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Improving efficiency of pulsed CO_2 Laser system for LPP EUV light source

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Abstract

Laser Produced Plasma (LPP) EUV light source system has been developed for EUV lithography. For this LPP EUV light source system, high power pulsed CO_2 laser is required as a main drive laser. Current approach for this application is a MOPA system based on a small average power pulsed master oscillator and a chain of power amplifiers. The current MOPA system cannot provide more than 25% overall operation efficiency. The main reason is an insufficient power level at initial amplifier stages.

In this presentation, some of the pressing technical challenges of the LPP laser driver, such as efficiency and stability of operation, are shown. A new master oscillator system and a pre-amplifier system based on a novel configuration of a RF-excited CO_2 laser are the key to high efficiency. Higher energy efficiency and multi-kW output from low input power level are predicted and verified in our experimental pre-amplifier. Feasibility of over 15kW CO_2 laser system is shown by numerical modeling.

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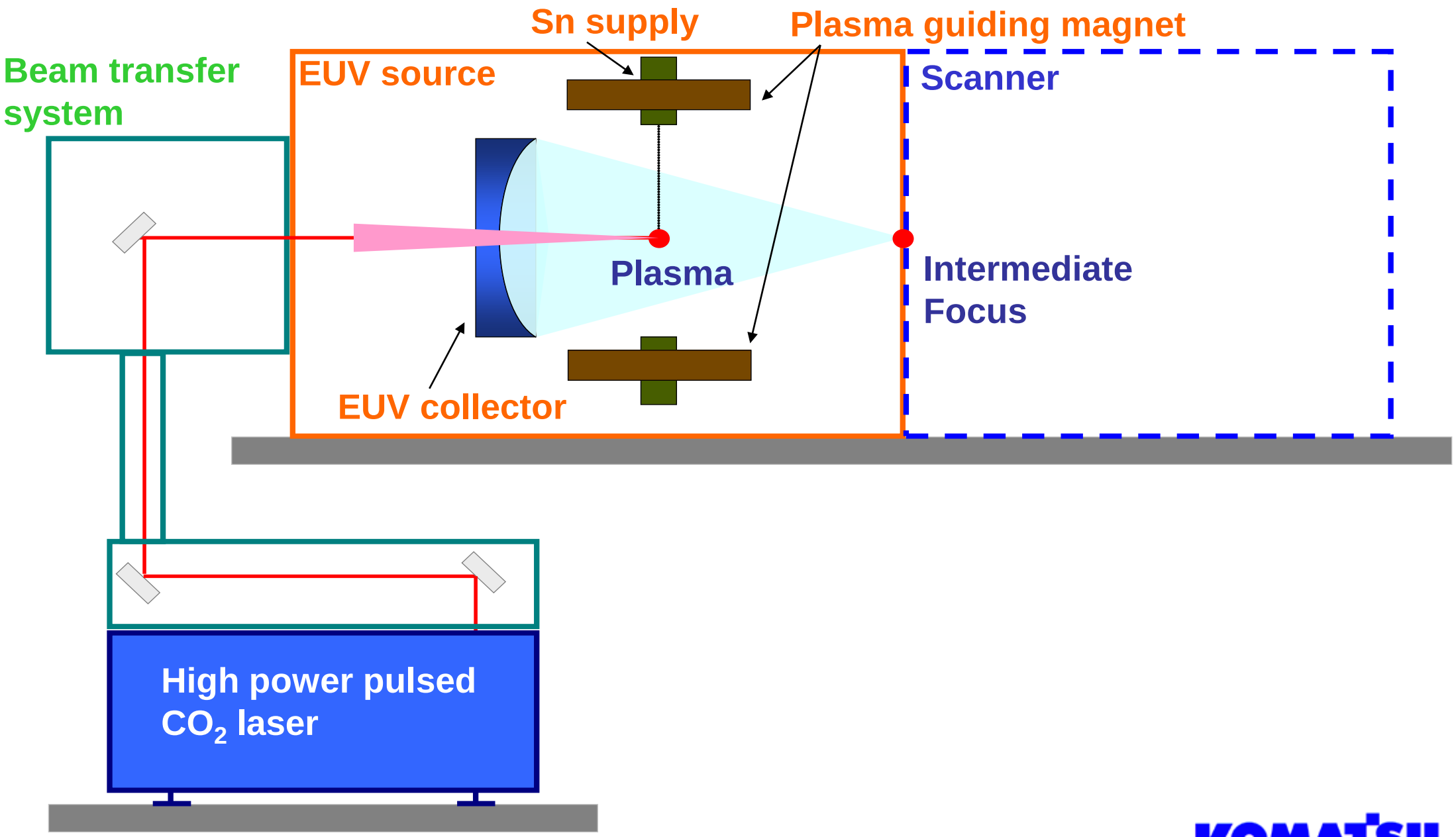
OUTLINE

- LPP EUV light source
- CO_2 laser system
- High-quality 20kW CO_2 laser system
  - Current status of multi-kW CO_2
  - Multi-line amplification for higher efficiency
  - Initial performance
    - Multi-line oscillator
    - High efficiency Pre-Amplifier
    - Main Amplifier
- Summary

LPP EUV light source



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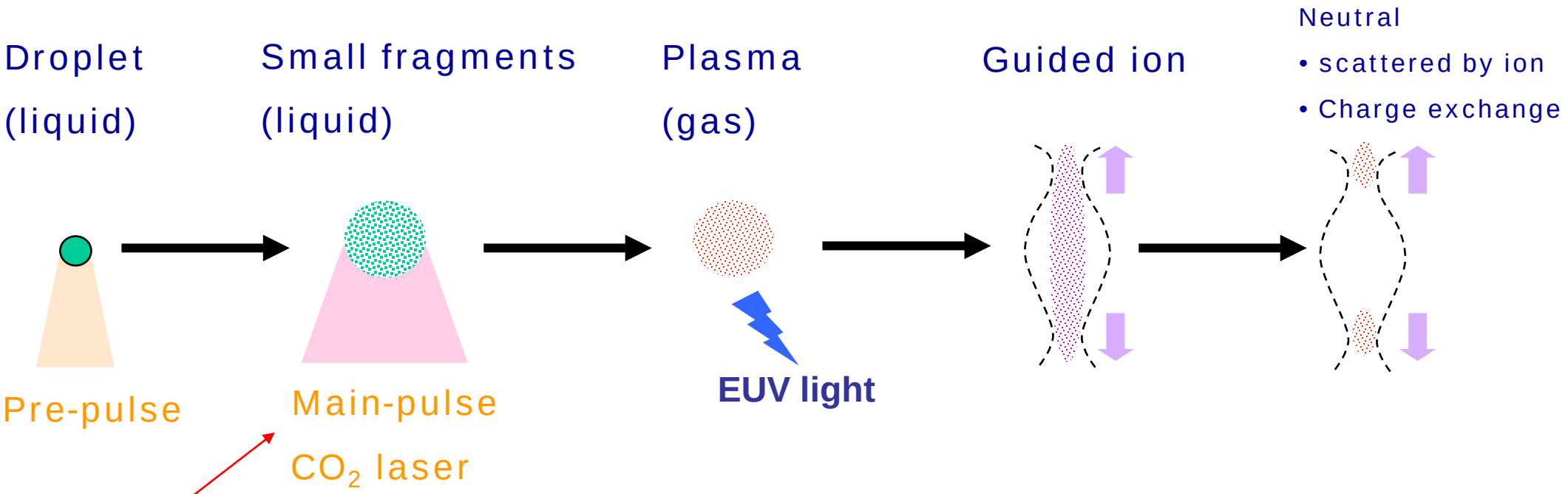
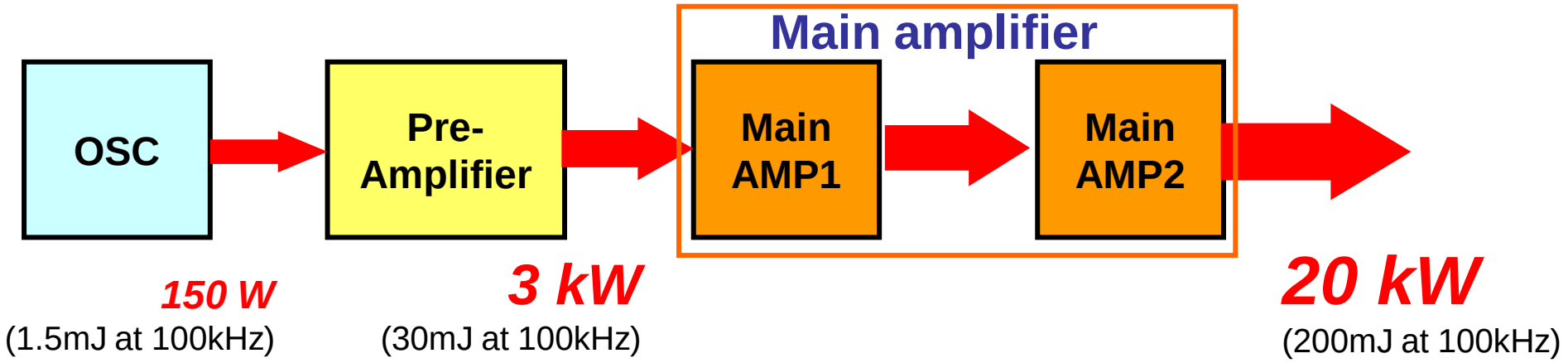
EUV light generation process



CO_2 laser system

- High power pulsed CO_2 laser
  - Combination of short pulsed high rep. rate Osc. and Industrial RF-excited CO_2 laser.



CO_2 laser system

Current status of multi-kW CO_2

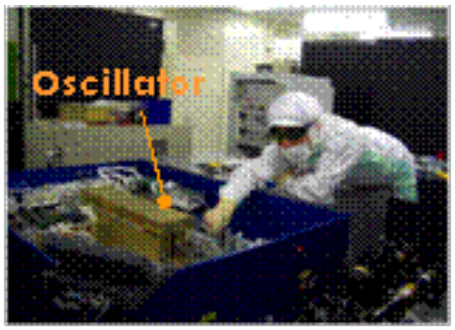
Laser Power	:	13 kW @ 30% duty
Pulse Width	:	20 ns
Repetition Rate	:	100 kHz
Beam quality	:	M2 <1.2

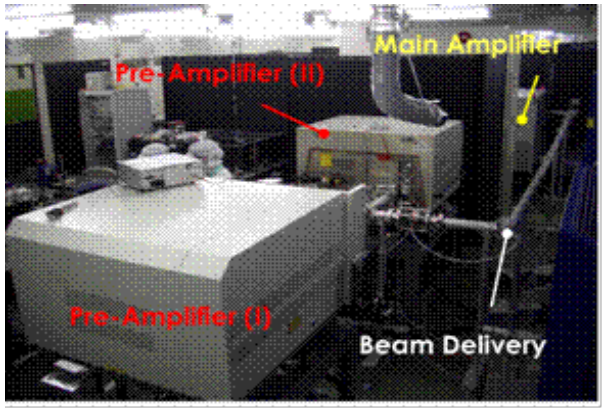
■ Laser System

Oscillator
Wave length: 10.6um
Rep. rate :100kHz
Pulse width :20 ns (FWHM)

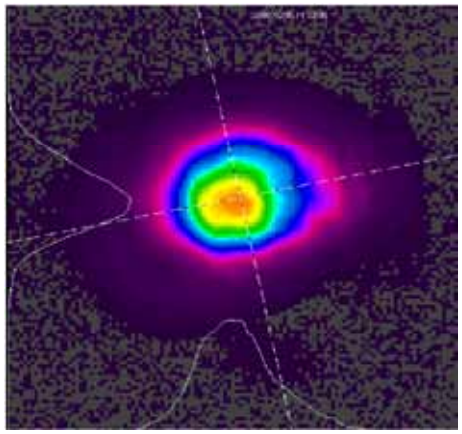
Pre-Amplifier
RF-excited CO_2 laser

Main-Amplifier
RF-excited CO_2 laser





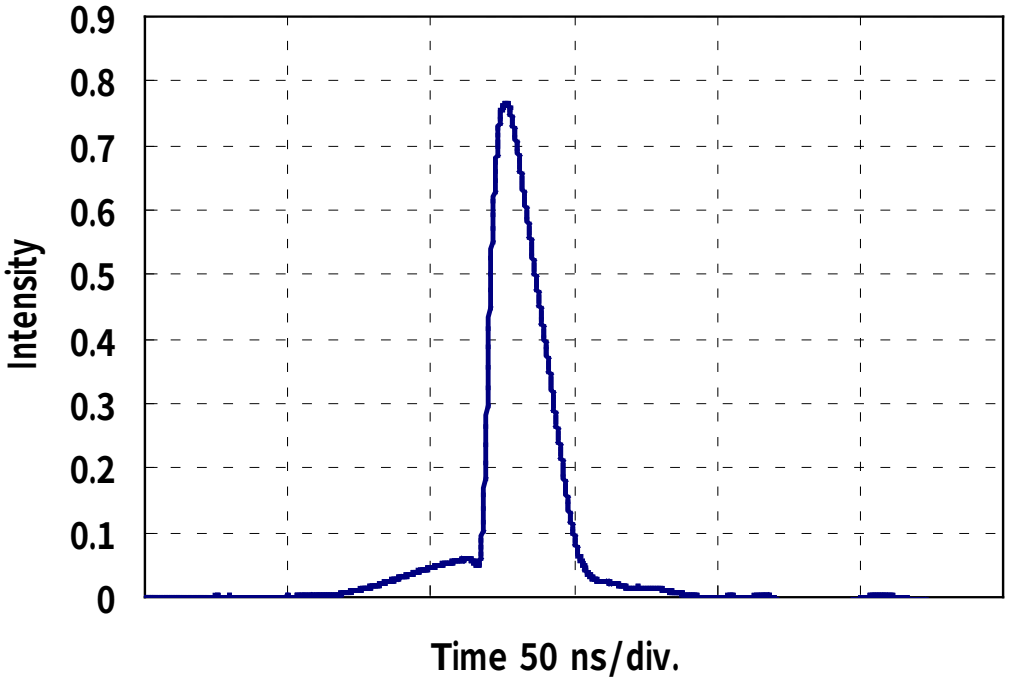
Laser beam profile



Current status of multi-kW CO_2

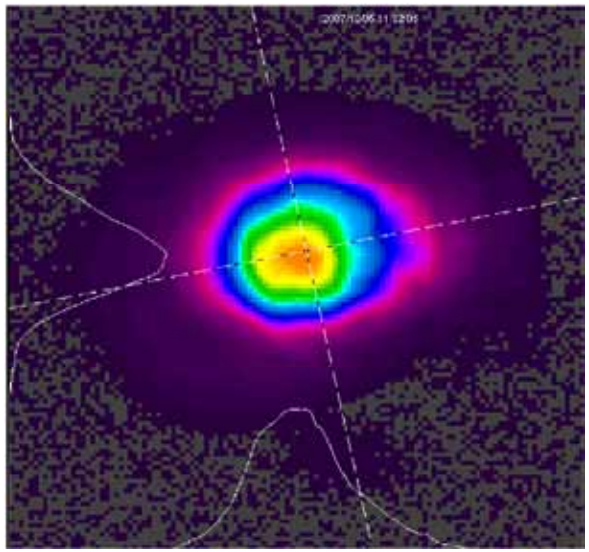
Ø Pulse shape and beam profile of current system

Temporal pulse shape



Pulse duration : 20 ns (FWHM)
Pedestal component : <10%

Laser beam profile

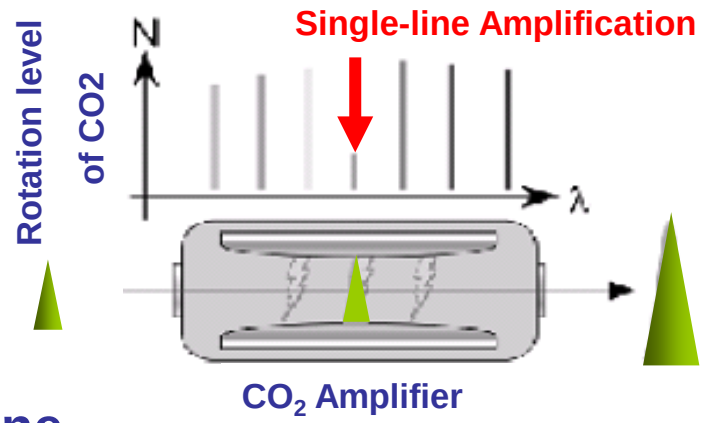


Multi-line amplification for higher efficiency

Ø Efficiency of Multi-line amplification

ü prediction of 1.3 times higher than Single-line

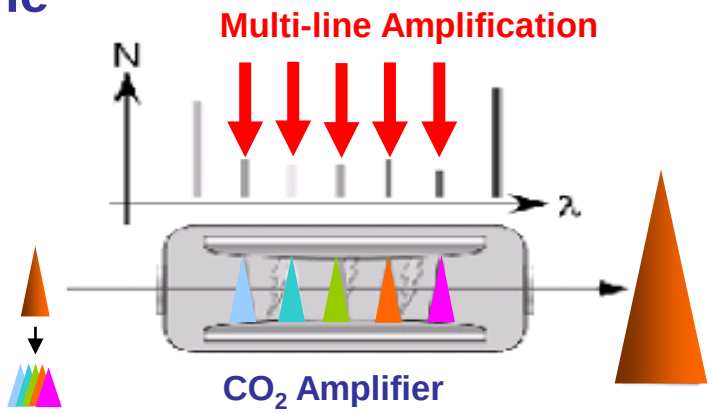
ØSingle line



Extraction efficiency

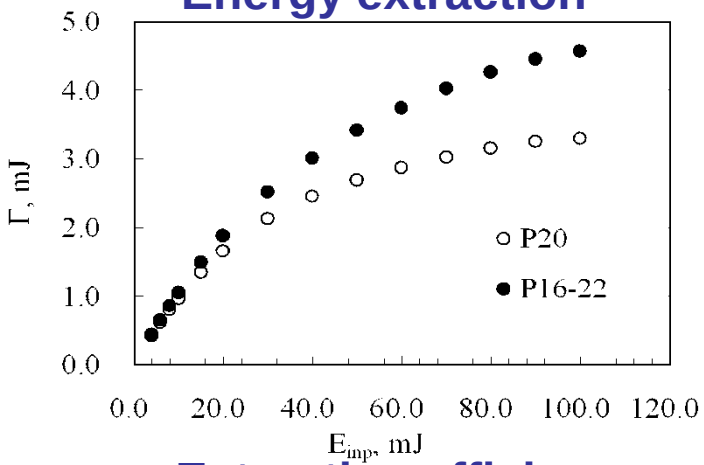
Low

ØMulti-line

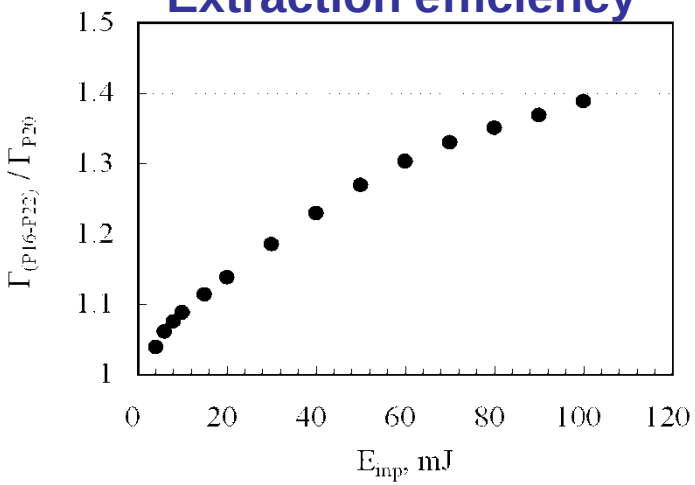


High

Energy extraction



Extraction efficiency



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

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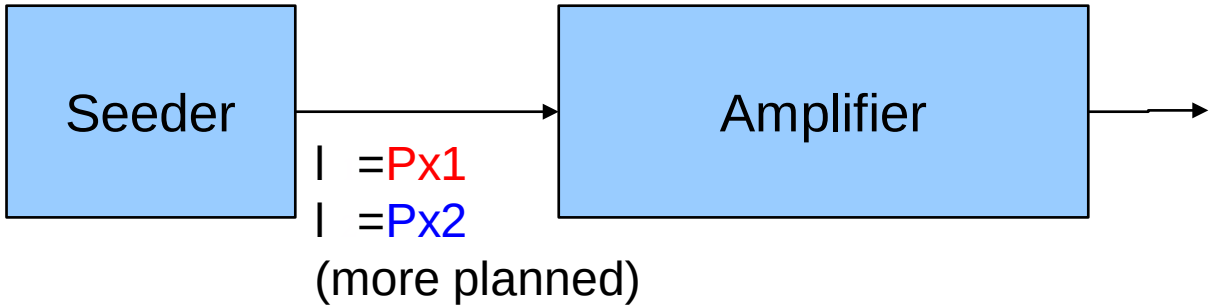
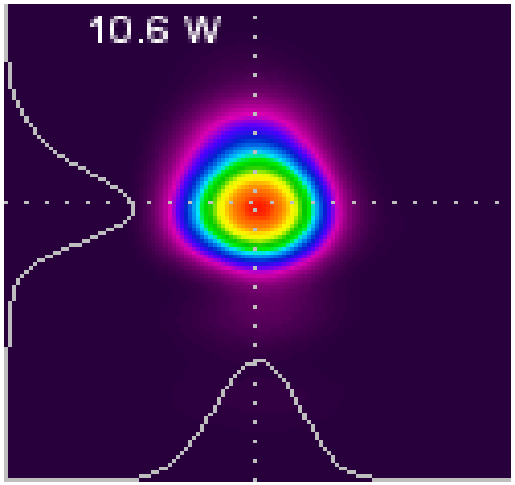
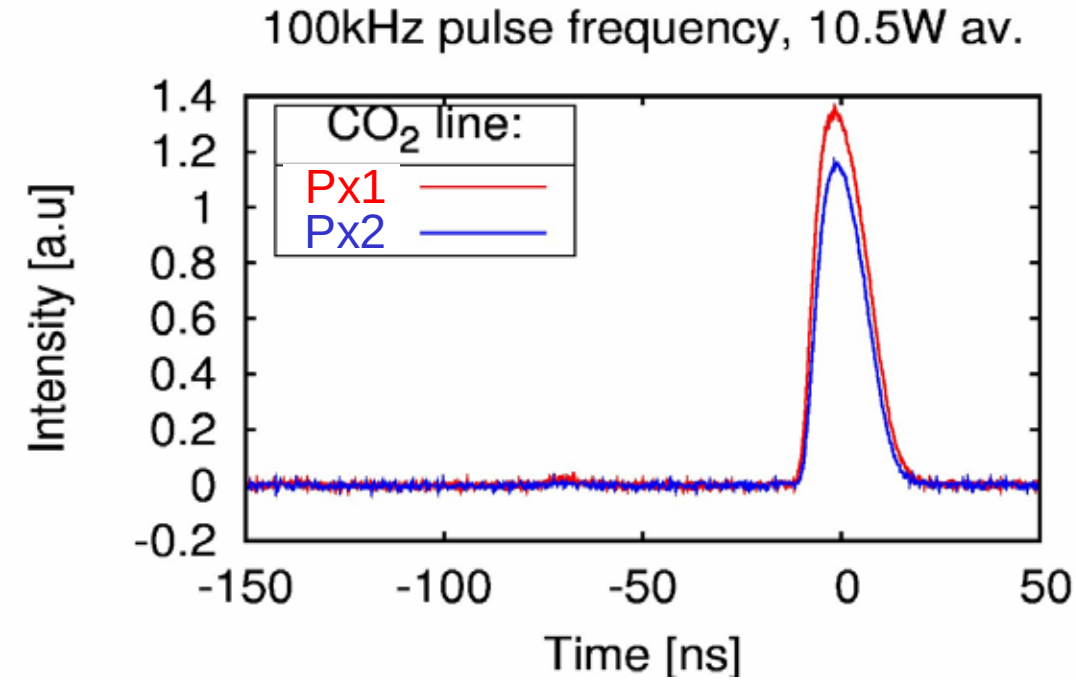
Multi-line Master Oscillator

Multi-wavelength seeded oscillator



High output beam quality M_2<1.3
(Far-field beam profile)





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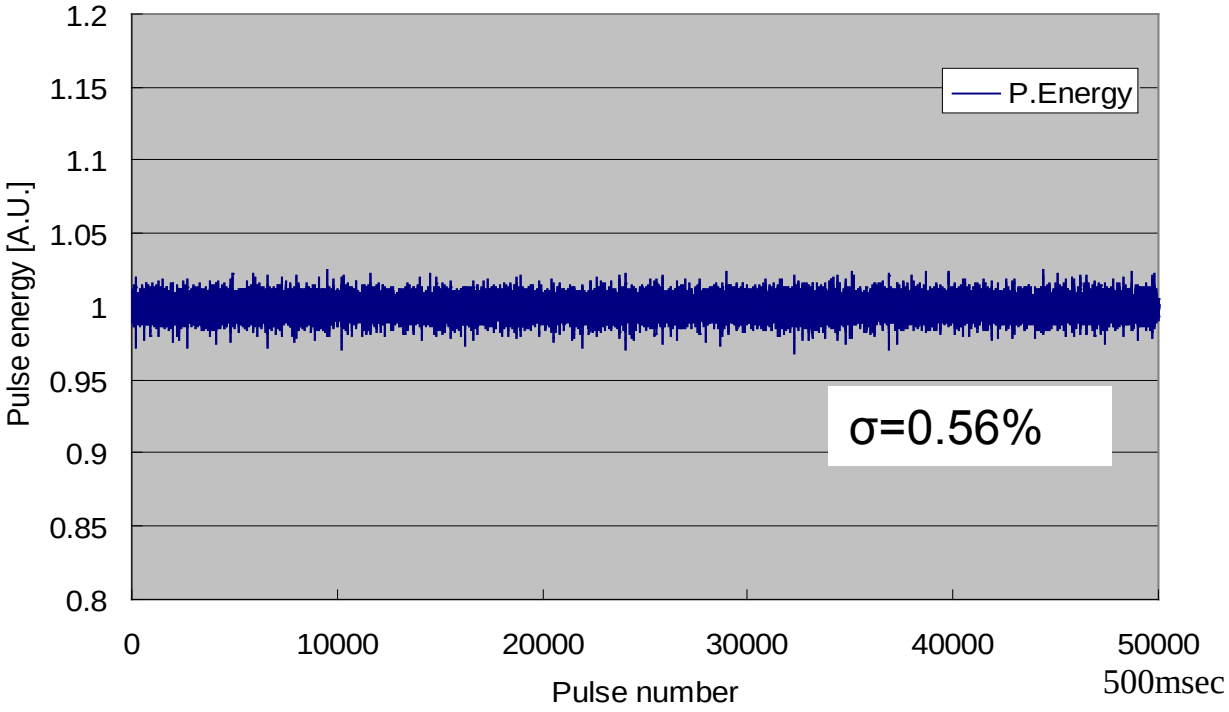
Multi-line Master Oscillator

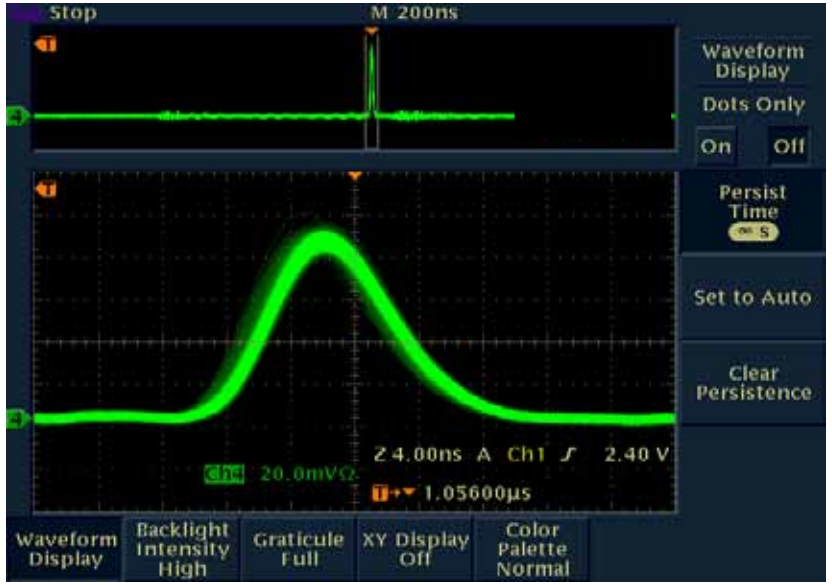
ØEnergy stability

üHigh pulse energy stability

Repetition rate : 100kHz

Closed loop operation

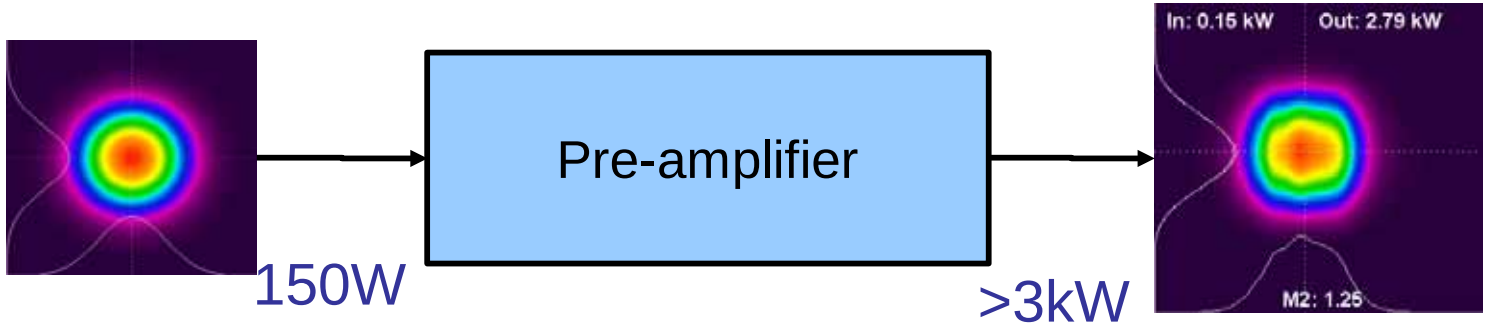




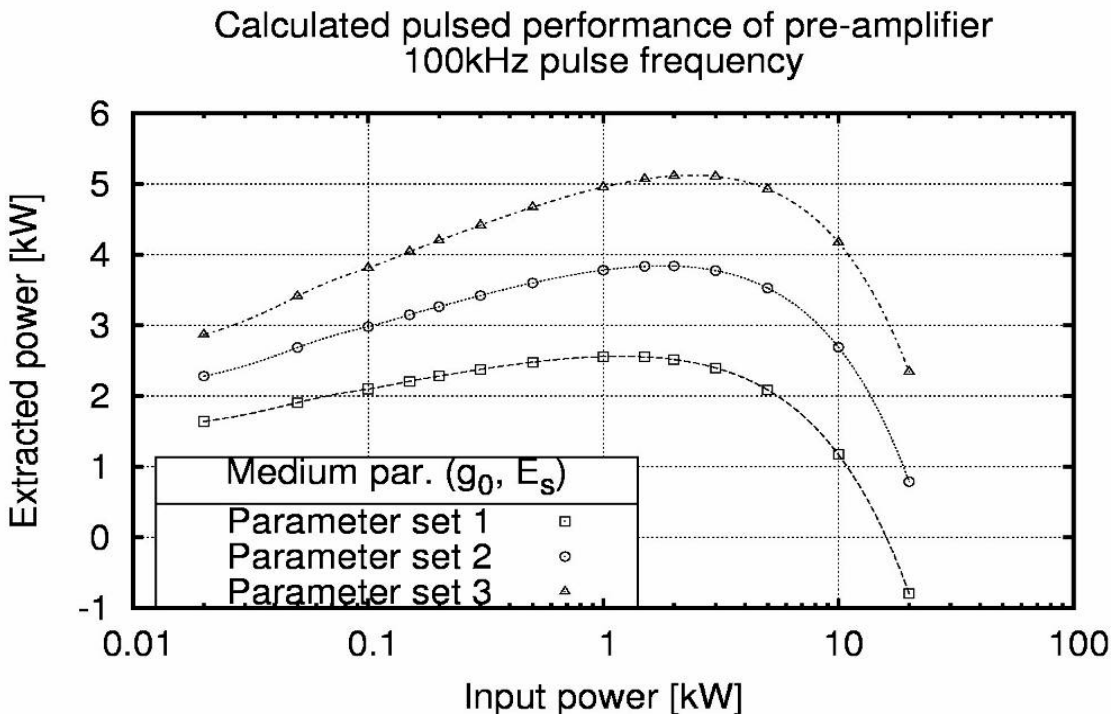
(3.5Mpulses)

High efficient Pre-Amplifier

ØEfficient pre-amplification – simulation results



Input beam Gaussian (M =1),
16mm 1/e2 diameter



- Ø >3kW output achieved at 150W input power
- Ø Good beam quality M^2 < 2 at multi-kW level
- Ø Compact size
- Ø Improved efficiency

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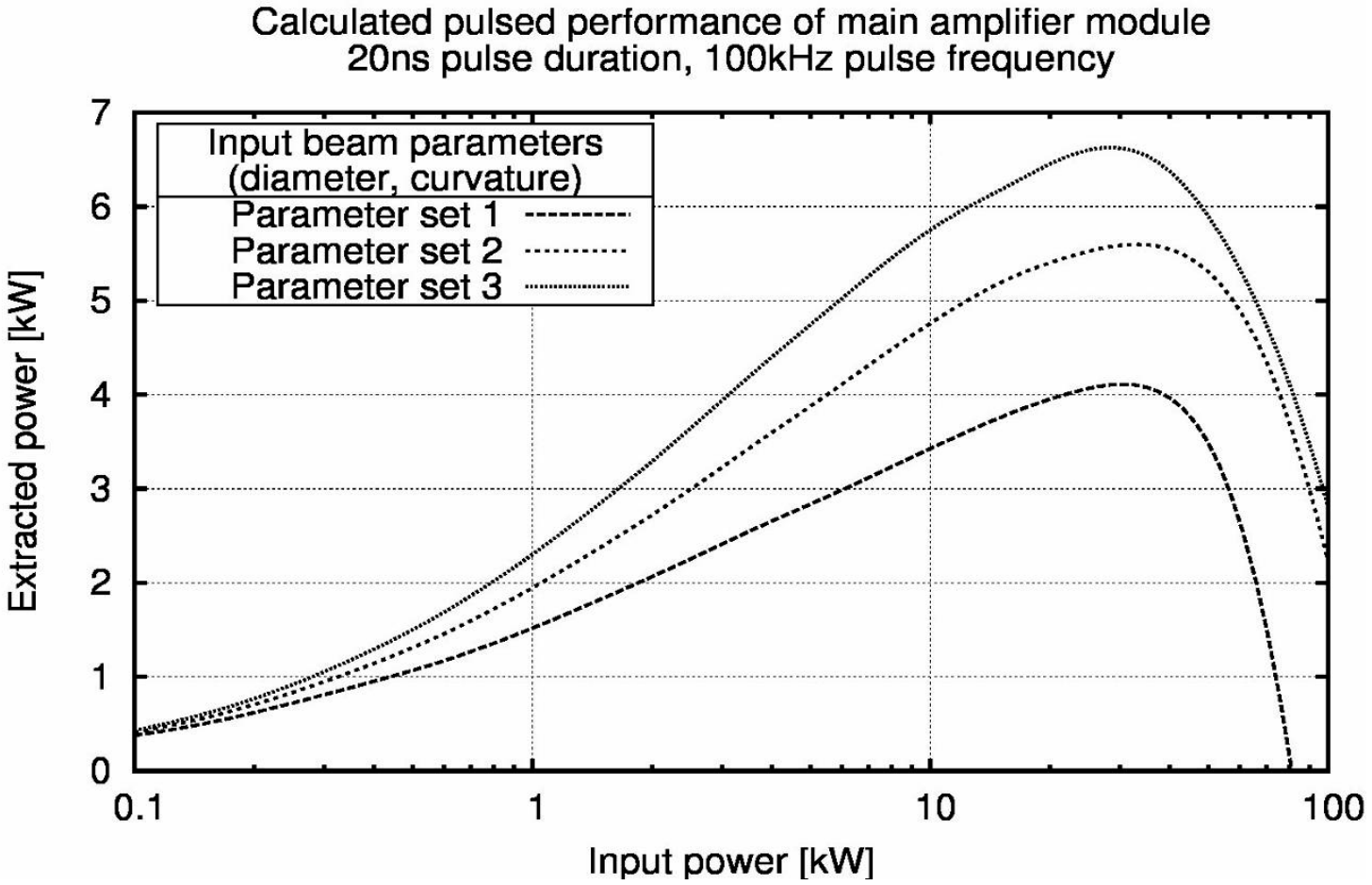
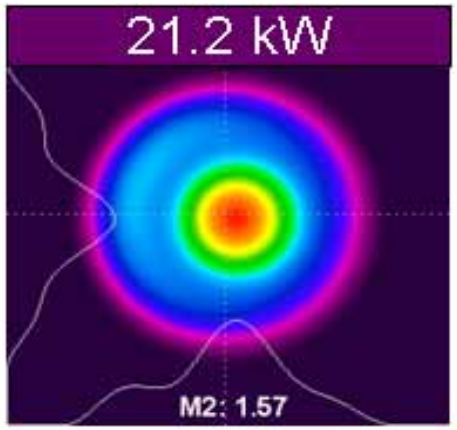
Main Amplifier

- Main amplifier characteristics – simulation
  - Good performance at 20kW average power predicted
  - Beam tilts and offset typical for good alignment





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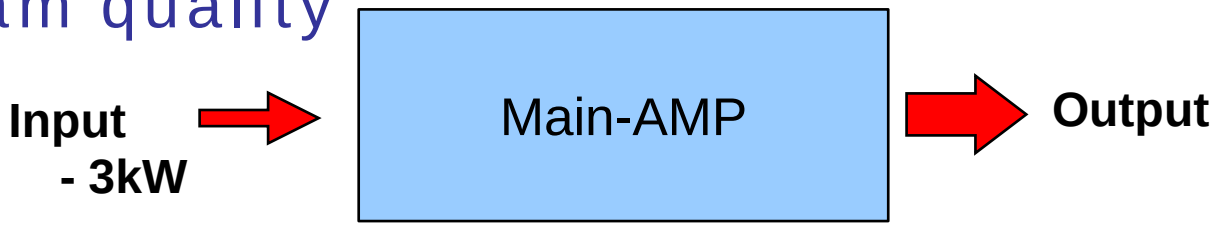
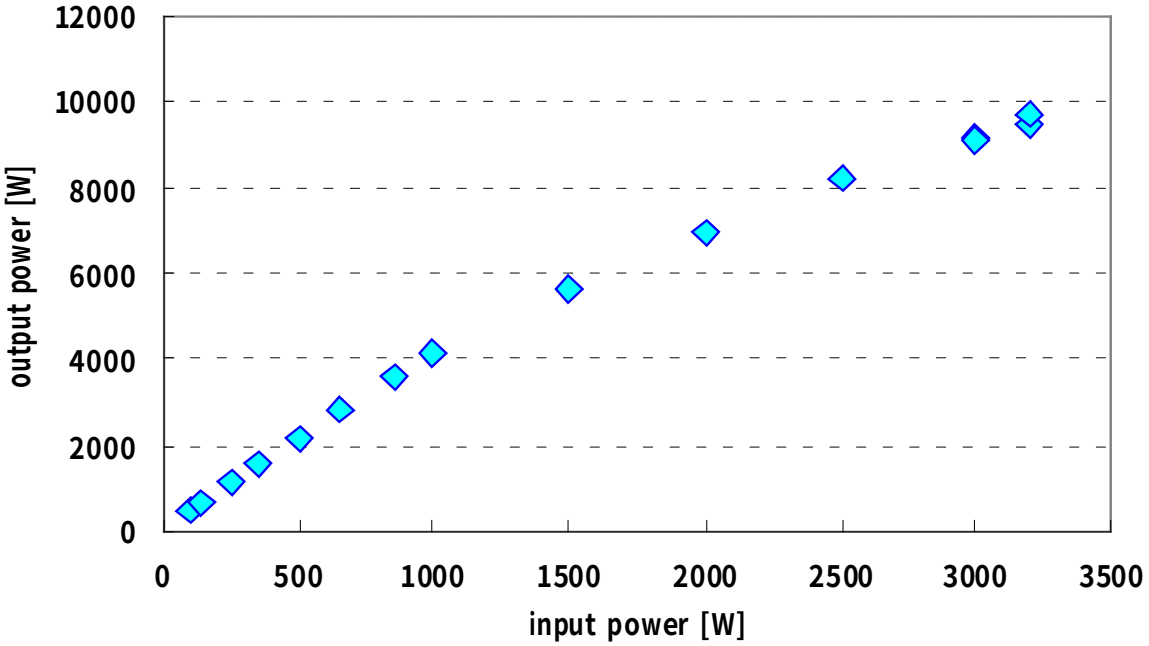
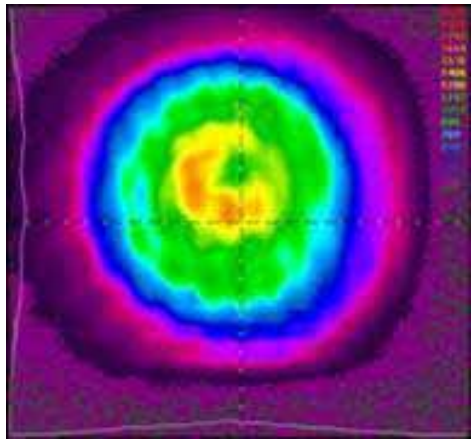
Main Amplifier

- Main amplifier characteristics : experimental results
  - ü >9kW output achieved at 3kW input power
  - ü Good beam quality





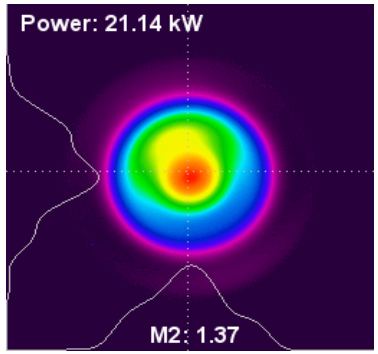
Output beam profile



20kW average power system

100% duty operation modelled

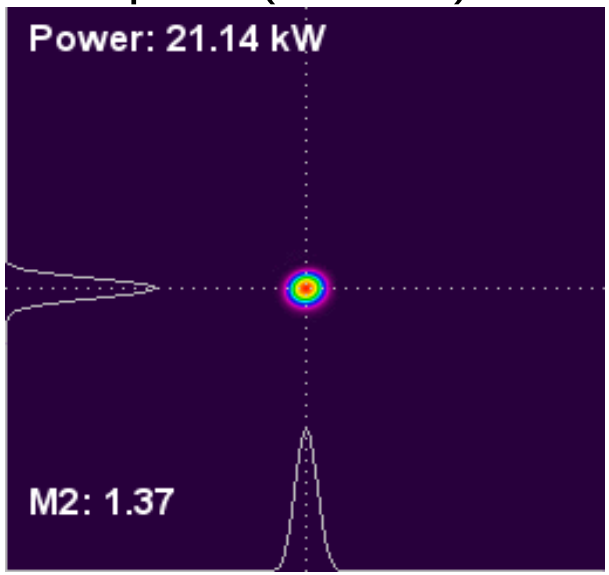
Output beam profile



– simulation results

- Ø 20kW operation at 100% duty
- Ø High beam quality maintained thanks to phase distortion compensation by adaptive optics
- Ø Improved overall efficiency thanks to efficient pre-amplification
- Ø Reduced footprint

Single-lobe high quality spot at focal point (far-field)



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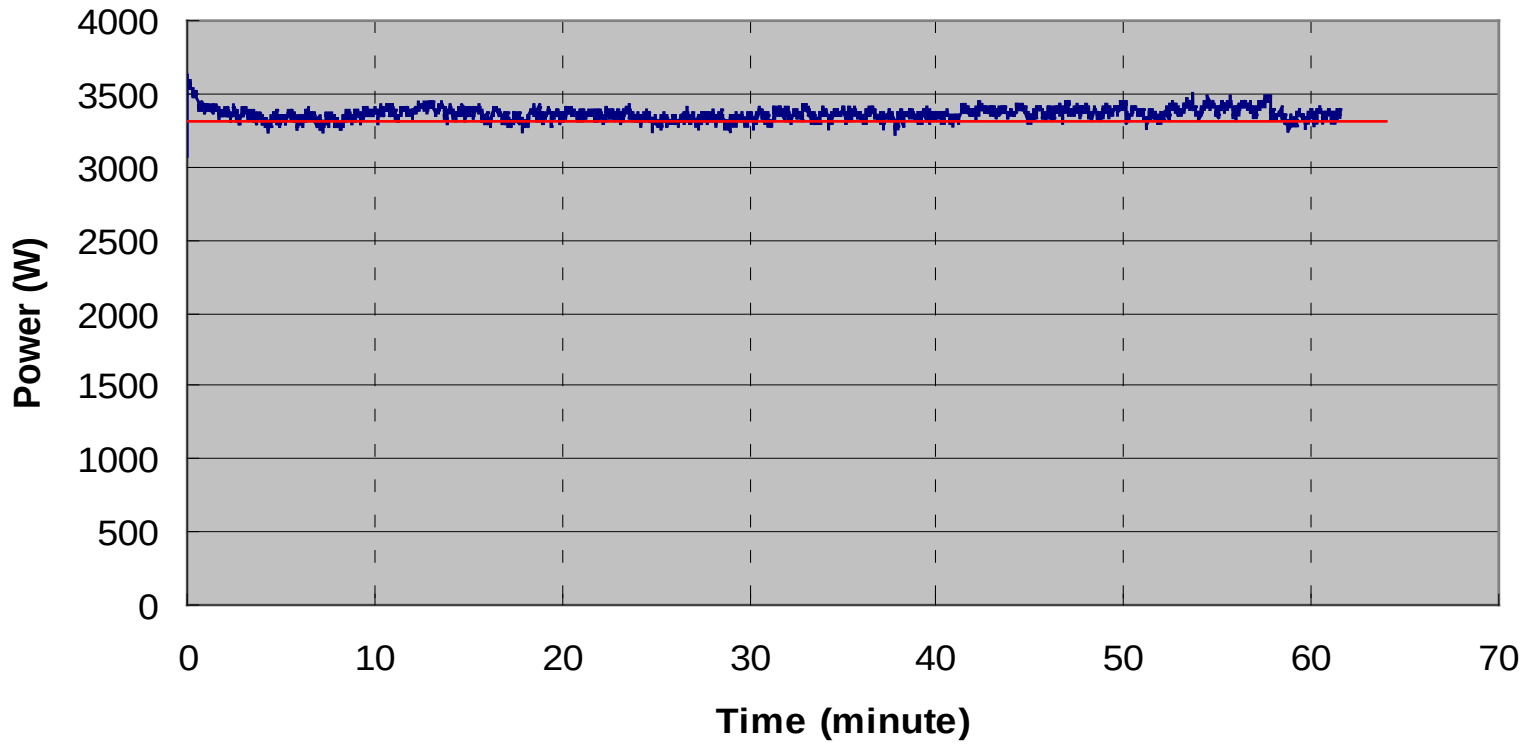
Operation data of current system

Ø 30% Duty operation for 1 Hour



3.4kW@ 30%
Stability σ1%

ü30% duty operation for 1 hr has been achieved.
ü3.4kW @30% is equivalent of 11.3kW at 100% duty cycle operation.

Summary

- High power CO_2 laser MOPA system has been achieved with :
  - 13kW output power at 100kHz, 20ns, duty 30% (on 30msec, off 100msec)
- Computer model capable of realistic performance prediction developed
- Efficient amplification with RF-excited CO_2 laser – effective pre-amplification + multi-line
  - Efficiency of Multi-line amplification – prediction of 1.3 times higher than Single-line
- 20kW system technically feasible
  - No showstopper at 20kW power level (as predicted by numerical modelling)

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Acknowledgments

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