
High Power CO₂ Laser, EUVA

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Acknowledgments

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▶ Introduction

- High Power CO₂ Laser development concept

▶ Topics

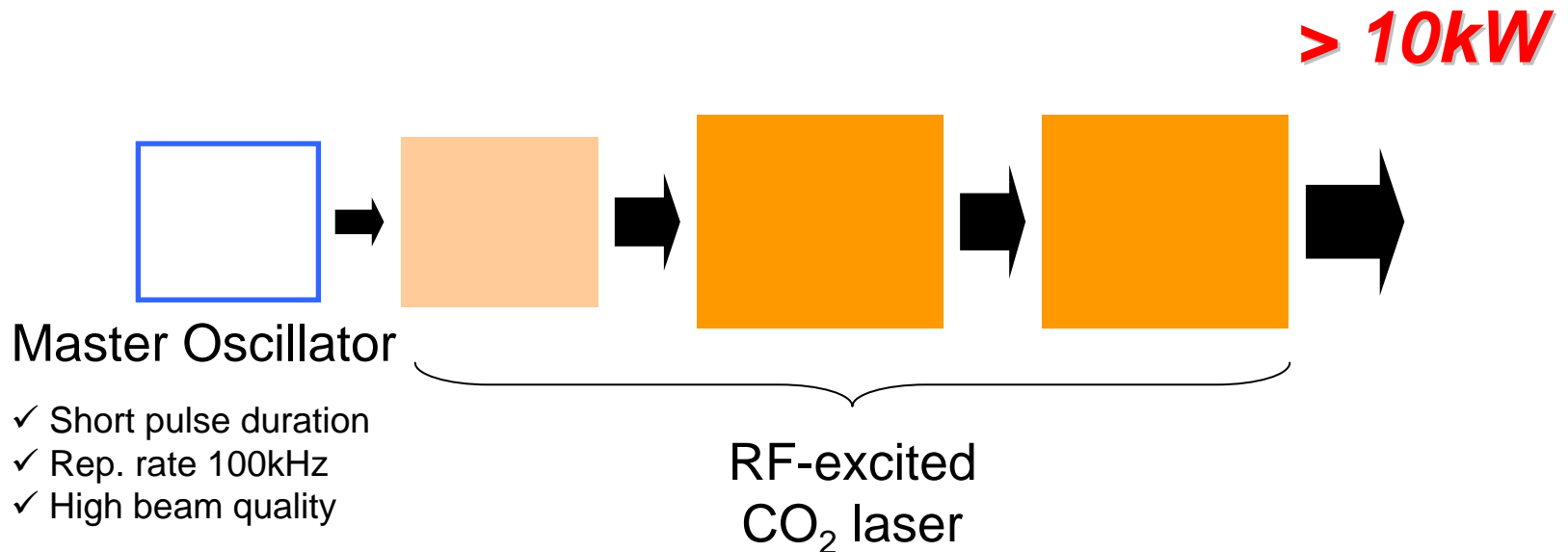
- CO₂ Laser system development result
- CO₂ laser amplification
 - with Single-line and Multi-line
- Estimated extracted power
 - with RF-excited CO₂ laser

▶ Summary

High Power CO₂ Laser development concept

CO₂ Laser for LPP EUVL

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

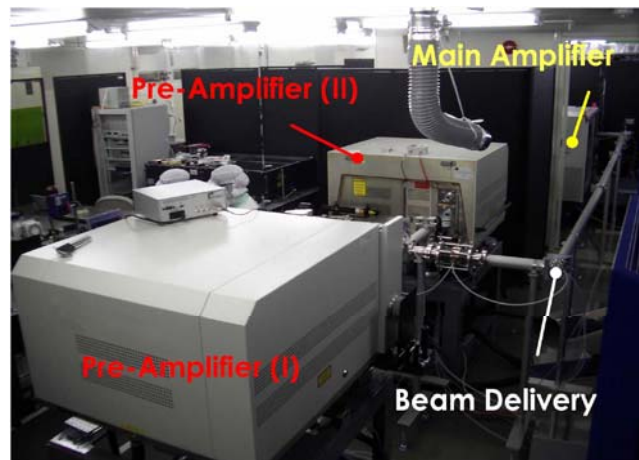
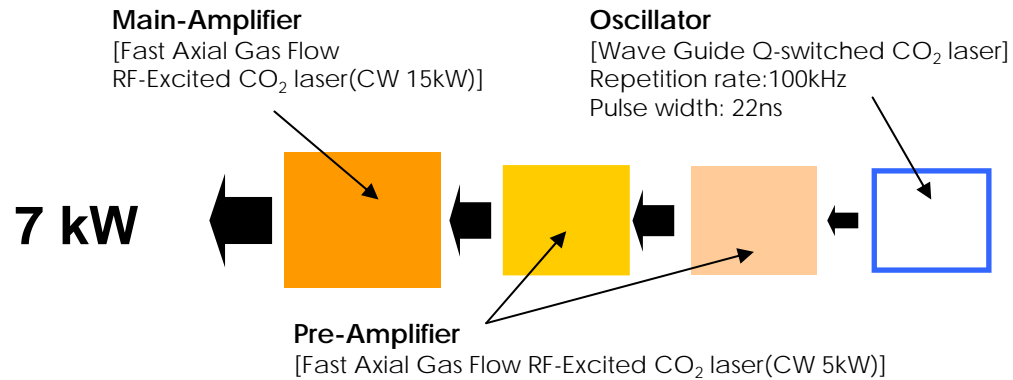


High Power CO₂ Laser MOPA System < Now >

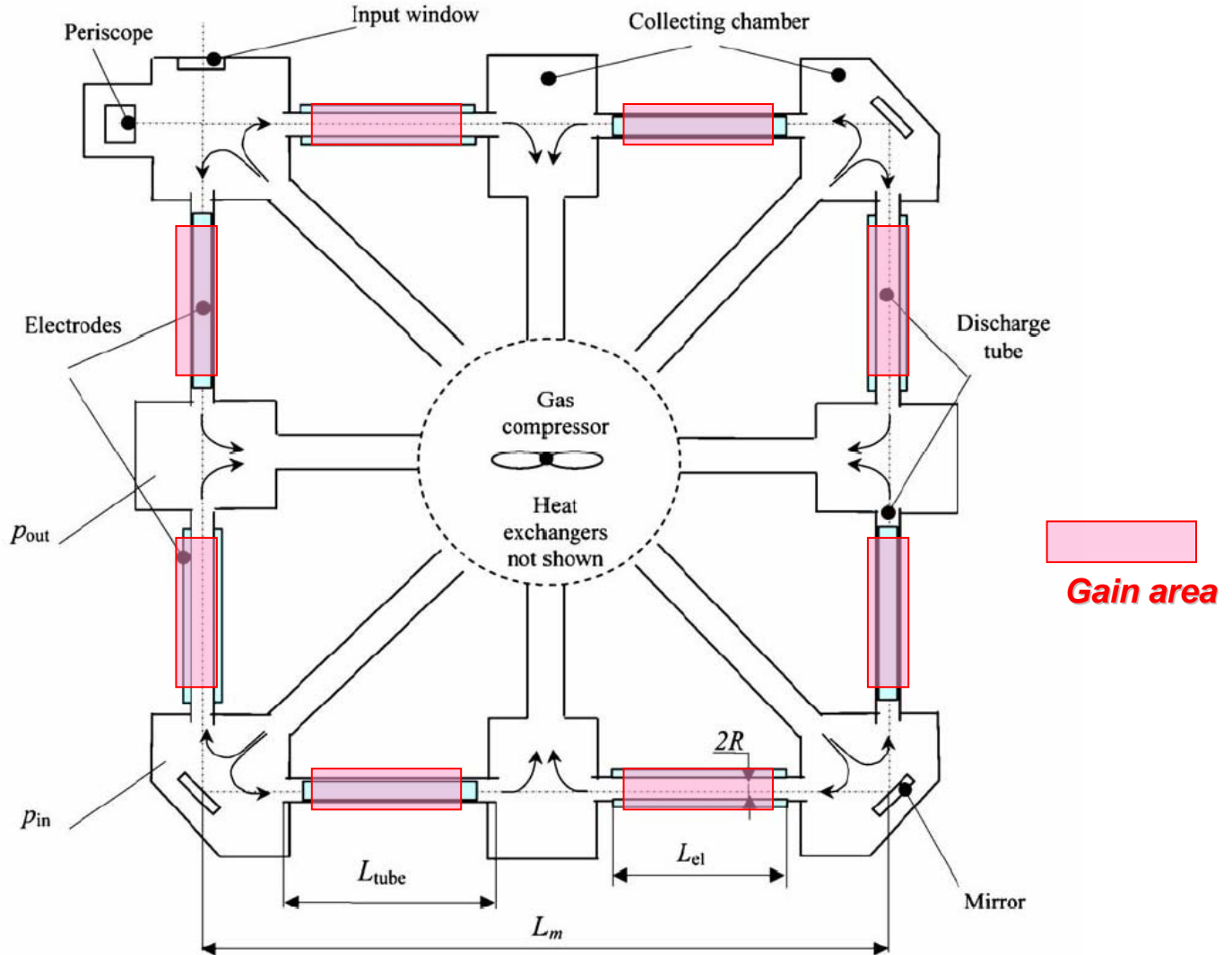
■ Performances

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

■ Laser System



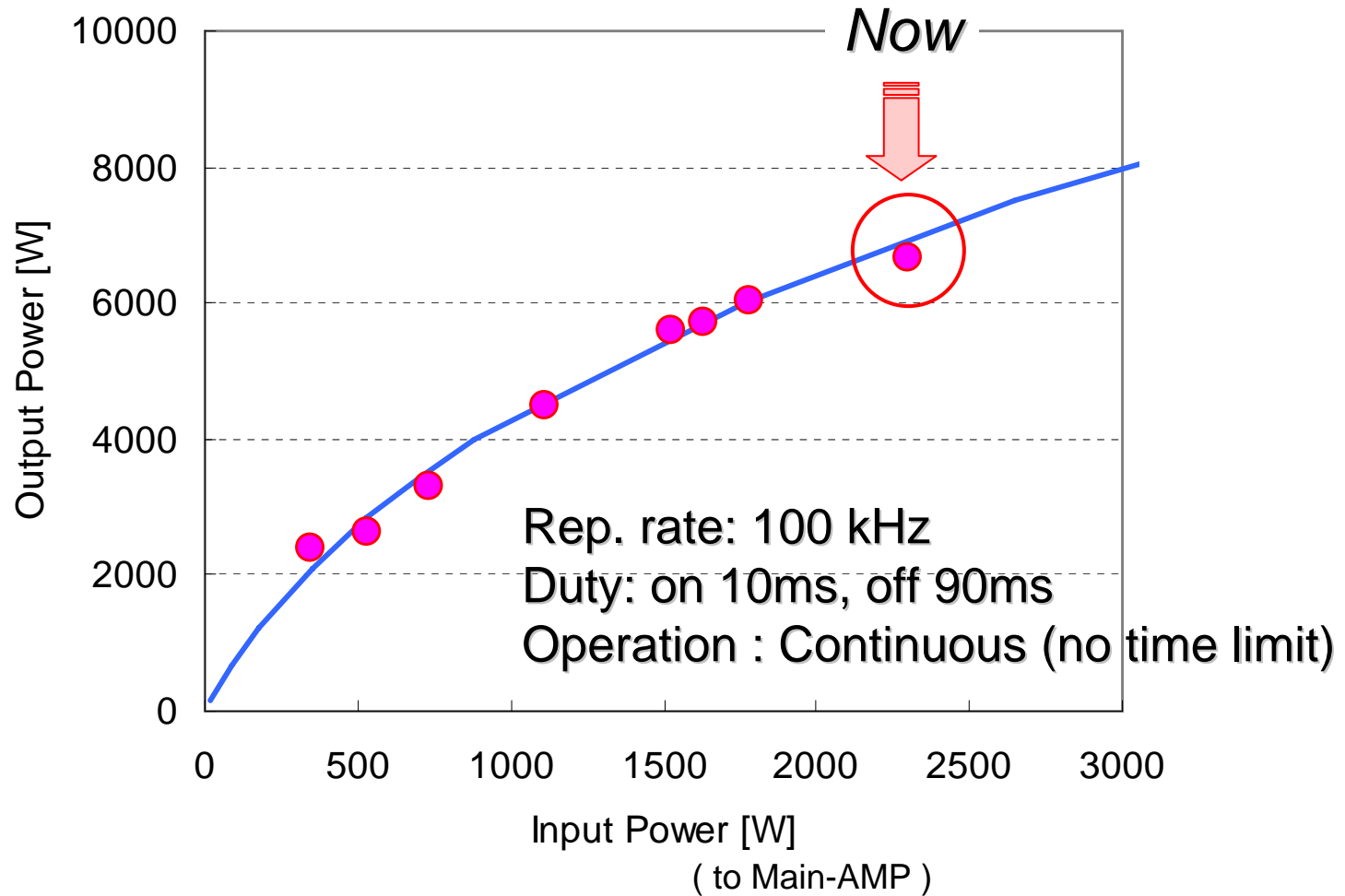
Configuration of Discharge Tubes of Amplifiers



Second floor of the tubes is not shown

CO₂ Laser MOPA System Average Output Power

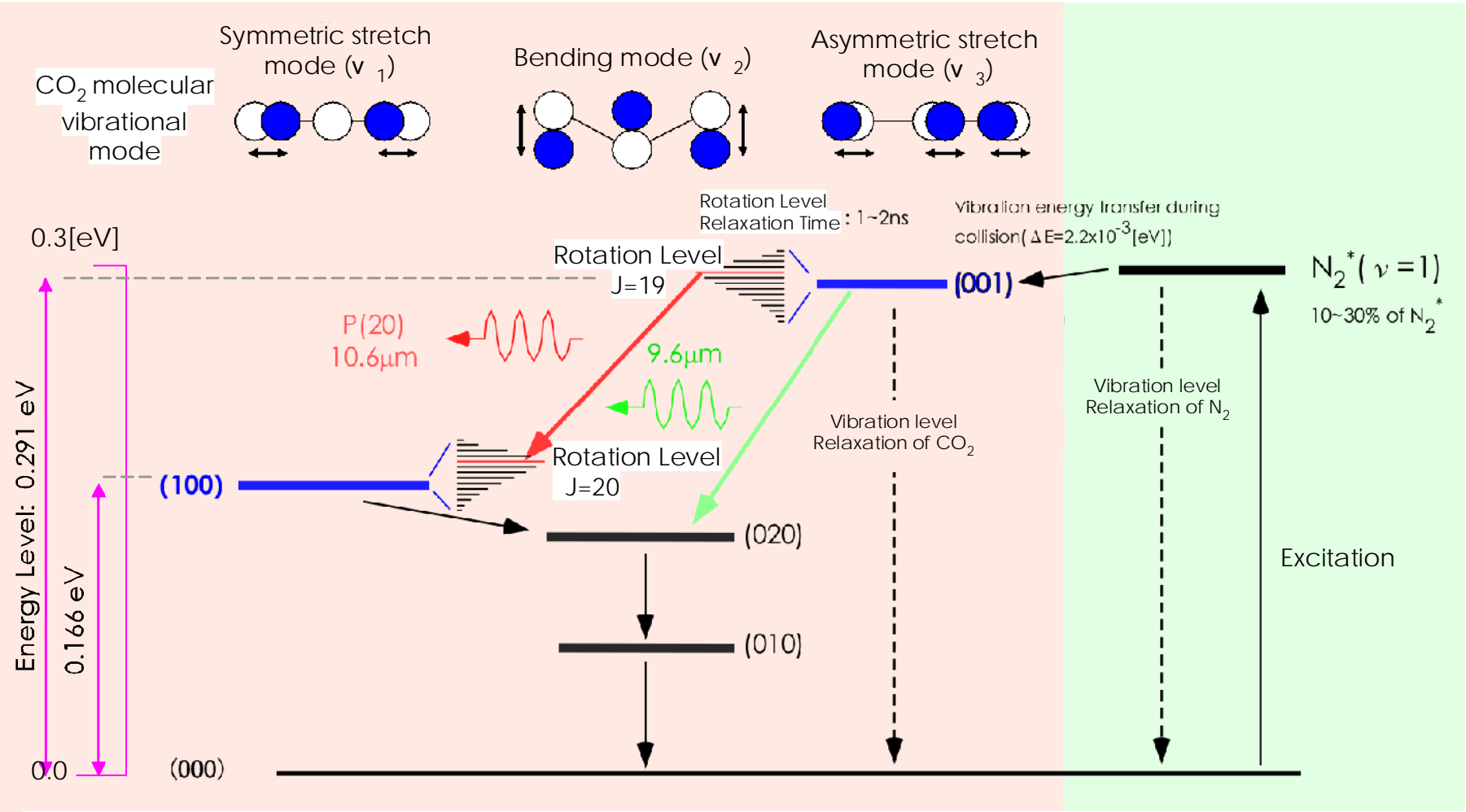
➤ Amplification Characteristic of Main - Amp



Vibrational-Rotational CO₂-N₂ Laser Energy Level Diagram

CO₂ Molecule

N₂ Molecule



CO₂ Laser Gain Bandwidth

➤ *Rotational Gain Bandwidth*

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

$$\Delta\nu = 7.58(\Phi_{\text{CO}_2} + 0.73\Phi_{\text{N}_2} + 0.64\Phi_{\text{He}}) \times P(300/T)^{1/2}$$

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

$$\Delta\nu = \mathbf{424 [MHz]}$$

Typical Gas Parameter

- CO₂:N₂:He=1:1:8
- Pressure: 100 [torr]
- Temperature: 450 [K]

⇒ *Estimate pulse duration*

from the Fourier transform limit of a Gaussian pulse

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

$$\Rightarrow \Delta t \sim \mathbf{1 ns}$$

Short pulse Amplification is limited of 1ns

Relaxation time (RF-excited CO₂ laser)

Oscillator Parameter

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

➤ Vibrational relaxation time

$$\tau_v = \mathbf{0.5 \mu s}$$

Pressure: 100 [torr]

➤ Rotational relaxation time

R.L.Abrams, Appl. Phys. Lett. 25, pp.609, 1974

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

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

$$\tau_r = \mathbf{2.3 ns}$$

Typical Gas Parameter

- CO₂:N₂:He=1:1:8
- Pressure: 100 [torr]
- Temperature: 450 [K]

**⇒ Gain of short pulse amplification is decreased
than CW amplification**

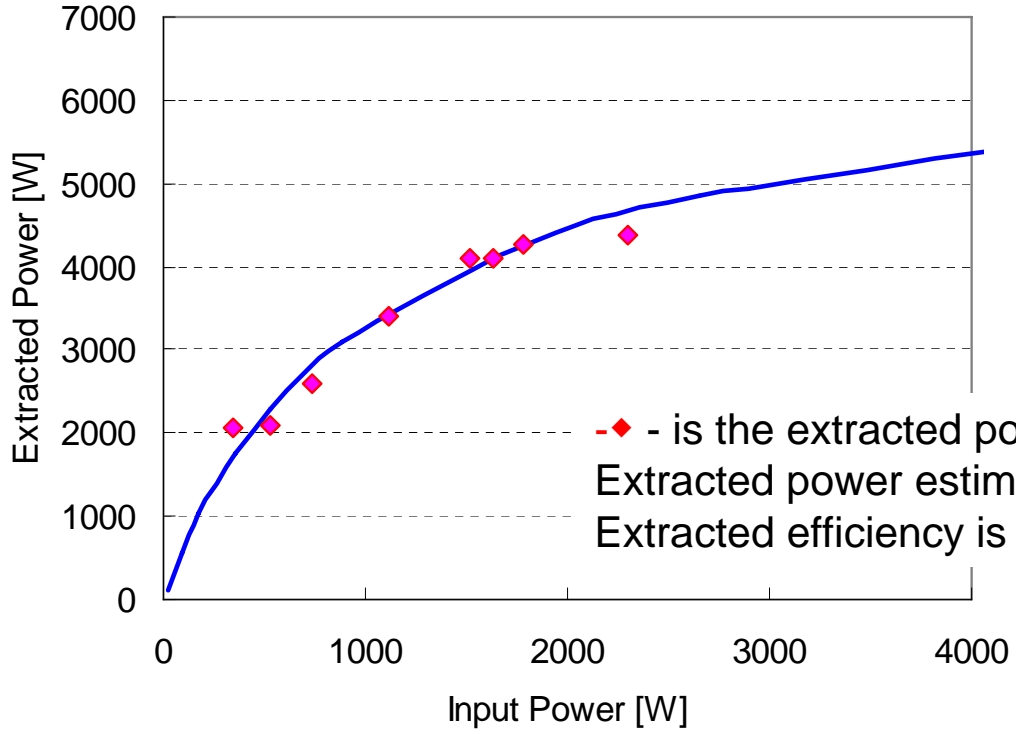
Estimated amplification with RF-excited CO₂ laser

★ Frantz - Nodvik Equation

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

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

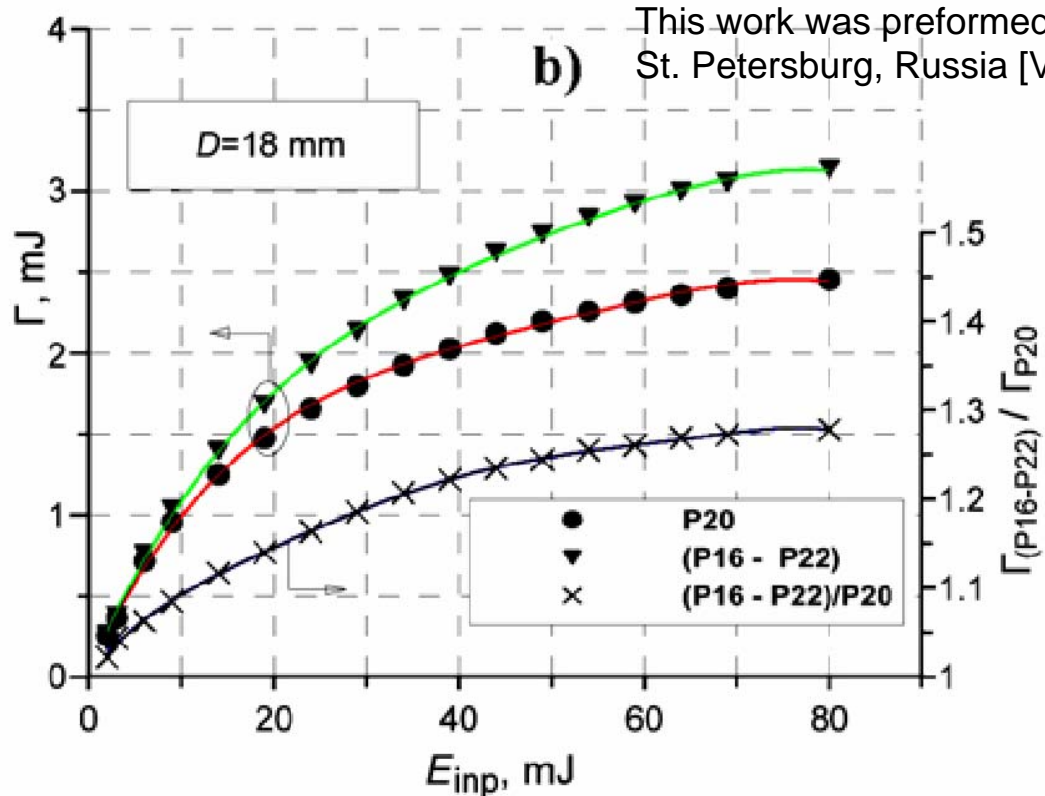


-♦ - is the extracted power of amplification result.
Extracted power estimation is over 5 kW.
Extracted efficiency is over 5.5% from pumping power

Estimated amplification with RF-excited CO₂ 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

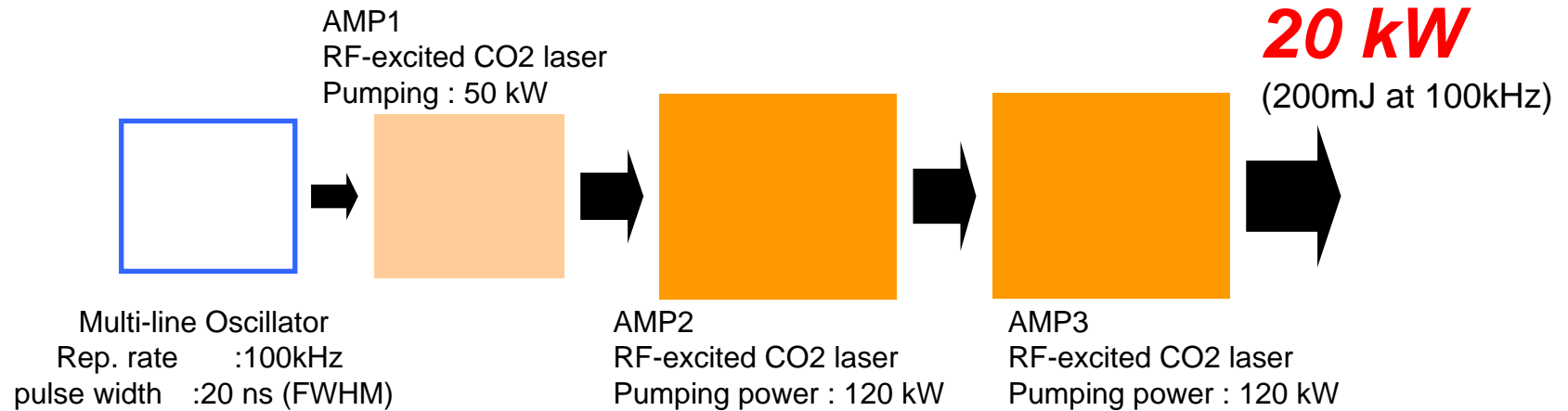
- Multi-line** : > **6.5 kW** (5 kW×1.3)
- Single-line** : > **5 kW**

Extracted efficiency from pumping power is estimated

- Multi-line** : > **7.2 %**
- Single-line** : > **5.5 %**



Multi 10 kW Short Pulse CO₂ 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 (?)

- High Power CO₂ 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 CO₂ 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 !!