# V. ELECTRODYNAMICS OF MEDIA*

## Academic and Research Staff

Prof. L. J. Chu
Prof. H. A. Haus
Prof. P. W. Hoff
Prof. J. A. Kong
Prof. P. Penfield, Jr.

## Graduate Students

B. L. Diamond
M. S. Elkind
H. Granek
D. L. Lyon
E. E. Stark, Jr.
L-h. Wang

## A. TEA $CO_2$ RING LASER

We have been studying the operation of transversely excited, atmospheric, $CO_2$ lasers.[1-3] In our earlier work we used gain tubes of varying lengths in Fabry-Perot, two-mirror, optical cavities. Under a wide range of operating conditions "self-locking" was observed in the outputs of these lasers.[2,4] That is, two oscillating modes were being supported with equal amplitudes during the duration of the giant, gain-switched pulse from the laser.

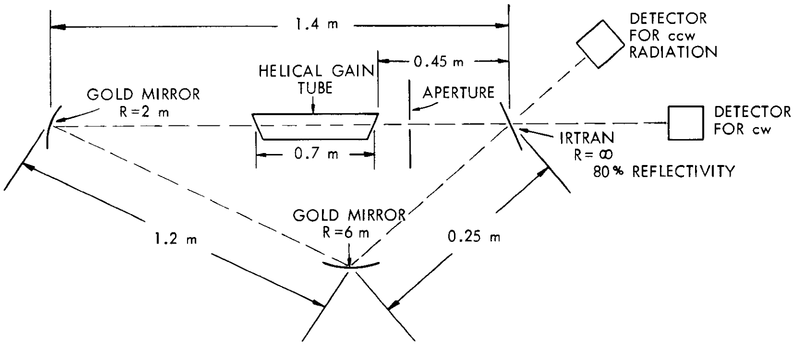

Fig. V-1. Ring laser schematic.

It has been suggested by E. E. Stark, Jr., and H. A. Haus that the self-locking may be due to the existence of spatial hole-burning caused by standing-wave patterns in the gain medium. In order to investigate this hypothesis, we have constructed a "ring" laser, using three mirrors and a single gain tube (see Fig. V-1). It was our aim to simultaneously monitor the clockwise and counterclockwise radiation emitted from the device. We could then compare the degree of self-locking with the degree of standing-wave character in the cavity. The gain tube used in the experiment had

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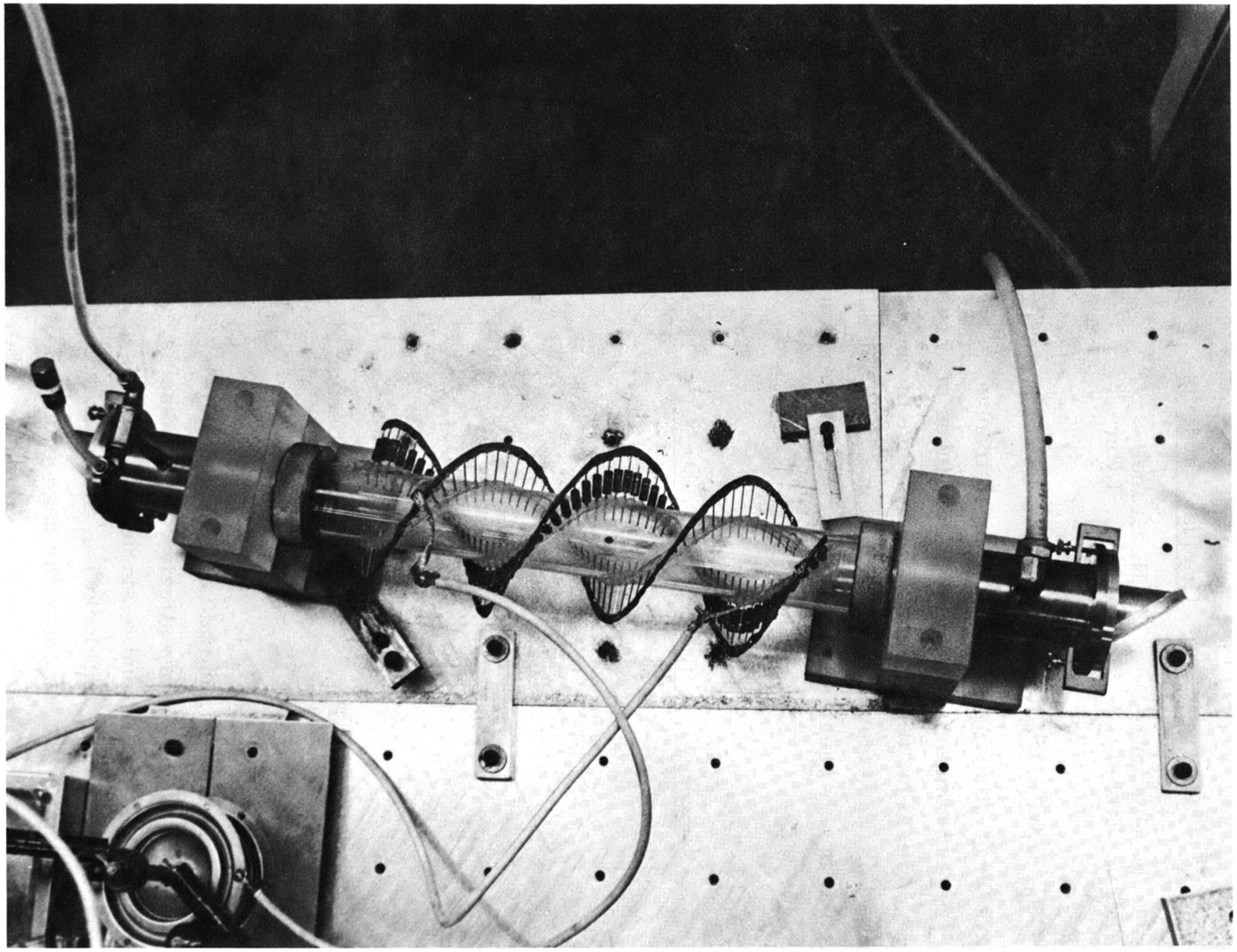


Fig. V-2. Helical gain tube.

an over-all length of 70 cm and an active discharge length of 35 cm (see Fig. V-2). The total volume of the tube is 0.3 liter. The anode and cathode were of helical geometry. The anode was made up of sixty, 1 kΩ resistors spaced 0.5 cm apart; the cathode consisted of 60 sharpened needles spaced 0.5 cm apart. Each resistor had a pin placed diametrically across the tube from it. Pin-to-resistor separation was 2.5 cm.

The helical construction was chosen because of its radial symmetry when viewed on-axis. The active discharge also has a radially symmetric shape, preferentially exciting radially symmetric optical modes of the cavity. With internal cavity aperturing we restricted the laser output as much as possible to the $TEM_{00}$ mode.

Because of the lack of reliable data concerning optimal TEA $CO_2$ laser operation we decided to maximize several operating characteristics vs all easily variable parameters. Total gas pressure, ratios of component gases, total gas flow rate, discharge voltage, capacitance, discharge pulse rate, and polarity of pins and resistors were all varied. We were looking for the highest possible time-averaged output power, along with reproducible "nicely behaved" light pulses on a fast time basis. In our studies we found that clean and reproducible electronic glow discharges correlated well with smooth, reproducible optical pulses. For this reason, we also noted relative amounts of arc-type vs glow-type discharging in the gain tube.

To measure output power, we used a Coherent Radiation (thermal) power detector followed by a Keithley microvoltmeter. Our supply voltage was set at 20 kV, capacitance at 0.01 μF, and total gas pressure at 350 Torr. The resistors acted as the anode, pins as cathode. The pulsing rate was 8 pulses/second. We then measured total power radiated as a function of the flow rates of the three component gases: $CO_2$, $H_e$, $N_2$.

It was observed that total output power and pulse repeatability were both sensitive functions of the $He/CO_2$ flow rate ratio. The $N_2$ flow rate was a less critical parameter. Also there was a threshold flow rate below which good pulse repeatability and output power were not attainable. $He/CO_2$ flow rate ratios between 5.6 and 6.0/1 maximized total output power (see Fig. V-3) at total flow rates of the order of 2 liter-atm/min. The optimal $He/N_2$ ratio was found to be in the vicinity of 10/1. This ratio was not terribly critical.

We then varied the supply voltage and the amount of capacitance in our trigger circuit (see Fig. V-4). These curves were taken with gas pressure equal to 350 Torr, 2 liter/min flow rate, gas ratios $CO_2$: $H_e$: $N_2$ : : 1.8: 10:1, and pulse repetition equal to 5/s.

Although a capacitance value of 0.014 μF yielded the highest output power there was a large amount (approximately 10% of the number of resistors) of high current arc discharges. The laser output pulses were correspondingly less stable at the highest

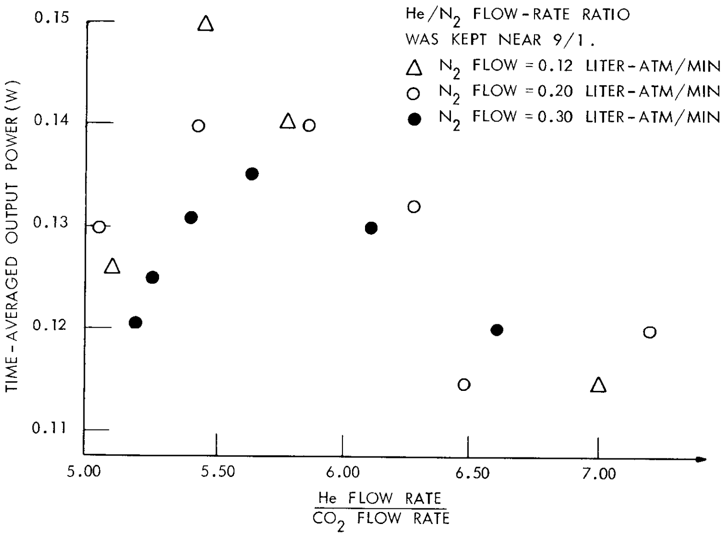
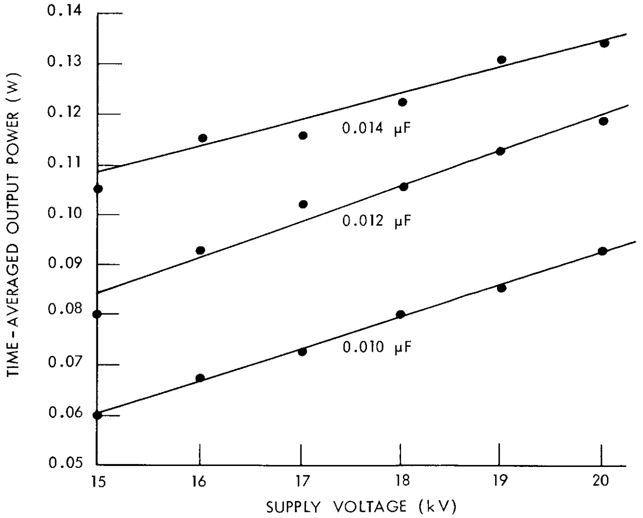


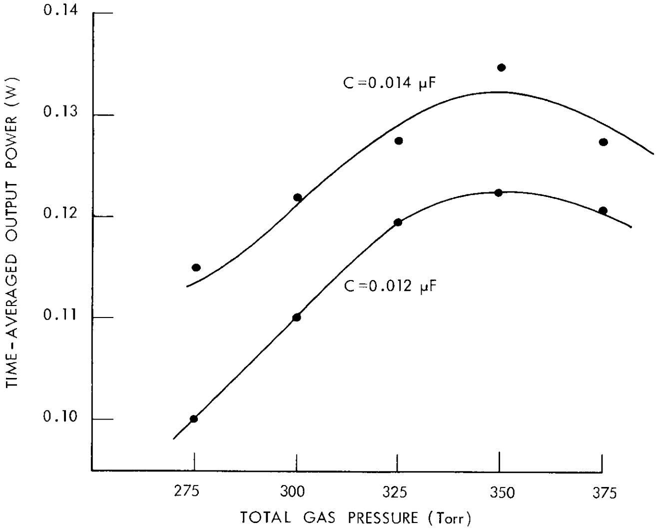
Fig. V-3. Power vs He/$CO_2$ flow ratio.



FLOW RATIO: 9:1.6:1: :He:$CO_2$:$N_2$

TOTAL PRESSURE: 350 Torr

Fig. V-4. Power vs supply voltage.



SUPPLY VOLTAGE = 19.5 kV

FLOW RATIO: 9:1.6:1::He:$CO_2$:$N_2$

Fig. V-5. Power vs gas pressure.

capacitance value.

Finally, we measured output power as a function of total gas pressure and parametrized on capacitance values (see Fig. V-5). We had also planned to parametrize the curves on pin-resistor polarity; however, we found that keeping the resistors positive and pins negative yielded approximately 3/2 the power under all operating conditions than the reverse polarity.

After this initial step-by-step optimization we again varied gas ratios and found similar results as obtained under the slightly suboptimal conditions illustrated in Fig. V-3.

Our final choices for optimizing total output power and pulse repeatability were the following.

Electrical Conditions – 20 kV supply voltage
0.012 $\mu$F capacitance
resistors positive (anode); pins negative (cathode).

Gaseous Conditions – 350 Torr total gas pressure
2.5 liter/min total flow rate
He: $CO_2$: $N_2$ flow ratio of 9:1.6:1.

Using these parameters values, we observed the two outputs simultaneously from our ring cavity laser. Each output corresponded to the radiation traveling in either the clockwise or counterclockwise direction in the cavity. Two liquid He cooled Cu:Ge were used to monitor the propagating 10.6 $\mu$ radiation. The output current from the detectors is essentially a function of the magnitude of the incident light. Two oscilloscopes with bandwidths greater than 150 MHz were used to display detector current. One was

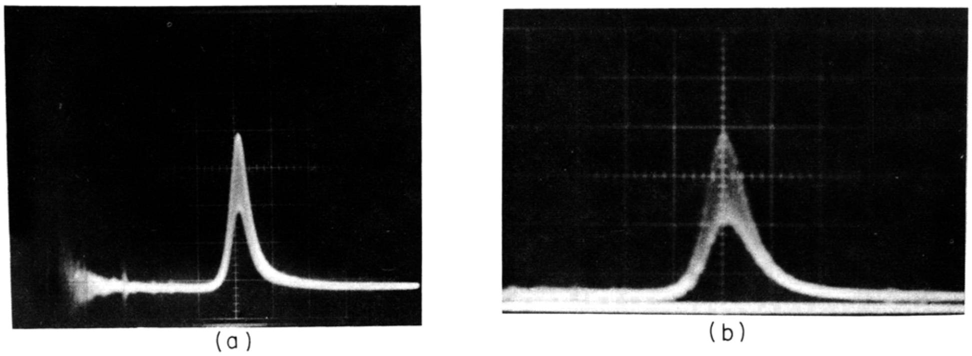

(a) (b)

Fig. V-6. (a) Type 7704 oscilloscope trace of current from detector monitoring the counterclockwise direction. Horizontal: 2 $\mu$s/div; vertical: 0.05 V/cm.
(b) Type 454 trace of response to cw traveling pulse; triggered simultaneously with oscilloscope in (a). Same scales.

a Tektronix Type 454 and the other a Tektronix Type 7704 main-frame with high-speed time base and vertical amplifier plug-ins. The two oscilloscopes were triggered simultaneously through an attenuated feed from the discharge current pulse. In the figures presented (see Fig. V-6) the start of the trace corresponds to the start of the discharge current in the gain tube.

The following general behavior was observed: (i) The clockwise and counterclockwise pulses generally had different amplitudes following a single discharge of the gain tube. No strict correlation between them was observed and their mean values were roughly equal. (ii) Both pulses had an equal delay time ($\tau$) measured from the start of the gain-tube discharge. (iii) $\tau$ varied around an average value of 8 $\mu$s, with standard deviation equal to 1.5 $\mu$s. (iv) In no single observation was the light pulse ever 100% "self-locked." The output signal corresponded to the presence of two unequal amplitude, longitudinal modes. This observation must be contrasted with those modes in a Fabry-Perot cavity.

These results do not constitute a proof that standing-wave patterns in the gain medium are necessary for "self-locking." They are suggestive, however, of that statement, and further experiments are planned to pin down the relationship. We are considering various cavity configurations that will allow us to vary deterministically the degree of standing-wave character in the cavity. We are also investigating the possibility of an optical circulator at 10.6 $\mu$.

D. L. Lyon, E. V. George

## References

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3. A. J. Beaulieu, Appl. Phys. Letters 16, 504 (1970).
4. D. L. Lyon, E. V. George, and H. A. Haus, Appl. Phys. Letters 17, 474 (1970).