Simple Inexpensive Laboratory-Quality Rogowski TEA Laser

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The design, construction, and operational parameters of a Rogowski-type TEA CO_2 laser are given. The device, which is simple and inexpensive to build, incorporates a provision for intracavity experiments and appears suited for studies in plasma physics and nonlinear optics.

INTRODUCTION

There has been considerable activity in the pulsed CO_2 laser field over the past few years, especially with the development of high pressure, transversely excited systems.[1–9] More recently several major advances in the state of the art have taken place in respect to the achievement of very high pulsed energies using preionization techniques.[10–16] Many of these lasers are finding increasing utilization as research tools in the field of plasma diagnostics and nonlinear optics. In addition it is becoming apparent that such devices can be effectively employed in various industrial and medical applications.

At the present time, however, there are few inexpensive sources of medium powered TEA lasers. This being the case, we wish to present here constructional and operational details of a simple and inexpensive laboratory-quality TEA laser so as to permit researchers to fabricate a similar device with minimum effort.

This relatively compact and uncomplicated structure utilizes Rogowski electrodes and a Lamberton preionization technique.[14,15,17,18] The device can be built for a total cost of about \$2000. This price includes, materials, power supplies, and machining costs. Most university-type machine shops should be able to fabricate this laser in less than three weeks at a labor cost of \$1000.

CONSTRUCTIONAL DETAILS

Electrodes

The electrode configuration adopted for the laser is shown in Figs. 1 and 2. The shape was generated on a milling machine using a cutter fabricated for the purpose. This cutter had a tool steel blade of the required Rogowski profile, as shown in Fig. 3, and thus permitted the electrodes to be duplicated with minimum effort. These electrodes were machined from standard ($60\times10\times1.9$ cm) aluminum stock.

Standard machining tolerances of ±0.1 mm were found adequate. A maximum electrode length of 60 cm was imposed by the particular milling machine used, and consequently three pairs of electrodes were cascaded to give an active laser length of approximately 180 cm.

Profile Cutter Fabrication

The shape of the milling cutter used to make the electrodes was determined from the Rogowski equation.[17,18] A template having this shape was made by plotting the x and y coordinates given in Fig. 3. This template was in turn used to generate the cutter blade in a tracer lathe from a 6 mm flat bar of untempered tool steel. After relieving the backside of the blade and sharpening one edge, the blade was hardened. Finally, the finished blade was bolted into a standard milling head holder. The mounted cutter blade and a profiled electrode are shown in Fig. 4. The ends of the electrodes were generated by mounting them on a rotary table as indicated. After profiling, the backsides were given a slight radius to break the edge and the entire surface was blended with emery. Final polishing was done with a cloth buffing wheel to obtain a smooth, scratch-free surface.

Main Laser Tube and Mounting Structure

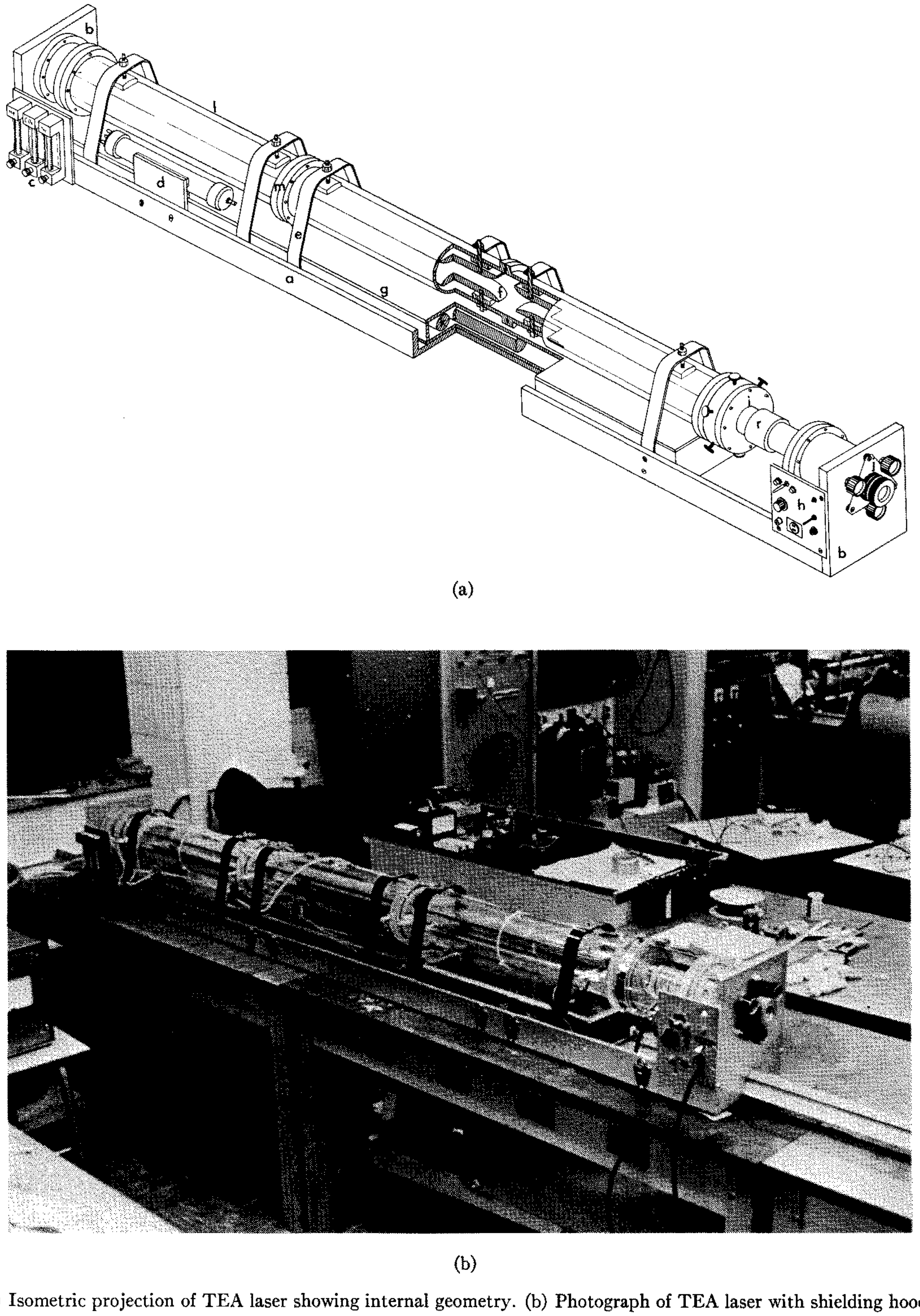
The main laser body was fabricated from three separate sections of 13 cm i.d. by 14 cm o.d. clear acrylic tubing, Fig. 1. Each section was flanged and O-ringed so that the entire unit was leak tight. The three sets of Rogowski electrodes were mounted inside each section with a 25 mm spacing. This was accomplished by means of 1 cm diam threaded brass rods and locking nuts. These threaded brass mounting rods also served as the electrical leads to the discharge capacitors and trigger wires, Fig. 2(a). The top electrodes (cathode) were bolted to six copper hangers, which served as ground return as well as support brackets for the entire tube assembly. The bottom electrodes were used as anodes so that high voltage lead lengths were minimized.

Mirror mounts were made integral with the laser tube and the entire assembly was bolted inside a standard ($8\times25\times250$ cm) aluminum channel which served as the backbone of the structure. Figure 2(b) shows the sectional details of the mirror mounting assemblies used in this laser. These mounts proved to be exceptionally stable, yet allowed full versatility for adjustment and cavity length tuning. Flexible rubber membranes rendered the assemblies leak tight.

The internal lens q, 20 cm metallic reflector s, and cavity length adjusting device t shown in Fig. 2(b) are used for intracavity gas breakdown or heating experiments. When operation in the normal mode is desired, items q and t are omitted and part s is replaced by a standard 4 cm$\times$5 mm germanium etalon.

Since in many applications the electrical interference produced by the discharge is unacceptable, this laser was provided with three tight-fitting shielding hoods, which eliminated this problem.

Short optical benches were built into the ends of the aluminum channel, Fig. 1. This feature proved especially



(a)

(b)

FIG. 1. (a) Isometric projection of TEA laser showing internal geometry. (b) Photograph of TEA laser with shielding hood removed.

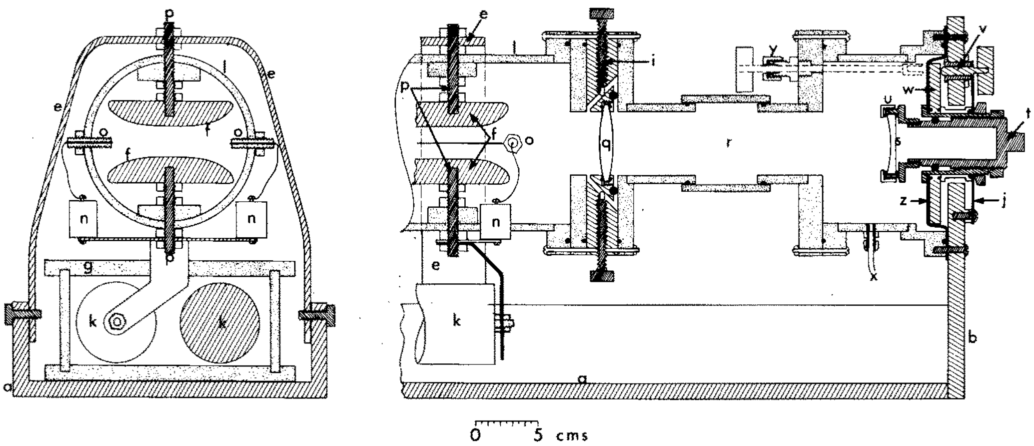
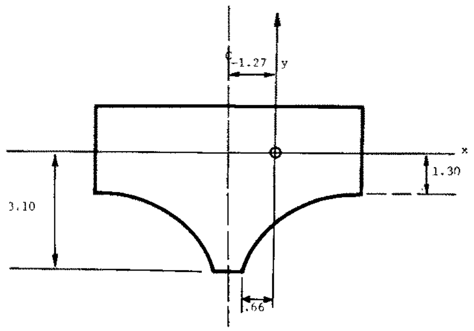


FIG. 2. Left—Sectional diagram of laser showing electrode geometry, trigger system, and layout of discharge capacitors; right—sectional view of intracavity region showing adjustable lens mount, test chamber, and internal mirror mount.

useful for mounting external alignment lasers, test optics, power measurement devices, etc.

ELECTRICAL EXCITATION SYSTEM

The charging ballast resistors, high voltage capacitors, triggering system and spark gap shown schematically in Fig. 5 were all mounted in a long, covered Perspex tank which was fitted inside the aluminum channel. This technique allowed all the components to be mounted in close proximity, thereby minimizing inductance. High voltage transformer oil in the tank also eliminated all insulation problems.



x	−	.66	.61	.56	.51	.48	.41	.36	.31	.25	.20	.15	.10	.05
y	−	3.10	3.00	2.90	2.79	2.69	2.61	2.51	2.44	2.39	2.31	2.24	2.21	2.13
x	+	.00	.05	.10	.15	.20	.25	.31	.36	.41	.48	.51	.56	.61
y	−	2.08	2.03	1.98	1.93	1.90	1.85	1.83	1.80	1.75	1.73	1.70	1.68	1.65
x	+	.66	.71	.76	.81	.86	.91	.96	1.02	1.07	1.12	1.17	1.22	1.27
y	−	1.63	1.60	1.60	1.57	1.55	1.52	1.52	1.50	1.50	1.47	1.47	1.45	1.42
x	+	1.32	1.37	1.42	1.47	1.52	1.57	1.62	1.73	1.78	1.83	1.88	1.93	1.98
y	−	1.42	1.42	1.40	1.40	1.40	1.38	1.38	1.38	1.38	1.35	1.35	1.35	1.35
x	+	2.03	2.08	2.13	2.18	2.24	2.29	2.44	2.49	2.54	2.79	3.05	3.30	3.56
y	−	1.35	1.32	1.32	1.32	1.32	1.32	1.32	1.30	1.30	1.30	1.30	1.30	1.30

FIG. 3. Diagram of profile milling cutter blade and coordinates used to make template. (Note: dimensions given in centimeters.)

In addition, because of the type of charging circuit used, the anodes remained at ground potential except during the short discharge period; thus no corona problems were experienced.

A 3 m length of RG-8 coaxial cable served as the power supply lead from the 50 kV, 16 mA dc power supply.

Preionization System

Figure 2(a) indicates the simplicity of the preionization system utilized. This consisted of two $\frac{1}{4}$ mm diam tungsten wires stretched along the length of each pair of electrodes. Two 30 kV, 500 pF door knob capacitors supplied trigger energy to each end of these wires by coupling to the anode leads. Horizontal positioning of the wires was not critical.

Discharge System

Only one spark gap was required to discharge the three capacitors employed in the system. These capacitors, one for each pair of electrodes, were standard energy storage types and not the low inductance variety normally

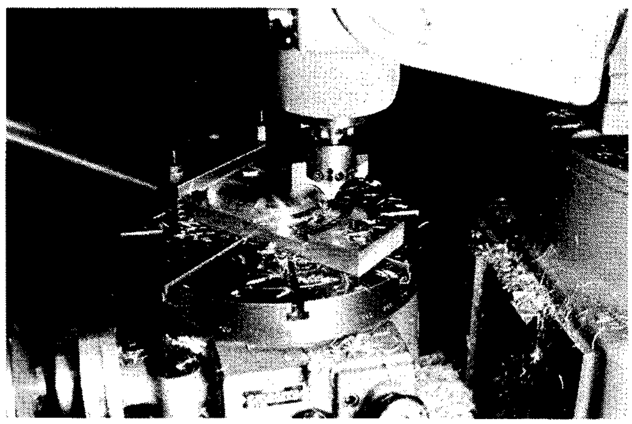


FIG. 4. Photograph of milling cutter and partially completed electrode.

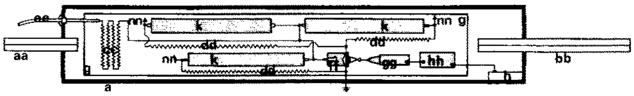


FIG. 5. Schematic diagram of discharge system showing component layout.

associated with TEA lasers. These were much less expensive but found to be adequate. Capacitor sizes up to 0.05 μF performed well, giving arc-free discharges. Higher output energies were obtained with the larger sizes.

Spark Gap

The details of the pressurized, triggered spark gap made for the laser are shown in Fig. 6. Perspex was used for the main body with copper and aluminum for the electrodes. A standard motorcycle surface gap spark plug served as the trigger electrode. A cleanable glass sputtering shield was incorporated in the device in the event that sputtering was excessive. To date this spark gap has performed very satisfactorily and has shown no noticeable electrode sputtering or wear.

Triggering System

Figure 7 is a schematic diagram of the trigger system developed. Basically it resembles an automotive SCR ignition system and has proven to be exceptionally reliable and consistent in operation. This inexpensive unit was mounted inside the oil filled tank along with the spark gap and capacitors.

Rate Generator

A compact rate generator was built into the front control panel on the laser body. This generator produced synchronization and triggering signals, for the laser and auxiliary monitoring equipment, which were adjustable in rate from 0.1 to 10 pulses/sec. A manual single pulse push button was also provided.

Gas Flow System

The proper mixture, [CO_2:N_2:He] of [1:1:9] and flow rate of about 1 liter per min were adjusted and

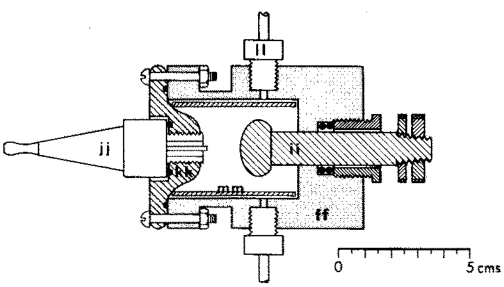


FIG. 6. Sectional view of triggered spark gap switch.

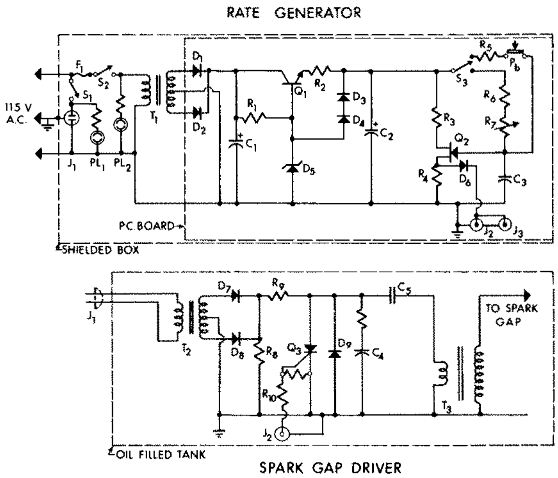


FIG. 7. Electrical schematic of trigger system and rate generator.

monitored on three small flow meters mounted on the laser body as shown in Fig. 1. A gas mixing chamber was fabricated simply from a 30 cm length of 5 cm PVC tubing, capped at both ends and tightly filled with "Chore Girl" copper scouring pad.

OPTICAL CAVITY DETAILS

Initially the 250 cm optical cavity was formed by a 20-m-radius gold-coated quartz reflector and a flat, uncoated germanium output etalon. With these components and a clear 25 mm aperture the laser produced 15 J pulses. It was found, however, that at these pulse energies the reflectors deteriorated quite rapidly and became badly pitted after about 5000 shots. The 100% quartz reflector has since been changed to a Kanigon[19] mirror which has solved that problem, but it appears that an unstable resonator configuration is required to eliminate the germanium output mirror damage problem. It was interesting to observe that at these energies the germanium output mirror glowed brightly at each pulse. Nevertheless,

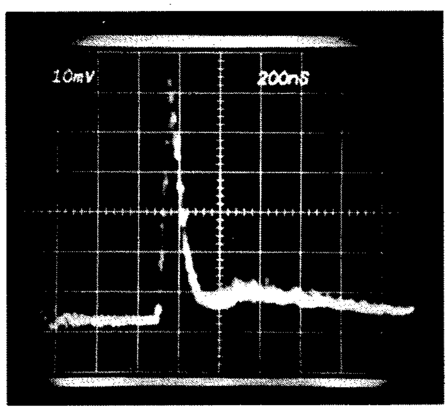


FIG. 8. Typical pulse output. (Sweep speed 200 nsec/div.)

Table I. Legend and parts lists to Figs. 1, 2, 6, 7, and 8.

a	Main laser support structure ($8\times25\times250$ cm, aluminum channel).
b	Laser end plates ($25\times30\times1.2$ cm, aluminum plate).
c	Gas flow meters [He, −7.0 S.C.F.H. and N_2, CO_2, −1.9 S.C.F.H. (Fisher Porter No. 10A-3135N)].
d	Gas mixing chamber (25×30 cm, PVC tube).
e	Grounding and support brackets (6 mm$\times$4 cm, copper bar).
f	Rogowski electrodes ($60\times10\times1.9$ cm, aluminum bar).
g	Oil filled tank ($10\times20\times180$ cm, Perspex).
h	Rep-rate generator and control panel (see Fig. 7).
i	Adjustable lens mount [brass, see Fig. 2(b)].
j	Triangular spring section of adjustable mirror mount [$\frac{1}{2}$ mm thick, spring steel, see Fig. 2(b)].
k	Primary discharge capacitors [0.02 μF to 0.05 μF (Film Capacitors Inc., No. KM 600-20 or KM 600-50)].
l	Main laser tube (13 cm i.d.$\times$14 cm o.d., cast acrylic tube).
m	Tube flanges (18 cm o.d.$\times$13 cm i.d.$\times$1.8 cm thick, Perspex sheet).
n	Trigger capacitors [500 pF, 30 kV door knob (Sprague Electric Co., No. 715 COO 9461D8303)].
o	Trigger wires and feedthrough ($\frac{1}{4}$ mm diam tungsten wire and nylon rod).
p	Electrode mounts and electrical leads (1 cm threaded rods, brass).
q	Intracavity lens (6 cm diam$\times$10 cm focal length, NaCl, A.R. coated.
r	Intracavity test chamber (5 cm i.d.$\times$6.3 o.d. and 6.3 cm i.d. $\times$7.1 cm o.d., cast acrylic tubing).
s	Laser metallic reflectors [5 cm diam$\times$10 cm focal length and 5 cm diam$\times$20 meter focal length, Kanigon (P.T.R. Inc.)].
t	Cavity tuning device for intracavity operation [brass—see Fig. 2(b)].
u	Mirror holder [brass—see Fig. 2(b)].
v	Mirror adjusting screws (1 cm diam$\times$40 T.P.I., three mounted at 120° on 12 cm pitch circle, stainless steel].
w	Mirror mount pressure plate (13 cm diam$\times$1 cm thick, aluminum plate).
x	Test chamber evacuation and pressurization port ($\frac{1}{4}\times\frac{1}{4}$ nylon Polyflow connector).
y	Vacuum-tight feedthrough ($\frac{1}{4}$ tube$\times\frac{1}{4}$ pipe, nylon Polyflow fitting).
z	Vacuum-tight rubber membrane (2 mm thick, surgical rubber sheeting).
aa	Optical bench [$\frac{1}{2}$ m, aluminum (Ealing No. A22-6803)].
bb	Optical bench [1 m, steel (Ealing No. A22-7041)].
cc	Charging ballast resistor [10, $\frac{1}{4}$ MΩ 50 W, in series).
dd	Charging bleed resistors (20, 1 MΩ 2 W, in series).
ee	Power supply lead (3 m length, RG-8 coaxial cable).
ff	Spark gap body (6.5 cm o.d. Perspex rod).
gg	Trigger driving transformer (see T_3 in Fig. 7).
hh	Spark gap driver electronics (see Fig. 7).
ii	Spark gap anode (see Fig. 7, aluminum).
jj	Spark gap trigger electrode [surface gap spark plug (Champion No. UL-17V)].
kk	Spark gap cathode (see Fig. 7, copper).
ll	Spark gap pressurization ports ($\frac{1}{4}\times\frac{1}{4}$, brass Polyflow fitting).
mm	Sputtering shield (Pyrex).
nn	Discharge leads to Rogowski electrodes (1 mm$\times$25 mm, flat copper strip).
oo	High voltage supply [50 kV, 16 mA (Voltronics BPO-50-16)].

Parts list

R_1 = 2.2 kΩ	C_2 = 160 μF
R_2 = 22 Ω	C_3 = 3.3 μF (Siemens B32234)
R_3 = 100 Ω	C_4 = 0.1 μF
R_4 = 56 Ω	C_5 = 6 μF, 380 V ac motor start capacitor (Mallory 0P670)
R_5 = 30 kΩ	
R_6 = 27 kΩ	
R_7 = 750 kΩ linear pot	Q_1 = 2N3904
R_8 = 680 kΩ, 2 W	Q_2 = 2N4870 or 2N2646
R_9 = 5 kΩ, 20 W	Q_3 = 2N689 S.C.R.
R_{10} = 100 Ω	
	T_1 = 20 V c.t., 0.1A
D_1 = 1N4001	T_2 = 115 V ac [Hammond 269JX]
D_2 = 1N4001	
D_3 = 1N4454	T_3 = 12V transistor ignition coil [DelCO D-514 or Mallory F-12T]
D_4 = 1N4454	
D_5 = 12V (Philips BXY69)	
D_6 = 1N4454	
D_7 = I.R. 5A8	J_1 115 V ac mains receptacle and plug
D_8 = I.R. 5A8	
D_9 = I.R. 6F60	J_2 BNC plug and socket spark gap trigger
C_1 = 160 μF	J_3 Trig output

s_1	115 V ac 5 A toggle switch
s_2	115 V ac 5 A toggle switch
s_3	miniature toggle switch [manual–auto mode selector]
Pb_1	pushbutton single shot manual switch
F_1	Fuse holder 115 V ac 5 A
Pl_1	miniature pilot lamp
Pl_2	miniature pilot lamp

using a standard germanium etalon several thousand shots can be obtained before repolishing is necessary.

Recently an unstable resonator has been constructed in accordance with the details given by Seigman.[20] This resonator has to date performed satisfactorily with no apparent degradation.

OPERATIONAL PARAMETERS

The laser was found to be particularly easy to operate; it delivered pulses well in excess of 15 J. These output energies were consistent with the energy densities of approximately 20 J/liter reported elsewhere.[14–16] Accurate measurement of pulse energy was difficult since the laser energy produced a plasma in the thermopile used. A higher powered calorimetric type energy measuring device is being developed for this purpose.

When focused by an uncoated 20 cm focal length sodium chloride lens, very intense air breakdown was achieved. At the higher output powers air breakdown on both sides of the lens was observed. The front breakdown corresponded to a reflection of energy from the uncoated NaCl lens.

A typical pulse length of 100 nsec was measured with a photon drag detector. Figure 8 shows the pulse shape obtained. The peak amplitude corresponds to a pulsed power of about 100 MW.

Intracavity Features

The design of the laser tube was such as to permit the inclusion of an intracavity 10 cm focal length lens. Thus by using a 10 cm 100% reflector in place of the output mirror, an intracavity gas breakdown test facility was obtained.[21] This particular configuration, shown in Fig. 2(b), permitted external adjustment of both lens and reflector and also allowed various gases to be introduced into the test region. In this manner intracavity gas breakdown was achieved over a wide pressure range. For pressures below about 500 Torr, parts w and z were interchanged with part j and the adjustment screws v were reversed so as to make the pressure differential. Adjustment of the mirror was then accomplished by means of three extension rods and rotary seals shown dotted in the figure.

With this vacuum tight arrangement very interesting gas breakdown phenomena down to a few Torr were observed.[22] The test chamber design also allowed other intracavity experiments such as plasma heating and nonlinear optical studies to be performed with relative ease.

DISCUSSION

Several other lasers similar to the one described here were built. The performance characteristics of these, including a small 20 cm unit, were essentially the same and suggests that the basic Rogowski design is uncritical. This particular aspect makes the construction of such a laser quite simple in that the actual dimensions used are relatively unimportant and so can be selected for convenience. Typical dimensions are itemized in the following parts list. The only item requiring special attention is the construction of the profile milling cutter; the data presented in Fig. 3 are adequate for this purpose.

The extent to which this particular electrode geometry can be scaled to higher energies is presently unknown. Scaling in length is straightforward, and it appears that apertures in excess of 100 cm^2 are feasible.

The details presented here should permit those interested to construct a similar device having consistent performance characteristics.

Researchers wishing to fabricate an equally simple and inexpensive standard CO_2 laser for additional or complementary investigations are referred to the publication in Scientific American on a low cost CO_2 laser.[23]

ACKNOWLEDGMENTS

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