“J-KAREN-P” 超高強度レーザー

光・量子ビーム科学合同シンポジウム 2018
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✓ Introduction
  - Capabilities of J-KAREN-P facility
  - Optical architecture

✓ Status and implementation of J-KAREN-P facility
  - Amplification performance
  - Recompression performance

✓ Summary
Ultra-high intensity lasers generate secondary sources with applications in basic science and industry

## Upgrade from J-KAREN to J-KAREN-P

<table>
<thead>
<tr>
<th></th>
<th>J-KAREN</th>
<th>J-KAREN-P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power on target [PW]</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>1 shot every 30 min.</td>
<td>0.1 Hz</td>
</tr>
<tr>
<td>Temporal contrast</td>
<td>$10^{-11}$</td>
<td>$10^{-12}$</td>
</tr>
<tr>
<td>Peak intensity on target [W/cm²]</td>
<td>$10^{21}$</td>
<td>$10^{22}$</td>
</tr>
</tbody>
</table>

## Important parameters to keep in mind for high field lasers

<table>
<thead>
<tr>
<th>Affiliation</th>
<th>Laser</th>
<th>Intensity [W/cm²]</th>
<th>Temporal contrast at -50ps (energy levels)</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan U.</td>
<td>Hercules</td>
<td>$2 \times 10^{22}$</td>
<td>$10^{-11}$ (?)</td>
<td>N. A. (Cal.)</td>
</tr>
<tr>
<td>IOP</td>
<td>XL-III</td>
<td>$\sim 5 \times 10^{21}$</td>
<td>$10^{-11}$ (@mJ)</td>
<td>○</td>
</tr>
<tr>
<td>Dresden</td>
<td>Draco</td>
<td>$\sim 5 \times 10^{21}$</td>
<td>$10^{-10}$ (@J) ⇒ $10^{-12}$ with PM</td>
<td>○</td>
</tr>
<tr>
<td>KPSI, QST</td>
<td>J-KAREN-P</td>
<td>$10^{22}$</td>
<td>$10^{-12}$ (@J)</td>
<td>○</td>
</tr>
<tr>
<td>IBS</td>
<td>UQBF</td>
<td>$\sim 5 \times 10^{22}$</td>
<td>$10^{-10}$ (@J) ⇒ $10^{-14}$ with PM</td>
<td>in 2018</td>
</tr>
<tr>
<td>LULI</td>
<td>Apollon-10P</td>
<td>$2 \times 10^{22}$</td>
<td>$10^{-11}$</td>
<td>2019</td>
</tr>
<tr>
<td>ELI</td>
<td></td>
<td>$10^{22} \sim 10^{23}$</td>
<td>$10^{-9}$</td>
<td>2019</td>
</tr>
<tr>
<td>SIOM</td>
<td>SULF</td>
<td>$10^{22} \sim 10^{23}$</td>
<td>$10^{-11}$</td>
<td>2019</td>
</tr>
</tbody>
</table>

Fundamental processes of laser-matter interaction at $10^{22}$ W/cm² intensities belong to an absolutely new branch of science that is the principal research task of our J-KAREN-P facility.
J-KAREN-P is in healthy operation
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“J-KAREN-P” laser schematic

Japan Kansai Advanced Relativistic Engineering Petawatt laser system

First CPA

Nd:YAG pump laser ~0.1 J, 10 Hz

E=~5 mJ

OPCPA preamplifier

AOPDF ~10 µJ

Stretcher ~ns

Saturable absorber (SA)

Ti:sapphire oscillator + preamplifier

First CPA

Nd:YAG pump laser
~0.7 J, 10 Hz

E=~45 mJ

cryogenic-cooled Ti:sapphire power amplifier

Ti:sapphire preamplifier

Nd:YAG pump laser
~5.5 J, 10 Hz

E=~2 J

Second CPA

Nd:glass pump laser
~45 J, 0.1 Hz

E=~25 J

Ti:sapphire booster amplifier-1 (BA1)

Nd:glass pump laser
~90 J, 0.1 Hz

E=~60 J

Ti:sapphire booster amplifier-2 (BA2)

Compressor ~70 %, ~30 fs

Deformable mirror

~PW (~40 J / ~30 fs)
Current view of the J-KAREN-P laser system

- Ti:sapphire oscillator + preamplifier
- OPCPA preamplifier
- Ti: sapphire preamplifier
- Cryogenic-cooled Ti:sap. power amplifier (~2 J, 10 Hz)
- Ti: sap. booster amplifier-1 (BA1) (~25 J, 0.1 Hz)
- Ti: sap. booster amplifier-2 (BA2) (~60 J, 0.1 Hz)
- Compressor ~ns
- Compressor ~50 TW (~1.5 J / 30 fs), 10 Hz, <10^{-12}
- Compressor ~PW (~40 J / ~30 fs), 0.1 Hz, ~10^{-12}

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✓ Summary
OPCPA technique is used as a high contrast and broad band preamplifier

~ 5 mJ energy is sent into subsequent amplifiers

First amp. (BBO)
Second amp. (BBO)
Third amp. (BBO)

Seed pulse
Pump pulse
Our OPCPA provides a maximum gain of only $3 \times 10^2$ and achieves spectral control from 29 nm to 83 nm.

Low-gain OPCPA is used to enhance the contrast and spectral shaping is possible.
The pulses from the OPCPA are amplified in the Ti:sapphire preamplifier and power amplifier.

- View of the Ti:sapphire preamplifier
- View of the Ti:sapphire power amplifier

- 20 mm diameter Ti:sapphire crystal
- 40 mm diameter Ti:sapphire crystal

- Seed pulse
- Pump pulse

~45 mJ of pulse energy has been extracted

~2 J of pulse energy has been extracted
We have prepared the major components for booster amplifiers (BA1, BA2)

- Ti:sapphire crystal (120 mm) is in my hands
- Compression gratings (W: 565 mm) have been delivered
- 6 pump lasers (150 J, 0.1 Hz, 527 nm) have been placed in position

Ti:sapphire crystal (120 mm) is in my hands
BA1 has been constructed

View of BA1

- Nd:glass pump laser 25J, 0.1 Hz
- Nd:glass pump laser 25J, 0.1 Hz
- 80 mm diameter Ti:sapphire crystal
- To booster amplifier-2 (BA2)
- Seed pulse

Extracted energy

- Output broadband energy from BA1 [J]
- Incident pump energy [J]
- Repetition rate: 0.1 Hz
- Theoretical curve
- Experimental data

23 J output energy is obtained with optical-to-optical efficiency of 49 % at 0.1 Hz
BA1 has been demonstrated to operate well at 0.1 Hz

✓ IR spatial profile

Homogeneous flat-top profile has been obtained

✓ Spectra

With BA1 amplification

Broad spectral bandwidth has been demonstrated
BA2 has been constructed

View of BA2

Extracted energy

- Seed pulse
- 120 mm diameter Ti:sapphire crystal
- Nd:glass pump laser 25J, 0.1 Hz
- Nd:glass pump laser 25J, 0.1 Hz
- Nd:glass pump laser 25J, 0.1 Hz
- Nd:glass pump laser 25J, 0.1 Hz
- To Compressor

Incident pump energy [J] vs. Output broadband energy from BA2 [J]

- Repeated rate: 0.1 Hz
- Theoretical curve
- Experimental data

- 63 J output energy has been obtained at 0.1 Hz
BA2 has been demonstrated to operate well at 0.1 Hz

- Homogeneous flat-top profile has been obtained
- Broad spectral bandwidth has been demonstrated
Booster amplifiers achieving full power shots
It started in Feb. 2013 with supplementary budget…

Photograph of the laboratory late 2013

Photograph of the laboratory TODAY
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Deformable mirror, compressor and target chambers have been also prepared.

Compressor

Deformable mirror

Long focus target chamber
~F/20

Short focus target chamber
F/1.4~F/3
Wavefront correction has been successfully carried out by a 95 mm diameter deformable mirror.

- View of the deformable mirror
- Without correction
- With correction

Calculated PSF Strehl ratio = 0.12
Calculated PSF Strehl ratio = 0.86

rms = 70 nm

Courtesy of Fukuda san, Pirozhkov san and Nishiuchi san et al.
Pulse compression has been successfully carried out by a newly constructed compressor.

For over 156 single shots, pulses are compressed down to 29.1±0.7 fs (FWHM) and 34.3±1.1 fs (Effective width), respectively, indicating a potential peak power of over PW.
300 mm diameter OAP in the short focus target chamber

✓ View of the short focus target chamber

Off axis parabola (f/1.4)
F=350mm, clear Φ280mm

✓ Wavefront quality

Calculated PSF
Strehl ratio=0.94

Courtesy of Nishiuchi san et al.
Temporal contrast has been confirmed

Contrast level: $10^{-12}$

- $\sim 1$ J output energy
- $\sim 10$ J output energy

Real intense pre-pulses !?

Contrast of $10^{-12}$ at sub-ns, $10^{-12}$ at -50 ps (@J) is confirmed

$\times$: Artificial pulses
Limiting factor in contrast

Further investigation on this nonlinear coupling effect is needed to fully understand and evaluate the degradation mechanism.
Focal spot has been evaluated using an OAP with f/1.4 – approaching diffraction limit –

✅ Focal spot

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2016-11-08 Ti:S BA1</th>
<th>Diffr. Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FWHM x, µm</td>
<td>1.32±0.05 (4%)</td>
<td>1.07</td>
</tr>
<tr>
<td>FWHM y, µm</td>
<td>1.37±0.03 (2%)</td>
<td>1.23</td>
</tr>
<tr>
<td>FW1/e² x, µm</td>
<td>2.19±0.15 (7%)</td>
<td>1.72</td>
</tr>
<tr>
<td>FW1/e² y, µm</td>
<td>2.30±0.17 (8%)</td>
<td>2.04</td>
</tr>
<tr>
<td>Energy above 1/2, %</td>
<td>32±4 (11%)</td>
<td>50</td>
</tr>
<tr>
<td>Energy above 1/e², %</td>
<td>56±2 (4%)</td>
<td>82</td>
</tr>
<tr>
<td>I₀ at 300 TW, W/cm² (f/1.25)</td>
<td>(0.93±0.12)×10²²</td>
<td>2.0×10²²</td>
</tr>
<tr>
<td>Strehl ratio</td>
<td>0.46±0.06</td>
<td>1</td>
</tr>
</tbody>
</table>

10²² W/cm² at 0.1 Hz is achieved at 0.3 PW power level

Evolution of laser intensity at KPSI, QST

10^{22} \text{ W/cm}^2 \quad 10^{21} \text{ W/cm}^2 \quad 10^{20} \text{ W/cm}^2 \quad 10^{19} \text{ W/cm}^2 \quad 10^{18} \text{ W/cm}^2

- J-KAREN power amp.
- J-KAREN booster amp.
- J-KAREN single-shot
- J-KAREN-P (0.1 Hz)

Where we reached!

10^{22} \text{ W/cm}^2 \quad \text{on target}

Evolution of laser intensity at KPSI, QST
✔ Successful campaign in the upgrade to J-KAREN-P
  - almost all goals achieved
  - still evaluating the data (contrast, spatial profile, stability…..)

✔ PW level performance on target
  - 63 J at 0.1 Hz before compressor demonstrated
  - 30 fs (FWHM) of recompressed pulse achieved
  - 10^{-12} (at sub-ns) of contrast confirmed

✔ 10^{22} W/cm^2 level performance on target
  - 1.3 µm (FWHM) focal spot confirmed
  - 10^{22} W/cm^2 at 300 TW achieved

✔ Currently gradually increasing the laser energy on target, checking the total system