High Power CO_2 Laser, EUVA

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Outline

- Introduction
  - High Power CO_2 Laser development concept

- Topics
  - CO_2 Laser system development result
  - CO_2 laser amplification with Single-line and Multi-line
  - Estimated extracted power with RF-excited CO_2 laser

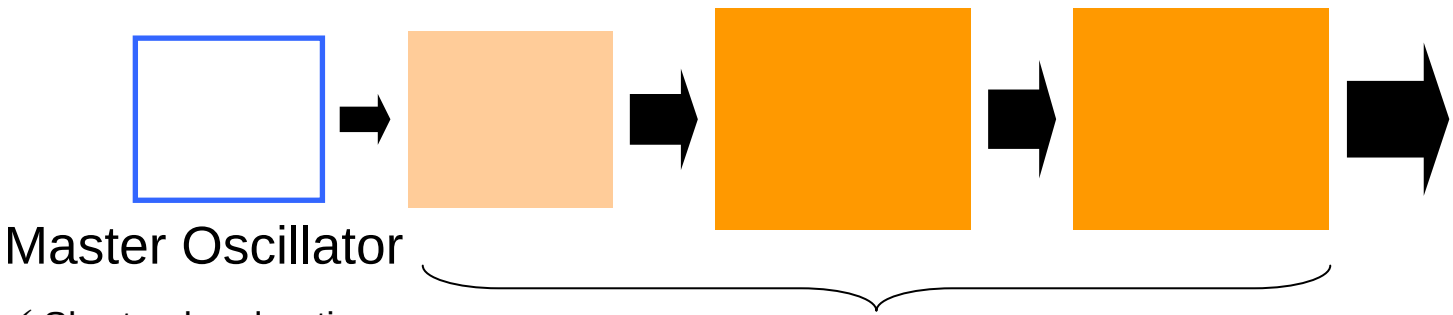
- Summary

High Power CO_2 Laser development concept

CO_2 Laser for LPP EUVL

- High Power
- High rep. rate (100 kHz)
- Short pulse duration (10 ns)
- High beam quality

> 10kW



Master Oscillator

- ✓ Short pulse duration
- ✓ Rep. rate 100kHz
- ✓ High beam quality

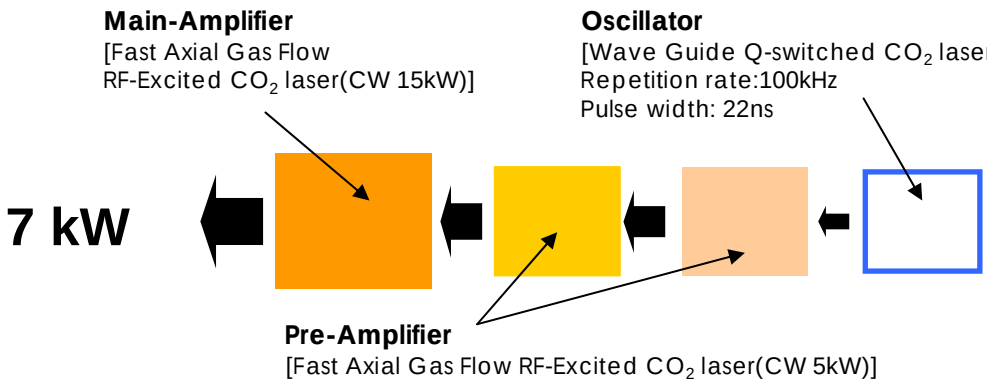
RF-excited
CO_2 laser

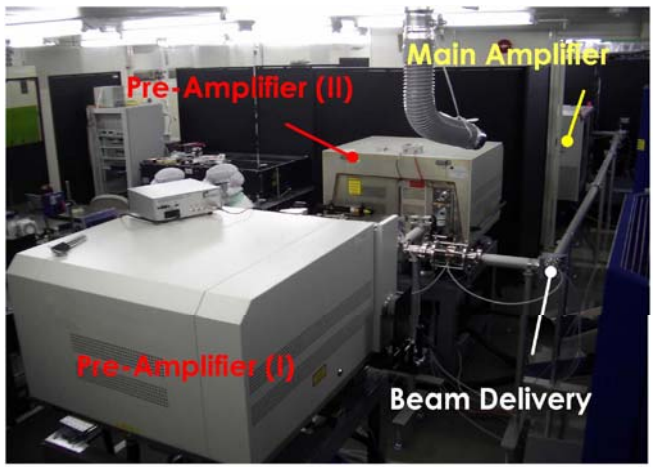
High Power CO_2 Laser MOPA System < Now >

- Performances

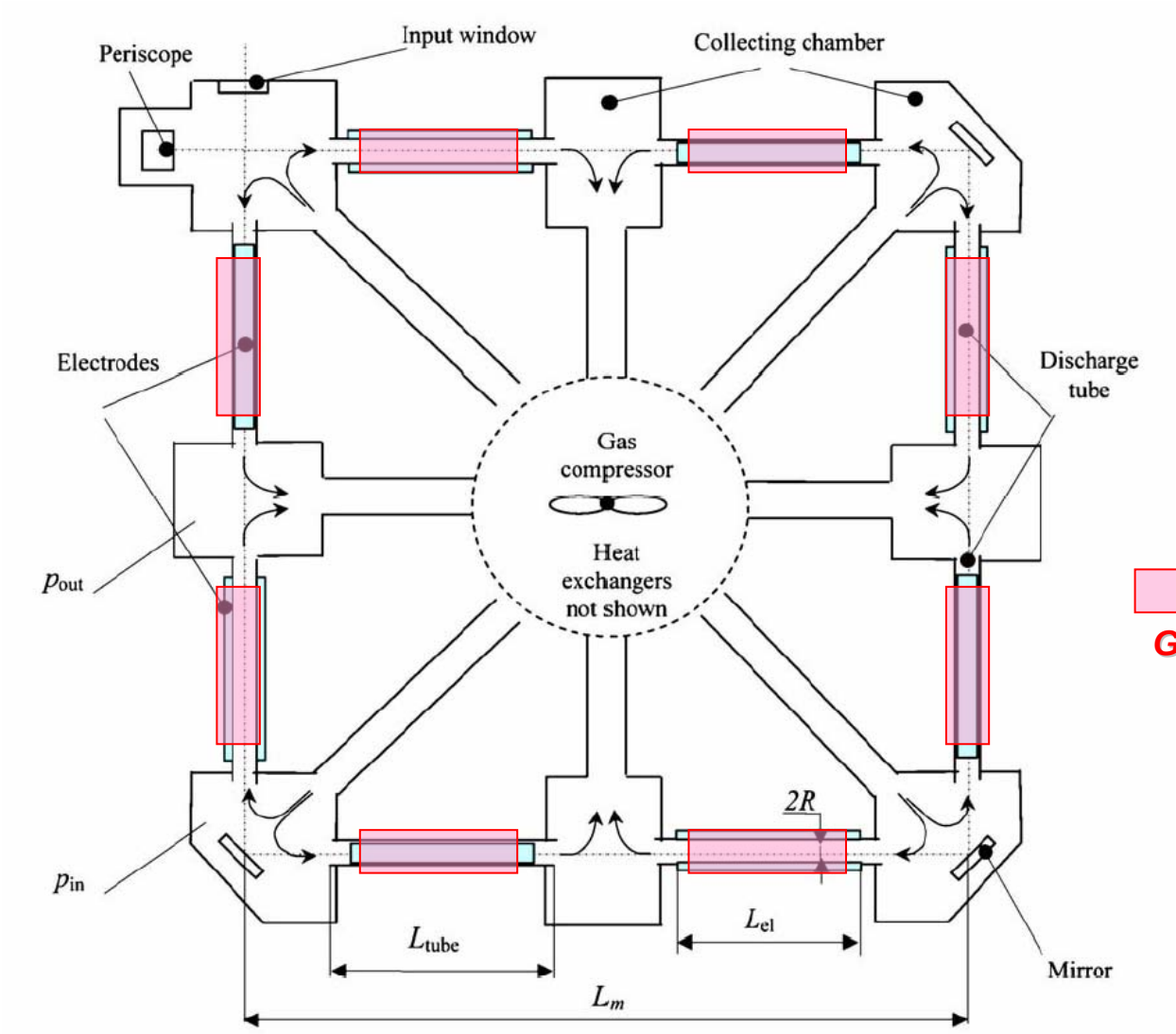
Laser Power : **7 kW**
Pulse Width : **22 ns**
Repetition Rate : **100 kHz**

- Laser System





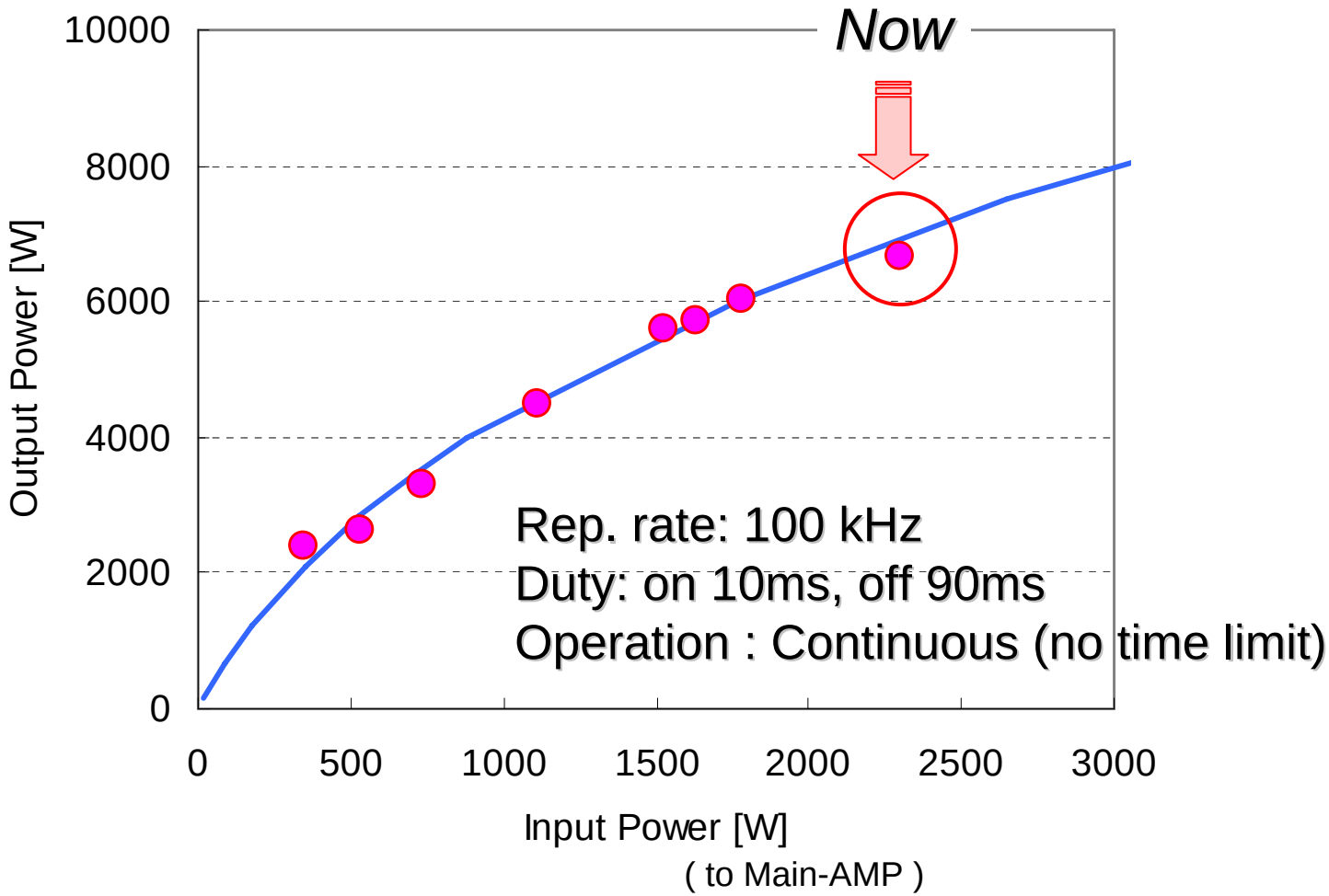
Configuration of Discharge Tubes of Amplifiers



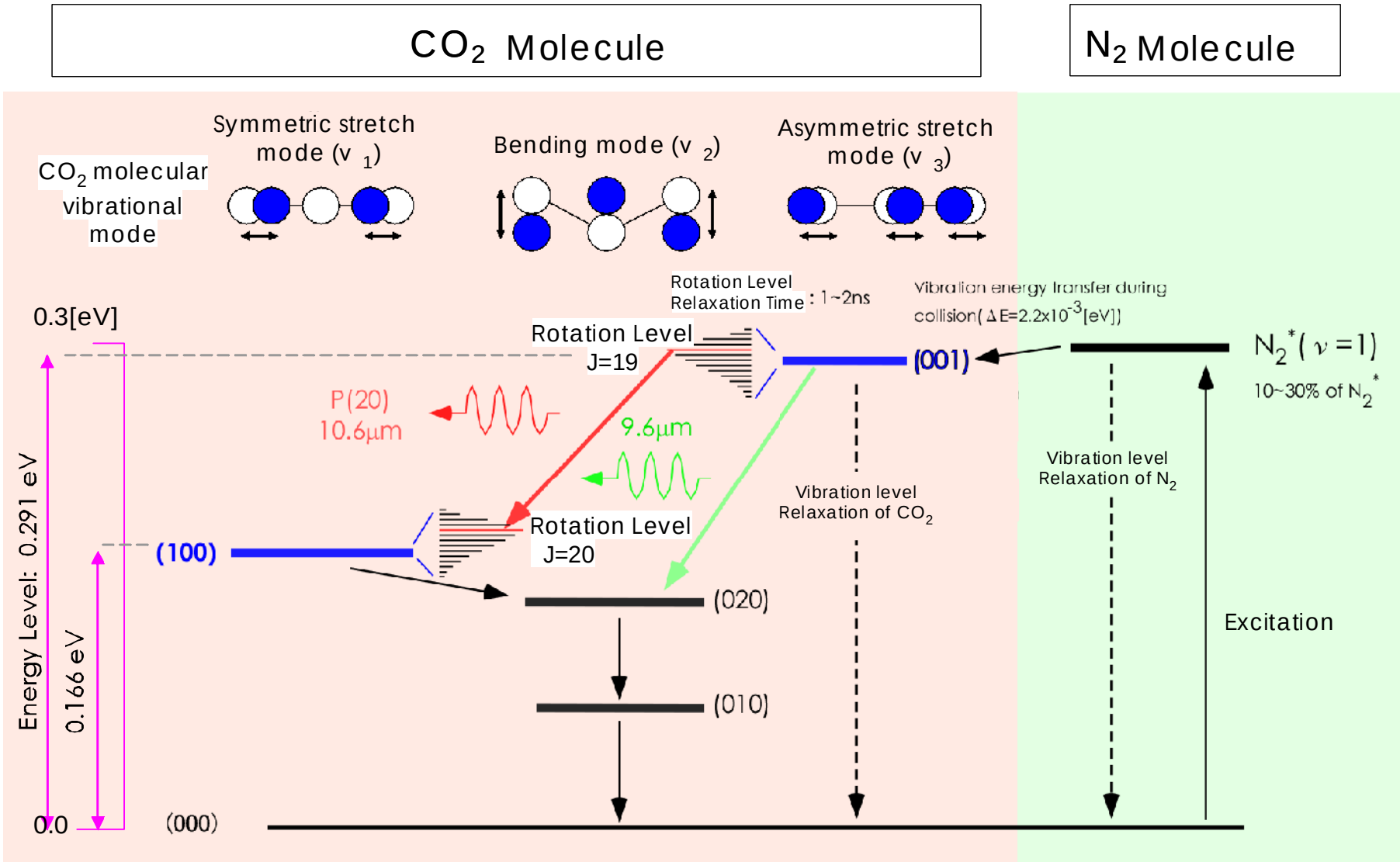
Second floor of the tubes is not shown

CO_2 Laser MOPA System Average Output Power

➢ ***Amplification Characteristic of Main - Amp***



Vibrational-Rotational CO_2-N_2 Laser Energy Level Diagram



CO_2 Laser Gain Bandwidth

➢ ***Rotational Gain Bandwidth***

< Pressure Broadening > R.L.Abrams, Appl. Phys. Lett. 25, pp.609, 1974

$$\Delta\nu = 7.58(\Phi_{CO2} + 0.73\Phi_{N2} + 0.64\Phi_{He}) \times P(300/T)^{1/2}$$

Φ: partial ratio
P: Pressure [torr]
T: Temperature [K]

$\Delta\nu$ = ***424 [MHz]***

Typical Gas Parameter
- CO_2:N_2:He=1:1:8
- Pressure: 100 [torr]
- Temperature: 450 [K]

⇒ ***Estimate pulse duration from the Fourier transform limit of a Gaussian pulse***

$$\Delta\nu \cdot \Delta t = 0.44$$

$$\Rightarrow \Delta t \sim \textbf{\textit{1 ns}}$$

Short pulse Amplification is limited of 1ns

Relaxation time (RF-excited CO_2 laser)

Oscillator Parameter

- ✓ Pulse to Pulse interval: ***10μs (100kHz)***
- ✓ Pulse duration: ***10 ns***

➢ ***Vibrational relaxation time***

τ_v = ***0.5 μs*** Pressure: 100 [torr]

➢ ***Rotational relaxation time*** R.L.Abrams, Appl. Phys. Lett. 25, pp.609, 1974

$$\tau_r = [7.58(\phi_{CO_2} + 0.73 \cdot \phi_{N_2} + 0.64 \cdot \phi_{He}) \cdot P \cdot \sqrt{\frac{300}{T}} .10^6]^{-1}$$

Φ: partial ratio
P: Pressure [torr]
T: Temperature [K]

τ_r = ***2.3 ns***

Typical Gas Parameter
- CO_2:N_2:He=1:1:8
- Pressure: 100 [torr]
- Temperature: 450 [K]

⇒ Gain of short pulse amplification is decreased than CW amplification

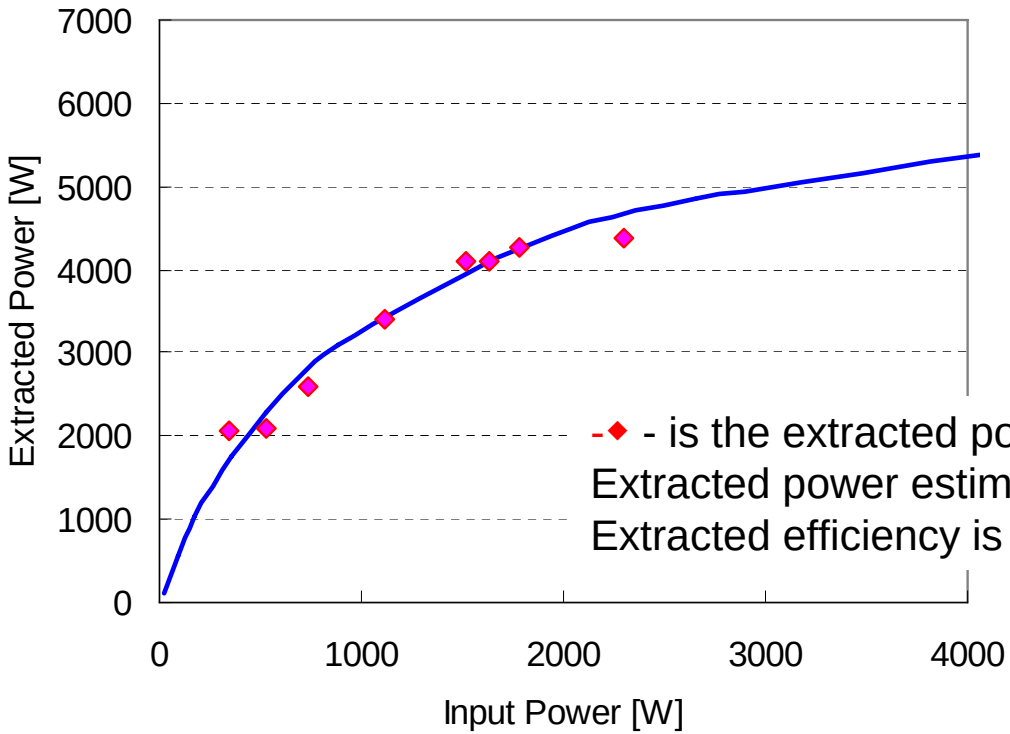
Estimated amplification with RF-excited CO_2 laser

★Frantz - Nodvik Equation

$$E_{out} = E_s \cdot \ln[(1+\exp(g_0 \cdot L)[\exp(\frac{E_{in}}{E_s}) - 1]]$$

E_{in}: input fluence [J/cm2]
E_{out}: output fluence [J/cm2]
g_0: gain [%/cm]
E_s: saturation fluence [J/cm2]
l: gain length [cm]

Experimental result of Extracted Power with Single-Line Oscillator and 15 kW amplifier module at 100 kHz

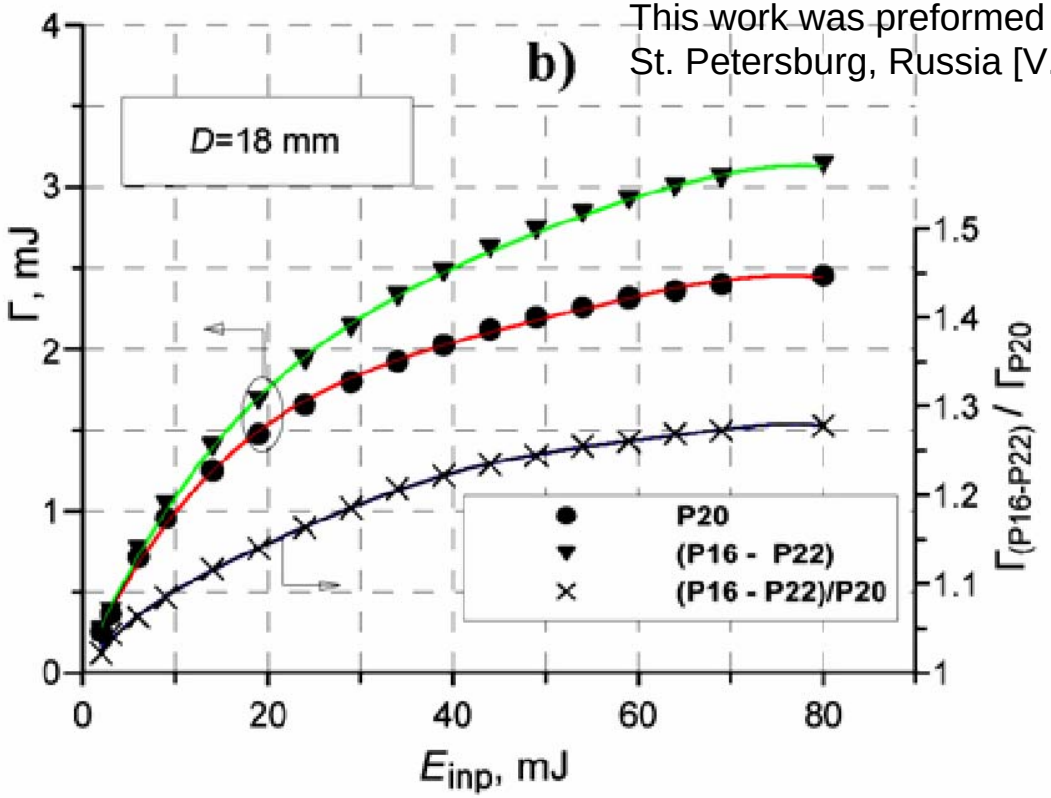


- ◆ - is the extracted power of amplification result.
Extracted power estimation is over 5 kW.
Extracted efficiency is over 5.5% from pumping power

Estimated amplification with RF-excited CO_2 laser

Numerical Calculation Result of Amplification with Multi-Line Oscillator

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



-X- is the amplification ratio between the (P16-P22) spectrum and the P20 line

Estimated extracted power of 15 kW amplifier module in case of input power with 3 kW

Multi-line **: > 6.5 kW** (5 kW×1.3)

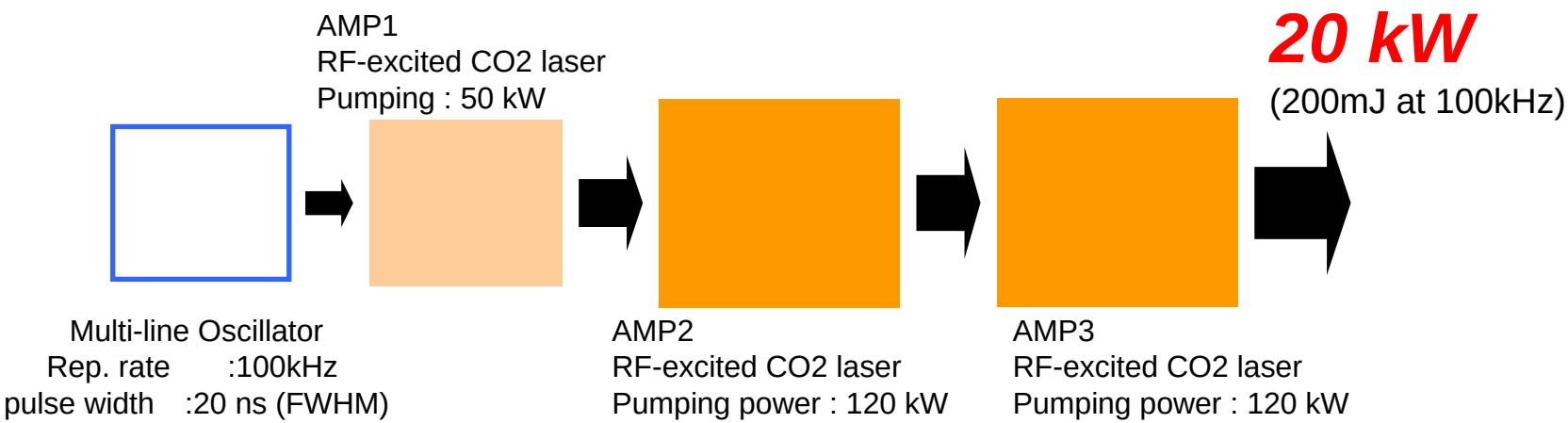
Single-line *: > 5 kW*

Extracted efficiency from pumping power is estimated

Multi-line **: > 7.2 %**

Single-line *: > 5.5 %*

Multi 10 kW Short Pulse CO_2 laser MOPA system



One beam, 20 kW is reasonable estimate !!

- Power Limitation
  - ***Damage of Optics***
    - ⇒ Short pulse damage threshold lower than CW threshold
  - ***Filling Factor***
    - ⇒ Laser beam diffraction
  - ***Saturation***
    - ⇒ Re-absorption from lower laser level (?)

Summary

- High Power CO_2 laser MOPA system has been achieved with*:*
  - *7 kW output power at 100 kHz, 22 ns(FWHM)*
  - *duty: 10% (on 10msec, off 90msec)*
- Estimated amplification with RF-excited CO_2 laser
  - *Extracted power of short pulse amplification is decreased compared to the case of CW amplification*
  - *Estimation of extracted efficiency from pumping power is over 5.5%*
  - *For Numerical Calculation Result, Multi-line amplification is 1.3 higher than Single-line*
- One beam, 20kW is a reasonable estimate !!

Only 3 times increase compared to present performance !!