OMEGA EP OPAL: A Path to a 75-PW Laser System

Ultra-broadband front end (NOPA1 to 4)

0.25 J, 2.5 ns, 160 nm

OMEGA EP
Beamline 4
6.3 kJ
2.5 ns

Beamline 3
6.3 kJ
2.5 ns

Beamline 2
ps (IR) + ns (UV) pulses to EP TC

Beamline 1

Noncollinear optical parametric amplifier

EP-OPAL beamline OPCPA in DKDP

OMEGA EP target chamber (EP TC)

1.6 kJ, 20 fs

~75 PW or ~10^24 W/cm^2

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The Laboratory for Laser Energetics (LLE) is exploring the possibility of using OMEGA EP to pump an ultrahigh-intensity \((10^{24} \text{ W/cm}^2)\) laser beamline

- Optical parametric chirped-pulse amplification (OPCPA)* makes it possible for solid-state lasers to pump ultrahigh-intensity lasers (tens of fs)
- Two OMEGA EP beams could be used to produce a 1.6-kJ, 20-fs (75-PW) OPCPA beamline—EP-OPAL (optical parametric amplifier line)
  - the two remaining beams would be available as ps or ns beams for target conditioning and pump–probe experiments
- EP-OPAL would extend the high-intensity frontier by two orders of magnitude

EP-OPAL’s combination of high-energy fs, ps, and ns beams would provide a unique research environment.

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Collaborators


University of Rochester
Laboratory for Laser Energetics
An ultra-intense OPCPA extension to OMEGA EP would reach focused intensities approaching $10^{24}$ W/cm$^2$.

This laser would be a world-class tool for fundamental science at new intensity regimes.
Noncollinear optical parametric amplifiers (NOPA’s) use a three-wave process

- Energy conservation:
  \[ \hbar \omega_P \rightarrow \hbar \omega_S + \hbar \omega_I \]

- Momentum conservation: (use crystal birefringence)
  \[ \hbar \mathbf{k}_P \rightarrow \hbar \mathbf{k}_S + \hbar \mathbf{k}_I \]  
  “phase matching”
The OMEGA EP Laser System could be used to pump a 75-PW, 20-fs OPCPA beamline: EP-OPAL

Ultra-broadband front end (NOPA1 to 4)

NOPA5 pump

100-J KDP

6.3 kJ
2.5 ns

EP-OPAL beamline OPCPA in DKDP

6.3 kJ
1.25 kJ

2.5 ns

25 J

2.5 kJ

1.6 kJ, 20 fs

~75 PW
or
~10^{24} W/cm^2

Two OMEGA EP beamlines would be used, leaving two ns/ps beamlines for pump–probe and other experiments.
There is room in the OMEGA EP Laser Bay for EP-OPAL

- There are technical challenges
  - gratings: size and damage
  - large KDP crystals
  - fs optics damage threshold
  - dispersion management

- LLE is developing a 7-J, 15-fs beamline to address these challenges

Existing technologies would allow for 10 PW.
EP-OPAL will use a two-element focusing system to provide experimental flexibility

- $f/4.6$ off-axis parabola outside the target chamber
- Elliptical plasma mirror inside the target chamber*
  - part of the experimental design/target
  - disposable
  - could be concave or convex to tune the $f/#$

EP-OPAL will provide a variety of beams for high-energy-density-physics research

• EP-OPAL should be able to generate a wide array of photon/particle beams, many with unprecedented fluences
  – THz
  – intense x rays up 100 keV
  – gamma ray
  – >10-GeV electron beams
  – multi-GeV proton beams (and other ions)

• The two remaining OMEGA EP beamlines can provide
  – 1- to 10-ns UV beams with up to 6.5 kJ
  – 1- to 100-ns IR beams with up to 2.5 kJ
EP-OPAL should extend K-shell extended x-ray absorption fine structure (EXAFS) measurements to high-Z materials

- Implosion-based continuum EXAFS sources* are not available above \( \sim 20 \) keV
  - researchers are developing more complicated L-shell EXAFS**
- Betatron sources show promise to produce tens of keV quasi-continuum x-ray sources†
- A spatially coherent quasi-continuum 10-keV x-ray source with a 2-J, 30-fs laser was recently demonstrated‡

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‡S. Kneip et al., Nat. Phys. 6, 980 (2010).
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EXAFS is modulations in x-ray absorption caused by interference of the ejected electron wave function with reflections from neighboring atoms.

\[ \hbar^2 k_e^2 / 2m = E_{ph} - E_K, \text{ phase is } k_e R \]

- If the two electron waves are
  - in phase: maximum absorption
  - out of phase: minimum absorption