OMEGA EP high-energy petawatt laser: Progress and prospects

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Abstract. OMEGA EP (extended performance) is a petawatt-class addition to the existing 30-kJ, 60-beam OMEGA Laser Facility at the University of Rochester. It will enable high-energy picosecond backlighting of high-energy-density experiments and inertial confinement fusion implosions, the investigation of advanced-ignition experiments such as fast ignition, and the exploration of high-energy-density phenomena. The OMEGA EP short-pulse beams have the flexibility to be directed to either the existing OMEGA target chamber, or the new, auxiliary OMEGA EP target chamber for independent experiments. This paper will detail progress made towards activation, which is on schedule for completion in April 2008.

1. Introduction

OMEGA EP (extended performance) is a high-energy, short-pulse addition to the OMEGA Laser System at the University of Rochester’s Laboratory for Laser Energetics (LLE) [1,2]. OMEGA EP has five primary missions, each of which complement and extend LLE’s current research activities: to extend high-energy-density (HED) research capabilities with high-energy and high-brightness backlighting; to perform OMEGA-integrated advanced-ignition experiments [3]; to develop advanced backlighter techniques for HED physics; to provide a staging facility for the NIF to improve its effectiveness; and to conduct ultrahigh-intensity laser–matter interaction research.

The OMEGA EP Laser System is housed in a new laser bay, built adjacent to the OMEGA target bay. It consists of four beamlines, two of which possess high-energy, short-pulse capability. For widths of 10 to 100 ps, the on-target energy will be up to 2.6 kJ. At 1 ps, the system will produce 1 PW of optical power on target. The focal-spot size for the short-pulse beams is 80% of the energy in a 10-μm-radius spot. These short pulses can be directed into either the OMEGA target chamber or into a new, dedicated OMEGA EP target chamber.

In addition, all four beamlines will have an ultraviolet (UV), long-pulse (0.1 to 10 ns) capability. The long-pulse, on-target UV energies can reach 2.5 kJ per beam for 1-ns pulses and 6.5 kJ per beam for 10-ns pulses and will be available in the dedicated OMEGA EP target chamber only.
2. Activation progress

A schematic of the short-pulse front end, infrared (IR) beamline, and grating compression to target is shown in Fig. 1 [1]. A mode-locked laser produces 200-fs pulses that are stretched and amplified in an OPCPA system. The pulse is then fed into the IR beamline, where it passes through a booster amplifier on its way to the main amplifier. A deformable mirror (DM) reflects the pulse back through the main amplifier. The plasma-electrode Pockels cell (PEPC) is switched to trap the pulse for one more round trip through the cavity before the pulse returns through the booster amplifier. It then enters a four-grating compressor that recompresses the pulse to a picosecond-scale pulse width. Many of these technologies vary from those currently used on OMEGA and have benefited significantly from development at the National Ignition Facility (NIF) [4]; these technologies include the disk amplifiers [5], multipass beamline architecture [6], PEPC switches [7], and DM’s [8]. In addition, the high-energy, short-pulse mission has necessitated technological development in other areas such as short-pulse front-end design [9,10] and diffraction-grating tiling [11,12].

![Schematic of OMEGA EP short-pulse beamline](image)

**Figure 1.** (a) Schematic of an OMEGA EP short-pulse beamline. (b) Post-shot wavefront recovery of a beamline.

2.1 High-energy, high-repetition-rate broadband front end

The OPCPA front end for each beamline has been activated and produces high-energy (250-mJ), high-repetition-rate (5-Hz) frequency-chirped pulses with apodized, flat-top spatial profiles [9,10]; this configuration is required for short-pulse setup. For target shots, each OPCPA front end output profile is apodized to precompensate for the gain profile exhibited by the cavity and booster beamline amplifiers. The bandwidth of these stretched pulses is 8 nm, which is sufficient to support the formation of picosecond-scale pulses. An OPCPA front-end feeds each of the two short-pulse beam lines; in addition, an optional long-pulse generation scheme using optical modulators feeds each of the four beam lines. The long-pulse front-end systems have also been activated.

2.2 Disk amplifiers

Taking advantage of the development of continuous melting of large laser glass disks [5,13], OMEGA EP uses the same 40-cm-aperture, Brewster’s-angle LHG-8 disks as the NIF. To ease maintenance, enhance single-beam control, and relieve packaging constraints on other beamline components, LLE designed and built a modular single-segment, 40-cm amplifier. The amplifier power-conditioning units have been activated for all OMEGA EP beamlines. The booster and main amplifiers consist of end-to-end stacks of 7 and 11 disk amplifiers, respectively. An OMEGA-style water-cooling system was deployed for all flash lamps, and resulted in a wavefront recovery of ~20 min, as shown in Fig. 1(b), which is sufficient to support a 1-h shot cycle. Activation shots have also been taken to demonstrate an IR output of over 3 kJ from each beamline.
2.3 Deformable mirrors and wavefront control

OMEGA EP has activated one NIF-designed DM in each beamline to correct the largely thermally induced wavefront error from the disk amplifiers [8]. These DM’s are routinely used during activation operations using LLE-designed wavefront sensors and control algorithms. Figure 2 shows an example of (a) the wavefront-controlled wavefront, converged to a flat reference, (b) the wavefront-controlled wavefront, converged to a reference which precompensates for amplifier thermal effects, and (c) the resulting on-shot wavefront, exhibiting an rms wavefront gradient of 0.07 waves/cm.

![Image](image.png)

**Figure 2.** Beamline wavefront control during shot cycle. (a) Converged wavefront to flat reference, (b) converged to precompensating reference, and (c) on-shot wavefront.

2.4 PEPC switches

PEPC switches have been activated in all beamlines. These devices were designed not only to support multipass operation through the main beamline amplifier [7], but also to reject IR pulses that may be retroreflected from the target chamber in short-pulse operation. The PEPC is fired a second time at the arrival of the target retropulse. This pulse subsequently reflects off of a polarizer (POL2 in Fig. 1). Figure 3(a) shows a typical minimum PEPC contrast of 1000:1, which exceeds the minimum requirement of 500:1 for retroreflected pulses [14]. Figure 3(b) shows the temporal evolution of the transmission through parallel polarizers, indicating successful operation of double pulsing. A solid-state switch-pulse generator was developed for dual-pulse operation by LLNL and assembled and activated at LLE [15].

![Image](image.png)

**Figure 3.** (a) The typical minimum contrast of the deployed PEPC exceeds 1000:1 [The white area represents the beam-expansion optics used for a single measurement, before re-positioning to capture the whole field of view]; (b) double-pulse operation is used to suppress target retroreflections.

2.5 Grating compressor chamber integration activities

Work is continuing to integrate and activate the grating compression chamber (GCC). The OMEGA EP pulse compressor uses a four-grating design to compress the ~1-ns main beamline output to an on-
target duration of 1 to 100 ps. Each grating has a 400-×1400-mm clear aperture and is constructed from three precision-aligned subaperture grating tiles. A closed-loop interferometric tile-alignment scheme has been developed and tested offline with three full-aperture gratings [12] to produce a diffraction-limited focus. Each short-pulse beamline within the compressor chamber has been loaded with all gratings as well as a vacuum-compatible DM to compensate for grating wavefront error.

3. Prospects
The OMEGA EP Facility is on track for completion in April 2008. OMEGA EP will then commence its missions of high-energy and high-brightness backlighting, integrated fast-ignition experiments, development of advanced backlighting techniques for HED physics, and ultrahigh-intensity laser–matter-interaction experiments.

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