DESIGN OF A "DOUBLE DISCHARGE TEA CO_2 LASER"

by

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Scope and Content:

This report deals with the design of an electrode system which utilizes the double discharge technique to achieve a uniform discharge between two continuous electrodes with the intent of using this electrode system as the excitation unit for a TEA CO_2 laser. The particular electrode configuration dealt with in this report involves a continuous cathode and a similar continuous anode which has a set of rounded tip, rod, preionization electrodes set into holes in it. Also included in this report is a preliminary measure of the gain of the resultant double discharge TEA CO_2 laser.

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INTRODUCTION

This project deals with the design and construction of a continuous electrode TEA CO_2 laser, that is, a Transverse Excitation at Atmospheric pressure Carbon Dioxide laser. For transverse excitation of the gas it is desirable that the electrical excitation occurs from as many points along the axis of the laser as is practical.

The pumping energy of these lasers is large enough to result in the production of an arc discharge between the two main electrodes if no special techniques are employed. As arc discharges are detrimental to the operation of the laser, this project involves the use of the double discharge technique to prevent arcing while spreading the electrical discharge uniformly throughout the gas between the main electrodes and hence along the laser axis.

The more common TEA CO_2 laser produces an extended discharge by using many discrete electrodes. In one example the electrical discharge occurs between two pin electrodes symetrically placed about the laser axis. To extend the discharge many of these pin electrode pairs are distributed in a helical pattern along the laser axis. Each electrode pair is connected to the common energy source through a ballast resistor which acts to distribute the energy evenly among all the electrode pairs and thereby preventing arc discharges by limiting the current through any one electrode pair.

This pin to pin discharge method does not produce a uniform discharge over the whole gas volume but instead the energy is concentrated at the laser axis. The use of continuous electrodes is an attempt to produce a uniform discharge not only along the axis but also across it. This is desired as it is much more conducive to the multimode operation of the laser which can then be studied.

The initial stages of this report are concerned with a test system which, when development was completed, was scaled upward in size to yield the final laser system.

MAIN ELECTRODE DESIGN

In order to produce a uniform discharge between the two main electrodes it is desirable to have an electrode shape which produces as uniform a field as possible between the two main electrodes. The most common designs for uniform field electrodes are the Bruce and the Rogowski profiles(1). Each profile is constructed as a surface of revolution with a central flat region generated by a line segment which is tangential to the curved line segment which generates the edge of the electrode. The shape of this curve characterizes each of the profiles. For example, the 90° Rogowski profile uses an exponential curve to generate the edge of the electrode. In addition the relation between the extent of the flat region and the extent of the curved (edge) region is dependent on the separation of the two electrodes when they are used in the laser.

Unfortunately, the 90° Rogowski electrode shape for this system would have been inconveniently large and a modified shape was used. The central flat region was 1 inch in diameter and was surrounded by 1 inch of exponentially curved edge. This exponential was chosen to make the electrode 0.75 inches in thickness. This 3 inch diameter circular electrode design was then elongated to an "oval" shape 3 inches wide by 6 inches long as illustrated in figure 1.

A wooden pattern was made from this design and the electrodes were formed from this pattern by aluminum casting. The castings were smoothed with number 260 emery paper and despite the few pin hole irregularities in the surface, which seemed inherent in the casting process, these electrodes worked well enough that no further improvement was attempted.

This basic design served for both the anode and the cathode throughout the major part of the testing. At one point in the testing narrower electrodes were tried. They were designed and constructed in the same manner by simply reducing the width of the electrode flat surface region and reducing the extent of the exponentially curved edge.

DOUBLE DISCHARGE TECHNIQUE

The desired uniform discharge for proper laser action is called a glow discharge. At the high current values to be used a glow discharge is unstable and will degenerate into an arc discharge. This arc discharge must be avoided as it is too localized and produces too high a temperature in the gas. To avoid an arc discharge it is

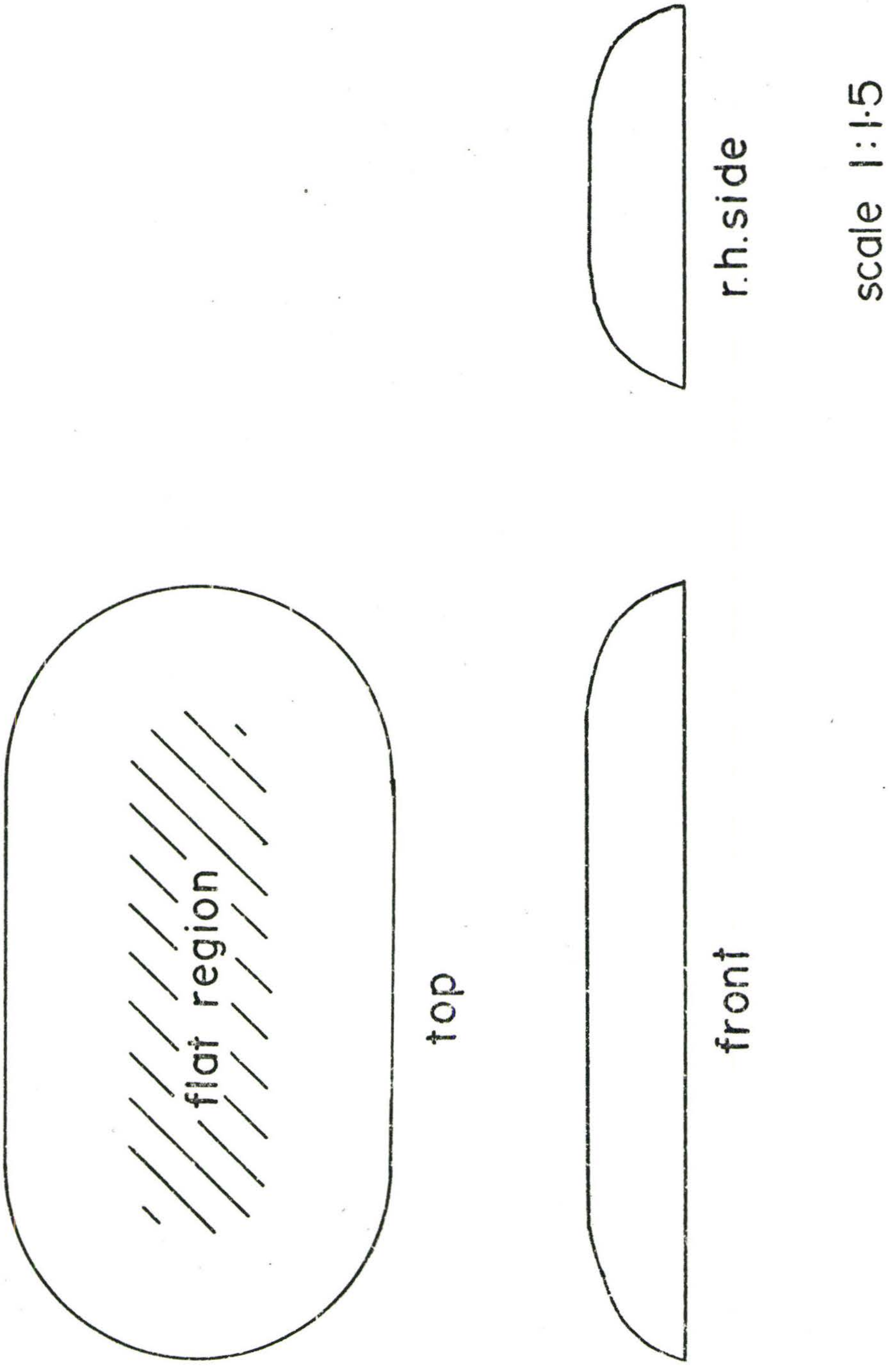

FIGURE 1 TEST ELECTRODE DESIGN

then necessary to keep the duration of the glow discharge short compared to the arc formation time. The discharge time can be kept short by minimizing the inductance in the circuit.

To initiate the glow discharge it is necessary to introduce electrons into the space between the electrodes. These electrons must be uniformly distributed if a uniform glow discharge is to be achieved. The purpose of the double discharge technique is to produce these electrons uniformly in the gap between the main electrodes. In addition to the two main electrodes there is a preionization electrode and a small discharge from it to one (or both) of the main electrodes produces the electrons used to initiate the glow discharge. These electrons may be produced as a direct result of the preionization discharge, or indirectly through photoelectric emission by the ultraviolet radiation generated by the discharge.

One example of the direct method is the use of a mesh cathode and a flat trigger electrode separated by a thin dielectric(2). The dielectric serves to make the preionization discharge uniform and this results in the uniform production of electrons throughout the mesh cathode. These electrons then help initiate the main discharge to the anode.

The indirect method is typified by the use of a wire preionization electrode placed in the median plane of the main electrodes, parallel to the cavity axis but off to one side(3). A discharge from this wire electrode to the anode produces the ultraviolet radiation which frees electrons from the cathode through photoelectric emission.

The preionization system I employed required that a hole be drilled through the anode. A rod is then introduced into this hole from the back or non active surface of the anode. The preionization discharge occurs between the tip of the rod and the edge of the hole at the front surface of the anode. To insure that the discharge occurs to the front edge of the hole, the hole was redrilled with a larger diameter drill to within 0.1 inches of the front surface. As can be seen from figure 2, the tip of the preionization electrode could then always be placed closer to the edge of the smaller hole than to the walls of the larger hole. A teflon rod was used to hold the electrode in the center of the hole as well as to insulate it from the walls of this hole.

The preionization technique could be either direct, indirect or a bit of each but in any event, the parameters which could be varied to achieve the best main discharge were the diameter of the opening in the anode,

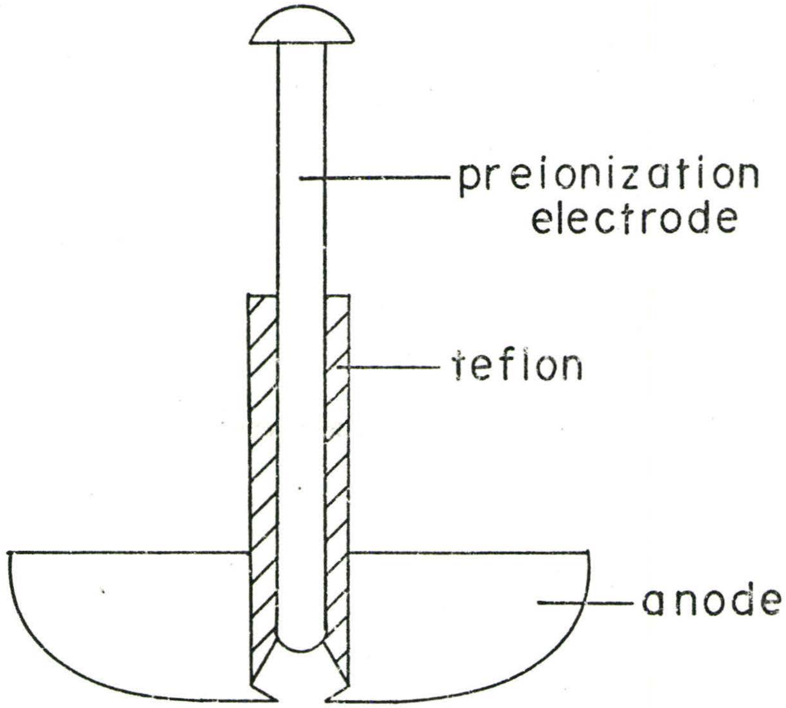

FIGURE 2 PREIONIZATION ELECTRODE (CROSS SECTION)

the height of the electrode above this hole, and the shape of the electrode tip.

ELECTRICAL CIRCUIT

The circuit, as shown in figure 3, functions as follows. The power supply high voltage output H.V. charges capacitor C through resistors R_1 and R_2. When the spark gap S.G. is triggered it connects the negative side of capacitor C to the cathode K. The preionization electrode is initially at the same potential as the cathode and the first discharge will be from this electrode to the anode. Both the electrode shape and the small gap distance force this preionization discharge to occur before the main cathode to anode discharge. The electrons produced by this preionization discharge aid the formation of the main glow discharge. The capacitor Cp is required to put an upper limit on the amount of energy which is used in the preionization discharge ($E=\frac{1}{2}CpV^2$). A typical value would be 2% of the energy stored in the main capacitor goes into preionization, with the remaining energy going into the main discharge. The resistor Rp is used to discharge Cp fully for the safety of the operator. It was a 3 megohom resistor. The resistor R_1 limits the current, from the power supply, through the

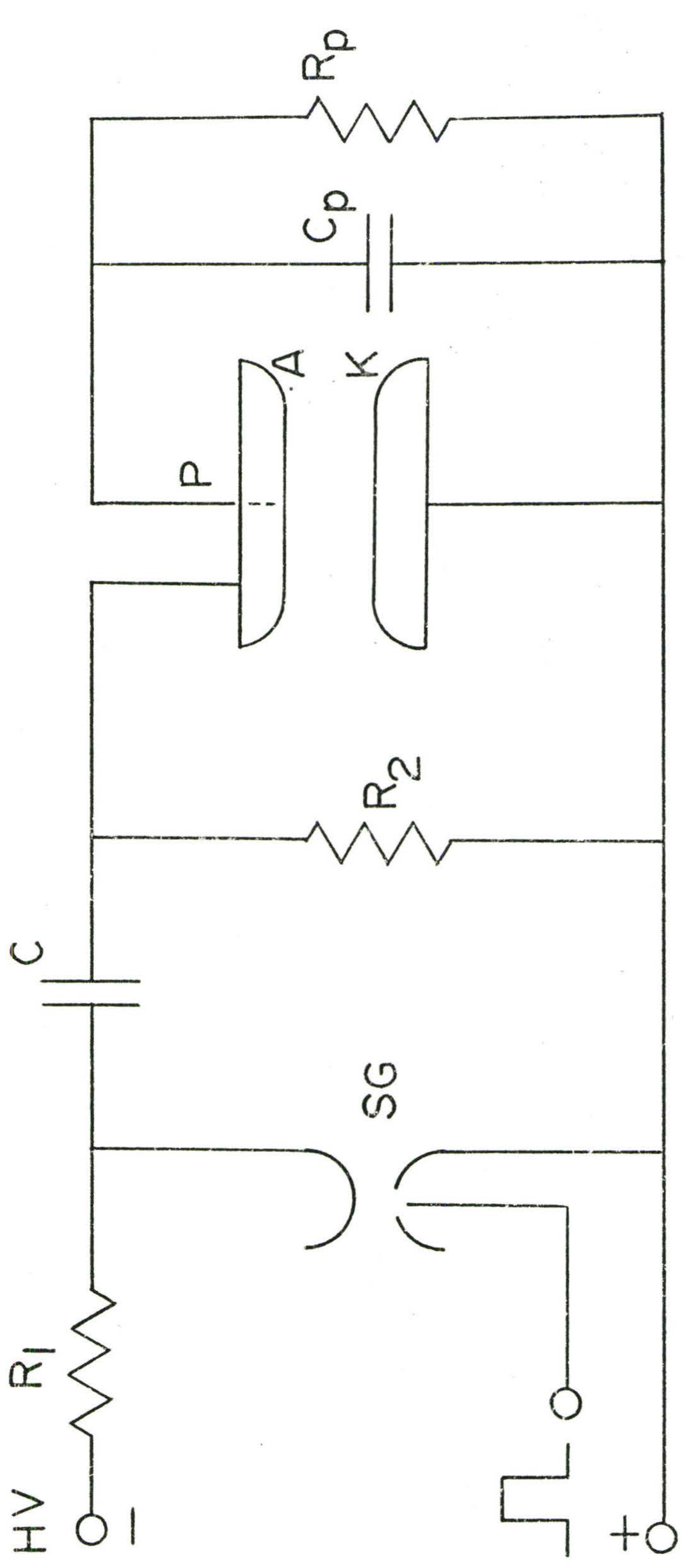

FIGURE 3 TEST ELECTRODE CIRCUIT

triggered spark gap. The resistor R_2 completes the charging path of the main capacitor. Both R_1 and R_2 were 2 megohms.

The circuit layout was kept compact to minimize the inductance in the connecting wires which would have altered the circuit timing.

Current measurements were made with a 0.1 ohm resistance and a resistor network for impedance matching. A commercial current transformer was also used when simultaneous current measurements were required. Voltages were measured with a capacitor network used as a voltage divider.

EXPERIMENTAL PROCEDURE

The main electrodes were mounted in a perspex box which had provisions for altering the interelectrode separation, changing the preionization structure as well as having an inlet and exhaust port for the helium, carbon dioxide gas mixture. The spark gap was triggered approximately twice per second during the run time. The luminous nature of the discharge was viewed by eye while any electrical measurements were made with the aid of an oscilloscope. The observations were generally carried out for supply voltages of 15, 20, 25, and 30 KV.

DISCHARGE TYPES

There were three distinct types of discharges. Each of these was characterized by both its physical nature as well as by its current pulse shape. Figure 4 is a representation of these pulse shapes.

The glow discharge appeared as a more or less structureless volume of luminous gas between the electrodes. The luminosity decreased near the edges of the electrodes. As can be seen in the diagram, the current pulse is roughly a half sine wave.

The partial arc discharge was characterized by an arc which started at the cathode but as it approached the anode it tapered to a point and never quite reached the anode. This partial arc was always accompanied by a glow discharge usually in the form of a sleeve or column centered on the partial arc. It should be noted that the partial arc always occurred directly under the preionization electrode and might be a direct result of such a structure. The current waveform resembles a highly damped sine wave.

The third type of discharge was the familiar arc discharge comprised of a single bright, crooked, narrow

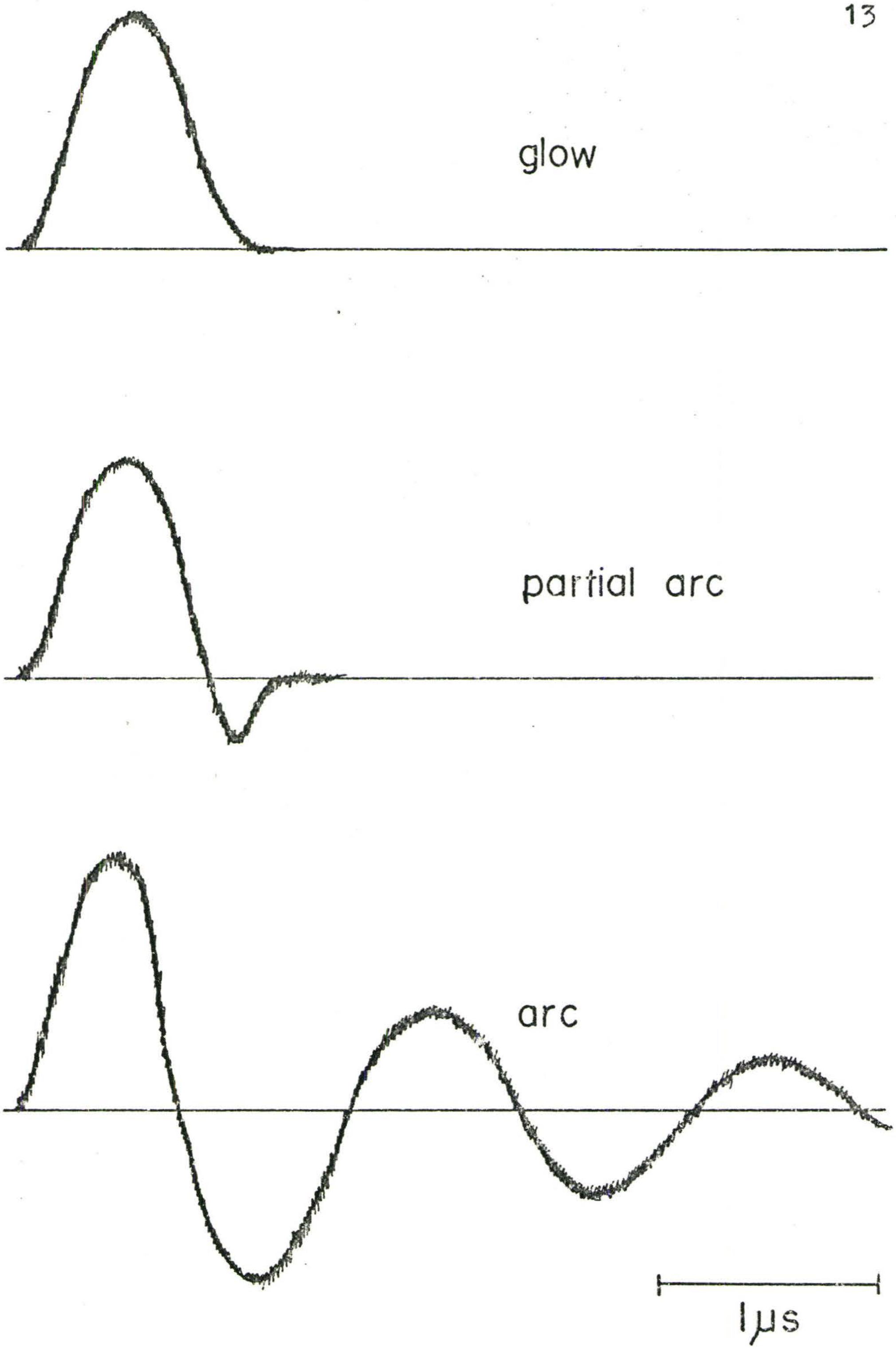

FIGURE 4 CURRENT WAVEFORMS

line between the cathode and the anode. The current waveform here, resembles a damped sine wave of about five or six cycles.

A glow discharge could usually be converted to a partial arc discharge by increasing the voltage. It is interesting to note that increasing the applied voltage decreased the resistance of the discharge and that this resistance represents the damping term in an LC circuit formed by the main capacitor and the circuit inductance.

PREIONIZATION STRUCTURE

The initial testing was done on the shape of the preionization electrode, the hole size and the distance from the electrode tip to the hole. The electrodes tried ranged from approximately 0.1 inch diameter wire to 0.25 inch brass rod. The hole size was varied from 3/16 to 3/8 of an inch. The distance from the tip to the hole was varied from 0 to 1 inch.

The quantitative results of these tests are of course dependent on the other circuit variables but a qualitative trend did appear. A rounded tip was better than a pointed tip for the preionization electrode (this was only noticed on the thicker electrodes). The thicker preionization electrodes were better than the thinner ones. "Better" refers to the effect on the main discharge. A glow discharge being better than an arc, and a glow discharge over most of the interelectrode volume being better than one over only part of this volume.

The effect of increasing the diameter of the hole in the anode (to which the preionization electrode discharged) was to spread out the main discharge. However, beyond a limiting size this ceased to be true and the main discharge degenerated.

The effect of the preionization electrode position was somewhat similar. When the electrode tip was level with the anode surface (i.e. at the edge of the hole) the main discharge was an arc from the cathode to the tip of the preionization electrode. If the other parameters were set for a good main discharge, then as the preionization electrode tip was withdrawn into the hole, the arcing would weaken and become a glow discharge at some hole to tip separation. Further increasing of the preionization electrode to hole separation would result in a less luminous main discharge but it remained in the glow state. However, the spatial extent of the discharge would decrease with a further increase of the preionization electrode to hole gap. If the other parameters were not at their "better" values then as the preionization electrode was withdrawn into the hole, the main discharge arc would go from the cathode to the anode rather than to the preionization electrode.

These results are reasonable if one assumes that direct generation of electrons in the main electrode gap is the preionization mechanism. The electrons generated by the preionization discharge will spread out in an approximately conical shower. The preionization electrode, being of negative polarity with respect to the anode, will be the apex of the cone. As the tip of the preionization electrode is moved closer to the hole, the cone of electrons will spread out over a greater angle giving a more spread out main discharge. As its tip approaches the hole it also is getting closer to the cathode and at some point it will produce an arc in the main discharge. This tendency for an arc to go from the preionization electrode to the cathode can be minimized if the breakdown voltage for this discharge is maximized. It is well known that a sphere to plane discharge has a higher breakdown voltage than a point to plane discharge at the same separation. This explains why the rounded tip preionization electrodes were better; they could be placed nearer the hole without creating an arc in the main discharge. By the same reasoning the thicker electrodes, which had a greater radius of curvature at the tip, should be better than the thinner electrodes.

The diameter of the hole determines two different things. The larger it is, the greater the spread of the electron cone. The smaller it is the more it shields the preionization electrode and hence, the closer this electrode can be placed. These competing effects determine a best hole size.

As a result of these findings I decided to use a quarter inch bolt with a rounded tip as the preionization electrode. This was held in a half inch diameter teflon rod with a central, threaded, quarter inch hole. The hole in the anode surface was five sixteenths inches in diameter and the preionization electrode was a quarter of an inch from this hole. The hole in the teflon was countersunk at the active end so that it didn't interfere with the discharge. Figure 2 illustrates the final preionization structure.

SEPARATION OF MAIN ELECTRODES

The separation of the main electrodes was varied from 0.75 to 2.0 inches while the discharge was observed over the voltage range from 15 to 30 KV. When the electrode separation was small, the discharge was glow like at the lower voltage range and an arc at the upper voltage range. Increasing the separation would increase the voltage range over which a glow discharge would occur. At a separation of 1.25 inches the discharge was a glow discharge over the full voltage range. Further increasing of the interelectrode distance resulted in an arc region at the lower voltage range and a glow region at the upper voltage range.

There are many factors affecting this type of behaviour. One factor is the overvoltage. The overvoltage is the difference between the static breakdown voltage and the voltage at which the discharge commences when a rapidly increasing voltage pulse is applied between the electrodes. The greater the slope of the applied voltage (at the static breakdown value) the greater will be the overvoltage. The greater the overvoltage the shorter will be the arc formation time and the more likely that the discharge will be an arc(4).

Decreasing the separation of the main electrodes decreases the static breakdown voltage which indirectly increases the overvoltage (due to the shape of the leading edge of the voltage). Increasing the applied voltage increases the slope of the leading edge of the voltage pulse which will also increase the overvoltage. This then suggests one reason that arcing is more prominent at high voltage and decreased electrode separation.

The behaviour of the discharge in the low voltage range was complicated by the erratic functioning of the spark gap. This effect was most prominent when the applied voltage was at the minimum breakdown voltage of the interelectrode gap. At this voltage when the trigger voltage pulse was applied to the spark gap to allow it to conduct, the preionization discharge would occur but the main discharge would not. The spark gap then ceases to conduct but after a time period of up to 20 microseconds, without the reapplication of its trigger pulse, it would suddenly return to the conducting state and the main discharge would then occur. This time period was random from one triggering to the next but on the average, it decreased when the applied voltage was increased. The state of the spark gap was observed by measuring the voltage across it.

This problem was never fully resolved although attempts were made to eliminate it. At the best main electrode separation of 1.25 inches the discharge resulting from this effect was a glow discharge and as a result it was unnecessary to complicate the circuit just to regulate the spark gap performance.

CAPACITOR VALUES

The two capacitors in the circuit were also varied in the quest for a better discharge. The best value for the main or energy storing capacitor was 0.01 microfarad. This was the value used in most of the testing. When a higher 0.02 microfarad capacitor was used the discharge was an arc over the full voltage range. Reducing the value to 0.005 microfarad produced a less luminous version of the 0.01 microfarad results.

The capacitor used to limit the energy in the preionization discharge was standardized at 100 picofarad. Values of 200, 250, and 500 picofarad were also tried but gave no better results.

ELECTRODE SIZE

The standard test electrodes were replaced with a narrower set to see if the discharge could be constricted to lie more along the cavity axis rather than being spread out across it. These narrower electrodes were still 6 inches long but were only 1.5 inches wide or half as wide as the previous electrodes. They had the same thickness but the curvature of the edges extended over only 0.5 inches rather than 1 inch as before. This greater curvature turned out to be too sharp. The result was that the narrower electrodes arced from their curved edges, preventing glow discharges from occurring at voltages at which the wider electrodes had produced glow discharges consistently.

NUMBER OF PREIONIZATION STRUCTURES

At this point in the development of the system, the remaining problem with the test set-up was that the discharge did not spread out over the whole electrode surface. Instead it was localized under the preionization electrode. To remedy this, rather than further alter the preionization electrode, an additional preionization electrode structure was added. A new anode was made with the holes for the preionization electrodes placed 3 inches apart. The two preionization electrodes were then connected in parallel to allow one energy limiting capacitor to service both of them. The result still was not a uniform discharge over the full interelectrode volume.

The next step in this process was to add a third preionization electrode structure to the anode. The spacing between centers of the adjacent holes was now 1.5 inches. The electrodes were again connected in parallel with a common energy limiting capacitor servicing them. This arrangement yielded a reasonably uniform discharge over the full volume. At the higher voltage values (25 and 30 KV) the discharge was more luminous directly under the preionization electrodes and less luminous in the region halfway between the holes but this was not considered to be too detrimental.

At this point the testing was discontinued and the full size laser electrodes and their preionization mechanism were designed and constructed, using the knowledge gained from this testing.

LASER ELECTRODE STRUCTURE

The anode and cathode for the final system were both just stretched versions of the original 3 by 6 inch test electrodes. They were stretched to a 3 by 14 inch size. As with all the main electrodes, these were also 0.75 inches thick. The flat section of the surface (over which the discharge is to take place) was now 1 by 12 inches. These electrodes were also cast in aluminum (alloy number 432).

To service the whole flat surface of the main electrodes, a total of 7 preionization structures were used. These were identical to the test design and were again placed along the anode at 1.5 inch intervals.

The electrodes were bolted to the inside of a perspex box of internal dimensions of 5 by 16 by 3.5 inches high. To the ends of the box were affixed short sections of a 1.5 inch internal diameter cylinder. These cylinders were aligned along the axis of the box to allow the use of removable end windows mounted on a 1.5 inch external diameter cylinder. Each of these holders, in addition to securing the sodium chloride end windows at Brewster's angle, also had a gas nozzle to allow one end of the box to have the gas inlet and the other the exhaust port for the helium, carbon dioxide mixture.

The separation of the main electrodes could be varied with the use of spacers between the back surface of the electrode and the top or bottom of the box. The best separation was found to be 1.2 inches. The use of spacers also permitted both electrodes to be moved up or down at a constant separation to allow the laser axis to sample different parts of the discharge volume.

The basics of the electrical circuit were retained from the test circuit but because the active surface (i.e. the flat region) of the electrodes was increased by a factor of 3. It was considered necessary to increase the value of the main capacitor by this factor.

This would have meant that a .03 microfarad capacitor would be the maximum value for the laser but unfortunately this value was not available. Instead a .02 microfarad capacitor was the maximum available value which gave good discharges. (A .05 microfarad capacitor yielded arcs.)

With 7 preionization electrodes it would also seem that a larger capacitor was required to service all of them. Unfortunately no value of the preionization capacitor could be found that would result in the energy of the preionization discharges being equally shared among the 7 preionization electrodes.

When the system was first fired it was not possible to get all the preionization electrodes to fire. As a result the main discharge was confined to the areas under the one or two preionization electrodes which did fire. The resultant discharge was the same as that produced by using a large capacitor on the test electrodes. It arced. There is a limiting discharge current density value above which an arc discharge will result. With the preionization mechanism only working over a small region of the electrode surface this maximum current density is more likely to be exceeded and arcs will result.

The problem was eliminated by connecting a separate energy-limiting capacitor to each of the preionization electrodes. The value used was 75 picofarads for each electrode and rather than construct a separate 3 megohm high voltage resistor for each electrode, this safety device was omitted. Each capacitor then discharged through its leakage resistance and the circuit still functioned properly.

The only drawback of this separate capacitor solution is that 7 new capacitors would be required to alter the preionization energy. Fortunately the circuit worked well and since previous results with the test electrodes indicated that the value of the preionization electrode capacitor was not critical, no attempt was made to vary it with this system.

VARIABLE DELAY TIME

Prior to the initiation of the main discharge, the population of the electrons generated by the preionization discharge will be decreasing due to recombination while the spatial distribution of these same electrons will become more uniform due to diffusion. The effect of these two processes on the main discharge will depend on the time delay between the preionization discharge and the main discharge.

With a view to finding an optimum time delay and possibly altering the standard circuit, a brief study was made of the effect of the delay time on the discharge. To allow the delay time to be varied, capacitor Cp (see figure 3) was removed and the energy for the preionization discharge was supplied through an independent circuit utilizing a power supply, capacitor and a spark gap in the standard configuration. The voltages which produce the preionization and the main discharge are now independent and controlled by two spark gaps. These spark gaps are controlled by a voltage pulse from their trigger modules which are in turn controlled by separate pulse generators. By interconnecting the two pulse generators it is possible to control and vary the time between the firing of the two spark gaps.

Variations in the trigger modules, in the spark gap breakdown time and in the duration of the preionization discharge made the measurement of the effects of short delay times too difficult. Thus, to make the errors in the time measurement less significant, the delay time was measured on a 0 to 10 microsecond scale. The procedure was to select a capacitor value for the preionization system and set its charging voltage to 10 KV. The main discharge voltage was varied through its standard range (15 to 30 KV) and at each step in the range, the delay time was varied to determine its effect on the main discharge. Both the laser electrodes and the test electrodes were used to yield the following general results.

The optimum delay time, as observed by this method, was approximately 0.5 microseconds. In varying the delay time the discharge went through the following stages. At zero delay time a steady glow discharge would occur. Increasing the delay time would help make the discharge more uniform. At the optimum value the discharge would be uniform and would cover the largest volume. Further increasing of the delay time would decrease the spatial extent of the glow discharge. Still further increasing of the delay time would eventually result in the discharge becoming an arc. The value of the delay time at which arcing first occurs could be reduced by increasing the applied voltage.

The main discharge was only moderately sensitive to small variations in the delay time about the optimum value and the resultant discharges were no better than those produced with the previous non variable delay circuit. For this reason the study of the effects of the delay time between the preionization and the main discharge was pursued no further.

PROPERTIES OF THE DISCHARGE SYSTEM

With the addition of the separate 75 picofarad capacitors on each of the preionization electrodes, the final arrangement of both the physical and electrical components of the system was achieved. The height of the preionization electrodes above their holes was not critical and was set at 0.3 inches for convenience. The standard value of the main capacitor became 0.02 microfarads when it was found to be the largest available value which yielded a non-arcing discharge at 30 KV.

As may be noted in the circuit, as illustrated in figure 5, the preionization capacitors are depicted as they were constructed. One plate of each capacitor was to be connected to ground potential so it was possible to use one large common plate to replace these seven smaller independent plates. Each capacitor now consists of one small brass plate (2 by 6 inches) separated from the larger common plate by 0.13 inch thick perspex. The edges of adjacent plates are insulated by 0.5 inches of perspex.

1) Preionization Subsystem

The preionization current was observed with an

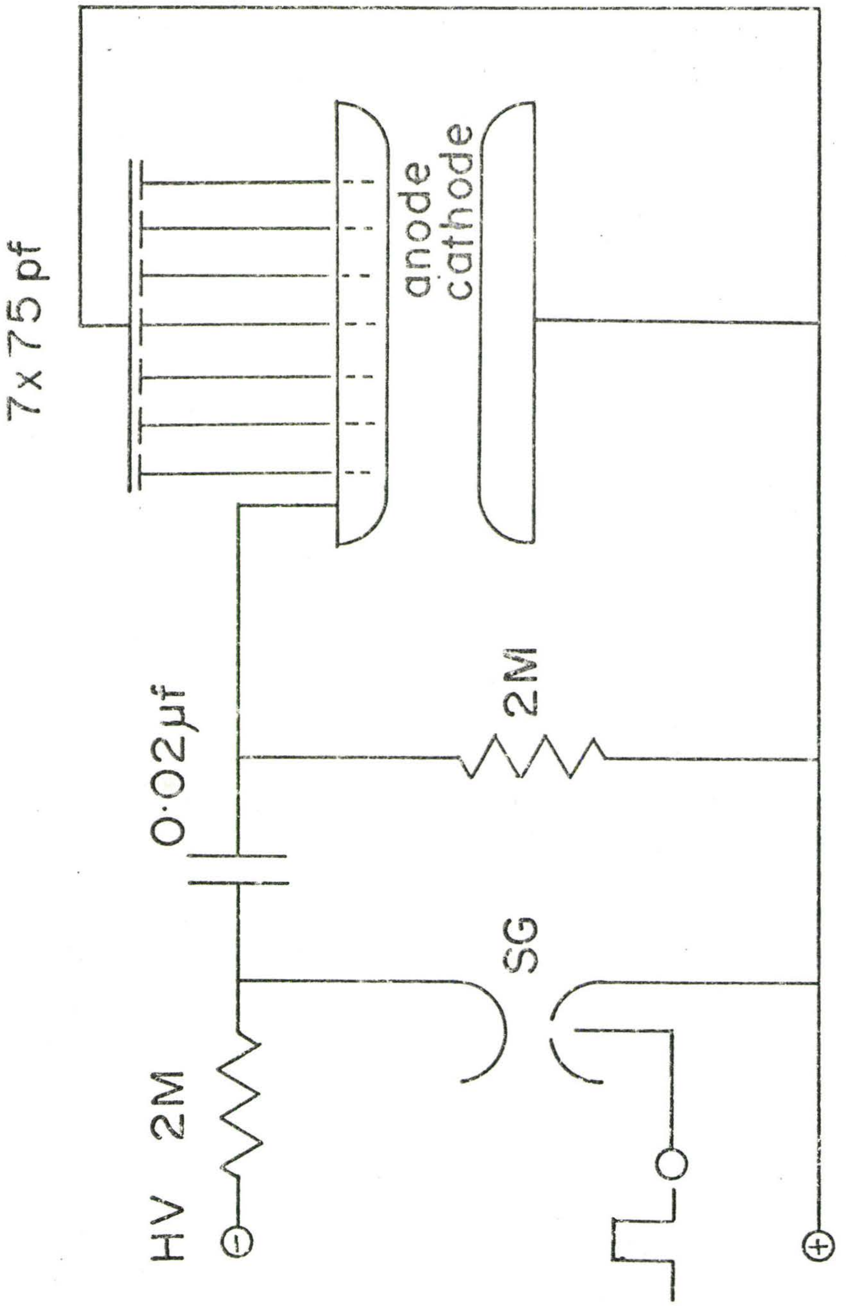

FIGURE 5 LASER ELECTRODE CIRCUIT

oscilloscope and it appeared as a 50MHz waveform of 0.5 microseconds duration. The peak value of the total preionization current went from 200A at 16 KV to 800A at 30 KV. The envelope of the waveform was ragged and nonrepetitive but it did have one consistent feature. The waveform could be divided into two parts; the initial section consisting of large amplitude oscillations, and the final section consisting of small amplitude oscillations. The relative amount of these two parts was dependent on the voltage. At 16 KV no small amplitude section was noted while at 30 KV the waveform was divided equally between the two amplitudes.

Based on similar observations on the test electrodes (where the duration of this waveform was longer) it was noted that the large amplitude section corresponds to the preionization discharge occurring alone while the small amplitude section results when both the preionization and the main discharge are occurring. This then gives an indirect method of observing the time delay between the two discharges. The results range from 0.5 microseconds at 16 KV to 0.25 microseconds at 30 KV. These values seem reasonable in light of the variable delay results.

11) Main Discharge Subsystem

The current and voltage waveforms were observed on a dual beam oscilloscope (Tektronix 556). The following observations were made under the standard conditions with a gas mixture of 96.9% He and 3.1% CO_2.

The voltage waveforms all had two common features. The leading edge of the waveform was a short duration spike with an amplitude which increased with increasing applied voltage. This 0.1 to 0.2 microsecond spike region was followed by a rough plateau voltage region. The plateau voltage was 15 KV and this was independent of the applied voltage. The trailing edge and the duration of the voltage waveform were the same as the corresponding current waveform characteristics.

The current waveforms also had two common features. Each waveform consisted of 0.5 microseconds of a high frequency oscillatory region followed by a half sine wave region. At 16 KV these two regions were distinct wheras at 30 KV the oscillations were superimposed on the leading edge of the half sine wave. These oscillations correspond to the preionization discharge.

The main discharge is represented by the half sine wave with a peak value which went from 400A at 16 KV to 1800A at 30 KV. The half width of this pulse remained constant at 0.5 microseconds independent of voltage.

The main energy storing capacitor was also varied. Values of .005, .01 and .02 microfarads produced glow discharges up to 30 KV while a .05 microfarad capacitor produced only arc discharges. The .005 microfarad capacitor produced such weak discharges that lasing was not observed.

111) Gas Mixture

Further investigation of the operating range of the system involved varying the gas mixture while leaving all other parameters at their standard values. The gas mixture was varied in four stages from the standard 3.1% CO_2 to a maximum of 12% CO_2. (The other gas is of course helium)

There were four changes in the discharge which were noted by visual observation. Increasing the percentage of CO_2 had the following effects. The luminosity of the discharge decreased. The colour of the discharge became a more saturated blue-violet. The spatial uniformity of the discharge decreased. That is, the most luminous part of the discharge occurred in a narrow column under each of the preionization electrodes. The repetitive stability of the discharge disappeared. That is, at the higher CO_2 levels, the discharge was sometimes a glow discharge and sometimes an arc discharge.

There were also two main electrical measurements related to the gas mixture. Increasing the CO_2 concentration resulted in a decrease in the peak discharge current. For example, at 25 KV the peak current dropped from 1500A to 660A when the CO_2 concentration was increased from 3.1% to 12%. In addition, increasing the CO_2 concentration resulted in a decrease in the voltage range over which a consistent glow discharge occurred. For example, the 16 to 30 KV glow region was reduced to a 24 to 27 KV glow region when the concentration of CO_2 was increased from 3.1% to 12%.

GAIN MEASUREMENT

The final stage of this project involved making a preliminary measurement of the gain of the system. The method used involved measuring the time interval between the peak of the current pulse and the beginning of the laser pulse. This delay time was then compared with the delay time generated by a model of the system. The gain amplitude used in the model was arbitrary and so by varying it until both delay times agree it is possible to estimate the gain(5).

Briefly, the model assumes that both the upper and lower (lasing) states of the carbon dioxide molecule have equal cross-sections for excitation by the discharge. The population inversion and hence the gain result because the exponential half-life of the lower state is less than that of the upper state (The values used were 0.8 and 13 microseconds respectively).

This model also involved an analytical current waveform requiring the value of the peak current and the current half-width as inputs. The only other input required was the loss per pass of the system. Rather than match each individual point, a voltage versus delay time graph is plotted for a given capacitor and the best match with a series of curves produced by the model determines the gain. A current versus delay time graph could be used but voltage is a more convenient axis.

The experimental points were generated in a cavity consisting of a 10 meter radius of curvature mirror and a plane mirror separated by 1.57 meters. The loss per pass of the system was approximately 1.5%. The detector was a Ge:Au photoconductor and its output and the laser discharge current were observed on an oscilloscope to determine the delay time. The results for two different capacitors are listed in table 1 together with the best fit results from the model.

TABLE OF DELAY TIME RESULTS

Gas Mixture: 96.9% He : 3.1% CO_2

Cavity Length: 1.57 meters

Voltage	Current		Delay Time	
	Peak	Half Width	Observed	Model
(kv)	(A)	(µs)	(µs)	(µs)
Capacitor 0.02 microfarad				
16	420	.6	7.3	6.4
18	620	.5	3.8	4.6
20	860	.5	3.0	3.2
22	1080	.5	2.5	2.6
24	1240	.5	2.3	2.3
26	1360	.5	2.2	2.2
28	1600	.5	2.0	1.9
30	1800	.5	1.9	1.8
Capacitor 0.01 microfarad				
22	840	.4	6.8	-
24	900	.4	5.0	-
26	1040	.4	4.0	-
28	1280	.4	3.2	-
30	1600	.4	2.8	-

TABLE 1 DELAY TIME RESULTS

The best fit for the 0.02 microfarad capacitor corresponds to a peak gain per pass of 15% at a voltage of 30 KV. As can be determined from figure 6 the match was not very good. The best match for the 0.01 microfarad capacitor was so much worse that no theoretical values are given.

As a comparison figure this laser produced a 15% peak gain per pass for a 9 joule energy input while a helical pin system using 1K ballast resistors produced a peak gain per pass of 25% for an energy input of 4.5 joules.

The optics for these lasers favour the 0,0 mode which has a small spot size and a gaussian cross-sectional energy distribution. This means that only the photons produced from the excited CO_2 molecules located very near the laser axis will contribute to the gain. The pin system is well suited for this mode for the following reasons. The discharge volume is a narrow cylinder spread along the axis and its averaged energy cross-section is gaussian. The double discharge system, however, has a shorter spread along the axis, a greater spread across it and a more uniform energy cross-section. Thus, it produces fewer excited molecules in a position to contribute to the gain.

To fully utilize this system new optics will be

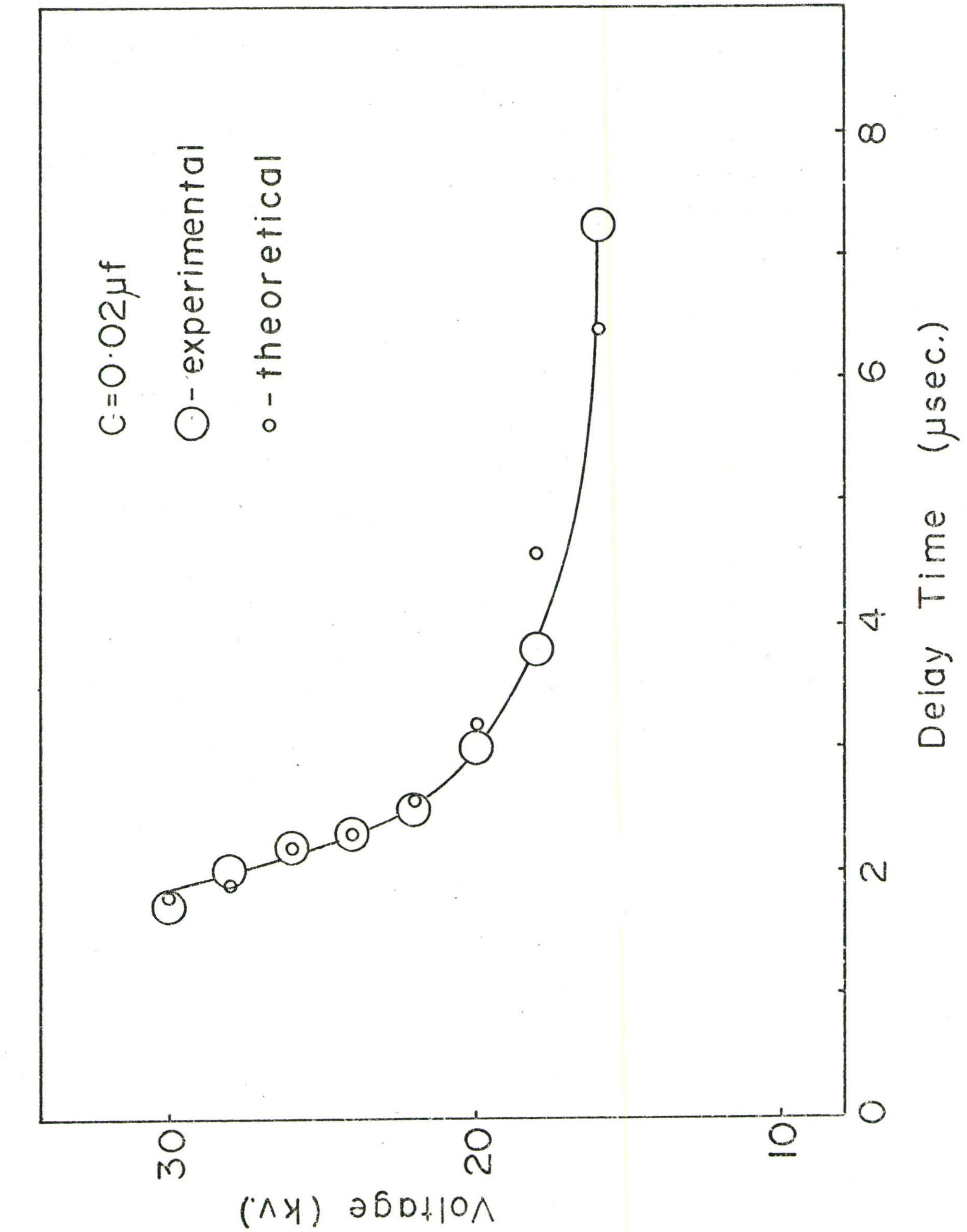

FIGURE 6 DELAY TIME CURVES

required with a view to multimode operation which, due to the wider mode size, will utilize more of the excited gas volume. The difficulty encountered in using the model (which worked for the pin system) to generate the gain measurements for the double discharge system suggests that further study is required to modify the model and better understand the physics of the double discharge TEA CO_2 laser.

SUMMARY AND RECOMMENDATIONS

A double discharge electrode system has been designed and constructed for use in a TEA CO_2 laser. A preliminary measurement of the gain of the system has been obtained. By comparing this gain with that of a similar pin TEA CO_2 laser as well as considering the energy input and the optically active volume of the excited gas it is possible to estimate the relative efficiency of these systems. Such an estimate indicates the double discharge system is of the same order of efficiency as the pin system and further study should be attempted.

Before the actual physics of the laser is studied it might be advisable to attempt to increase the voltage range of the system and vary the gas mixture in order to produce a more efficient laser which in turn would be easier to study.

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