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Life Test Results for an Ensemble of CO_2 Lasers

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National Aeronautics and
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Goddard Space Flight Center
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ABSTRACT

An ensemble of CO_2 lasers was tested to determine the effects of cathode material, cathode operating temperature, anode configuration, window materials and hydrogen additives on laser lifetime. Internally oxidized copper and silver-copper alloy cathodes were tested. The cathode operating temperature was raised in some tubes through the use of thermal insulation. Lasers incorporating thermally insulated silver copper oxide cathodes clearly yielded the longest lifetimes – typically in excess of 22,000 hours. The use of platinum sheet versus platinum pin anodes had no observable effect on laser lifetime. Similarly, the choice of germanium, cadmium telluride, or zinc selenide as the optical window material appears to have no impact on lifetime. No conclusions with regard to the effectiveness of the hydrogen additives can be deduced from the result of the tests performed thus far.

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LIFE TEST RESULTS FOR AN ENSEMBLE OF CO_2 LASERS

I. INTRODUCTION

An extensive program has been carried out to develop the technology of CO_2 laser communication systems for space-to-space applications.[1] One aspect of that program has been a careful study of CO_2 laser lifetime. Modern communication satellites are designed to operate for a period in excess of five years – this represents an operating lifetime of more than 50,000 hours. That figure is the long term goal of the technology program, and this report summarizes the technology status as of late 1977. Prior to the initiation of this program isolated cases of the achievement of modestly long life CO_2 lasers had been reported. Without exception, however, these results were obtained for a single laser tube – and were frequently unrepeatable. The principal objective of this work was to determine if encouraging results obtained at the University of Maryland under NASA grants NGR-21-002-345[2] and NGR-21-002-216[3] could be verified on a sample of laser tubes large enough to prove that the success, or failure, was not a single isolated example. As will be seen below, this objective was met. The results that will be presented show that the techniques can be transferred from one group to another (a key issue in reliability) and that a small volume laser tube can be built having a predictable lifetime of not less than 10,000 hours.

II. BACKGROUND

The work upon which this effort was based concerned the use of a cold cathode for the CO_2 laser.[2,3] It was regarded as the simplest and most reliable approach to obtaining long life. This is not to say that the chemistry of the cathode is simple – only that the use of competing technology, e.g., a thermionic cathode, would have been even more complex. A proper cold cathode must satisfy the following criteria:

a. Any oxidation of the cathode must be reducible in the laser gas at a sufficiently fast rate to prevent the buildup of oxide layers on the active surface.

b. The oxides must be electrically conducting at the operating temperature of the cathode; the temperature is that which allows emission of the required current density, approximately 12 mA/cm^2, without excessive sputtering.

c. The sputtering products should not form negative ions. This is a requirement that leads to a preference for elements in the first column of the periodic table. The requirement is based on the need to avoid the migration of sputtering products away from the immediate cathode area.

The two most successful cathodes tested to date are an internally-oxidized silver-copper oxide matrix cathode and a pure copper cathode. Figure 1A shows results obtained at the University of Maryland with the two cathodes and Figure 1B shows results obtained

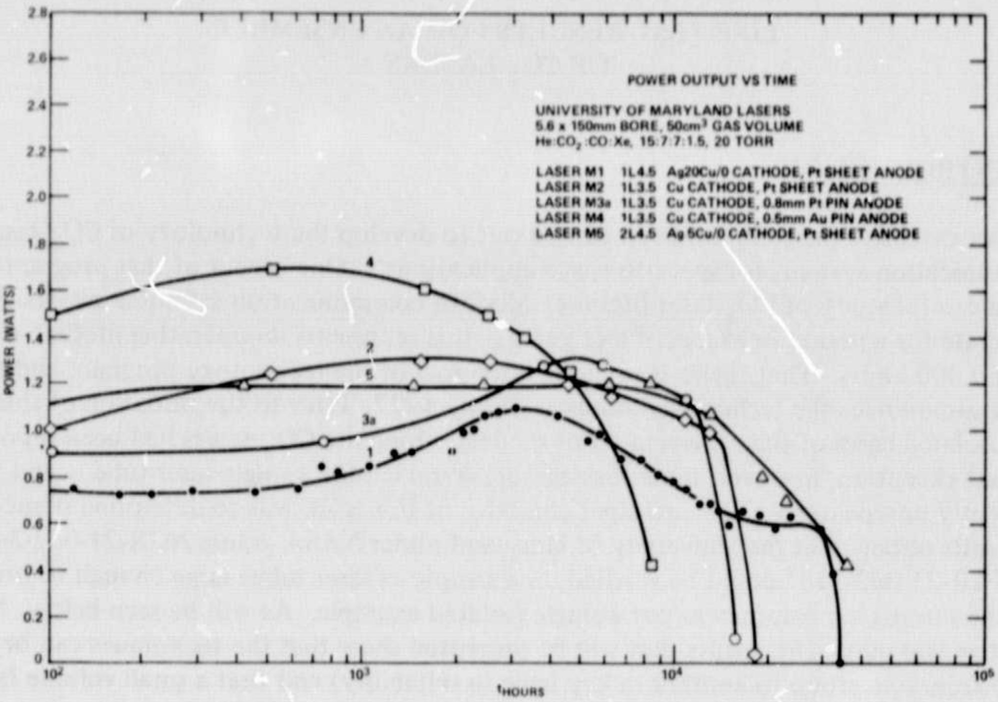

Figure 1A. Performance Summary – University of Maryland Lasers

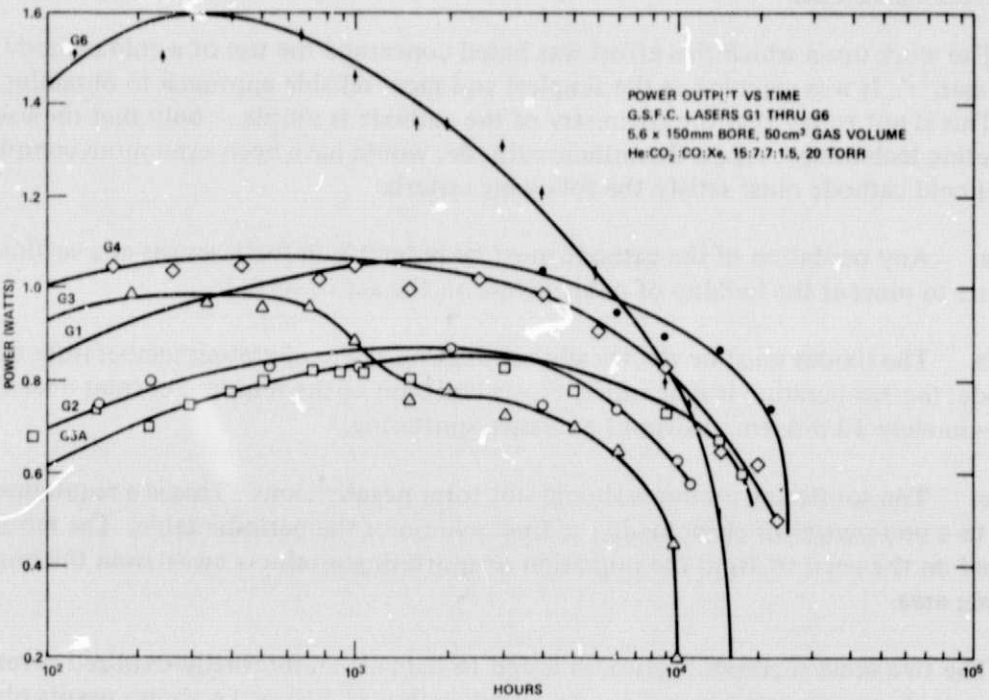

Figure 1B. Performance Summary – GSFC Lasers with Ag5CuO Cathodes and Platinum Pin Anodes with laser tubes built and tested at Goddard Space Flight Center. Table 1 lists the combined results along with construction details and a qualitative description of the sputtering produced by the cathode.

III. LASER TUBE CONSTRUCTION

Eight laser tubes were fabricated at Goddard Space Flight Center with the designs shown in Figures 2A and 2B. The first six were of the former construction and the last two of the latter. Single crystal and polycrystalline cadmium telluride Brewster windows were used on six tubes and zinc selenide was used on two. All of the Brewster windows were obtained from II-VI Corp. Gallium arsenide Brewster windows and internal gold mirrors were used in the University of Maryland tubes.

Platinum pin anodes or anodes made from platinum sheet were used in all tubes. The anodes were attached to tungsten feed-throughs to bring the electrical connection outside the glass envelope. A silver cathode with 5% copper was used for seven of the tubes, and a pure copper cathode was used for the last. The cathode dimensions and construction are

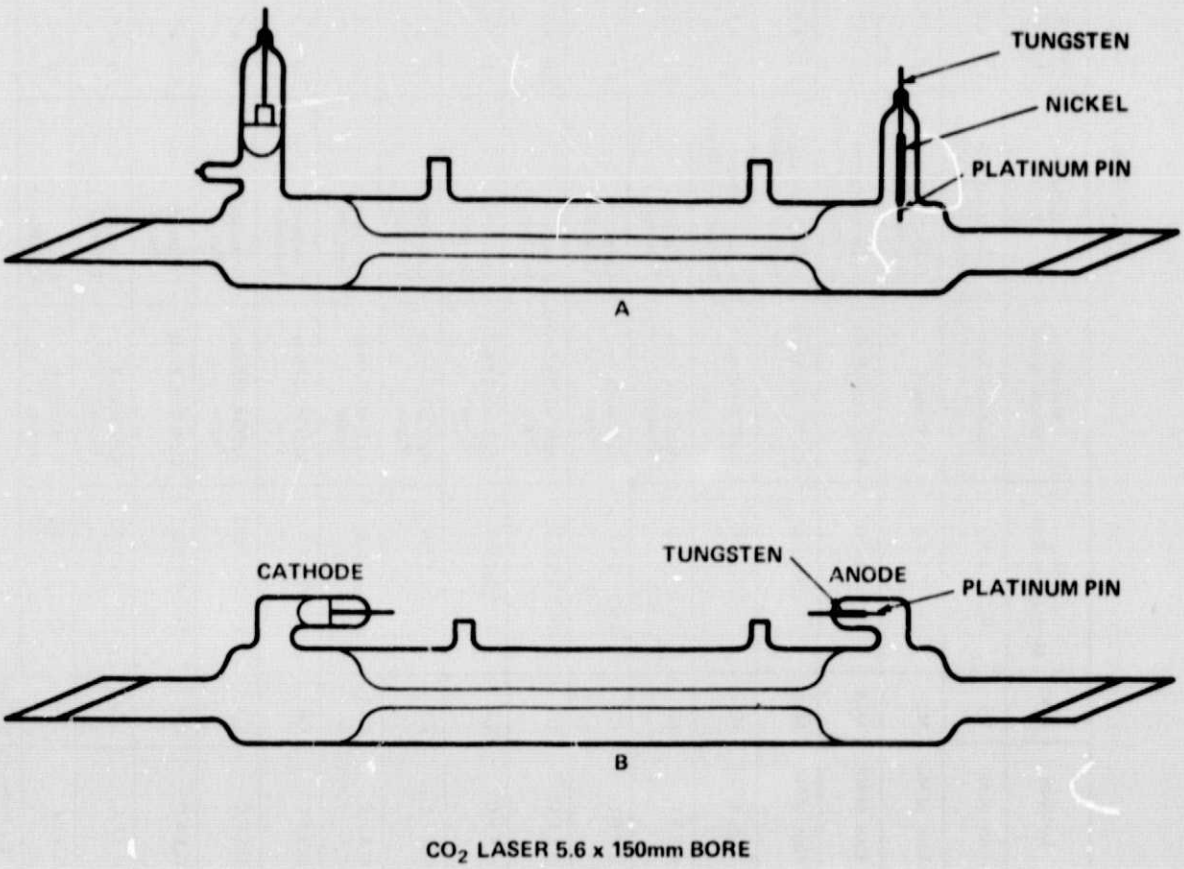

Figure 2. Laser Tube Construction

TABLE I

Location	Laser	Gas Mix $He:CO_2:CO:Xe:H_2$	Material Cathode/Anode	Material Window	Cathode ID Lgth mm	Lifetime 1/2 Power hrs	External Insulation	Sputtering Products	Comment
Univ. of Md.	M1	15:7:7:1.5:0	Ag20Cu/Pt sheet	Gallium Arsenide Internal Gold Mirror	3.5 4.5	33,000	Yes	Very heavy	
Univ. of Md.	M2	15:7:7:1.5:0	Cu/Pt sheet	Gallium Arsenide Internal Gold Mirror	3.5 3.5	17,500	Yes	Light	
Univ. of Md.	M3A	15:7:7:1.5:0	Cu/0.8mm Pt pin	Gallium Arsenide Internal Gold Mirror	3.5 3.5	15,200	Yes	Moderate	
Univ. of Md.	M4	15:7:7:1.5:0	Cu/0.5mm Aupin	Gallium Arsenide Internal Gold Mirror	3.5 3.5	7,500	Yes	Heavy	Possible Water Contamination
Univ. of Md.	M5	15:7:7:1.5:0	Ag5CuO/Pt sheet	Gallium Arsenide Internal Gold Mirror	5.0 4.5	26,800	Yes	Very light	
G.S.F.C.	G1	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	25,552	Yes	Heavy	Intense Anode Spot
G.S.F.C.	G2	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	12,500	No	Very heavy	
G.S.F.C.	G3	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Zinc Selenide	5.0 4.5	10,540	No	Very heavy	Inside Window Contamination
G.S.F.C.	G4	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Zinc Selenide	5.0 4.5	22,021	Yes	Moderate	Sputter Shield Segment Worked Away
G.S.F.C.	G5	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	3,600	No	Very heavy	Ceramic Sleeve Separated Cathode
G.S.F.C.	G5A	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	(>18,145*)	Yes	Moderate	Zirconium Retaining Ring Used
G.S.F.C.	G6	15:7:7:1.5:0	Ag5CuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	12,500	Yes	Light	Small Particle Burned Away
G.S.F.C.	G7	15:7:7:1.5:0.2	Ag5CuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	(>15,158*)	Yes	Heavy	Developed Silver Droplets
G.S.F.C.	G8	15:7:7:1.5:0.2	Cu/0.8mm Pt pin	Cadmium Telluride	3.5 4.5	(>15,158*)	Yes	Light	Stainless Steel Retaining Ring
G.S.F.C.	G2A	15:7:7:1.5:0.2	Ag5CuO/0.8 Pt pin	Cadmium Telluride	5.0 4.5	(>9443*)	Yes	Light	Slight H_2 Overfill, Power Lower
G.S.F.C.	G3A	15:7:7:1.5:0.2	Ag5CuP/0.8 Pt pin	Zinc Selenide	5.0 4.5	(>9310*)	No	Very heavy	Inside Window Contamination

*1/2 power not reached.
Volume and pressure all tubes – apprx. 50 cm^3 and 20 Torr.

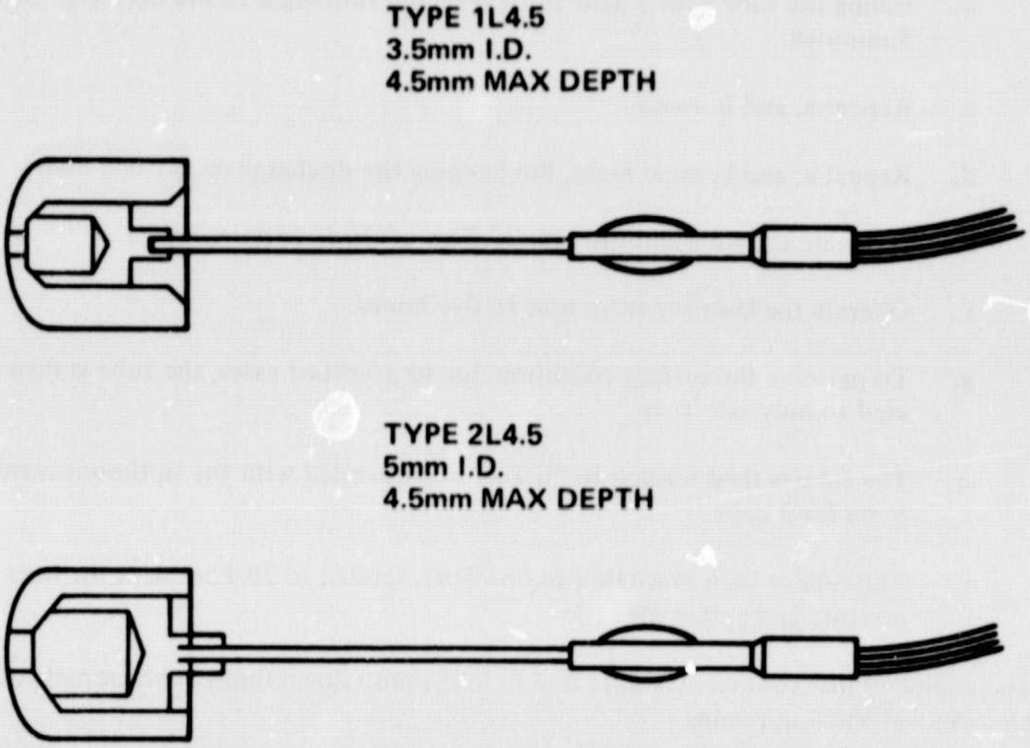

Figure 3. Cathode Types

shown in Figure 3. The ceramic insulator serves as a sputter shield. The tubes are 15 inches in length with a 5.6 mm inside bore diameter and have a plasma length of 20 cm, and 50 cm^3 volume. The Brewster windows were indium-sealed to the laser bore at the University of Maryland[6] after being masked and coated with gold and chrome at the Goddard Space Flight Center.

IV. TUBE PROCESSING

An ultra-clean processing station, shown in Figure 4, was designed to process the gas laser tubes. A typical processing sequence included the following steps:

a. Evacuation of the laser tube to 10^{-6} Torr.

b. Filling the tube with 5 Torr of oxygen and running a 10 ma discharge current for 5 minutes.

c. Repeat a. and b. twice.

d. Repeat a. and b. once again, but keeping the discharge on for one hour.

e. Evacuate the tube and fill with 20 Torr of the laser gas mixture.

f. Operate the laser for from four to five hours.

g. To preserve the surface condition due to adsorbed gases, the tube is then evacuated to only one Torr.

h. The tube is then refilled to 20 Torr and operated with the optimum current of 6 ma for 3 days.

i. The tube is then evacuated to one Torr, refilled to 20 Torr with the laser gas mixture and sealed off.

The complete process takes six days due to long pump down times characteristic of molecular sieve and Vac-Ion pumps.

Before gas processing each laser tube's residual gas background was recorded with a Quad 1210 Residual Gas Analyzer to assure that the residual gases and the H_2O group were at a minimum. Several laser tube background graphs are shown in Figures 5 through 10. The hard copies of the residual gas background were obtained by interfacing the Quad 1210 Residual Gas Analyzer with a Varian Associates Model F100 X-Y recorder.

V. TEST SETUP

For all of the test lasers, a mirror mount was designed to accommodate a piezoelectric double disk bender upon which the laser mirror was mounted. This permitted the P-20 line to be obtained from each laser. The cavity length was 19 inches. All eight tubes were cooled with distilled water. The reservoir temperature was maintained at 15°C. A special ballast network was designed to permit the laser tube current to be maintained constant in spite of degradation. Had a current-controlled power supply been available, this feature could have been dispensed with.

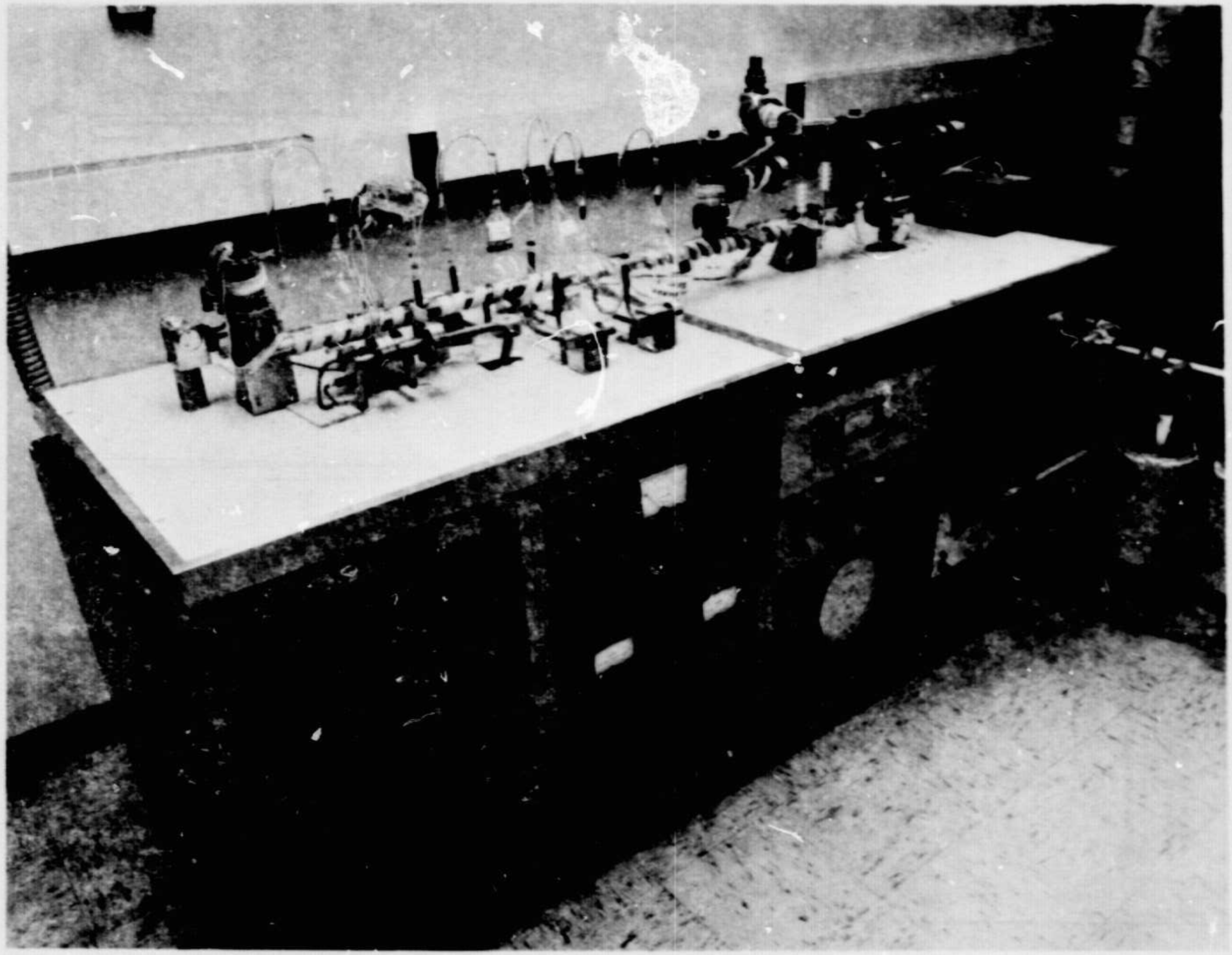

Figure 4. Gas Processing Station

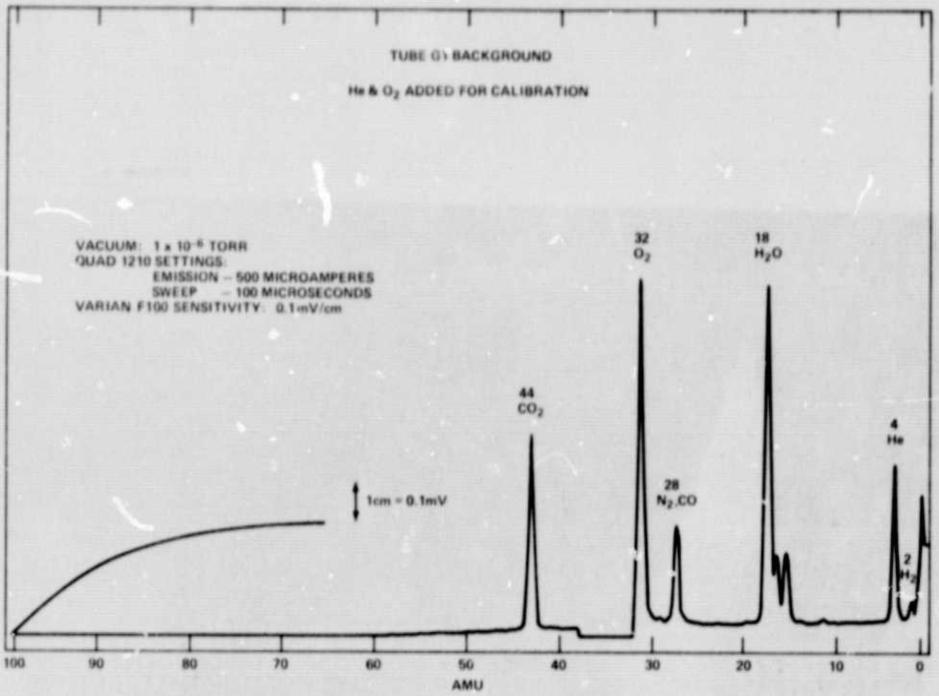

Figure 5. Tube G1 Background

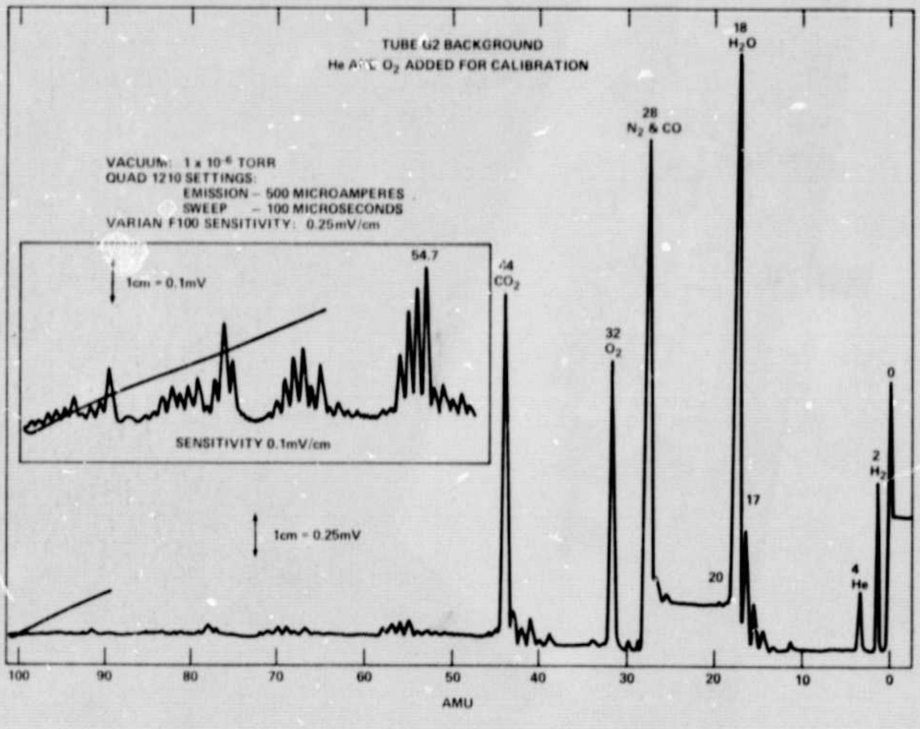

Figure 6. Tube G2 Background

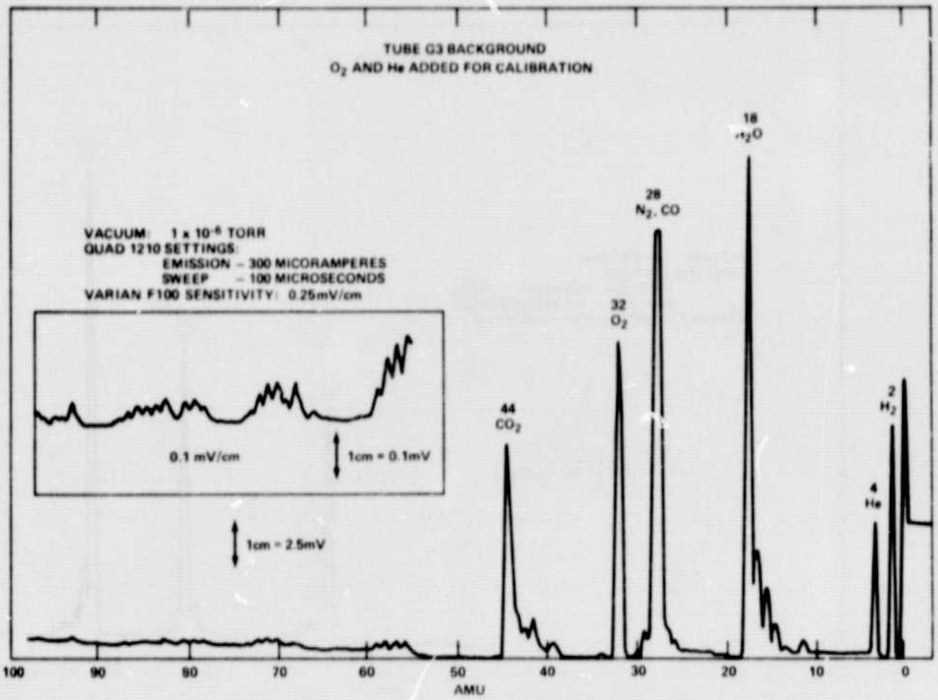

Figure 7. Tube G3 Background

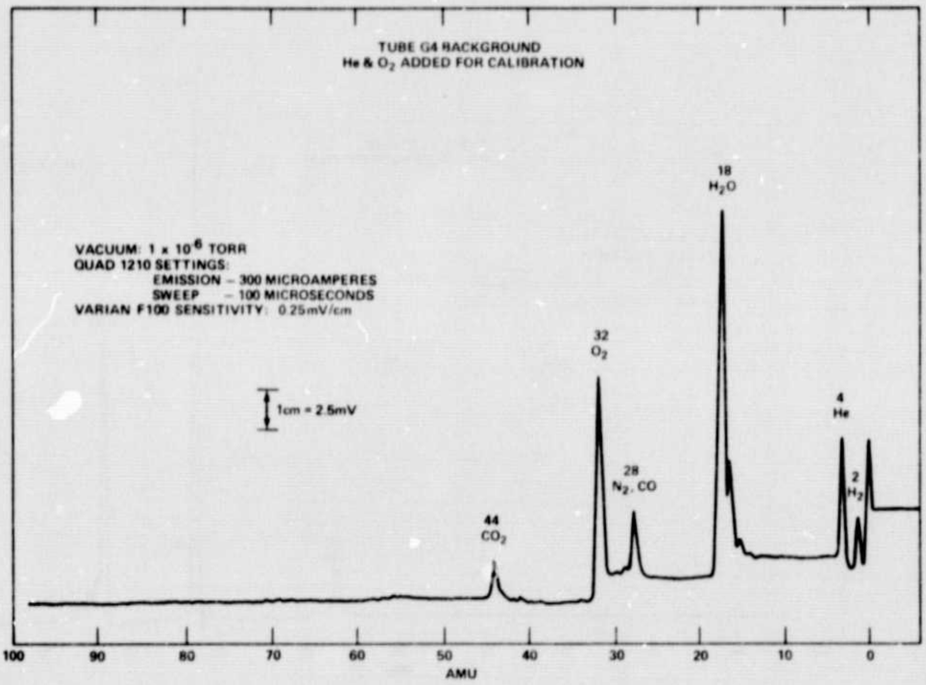

Figure 8. Tube G4 Background

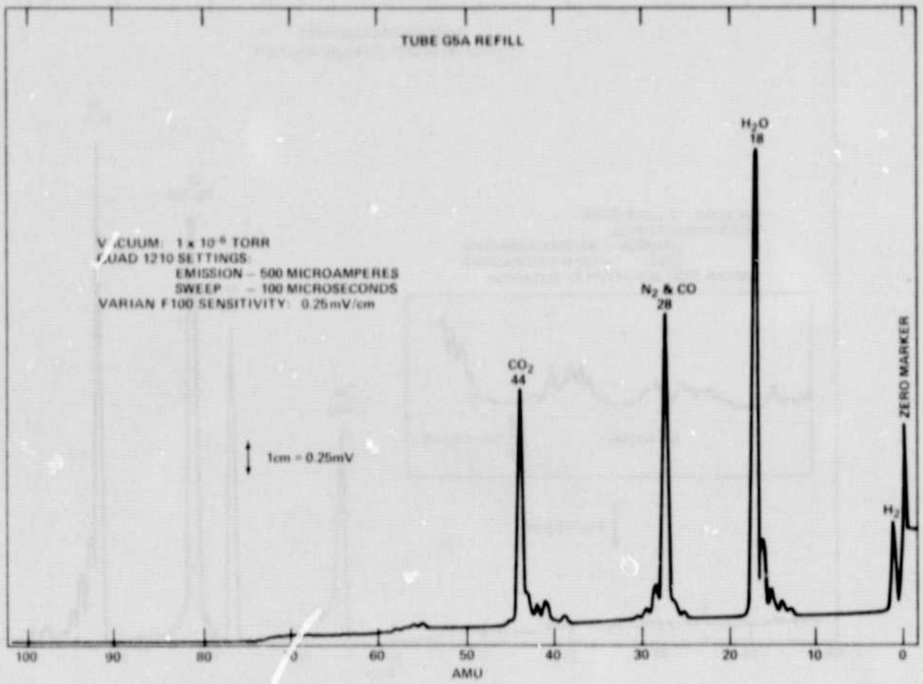

Figure 9. Tube G5A Refill Background

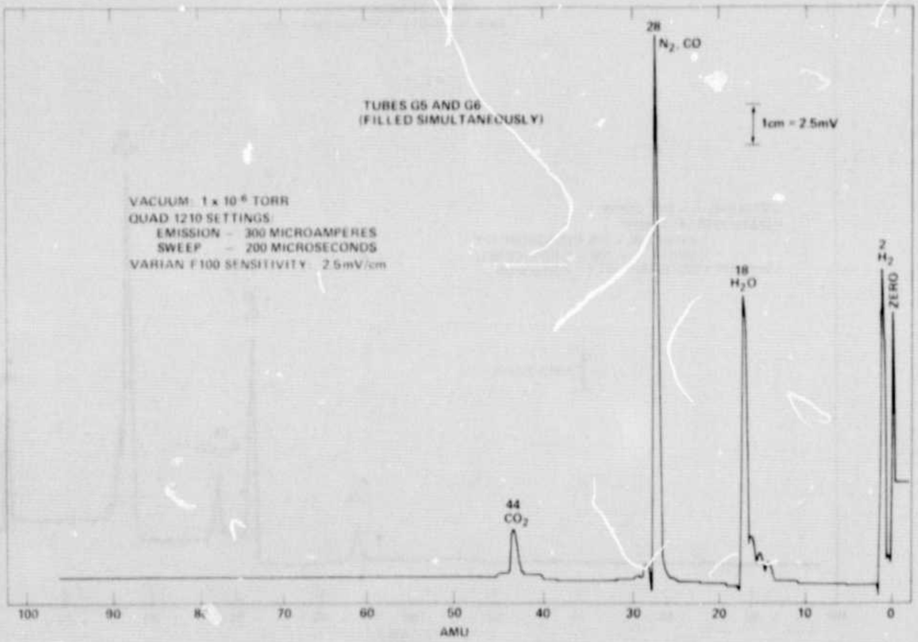

Figure 10. Background for Tubes G5 and G6 (Filled Simultaneously)

The voltage drop across the tubes was approximately 5 kV. All laser tubes were placed on a laboratory bench covered with plexiglass. The cover served the dual purpose of preventing accidental contact with the high voltage or laser beams, as well as maintaining a reasonably clean environment for the laser tubes. The test setup is shown in Figures 11A and 11B. Although the water jacket temperature was maintained at approximately 17°C, the lasers were exposed to the laboratory environment where temperatures varied over the range 60 to 100°F and the relative humidity varied from 37 to 90 percent.

After each week of operation the lasers were shut down to clean the Brewster windows with CH_2Cl_2, as well as to record the laser power, voltage, temperature, and hours of operation.

VI. DETAILED LIFE TEST RESULTS

Laser G1 – The windows on this tube are polycrystalline cadmium telluride. After 100 hours of operation, an external fiberglass insulation was placed around the cathode to provide comparison with lasers G2, G3, and G5 which were uninsulated. The anode is a platinum pin with a tungsten lead. The end of the pin was cut with wire cutters to compare the performance of a flat anode end with that of a ball end.

During the first 1000 hours of operation, two dark rings appeared around the inside of the laser tube near the cathode. They appeared to be caused by sputtering products. After the insulation was added to the outside of the cathode, the rings totally disappeared. They reappeared at around 20,000 hours of operation, but with a slightly different form. One of the rings was a silvery film about 6 mm in width, while the other was a dark film about 7 mm in width. During the life test, a slowly moving and relatively quiet cathode glow spot was observed. In comparison to tubes 2, 3, and 5, the discharge was quieter and more stable and there was little evidence of sputtering. This is attributed to the higher cathode temperature.

The laser bore and the anode area remained very clean throughout the tube's lifetime. The tube reached half power after 25,552 hours of operation. The power output and discharge voltage are shown in Figure 12 as a function of operating hours.

Laser G2 – The second laser was assembled as the first, but without the external insulation on the cathode. Sputtering deposits began developing in the cathode region after four hours of operation and became very heavy at 2400 hours. They remained very heavy for the duration of the tube's life. The bore region and anode area remained clean as in laser G1. A slowly moving cathode glow spot developed early, but remained stable most of the time. Figure 13 shows the performance of this laser. The tube reached half power at 12,500 hours.

Laser G2A (Refill) – The tube was reprocessed and refilled at the University of Maryland with the following changes: (1) The cathode was replaced, (2) The gas mixture was modified to include 0.2 Torr of H_2, and (3) External insulation was added around the cathode.

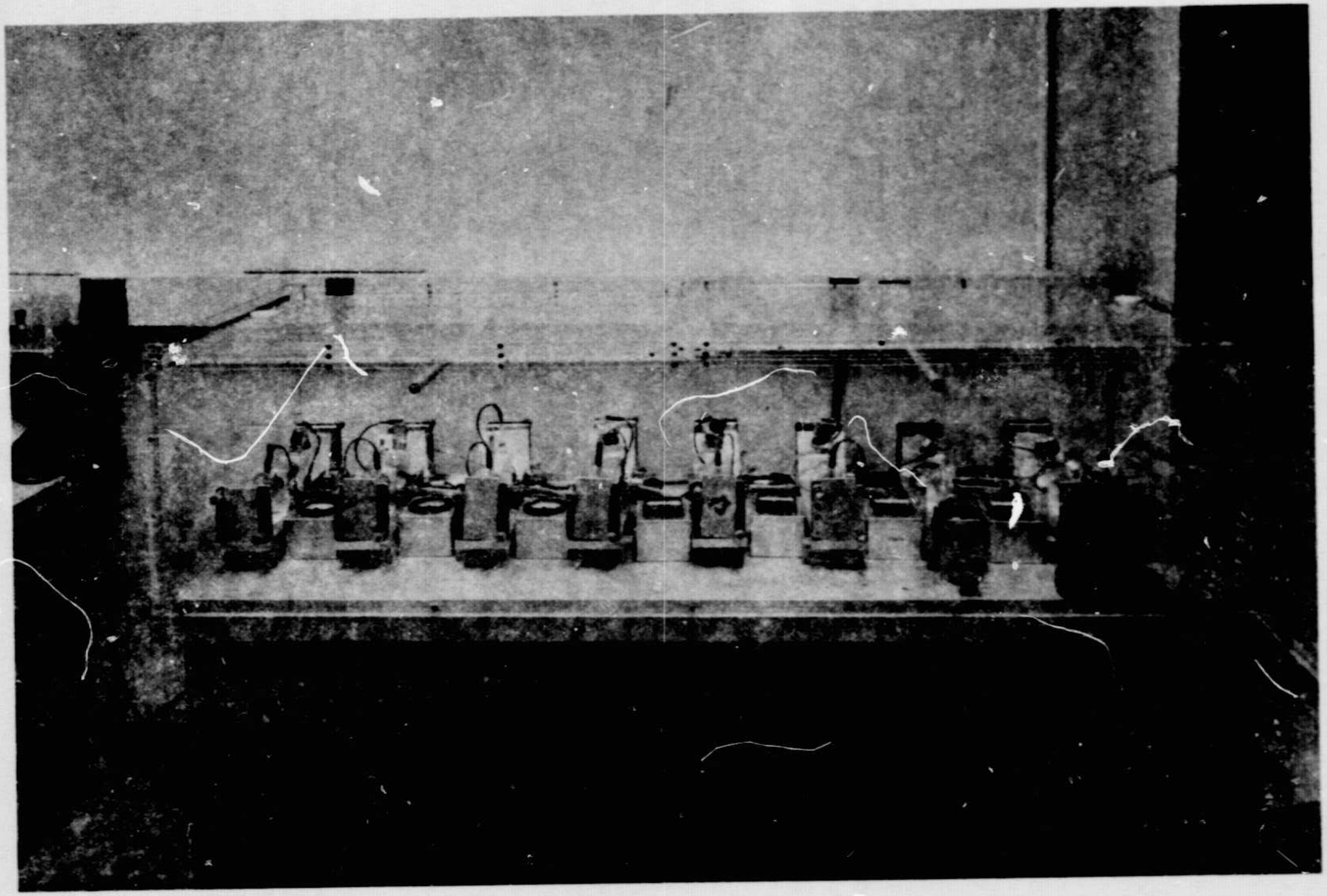

Figure 11A. Laser Ensemble During Life Test

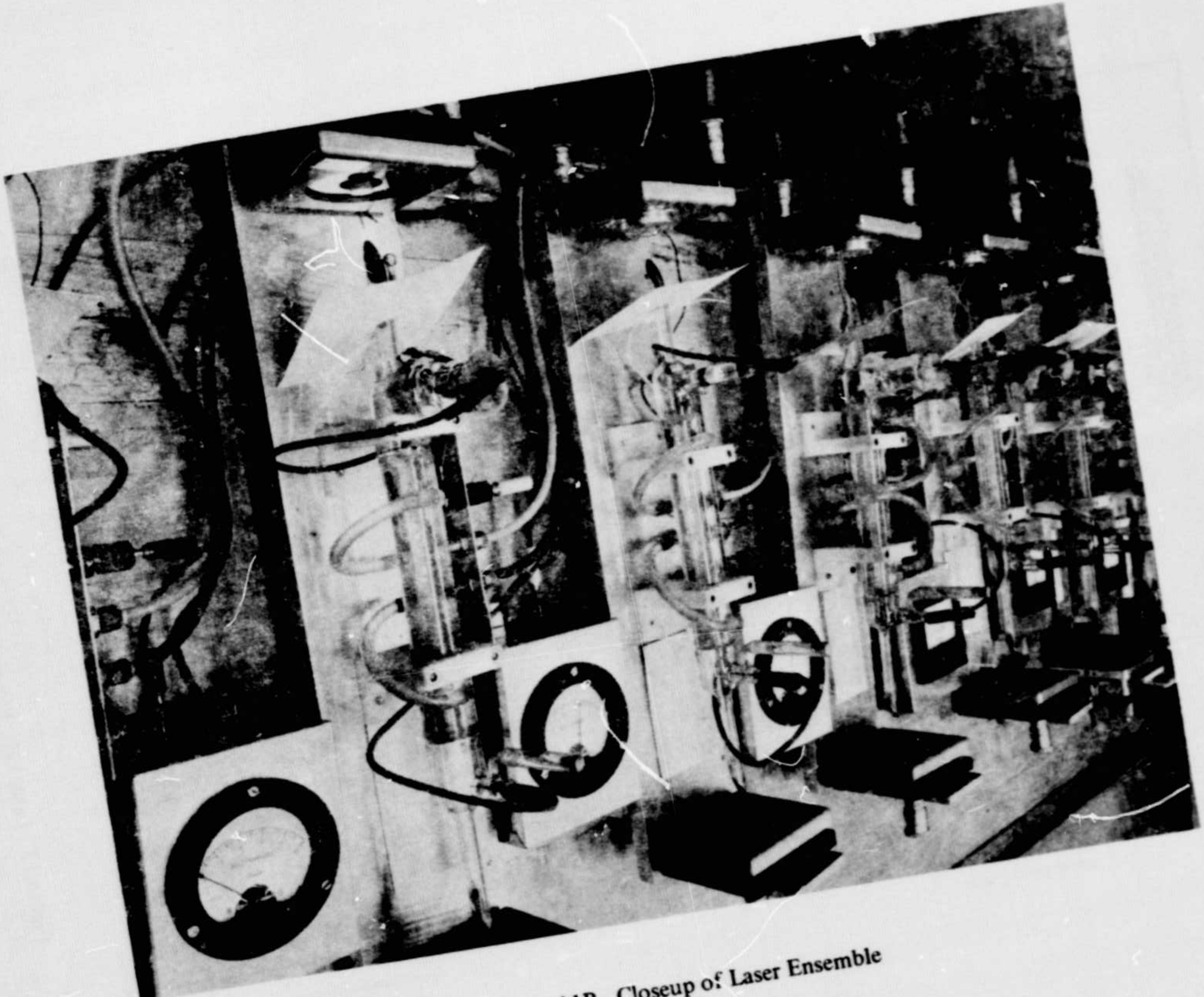

Figure 11B. Closeup of Laser Ensemble

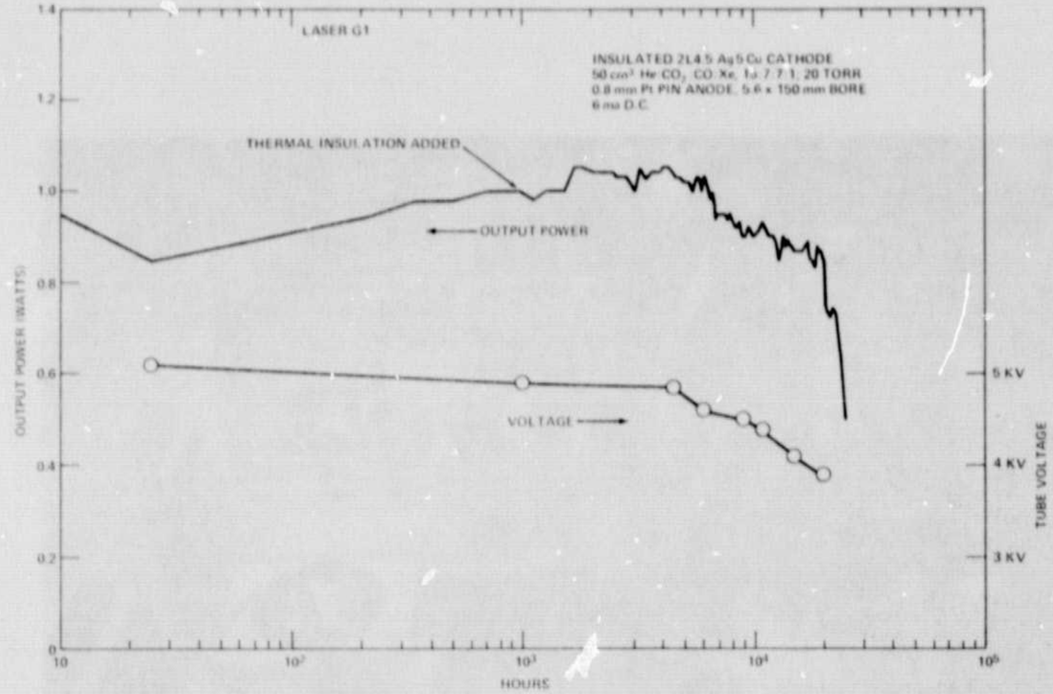

Figure 12. Laser G1: Power Output and Voltage versus Time

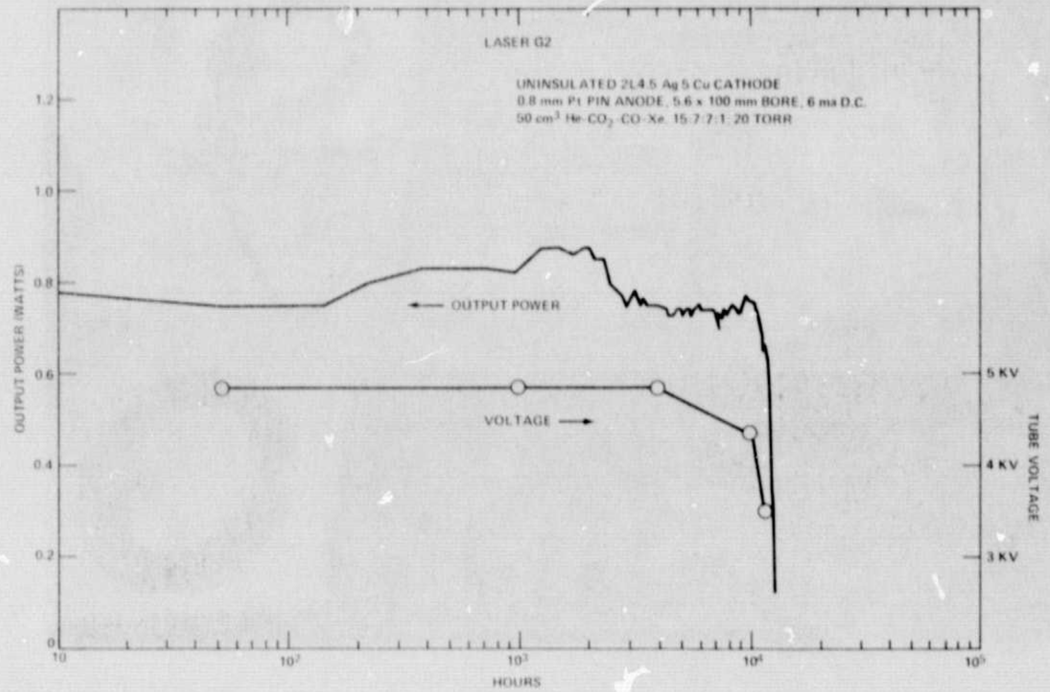

Figure 13. Laser G2: Power Output and Voltage versus Time

The power output of the rebuilt tube was lower due to a slight H_2 overfill and some window contamination on the cathode end that occurred during reassembly. After 8415 hours the cathode was very clean with only a 1 mm wide ring around the exit hole and a faint yellow ring, also about 1 mm wide, on the glass sleeve. The interesting behavior of the refilled tube is shown in Figure 14. The life test is continuing.

Laser G3 – In order to place this tube in life test quickly, zinc selenide rectangular window material was polished and indium sealed to the tube. There was no external cathode insulation, so that a comparison could be made with tubes G1, G4, and G6 which were insulated. The anode platinum pin was rounded with a file.

A moving cathode glow spot became apparent after 505 hours of operation. After 1004 hours particles formed on the inside of the ZnSe window at the anode end. At about 335 hours cathode sputtering rings had appeared which averaged 3 mm in width. The anode and bore of the tube remained very clean.

After 7055 hours the anode glow uniformly covered 1/2 inch of the platinum wire. The half power point occurred at 10,540 hours and the output power decreased very rapidly thereafter. The performance of the tube is shown in Figure 15.

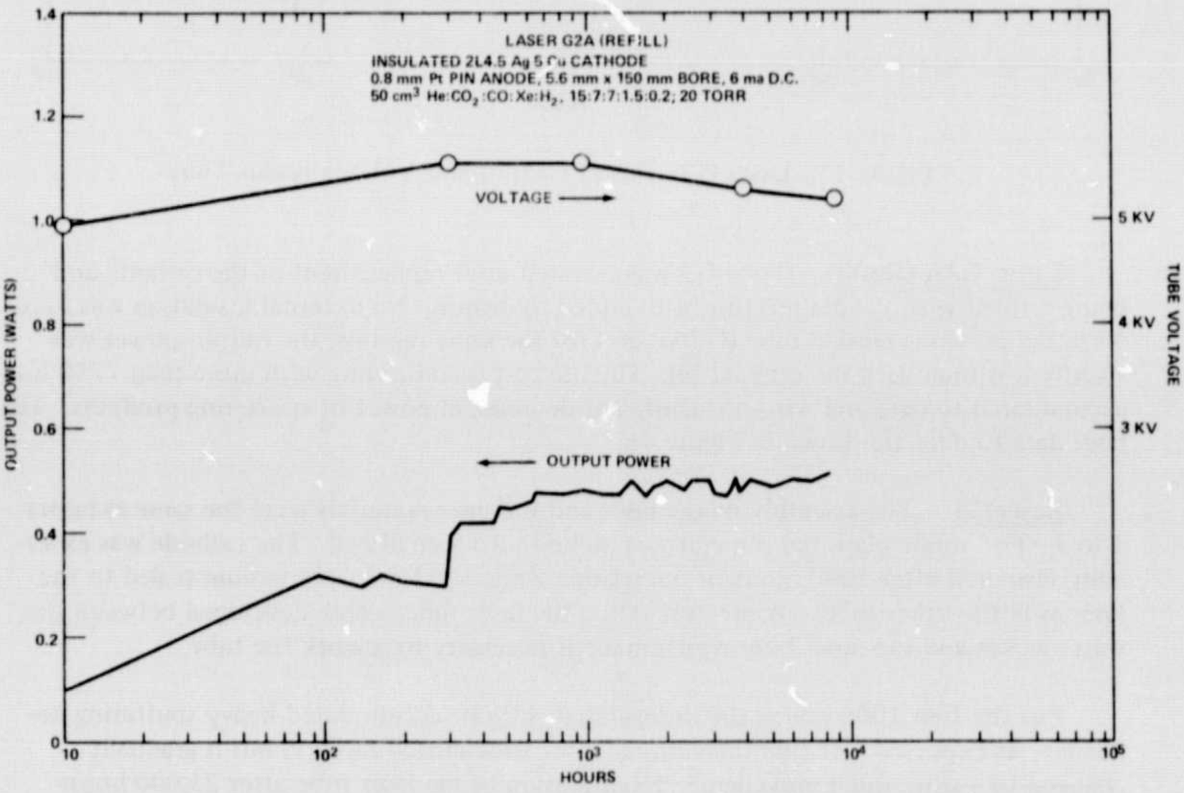

Figure 14. Laser G2A: Power Output and Voltage versus Time

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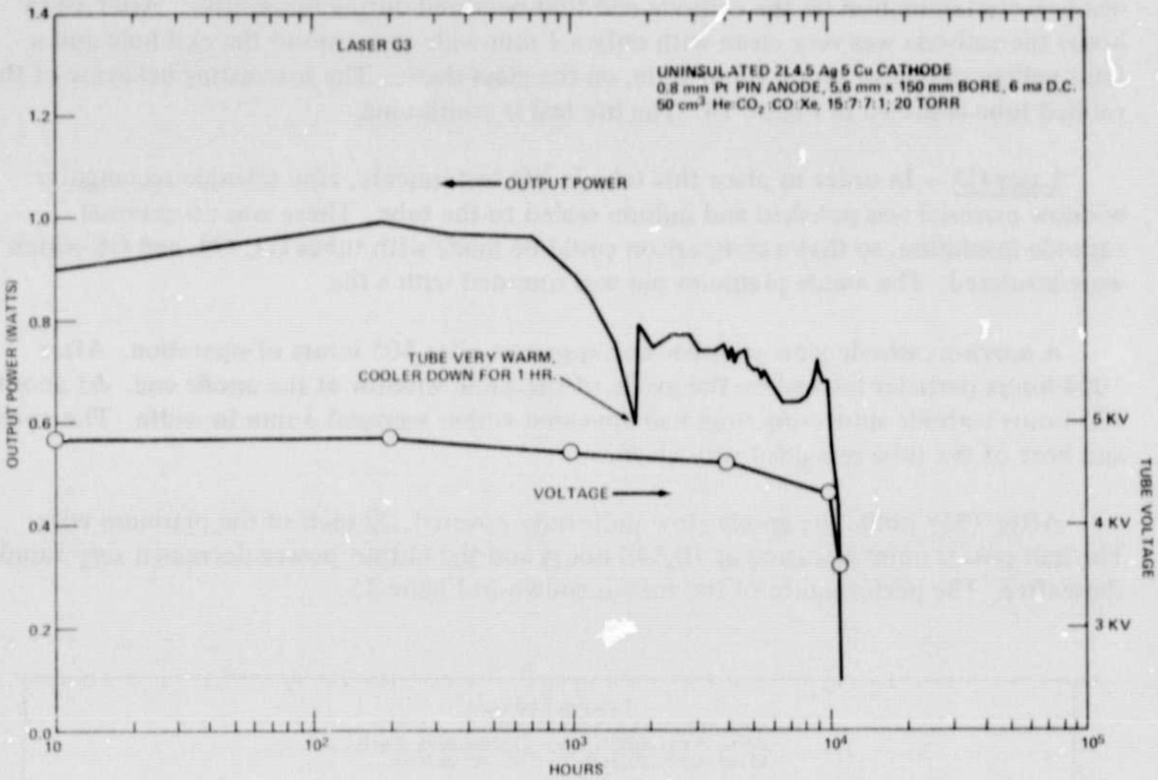

Figure 15. Laser G3: Power Output and Voltage versus Time

Laser G3A (Refill) – Tube G3 was retested after replacement of the cathode and being refilled with the gas mixture with added hydrogen. No external insulation was used. As in the previous refilled tube (G2A), and for the same reasons, the output power was slightly less than with the original fill. The life test is continuing with more than 7750 hours accumulated to date and with no significant decrease in power or sputtering products. The laser data to date are shown in Figure 16.

Laser G4 – The assembly of the laser and the laser materials were the same as lasers 1 to 3. The anode platinum pin end was melted into a small ball. The cathode was externally insulated after 1000 hours of operation. ZnSe windows were indium sealed to the laser as in the other tubes. While evacuating the laser tube, a leak developed between the water jacket and the inner bore which made it necessary to rework the tube.

For the first 1000 hours, the uninsulated cathode accumulated heavy sputtering deposits – as expected. At first the cathode glow spot shifted rapidly, but it gradually changed to a slow, quiet movement. Examination of the laser tube after 23,000 hours revealed that a segment of the ceramic sputter shield had cracked and separated from the cathode. The sputtering products disappeared, as before, when the insulation was added.

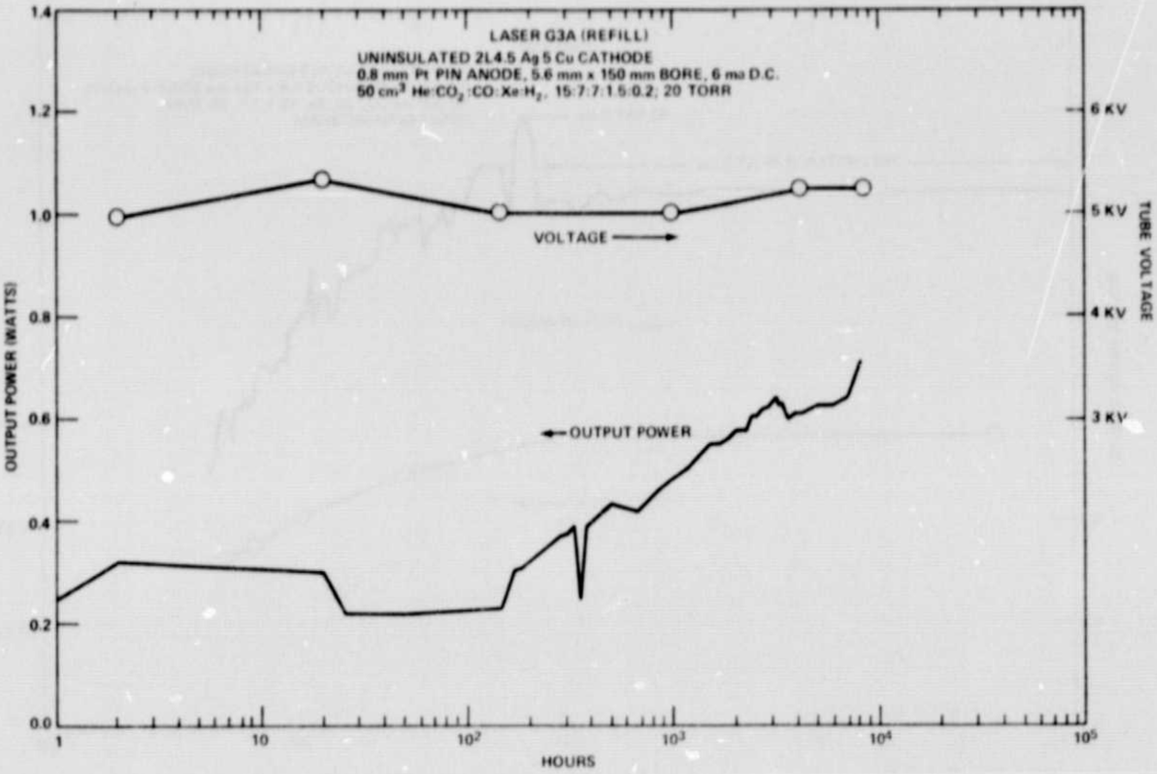

Figure 16. Laser G3A: Power Output and Voltage versus Time

They were still absent, and the laser bore and anode area were clean, at the end of the life test. The laser performance is shown in Figure 17; half power was reached at 22,021 hours.

Laser G5 – Laser G5 has the same materials as the preceding tubes, except for the use of single crystal cadmium telluride Brewster windows. The cathode was not externally insulated. This tube was processed simultaneously with laser G6 but expired early at 3694 hours (54% power decrease) when the ceramic sleeve around the cathode separated from the cathode and sputtering increased greatly. Figure 18 shows the lifetime history of the tube.

The cathode ceramic structure was redesigned to make it more resistant to vibration, and in particular the vibration levels that might be experienced in space flight applications. A circular disk made of zirconium alloyed with 1% tin was used to lock the ceramic insulator to the cathode. This design was used in the reassembled and refilled laser tube designated G5A.

Laser G5A (Refill) – In addition to replacing the cathode, one of the cadmium telluride windows was also replaced when it was found to be spotted during reassembly. The tube was refilled and placed on life test. External insulation was placed around the cathode before the start of life testing. After 1000 hours the zirconium ring locking the ceramic

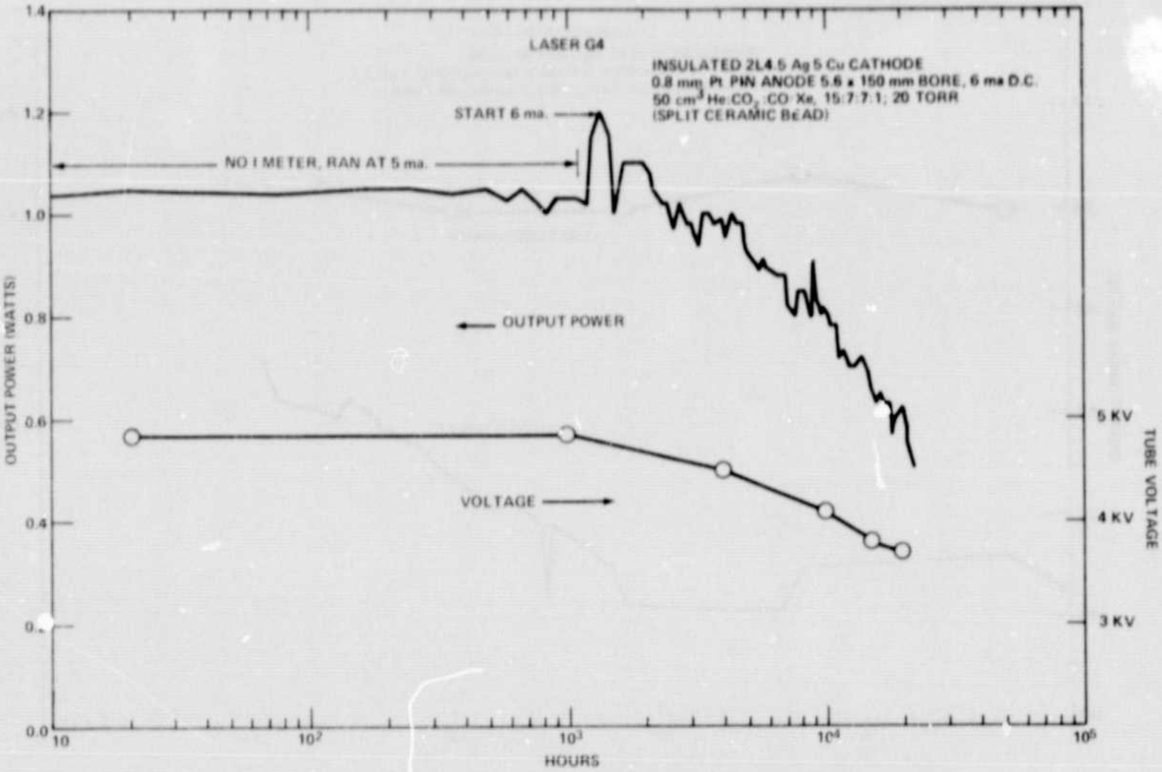

Figure 17. Laser G4: Power Output and Voltage versus Time

sputter shield to the cathode was covered with a black oxide layer. Due to this observation, it was felt to be unwise to use the ring in future laser tubes.

After 16,590 hours of testing, the cathode sputtering products were minimal, although a 1.5 mm wide dark ring and a 6 mm wide lighter ring had appeared. At the present time, there is no degradation of laser power from the initial power of 650 mW, (see Figure 19).

Laser G6 – The sixth laser used the melted platinum pin anode and external insulation around the cathode. The Brewster windows were made of single crystal CdTe. As expected, the usual sputter deposit rings formed around the cathode at about 171 hours and became heavier before the external insulation was added at 1082 hours. The initially stable cathode glow spot soon gave way to a randomly moving spot. The sputter rings again were reduced to very light deposits. The life test behavior of the tube can be seen in Figure 20. It accumulated 12,506 hours before reaching half power. The tube was allowed to continue on test for an additional 3455 hours past the half power point. At that time the power had dropped to 110 mW and relatively large amounts of sputtering were observed, along with the typical low pressure striations that indicate a loss of pressure. The bore and anode area were relatively clean of sputtering products. However, during processing, a small particle in the bore glowed and burned for about 10 minutes before vanishing. This may have been responsible for the relatively short lifetime of the tube.

Lasers G7 & G8 – The role of small amounts of hydrogen or water vapor has always been an obscure one.[7,8] Are small amounts of these impurities essential for long life? Are tubes that are better outgassed during processing more prone to failure than the less well outgassed tubes? To obtain a partial answer, some of the tubes that had failed were rebuilt and a small amount of H_2 was added.

In addition, two additional tubes containing an H_2 additive (G7 and G8) were added to the original six. Laser G8 also employed a pure copper cathode. A further modification in these tubes was the use of cathodes and anodes mounted parallel to the laser bore.

Lasers G7 and G8 were placed in operation at the same time and observed closely, without external insulation, for the first 4223 hours. External insulation was then added. By 1127 hours heavy brownish-black sputter rings formed and the cathode glow spot was observed to move slowly, but continuously. Earlier, after only five hours of operation, a small spot had developed on the inside of one Brewster window on laser G7; the remainder of the tube was very clean.

Although the tube's initial power output was very low, 500 mW, it increased to 1.2 W and remained there for approximately 2700 hours. The output power has recently been

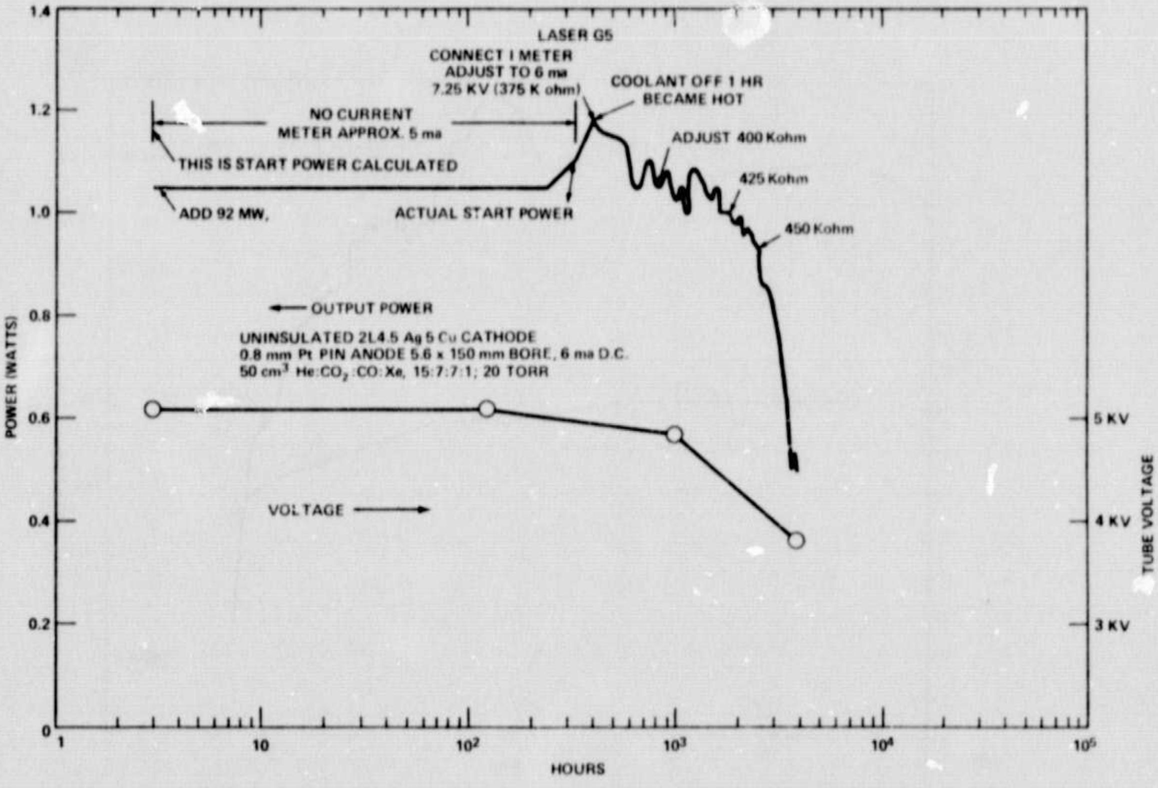

Figure 18. Laser G5: Power Output and Voltage versus Time

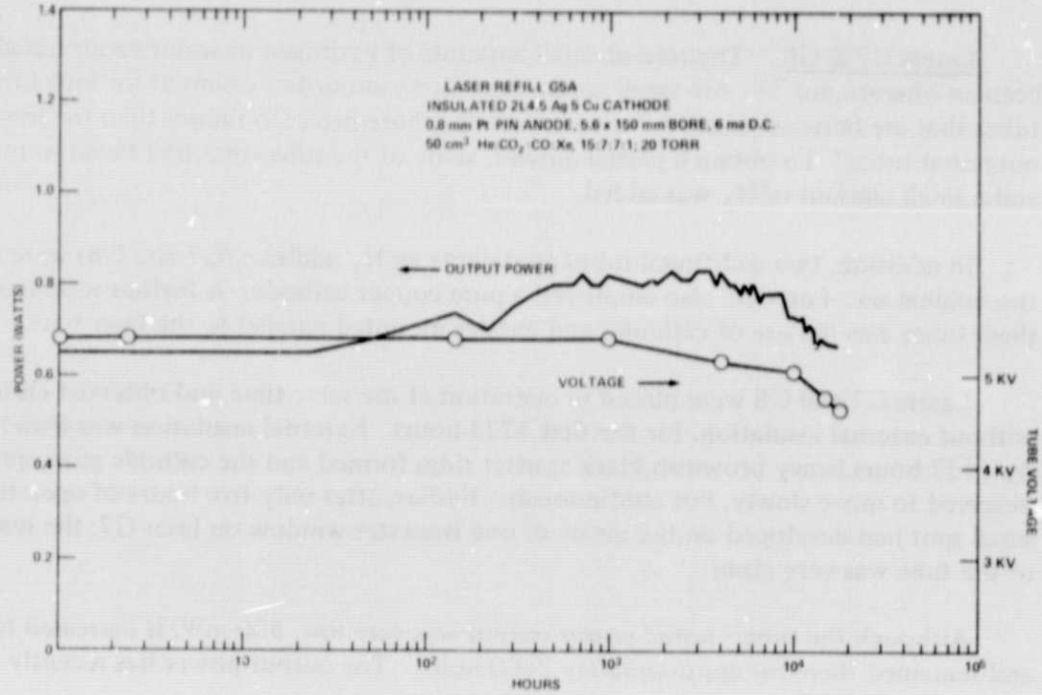

Figure 19. Laser G5A: Power Output and Voltage versus Time

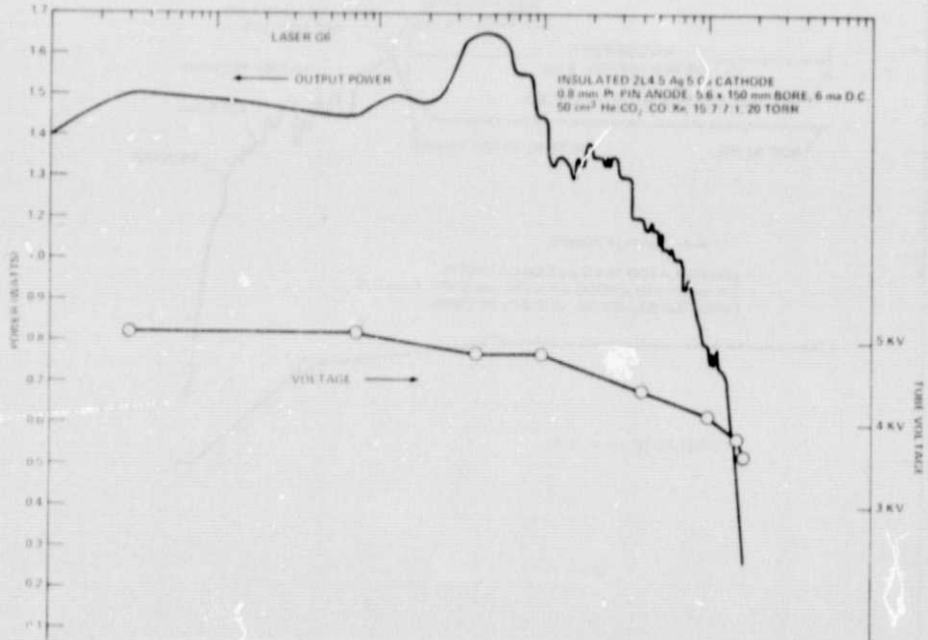

Figure 20. Laser G6: Power Output and Voltage versus Time

decreasing and has now dropped below its starting value. An inspection of the cathode on tube G7 around 13,000 hours showed heavy sputtering and a silver film near the cathode, encircled by a dark 5/8" wide film. Small silvery droplets have oozed out between the retaining ring and the ceramic shield. The anode discharge now extends beyond the platinum pin to the tungsten wire. Figure 21 shows the life test results for laser G7.

Laser G8 is identical to G7 except for the use of a pure copper cathode. From the beginning of the life tests until 2808 hours, the cathode glow spot was very stable. It then began to move slowly. The following day it stopped moving and has remained exceptionally stable to the present time – 13,776 hours. Beginning at an initial power of 500 mW, the laser reached a peak power of 1.4 W and is now remaining steady at the 1 W level. Its performance is shown in Figure 22. At 1559 hours a thin, transparent layer of copper-colored material had formed inside the cathode shield. After 4223 hours the external insulation was added. At 13,608 hours the film was no longer present. Again, as in all the tubes, the anode and bore areas are quite clean, although the anode is slightly oxidized.

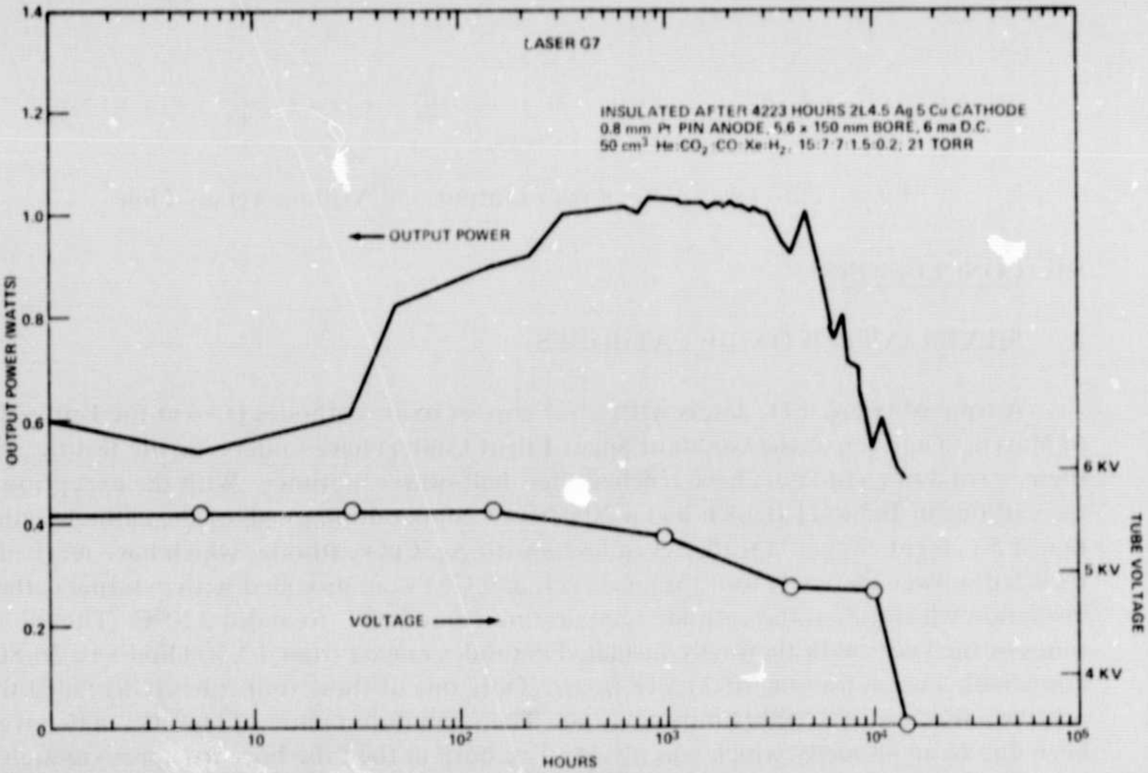

Figure 21. Laser G7: Power Output and Voltage versus Time

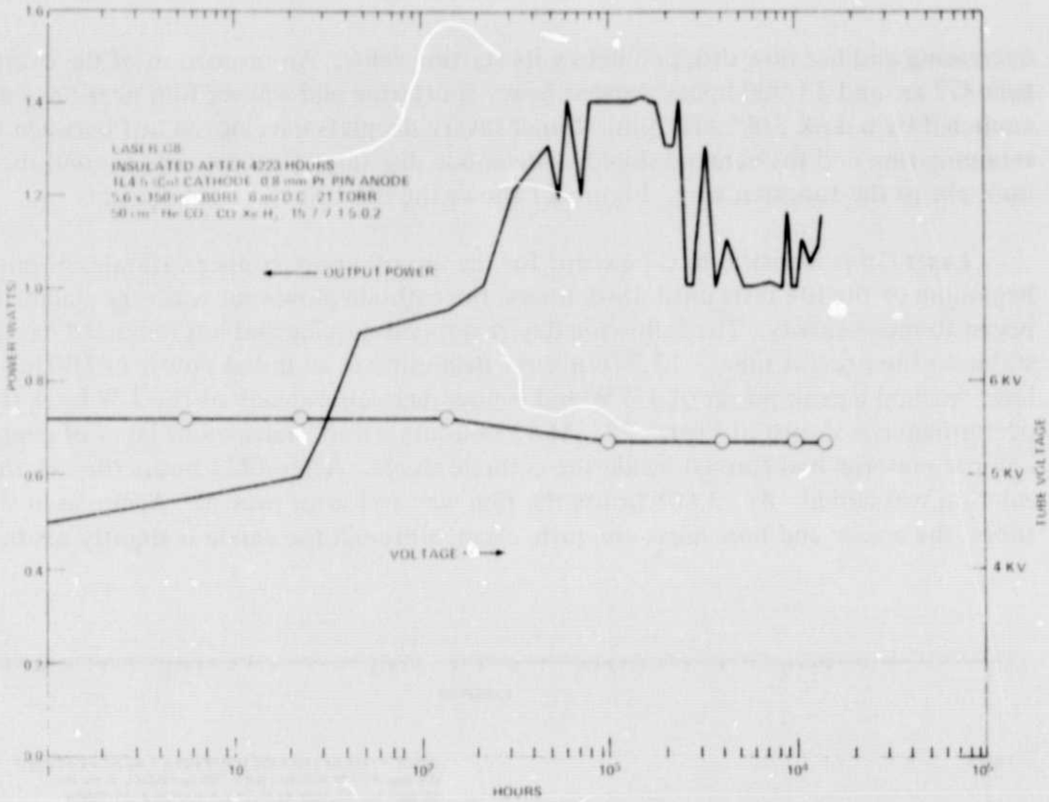

Figure 22. Laser G8: Power Output and Voltage versus Time

VII. CONCLUSIONS

A. SILVER COPPER OXIDE CATHODES

A total of twelve CO_2 lasers with silver copper oxide cathodes (two at the University of Maryland and ten at the Goddard Space Flight Center) have undergone life testing. Of these, a total of eight lasers have reached their half-power lifetimes. With the exception of the cathode in Tube M1 (which had a 20 percent copper doping), all of the cathodes contained 5 percent copper. Of the seven lasers with Ag5CuO cathodes which have reached their half-power lifetimes, four (M5, G1, G4, and G6) were provided with external cathode insulation which raised the cathode temperature from 200°C to about 320°C. The lifetimes of the lasers with thermally-insulated cathodes ranged from 12,500 hours to 26,800 hours with a mean lifetime of 21,718 hours. Only one of these four tubes (G6) failed to achieve a lifetime of 22,000 hours or more. The premature failure of laser G6 may have been due to an impurity which was observed to burn in the tube bore for approximately ten minutes during processing. The three lasers incorporating Ag5CuO cathodes without thermal insulation (lasers G2, G3 and G5) had lifetimes ranging from 3600 hours to 12,500 hours and a mean lifetime of 8880 hours. Inspection of laser G5, which failed after only 3600 hours, revealed a sputter shield that had dropped about 3mm and had exposed the rim of the cathode hole. It is believed that excessive sputtering at this exposed rim led to the premature failure. This laser was later rebuilt by replacing the cathode only. The laser (G5A), now running with a thermally insulated cathode, has already surpassed 18,145 hours and will most likely live 20,000 hours or more.

In light of the aforementioned results, it is apparent that thermally insulating the silver-copper oxide cathode increases the lifetime by at least a factor of two. It was also observed that the sputtering products were light to moderate in tubes with thermally insulated cathodes and typically very heavy in tubes without insulated cathodes.

Laser M1, which utilized a cathode containing twenty percent copper, achieved the maximum half-power lifetime of 33,000 hours, but heavy sputtering products were observed in spite of the thermal insulation surrounding the cathode. Previously reported discharge tube lifetime results[2] have demonstrated that higher copper doping levels (10 to 20 percent) give increased sputtering and introduce an imbalance in the CO-CO_2 composition over long periods of time. In these cathodes, sputtered CuO is reduced to Cu_2O giving off oxygen. Thus the imbalance favors the formation of CO_2 with a corresponding decrease in the CO concentration. In contrast, cathodes with 5% copper doping lend themselves to stable CO-CO_2 compositions while pure silver cathodes favor CO formation at the expense of the CO_2 concentration.

B. COPPER CATHODE RESULTS

A total of four lasers with thermally insulated, pure copper cathodes (three at the University of Maryland and one at the Goddard Space Flight Center) have undergone life testing. Three of these lasers (M2, M3A, and M4) have reached their half-power lifetimes. The lifetimes ranged from 7500 hours to 17,500 hours with a mean lifetime of 13,400 hours which is about half of that achieved with thermally insulated Ag5CuO cathodes. Pure copper cathodes, however, have been observed to yield consistently quieter discharges and lighter sputtering products. Furthermore, laser G8, which contains a small amount of hydrogen in the gas mixture, has already accumulated over 15,000 hours with no signs of imminent failure.

C. ANODE CONFIGURATION

Platinum anodes were used in all but one of the lifetime experiments. Three University of Maryland lasers (M1, M2, and M5) incorporated platinum sheet anodes in an effort to spread the discharge over a wider area. The anodes in the remaining lasers were made from 0.8 mm platinum wire with the exception of the anode in laser M4 which was made from 0.5 mm gold wire. The anodes of tubes G1 and G2 were cut off with wire cutters and had a sharp edge. High current densities, visible by their highly concentrated anode glow, had apparently no detrimental effect. All of the remaining anodes had a round end formed by melting the sharp tips. An examination of Table I suggests that there is little or no effect of the anode configuration on laser lifetime.

D. WINDOW MATERIALS

The choice of cadmium telluride or zinc selenide as the Brewster window material had no observable effect on the laser lifetime.

E. HYDROGEN ADDITIVE

Hydrogen gas was added to the mixtures in four lasers. Two tubes (G7 and G8) have accumulated over 15,000 hours while two refill tubes (G2A and G3A) have surpassed 9,000 hours with no signs of imminent failure. Laser G8, which has a thermally insulated pure copper cathode, is performing well relative to three other copper cathode lasers with no hydrogen in the gas mixture (M2, M3A, and M4). Because the lasers with hydrogen additive have not yet reached their half-power lifetimes, however, no conclusions with regard to the effectiveness of the H_2 additive can be deduced at this time. It should be noted, however, that, due to an H_2 overfill at the outset, the initial output power of tubes containing hydrogen was always lower ($\sim 50\%$) than those without hydrogen. Furthermore, the output power tended to increase over the first 1000 hours of operation suggesting the possibility that the hydrogen concentration is being depleted during this time interval.

F. REPRODUCIBILITY AND PROJECTED LIFETIMES

The tube-processing technology required for the fabrication of long-lived CO_2 lasers has been successfully demonstrated at two facilities, the University of Maryland and the Goddard Space Flight Center. Lasers with lifetimes in excess of 20,000 hours have been constructed with good reproducibility, and the test results suggest that, with further development, lasers with 30,000 hour lifetimes might be achieved routinely.

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16. Abstract

An ensemble of CO_2 lasers was tested to determine the effects of cathode material, cathode operating temperature, anode configuration, window copper and hydrogen additives on laser lifetime. Internally oxidized copper and silver-copper alloy cathodes were tested. The cathode operating temperature was raised in some tubes through the use of thermal insulation. Lasers incorporating thermally insulated silver copper oxide cathodes clearly yielded the longest lifetimes - typically in excess of 22,000 hours. The use of platinum sheet versus platinum pin anodes had no observable effect on laser lifetime. Similarly, the choice of germanium, cadmium telluride, or zinc selenide as the optical window material appears to have no impact on lifetime. No conclusions with regard to the effectiveness of the hydrogen additives can be reduced from the results of the tests performed thus far.

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