INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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WINTER COLLEGE ON LASERS, ATOMIC AND MOLECULAR PHYSICS

(24 January - 25 March 1983)

CW CO2 Lasers

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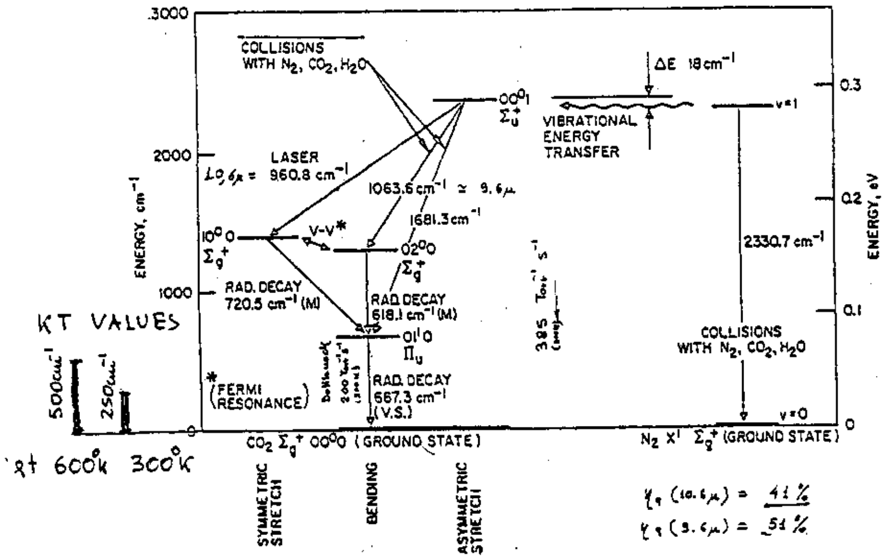
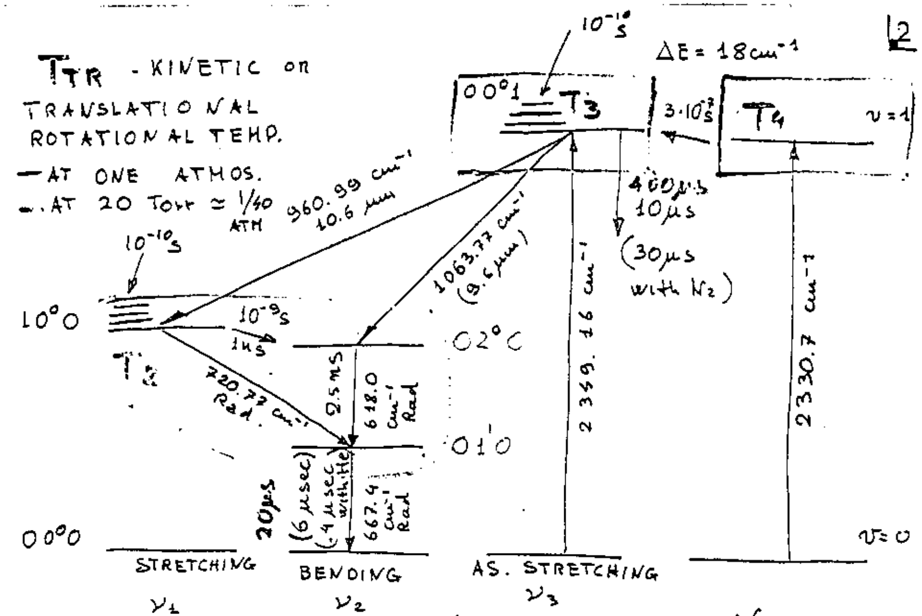
CW CO_2 LASERS

- Excitation Mechanism & Limits to available power
- Conduction cooled lasers
- Convection cooled lasers
  - Fast axial flow
  - Helical flow
  - Transverse flow
    - self sustained discharge
    - Electron beam preionized.
- Gasdynamic Lasers

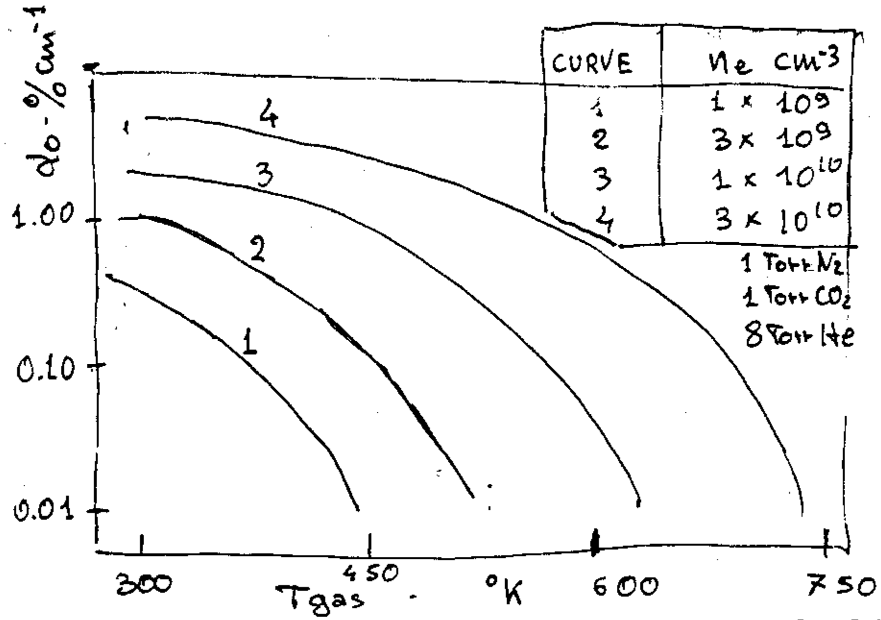
1a A. J. De Maria
"Review of CW High-Power CO_2 Lasers"
Proceedings of IEEE. 61, 731 (1973)
2a GERRY E. T.
"Gasdynamic Lasers"
IEEE Spectrum 7, 51 (1970)



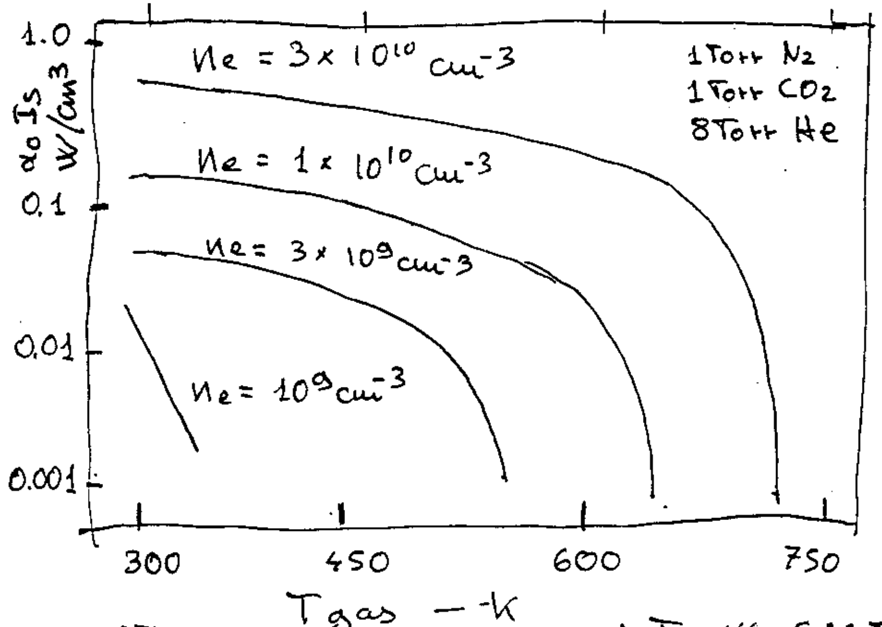
KT ≃ 25 meV ≃ 250 cm^{-1} at 300 K



CO_2 MOLECULE
FOUR TEMPERATURE MODEL

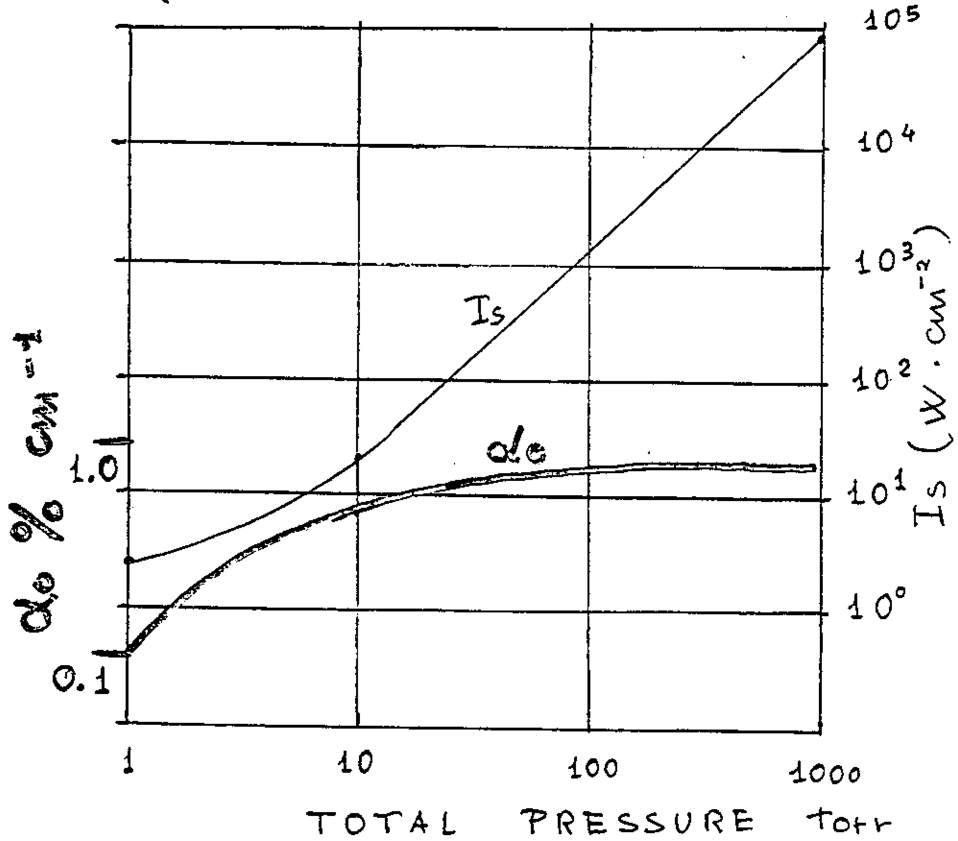


SMALL SIGNAL GAIN VS GASTEMPERATURE



OPTICAL POWER DENSITY $\alpha_0 I_s$ VS GASTEMP

(Ex: at 100 Torr $I_s \alpha_0 \simeq 10^3 \cdot 10^{-2} = 10$ W/cm³

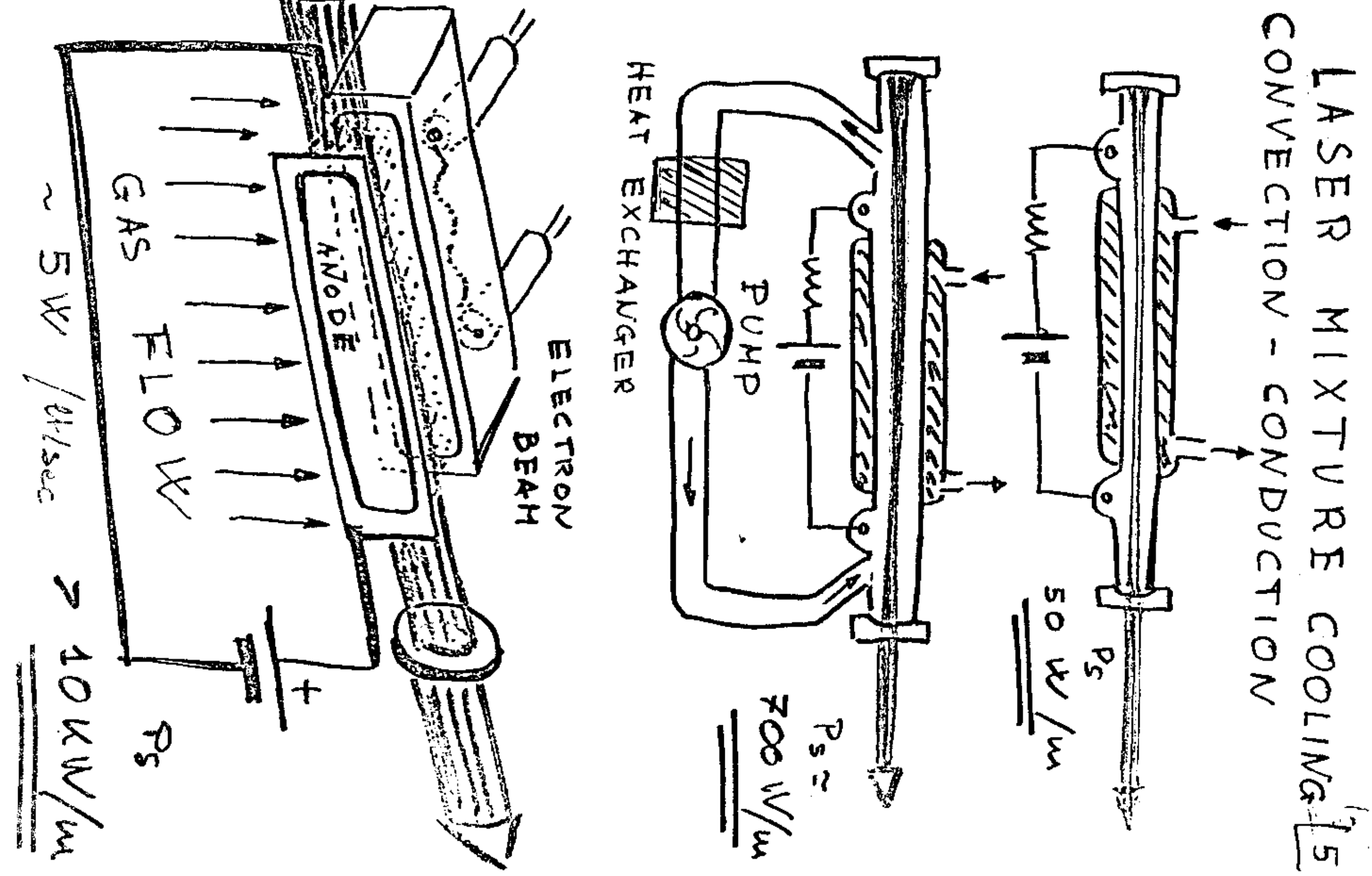


He : N_2 : CO_2	at 450 °K
8 : 1 : 1	Average el density
$n_e / p = 10^9 \frac{cm^{-3}}{Torr}$	1.50 eV

I_s increases as p^2 for $p > 30$ torr

$\alpha_0 I_s$ increases as p^2

(From H. Fowler
pgg 3485 J. Appl. Phys 43, 8, (72))



CONDUCTION COOLED LASER 5

HEAT DIFFUSION TIME : τ_D

D - diameter of the discharge

Λ - mean free path

v_t - thermal velocity

Λ / v_t - mean free time between collisions.

$(D/\Lambda)^2$ - number of collisions required to reach the walls in a random walk

$$\tau_D = (D/\Lambda)^2 \cdot \Lambda / v_t = D^2 / \Lambda v_t$$

Power achievable from a laser inversely proportional to τ_D

$$P_L \propto \rho \times (\Lambda v_t / D^2) \cdot A$$

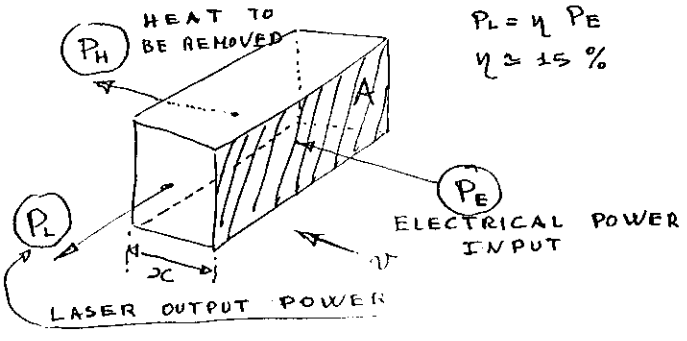
where ρ is the gas density inversely proportional to Λ

$\Lambda \rho$ = const

- Power per unit length is not increased by increasing ρ
- Power per unit length is not increased by increasing D as $A = \pi D^2/4$

50 W/meter Typical Value

CONVECTION-COOLED LASER or GAS TRANSPORT 6



$P_L = \eta P_E$

$\eta \simeq 15\ \%$

$$P_H = (1-\eta) P_E = \left(\frac{1-\eta}{\eta}\right) P_L$$

$$P_H = \rho\ C_p\ v\ \Delta T\ A' \cdot \begin{pmatrix} \text{at } 100 \text{ torr} \\ \alpha\ 1\ \text{lt/s} \\ P_L = 5W \end{pmatrix}$$

ρ : gas density

C_p : specific heat of the gas

v : velocity of flow

A : cross section of the disch.

x : dimension along the flow

$$P_L = \rho\ C_p\ v\ \Delta T\ A\ (\eta / 1-\eta)$$

If $\Delta T \simeq 300°K$ $\eta \simeq 15\ \%$

- $P_L = 2.5 \times 10^{-2}\ W\ \text{torr}^{-1}\ (\text{cfm})^{-1}$

(1 cfm) $\simeq$ 0.5 lt/sec

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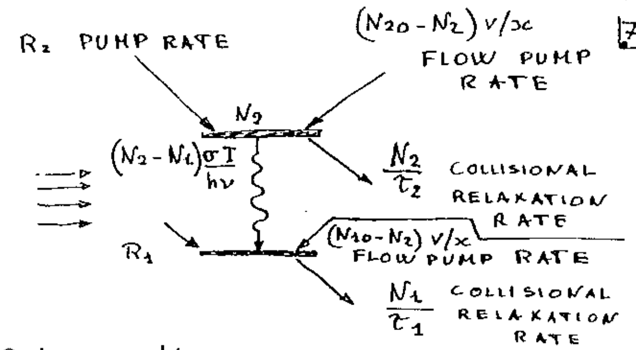


Rate equations:

$$\frac{\partial N_2}{\partial t} = R_2 - \frac{N_2}{\tau_2} - (N_2-N_1)\frac{\sigma I}{h\nu} + \frac{(N_{20}-N_2)}{\tau_F}$$

$$\frac{\partial N_1}{\partial t} = R_1 - \frac{N_1}{\tau_1} + (N_2-N_1)\frac{\sigma I}{h\nu} + \frac{(N_{10}-N_1)}{\tau_F}$$

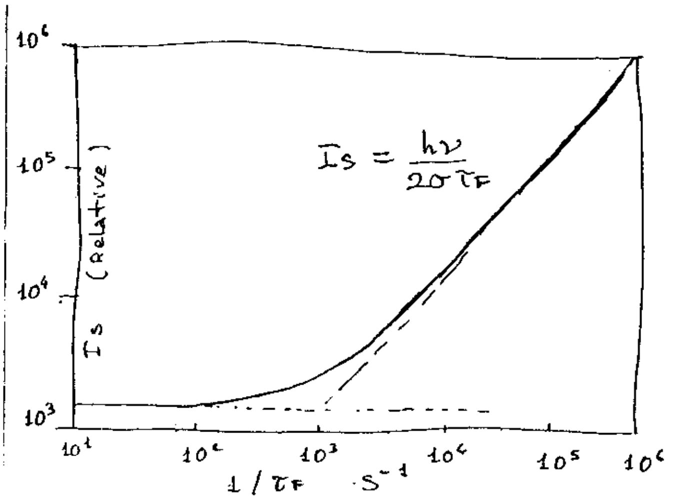
where: $v/x = 1/\tau_F$

$$\alpha = \sigma(N_2-N_1) = \frac{\sigma(R_2\tau_2 - R_1\tau_1)}{1 + I\frac{\sigma}{h\nu}\left[\frac{\tau_2\tau_F}{\tau_2+\tau_F} + \frac{\tau_1\tau_F}{\tau_1+\tau_F}\right]}$$

$$\alpha = \alpha_0 \cdot \frac{1}{1+I/I_s}$$

$$\alpha_0 = \sigma(R_2\tau_2 - R_1\tau_1)$$

$$I_s = \frac{1}{\frac{\tau_2\tau_F}{\tau_2+\tau_F} + \frac{\tau_1\tau_F}{\tau_1+\tau_F}} \xrightarrow[\tau_F \ll \tau_1, \tau_2]{\text{FOR}} I_s = \frac{h\nu}{2\sigma\tau_F}$$



Critical value for $\tau_F \simeq 1$ msec

Typical values of flow velocities

In transverse flow discharges:

$x \simeq 5$ cm $\quad \tau_F = 1$ ms

$v_t \simeq 50$ m/s

(Example: 100 cm x 5 cm x 5 cm
Flow rate 5 dm² x 500 dm/s = 2500 dm³/s
Laser power 5 W/lts⁻¹ x 2500 lts⁻¹ = 12500 W)

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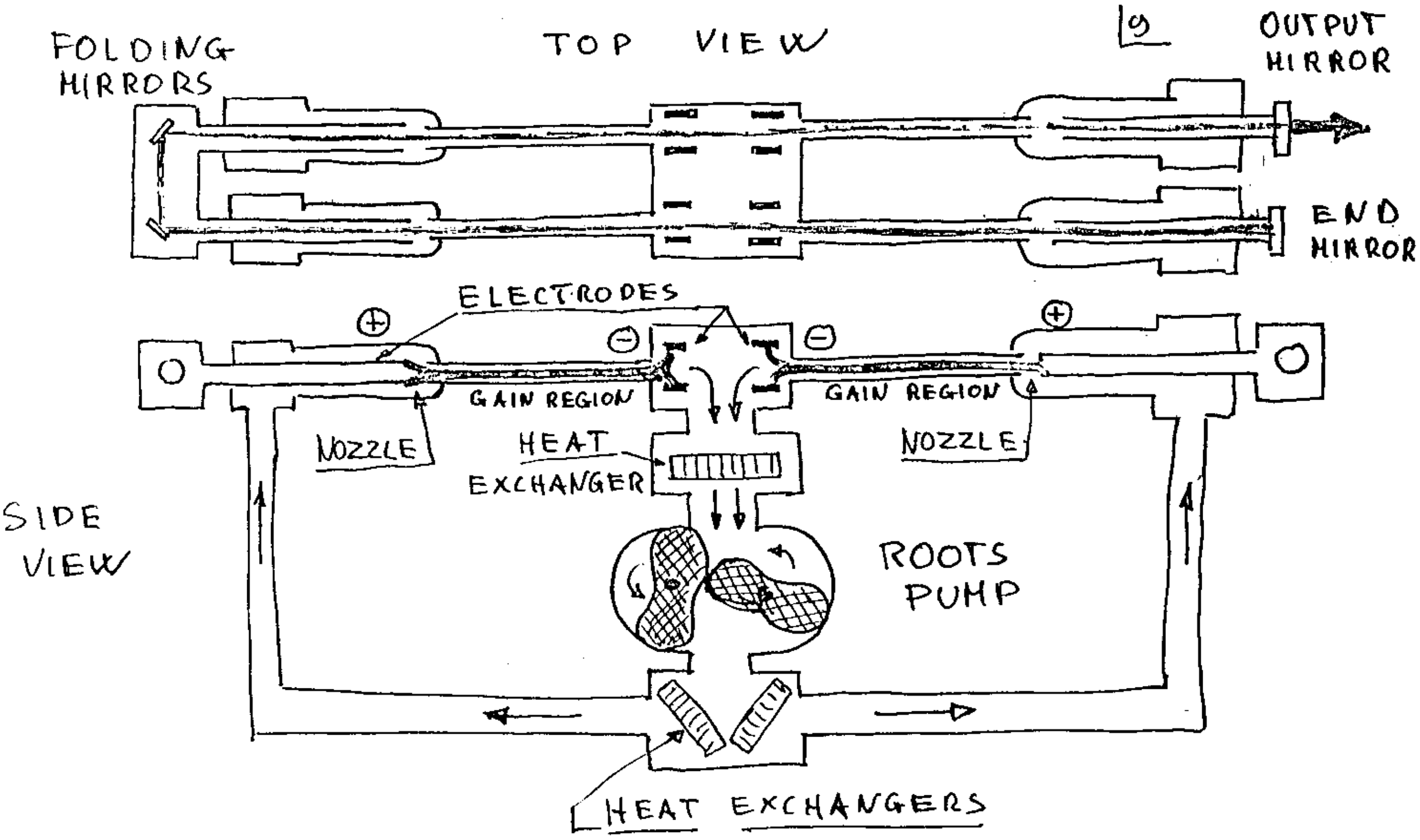
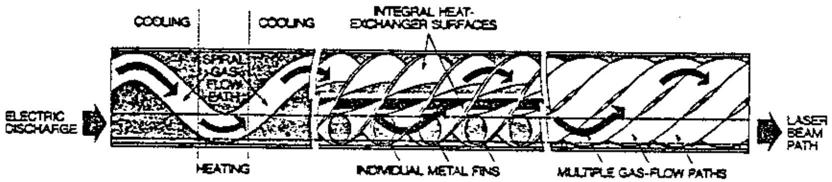


FAST AXIAL FLOW LASER (B.O.C.)
2 KW

S2,85

Spiral Flow Technology. New technology implemented in the TURBOLASE Series retains the discharge stability and long beam path of conventional CO_2 laser technology, while increasing the power output to over 400 watts per meter of discharge length. The direction of both the electrical discharge and the optical path of the laser beam are transverse to the gas flow. With this technology, the carbon dioxide, nitrogen, and helium gases are circulated at higher speed through the heat exchanger, which is integral with the optical laser cavity. Spiral metal fins within this heat exchanger direct the gas periodically through an electrical discharge which is offset from, but parallel to, the TURBOTUBE™ axis, as the next figure illustrates. The metal fins act as integral heat exchange surfaces for the gas after each pass through the discharge.

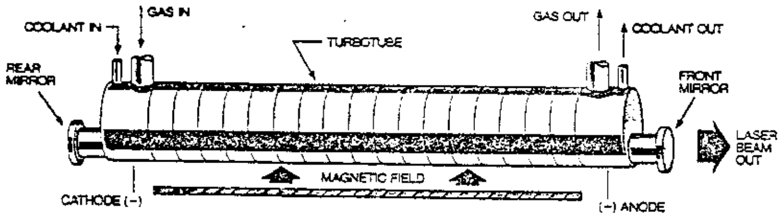
TURBOLASE™ Technology

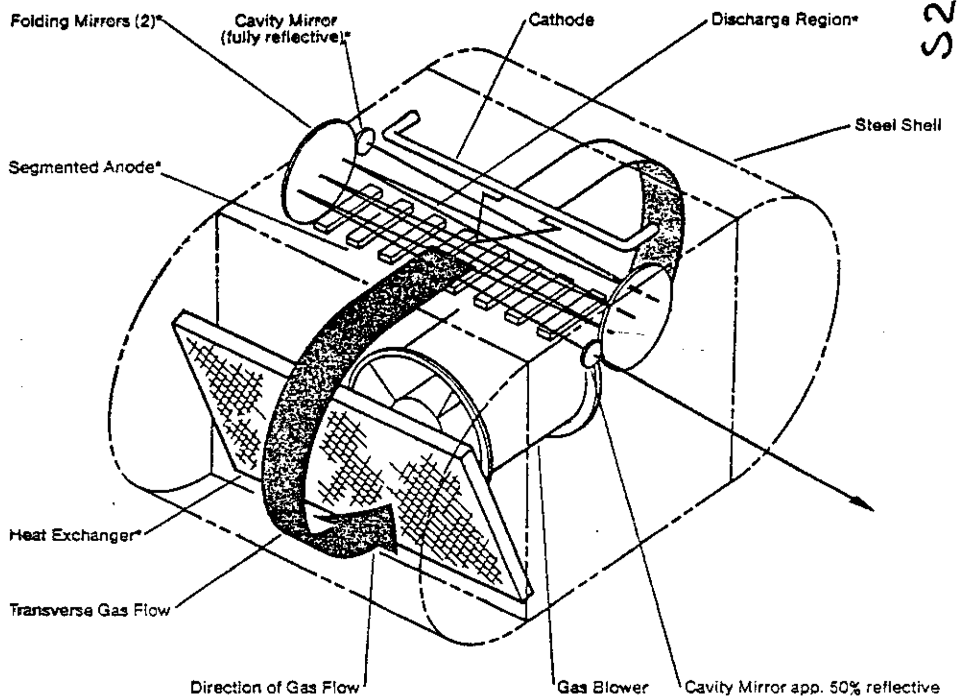


The multiple spiral gas flow paths optimize the heat removal capacity of the fins. Although heat is removed from the gas by means of convection cooling, heat is removed while the flowing gas is still in the laser tube. This integral heat exchanger technology results in the gas being heated and cooled a number of times as it flows through the TURBOTUBE, utilizing the same volume of gas more effectively than externally-cooled, transverse-flow CO_2 lasers.

Like lasers employing the conventional slow axial gas-flow, diffusion-cooled technology, the TURBOLASE Series also employs a long, small diameter resonant optical cavity and discharge path, producing beam quality and discharge uniformity which permits focusing to small areas for high energy densities. Stabilization of the position of the electrical discharge within the TURBOTUBE assembly, as illustrated below, is achieved by a magnetic field.

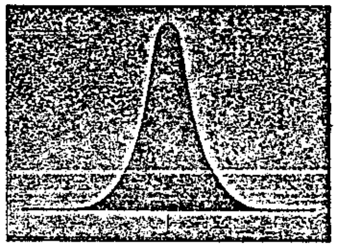
TURBOTUBE™



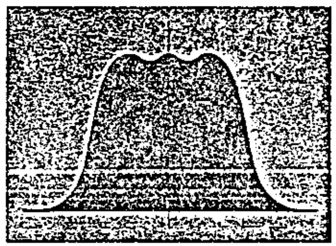


*Patented Design Features #3,772,610. #3,836,236. #3,986,481. #3,904,983

Choice of energy distributions across the laser beam generated by the Model 971 HELP.

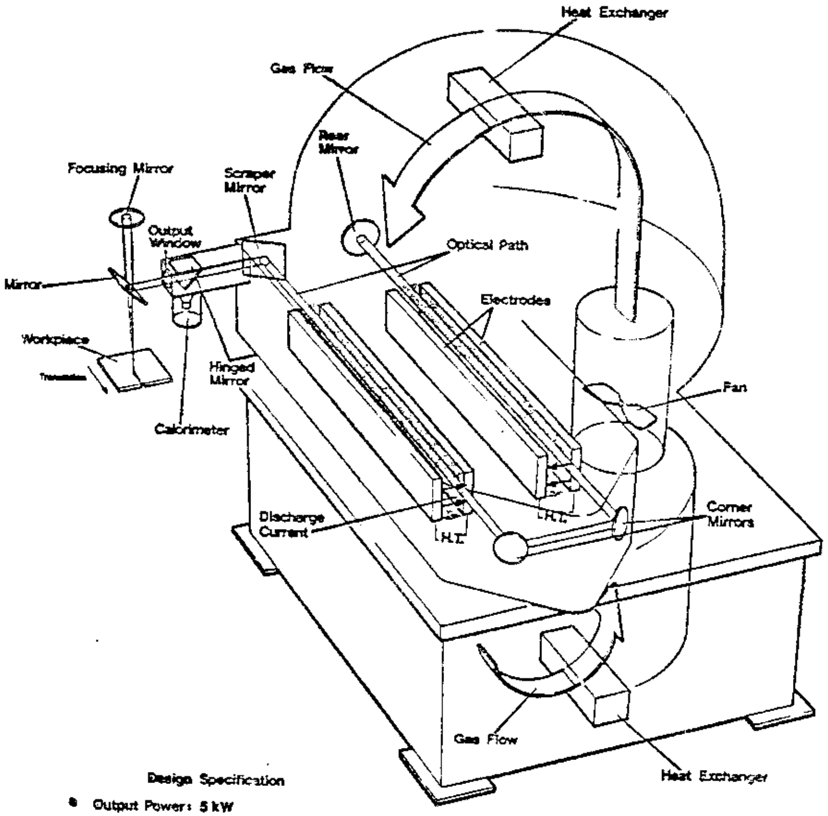


Gaussian Mode—(or TEM_{00} Mode) is ideally suited for high quality cutting. Power densities up to 10^{+9} watts/inch². Mode quality is maintained throughout the power range.



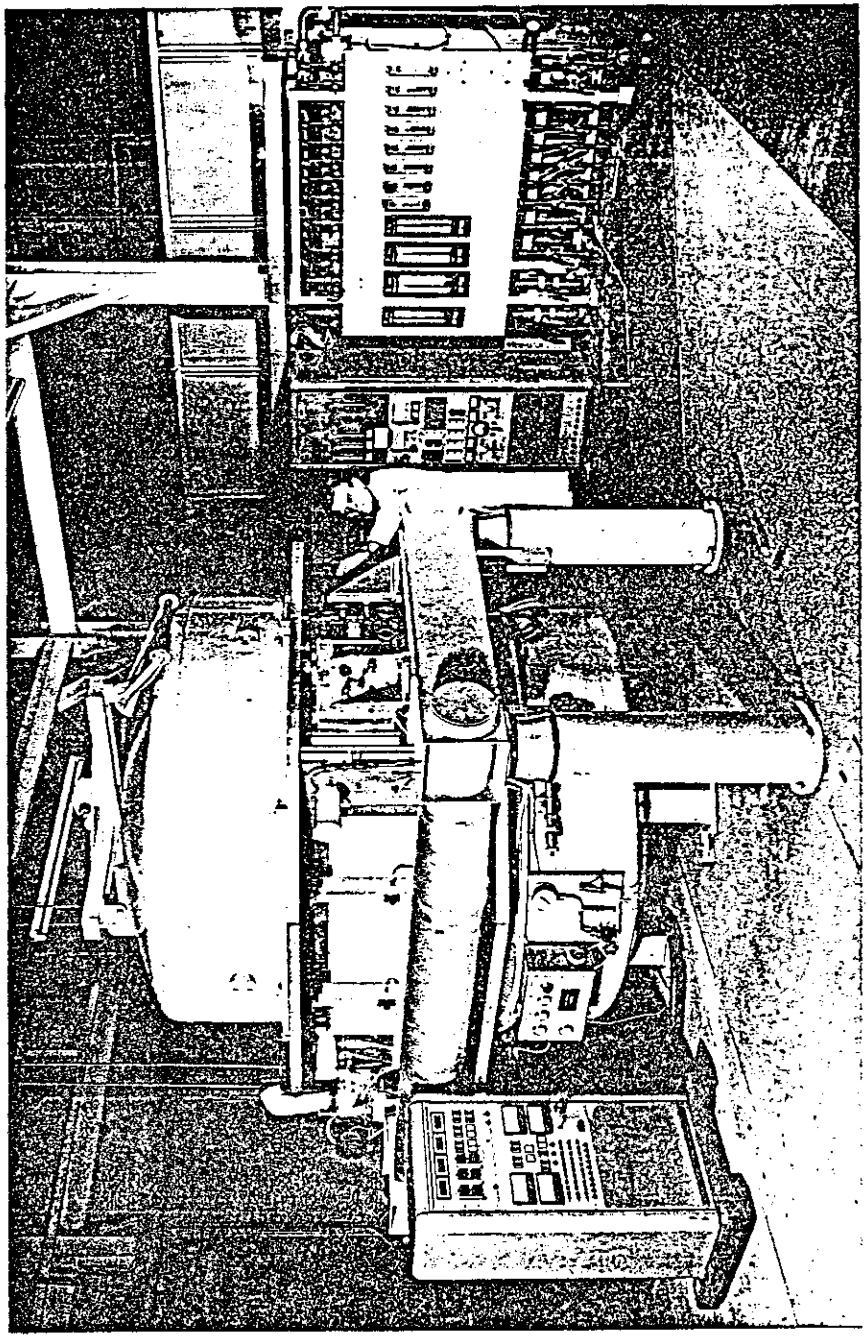
Mixed Mode—(app. 50% each of TEM_{00} and TEM_{01}) because of its flat topped distribution is ideal for welding and heat treating.

Culham's fast transverse gas flow system for multi-kilowatt laser beams

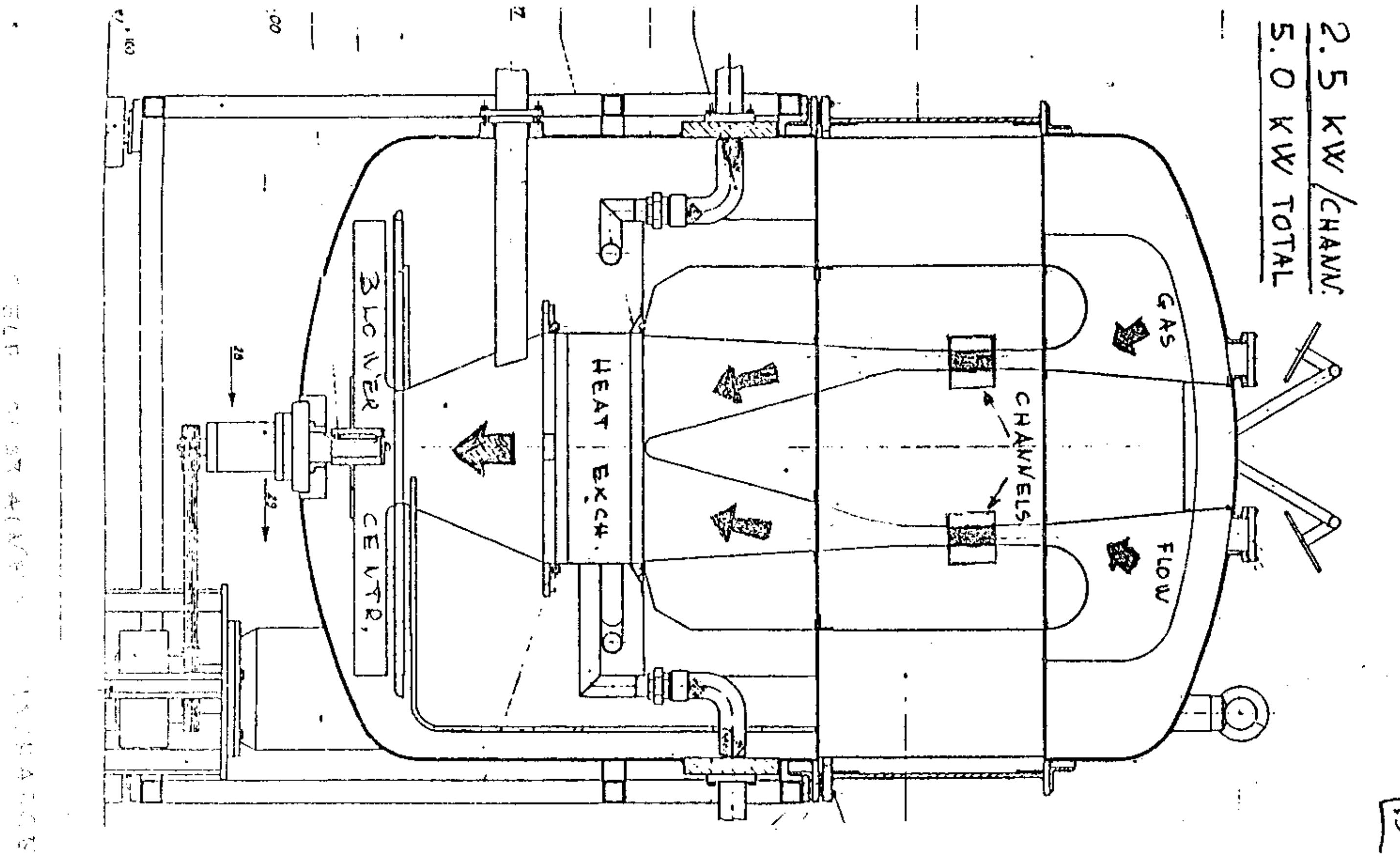


Design Specification

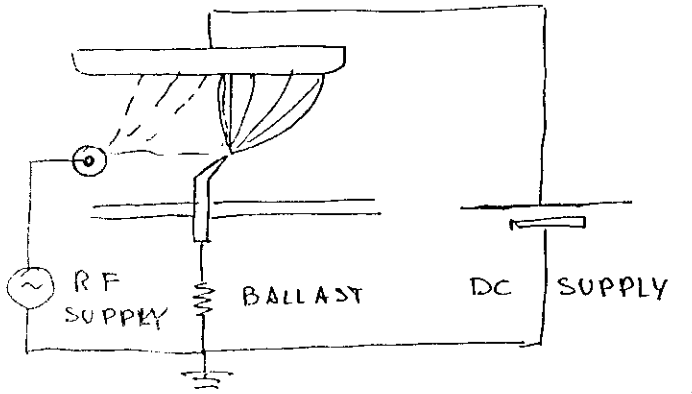
- Output Power: 5 kW
- Head Dimensions: 1·6m x 1·4 x 2·0m high
  Head Weight: Approximately 2·0 Tonnes
  Power Supply: 75 kVA at 415 Volts A.C.
- Gas Consumption: 150 l/Hour
  Cooling Water: 3,000 l/Hour – 15°C (70 kW Power Dissipation)



2.5 KW/CHANN.
5.0 KW TOTAL



MIXED DC + RF EXCITATION
(MITSUBISHI 10 KW)



Interelectrodic distances
up to ≃ 8 cm

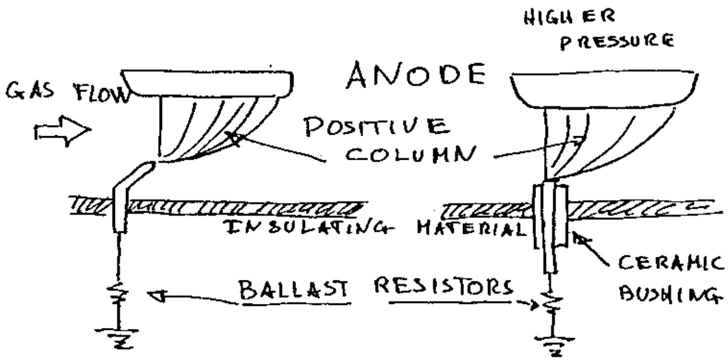
Power input (without arcing)
4 times larger than DC only

Excitation frequency ~ 50 KHz

$\frac{\text{RF POWER IN}}{\text{DC POWER IN}} \simeq 5\%$

Working pressure ≃ 100 Torr

High-Pressure Sealed
CW CO_2 LASERS



Operation in the range
100 - 760 TORR

at 100 TORR 1 KW OUTPUT
with 10 % EFFICIENCY

flow velocity 30 m/s

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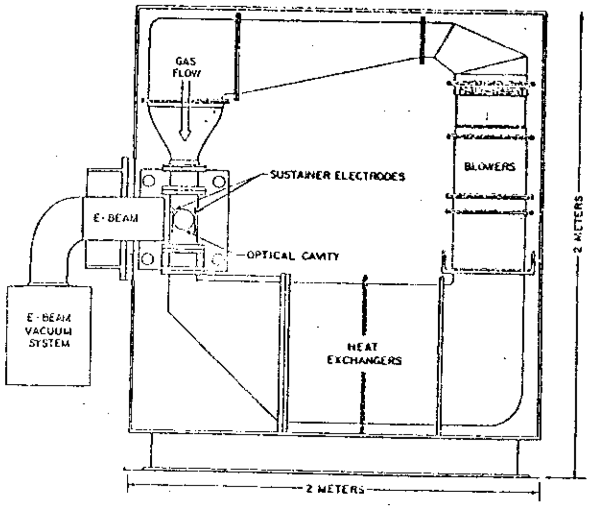

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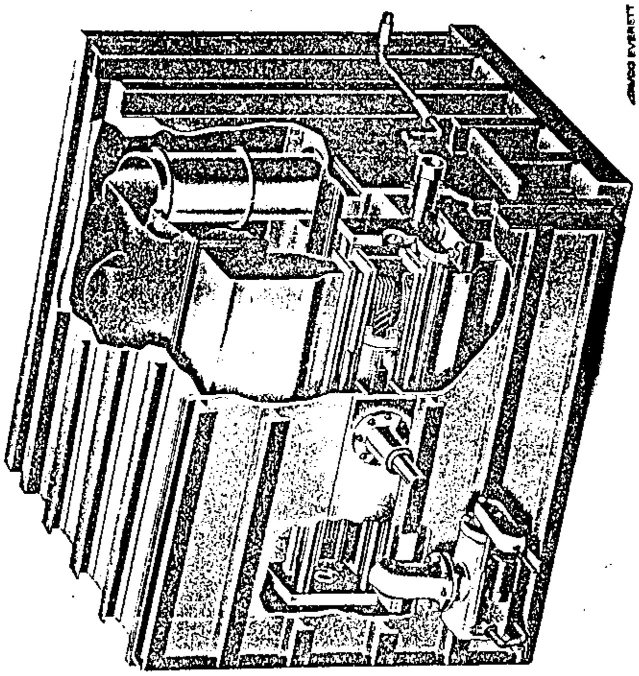
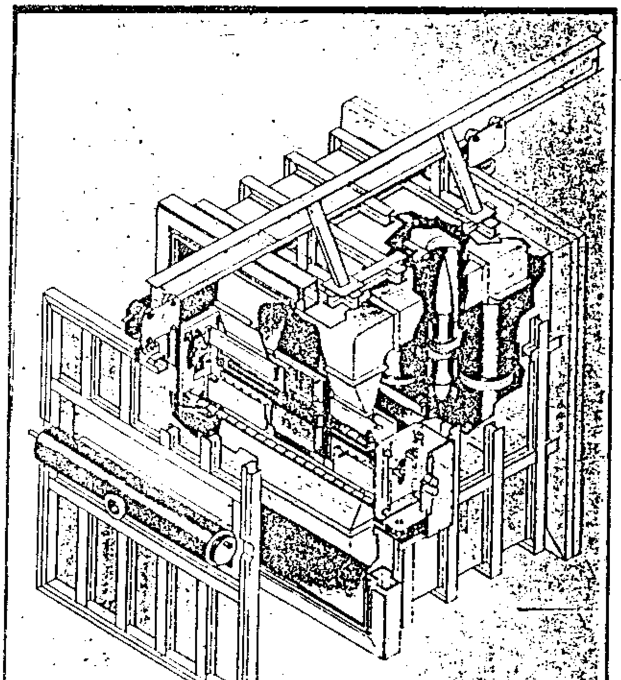


S 4"

17°

P_L = 10 KW up to 12 KW (few min)

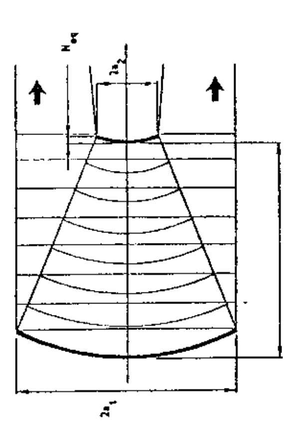


5 KW → 10 KW → (12 KW)
NOMINAL EFFECTIVE EXPECTED

E-BEAM EXCITED LASER

S 13

18°



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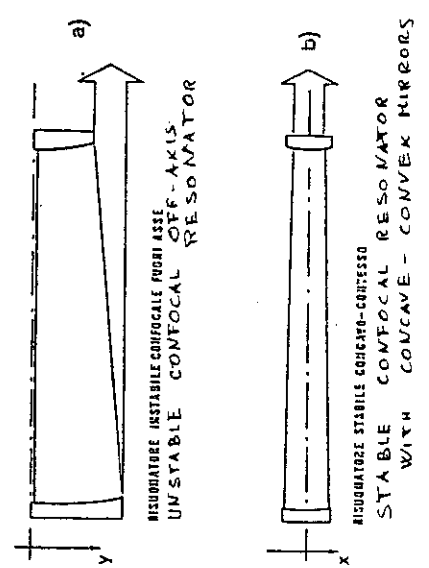

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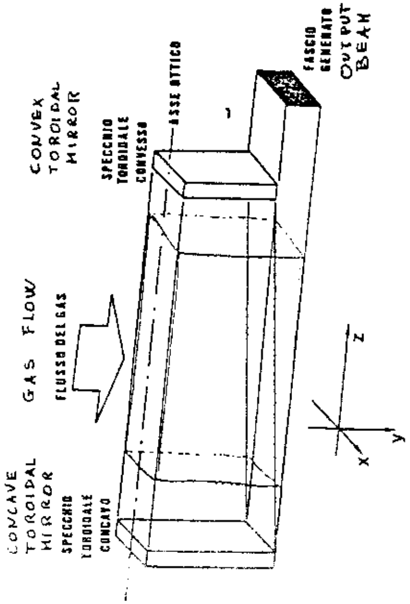

STABLE PLANE X Z
CONFOCAL UNSTABLE PLANE Y Z

UNSTABLE - STABLE RESONATORS
APPLIED OPTICS
Vol. 20, No. 20 15 OCT 1981

A. BORGHESE R CANEVARI V DONATI
L. GARIFO

δ output coupling coefficient $\begin{cases} 1 - 1/M^2 \begin{cases} -a \\ -b \end{cases} \\ 1 - 1/M \quad c \end{cases}$

If $\eta_0 = P_{out} / P_{avail.}$ Extraction efficiency

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P_{out} output power

$P_{av.}$ $g_0 I_s V$

$\eta_F = P_F / P_{out}$ Focusing efficiency

$Q = P_F / P_{av} = \eta_0 \times \eta_F$

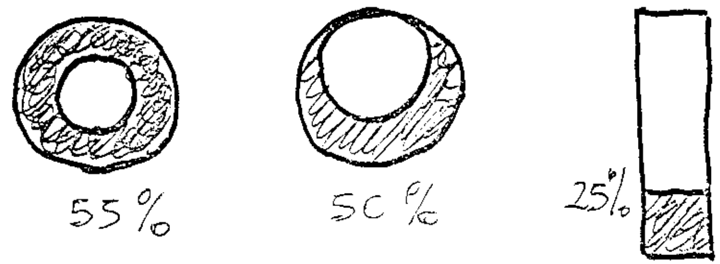
Fraction of P_{av} focused

For $V = L \times S = 1000\ cm^3$

$(L = 1\ mt \quad S = 10\ cm^2)$

$g_0 = 0.01\ cm^{-1}$

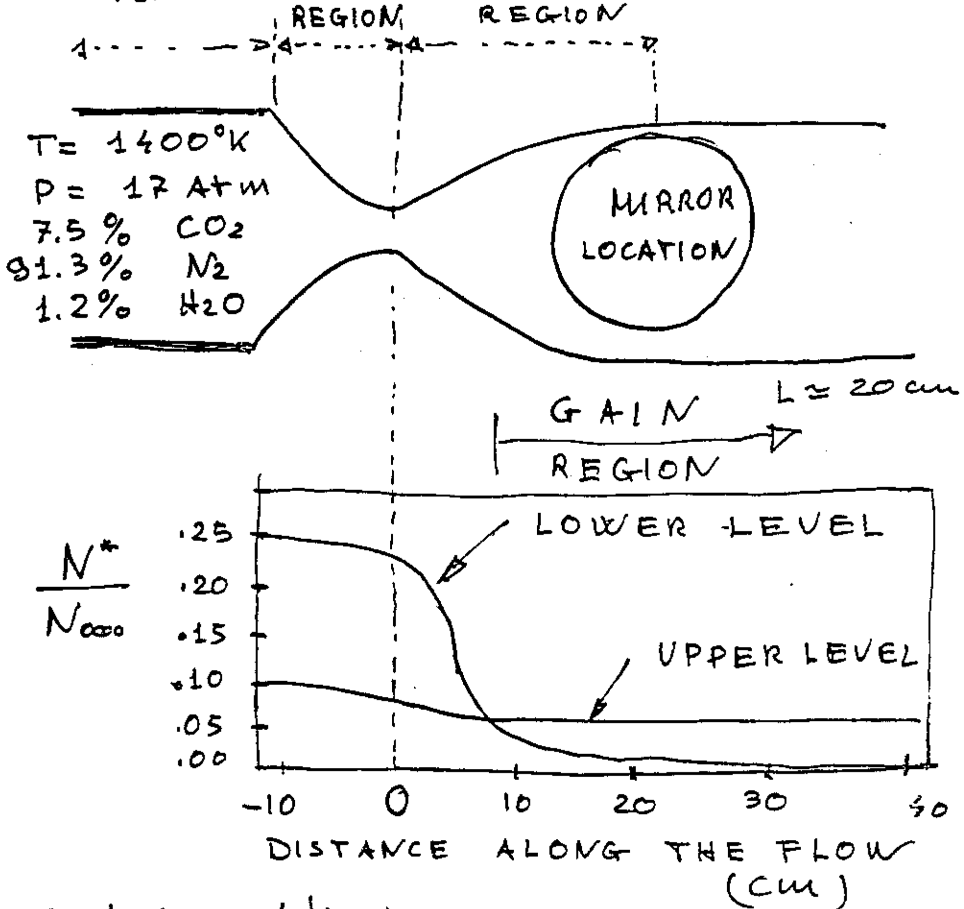
passive losses ~ 0.03

	Annular Cavity a	Crescent Beam b	Toroidal Unstable c
			
δ_{opt}	55 %	50 %	25%
Q =	14%	25%	63 %

GAS DYNAMIC LASER

UP TO > 100 kW

CHEMICAL EFFICIENCY ~ 1%



RELAXATION $V \to T$

Initial condition:

Upper level 00^01 ≃ 10%

Lower level ≃ 25%

UPPER STATE LIFETIME LONGER THAN LOWER

Length L depends on τ_r