The Apollon-10P project: Design and current status

Dimitrios Papadopoulos, Catherine Leblanc, Gilles Chériaux, Patrick Georges, J-P Zou, Gabriel Mennerat, Frédéric Druon, Alain Pellegrina, Patricia Ramirez, Fabio Giambruno, et al.

To cite this version:

Dimitrios Papadopoulos, Catherine Leblanc, Gilles Chériaux, Patrick Georges, J-P Zou, et al.. The Apollon-10P project: Design and current status. Advanced Solid State Laser (ASSL 2013), Oct 2013, Paris, France. 10.1364/ASSL.2013.ATu3A.43 . hal-01370492

HAL Id: hal-01370492
https://hal-iogs.archives-ouvertes.fr/hal-01370492

Submitted on 14 Sep 2022

The Apollon-10P project: Design and current status

D. N. Papadopoulos [1], C. Le Blanc [1], G. Chériaux [2], P. Georges [3], J.P Zou [1], G. Mennerat [4], F. Druon [3], A. Pellegrina [1,3], P. Ramirez [1,3], F. Giambruno [1,2], A. Fréneaux [1,2], F. Leconte [1,2], D. Badarau [1], J.M. Boudenne [1], P. Audebert [1], D. Fournet [1], T. Valloton [1], C. Greverie [1], J.L. Paillard [1], J.L. Veray [1], M. Pina [1], P. Monot [4], P. Martin [4], F. Mathieu [1], J.P. Chambaret and F. Amiranoff [1]

[1]Laboratoire pour l'Utilisation des Lasers Intenses, CNRS, Ecole Polytechnique, Palaiseau, France,
[2]Laboratoire d'Optique Appliquée, ENSTA ParisTech, CNRS, Palaiseau, France,
[3]Laboratoire Charles Fabry, Institut d'Optique, CNRS, Univ Paris Sud, Palaiseau, France,
[4]CEA, Iramis, SPAM, Saclay, France
e-mail address: dimitrios.papadopoulos@polytechnique.edu

Abstract: The principal objective of Apollon-10P project is the generation of 10 PW peak power pulses of 15 fs duration at 1 shot/minute. The technological challenges and the current status of the Apollon laser system are discussed in detail.

OCIS codes: (140.7090) Ultrafast lasers; (140.3590) Lasers, titanium; (140.3615) Lasers, ytterbium;

1. Introduction

The Apollon-10P is a laser facility which will provide 10 PW peak power pulses at a repetition rate of 1 shot/minute. To reach this extreme peak power level, Apollon will be based on the generation of extremely short pulses of 15 fs and a corresponding moderate energy of 150 J after compression. The contrast ratio (CR) of the generated pulses will be better than 10^{12} at intensity levels surpassing the barrier of $2\cdot10^{22}$ W/cm^2. This unique laser will be used for the generation of ultra-intense and ultra-short sources of particles (electrons, protons...), coherent and high energetic X rays. The possibility of combining the main 10 PW beam line with three additional secondary beams (an 1 PW beam, a 10 TW probe and the uncompressed beam) will be provided. A consortium of three Laboratories (LULI, LOA and LCF) has undertaken the responsibility of the development of the main individual parts of this laser system. The final integration of the subsystems of Apollon is scheduled for the beginning of 2014. The laser facility will be hosted in an old accelerator facility (l'Orme des Merisiers, Saclay, France) which is currently under reconstruction and is expected to be delivered by the end of 2013.

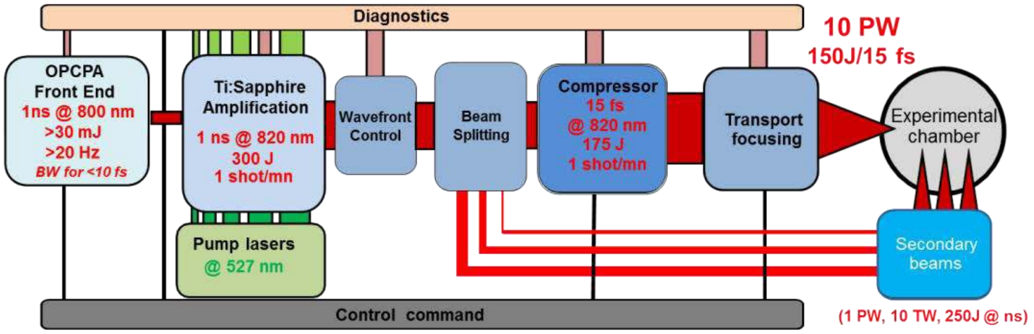

Fig. 1. Global schematic of the Apollon-10 PW laser installation.

To meet the complete set of requirements, Apollon design is based on a hybrid OPCPA-Ti:Sapphire architecture. The OPCPA based front-end employs state of the art technology to guarantee the generation of high quality and high CR pulses with a spectrum supporting sub-10 fs pulses. Main amplification will take place in Ti:Sapphire multipass amplifiers up to 300 J. A specific spectral management configuration within the amplification chain will guarantee the preservation of the spectral bandwidth to support the 15 fs output pulses. The amplified beam will finally be compressed in a four grating unfolded compressor. Higher order residual spectral phase will be pre-compensated actively by a high capacity Dazzler located in the front-end. To guarantee the optimal beam and wavefront quality a sophisticated relay imaging configuration based on off-axis parabolic telescopes is adopted associated to a deformable mirror at the output of the amplification chain. The goal is to deliver to the experimental halls a beam with a Strehl ratio >0.5. A simplified schematic of the Apollon laser is show in figure 1.

2. Design and operation of Apollon sub-systems

The front-end of Apollon is based on a non-collinear OPCPA architecture using BBO crystals to allow the amplification of broad-bandwidth pulses. A schematic of the front-end configuration is show in figure 2-left. A particularity of our design is that the Apollon Offner stretcher is integrated in the front-end between two OPCPA stages. The first one provides the main gain (~1000x) operating in the picosecond regime while the second OPCPA stage operates in a low gain (~50-100x) but energetic nanosecond regime. Both the injection pulses at 800 nm and the pump pulses (SHG of 1030 nm) are provided by a broad-bandwidth Ti:Sapphire oscillator (Rainbow, Femtolasers) for optimal temporal synchronization.

The 800 nm pulses are first amplified by a commercial Ti:Sapphire CPA system (Femtopower) and temporally cleaned and spectrally broadened in a novel double XPW (crossed polarized wave) configuration [1]. The pulses are then stretched in a bulk stretcher (BK7) and their phase is actively controlled by a double passed Dazzler. After a final spatial filtering stage, about 2 µJ, 6 ps pulses of excellent spatial, temporal and spectral quality and stability are then provided as the injection signal of the ps-OPCPA stage.

For the pump pulses the diode pumped Yb-doped crystal technology is used. The pJ level pulses at 1030 nm from the Ti:Sapphire oscillator are first temporally stretched and pre-amplified to the nanosecond/mJ regime. Amplification then takes place in two parallel chains: a) the picosecond line which is based on an Yb:CaF_2 multipass amplifier providing >15 mJ of pump energy at 515 nm (after compression and SHG) and b) the nanosecond line which is based on an Yb:YAG regenerative amplifier [2] followed by an Yb:CaF_2 booster to reach >600 mJ in the IR (>300 mJ at 515 nm) at 20-100 Hz repetition rate [3] .

So far we have performed OPCPA experiments in the picosecond regime resulting in more than 7 mJ pulses at 100 Hz and bandwidth >130 nm supporting sub-10 fs pulses (figure 2-right). Completion of the nanosecond OPCPA stages and commissioning of the front-end is scheduled for the middle of 2014.

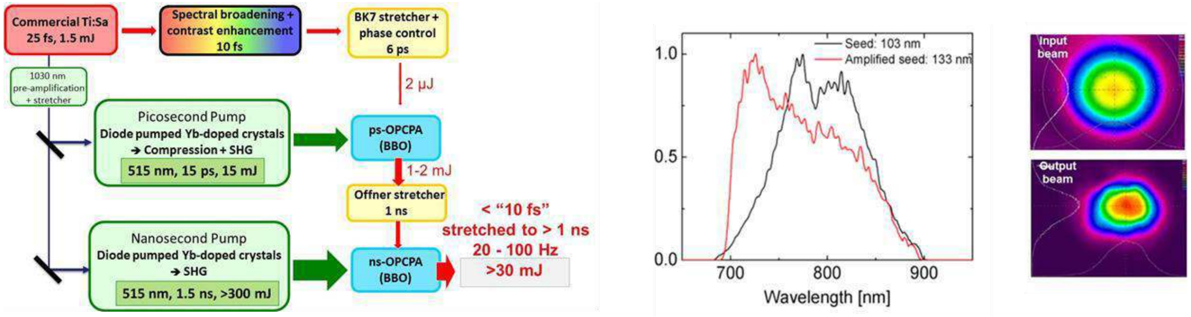

Fig. 2. Schematic of the front-end of Apollon (left). OPCPA spectra (input/output) and corresponding beam profiles (right).

The power amplification section (PAS) is based on 5 multipass Ti:Sapphire amplifiers to obtain 300 J (before compression) while targeting to optimal spectral forms and widths compatible with high contrast 15 fs pulses. To achieve these characteristics four main points have to be addressed:

1) The spectral evolution management: Spectral filters are designed to fight against gain narrowing and spectral shifting due to the saturation [4]. Two sets of these filters will be located at the entrance of the PAS and before the 3rd amplifier to allow amplification to the maximum energy preserving ~70 nm bandwidth (FWHM) centered at 820 nm. In very recent experiments the capacity of this technique has been demonstrated up to 3 J (output of the second amplification stage). Using a different front-end (50 nm bandwidth pulses) compressibility of the amplified pulses down to 22 fs has been demonstrated (figure 3-left).

2) The beam energy distribution quality: This will be achieved through the implementation of an imaging system in which a reference input plane is relay-imaged at the output of each amplifier successively. To reduce the chromatic effects, imaging is performed with the use of off-axis parabolic telescopes (beam cross sections >20 mm). Spatial filtering is also implemented to minimize the intensity modulations at high spatial frequency (>1 mm^{-1}).

3) Transverse lasing suppression: The targeted output energy level requires the use of very large diameter Ti:Sapphire crystals, especially for the 4th and 5th amplifiers (figure 3-right). In fact, Apollon employs the largest ever grown crystals reaching 175 mm in diameter (GT Crystal Systems) and pumped areas as large as 150 mm for the last stage. Thickness-to-diameter ratios even greater than 3.5 and the high pump energy densities (>1 J/cm^2) make the management of parasitic transverse effects a challenging task. For the suppression of transverse lasing different techniques have been explored based on the use of index-matched liquid in innovative and high efficiency configurations. First experimental results obtained with the use of LULI2000 laser facility (Palaiseau, France) to simulate the pumping conditions of the final amplification stage will be presented.

4) High energy pump lasers: A total energy amount of 800 J in the green is required for pumping the three last stages of the PAS. A commercial pump system will be used in Apollon (Continuum & National Energetics) based

on flashlamp pumped Nd-glass amplifiers. An innovative technology using the multislab approach and liquid cooling of the active medium allows the operation of the system at least up to 1 shot/minute. The first module of the pump system, providing 400 J for the 3rd and 4th amplifier will be delivered in France at the beginning of 2014.

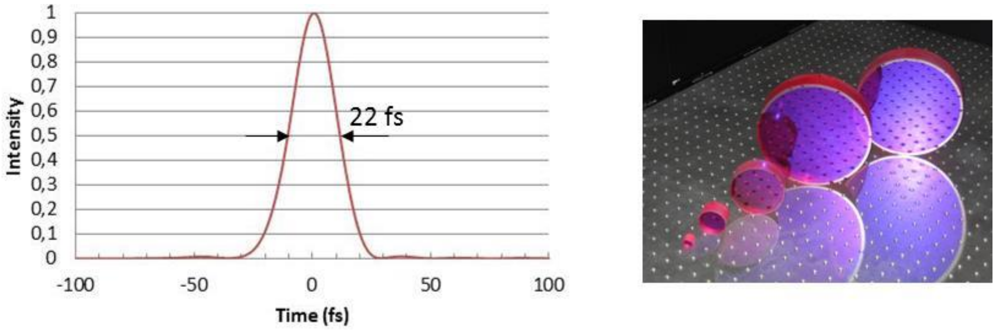

Fig. 3. Compressed output pulse at 380 mJ (left). The power amplification section Ti:Sapphire crystals (GT Crystal Systems) (right).

The main beam line compressor of Apollon is based on a typical four grating unfolded configuration and has been designed on the basis of three principle considerations: the very short pulse duration and the necessity of accurate spectral phase management up to the 3rd order, the very large pulse bandwidth (200 nm full bandwidth at 820 nm) and the damage threshold of the gratings. In fact, to deliver 10 PW pulses to the experimental halls, including the transport mirrors losses, an energy of 175 J is required at the output of the compressor corresponding to about 250 J at the input (for 70% transmission). Existing grating technology however, limits our choice in gold-coated gratings as the only compatible with the required bandwidth (720-920 nm) with damage threshold in the range 200-300 mJ/cm^2. In our design the peak fluence on the first grating is <110 mJ/cm^2 imposing the use of a 400 mm beam size and therefore meter-long gratings.

Apollon compressor employs the world largest gratings of 910×455 mm² manufactured by LLNL (Laurence Livermore National Laboratory). Since January 2012, six of these gratings have been received and fully characterized. The gratings have 1480 l/mm and their diffraction efficiency has been measured to be better than 92% on three wavelengths (780, 800 and 840 nm). The wavefront error of the diffracted beam is lower than $\lambda/3$ over the whole effective surface. Taking into account the geometrical limitations due to the large beam cross section the angle of incidence has been set at 56°. Residual phase minimization (due to the dispersion of different materials in the laser chain) has then been based on the design of an unmatched stretcher (in the front-end) which uses two 1450 l/mm gratings at 52.4° angle of incidence. Based exclusively on this stretcher-compressor dispersion compensation the final pulse duration would be 18 fs (~1.25xFTL for 70nm FWHM Gaussian pulses). This residual higher order phase nevertheless is well within the capacity of the Dazzler, allowing ideally compression even bellow 15 fs.

The compressor will be installed in a large stainless steel vacuum chamber (6.2x3x3.1m^3) specified to provide vacuum level of 10^{-7} mbar and cleanliness of ISO6. The large size of the chamber allows entering the compressor from a single entrance and handling and alignment of the gratings inside the chamber. Delivery of the chamber is scheduled for September 2014.

According to our planning Apollon will provide the first PW level pulses at 1 shot/minute for first experimental demonstrations in the first trimester of 2015 and multi PW pulses through the main, full cross-section beam line before the end of the same year. Final upgrades to the full capacity of Apollon will follow during 2016-2018.

This work is supported by French state funds managed by the ANR within the "Investments for the Future" program under reference ANR-10-EQPX-25, by the ILE-APOLLON 07-CPER 017-01 contract and by the European FEDER APOLLON MPW contract.

3. References

[1] L. P. Ramirez, D. N. Papadopoulos, A. Pellegrina, P. Georges, F. Druon, P. Monot, A. Ricci, A. Jullien, X. Chen, J. P. Rousseau, and R. Lopez-Martens, "Efficient cross polarized wave generation for compact, energy-scalable, ultrashort laser sources," Opt. Express **19**, 93-98 (2011).

[2] J. Tümmler, R. Jung, H. Stiel, P. V. Nickles, and W. Sandner, "High-repetition-rate chirped-pulse-amplification thin-disk laser system with joule-level pulse energy," Opt. Lett. **34**, 1378-1380 (2009).

[3] D. N. Papadopoulos, "High energy diode pumped Yb:doped crystal amplifiers for ultrashort OPCPA," in *Frontiers in Optics 2012/Laser Science XXVIII*, OSA Technical Digest (online) (Optical Society of America, 2012), paper FM4G.2.

[4] F. Giambruno, C. Radier, G. Rey, and G. Chériaux, "Design of a 10 PW (150 J/15 fs) peak power laser system with Ti:sapphire medium through spectral control," Appl. Opt. **50**, 2617-2621 (2011).