1J, 100Hz GENBU-Front End Laser System with Multi-TRAMs

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“玄武” GENBU Laser

Main Laser

Front End (Fiber Laser) → Pulse Stretcher → 1st Amplifier (Cryogenic Yb:YAG) → 2nd Amplifier (Cryogenic Yb:YAG) → Pulse Compressor

Neutron Source

E = 1 kJ
Δt = 10 - 100 ps
f = 50 - 100 Hz
λ = 1030 nm

Medical Applications

E = 30 J
Δt = 5 fs - 8 ps
P_{peak} = 0.04 - 6 PW
f = 100 Hz
λ = 1030 nm
Δλ = 600 nm

OPCPA Laser

- GENBU (Generation of ENergetic Beam Ultimate) Laser was proposed as a milestone in the reactor driver developments.
- Front-End part will be commonly utilized.
There are 4-stage amplifiers in the DPSSL system.

**Cryogenic Yb:YAG Ceramics** are used for main-amplifier.

Our initial objective is a development of **Joule Class** high energy CPA system.
Chirping Regenerative Amplifier with cryogenic Yb:YAG TRAM and CVBG
Total-Reflection Active-Mirror (TRAM)

**High absorption** due to the long optical length allows
- Simple pumping with just 1- or 2-passes.

**No spatial overlap** of input and output pulses on the surface
- Avoids damage threshold reduction due to interference.

**Brewster angle** with no coating realizes
- Less cost

**Total reflection** with no coating ensures
- Less temperature rise.

**Direct cooling** by liquid nitrogen realizes
- Less temperature rise
- Efficient hydrodynamic cooling

Yb:YAG
- 20 at.%
- $t = 400 \mu m$

**Horizontal**
- Vertical

Chirped Pulse Regenerative Amplifier in HEC-DPSSL 2010

Master Oscillator is a stable mode-locked Yb:Fiber Oscillator.

After Offner pulse stretcher and pulse picker, the seed pulse was amplified by Regen. AMP. with a cryogenic Yb:YAG TRAM to $E > 3.5$ mJ.

Optical loss of the stretcher was crucial, and its size was large…

$\lambda_c = 1030$ nm
$\Delta \lambda = 60$ nm
$\Delta t = 42$ fs
$E = 1$ nJ
$f = 78$ MHz

$\lambda_c = 1029.4$ nm
$\Delta \lambda = 0.4$ nm
$\Delta t = 650$ ps
$E = 5$ pJ
$f = 10 -- 100$ Hz

$\lambda_c = 1029.4$ nm
$\Delta \lambda = 0.14$ nm
$\Delta t = 460$ ps
$E = 3.5$ mJ
$f = 100$ Hz
We removed the temporally wave-form shaping part (CVBG, Fiber AMP., Offner pulse stretcher, and Pulse slicer), and we installed them to the Regen. AMP. part!!
Mode-Locked states are accessible by adjustment of the wave-plates (\(\lambda/2\), \(\lambda/4\)) which control the **Nonlinear Polarization Rotation (NPR)**.

Mode-Locked pulses were compressed by using external transmitted grating pair.
We have obtained ultra short pulses (~42 fs) after compression.

Spectral Bandwidth was about \( \Delta \lambda \sim 60 \text{ nm} \) (FWHM) at the center wavelength of 1030 nm (Yb:YAG wavelength).

Maximum output energy was 1.18 nJ.
Chirping Regenerative Amplifier With CVBG

Seed in
$E = 0.96 \text{ pJ}$
$\tau = \sim 1 \text{ ps}$
$f = 78 \text{ MHz}$

output
$E = 1.2 \text{ mJ}$
$t = 424 \text{ ps}$
$f = 100 \text{ Hz}$

Fiber-Coupled LD
$140 \text{ W, 0.7 ms, QCW}$

TRAM (20at.% $\%$, 0.4mm)
(Total-Reflection Active-Mirror)

Cavity length: 1.8 m
Chirped Volume Bragg Grating

8 mm x 8 mm x 25 mm
λ<sub>c</sub> = 1030.5 nm (0 degree)
→ 1029.4 nm (5 degrees)
Chirp Rate : 240 ps/nm

Transmitted Intensity (a.u.)

Wavelength (nm)

1000 1020 1040 1060

1029.4 nm

CVBG : 5 degrees
The maximum output pulse energy of 1.2 mJ was obtained at 10 Hz.
The output profile has distortion due to the wavefront of CVBG.
The round trip number was around 60.
The pulse duration was stretched to 424 ps and the spectral width was narrowed at 0.2 nm due to both the gain-narrowing and narrow reflection spectra of the CVBG.

Chirp Rate $= 0.424 \text{ns}/0.2 \text{nm} \sim 2.1 \text{ ns/nm} \quad \rightarrow \quad 39\sim59$ round trips

Summary of Regen. Amp. Part

◆ Stable Master Oscillator
  • Mode-locked Fiber Oscillator 42 fs, 1.2 nJ@ 78 MHz, Δλ = 60 nm@1030 nm

Previous system

◆ Temporal Spectral Shaping + Regenerative Amplifier
  • Cryogenic TRAM Regen. 460 ps, 3.5 mJ@100 Hz, Δλ = 0.14 nm

Current system

◆ Chirping Regenerative Amplifier
  • Cryogenic TRAM Regen. 424 ps, 1.2 mJ@10 Hz, Δλ = 0.2 nm

- The dispersion of CVBG is fixed, and the wavefront is not good.
- To adjust the total dispersion and to improve the beam profile, grating pair is more useful.
Multi-Pass Amplifier system for 1 J and 100 Hz
Schematic of previous multi-Pass Amplifier System

Seed Pulse > 2 mJ (from R.A.)

Output Pulse > 1 J

Fiber-Coupled LD (2.5 kW QCW x 2)

Cryostat

Sample

\(\frac{\lambda}{2}\) w.p.

Mirror

Vacuum spatial filter with pinhole

Image relay lenses

Image point aperture

\(\frac{\lambda}{2}\) w.p.

PC

TFP

FR

Hamamatsu Photonics K.K.
We obtained 22.2 mJ output energy after 2 pass amplification with 2 mJ seed pulse energy. The output energy saturated with increasing pump power. → ASE or Parasitic Lasing decreased the laser gain...
By studying the laser gain in more detail, we have measured small signal gain and a parasitic oscillation condition for one TRAM.

A single frequency cw seed beam (Koheras, 1029.4 nm, 5 mW) was used as a seed beam.
Parasitic Oscillation is observed at the SSG of more than 1.33.

The small signal gain coefficient is $g_0 = 1.78 \text{cm}^{-1}$ for SSG = 1.33.

The parasitic oscillation condition was $g_0 I_{ASE} = 3.5$. 
With enlarging pump size, the saturation of SSG occurred at lower pump intensity since ASE length is also enlarged, however, the stored energy becomes higher.

We found that the maximum stored energy of this TRAM is around 150 mJ, therefore, it is not enough for 1 J pulse energy.
Based on the parasitic oscillation condition, we have designed a new material!!
This has 3 Yb:YAG layers and each total-reflection faces were Evanescent-coated to avoid impurity attachment, and to increase the damage threshold.
The laser beams incident under the Brewster angle, and the reflection angle at Yb:YAG layer was 70 degrees.
This material is pumped by 2 laser diodes from both sides.
## Sample Design

<table>
<thead>
<tr>
<th>Disk</th>
<th>Doping of Yb$^{3+}$ (at.%)</th>
<th>Thickness (mm)</th>
<th>Absorption (%)</th>
<th>Pump Power (W)</th>
<th>Stored Energy (J)</th>
<th>$\Delta T$ (K)</th>
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<tr>
<td>Yb1</td>
<td>2</td>
<td>0.8</td>
<td>67.4</td>
<td>2100</td>
<td>0.6</td>
<td>4.7</td>
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<td>Yb2</td>
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- The doping concentration for each Yb:YAG layer are designed to avoid parasitic oscillation.
- The absorbed pump power for each Yb:YAG layer are almost the same (~ 1300 W).
- The total pump energy is 2.9 J at 0.7 ms pump duration, and the total stored energy is 1.8 J.
- The average absorbed pump power for each Yb:YAG is about 100 W for 100 Hz rep. rate, which corresponds to the average pump intensity of 50 W/cm$^2$.
The seed pulse from Regen. Amp. passes through TFP, FR, HWP.
The seed beam incident under Brewster angle, therefore, the polarization direction is limited.
For multi-pass amplification (> 2 passes) a Pockels Cell is used.
After multi-pass amplification, the output pulse will be extracted.
Amplification Calculations

With 10 mJ input energy, 1 J would be achieved using 4 pass amplification.

Using 8 pass amplification, over 1.5 J pulse energy will be obtained with several mJ input energy.
A new amplifier for 1 J/100Hz is **under construction**.
“玄武(GENBU)”- laser has been conceptually designed for high power applications in ps and fs regime.

- **Front-End**
  - **Stable Master Oscillator** (Mode-locked Fiber Oscillator)
    - 42 fs, 1.2 nJ @ 78 MHz, $\Delta\lambda = 60$ nm @ 1030 nm
  - **Chirping Regenerative Amplifier** (cryogenic Yb:YAG TRAM)
    - 424 ps, 1.2 mJ @ 100 Hz, $\Delta\lambda = 0.2$ nm

- **Multi-Pass Amplifier**
  - Double TRAMs (with 20 at.%, 0.4 mm-thick Yb:YAG)
    - Parasitic lasing occurred and stored energy was about 150 mJ per TRAM.
  - A monolithic 3-TRAMs has been prepared.
    - total stored energy of 1.8 J is possible
    - over 1 J and 100 Hz can be possible (under construction)
Collaborators on “玄武” - project

玄武 (GENBU)

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