The Explosion of Intense Laser Activities Around the World and Related PW Activities at LLNL

10th DOE Laser Safety Workshop
Lawrence Livermore National Laboratory
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Opportunities at $> 10^{23}$ W/cm$^2$

- $3.3 \times 10^{12}$ J/cm$^3 = 600$ TonsTNT/cm$^3 = 33$ TBar photon pressure
- 10-GeV unguided laser plasma accelerators — table top x-ray FELS
- Relativistic proton and muon interactions — compact hadron therapy
- Ultrafast ionization — complete ionization through Zinc — U$^{82+}$ and Pu$^{85+}$
- Cluster fusion — fusion materials lifetime testing
- Multi-GeV quiver energy and nuclear excitations
- $e^+/e^-, p^+/p^-$, pion production
- Relativistic vacuum nonlinear optics — blue photons from “nothing”!
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2004 Feb - ICUIL Kickoff Meeting (10 laser lab members, 6 user community members)
About ICUIL

Objectives
The International Committee on Ultra-High Intensity Lasers (ICUIL) is an organization concerned with international aspects of ultra-high intensity laser science, technology and education.

History
Charter
Committee

The objectives of ICUIL

- To provide a venue for discussions among representatives of high-intensity laser facilities and members of user communities, on international collaborative activities such as the development of the next generation of ultrahigh intensity lasers, exploration of new areas of fundamental and applied research, and formation of a global research network for access to advanced facilities by users.
- To promote unity and coherence in the field by convening conferences and workshops dedicated to ultrahigh intensity lasers and their applications.
- To accelerate progress in the field by sharing information, exploring opportunities for joint procurement, and exchanging equipment, ideas and personnel among laser laboratories world-wide.
- To attract students to high-field science by promoting their education and training, their interactions with prominent scientists, and access to the latest equipment, results and techniques.
- To strengthen and exploit synergy with other relevant fields and techniques, notably accelerator-based free electron lasers.
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Biennial International Conference on Ultrahigh Intensity Lasers

ICUIL 2010 Watkins Glen
ICUIL 2012 Mamaia
ICUIL 2008 Tongli
ICUIL 2004 Lake Tahoe
ICUIL 2006 Cassis
ICUIL 2014 Goa
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ICUIL World Map Starting Points

Reflect worldwide activity in the “ultrahigh intensity” lasers & apps

Include all existing & planned “ultrahigh intensity” facilities
ICUIL Definition of “Ultrahigh Intensity”

‘ultrahigh’ intensity = any laser with focal capability within 3 orders of the published intensity record

currently

$10^{19}$ W/cm$^2$ or ~10 TW or greater
2009 ICUIL World Map of Ultrahigh Intensity Laser Capabilities

Labels represent the establishments with physical and administrative responsibility for the ultrahigh intensity laser system or facility
### Update to ICUIL World Map

- **130 individuals poled**
- **100+ responses**
- **100+ ppt, pdf and jpeg files sent**
- **300+ pages of info and pictures received**
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- These estimates did not include MJ systems or planned Exawatt-scale projects
It started in 1985 with the invention of chirped pulse amplification.
1987 - Stanford University

Stanford

6 J, 0.6 TW

Milton Roy 1200 gr/mm gratings
>300 mJ/cm²
1989 - Institute for Laser Engineering @ Osaka University

ILE-j

30 J, 30 TW
1996 - Lawrence Livermore National Laboratory

600 J, > 1PW

LLNL
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600 J, > 1PW

LLNL
Today - Rutherford Appleton Laboratory
Today - Atomic Weapons Establishment
Today - GSI Germany
Today - UT Austin Texas PW
Today - Omega EP at LLE
Tomorrow - “ARC” 10 kJ in 10 ps at the NIF
The Advanced Radiographic Capability (ARC) will produce eight Petawatt-class laser pulses from 4 NIF beamlines.

- Two beamlets per beam line
- Pulse durations from 1-50 ps with adjustable inter- and intra-beam delays
ARC high energy backlighting capability is required for the high energy density science & ICF programs.

Planned NIF experiments will use ARC to produce backlighters at energies up to 100 keV.
The capsule starts at 2mm diameter
Re-emission sphere measures early time x-drive symmetry

Bang time – 19 ns

1 billionth of a second into the laser pulse
Radiography measures the shape of the capsule in-flight

N121004
Bang time – 600 ps

~ 2 mm diameter
Radiography measures the shape of the capsule in-flight

N121004
Bang time – 300 ps

~ 2 mm diameter

Early hot spot formation
Compton radiography probes fuel shape at stagnation

N121005
Bang time

150 µm

~ 2 mm diameter
Point projection high energy (>75keV) radiography is ideally suited to probe fuel shape and uniformity.

- Compton radiography is sensitive to $n_e$ (not $Z$): ideal for probing DT fuel shape and density uniformity inside ablator.

- Allows broadband operation as Compton cross section that dominates at high energy is weakly dependent on photon energy.

- Radiography source is independently timed, in contrast to burn products.

- Would require up to 60 long pulse beam lines to do the same job!
Each ARC beamlet uses chirped-pulse amplification to produce ps-timescale, laser pulses w/ > kJ energy.

**NIF master oscillator room**
- Short Pulse Oscillator
- CFBG stretcher
- Dispersion Tweaker

**NIF Laser Bay**

**NIF target bay**
- Compact, high efficiency, pulse compressor

5.5 m
Conversion of NIF beam lines to high-intensity, picosecond operation requires 4 top level changes:

1. New short pulse fiber front-end with stretcher and pulse width control
2. Broadband preamplifier and split-beam injection system
3. Pulse compression in the NIF Target Bay and final focusing optics
4. Improved amplifier isolation for backscatter protection
ARC requires a new master oscillator to propagate wide bandwidth pulses through NIF
ARC injection laser hardware amplifies and injects the master osc. room pulse into the NIF main laser.

- Modified PAM MPA
- 2.6 m PABTS Trombones
- Dual Regen Table & Supporting Electronics Rack
- ARC Split-Beam Injection System
The ARC injection laser system has been performance tested in the ARC testbed facility.
The ARC Injection Laser System (ILS) is installed and commissioned on the NIF.
Pulse compression of 40-cm wide beams would require ~2 m gratings.
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Tiling must be done “coherently” to avoid cross talk issues.
The NIF beam is split prior to amplification to avoid cross talk & the need to coherently “tile” gratings.

Two independent pulse compressors with double the outputs for back lighting.
The NIF beam is split prior to amplification to avoid cross talk & the need to coherently “tile” gratings.

However the gap between the beams corresponds to an unwanted loss of energy.
To avoid cross talk & the need to coherently “tile” gratings, the NIF beam is split prior to amplification.

Beamlet energy is increased by slight modification of the left & right grating pairs.
All beam path and vacuum vessels have been installed for pick-off mirrors, compressor gratings and final optics.
Damage test data of ARC multi-layer dielectric grating samples supports >1.5 kJ per beamlet.
In-house MLD grating fabrication is complete 81cm x 45cm & 91cm x 45cm by 10cm thick Average diffraction efficiency 96.8%
World’s largest holographic exposure station has been operational at LLNL w/ 1100mm diameter optics since 1997
World’s largest ion beam etch machine has been operational at LLNL since 2003 and is capable of handling 2m x 1m optics.
Installation of the ARC compressor gratings is complete for the first compressor vessel.
Volatile organic compound (VOC) cleanliness is extremely important.

<table>
<thead>
<tr>
<th>Vacuum system</th>
<th>Witness transmission change after 5 days exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLNL Grating manufacturing facility</td>
<td>~0.01% (detection limit)</td>
</tr>
<tr>
<td>ARC compressor vessel 1</td>
<td>0.1%</td>
</tr>
<tr>
<td>ARC compressor vessel 2</td>
<td>0.1%</td>
</tr>
<tr>
<td>NIF target chamber</td>
<td>0.1%</td>
</tr>
<tr>
<td>Facility 1 (US)</td>
<td>2.4%</td>
</tr>
<tr>
<td>Facility 2 (US)</td>
<td>0.6%</td>
</tr>
<tr>
<td>Facility 3 (US)</td>
<td>2.1%</td>
</tr>
<tr>
<td>Facility 4 (Europe)</td>
<td>1.7%</td>
</tr>
</tbody>
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Present ICUIL World Map - Nd:Glass
Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities
Present ICUIL World Map - Ti:sapphire Systems
The Early Days of Ti:sapphire

- >100 fs, kHz, 1991
- 30 fs, 3 TW, 1993
- 18 fs, 50 TW, 1997
Japan’s $600M Kansai Photon Science Institute created the 1st PW-scale fs system
S. Korea has invested ~$0.5B to create a multi-beam line, PW laser user facility
Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

LBNL’s BELLA 1 Hz, 1 PW laser system for laser-based particle acceleration
Present ICUIL World Map of Ultrahigh Intensity Laser Capabilities

800M euros will be invested in the Extreme Light Infrastructure Project in Europe
E23 HAPLS* will be integrated into the “ELI Beamlines” facility in Czech Republic

L1: kHz rep-rated ultrashort pulses laser systems
L2: Repetition-rate petawatt beamline
L3: Repetition-rate high energy petawatt beamlines
L4: 10-PW beamline for high-field experiments

* High Repetition-rate Advanced Petawatt Laser System
E23 builds on our expertise in high power and high-energy laser systems.
The E23 Laser System contains two major subsystems.
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Pump Laser System (high energy, high rep-rate)
Mercury Laser at LLNL
• 50 W/cm²
• Scalable architecture
• 0.3 M shots to date

- Up to 617 W achieved
- 0.3 Million shots to date in consecutive 0.5 - 2 hr operations
The E23 Laser System contains two major subsystems

Short-pulse System (short pulse, high rep-rate)
10 Hz operation enables real time feedback for dispersive and spatial control of petawatt pulses

A diffraction-limited PW laser can produce intensities in excess of $10^{23}$ W/cm²
The ELI-Nuclear Physics facility has funded construction of 2, 10PW laser systems
The Tata Institute is considering systems beyond 10 PW for its Hyderabad facility.
Concepts for Exawatt capability at large facilities are being formulated
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Present Performance:
- 10 Peta Watt, 30 µm spot, 10^21 W/cm^2
- Ultra Broadband Amplification: 1 ps → 10 fs (3 Optical Cycles)
- Wavefront correction
- Coherent adding
- Plasma Mirror
- All together result in >10^27 W/cm^2
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If you wish to see more of world of ultrahigh intensity lasers, visit www.icuil.org and explore the “interactive” world map.