High power drive laser development for EUV Lithography

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ABSTRACT

Extreme ultraviolet (EUV) is established as a drive wavelength of a next generation lithography. We have been developing a 13.5nm wavelength, laser-produced-plasma (LPP) EUV light source, using tin (Sn) as a fuel and a high-power, pulsed CO_2 laser as a plasma driver. Such combination of fuel and laser wavelength is the most promising candidate for a high-power-capable, EUV light source.
Our CO_2 laser system consists of Master Oscillator and Power Amplifier (MOPA), producing >200mJ energy in pulses of 15-20ns duration and repetition rate of 100 kHz. Master oscillator (MO) uses quantum cascade laser as seeder, RF-discharge excited, and multi-pass amplifier as amplifier. Power amplifier (PA) is a multi-stage system employing RF-discharge excited, fast-transverse-flow (FTF) CO_2 lasers.
We demonstrate high power CO_2 laser system more than 20kW with 100 kHz operation. Further improvement of our CO_2 laser system is underway. We report up-to-date MO and PA data of our laser system.

1. Requirement

To generate high power EUV efficiently, the CO_2 laser driver must meet the following requirements:

CO2 Laser Power >24kW × Conversion Efficiency > 4.0% × Coefficient (Plasma – IF)～30% = EUV power > 250W

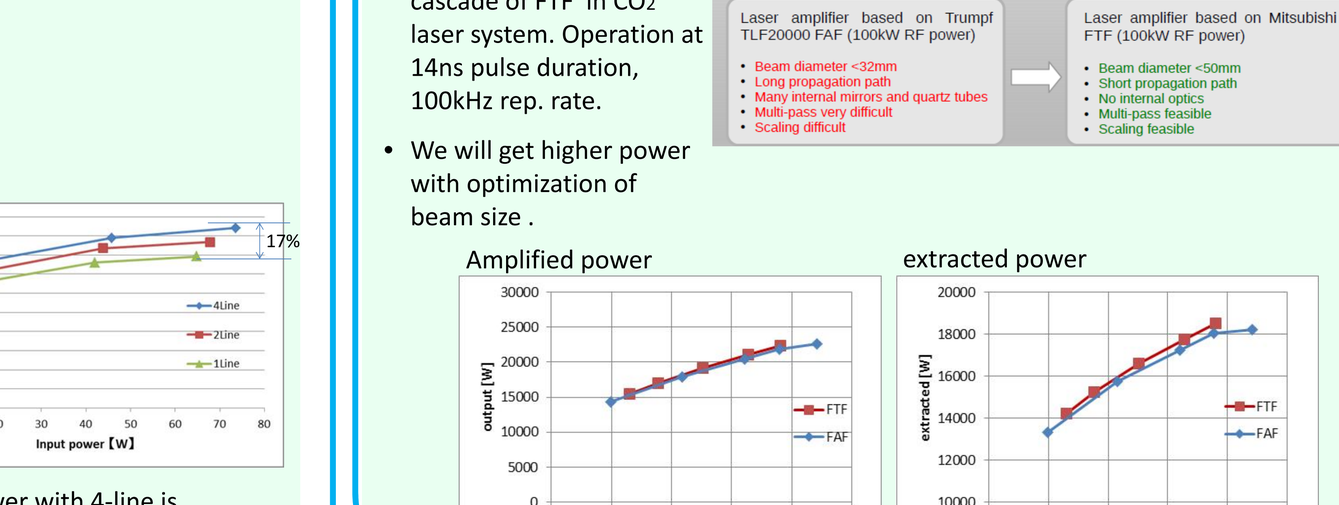
Multi-line MOPA | Short Pulse < 20ns

(Repetition Frequency : 100kHz)

And to generate high conversion efficiency and stable operation, CO2 laser driver meet good beam quality and stable pointing.

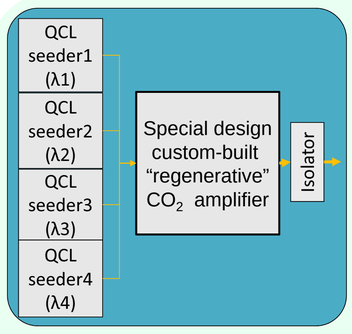
2. CO_2 Laser System configuration

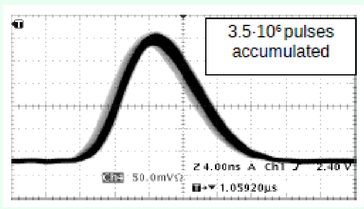
- Our CO2 laser system consist of Maser Oscillator Power Amplifier(MOPA) system in order to get short pulse and high power. Maser Oscillator uses quantum cascade lasers as seeder, RF discharge excited, and multi-pass amplifier. short pulse and high repetition rate. Power Amplifier is a multi-stage system employing RF-discharge excited, fast-transverse-flow (FTF) CO_2 lasers.



3. Multi line Oscillator

- We use 4-line seeding for more efficient pulse amplification.
- 4-line seed lasers are synchronized in order to get short pulse duration.

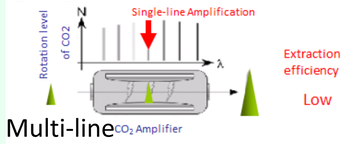




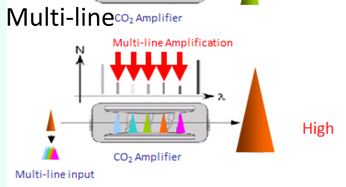
＜Master Oscillator performance>
- Pulse Width : 14ns (FWHM)
- Jitter : < 2ns
- 150W output

Amplification model

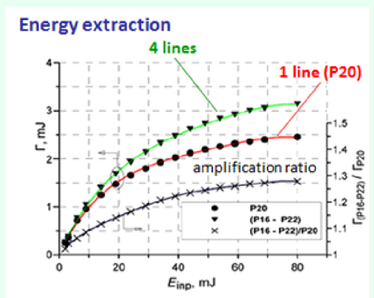
- 1-line



- Multi-line



Simulation result



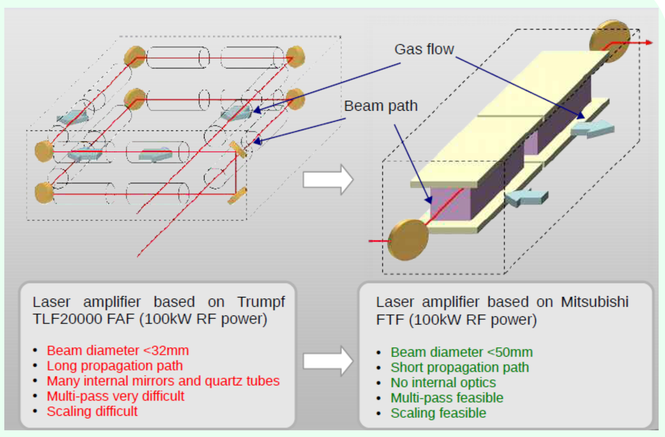
This work was preformed
by Research Institute for Laser Physics,
St. Petersburg, Russia [V.E. Sherstobitov et al]

test result

PreAMP power with 4-line is achieved 17% higher than 1-line.

4. Power amplifier

- Fast-transverse-flow CO_2 lasers offer a higher gain and a shorter optical path in the amplification as compared to the fast-axial-flow (FAF) CO_2 lasers.
- 22.4kW achieved in a cascade of FTF in CO_2 laser system. Operation at 14ns pulse duration, 100kHz rep. rate.
- We will get higher power with optimization of beam size .

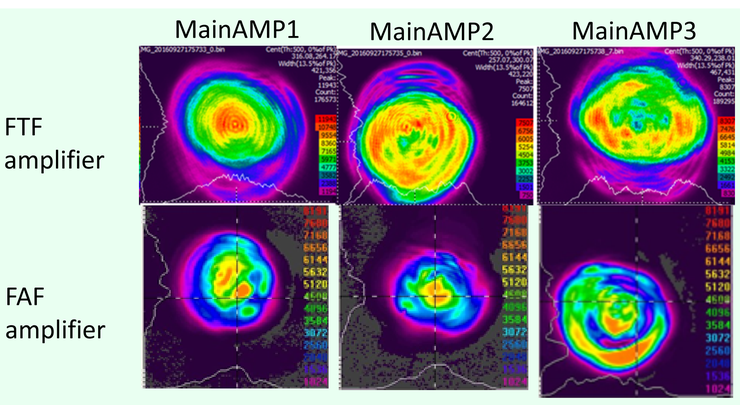


Amplified power

extracted power

5. Beam profile

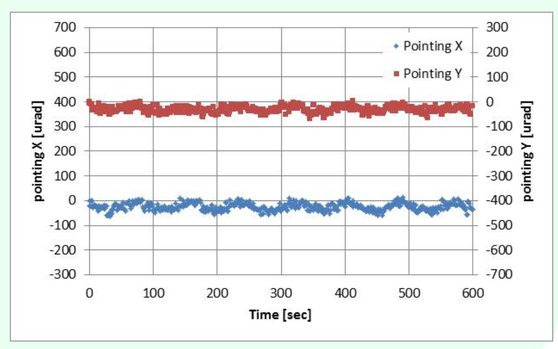
- FTF amplifiers are characterized by a larger beam sizes than FAF – reduced pulse fluence on optics
- Beam profiles exiting FTF system were seen to be more stable than those emerging from FAF.
- Better and more stable profiles produced by FTF system may facilitate higher C.E. operation



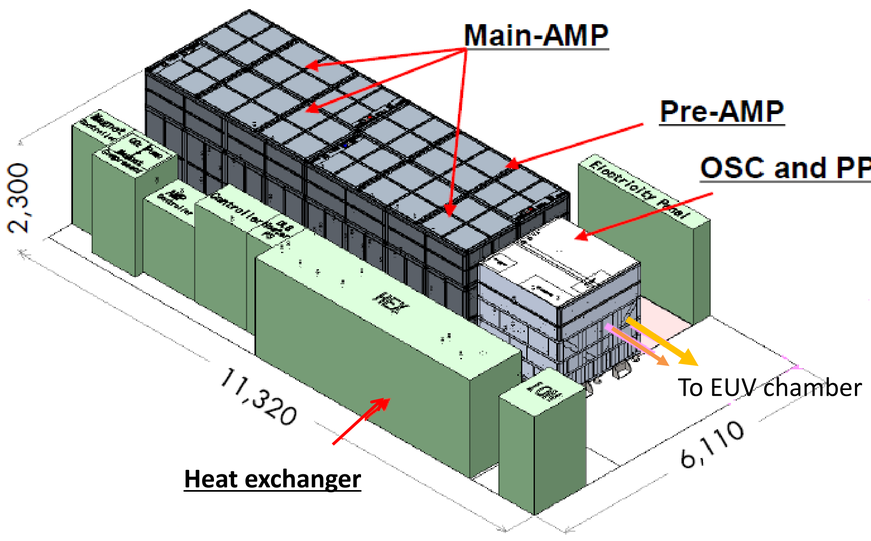
6. Optical axis Control

Master Oscillator → PreAmp (FTF) → MainAmp1 (FTF) → MainAmp2 (FTF) → MainAmp3 (FTF)

- We operate feedback loop between each amplifier to stabilize optical axis.
- Optical axis stability at MainAMP3 output is achieved below <+/-100urad.



7. Pilot#1 CO2 laser driver system



Power Amplifier

	Target	Current
Rep. rate	～100kHz	～100kHz
power	>27kW	22.4kW@100kHz (Optimization of beam size yet)
pulse duration	<20ns	14ns
Pointing stability	<100urad	<100urad
Conversion efficiency to EUV	5.0%	Testing now

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