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Intermediate report on the technological options investigated for time/space pulse sculpting

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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)	PP

A. Abstract / Executive Summary

We describe the evolution of the work towards studying pulse-shaping mechanisms in tens of fs to tens of ps pulse duration domain. This document concerns the development of the optical parametric chirped pulse amplification (OPCPA) laser system used for the experimental work and the first measurements of its performance.

B. Deliverable Report

1 Introduction

Accurate time/space shaping of ultra-short laser pulses is a powerful concept that can be used e.g. to shape OPCPA pump pulses, to engineer pulses for efficient second harmonic generation (SHG), or to create specific ultra-short pulse shapes. The objectives of this work are the investigation and evaluation of spatial and temporal pulse shaping concepts for this pulse regime, with application to large beam apertures. In this deliverable we describe the development of the OPCPA chain that will be used for the tests, envisaging the pump and the signal pulses.

2 Objectives

The goal is to study and test methods and technologies for temporal and spatial pulse shaping, in pulse durations from tens of fs to tens of ps. This will be applied to the particular cases of (i) broadband OPCPA pulses and (ii) high energy pulses for efficient SHG and OPCPA pumping.

To achieve this we have been working on the development and commissioning of a noncollinear, ultra broadband OPCPA system pumped by ytterbium-based diode-pumped amplifiers, allowing high repetition rates for both instantaneous and average powers. Pulse shaping mechanisms are being tested at the level of the pump pulse (~50 ps), in order to optimize frequency doubling and pump, and at the level of the signal pulse, for efficient signal compression (~20 fs) and high contrast.

3 Work performed / results / description

The main achievements over the reporting period are described below.

<u>a) Development of a 100-mJ-level diode pumped hybrid picosecond laser for broadband OPCPA pumping</u>

We have installed a 100 mJ, diode-pumped, hybrid picosecond laser amplifier for OPCPA pumping, consisting of a 3 mJ, 10 Hz, Yb:CaF_2 regenerative amplifier and 100 mJ, 1 Hz, eight passes Yb:YAG amplifier at 1032 nm.

The amplification chain follows the chirped pulse amplification (CPA) arrangement, seeded by a commercial mode-locked Ti:sapphire oscillator delivering 4 nJ, 150 fs, 76 MHz pulses at 1030 nm. A 35.2 mm long, 5 × 8 mm^2 aperture chirped volume Bragg grating (CVBG) in double pass configuration is used as stretcher/compressor. In the present configuration, pulses from the oscillator are stretched to ~330 ps. An auxiliary compact (19 cm long) and low dispersion (600 grooves/mm) Treacy compressor was added before Yb:CaF_2 amplifier in order to pre-compensate the intra-cavity material dispersion, ensuring the overall temporal reciprocity between pulse stretching and compression.

The regenerative amplifier consists in a 1.35 m linear cavity, where a 3at% Yb-doped CaF_2 crystal, placed at the cavity waist, is pumped by a 75 W fibre-coupled diode laser (Amtron GmBH) at 940 nm in a double-pass configuration. This pre-amplifier delivers 3 mJ pulses with good energy stability (RMS <1.8%) at a repetition rate of 10 Hz and at a central wavelength of 1035 nm. The output pulses are then divided at an 80:20 beam splitter. The most energetic fraction is sent to the CVBG for compression. This process has an efficiency of ~50 %, resulting in <400 fs, ~1.2 mJ pulses are used to generate ~µJ of white light continuum to seed the OPCPA.

The remaining fraction (~0.6 mJ) after the beam splitter seeds the multipass amplifier, reaching 110 mJ after eight passes through a 3at% Yb-doped YAG crystal pumped by a 4 kW diode laser stack at 940 nm. This amplifier operates at 1 Hz, with pulse stability similar to that of the regenerative amplifier. The output pulse spectrum shifts to 1032 nm and narrows down to 3 nm FWHM, corresponding to a final output (chirped) pulse length of ~150 ps. They are then sent to a 15 mm length DKDP crystal cut for type I SHG, generating green pulses at 516 nm with ~30 % efficiency conversion, and used to pump the OPCPA.

Current research is focused of aperturing the spatially dispersed pump pulse between the two passes of the CVBG, as a means to create a temporally top-hat pulse, in a simple and ultra-compact pulse shaping concept.

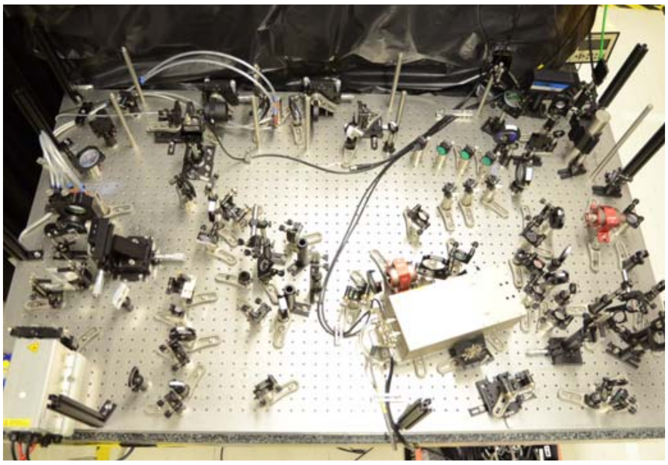

Fig. 1 – Diode-pumped hybrid Yb:CaF$_2$/Yb:YAG amplification laser chain.

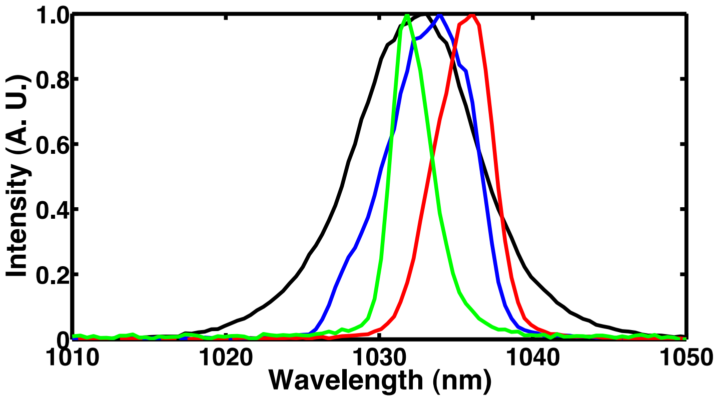

Fig. 2 – Spectra from amplification laser chain: Oscillator (black), CVBG stretched pulse (blue), regenerative (red) and multipass (green) amplifiers.

<u>b) Noncollinear ultrabroadband OPCPA in YCOB</u>

The main focus of this period was the development of the two-stage OPCPA setup based on the nonlinear crystal Yttrium Calcium Oxyborate (YCOB), their characterization and optimization. This amplifier aims at generating 20 mJ, 20 fs pulses at 1 Hz, and will serve as the test bed for broadband pulse shaping. We have also tested and characterized the performance and spectral transmission of the stretching and compression stages, consisting respectively of a 10 cm long SF11 block (stretcher) and a transmission grating + prism pair (compressor).

The first objective consisted in achieving temporal synchronization between the white light continuum signal pulse and the green (516 nm) pump pulse (see previous section). This was ensured by careful planning of the experimental layout, as well as through the installation of both a coarse and a fine delay stages, allowing a perfect overlap of the two pulses.

The YCOB crystals are cut at specific phase matching angles to maximize nonlinear efficiency. They were first used to benchmark the DKDP crystal used frequency doubling of the pump beam and were found to present high conversion. The white light continuum (WLC) signal efficiency was optimized by monitoring the WLC seed pulse duration in an SHG frequency resolved optical gating (FROG) diagnostic. Their polarization was then adjusted by using the YCOB crystal as a SHG crystal. The same procedure was repeated for the pump beam, in order to ensure that type I phase-matching conditions were satisfied.

We started by performing single stage amplification (i.e. one single YCOB crystal), and by adjusting the phase-matching angle we were able to enhance amplification over a given bandwidth of the WLC. The maximum amplified bandwidth (FWHM) occurred for spectra centred in the wavelength region 850-900 nm.

We evaluated the dependence of the amplification bandwidth with the noncollinear angle (Fig. 3). As predicted by earlier simulations (Fig. 4) there is an increase of the phase-matched bandwidth as the noncollinear angle decreases from ~4°, until a maximum is reached at ~3.8°. After this, the spectrum splits into three narrow band regions.

Temporal resynchronization of the outgoing signal and pump pulses was performed into a second YCOB crystal and a double stage was put into place, to further amplify the laser pulses. However, because of damage to the optics it was not possible to operate the double-stage setup at full power yet. Nevertheless, the second stage was optimized in terms of the amplification bandwidth (Fig. 5), extending 215 nm, from 825 to 1040 nm. The compression of such a broad spectrum to its Fourier transform limited duration would potentially allow the generation of high energy, sub-10 fs pulses, even shorter than the 20 fs goal.

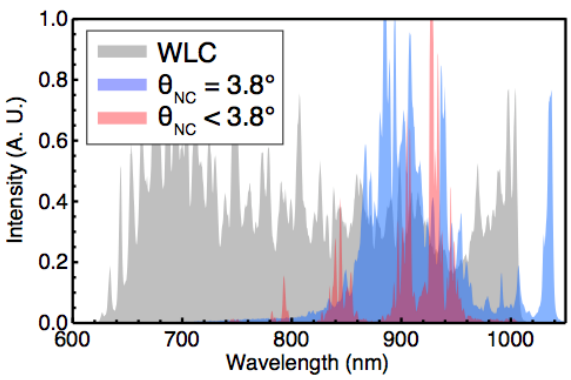

Fig. 3 – Original supercontinuum (grey) and amplified spectra in ideal and excessive noncollinear angle (blue and red, respectively).

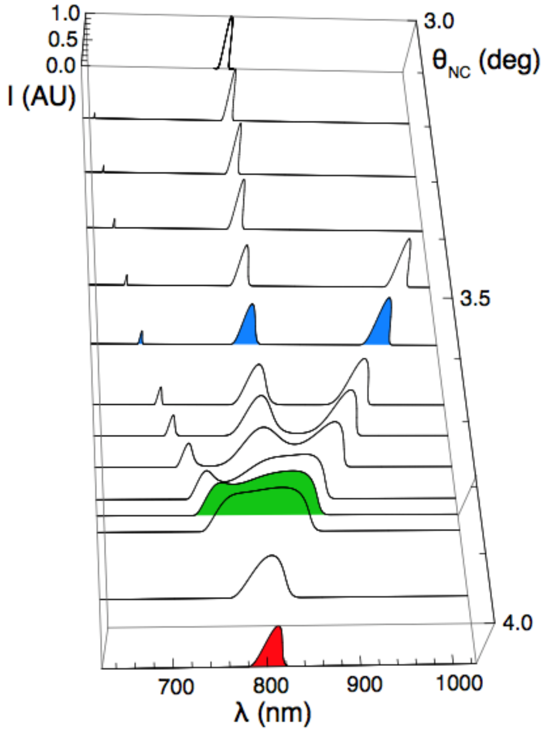

Fig. 4 – Amplification gain bandwidth for a YCOB-based parametric amplifier stage vs. the noncollinear angle θNC.

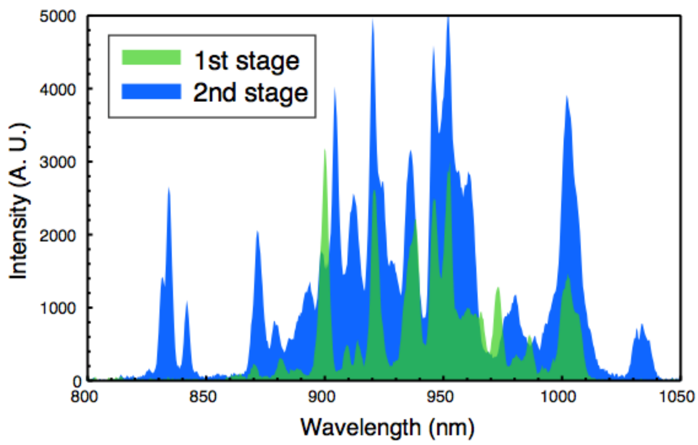

Fig. 5 – Gain bandwidth for the output spectra after the first optical parametric amplifier stage (green) and after the second amplifier (blue).

4 Conclusions

A diode-pumped laser, consisting of a 100 mJ, 1 Hz, Yb:CaF_2 / Yb:YAG amplifier at 1032 nm was successfully developed. Frequency-doubling was achieved, and the pulses are currently being used to pump a two-stage YCOB-based optical parametric chirped pulse amplifier.

The first experimental OPCPA tests have shown a performance compatible with that predicted by numerical simulations. The amplifier spectrum allows the potential generation of pulses well within the target parameters of the system.

We are currently working in increasing the overall output energy. We have started by implementing double pass in the SF11 stretcher in order to adjust it to the pump pulse duration, as a means to improve the efficiency of the parametric process. The near-term goals consist in the following steps:

- completing the double pass setup, and evaluating pump-signal overlap by measuring the amplification efficiency at low power;
- enabling operation at full pump power, and optimizing the signal-pump duration ratio and overlap for optimal efficiency;
- use the spatially chirped pulse at the output of the CVBG for introducing soft spectral shaping;
- align and implement the compressor optical components and measure the spectral phase of the amplified, compressed pulses, which will allow us to define further actions.

5 References/Publications

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