LFEX-Laser
A Multi-Kilojoule, Multi-Petawatt Heating Laser for Fast Ignition

and Plasma Exp. Group

Institute of Laser Engineering, Osaka University
1. A view of the whole LFEX system

2. Key technologies of LFEX
   2-1 Large aperture dielectric grating for kJ, ps pulses in a pulse compressor
   2-2 Deformable Mirror for wavefront compensation
   2-3 Novel pulse cleaner for high intensity contrast

3. Summary
Implosion
by
multiple beams

Fast heating
by
Intense laser

Ignition
and
burn

Implosion
by
multiple beams

Fast heating
by
Intense laser

Ignition
and
burn

Gekko XII

LFEX

For >5-keV heating of dense fuel,

ps-Laser
4 beams
10 kJ
1~20 ps
0.5~10 PW

ns-Laser
12 beams
6 kJ (2ω)
2.4 kJ (3ω)
1~10 ns
PW lasers in the world

![Graph showing peak power (PW) vs pulse energy (J) for Ti:sapphire and Nd:glass lasers.]

- **Ti:sapphire**: Astra-Gemini, IOP CAS, J-KAREN, SIOM, GIST
- **Nd:glass**: Astra-Gemini, IOP CAS, J-KAREN, SIOM, GIST, TX-PW, OMEGA-EP, Vulcan, Orion, Z-Petawatt (Nova)
How can we generate PW peak power?

Seed pulse

Amplifier

High electric field of a laser damages optics, which are used in the amp.

Chirp Pulse Amplification (CPA)

Osc.

Pulse Strecher

Amplifier

Pulse Compressor

$\Delta t \sim x 10^3 \sim 10^5$

PW with kJ

High electric field of a laser damages optics, which are used in the amp.
Block diagram of the LFEX system

**Main Amplifier**
- 3-stage OPCPAs
- ~ 40 mJ
- Spatial Light Modulator
- Pulse Stretcher
- ML Fiber Osc.
- 100 fs, 1 nJ

**Image Relay**
- Double Rod Amps
- ~ 10 J/beam
- Beam Divider
- 4-pass Rod Amp.
- ~ 10 J

**Compressor**
- ~ 2.5 kJ/beam
- 1 ps
- X 4

For >5-keV heating of dense fuel,

**LFEX spec.**
- Wavelength: 1053 nm
- Pulse energy: 10 kJ
- Pulse width: 1-20 ps
- Peak Power: 0.5~10 PW
- Pulse Intensity: >10^{20} W/cm^2 (on target)
- Pulse Contrast: <10^{-11}
- Focal spot: 20-30 μm

High power shots are available now!!
1) Monochromatic (ns) > 3 kJ/beam
2) Chirped pulse (ns before compression) ~ 3 kJ/beam
3) Compressed pulse (ps): 2 kJ (4 beams)
   - 1 ps (shortest)
   - 2 PW (Maximum)
   For >5 keV heating of dense fuel, LFEX spec.
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   ~ 2.5 kJ/beam
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As for novel technologies, the following are important:

- Large-aperture Dielectric Grating
- Large-aperture Deformable Mirror
- Novel Pulse Cleaner
- Double Rod Amps
- Main Amplifier
- Image Relay
- Beam Divider
- 3-stage OPCPAs
- 4-pass Rod Amp
- Spatial Light Modulator
- Pulse Stretcher
- ML Fiber Osc.
Key Technologies

Main Amplifier

3-stage OPCPAs

4-pass Rod Amp

Double Rod Amps

Beam Divider

Spatial Light Modulator

Pulse Stretcher

ML Fiber Osc.

Image Relay

Large-aperture Deformable Mirror

Novel Pulse Cleaner

Large-aperture Dielectric Grating

High power shots are available now!!

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2) Chirped pulse (ns before compression) ~ 3 kJ / beam

3) Compressed pulse (ps) 2 kJ (4 beams)

1 ps (shortest)

2 PW (Maximum)

Large-aperture

Deformable Mirror

Novel Pulse Cleaner

Large-aperture Dielectric Grating
High power shots are available now!!

1. Monochromatic (ns) > 3 kJ/beam
2. Chirped pulse (ns before compression) ~ 3 kJ/beam
3. Compressed pulse (ps) 2 kJ (4 beams)

~ 1 ps (shortest)

2 PW (Maximum)

Pulse energy
E = 2.5 kJ/beam

Damage threshold
U_{th} \sim 0.2 \text{ J/cm}^2 \text{ (Au)}
2 \text{ J/cm}^2 \text{ (Dielectric)}

Minimum cross section
S = 5000 \text{ cm}^2
1250 \text{ cm}^2

Not Existed Yet!
All large aperture dielectric gratings are fully installed.

The world’s largest dielectric gratings

**Difficulties**
- Dielectric coating on large aperture silica glass
- Extremely precise grooving (0.05ppm)
Development & manufacturing system of large-aperture, high performance dielectric gratings

**Japan**
- Quartz material (Tosoh Co.)
- Grating blank
- Polishing
- Wavefront Inspection

**ILE, Osaka Univ.**

**U.S.**
- Wavefront Inspection
- Cleaning
- Ion Etching
- Scanning Exposure (1.3-m stage)

**2m-size Coating machine**
- Dielectric coating
- Resist coating

**Okamoto Optics Works (Yokohama)**

**Development & manufacturing system of large-aperture, high performance dielectric gratings**
The pulse energy is limited below 500 J/beam because of optical damage of mirrors.

\[ \downarrow \]

2 kJ with 4 beams

Pulse energy

Pulse width

(Single Shot Auto-Collimator)

2kJ, 1 ps, 2 PW
LFEX is the highest peak-power laser in kilojoule Pulse Energy (J).
Key Technologies

Main Amplifier

3-stage OPCPAs
ML Fiber
Osc.

Pulse Stretcher
Spatial Light Modulator
ML Fiber Osc.

4-pass Rod Amp.

Double Rod Amps
Beam Divider

Image Relay

Deformable Mirror

Target Chamber

Compressor

4-pass Rod Amp.

3-stage OPCPAs

Pulse Cleaner

Pulse compressor with large aperture dielectric gratings
Wavefront compensation with Deformable Mirror

1. Monochromatic (ns) > 3 kJ/beam
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3. Compressed pulse (ps) 2 kJ (4 beams)
   - 1 ps (shortest)
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Normal Mirror

Defomable Mirror (DFM)

Distorted Wavefront

Mirror

Distorted Wavefront

DFM

Wavefront Compensation!!
Active pre-compensation with large-aperture DFM

Major cause of phase aberration

w/o DFM

Wavefront

0.54\mu m rms

w. DFM

Wavefront

0.11\mu m rms

DFM75

DFM125

High focusability

5% @5\lambda
35% @5\lambda
High power shots are available now!!

1) Monochromatic (ns) > 3 kJ / beam
2) Chirped pulse (ns before compression) ~ 3 kJ / beam
3) Compressed pulse (ps) 2 kJ (4 beams)
   1 ps (shortest)
   2 PW (Maximum)

Pulse compressor with large aperture dielectric gratings
Main Pulse

AOPF (Amplified Optical Parametric Fluorescence)

Pre-Plasma Production

Target

\[
\frac{I_{\text{AOPF}}}{I_{\text{main}}} = \text{Intensity Contrast}
\]

Pulse Intensity (on target) : \(>10^{20}\) W/cm\(^2\)
Laser intensity to generate plasma : \(~10^9\) W/cm\(^2\)
Required Intensity Contrast : \(<10^{-11}\)
Saturable absorber as pulse cleaner

General

Main Pulse

AOPF

SA (Cr⁴⁺:YAG)

Pre-Plasma Production

Compressed Main Pulse

Residual AOPF

CPA

Chirped Main Pulse

AOPF

Pulse Compression
Original Spectrally Resolved Pulse Cleaner

Chirped Main Pulse

2~3 ns

AOPF

~20 ps

Transmission Grating

Lens

Saturable Absorber (Cr$^{4+}$:YAG)

Lens

Transmission Grating

4-f non-dispersive optical layout
Pulse intensity contrast after OPCPA

High contrast is successfully achieved for plasma experiments.
Key technologies

- Large aperture dielectric gratings has been developed for kJ, ps pulse compressor.
- Large aperture deformable mirrors has been successfully pre-compensated the wavefront distortion to improve focusability.
- Our original pulse cleaner improved the intensity contrast.

As a result,

The world’s highest peak-power laser in kilojoule, LFEX has been successfully demonstrated.

1. Pulse energy : < 500J / beam (due to mirror damage after compression)
2. Pulse duration: 1~2ps (observed with single-shot auto-correlator)
3. Peak Power : ~ 2 PW
4. Pulse contrast : <10^{-10} (@ -170ps by using our new pulse cleaners)

In future,

Pulse energy will be increased for fast ignition demonstration by improving filling factor and so on,
Large aperture grating with high optical strength is necessary to kJ pulse energy.
Pulse compressor and focusing optics

Sensor - 3
Sensor - 1

105cm × 85cm

Target Chamber

Focusin Optic

Beam transport

Output from amplifier

1x4

2x2

Lens

Grating 1

Grating 2

Monitor 1

Monitor 3

Off axis parabola mirror

SM 1

SM 2

M 1

M 2

M 3

M 4

M 5

M 6

M 7

M 8

M 9

M 10

BS3

OAP

GXII

途中大幅設計変更

・ LLNLとの共同研究

連携企業：三菱電機通信機製作所

・ 途中大幅設計変更

・ LLNLとの共同研究

連携企業：三菱電機通信機製作所
Irradiation to metal target with high energy pulses


No pre-plasma at 140ps before the main pulse
Electron temperature in plasma

2013 before cool REB

2014 after cool REB

Arikawa et al.,

Reducing electron temperature

Electron temperature in plasma w/o pulse cleaners

Electron temperature in plasma w pulse cleaners

Electron number (MeV)

Energy (MeV)

Energy (MeV)
Scaling of proton energy with PW laser

Our experimental results are higher than the prediction of TNSA model. Proton energy increases with the pulse duration on a fixed intensity.

The results were well scaled by TNSA model involving adiabatic cooling and 3D effect that weaken the ion energy.

ExperimentsWeak focusing, High contrast
$t_L = 1.5$ ps
$t_L = 3$ ps
$t_L = 6$ ps

High-contrast pulse
Large focal spot
LFEX (present)

Target: Al, $5 \, \mu$m

Low-contrast pulse
Small focal spot

Scaling of proton energy with PW laser

Our experimental results are higher than the prediction of TNSA model. Proton energy increases with the pulse duration on a fixed intensity.

The results were well scaled by TNSA model involving adiabatic cooling and 3D effect that weaken the ion energy.
Plasma Enthusiasts


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