Ultra-high Intensity Laser Initiative at the University of Rochester's Laboratory for Laser Energetics

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The ability of the facility to contribute to world-leading science in the next decade (2014-2024)

The Laboratory for Laser Energetics (LLE) at the University of Rochester proposes to upgrade the OMEGA EP Laser System to add the capability to produce focused laser intensities of ~10^{24} W/cm^2 with multi-kJ, femtosecond laser pulses. The highest laser intensities currently available world-wide are ~10^{22} W/cm^2.[1]

The OMEGA EP Laser System is part of the Omega Laser Facility that is operated as a User Facility funded by the National Nuclear Security Administration (NNSA) to perform high energy density physics (HEDP) research to support the Stockpile Stewardship Program and Fundamental HEDP science. The scientific benefits of extending this high-intensity frontier were described in the high energy density (HED) ReNew report [2] and numerous other reports. [3, 4] At these intensities, proton motion is relativistic, leading to a new regime of intense-field–matter interactions.[5] Nonlinear quantum electrodynamics leads to nonlinearities in photon–photon and photon–plasma interactions as a result of the polarizability of the vacuum.[6] The European Union is currently developing the Extreme Light Infrastructure (ELI, http://www.extreme-light-infrastructure.eu/) at three facilities that will support new attosecond science, high-energy particle acceleration and secondary radiation, and laser-based nuclear physics using lasers with peak powers up to 10 PW. A 10-PW facility has been proposed but not funded at the Rutherford-Appleton Laboratory in the United Kingdom.[7]

The goal of the proposed upgrade to the OMEGA EP Laser System would be to produce 15-fs pulses with energies of 3 kJ leading to peak powers of ~200 PW and focused peak intensities of ~10^{24} W/cm^2. It would be used for a wide variety of fundamental science experiments including the generation of many-GeV electron and gamma beams and ion beams with energies up to, and perhaps exceeding 1 GeV. Extremely intense attosecond pulses could potentially be generated through high harmonic generation from solid targets. The potential exists to generate a wide range of electromagnetic radiation from THz through visible, x-ray and gamma radiation that will enable a wide range of pump-probe experiments that would extend the capabilities in many fields. New regimes of HED matter would be accessible due to the extreme energy density coupled to the target; at ~10^{24} W/cm^2 the energy density of electromagnetic radiation is 3x10^{19} J/cm^2 corresponding to a pressure of 3x10^8 Mbar. These focused intensities will allow access to new regimes of intense laser interactions with ions and molecules.

Facility Description

The proposed facility is an ultra-intense optical parametric chirped-pulse–amplification (OPCPA) system pumped by the existing OMEGA EP Laser System. The four long-pulse beamlines could provide a total of 12 kJ in 1.5ns at 526 nm for pumping optical parametric amplifiers using large deuterated potassium dihydrogen phosphate (DKDP) crystals to provide 190 nm of gain bandwidth centered at 910 nm.[8-11] After compression, 15-fs pulses with energies of 3 kJ would produce peak powers of ~200 PW and peak intensities of ~10^{24} W/cm^2. The pulse injected into the final amplification stage would be generated through multiple OPCPA stages, designed to produce a highly compressible and focusable pulse allowing the highest possible intensities to be achieved. LLE is currently developing a mid-scale, all-OPCPA system [12] pumped by a multi-terawatt (MTW) laser system that was recently upgraded to 100 J. [13] This optical parametric amplifier line (MTW-OPAL) will produce 15 fs, 7.5 J pulses using existing compression-grating technology and serves as a prototype front-end for the OMEGA EP-pumped system (EP-OPAL).

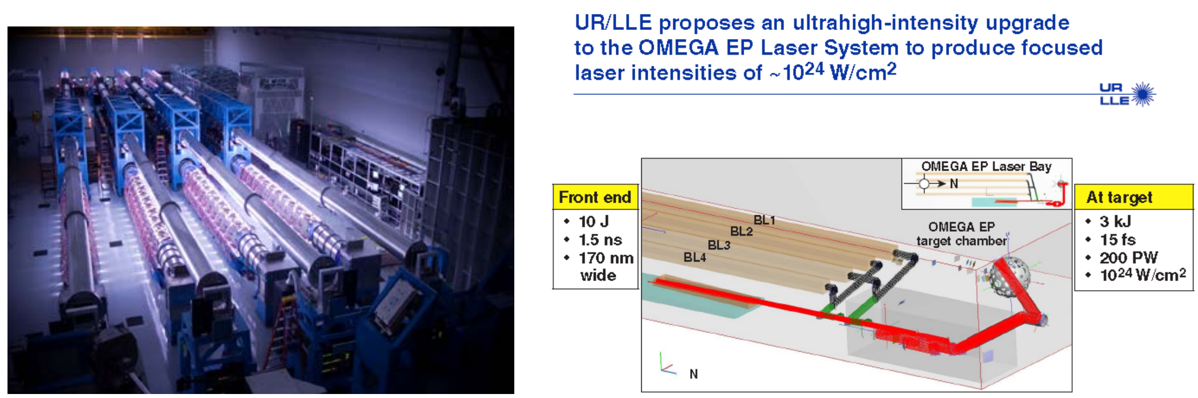

Figure 1 showing the four-beam OMEGA EP laser system firing and a schematic of how the beams would be rerouted to pump an OPCPA ultrahigh intensity laser (a fifth OMEGA EP beamline.

Scientific community considerations

LLE has a long and successful history of building large laser systems, completing them on schedule and on budget. They are subsequently operated as productive user facilities. The Omega Laser Facility consists of the OMEGA Laser System completed in 1995 [14] and the OMEGA EP Laser System completed in 2008. [15] The Omega Laser Facility is operated as a User Facility for NNSA with more than 60% of the shots performed for Principal Investigators from institutions other than the University of Rochester. Access to shot time for fundamental HED science is granted through the peer-reviewed National Laser Users' Facility (NLUF) and Laboratory Basic Science (LBS) programs (for more information, see www.lle.rochester.edu). The Omega Laser Users Group (OLUG) was founded in 2008 and has more than 300 members (http://www.lle.rochester.edu/about/omega_laser_users_group.php). It operates independently of LLE. The University of Rochester hosts the OFES-funded Fusion Science Center for Extreme States of Matter.

The readiness of the facility for construction

Grade b: some technical challenges need to be overcome

The main technical challenge is to develop gratings for pulse compression that provide sufficiently high damage thresholds at the broad bandwidths required to support the 15 fs pulses. The other technical issues should be resolved with the completion of the MTW-OPAL laser system described above. The desired development would be to produce single gratings large enough to compress the full pulse energy. Two alternate approaches to mitigate this risk might be possible: compressing and coherently combining a 4x4 array of beams or plasma amplification/compression.

Cost estimates

The estimated cost of this upgrade is $50-$100 million with major costs attributed to diffraction grating development and procurement, a new vacuum chamber and opto-mechanics for the grating compressor, large DKDP crystals for frequency doubling the OMEGA EP beams and the high-energy OPCPA, a new beam-transport-and-focusing system, and new laser diagnostic systems.

A major advantage of siting this capability at LLE is that existing infrastructure is operational and carries no cost, schedule, or performance risk to the project. The four NIF-like OMEGA EP beams, available space in the OMEGA EP laser bay, the laser-target interaction chamber and experimental infrastructure all represent direct value to this new project. These items are part of the OMEGA EP system that was completed in 2009 at a total project cost of $120.5 million, including $99.5 million for the laser system and $21 million for the building. The complex timing, alignment, and device control infrastructure is readily expandable to operate the new capability. The cost is significantly less than that estimated for the comparable part of European ELI system. Each of the three ELI systems is estimated to cost approximately $350 million. The significantly reduced cost (and higher performance) are possible because the high-energy pump laser (OMEGA EP) and the building exist. There is sufficient space in the OMEGA EP laser bay to house this ultra-high intensity beamline.

It is estimated that it would take five years from project approval to the system being available for Users. This is based on experience building the OMEGA EP Laser System. The conceptual design and cost refinement for the proposed future facility could proceed in parallel with development of the enabling technologies that will be demonstrated by the MTW-OPAL system. Acquisition, construction, activation, and operation phases are contingent on successful completion of the MTW OPAL project and progress towards mitigating the technical risk.

The annual operating costs for the EP-OPAL system are estimated to be between $5 and $15 million (FY13 dollars). The range depends upon what fraction of the OMEGA EP Laser System time is devoted to operating the EP-OPAL system.

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