror, the beam can be focused down to reach maximum intensities of up to 10^{21} W/cm^2. This requires a good contrast to prevent ionization of targets prior to the main pulse.

A main challenge of the uOPA is the generation of a pump pulse which fulfills the following requirements: a duration of not more than one picosecond, as well as a low temporal jitter between the pump and signal pulses. An additional demand for the pump laser is a setup as compact as possible to be suitable for the PHELIX system. The setup of the uOPA is shown in a schematic in Fig. 2. In our realization, both pump and signal pulses originate from the same oscillator in order to account for the low jitter requirements. By using a 50:50 beamsplitter, half of the beam directly propagates to the beta barium borate (BBO) crystal, where it is amplified in the OPA process. A motorized delay line is used to temporally overlap the seed with the pump pulse. The other part is amplified in a compact CPA system and serves as the pump pulse in the OPA. First, the pulse is stretched to 300 ps after being reflected in a VBG (OptiGrate Corp.). This VBG was designed to reflect a 5-nm bandwidth pulse centered at 1,040 nm. The central wavelength matches the amplifiers which both use Ytterbium as active material. The main advantage of the VBG compared with conventional grating- based stretcher–compressor assemblies is its compactness, cost and ease of use. Both stretching and recompression of the pulse are carried out in the same VBG with dimensions in the order of a few centimeters. The stretched pulses are then amplified in two consecutive amplifiers. The first amplification takes place in a two-stage Ytterbium-doped fiber amplifier. In a single mode fiber, the stretched pulses with an average power of 1–2 mW and a repetition rate of 72 MHz are amplified to 160 mW. The repetition rate is then reduced to 1 MHz using an acousto-optical modulator (AOM) synchronized with the PHELIX laser system. A second stage then creates an output of 1 W corresponding to pulse energies of 1µJ. The beam then goes to a regenerative ring amplifier operating at 10 Hz [13].

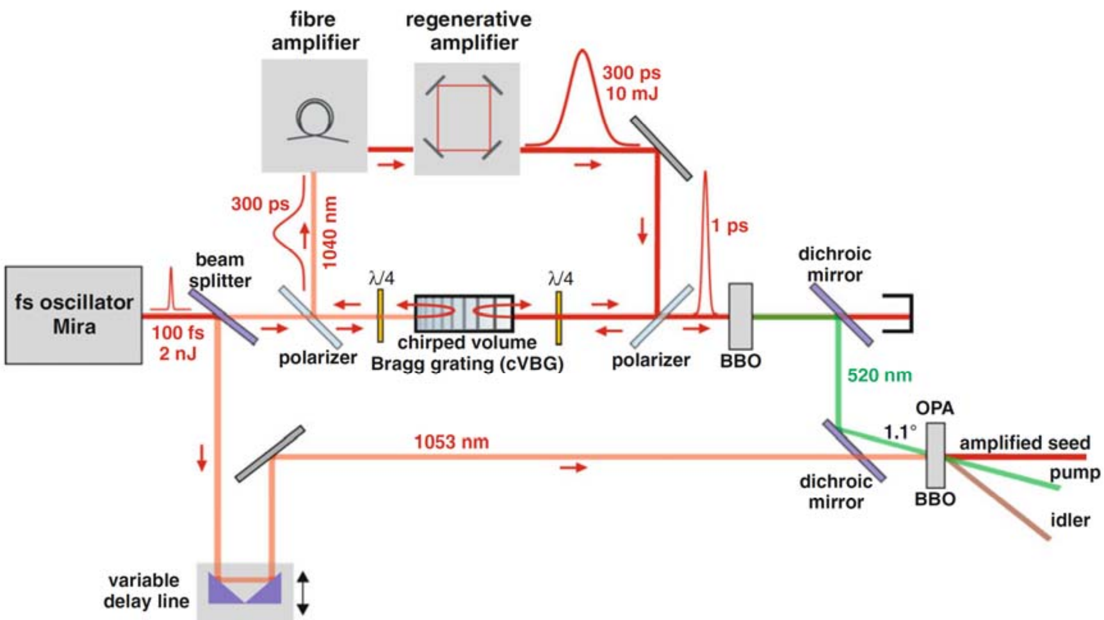


Fig. 2. The uOPA set-up

The amplifier uses Yb:KGW as an active medium pumped by a laser diode module (Lastronics GmbH) which is capable of delivering up to 2.4 kW peak power at 940 nm. Output of the ring is a pulse train with nominal pulse energies of 10 mJ and a bandwidth of 5 nm centered at 1040 nm. The spectrum after the ring amplifier exhibits the same bandwidth as the input beam, which enables compression of the pulses to 1 ps with the VBG. This is accomplished by using the VBG in the direction opposite to the stretching direction. In order to use the pulses as pump pulses in the OPA process, they need to be frequency doubled, which is accomplished in a BBO crystal. The frequency-doubling stage for the pump laser and the parametric amplifier were simulated and dimensioned using the Miro software with the specific module handling four wave mixing of broadband pulses. A fraction of 50 % from the 4.5 mJ at fundamental wavelength can be converted to green, which results in a pump-pulse energy of about 2.3 mJ at the OPA-crystal. Two dichroic mirrors are used to separate the pump beam at 520 nm from the residual infrared radiation that has not been converted in the BBO crystal.To meet the requirements for phase matching in the BBO crystal, the angle between the pump pulse at 520 nm and the seed pulse at 1,053 nm has to be unequal to zero degrees. Using the Miro software, an optimum angle of 1.1 degrees was calculated. This also enables to separate the amplified signal from the residual pump and the idler. With a pump-pulse energy of 2.3 mJ, we reach saturation in the OPA, which corresponds to a conversion efficiency of about 3 %. This value can be explained by the not optimally matched pulse duration of the pump and seed pulses. To improve the conversion efficiency, the seed pulse was stretched to a duration of 300 fs using multiple reflections from two chirped mirrors. The uOPA module was integrated to the PHELIX shortpulse system and can be used at any time during daily operation. Switching between the configuration with and without the pulse cleaner is very easy and can be arranged within minutes. As illustrated in Fig. 1, the uOPA is placed directly behind the short-pulse oscillator. After the uOPA the amplified signal pulse is sent to the grating stretcher and subsequently to the two regenerative amplifiers of the PHELIX short-pulse front end. Due to the higher input signal the amplification in the regenerative amplifiers can be reduced to deliver the same output energy level of 20 mJ. This is accomplished by decreasing the pumping laser energy in the linear regenerative amplifier which results in less ASE production. Because the optical path and timing of the regenerative amplifier is identical for both operation modes, the changeover between the two configurations is straightforward.

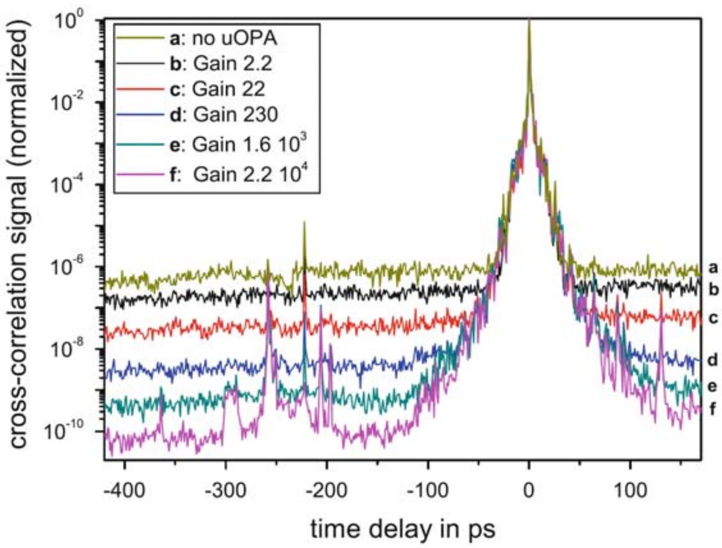
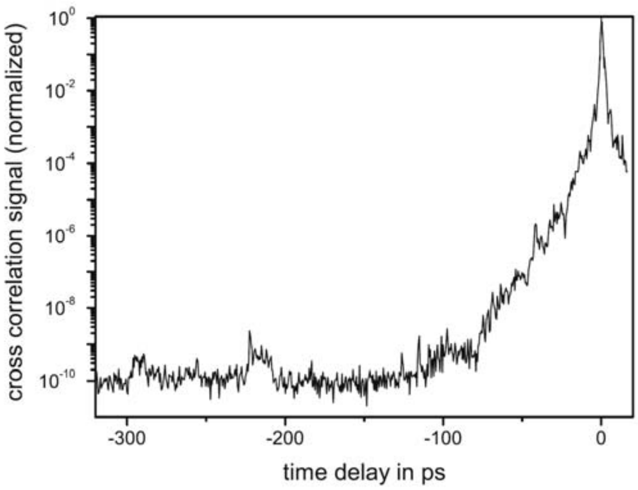


Fig. 3 Improvement of the ASE contrast for different gain levels in the uOPA

To measure the contrast with the new module, the laser pulses amplified in the front end were sent to a local compressor. Because the amplification in the glass amplifier is not saturated, we do not expect a degradation of the temporal contrast between the front part of the pulse and its peak. In addition, the ASE contribution of the glass amplifier was estimated theoretically and measured experimentally to be negligible to play any role in the picosecond ASE contrast level of the laser pulse. Therefore, we believe that the measurement done at the output of the front end is also representative of the temporal contrast of the laser pulse at full energy. At this stage, the system is still operating at 10 Hz. Hence, a scanning third-order cross-correlator with high dynamic range (Sequoia, Amplitude Technology) was used. We performed the measurement for different gain levels in the uOPA by variation of the OPA pump-pulse energy. This was done with a half-waveplate and polarizer arrangement, used together with a photodiode that monitored the uOPA gain on an oscilloscope. For each gain level, the subsequent regenerative amplifier was maintained in saturation by adjusting the pump energy of the driving Nd:YAG pump laser using a waveplate and polarizer. By doing so, the energy at the output of the regenerative amplifier remains nearly unchanged, while the gain is shifted from the regenerative amplifier to the uOPA and the ASE originating in the regenerative amplifier accordingly reduced. The results are shown in Fig. 3. In order to compare the different ASE levels, the curves were normalized with respect to each other. The upper curve was recorded with no gain in the OPA corresponding to the standard setup without the uOPA module. The ASE is at the 10^{-6} level which is typical for a front end with no additional contrastimproving components. Starting with a gain factor of 2.2 and increasing it stepwise by factors of nearly 10, the ASE drops down almost linearly with the OPA gain. For a gain of 10^4, the ASE level exceeds the detection limit of the cross-correlator which is slightly below 10^{-10}. The curve with the highest contrast exhibits a slowly rising slope ranging up to 100 ps before the peak. This is attributable to coherent effects such as clipping of the spectrum or scattering from the diffraction gratings in the stretcher. The final contrast level after the prepulse removal and with an applied gain of 10^4 in the uOPA is shown in Fig. 4.

Fig. 4 Temporal contrast after the removal of all prepulses for a gain of 10^4 in the uOPA



Conclusion

A compact preamplifier based on sub-picosecond OPA was developed and successfully integrated to the PHELIX petawatt laser system. With this module, an improvement of the ASE contrast from 10^6, which is typical for CPA systems, to more than 10^{10}, could be demonstrated by a purely active component. This enlarges the spectrum of experiments feasible at the PHELIX laser facility. Alternative passive methods were also studied, including the feasibility of frequency doubling at the large final beam diameter, and plasma mirrors. The availability of thin frequency doubling crystals at large beam diameters was still found to be a problem. Studies with full diameter wave-plates, which are available, showed problems with the uniformity over the full diameter. Plasma mirrors show reasonable performance, but decrease the applicable power density.

Using the uOPA installation at full energy, ion acceleration with thin targets showed that the current contrast allows studying laser matter interaction with targets in the submicrometer range. Since the ASE level in a CPA system linearly depends on the energy of the seed pulse, by proper tuning the gain between the uOPA and the following linear regenerative amplifier, an arbitrary ASE level between 6 and 10 orders of magnitude can be accomplished, while maintaining the total output energy level of the system. This is very favourable for a user laser facility, since a controllable preplasma can be useful for many types of applications.