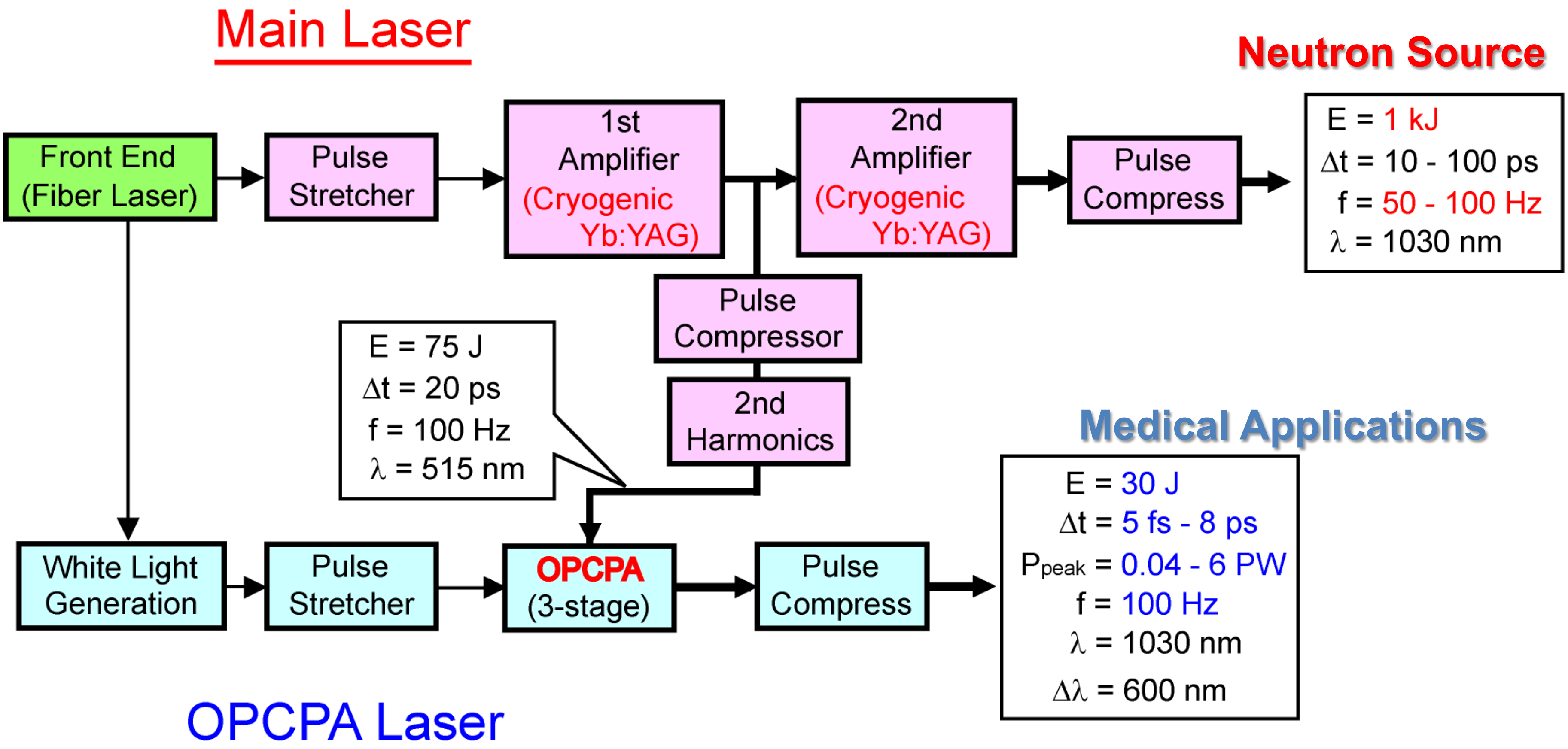
1J, 100Hz GENBU-Front End Laser System with Multi-TRAMs

Hiroaki Furuse and Junji Kawanaka

Institute for Laser Technology (ILT), Japan

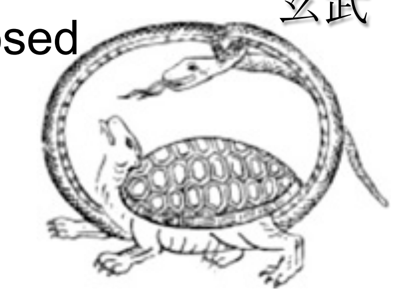
Institute of Laser Engineering (ILE), Osaka University

“玄武” GENBU Laser

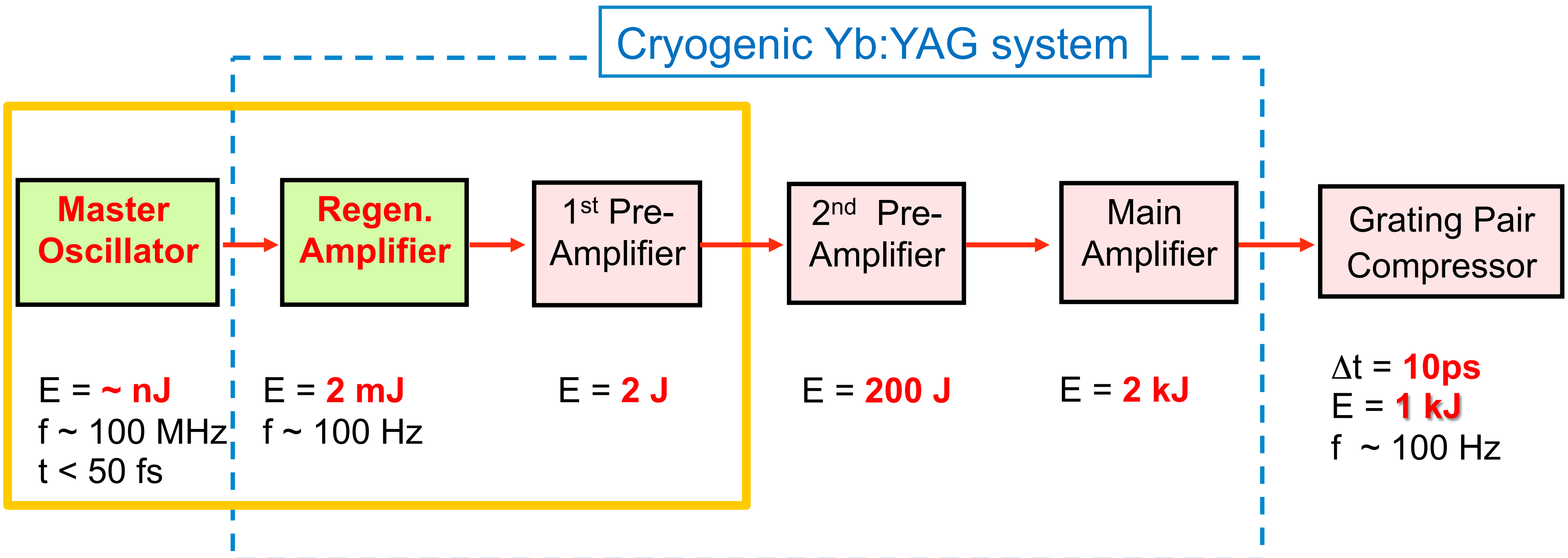


- **GENBU** (**G**eneration of **EN**ergetic **B**eam **U**ltimate) Laser was proposed as a milestone in the reactor driver developments.
- Front-End part will be commonly utilized.

玄武



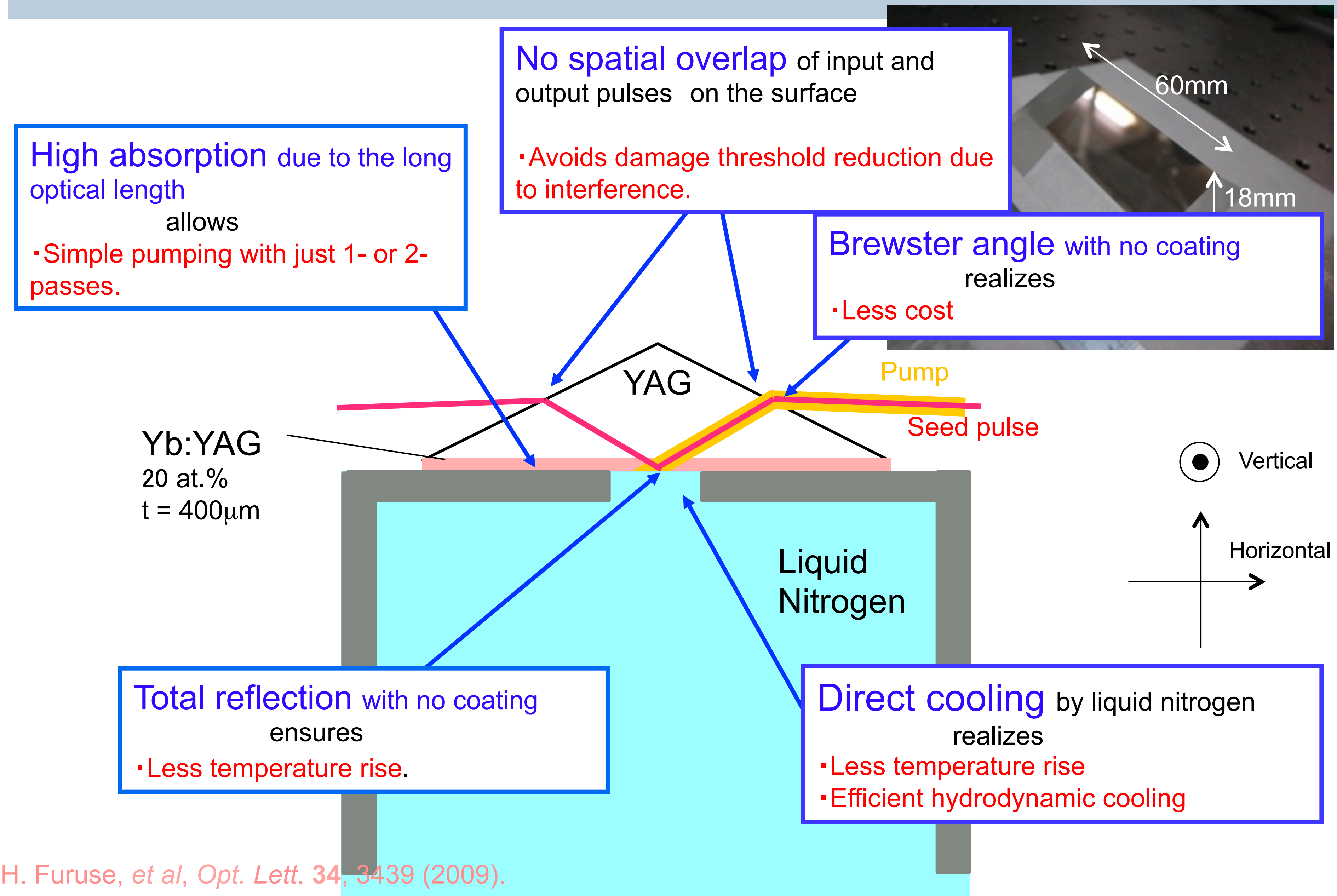
Amplifier parts of the Main laser



- 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)



H. Furuse, *et al*, *Opt. Lett.* **34**, 3439 (2009).

Chirped Pulse Regenerative Amplifier *in HEC-DPSSL 2010*

Mode-locked Fiber Oscillator → **Temporal wave-form shaping** (CVBG, Fiber AMP. Offner pulse stretcher, Pulse slicer) → **Regen. AMP. using TRAM**

Mode-locked Fiber Oscillator	Temporal wave-form shaping	Regen. AMP. using TRAM
λ_c = 1030 nm	λ_c = 1029.4 nm	λ_c = 1029.4 nm
$\Delta\lambda$ = 60 nm	$\Delta\lambda$ = 0.4 nm	$\Delta\lambda$ = 0.14 nm
Δt = 42 fs	Δt = 650 ps	Δt = 460 ps
E = 1 nJ	E = 5 pJ	E = 3.5 mJ
f = 78 MHz	f = 10 -- 100 Hz	f = 100 Hz

- **Master Oscillator** is a stable **mode-locked Yb:Fiber Oscillator**.
- After Offner pulse strecher 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…

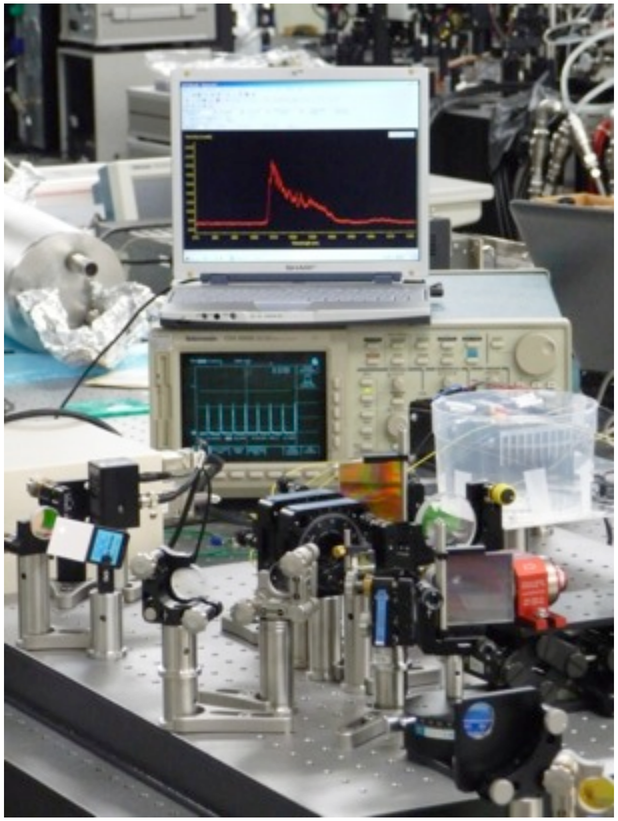
Chirped Pulse Regenerative Amplifier *in HEC-DPSSL 2010*

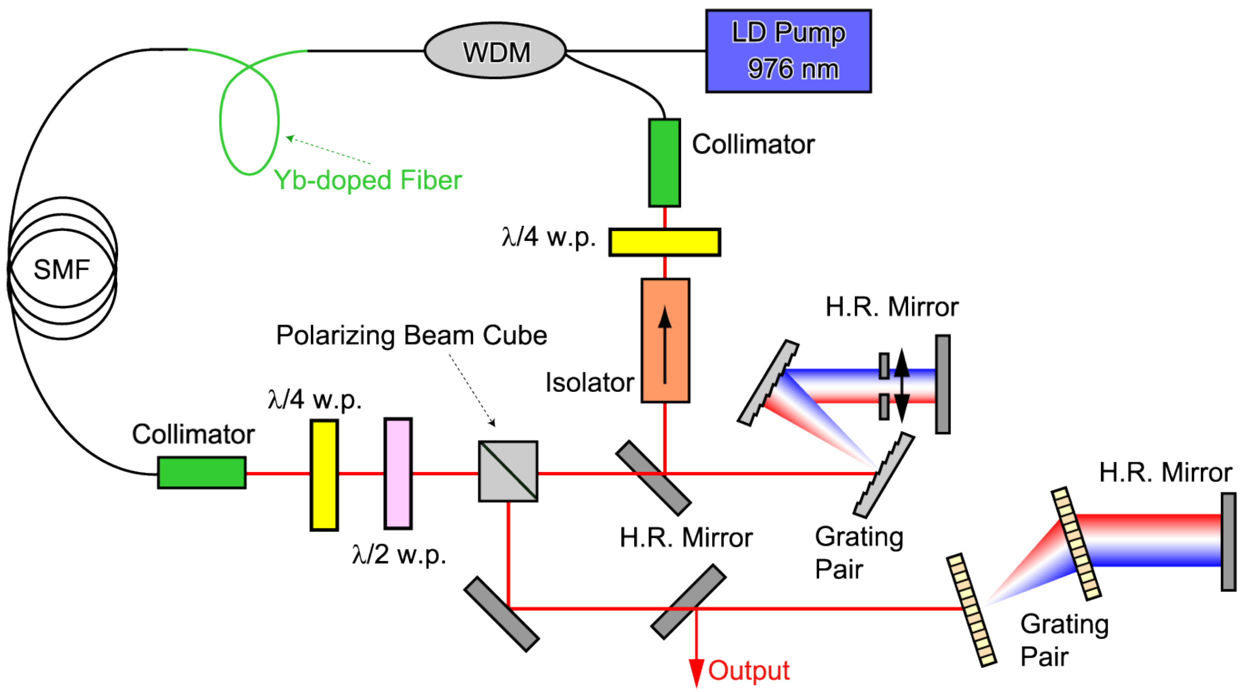
Mode-locked Fiber Oscillator → Chirping Regen. AMP. with CVBG

Mode-locked Fiber Oscillator	Chirping Regen. AMP. with CVBG
λ_c = 1030 nm	λ_c = 1029.4 nm
$\Delta\lambda$ = 60 nm	$\Delta\lambda$ = 0.14 nm
Δt = 42 fs	Δt = 424 ps
E = 1 nJ	E = 1.2 mJ
f = 78 MHz	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 !!

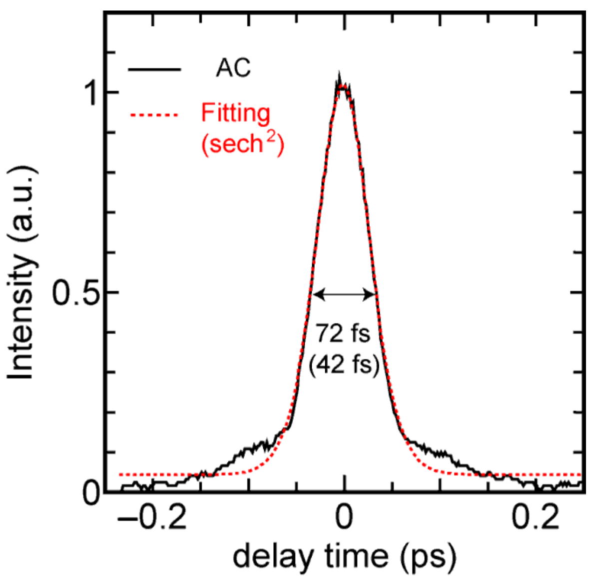
Ultra-short Mode-Locked Fiber Oscillator

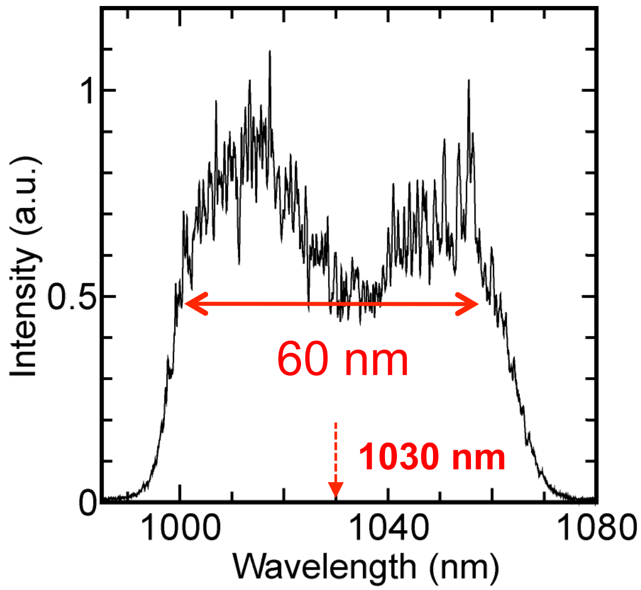


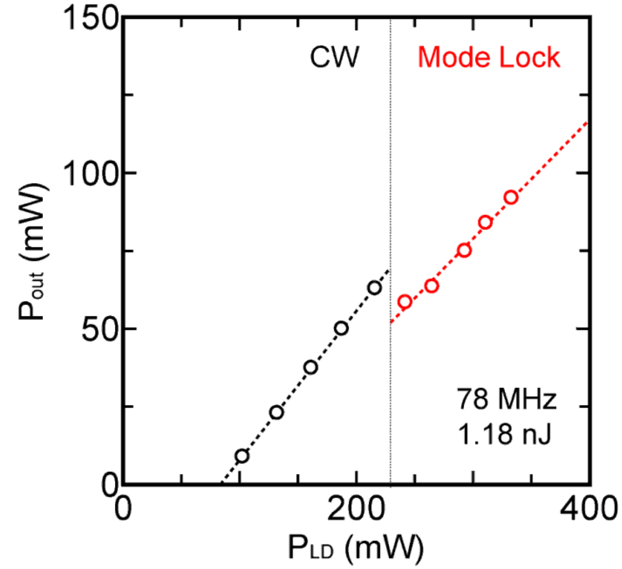


- Mode-Locked states are accessible by adjustment of the wave-plates (λ/2, λ/4) which control the Nonlinear Polarization Rotation (NPR).
- **Mode-Locked pulses were compressed by using external transmitted grating pair.**

Mode-Locked Fiber Oscillator

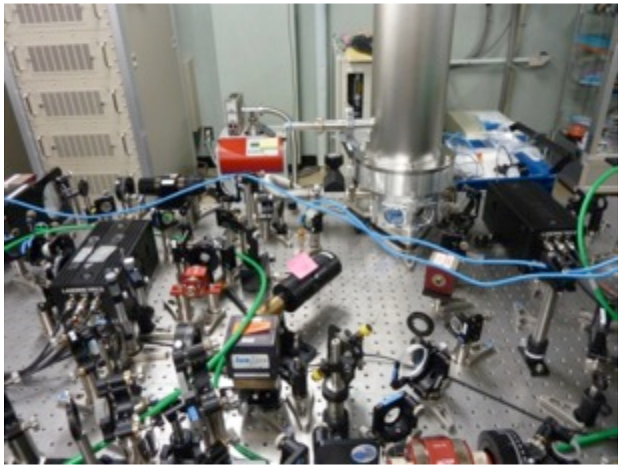




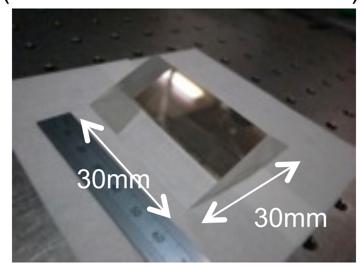


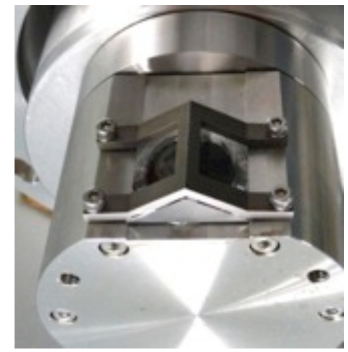
- We have obtained ultra short pulses **(~ 42 fs)** after compression.
- Spectral Bandwidth was about $\Delta\lambda$ ~ 60 nm (FWHM) at the center wavelength of **1030 nm** (Yb:YAG wavelength).
- Maximum output energy was **1.18 nJ**.

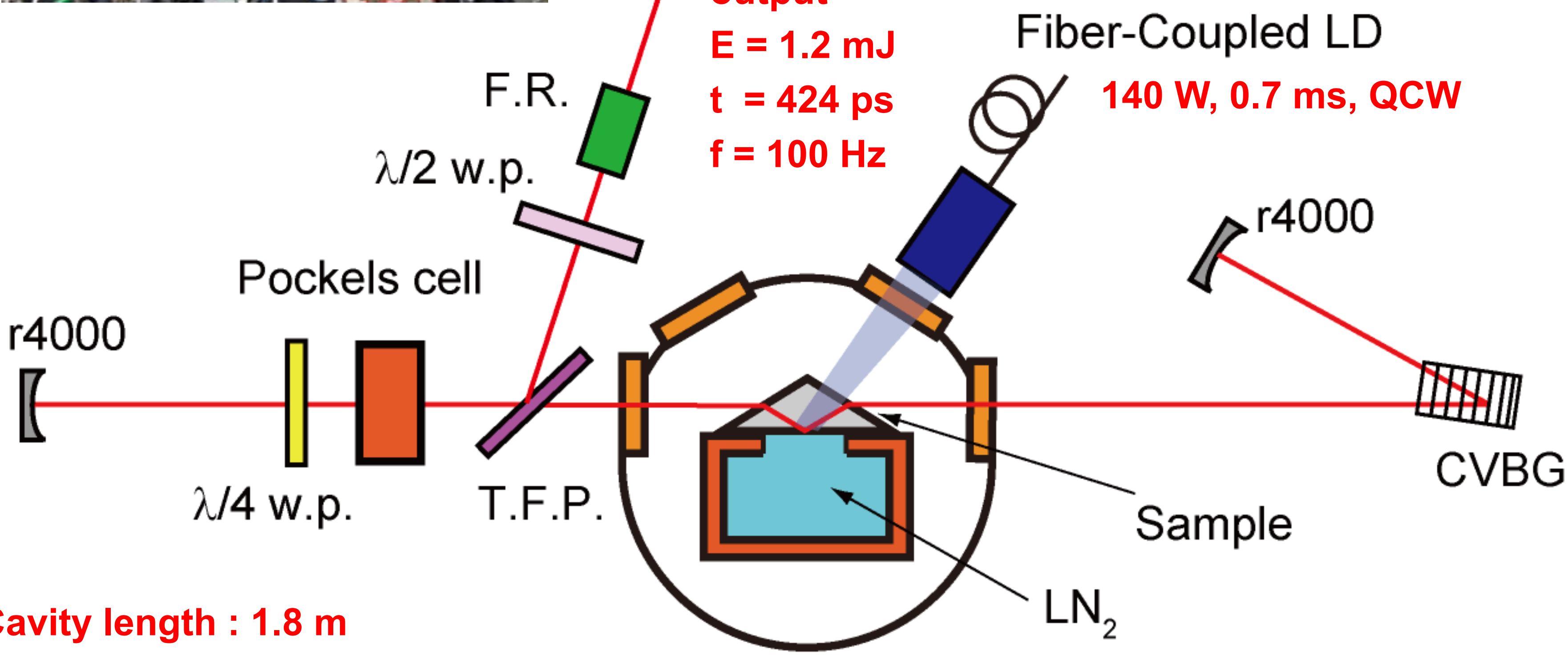
Chirping Regenerative Amplifier With CVBG



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

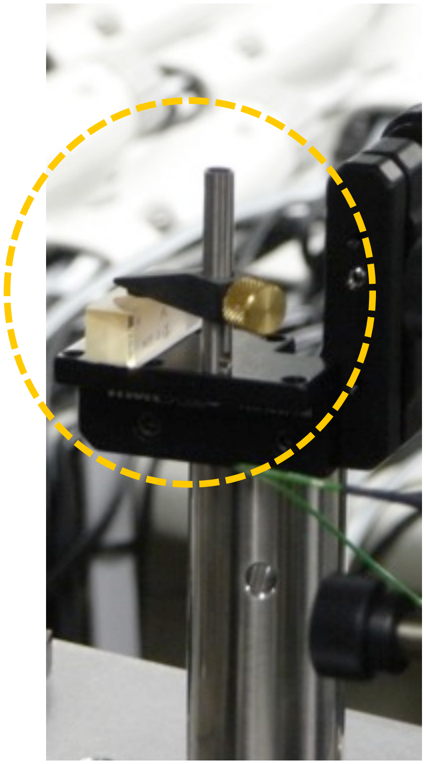




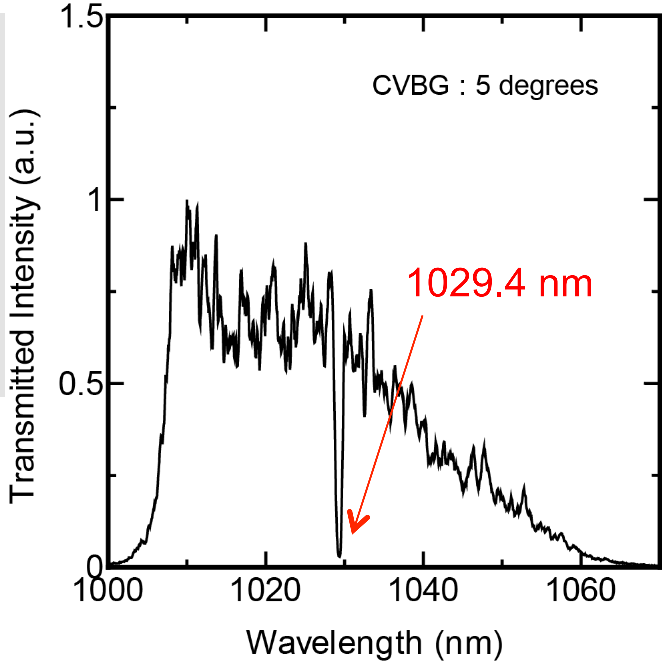


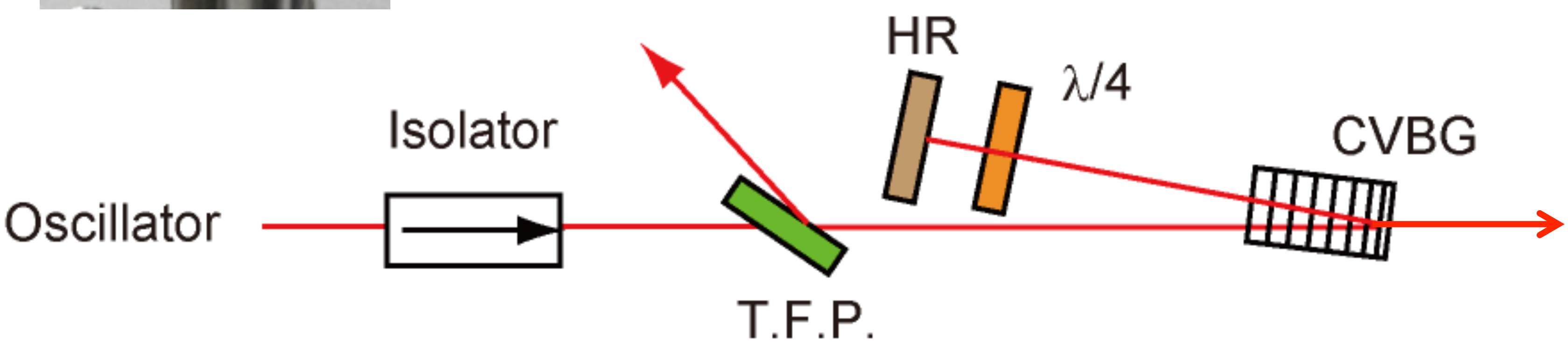
Cavity length : 1.8 m

Chirped Volume Bragg Grating

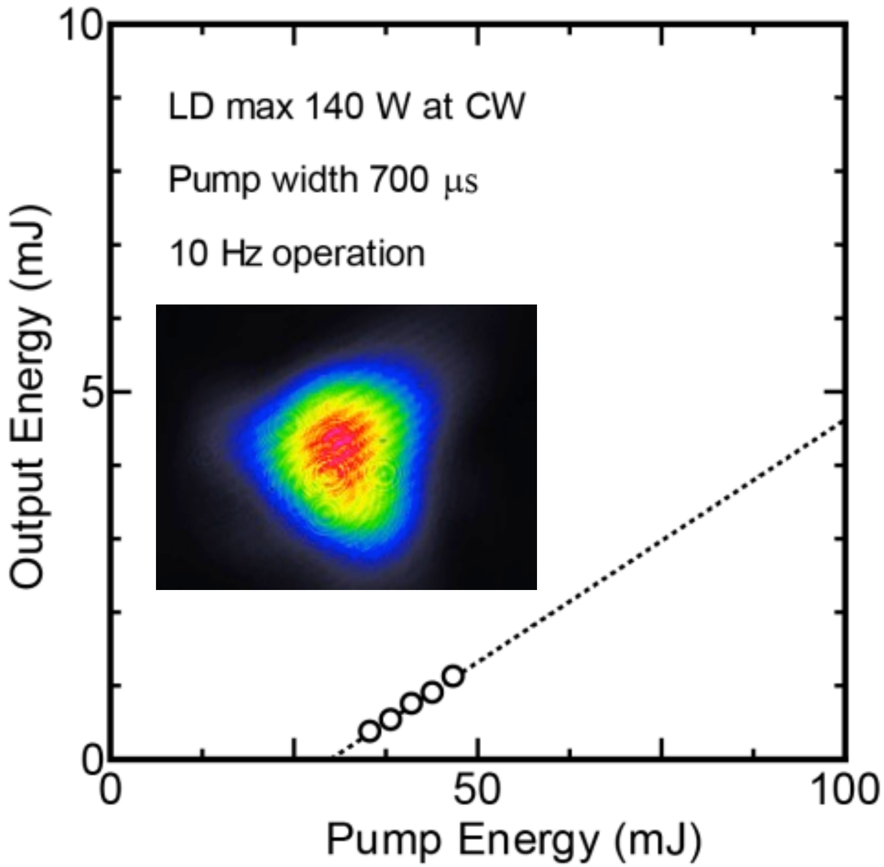


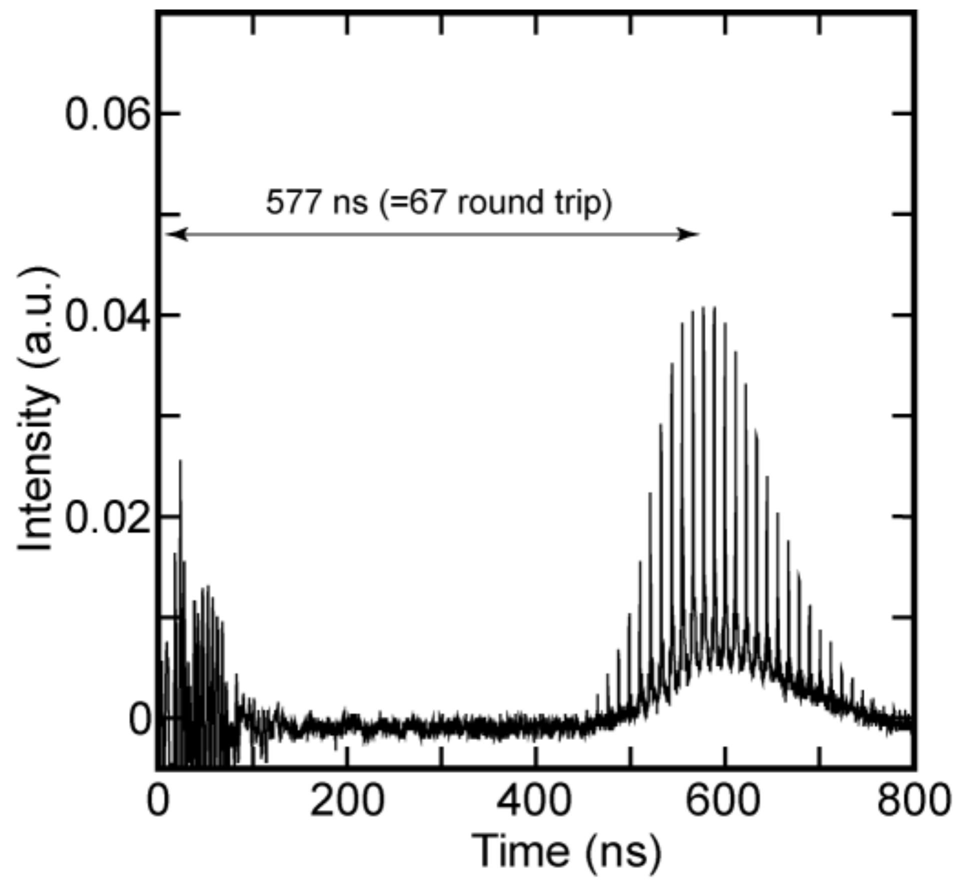
Chirped Volume Bragg Grating
8 mm x 8 mm x 25 mm
λ_c = 1030.5 nm (0 degree)
→ 1029.4 nm (5 degrees)
Chirp Rate : 240 ps/nm





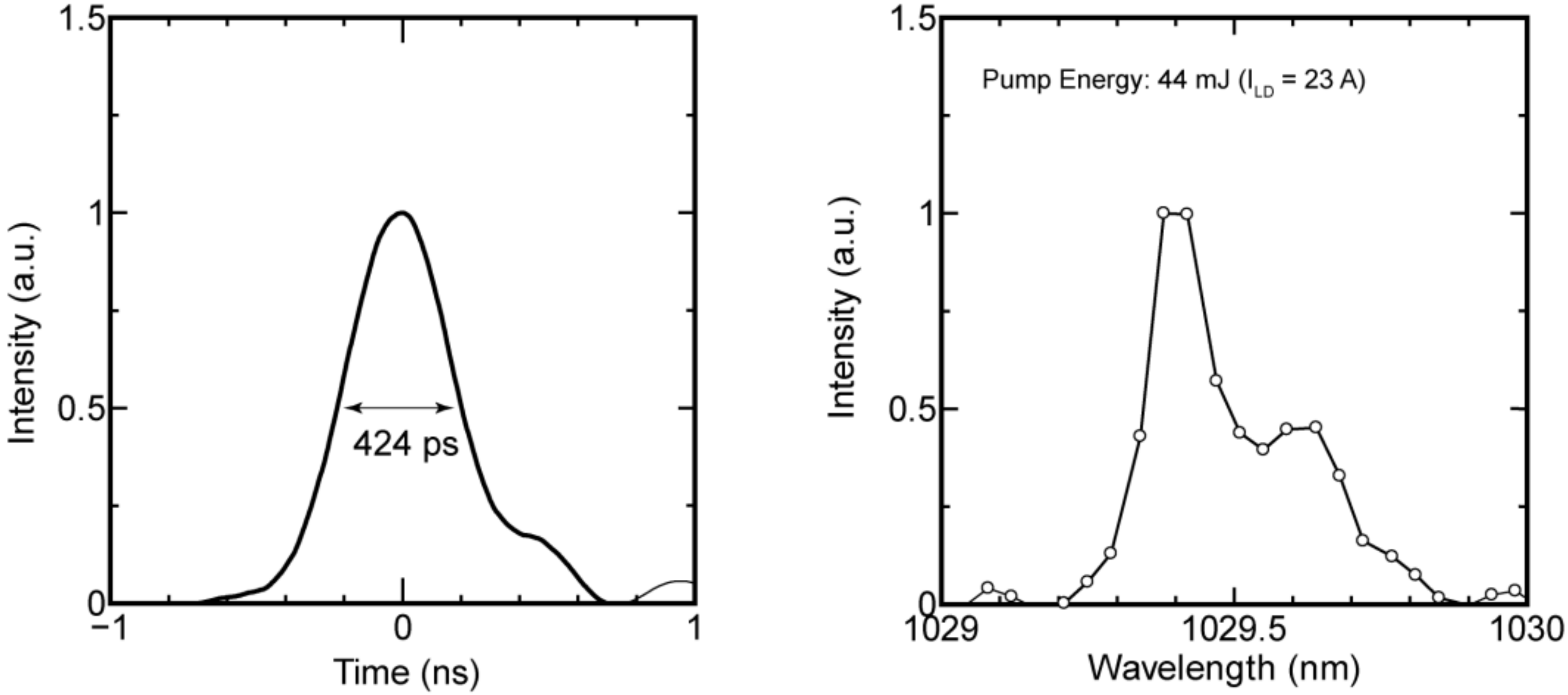
Output Energy and build-up signal





- 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.

Output Spectrum



- 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 = 0.424ns/0.2nm ~ 2.1 ns/nm → 39~59 round trips

J. Kawanaka, *et al*, in *Advanced Solis State Photonnics* (ASSP2012), AT4A.19.

Summary of Regen. Amp. Part

◆ **Stable Master Oscillator**

- Mode-locked Fiber Oscillator **42 fs**, 1.2 nJ@ 78 MHz, $\Delta\lambda$ = 60 nm@1030 nm

Previous system

◆ **Temporal Spectral Shaping + Regenerative Amplifier**

- Cryogenic TRAM Regen. 460 ps, **3.5 mJ**@100 Hz, $\Delta\lambda$ = 0.14 nm

Current system

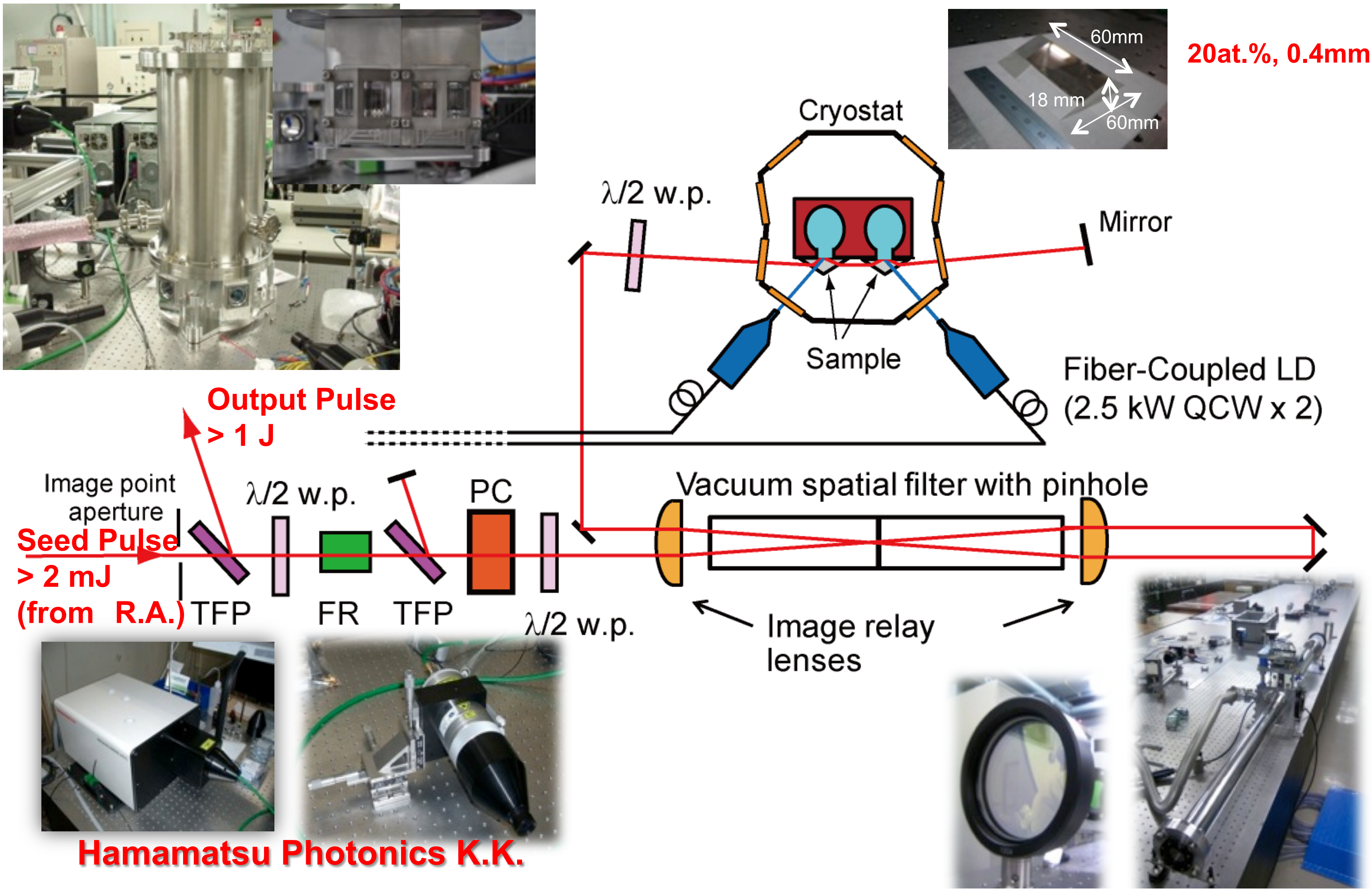
◆ **Chirping Regenerative Amplifier**

- Cryogenic TRAM Regen. 424 ps, **1.2 mJ**@10 Hz, $\Delta\lambda$ = 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.

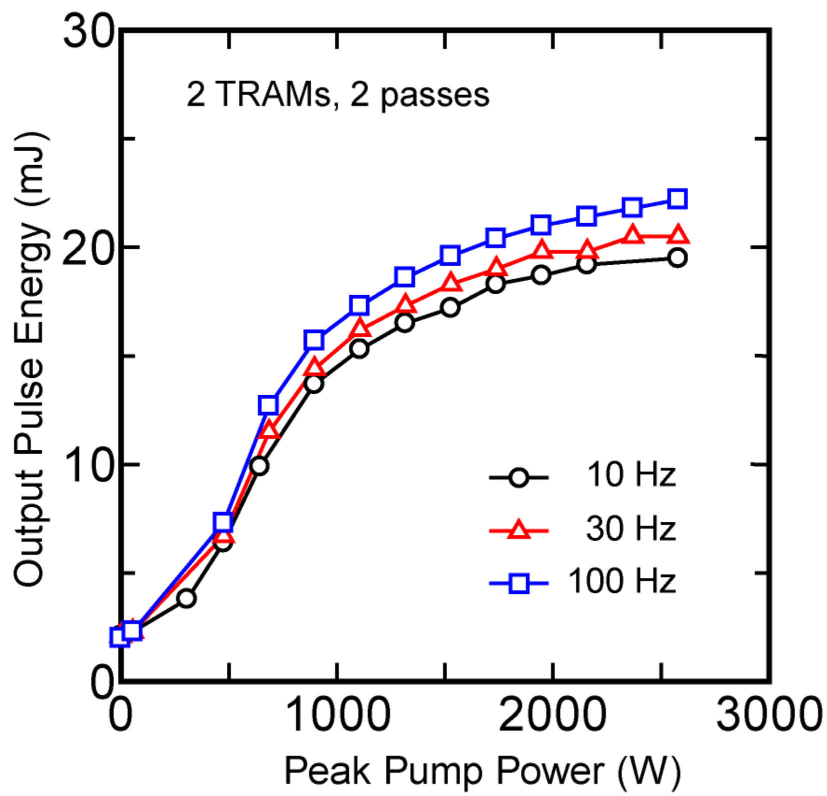
Multi-Pass Amplifier system for 1 J and 100 Hz

Schematic of *previous* multi-Pass Amplifier System



2 pass amplification

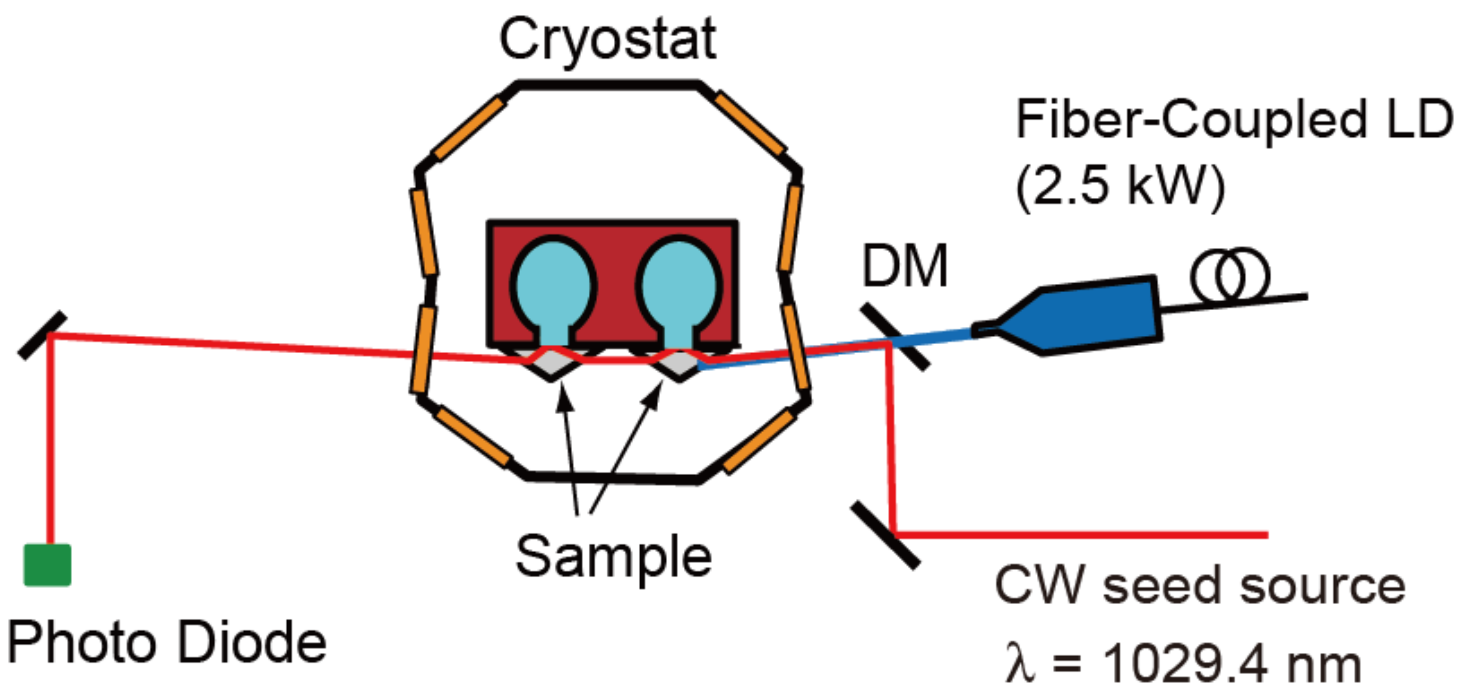
by Dr. Daniel Albach



- 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…

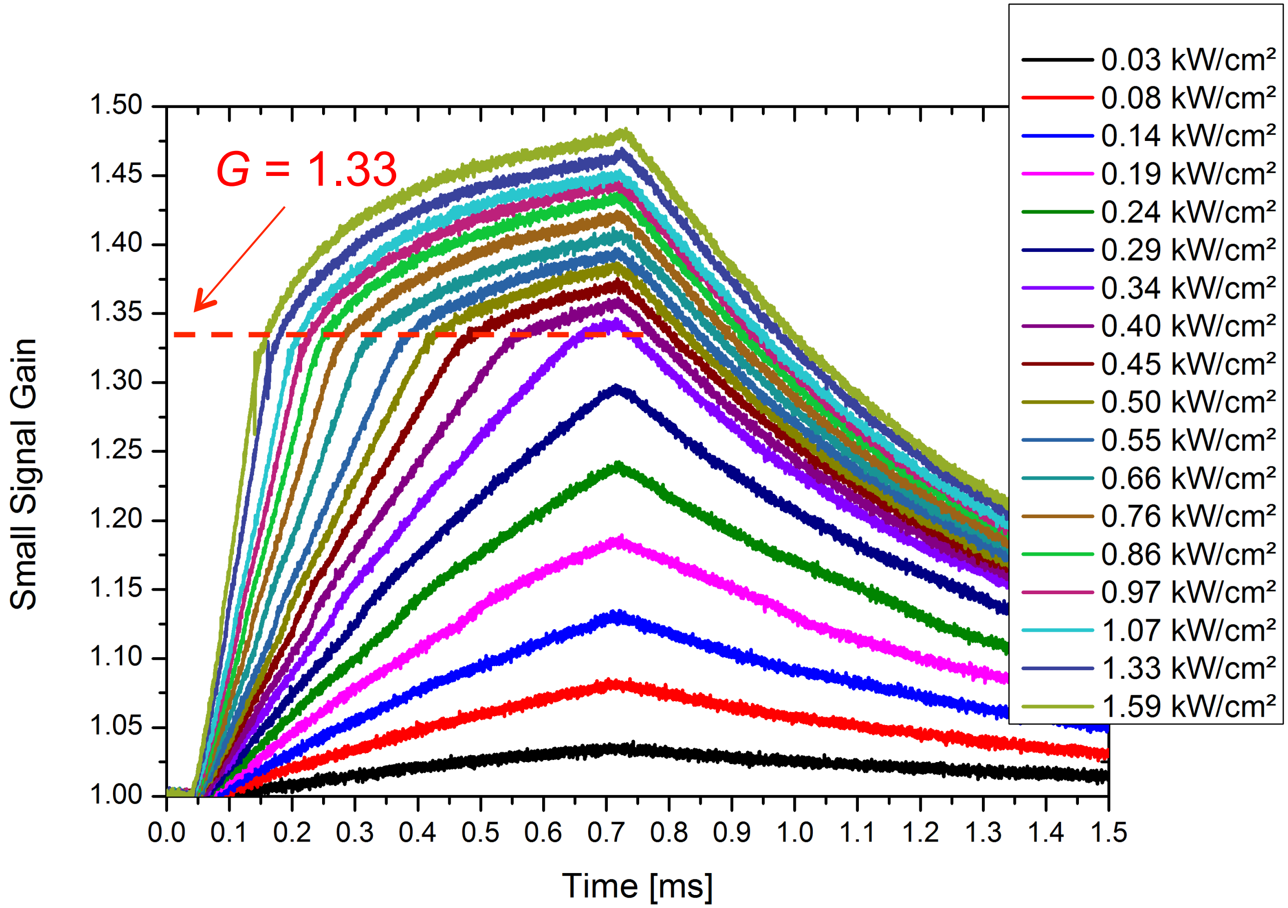
Small Signal Gain measurements

by Dr. Daniel Albach

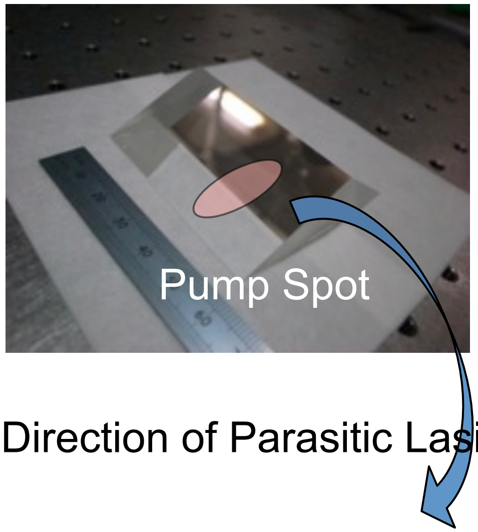


- To study the laser gain in more detail, we have measured small signal gain and a parasitic oscillation condition for one TRAM.
- A single frequency cw seed beam (Koheras, 1029.4 nm, 5 mW) was used as a seed beam.

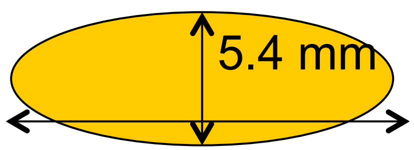
Small Signal Gain per TRAM (pump spot size : 5.4 mm)



by Dr. Daniel Albach



Direction of Parasitic Lasing

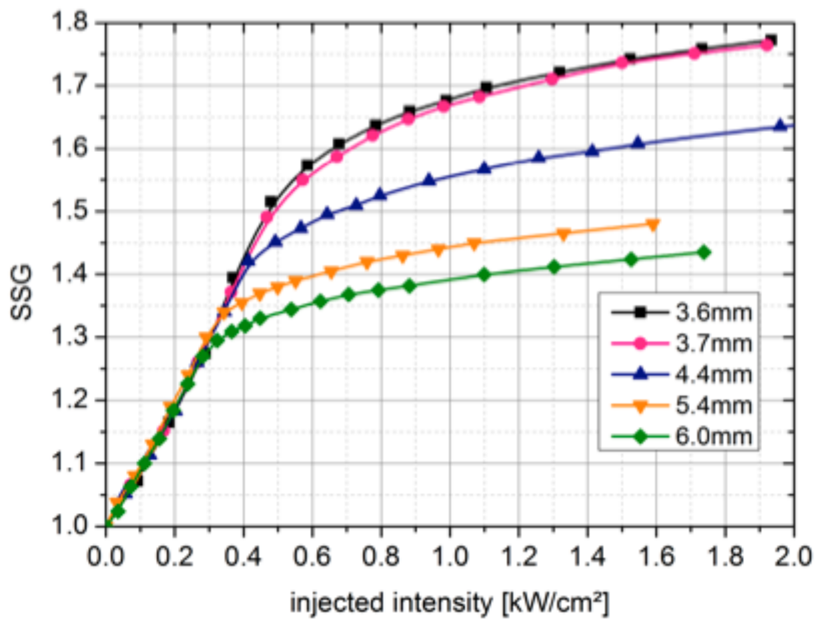


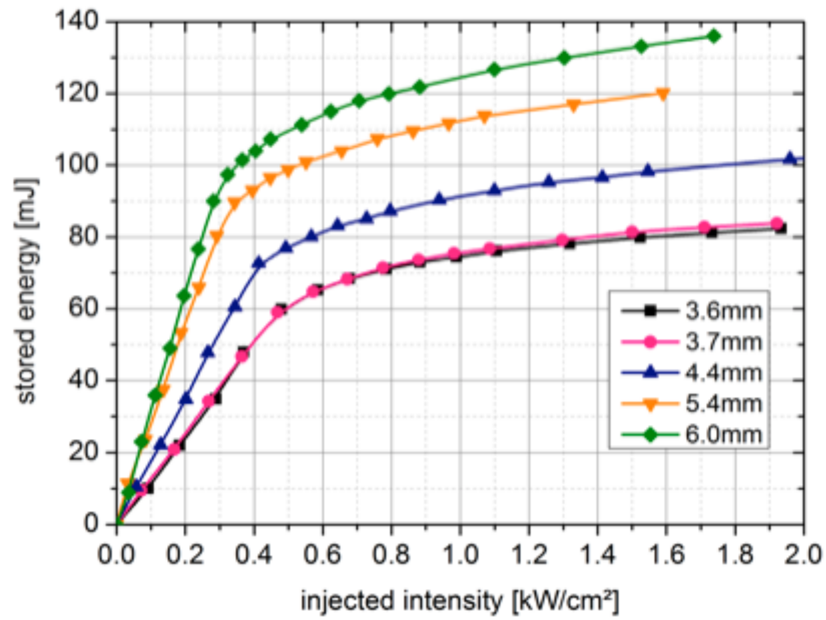
l_{ASE} = 3.64 x 5.4 mm

- *Parasitic Oscillation* is observed at the SSG of more than 1.33.
- The small signal gain coefficient is g_0 = 1.78cm^{-1} for SSG = 1.33.
- The parasitic oscillation condition was $g_0 l_{ASE} = 3.5$.

SSG and Stored Energy for different beam sizes

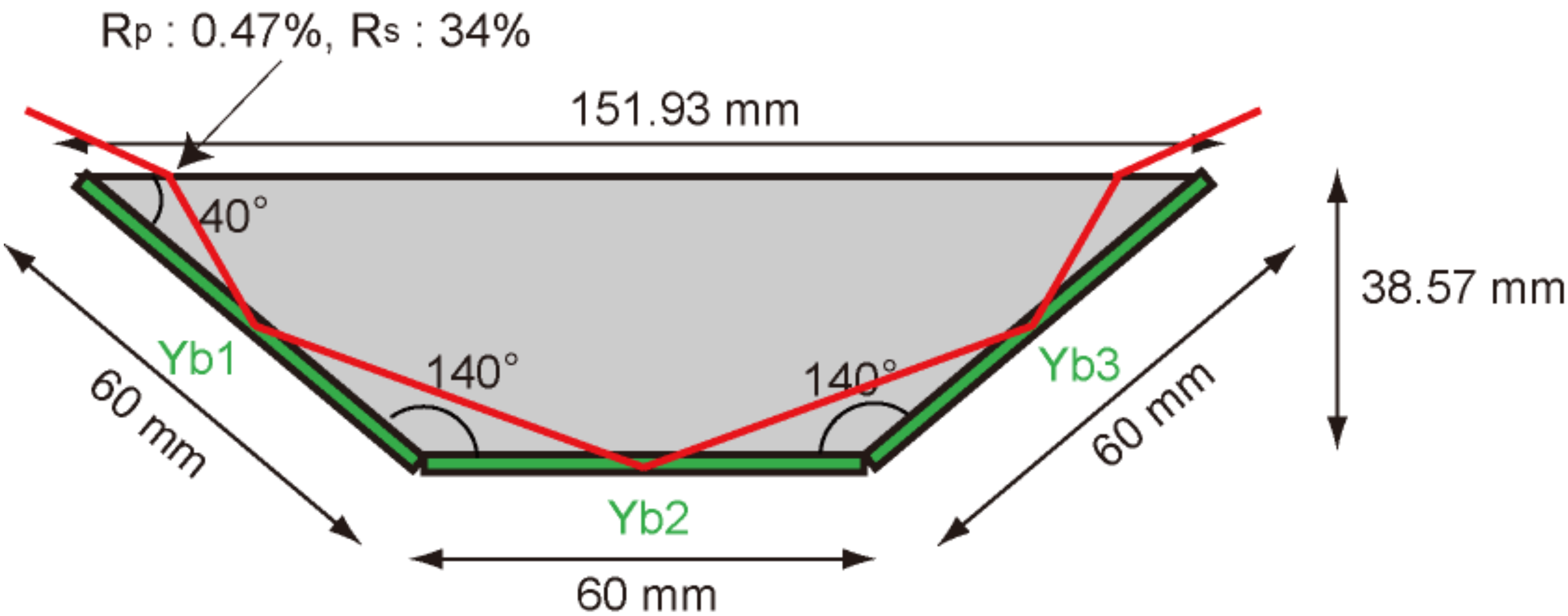
by Dr. Daniel Albach





- 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*.

New design 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.

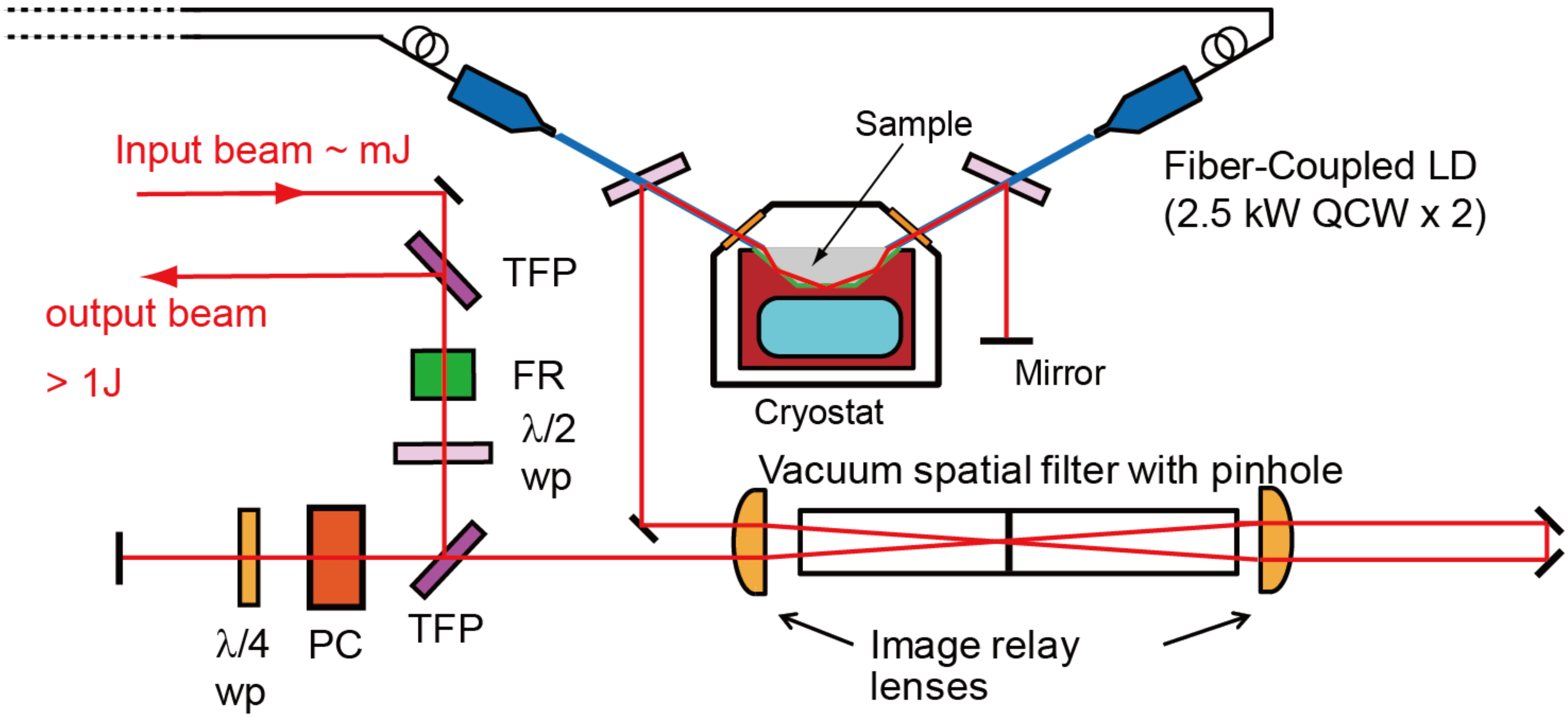
Sample Design

Pump spot size: 7mm → pumped area : 2cm^2

Disk	Doping of Yb^{3+} (at.%)	Thickness (mm)	Absorption (%)	Pump Power (W)	Stored Energy (J)	ΔT (K)
Yb1	2	0.8	67.4	2100	0.6	4.7
Yb2	5	0.8	95.2	1300	0.6	4.1
Yb3	2	0.8	67.4	2100	0.6	4.7

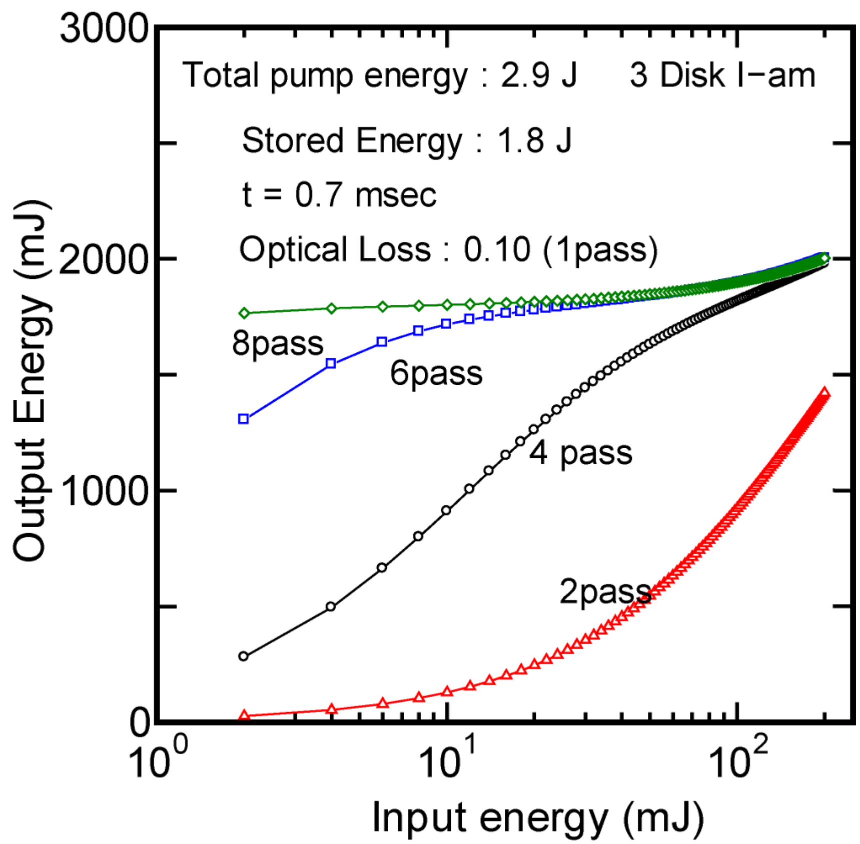
- The doping concentration for each Yb:YAG layer are designed *to avoid parasitic oscillation*.
- The absorbed pump power for each Yb:YAG layer are almost the same (~ 1300 W).
- The total pump energy is 2.9 J at 0.7 ms pump duration, and the total stored energy is 1.8 J.
- The average absorbed pump power 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

1 J multi-pass Amplifier laser system



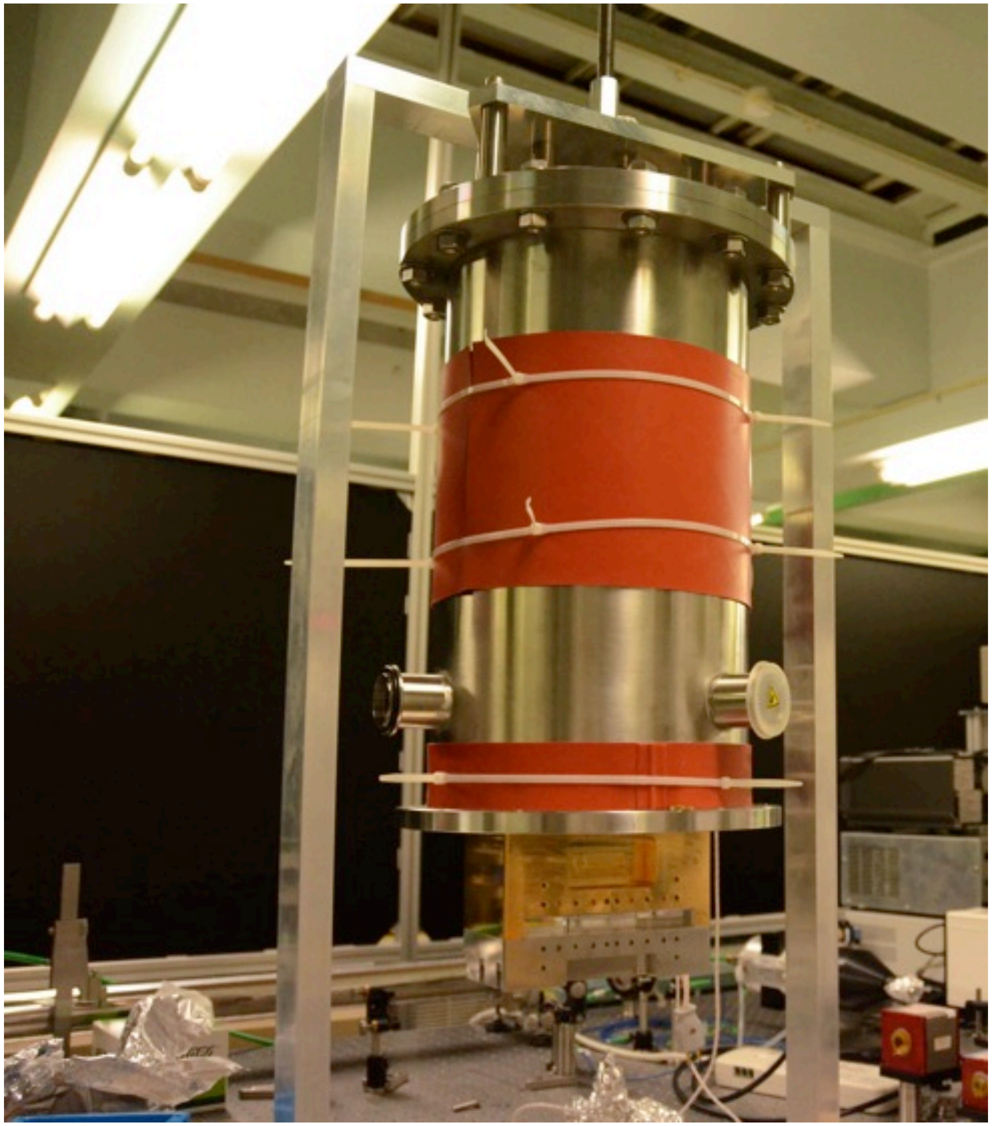
- The seed pulse from Regen. Amp. passes through TFP, FR, HWP.
- The seed beam incident under Brewster angle, therefore, the polarization direction is limited.
- For multi-pass amplification (> 2 passes) a Pockels Cell is used.
- After multi-pass amplification, the output pulse will be extracted.

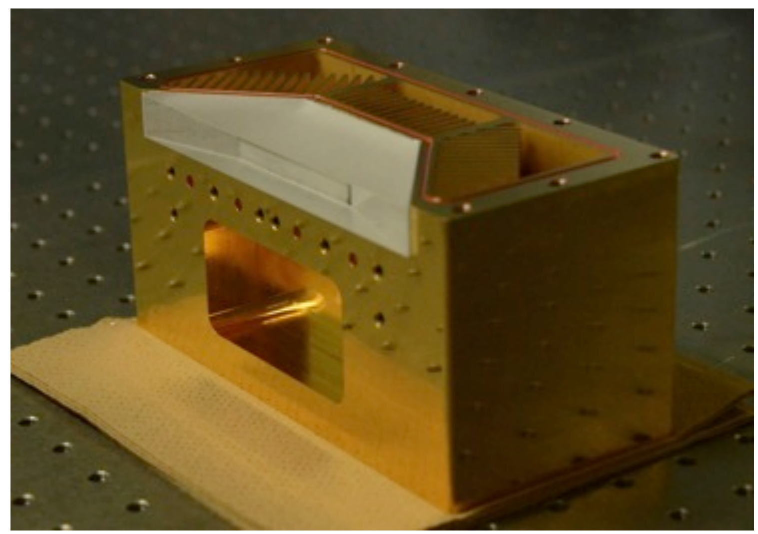
Amplification Calculations



- 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***.





Summary

"玄武(GENBU)"- laser has been conceptually designed for high power applications in ps and fs regime.

- Frond-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)

ILE/Osaka

Junji KAWANAKA
Yasuki TAKEUCHI
Akira YOSHIDA
Takuya NAKANISHI
Yusuke IOKA

ILT

Hiroaki FURUSE

LULI

Daniel ALBACH

JAEA

Koichi YAMAKAWA

Kinki Univ.

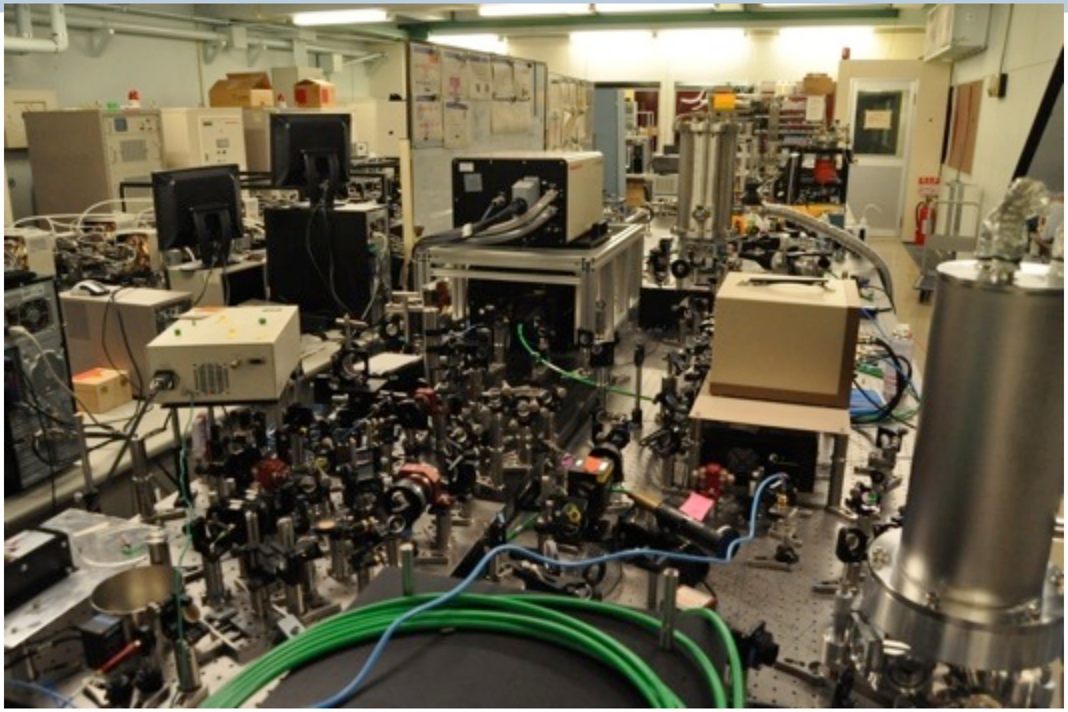
Naoki YONEDA
Miroru YOSHIDA

NIFS

Ryo YASUHARA

HPK

Toshiyuki KAWASHIMA
Hirofumi MIYAJIMA



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