Electrical Engineering Department

UNIVERSITY OF MARYLAND, COLLEGE PARK, MD 20742

Continued Life Test Results for an Ensemble of CO_2 Lasers

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Dr. J. Degnan

by

U. Hochuli

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CONTINUED LIFE TEST RESULTS FOR AN ENSEMBLE OF CO_2 LASERS

Urs. E. Hochuli
Electrical Engineering Department
University of Maryland
College Park, MD 20742

ABSTRACT

Technical Memorandum 79536 of April 1978 reported the life test results of an ensemble of 16 low pressure CW CO_2 lasers with a nominal output of 1 watt. At that time five lasers were still working and this report shows the final life test results of these remaining lasers. One laser quickly died while the remaining four lasers reached half power output at 38,000, 40,000, >40,000 and >40,000 hours respectively. These results show the potential for a 50,000 hour laser while the average life of the 16 tested lasers was 22,500 hours. It should also be noted that the cathode sputtering products, that settle on the glass walls of the cathode sleeve, form an increasingly heavy film as the laser ages. After 25,000 hours parts of this film sometimes flake off and can rapidly reduce the laser output during field use by ending up on optical surfaces such as internal mirrors, gratings or windows. The 50,000 hour life potential can only be achieved provided this problem is properly solved.

INTRODUCTION

After the discontinuation of NASA's CO_2 laser space to space communications program it was felt that it would be very wasteful to also abandon NASA's life test program on the ensemble of CO_2 lasers reported in the NASA Technical Memorandum 79536 of April 1978. The decision was made to transfer the five remaining lasers to the University of Maryland where continued testing was performed under a cost free extension of NASA Grant NSG 5042.

A description of the life history of these five lasers follows and the results show that this decision was an excellent one.

<u>Laser G2A(Refill)</u> - 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.

The power output of the rebuilt tube was lower due to 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. After 37,000 hours these sputtering deposits have grown to a heavy, 1 cm wide metal film on the cathode sleeve, just in front of the cathode bead. Flakes seem ready to break loose but cannot be displaced by tapping with a finger. The behavior of this tube is shown in Figure 1 below.

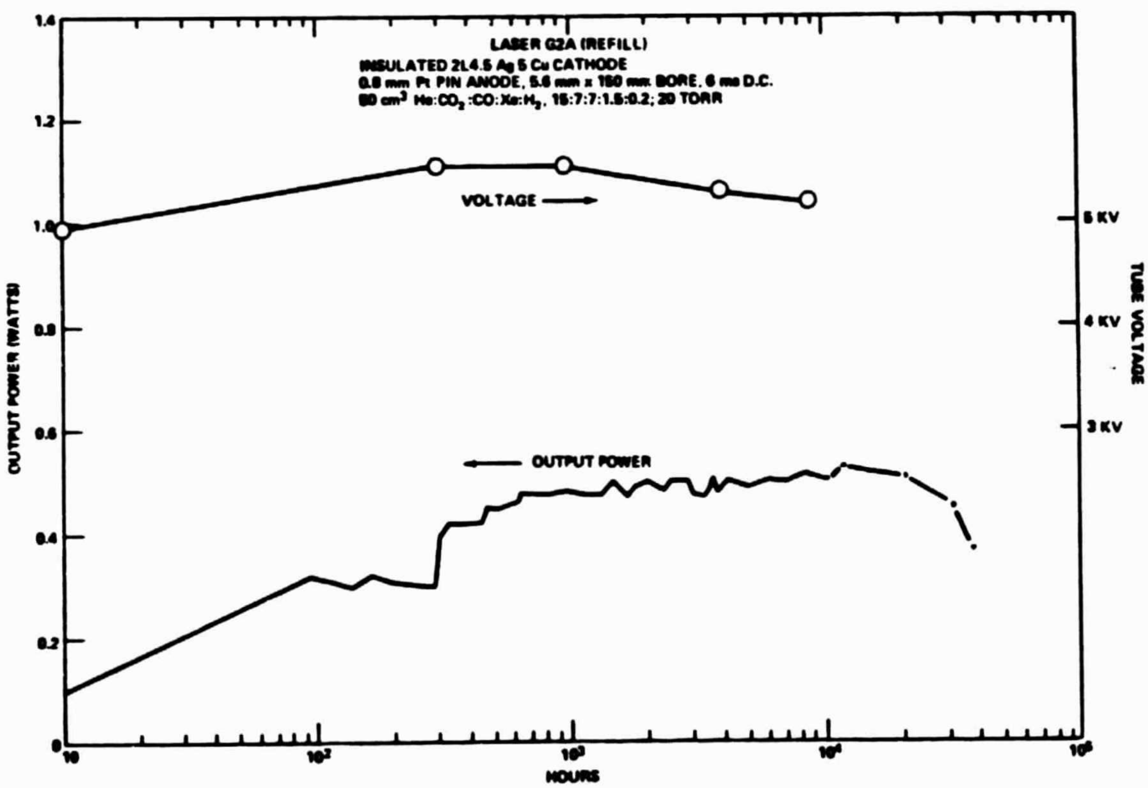


Figure 1 . Laser G2A: Power Output and Voltage versus Time

<u>Laser G3A (Refill)</u> - 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. This tube is the most successful one of the ones without thermal insulation on the cathode sleeve. Sputtering deposits amount to a heavy, flaky, 17 mm wide metallic ring on the cathode sleeve, just in front of the cathode after 37,000 hours of continuous service. We also observe a flake that dropped off from this film. The output power versus time is shown in Figure 2.

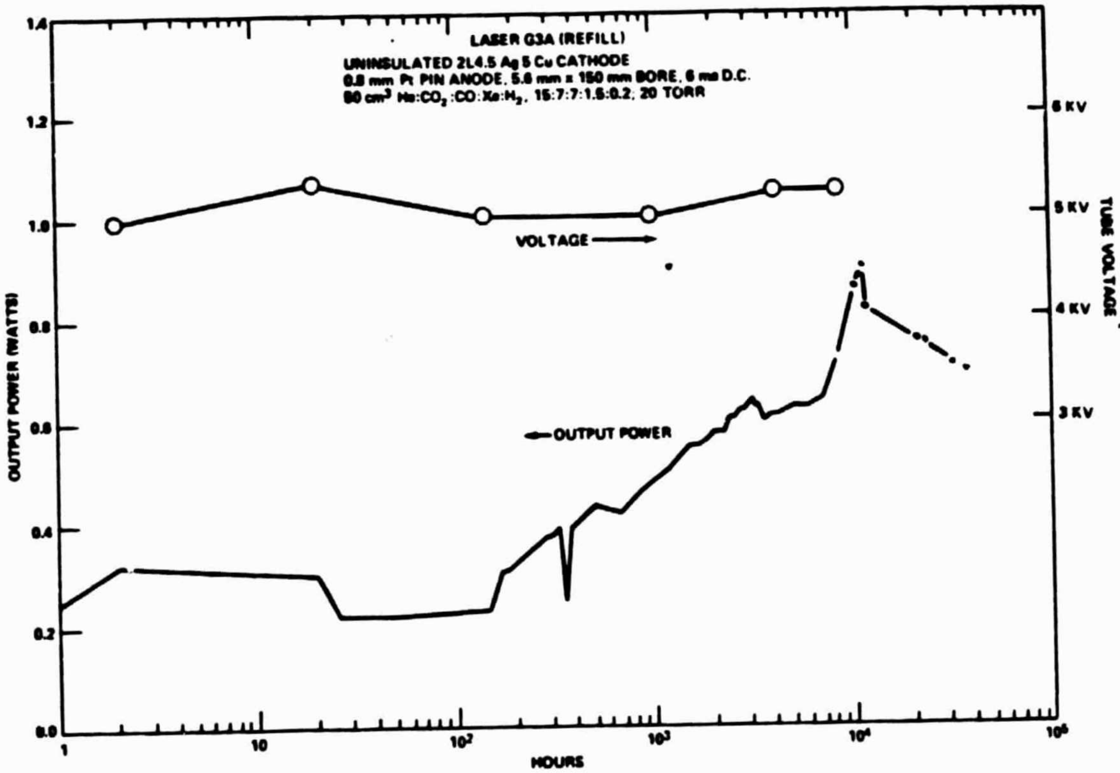


Figure 2. Laser G3A: Power Output and Voltage versus Time

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 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 end, after 45,000 hours, these sputtering deposits have grown into a 20 mm wide metallic ring on the cathode sleeve just in front of the cathode. The envelope shows a black film spot opposite to the opening for the cathode sleeve. This spot may be due to the laser working at too low a gas pressure near its end, resulting in a larger mean free path with increased range for the sputtering products. Light tapping of the cathode sleeve with the finger produced a few loose flakes. Life data for this laser are shown in Figure 3 below.

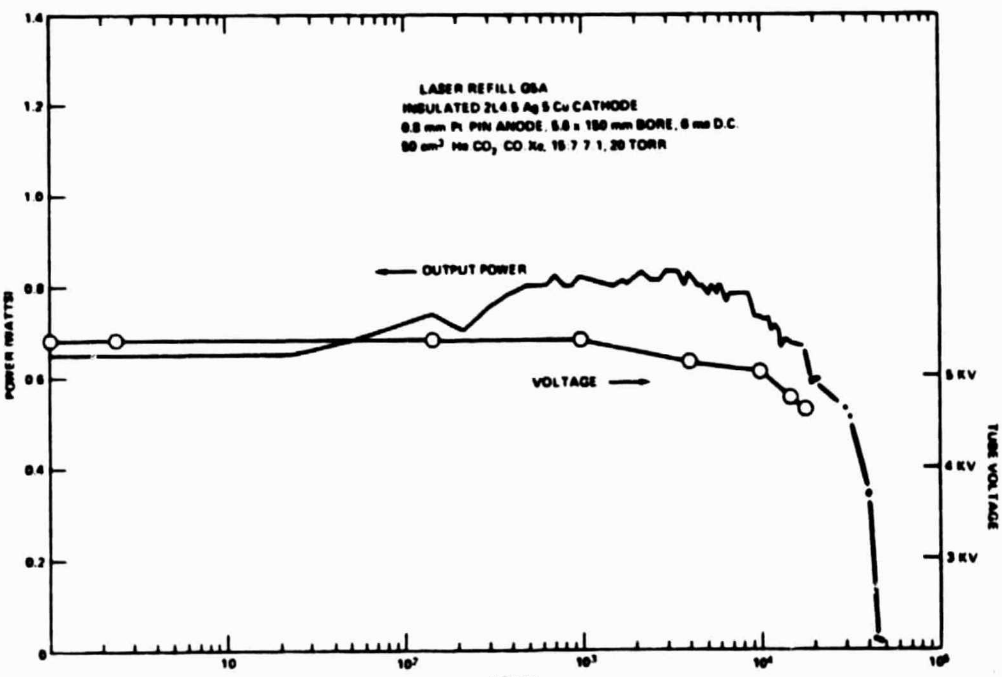


Figure 3. Laser G5A: Power Output and Voltage versus Time

<u>Laser G7</u> - This laser was originally filled with a small amount of hydrogen and its silver copper oxide cathode was secured in its sputter shield with the help of a stainless steel retaining ring. The life of this laser was relatively short and is shown in Figure 4. The stainless steel retaining ring showed oxidation colours at the end of the lasers life but it oxidized far less than the similar zironium ring in laser G5A. Sputtering deposits finally covered about 18 mm of the cathode sleeve ranging from a heavy silver film in front of the cathode to a black brown transparent film 18 mm away from the cathode.

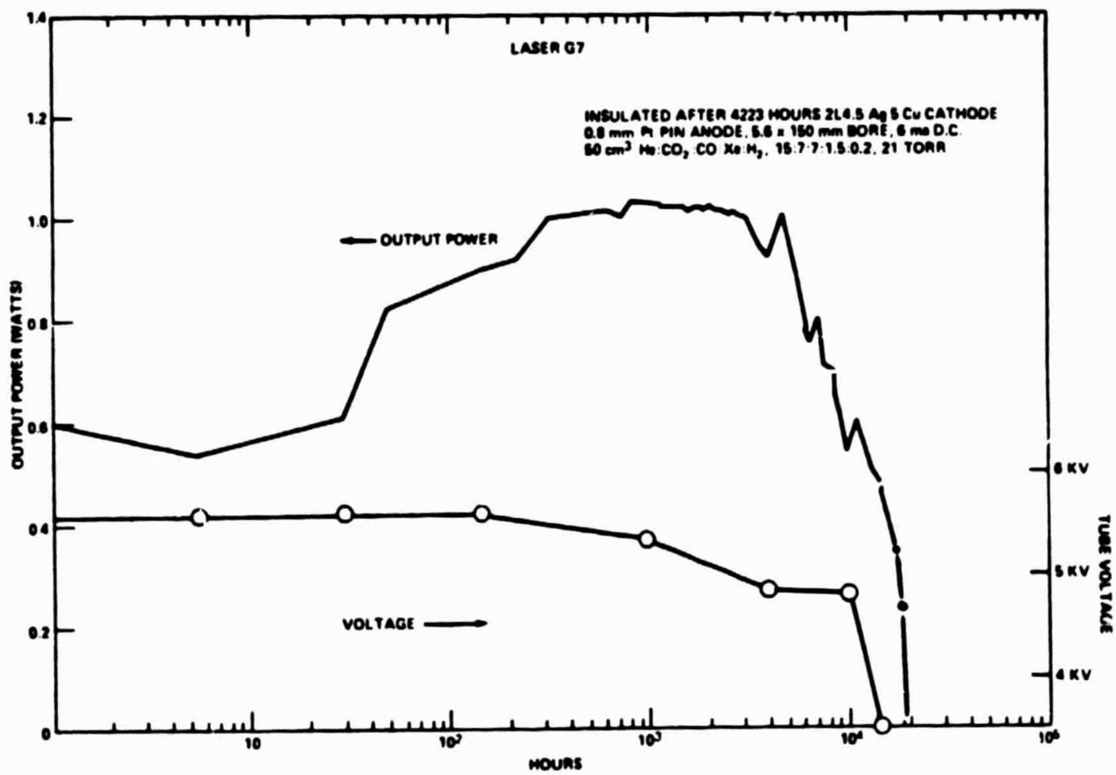


Figure 4. Laser G7: Power Output and Voltage versus Time

Laser G8 used a pure copper cathode and hydrogen addition to its gas mixture. Of the four lasers tested with pure copper cathodes this was the most successful one with a life of the order of 40,000 hours as shown in Figure 5. A silvery shiny deposit with droplets was observed at the cathode feed through lead, the coolest place of the cathode sleeve. A similar deposit exists in the same place in laser M3A. Both of these lasers use pure copper cathodes made from copper bought as 4N pure! Heavy sputtering deposits and loose flakes are now clearly visible.

Fluorescent x-ray spectroscopy analyses were performed on the cathode and sputter shield, and the shiny silvery deposits of the M3A laser. The analysis of the cathode showed that it was composed of fairly pure Cu; while the sputter shield furnished a main peak for Si, followed by lower peaks for Na and Mg. Even though the sputtershield showed the normal white appearance expected from alumina ceramics, the composition appears to be SiO_2 with Na and Mg binders. A closer examination of the cathode showed

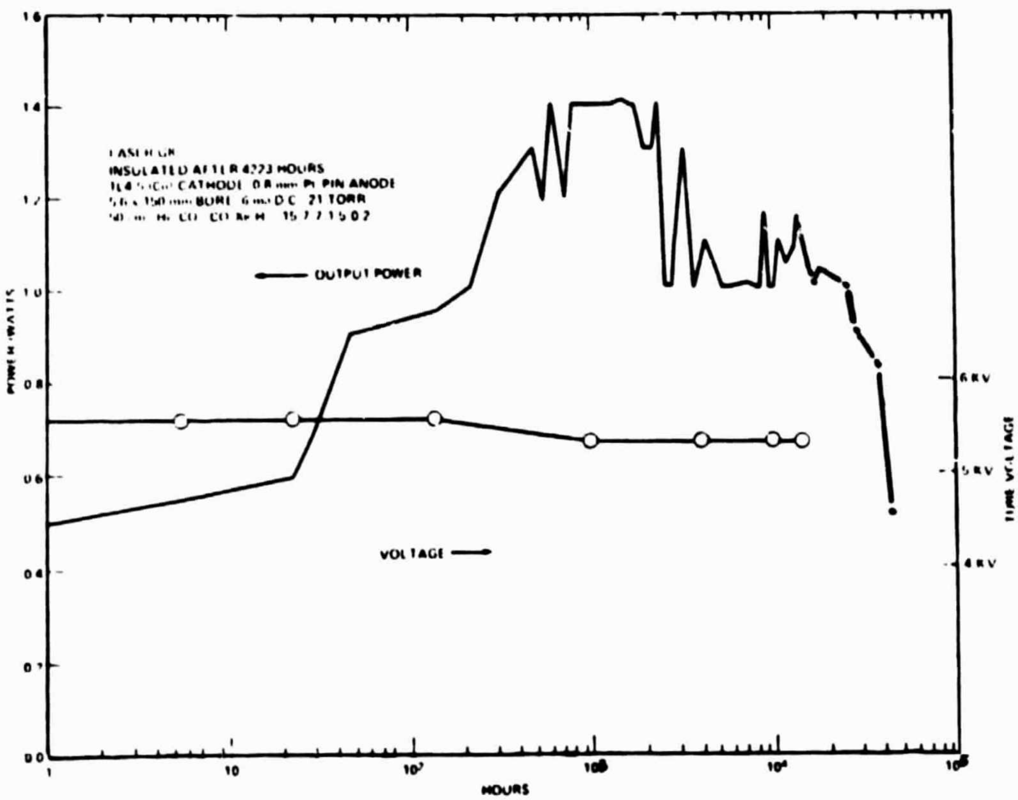


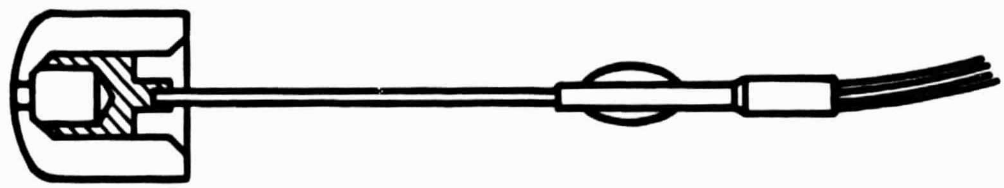
Figure 5. Laser G8: Power Output and Voltage versus Time

that the ceramic sputter shields from the M3A and G8 laser were both split lengthwise. Considerable erosion of sputter shield throat and the sharp Cu cathode entrance edge were visible in the M3A Laser. In addition the cathode was filled with hard sputtering products which strongly adhered to the Cu.

The shiny silvery deposits, with an estimated volume of 1/2 mm^3, turned out to be Na metal. Since no obvious errosion of the Pyrex envelope or the laser bore were visible, the deposits must have originated from the sputter shield. Na, with a vapor pressure of 10^{-2} Torr at 300°C, can be expected to be transported and condensed on the coolest part of the cathode sleeve. What is extremely surprising is that the Na did not oxidize in the CO_2 gas mixture. Since the Na was discovered after 15,000 hours of life in the G8 laser, and was still present after 43,000 hours, it has been present throughout most of the life of the laser. Additionally this G8 laser had hydrogen added, while the M3A laser did not; thus the only cause of these metallic deposits appears to be excessive sputter shield errosion. At the present time we are unable to state that the Na deposits are caused by a chemical exchange reaction requiring copper. The excessive sputtering of the Cu cathodes can be caused by the sharp front edge of the 1L4.5 cathode type required by the original design of this sputter shield. To accommodate the larger diameter AgCu|O type 2L4.5 cathodes, the sputter shields were modified as shown in Figure 6. This modification offers better protection for the cathode edge. In addition this larger type of cathode had a slightly smaller end diameter, which reduced the differential thermal expansion forces on the sputter shield. This precaution was not used in the construction of the 1L4.5 Cu cathode, an omission which may have caused the split sputter shields of the G3A and G8 Lasers.

Unfortunately the other two 1L4.5 Cu cathode lasers, the M2 and the M4, were stolen. So no additional confirmation of the Na deposits could be obtained.

TYPE 1L4.5
3.5mm I.D.
4.5mm MAX DEPTH



TYPE 2L4.5
5mm I.D.
4.5mm MAX DEPTH

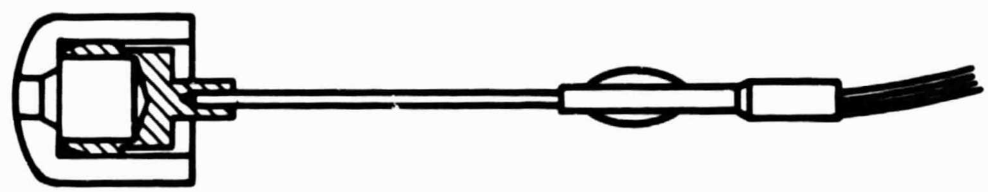


Figure 6. Cathode Types

CONCLUSIONS

Our updated Table I shows an average lifetime for the 16 tested lasers of 22,500 hours. Two of these lasers failed in less than 10,000 hours. One of these failures is explained by a purely mechanical accident, namely a split sputter shield that fell off the cathode and caused the shortest laser life of 3,600 hours. By eliminating the two shortest lived lasers and dividing the remaining 14 lasers into three groups according to their cathode types we still find extreme laser lives between 10,000 and 40,000 hours in each group as shown below:

Lifetime in hours	AgCu/0 cathode + thermal ins.	AgCu/0 cathode no thermal ins.	Cu cathode + thermal ins.
min.	12,500	10,500	15,200
average	26,600	21,000	20,000
max.	>40,400	>40,000	40,000
No. of lasers tested	8	3	3

All three of the 40,000 hour tubes had hydrogen added which seems to be beneficial in extending the lasers life. Contradictions to this conclusion are lasers G5A and G7. The former reached half power output after 38,000 hours without such an addition while the latter reached a life of only 16,000 hours despite of the added

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	Developed Silver Droplets
Univ. of Md.	M4	15:7:7:1.5:0	Cu/0.5mm Au pin	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	AgSCuO/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	AgSCuO/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	AgSCuO/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	AgSCuO/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	AgSCuO/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	AgSCuO/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	AgSCuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	38,000	Yes	Very heavy	Zirconium Retaining Ring Used
G.S.F.C.	G6	15:7:7:1.5:0	AgSCuO/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	AgSCuO/0.8mm Pt pin	Cadmium Telluride	5.0 4.5	16,000	Yes	Heavy	Stainless Steel Retaining Ring
G.S.F.C.	G8	15:7:7:1.5:0.2	Cu/0.8mm Pt pin	Cadmium Telluride	3.5 4.5	40,000	Yes	Very heavy	Developed Silver Droplets
G.S.F.C.	G2A	15:7:7:1.5:0.2	AgSCuO/0.8 Pt pin	Cadmium Telluride	5.0 4.5	>40,000	Yes	Very heavy	Slight H_2 Overfill, Power Lower
G.S.F.C.	G3A	15:7:7:1.5:0.2	AgSCuP/0.8 Pt pin	Zinc Selenide	5.0 4.5	>40,000	No	Very heavy	Inside Window Contamination

Volume and pressure all tubes approx. 50 cm^3 and 20 Torr.

hydrogen. As a note of caution, it must be stressed that all the 16 lasers were tested in the laboratory and not in the field. Critical observations show that the sputtering deposits become increasingly voluminous as the laser ages. For quite a while this does not affect the gas composition and power output too much. After 25,000 hours of continuous service we occasionally see loose parts of these deposits flaking off. Loose particles can not be tolerated in a laser for field use where mechanical motion will distribute them over all the inside surfaces of the tube. A particle, resting on a delicate optical surface (mirror, grating, window) within the beam region, not only increases the losses, it usually also absorbs enough energy to form a hot spot that easily destroys the dielectric coating underneath. By using the present cathode technology the potential exists to build a low power, CW, 50,000 hour, CO_2 laser provided these loose deposits can be avoided.