A multi-beam, multi-terawatt Ti:sapphire laser system for laser wake-field acceleration studies

Csaba Tóth, Cameron G. R. Geddes, Jeroen van Tilborg, Eric Esarey,
Carl B. Schroeder, and Wim P. Leemans

L'OASIS Group, Accelerator and Fusion Research Division, Lawrence Berkeley National Laboratory,
BLDG 71R0259, 1 Cyclotron Rd., Berkeley, CA 94720, USA, e-mail: ctoth@lbl.gov

Abstract. The Lasers, Optical Accelerator Systems Integrated Studies (L'OASIS) Lab of LBNL operates a highly automated and remotely controlled Ti:sapphire chirped pulse amplification (CPA) laser system that provides synchronized beams of 2x1.0 TW, 12 TW, and 100 TW peak-power, in a unique, radiation shielded facility. The system has been specially designed for studying high field laser–plasma interactions and particularly aimed for the investigations of laser wake-field particle acceleration. It generates and recombines multiple beams having different pulse durations, wavelengths, and pulse energies for various stages of plasma preparation, excitation, and diagnostics. The amplifier system is characterized and continuously monitored via local area network (LAN) from a radiation shielded control room by an array of diagnostics, including beam profile monitoring cameras, remote controlled alignment options, self-correcting beam-pointing stabilization loops, pulse measurement tools, such as single-shot autocorrelator for pulse duration and third-order correlator for contrast measurements, FROG for pulse shape studies.

INTRODUCTION

Complex laser–plasma interaction studies, such as development of laser wake-field accelerators [1-4], X-ray lasers, and laser fusion research require synchronized, multiple beams of high intensity light pulses. In most cases, it is also desirable, that these multiple beams have wildly different pulse durations, wavelengths, and pulse energies for various stages of plasma preparation, excitation, and diagnostics. In this report we describe the L'OASIS (Lasers, Optical Accelerators Integrated Studies) Laser Facility of LBNL, which facility has been specially designed for studying high field laser–plasma interactions and particularly aimed for the investigations of laser wake-field particle (electron, protons, ions) acceleration.

CHIRPED PULSE AMPLIFICATION LASER SYSTEM

The flowchart of the L'OASIS laser system is shown on Figure 1. The different shapes and colors on the chart represent different types of active (pumping, amplification), and passive (stretching, propagation, beam-expansion, delays, compression) elements. In the paragraphs below we describe these components in the order of increasing laser energy along the laser beam paths.

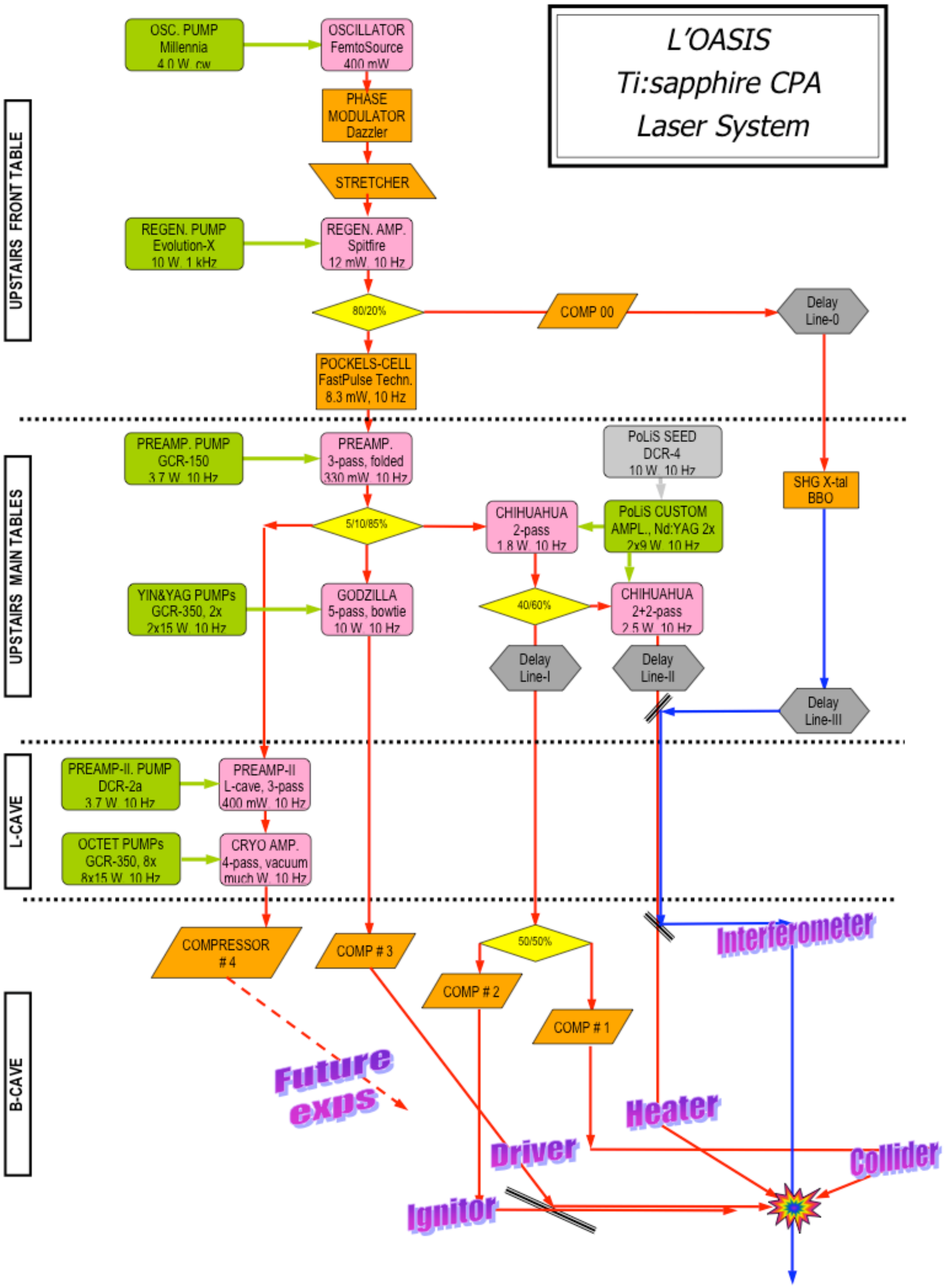

FIGURE 1. Flowchart of the L'OASIS Laser Facility.

Front End of the Laser Chain

The core element of the chirped pulse amplification (CPA), Ti:sapphire laser system is a Kerr-lens mode-locked, chirped-mirror compensated master oscillator (Femtolasers "Femtosource", 400 mW), pumped by 3.5 W cw power of a diode-pumped Nd:YVO laser (Spectra Physics "Millennia"). Femtosecond pulses from the oscillator are propagating through an acousto-optic spectral phase compensating device (FastLite "Dazzler") and lengthened to ~220 ps in a grating-based 4-pass optical stretcher. The stretched pulses are amplified in a regenerative amplifier (Positive Light "Spitfire", pumped by a Q-switched Nd:YLF laser - Positive Light "Evolution X") to ~ 1.2 mJ energy. About 20% of this output energy is compressed right here with the built-in pulse compressor of the Spitfire system and subsequently its optical frequency is doubled in a BBO crystal for plasma diagnostic purposes (see Table 1, row #5). The majority (~80%) of the output energy of the regenerative amplifier, after passing through a Pockels-cell pulse cleaner, is amplified further to about 40 mJ level in a 3-pass 'pre-amplifier', which is pumped by a 10 Hz, frequency doubled Nd:YAG laser (Spectra Physics "GCR-150"). The beam is split at this point toward three independent power amplifiers.

Power Amplifiers

The first power amplifier is pumped with two Nd:YAG lasers (Spectra Physics "GCR 350-PRO"), each providing about 15 W average pump power at 532 nm, at 10 Hz repetition rate. The 28 mm diameter, 25 mm long Ti:sapphire crystal is pumped from both sides, and is seeded by ~10% from the pre-amplified beam. After 5 passes the beam energy is ~1 J at 800 nm. This beam is then transported through an evacuated beam pipe into the vacuum chamber containing optical compressors in a radiation-shielded target cave. After compression, the main pulses are propagated into the target chamber, containing focusing off-axis parabolas and turning mirrors (Figure 2).

The second power amplifier is pumped by a custom-designed Nd:YAG amplifier system from Positive Light. The frequency doubled (532 nm) output of this pump laser provides 1 Joule energy per arm in two arms for two-side pumping of the 20 mm diameter Ti:sapphire crystal. The total 4-pass amplification is partially damped after the second pass, resulting a 1.8 W (partial 2nd pass output) and a 2.5 W (2+2 pass final output) average power beams. The former output is split again for separate compression in the target chambers, and the latter one is kept uncompressed, serving as a heater beam in plasma channel formation experiments.

The third power amplifier is currently under construction and aims at producing 100 TW pulses at a 10 Hz repetition rate (~3.5 J/pulse in ~35 fs duration pulses). This laser arm is using the third portion (~1 mJ) of the preamplifier as a seed for another 3-pass amplifier (called "preamp-II", identical in pumping and optical arrangement to the first pre-amplifier). Then, the 40 mJ output of this "preamp-II" is injected into a cryogenically cooled Ti:sapphire amplifier. This 4-pass amplifier, enclosed in a vacuum chamber, is pumped from two sides by eight Nd:YAG lasers (Spectra Physics "GCR 350-PRO"), each providing about 15 W average power at 532 nm. The amplified beam is propagated in vacuum tubes to the same radiation shielded experimental area for final compression with a grating based optical compressor. In addition to the flowchart of the system shown in Fig. 2, the key parameters of the various beam paths are summarized in Table 1.

TABLE 1. Laser beam parameters in the current laser wake-field accelerator setup

Amplifier	Purpose	Pulse energy	Pulse duration	Peak power	Average power
Main Power Amplifier	Wake-field Driver	550 mJ	46 fs	12 TW	5.5 W
Secondary Amp. 2nd pass/Comp#1	Collider Beam	50 mJ	50 fs	1 TW	0.5 W
Secondary Amp. 2nd pass/Comp#2	Plasma Igniter	50 mJ	50 fs	1 TW	0,5 W
Secondary Amp. 4th pass	Plasma Heater	250 mJ	220 ps	1.1 GW	2.5 W
Regen. Amp. partial output	Probe – blue interferometry	~30 μJ	50 fs	~0.6 GW	~0.3 mW
Cryo. Amp.(under construction)	Wake-field Driver & Solid Targets	3.5 J	35 fs	100 TW	35 W

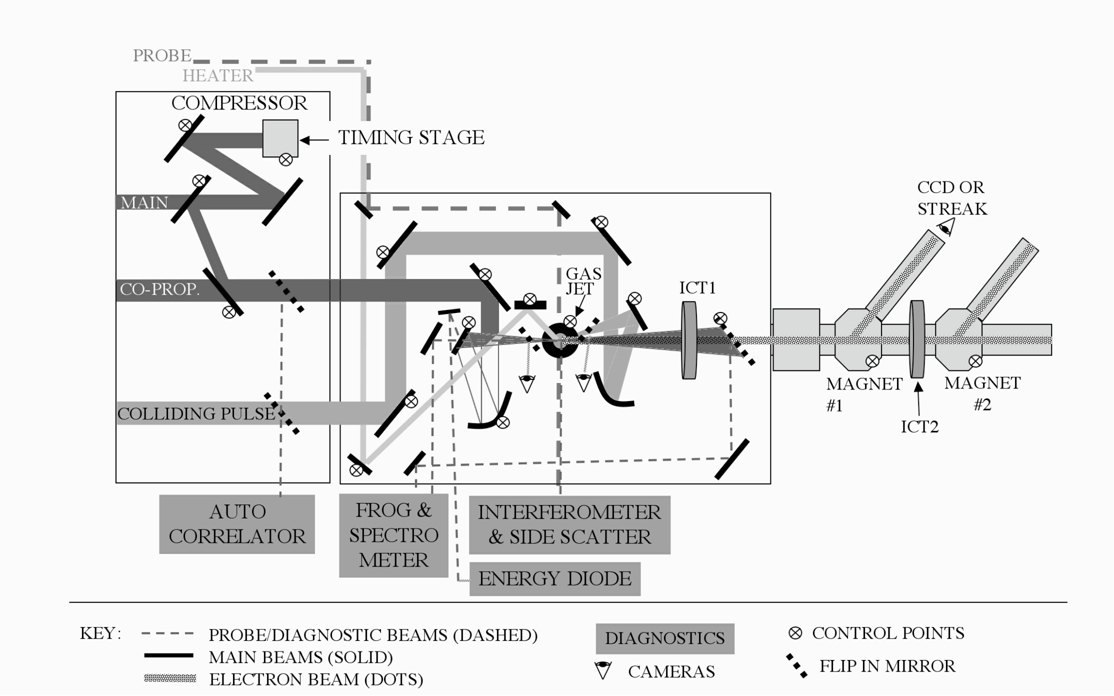

FIGURE 2. The 4-beam-excited interaction region and diagnostic setup of the L'OASIS laser wake-field accelerator.

Beam Diagnostics

The amplifier system is characterized and continuously monitored by a swarm of optical diagnostics, such as beam profile monitoring cameras, remote controlled alignment options, self-correcting pointing stabilization loops, pulse measurement tools including single-shot autocorrelator for pulse duration, third-order correlator for contrast measurements, and frequency resolved optical gating (FROG) setup for pulse shape studies. The system is fully controllable from a radiation shielded control room.

LASER WAKE-FIELD ELECTRON ACCELERATION EXPERIMENTS

The laser system described in the previous paragraphs has been successfully used in laser driven plasma acceleration experiments both in the single-beam regime for radioisotope production via gamma-neutron activation [3], for intense THz beam generation via laser-plasma accelerated electron bunch crossing a plasma-vacuum boundary [6], and in the multi-beam regime for high quality, quasi-monoenergetic electron beam production from a plasma-channel guided laser wake-field accelerator [7]. Details of these measurements can be found in other reports of the L'OASIS group in this Proceedings.

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