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Development of the reliable 20kW class pulsed carbon dioxide laser system for LPP EUV light source

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Abstract

Laser Produced Plasma (LPP) Extreme Ultra Violet (EUV) light source is expected to be used for next generation lithography. To realize such performance for industrial use, the main driver laser is one of the key components. Our source uses a high power pulsed carbon dioxide (CO_2) laser as a plasma driver. A master oscillator and a power amplifier (MOPA) system based on a new configuration of an RF-excited CO_2 laser is the key to high efficiency. This pulsed CO_2 laser system has started to operate. This report shows its initial performance. Also for a reliable industrial system, the optical instability caused by vibration and thermal distortion of optics should be suppressed at 20 kW output level. The primary design of key modules, such as mirrors, for the CO_2 laser, and dynamic design concepts are shown in this report. We have achieved 7.6 kW, 14 nsec, 100 kHz pulsed output in this configuration.

Requirement for EUV

Requirements of a CO_2 laser

as an industrial LPP type EUV light source.

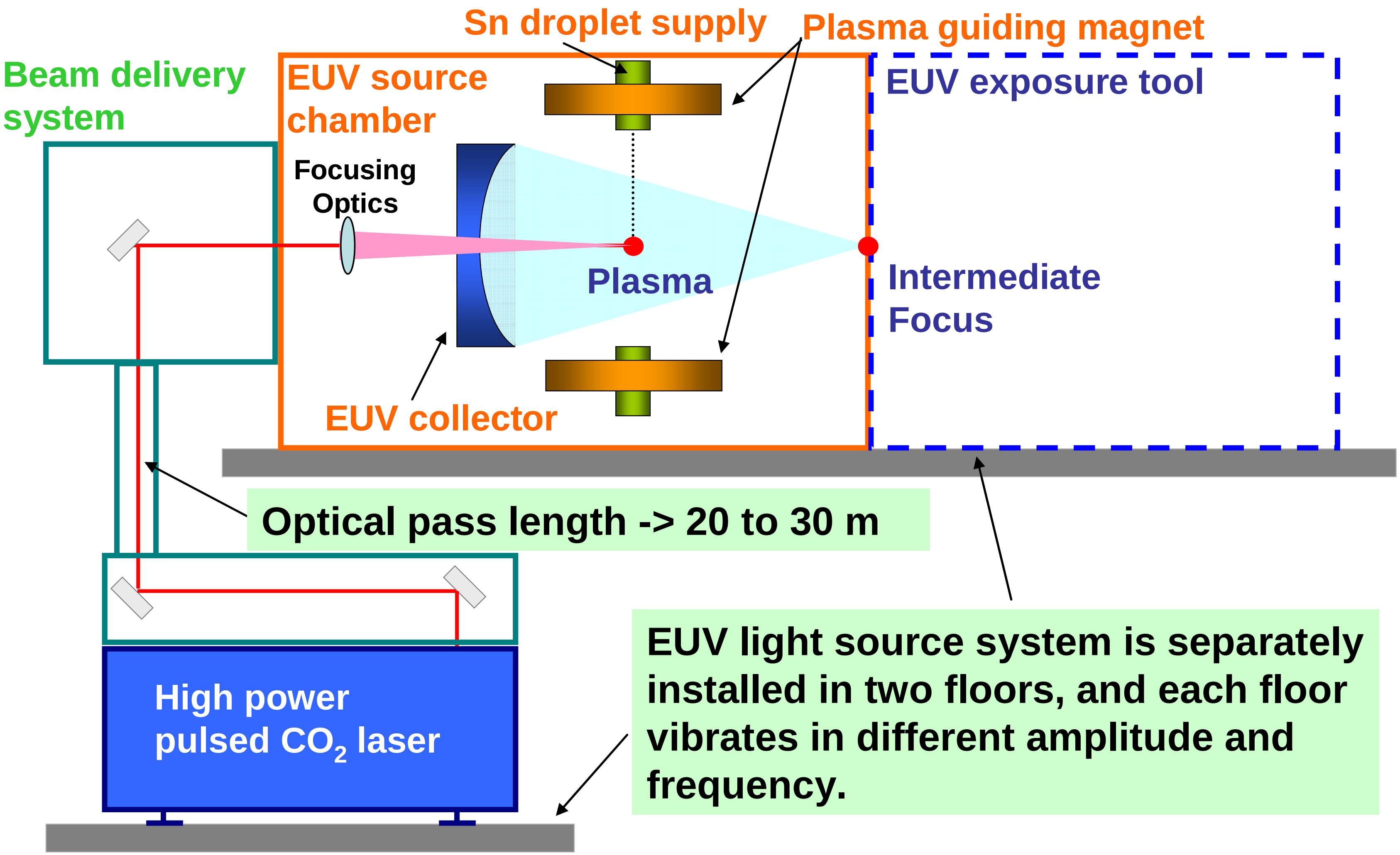
- Higher efficiency and operational reliability of the system are key for industrial use.
- To minimize optical loss of EUV, the EUV generation vessel is located closely beside the scanners.
- To minimize footprint in a clean room, the CO_2 laser system is located on a different floor (usually downstairs) from where the scanner is located.
- These two places have different vibration design specifications. Usually, the floor where the CO_2 laser is installed is less stiff than where the scanner is located. Table 1 shows the major requirements of EUV light source system and the driver laser.

Major target specifications of EUV and CO_2 Laser

	units	Specifications
EUV power (13.5 nm)	W	200
EUV power stability 3σ	%	12.0
Conversion Efficiency	%	5.0
CO_2 power (10.6 μm)	kW	20
CO_2 laser pulse duration	nsec	15 – 20
CO_2 laser energy stability 3σ	%	6.0

►CE: conversion efficiency from CO_2 laser to EUV light

LPP EUV light source system



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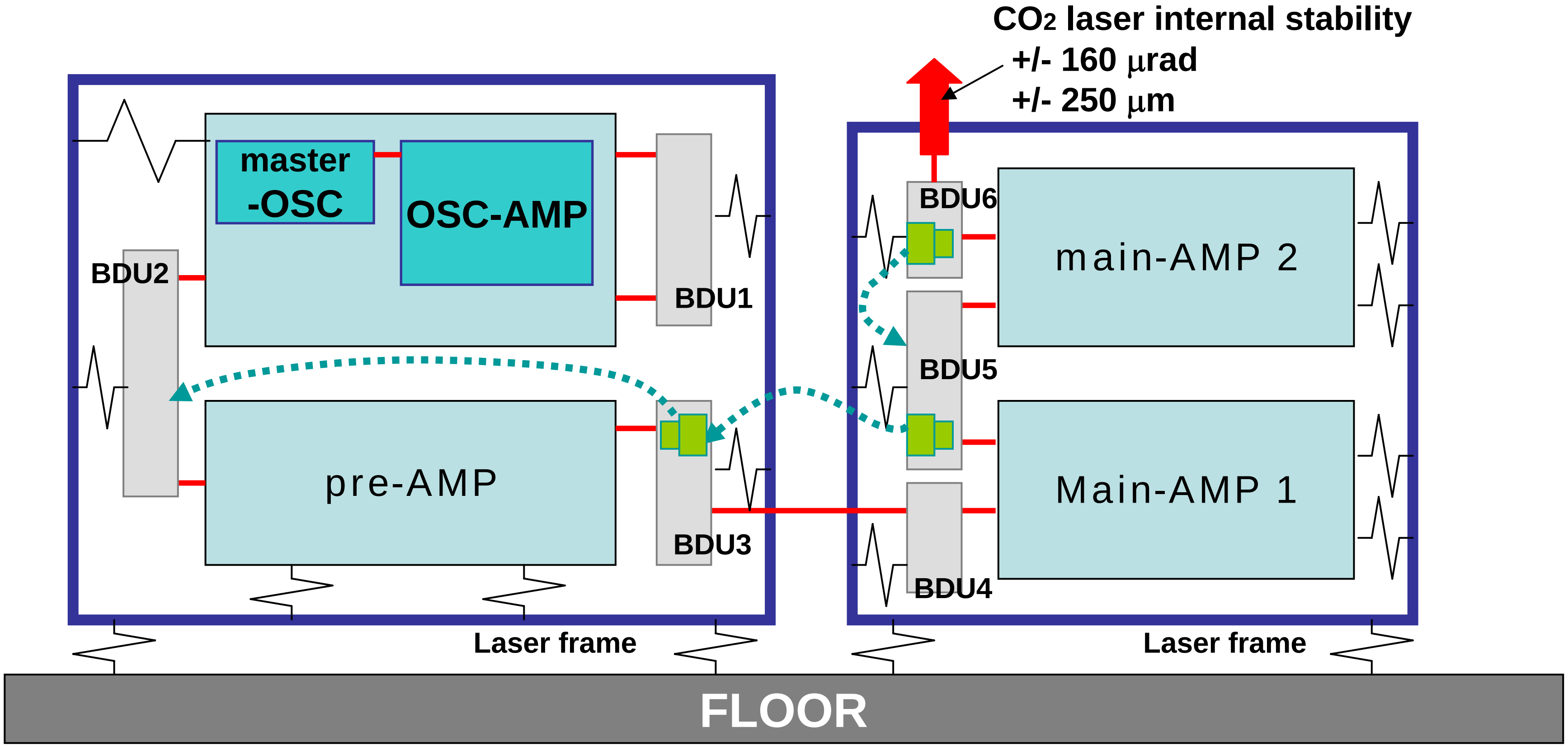
CO_2 laser pointing & position stability with control



BDU:Beam Delivery Unit

- This system has four major units
  - Master-OSC, OSC-AMP
  - pre-AMP, main-AMP

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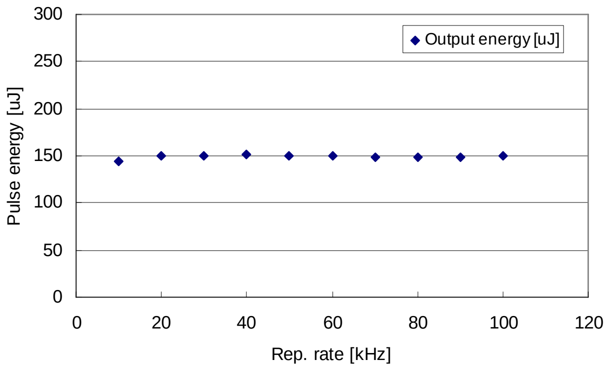
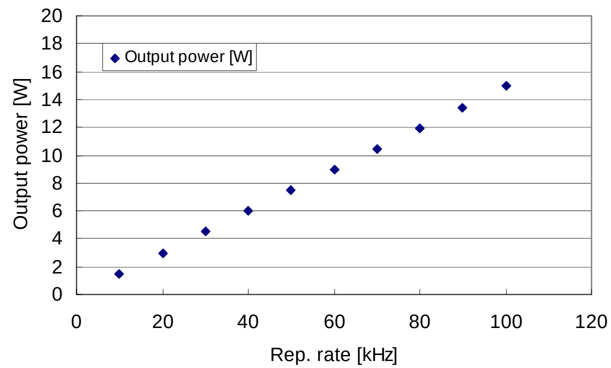
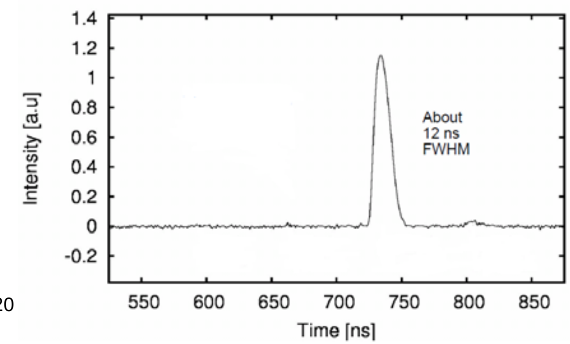
Results

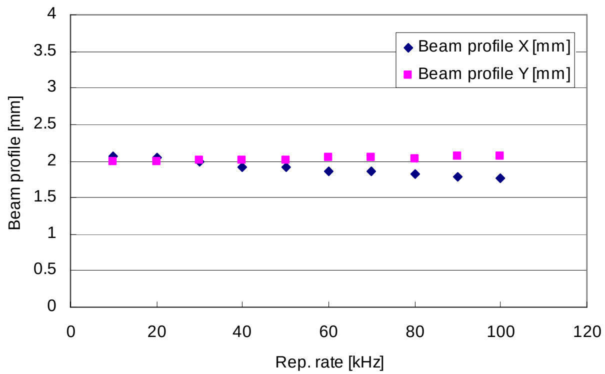
- The main performance of the master-OSC, OSC-AMP, pre-AMP, and main-AMP modules
- The master-OSC has constant pulse energy 150 μJ up to 100 kHz. Also the beam profile is stable at 100 kHz, 15W power level.
- OSC-AMP amplifies the pulse from 10 W (100 μJ, 100 kHz) to 100 W (1 mJ, 100 kHz, target 150 W) and inputs the pulse to the pre-AMP. The performance of the output v.s. RF duty of 100% at 4 kW with 6 W input, the beam profile, and the pulse duration are also shown.
- The pre-AMP amplifies the pulse from 100W to 1.7 kW (target 3 kW) and inputs the pulse to the main-AMP. The performance of the input and output characteristics at RF duty of 85% at 80 kW, output power v.s. RF duty at input of 100W, the beam profile, and the pulse duration are also shown.
- The main-AMP amplifies the pulse from 1.7 kW (17 mJ, 100 kHz) to 7.6 kW (76 mJ 100 kHz, target 20 kW) and inputs the pulse to the EUV vessel. The performance of the input and output characteristics at RF duty of 80% at 200 kW, output power at input of 1.7 kW, the beam profile, and the pulse duration are also shown.
- Each module shows the performance at feasible level to meet the system specifications. The master-OSC, the OSC-AMP, the pre-AMP, and the main-AMP are going to be tuned for meeting the targeted specifications.

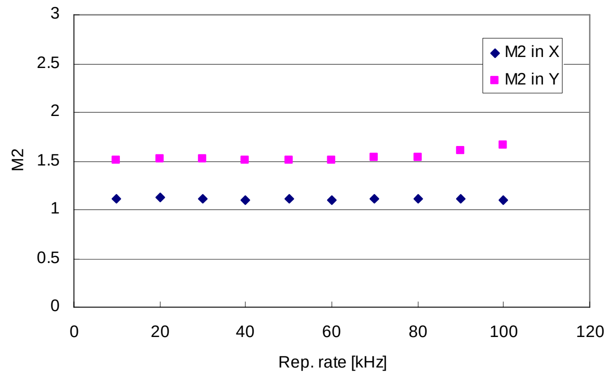
master-OSC performance

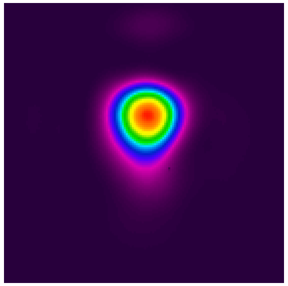












beam profile ($1/e^2$)

H : 3.4mm / V : 3.8mm

-Target:150 μJ pulse energy was achieved

-Good beam profile & rep rate performance

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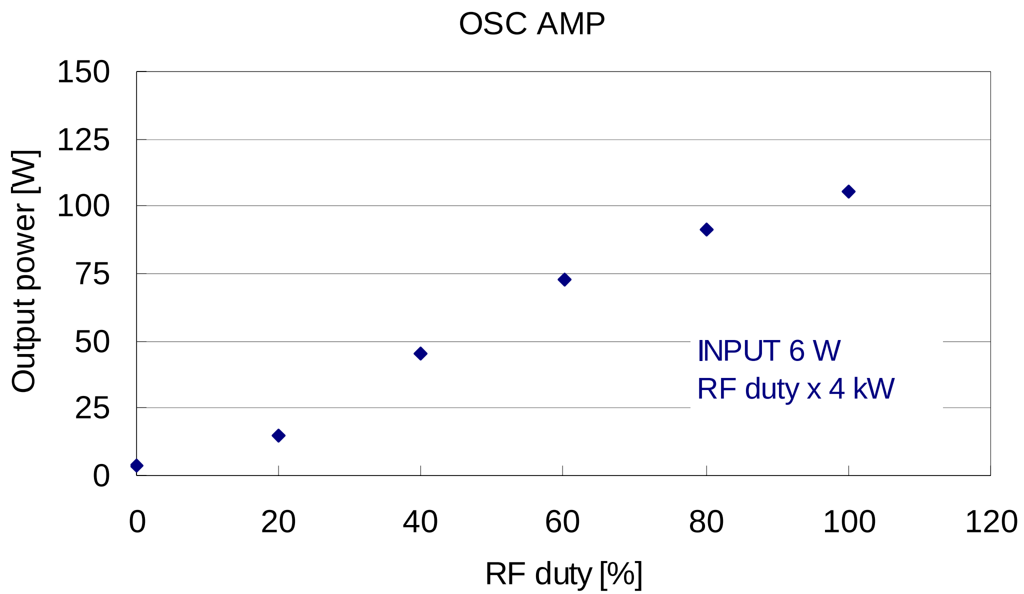
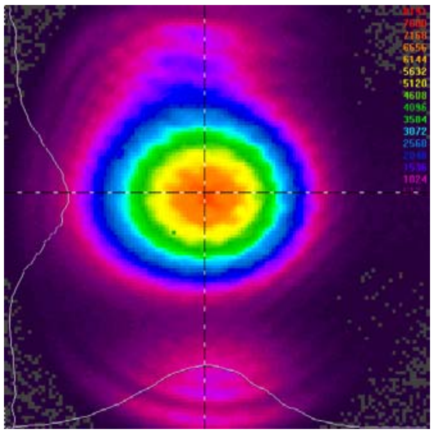
OSC-AMP performance



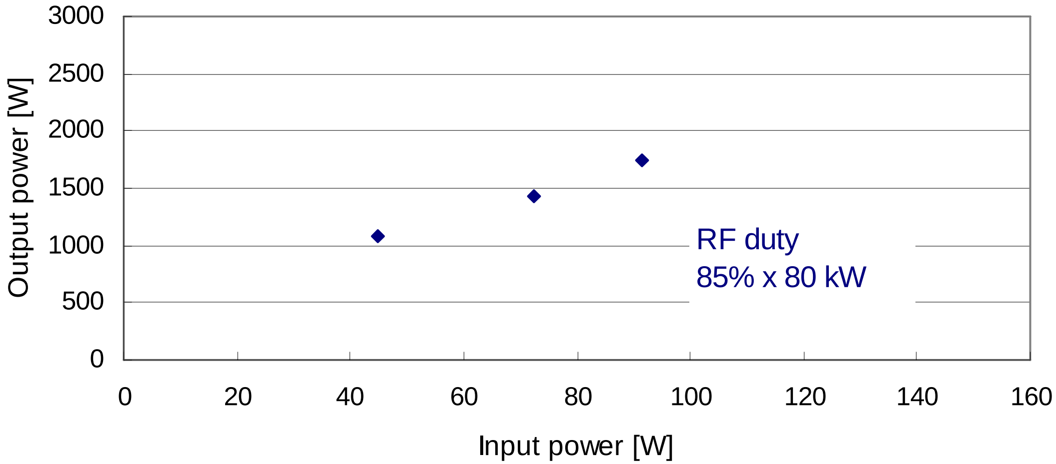
beam profile (1/e^2)

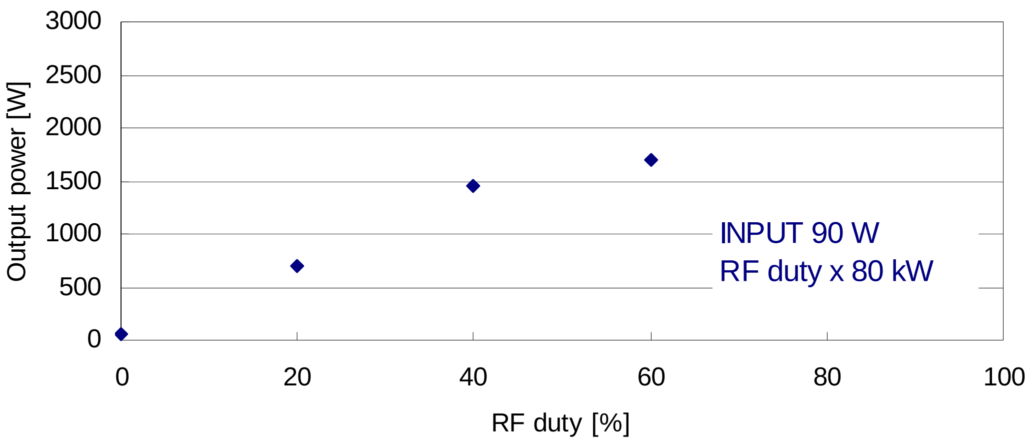


H : 18.0mm / V : 16.8mm

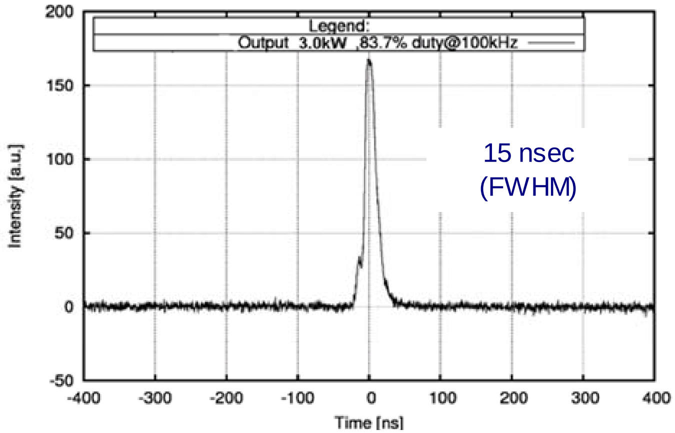
- Amplification result is OK
- more OSC power needed (planning wk1108)

pre-AMP performance

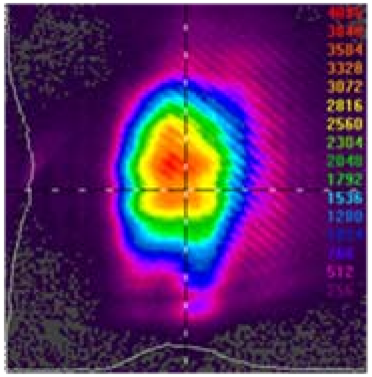




pulse shape



beam profile ($1/e^2$)



V : 15.9mm / H : 11.6mm

- Amplification result is OK
- Need more precise alignment to obtain good beam profile

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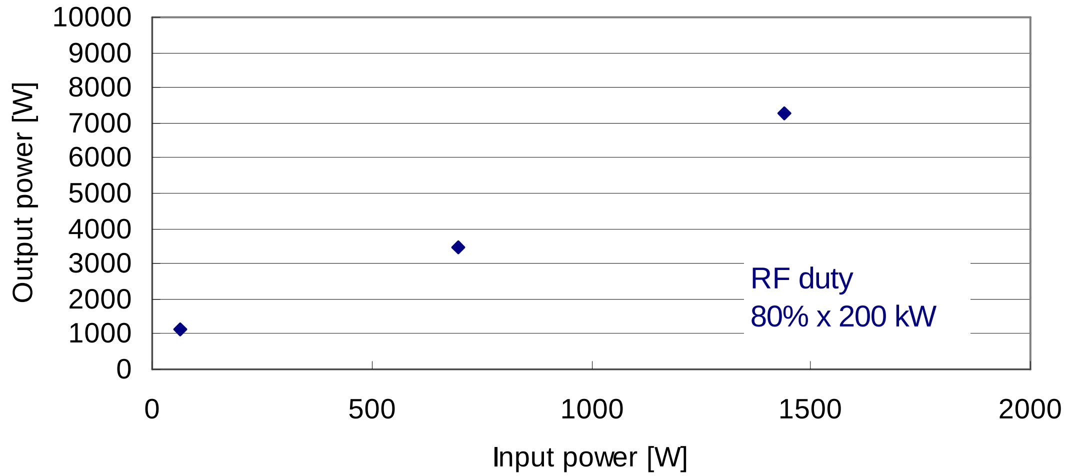
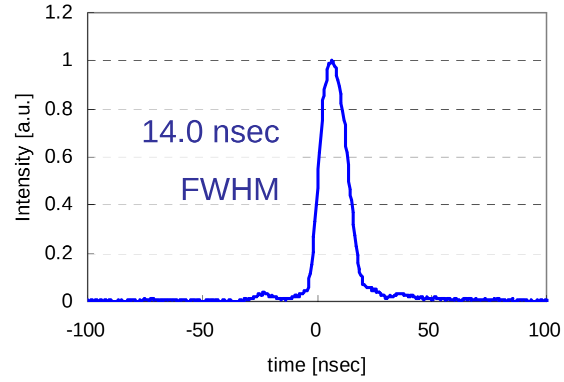
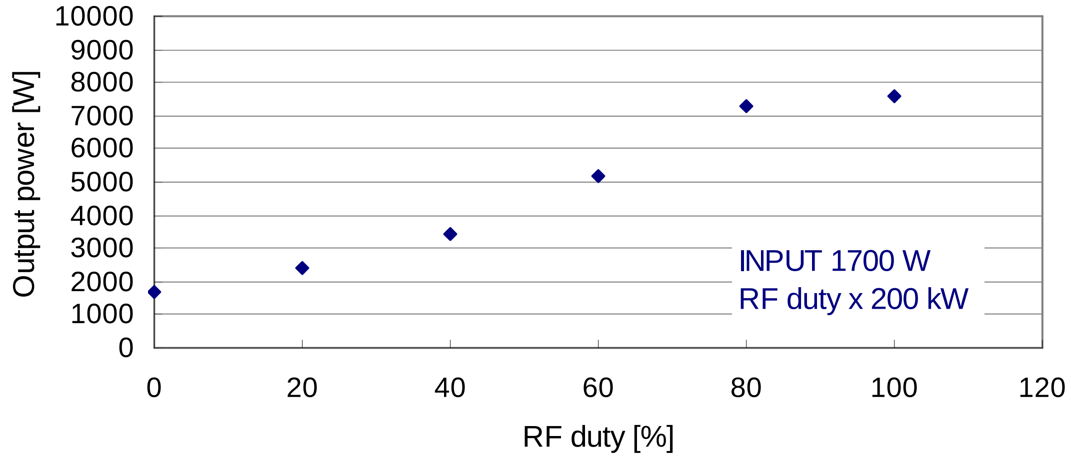
main-AMP performance

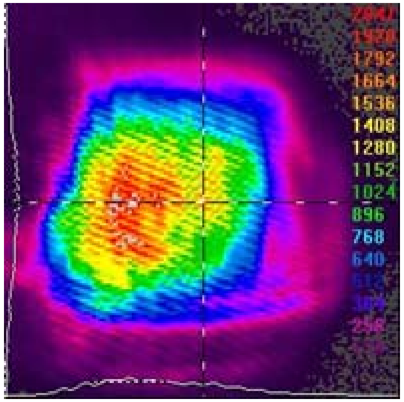


pulse shape





beam profile (1/e^2)



H : 16.5mm / V : 17.1mm

- Amplification result is OK
- Need more precise alignment to obtain good beam profile

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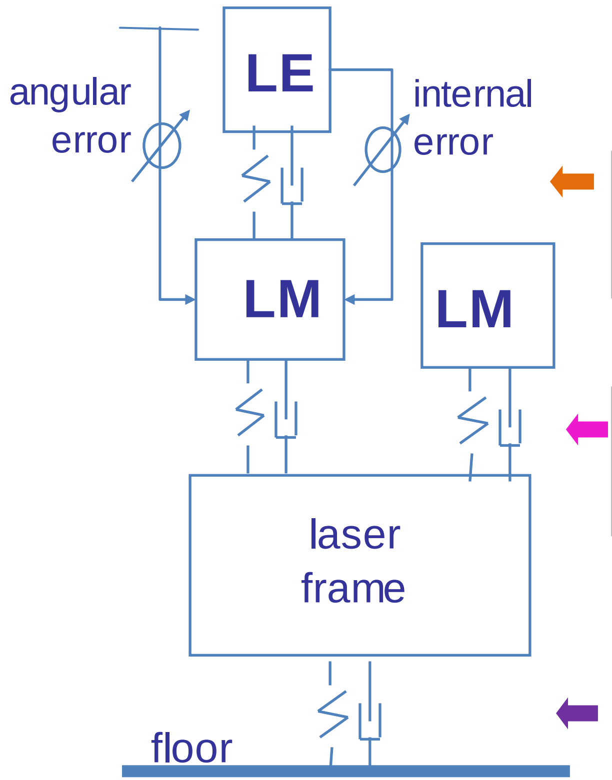
Dynamic stability

For industrial use, laser alignment also should be protected from the vibration which mainly propagates from the floor. For this purpose, there are two main issues that need to be taken care of. One is the mechanical stiffness of optical construction, and the other is the fast (>100 Hz) feedback system for the correction of the alignment.

Figure shows the schematics of dynamic design of the optical components. The installation floor for a laser frame needs to have greater stiffness of more than 5 to 10 Hz. The laser frame to the main module (e.g., OSC, pre-AMP, and main-AMP) needs more than 15 to 20 Hz stiffness. And the main module to each optical element (e.g., optics holder, optics, and sensor) needs more than 100 Hz stiffness. This system is designed to meet these design specifications. And the fast feedback alignment correction system will be equipped in BDU5-6.

Dynamic design of CO_2 laser system



Elements in main modules:
>100Hz

Main modules to laser frame:
15-20Hz

Mounting to floor:
5-10Hz

LM = laser module (ex: OSC, pre-AMP & main-AMP)
LE = laser element (ex: optics holder, optics & sensor)

Thermal stability -1

- Thermal distortion of optical components causes the beam profile to deform and the beam to go out of alignment. When the reflective mirrors and the window receive a heat load from the CO_2 laser beam at their coating and base materials, the optics deforms and the diffractive index of the material change. Deformation of the mirror surfaces result in the distortion of the beam profile. The window design will be reported later.

- Way for solving the thermal influence on the mirror

  1. Improvement of material

     --- lower thermal expansion, higher thermal conductivity

  2. Improvement of cooling structure

     --- the symmetrically shaped cooling channel
     for uniform distortion

Thermal stability -2

- Figure shows the simulation results of the distortion of the mirror surfaces with various design conditions. The input beam of the CO_2 laser is the Gaussian profile beam with 40 kW (= 80 w; 0.2% surface absorption safety factor 2.3). The standard, commercially available mirror for a CW CO_2 laser is mainly made of copper ("Cu current" in figure). The cooling channels behind the mirror surface are not symmetric with respect to its center.
- The symmetrically shaped water cooling channel

  To improve symmetrical cooling property ("Cu improved" in figure).

  To reduce the surface distortion, we have designed with lower surface expansion material, which is silicon carbide ("SiC improved" in figure). According to the calculation results, 80% improvement has been obtained by improving the water channel. 61% improvement has been obtained by changing the material.
- These mirrors with the improved design are going to be applied in our system.

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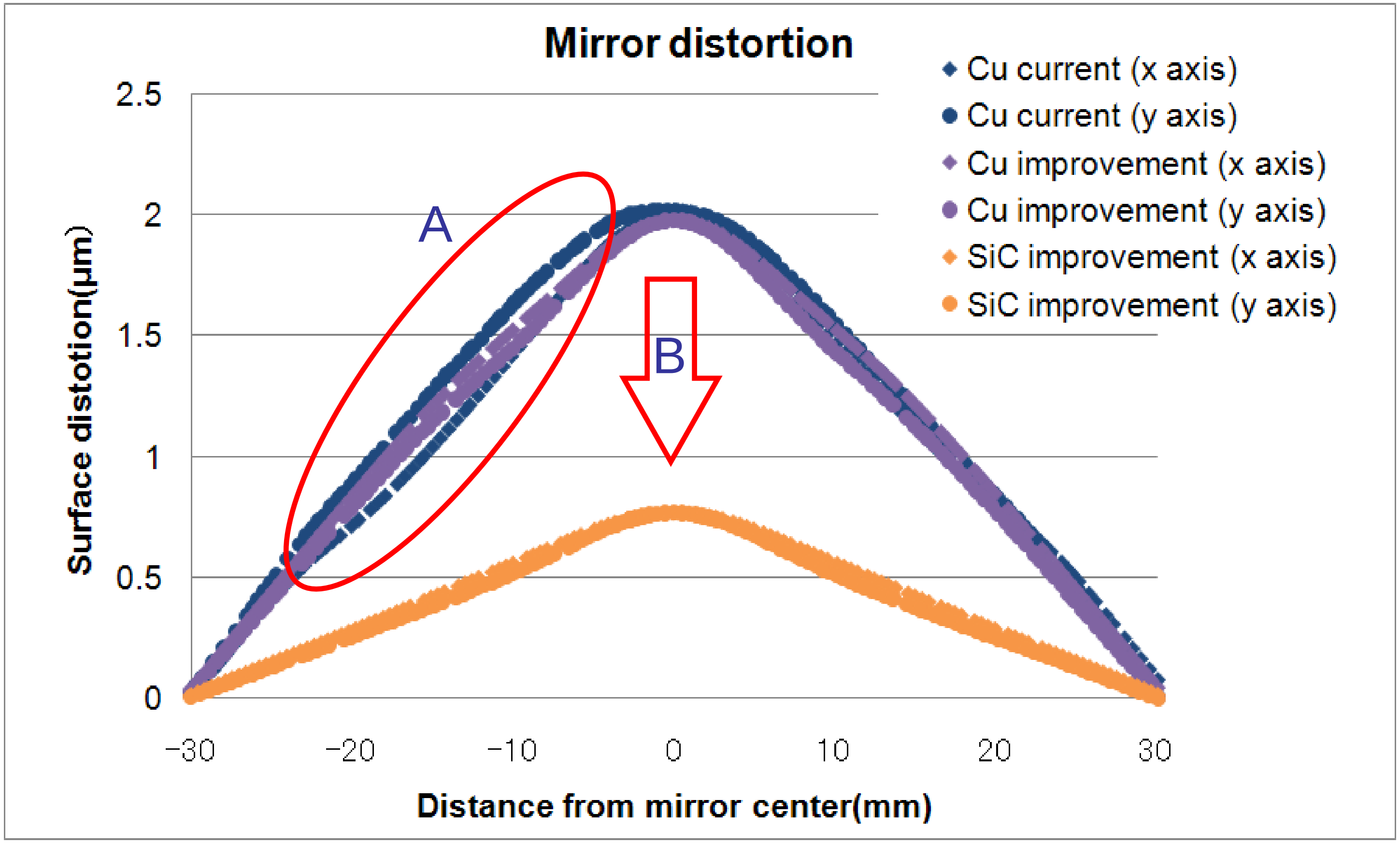
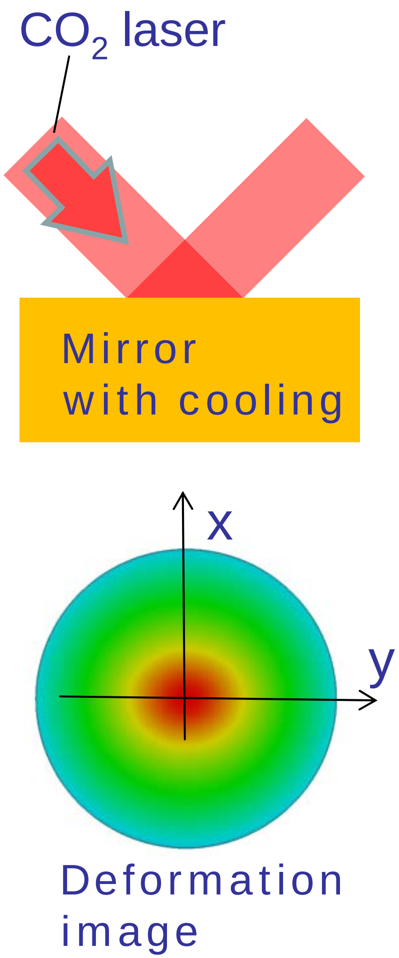
Optical thermal distortion





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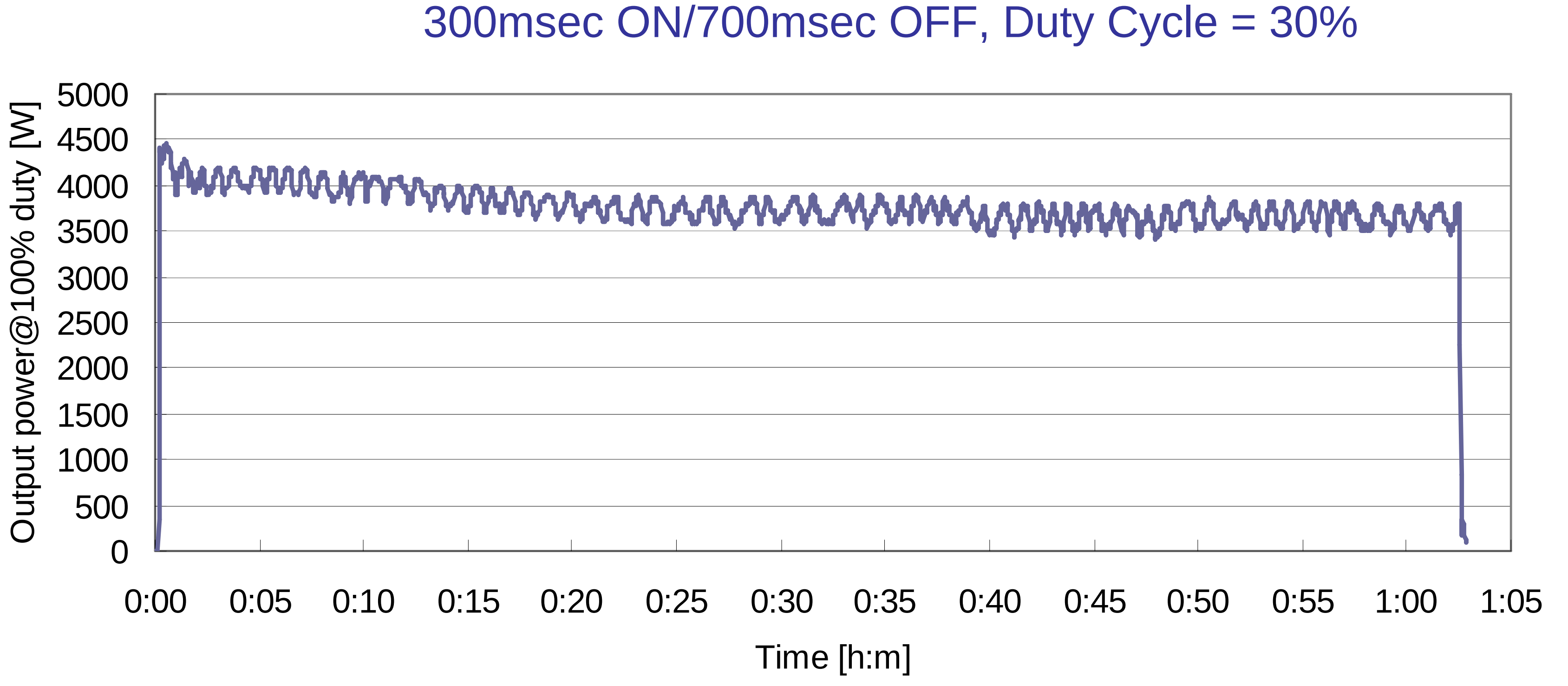
CO2 laser 1 hour operation

✓Output power

➢3.5 kW w/o energy control



- 1 hour operation was demonstrated at 30% duty cycle

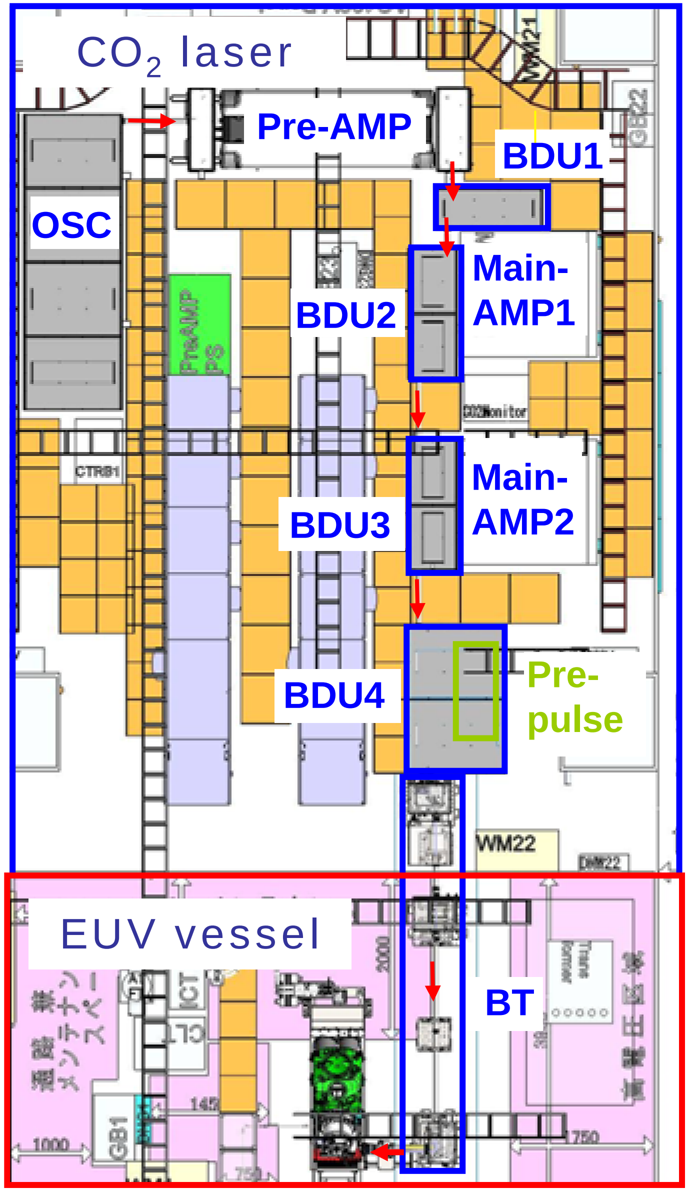
Conclusion

- The main performance of the CO_2 laser in this study and the target are shown in Table. In this initial experiment, these performances suggest that the targeted specifications for the driver laser for EUV light source are achievable. We have obtained the fundamental performance results of the key modules. Our system with the MOPA configuration shows basic performance to achieve the final target. Also there are still more room for improvement to get higher power.
- For the next step, we are going to employ the new optics that we have described in this paper and the active compensation feedback control device in our system for longer and reliable operation. Also the Sn target will be adopted to obtain EUV light performance. We believe the stable performance of the driver laser is one of the key requirements to achieve reliable EUV light source for industrial use.
- To obtain higher throughput in wafer fabrication, more EUV power will be required for the years to come. That means that higher CO_2 laser power is also required shortly. We need to improve each element to obtain more stable and higher laser power.

CO2 performance summary

	units	Final Target	Current results
Output power	kW	20	7.6
Rep. rate	kHz	100	100
Pulse energy	mJ	20	7.6
Beam profile ($1/e^2$)	mm^2	18 dia.	16.5 × 17.1

First CO_2 laser System Outlook



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