TECHNICAL
RESEARCH
REPORT

CO_2 Laser

Cold Cathode Research Results

Final Report

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Introduction

The results we were able to show in our progress report and NASA Technical note TN D-7303 are now even more impressive. The original laser with the silver matrix cathode is still working after 16,600 hours with an output power that is now about 70% of its initial value.

In order to answer the question of reproducability we have built four more lasers that have now a history over a period of 6200 hours. We have had sufficient initial confidence in the validity of our research results that we could not resist the temptation to include variations in anode as well as cathode materials. From the four lasers built one failed after 1500 hours. This laser had a nickel ball anode and was later rebuilt by only exchanging the anode for a platinum wire anode. The laser is now working with the same envelope and the same initial cathode in a perfectly satisfactory way for nearly 4000 hours. This is a very significant result because it veryfies our suspicion that not only the cathode material, but the anode material as well has to be carefully selected. The suitable anode materials seem to be again the ones whose oxides are easily reduced in the laser gas mixture. Logical choices are therefore gold, silver, platinum and perhaps palladium and copper. Both platinum as well as gold anodes are presently under investigation and so far seem to work properly.

We do not know if every one of the four lasers will live as long as the first one but the results clearly show that the new technology we developed allows without difficulty to build and duplicate CO_2 lasers that last for more than 6000 hours. A better cathode geometry and somewhat higher operating cathode temperatures have elliminated the unstable cathode spot motion and greatly reduced cathode sputtering deposits, as compared to the first laser. From this result perhaps even longer laser operation can be expected.

We have also included new research results gained from discharge tubes with platinum-copper cathodes. These cathodes are so far the most promising ones we have found if nitrogen has to be used in the laser gas mixture. However, a small amount of hydrogen is needed in the laser gas mixture and cathode sputtering products contain, as expected, negative ions that form anode deposits.

Scaling of the successful cathodes for use in the CO_2 wave guide laser has now been started under a research program funded by ARPA. Below we have a more detailed description of our research results:

Reasons for the Test Lasers Electrode Selections

Despite the fact that the performance of our first sealed off CO_2 laser with the silver matrix cathode makes it to the best of our knowledge the most impressive long life CO_2 laser built anywhere we have often encountered doubts if this result could be duplicated. Our answer, that this result was solidly backed with as impressive performances of carefully analyzed gas discharge tubes was never accepted as a sufficiently convincing argument. It is true that the CO_2 laser history records quite a few encouraging long life results that turned out to be deceptively evasive once they had to be duplicated or scaled to different situations. Most of these results were achieved with fairly large gas volumes and far less care was devoted to details such as proper sealing techniques. Gas volume reductions from volumes of the order of 1000 cm^3 to 50 cm^3 most of the time resulted in laser lifes of 500 hours or less.

This situation left us with no other choice than to actually demonstrate that the new CO_2 cold cathode technology and principles we have invented and developed are of a sound nature and can be duplicated. For this purpose we have built four additional lasers that are now under test and so far justify our confidence. From the standpoint of minimal risk we should have meticulously duplicated the first laser that performed so beautifully over 16,000 hours. There were several arguments against this minimum risk policy. In the meantime since the first laser was put on test we learned from gas analysis results that silver matrix cathodes with only 5% copper give a more balanced CO_2-CO composition over long periods of time. At the same time the sputtering and electrical instabilities of this cathode could be much reduced with a cathode of slightly larger diameter working at a somewhat higher temperature. The temperature increase was achieved by thermal insulation of the cathode sleeve as shown in the NASA technical note TN D-7307 (Fig. 28) We also realized that the simpler copper cathode had very promising life characteristics. For the relatively high cathode current densities of 15 to 18 mA per square cm electrical instabilities could be observed in the form of a slowly rotating cathode spot. A current density reduction to 12 mA per square cm increases the sputtering somewhat but results in a quiet cathode. Quite often the argument is heard that the choice of the anode material is relatively unimportant due to the fact that much gentler processes take place at the anode than at the cathode (anode fall ~ 20 eV, cathode fall ~ 300 eV). Indeed the pertinent literature shows a large variety of different anode materials from nickel, Kovar to the inert platinum. From our cathode experience we would have a tendency to strongly prefer anode materials from metals whose oxides can easily be reduced in the laser gas mixture such as gold, silver, platinum to perhaps palladium and copper over materials such as nickel or Kovar.

For the reasons mentioned we could not resist to include variations of the nature mentioned in the four test lasers. We fully realize the fact that four lasers are a very small sample for statistical purposes. It is therefore obvious that a failure of two or three out of the four test lasers would seriously jeopardize the confidence in our cathode technology that could not easily be restored by accusing the additional variables introduced. We now outline the construction and processing of the four test lasers and the individual test results so far achieved.

Laser Construction

The main features of the four test lasers are identical to the ones of the first laser shown in Figure 1. Pyrex is used for the envelope material and all the leads have tungsten sections entering the envelope through uranium glass beads. The GaAs Brewster window and the internal, gold coated, quartz mirror are attached to the Pyrex envelope with indium film seals. A simple plastic sleeve with "O" rings serves as cooling jacket. The anode and cathode configurations of the individual lasers are described together with their test results.

Processing of the Laser Tubes

The laser tubes were evacuated to 10^{-6} Torr, filled with 5 Torr oxygen, run for 5 minutes with a discharge current of 10 mA and pumped out again. Two more of these 5 minute oxygen cycles followed. The discharge was then run with a 4th 5 Torr oxygen filling for one hour at 10 mA, pumped out and filled with the laser mixture to a pressure of 20 Torr. The laser was then operated for a few hours at 6 mA, turned off, evacuated, refilled with new gas and run again for a few hours. In order to disturb the surface condition due to the adsorbed gasses as little as possible the tube was now evacuated from 20 Torr down to about 1 Torr, refilled and burned in for a few days under normal operating conditions. A similar evacuation step followed then before the final fill was put in and the tube sealed off.

Test Results

Laser No. 1

Has a 18 x 18 x 0.1 mm platinum sheet anode. The anode is mounted with its surface vector perpendicular to the laser bore axis. This way the discharge strikes the edge of the anode and under normal operating conditions the visible anode glow covers the edge over the full width (on one side of the sheet only) to a depth of about 1 mm.

The 1L 4.5 type cathode consists of an internally oxidized 80% Ag 20% Cu (by weight) alloy and its dimensions are given in Figure 2. The internal oxidation was achieved by heating the machined cathode at 750° C for 36 hours in an oxygen flow at a pressure of 760 Torr.

Figure 3 shows the power output and the voltage referred to the discharge tube terminals over a period of more than 16,000 hours. The accompanying electrode pictures show the cathode sputtering deposits that have accumulated over a period of 16,000 hours. The relatively heavy sputtering deposits have cleaned up a surprisingly small amount of gas. This is due to the fact that the cathode consists of the materials Ag and CuO, both of them chemically completely inert in the He-CO_2-CO-Xe gas mixture used. The picture also shows that the sputtering deposits are sharply limited to the cathode space, an indication of the lack of negative ions in the sputtering products. Bore and anode are quite clean and free of deposits after continuous operation for almost two years.

It is interesting to compare the sputtering deposits of the cathode used in laser No. 1 with pictures of discharge tubes using similar cathodes, taken after continuous operation over 13,000 hours. Among the internally oxidized Ag-Cu alloy cathodes the one with 20% Cu by weight shows the heaviest sputtering deposits. These deposits are considerably smaller than the ones generated by the laser cathode using the same alloy. This is due to the fact that the cathode in the discharge tubes uses the larger 2L 4.5 type cathode at a somewhat higher temperature. The temperature rise is due to added thermal insulation around the cathode sleeve and typical temperature curves are shown by Fig. 28 in the technical note TN D-7307. Sputtering deposits reach a truly remarkable minimum for the alloy using only 5% Cw by weight and sharply increase again for pure silver.

Laser No. 2

Has a similar platinum sheet anode as laser No. 1. Its 1L 3.5 type cathode is made from 4N pure copper according to the design shown in Fig. 2. The cathode works in a thermally insulated sleeve and typical operating temperatures are shown in Fig. 28 in technical note TN D-7307. Fig. 4 shows the power output and the voltage referred directly to the discharge tube terminals as a function of time. The cathode sputtering deposits after 6000 hours of continuous operation are modest and shown among the accompanying pictures. These deposits are again confined to the immediate neighborhood of the cathode, and the laser bore as well as its anode are quite clean.

Lasers No. 3 and No. 3a

Laser No. 3 was assembled with the same pure, insulated, Cu cathode as laser No. 2 A sphere of 5 mm diameter, made from 270 type nickel, served as anode. Once in service we soon observed current concentrations on the anode in form of luminous spots. Later on black deposits developed at the site of these spots and a particular spot shifted position from time to time. The appearance of the anode after 1500 hours of service is shown in one of the attached electrode deposit pictures. Figure 5 shows the not unexpected short performance of this laser over its life span of only 1500 hours.

This laser was later rebuilt as laser No. 3a with the nickel ball anode replaced by a platinum wire of 0.8 mm diameter. The cathode was left unchanged and the laser reprocessed with the standard procedure. The behavior of the rebuilt laser is shown in Figure 6. So far the performance of this laser is normal over the observation period of 3700 hours. The sputtering deposits of the cathode accumulated over 5200 hours (1500 + 3700) are modest as shown in one of the attached pictures. Bore and anode of this laser have so far stayed clean.

Laser No. 4

Uses the same pure, insulated, Cu cathode as the two previous lasers. A gold wire of 0.5 mm diameter serves as anode. The performance of this laser is shown in Figure 7. The cathode sputtering deposits are considerably heavier and are shown on the appropriate electrode deposit picture. Bore and anode of this laser have so far stayed clean. The anode seems to behave in a normal way and yet there are indications that this laser, which had originally the highest power output of the five lasers built, will be the first one to die.

Laser No. 5

Uses the same platinum sheet anode as Laser No. 1 and its thermally insulated, internally oxidized Ag-Cu alloy cathode with 5% Cu by weight is of type 2L4.5 shown in Figure 2. The internal oxidation of the cathode was achieved the same way as for the cathode of laser No. 1. The beautiful performance of this laser is represented by Figure 8. Cathode sputtering deposits are truly minimal as shown by the appropriate picture.

Discharge Tube Performances

Ag-Cu Alloy Cathodes

Five discharge tubes with cathode alloys including pure silver, 5%, 10%, 20% and 100% copper by weight have been investigated. All the alloys containing silver and copper were internally oxidized at 750°C for 36 hours in our oxygen flow furnace. These tubes had platinum sheet anodes and a total gas volume of about 50 cm^3. The partial pressures of CO_2 and CO were monitored by infrared absorption spectroscopy methods. For this purpose we attached 8 cm long infrared absorption cells to the discharge tubes as described in TN D-7307.

The electrical characteristics of the five discharge tubes including the results of the partial gas analysis are shown in Figure 9 to 13. The cathode sputtering deposits that have accumulated after 13,000 hours of continuous service for the Ag cathode and 14,400 hours for the other tubes are displayed on the attached pictures. The appearance of sputtering deposits for the discharge tube with the pure copper cathode is very similar to the deposits shown for laser No. 4.

Pt-Cu Alloy Cathodes

Containing 30%, 50% and 70% Cu have been investigated. These cathodes work with the nitrogen containing mixture provided a small amount of hydrogen is added. Their electrical characteristics as well as the pertinent gas analysis results are included in Figures 14 to 16. The cathode sputtering products of these alloys contain negative ions that form anode deposits. So far the alloy containing 50% Cu (by weight) seems to give the best results. As already expressed in TN D-7307 we do not have very much confidence in a system that needs a small amount of H_2 to perform and the anode deposits are certainly not welcome in an actual laser. In all fairness we also have to state that much smaller effort has so far been devoted to this type of cathode.

Conclusions

Under a Research Program started with ONR and ARPA funds and continued by NASA we have invented new cold cathode principles that are applicable to the CO_2 laser. The best cathodes so far tested were made from internally oxidized Ag-Cu alloys or pure Cu. One test laser delivers still 70% of its initial output after more than 16,000 hours of continuous service. Four additional test lasers, three of them with pure Cu cathodes and one with a Ag-5% Cu cathode were built and tested. Three of these lasers have so far performed well over a period of 6000 hours. One laser failed after 1500 hours. This failure was due to an improperly selected nickel anode. The anode was replaced by a platinum wire and the laser performs now as expected. The only suspected behavior is the one of Laser No. 4 with a gold wire anode. Its output power seems to decrease faster and the cathode sputtering products are considerably larger. We do not believe that the gold anode is responsible for this defect. We suspect that perhaps the envelope was not as well outgassed and that some water vapor may still be present in the discharge.

Presently we are not able to tell if the pure Cu cathode or the internally oxidized Ag 5% Cu cathode performs better. The sputtering products of the Ag-Cu alloy cathode are smaller but the gas analysis results of the discharge tube with the Cu cathode are just as good despite the somewhat larger sputtering of this cathode.

To conclude we can in our opinion safely state that the newly developed cold cathode technology allows to duplicate sealed off 1W CO_2 lasers with gas volumes of only 50 cm^3 that perform satisfactory for more than 6000 hours.

CO_2 LASER

5.6 X 150mm BORE

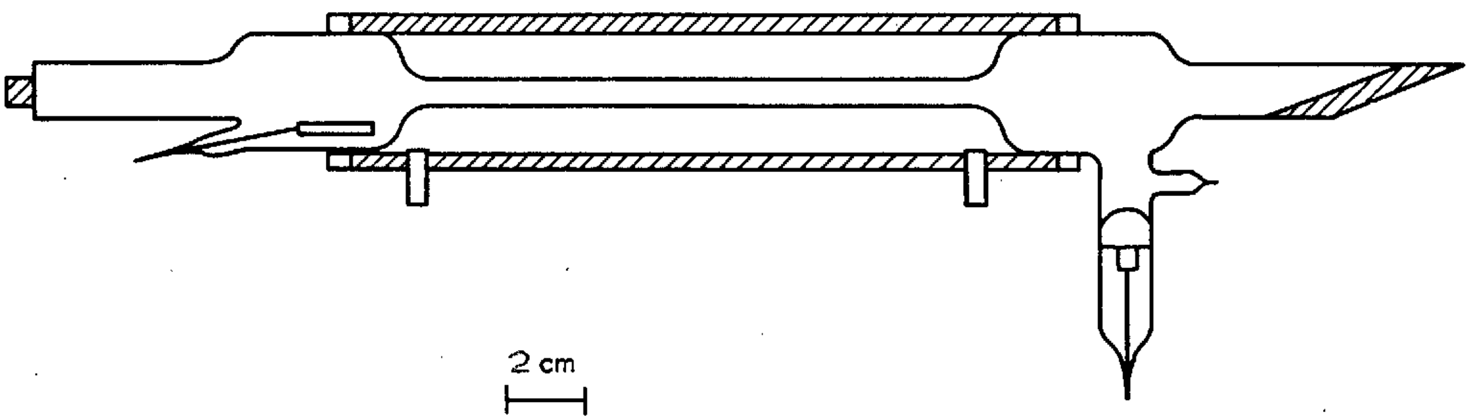


Figure 1.

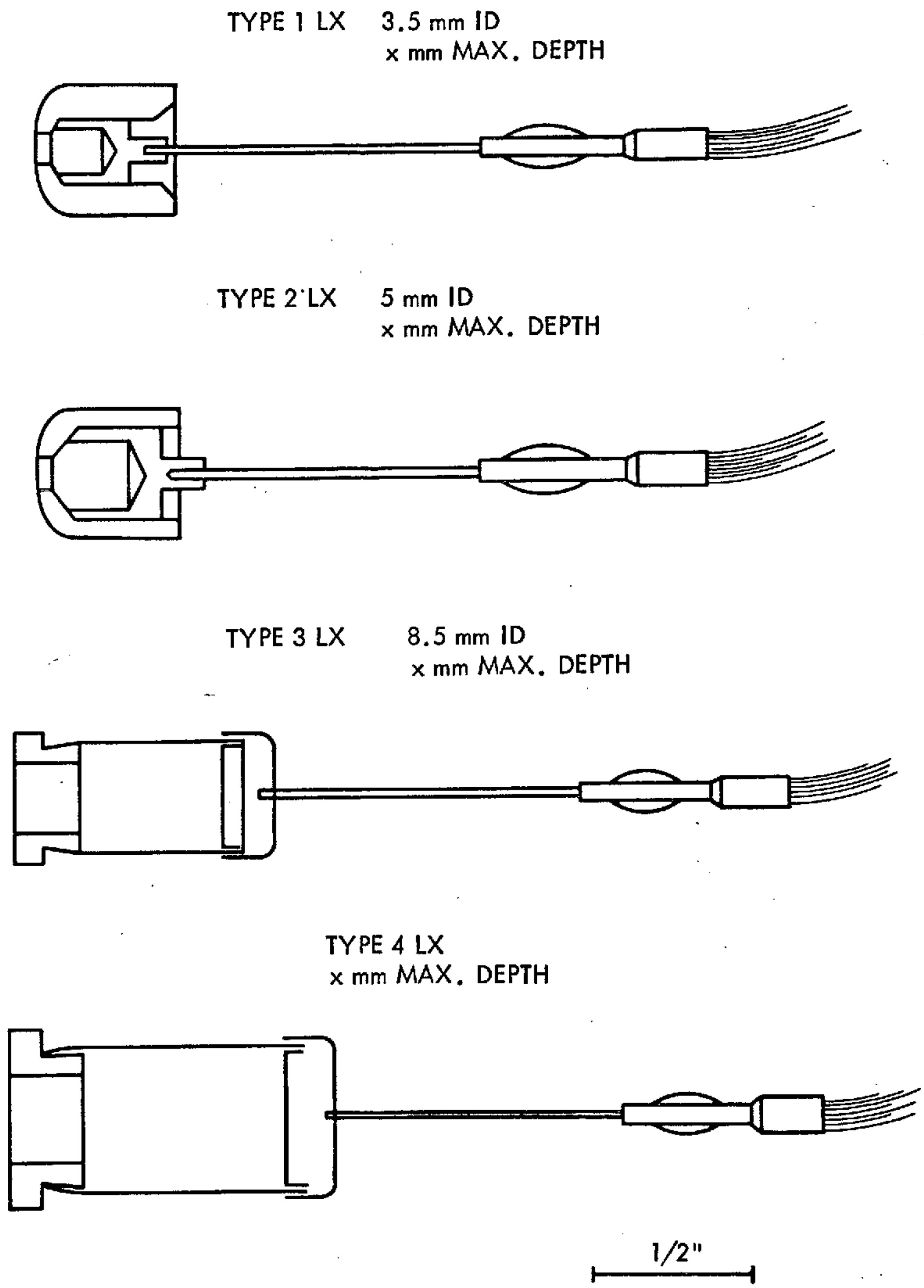


Figure 2 . Cathode types.

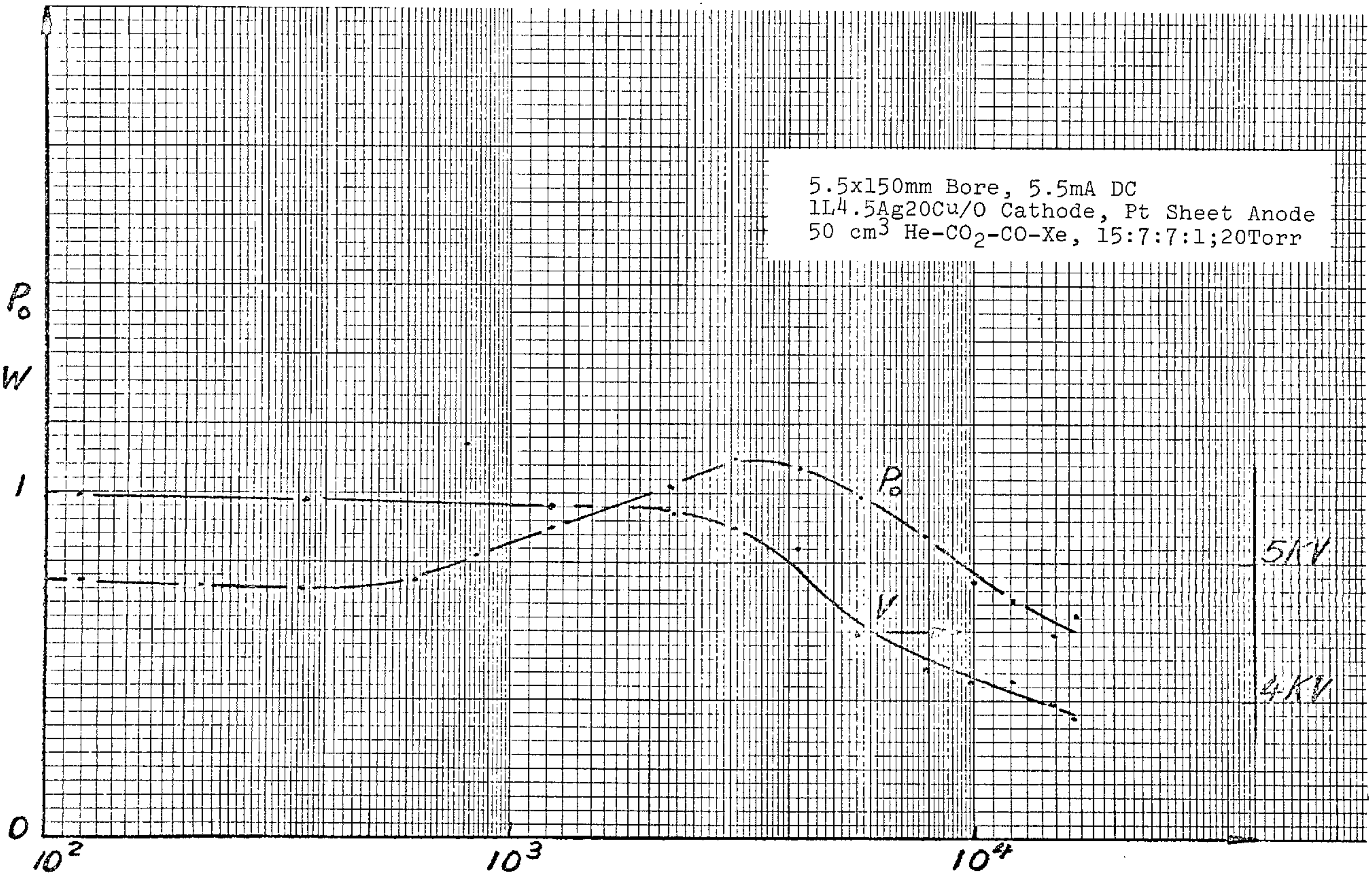


Figure 3. LASER #1, Power output and voltage versus time

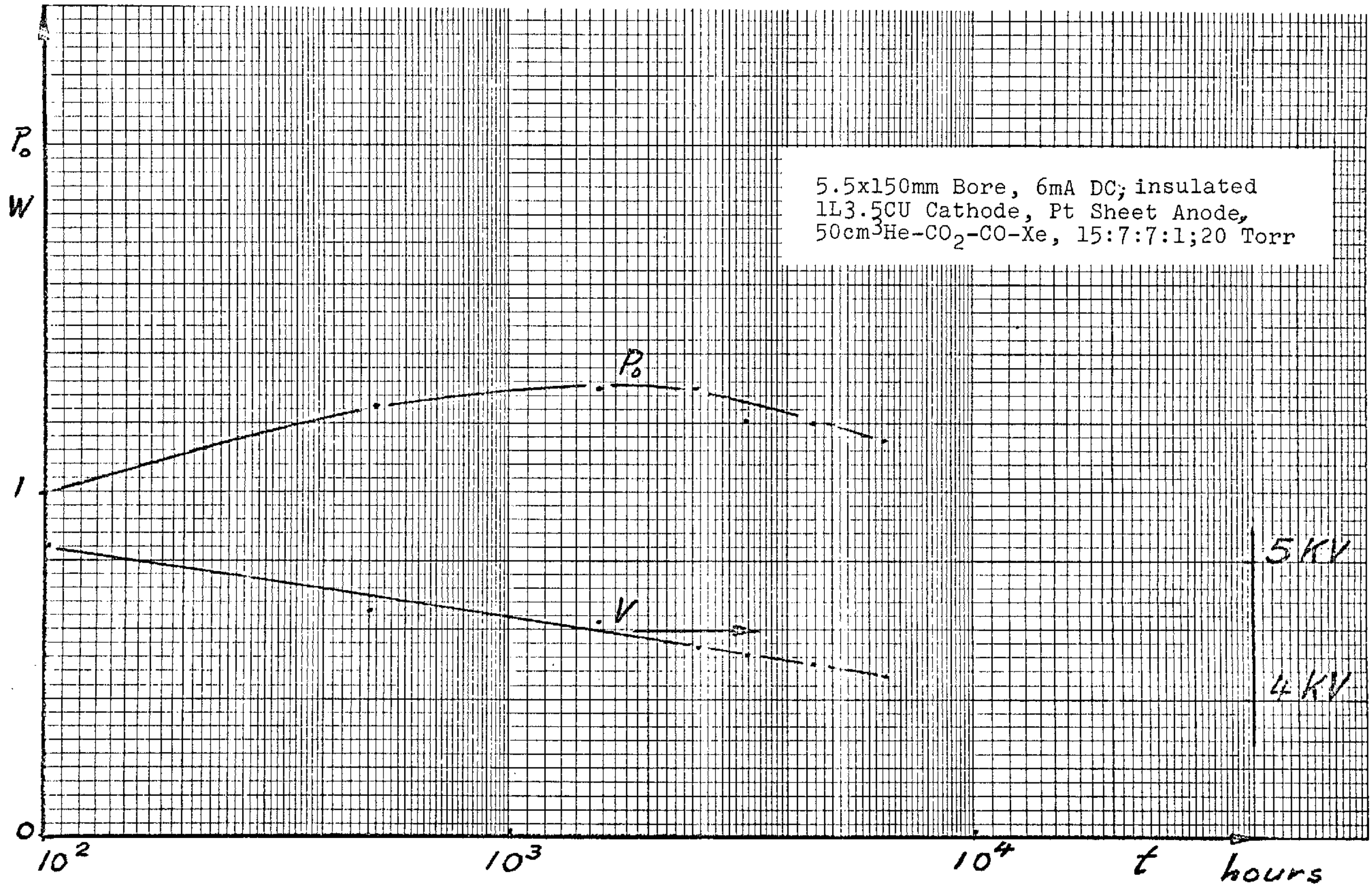


Figure 4. LASER #2, Power output and voltage versus time

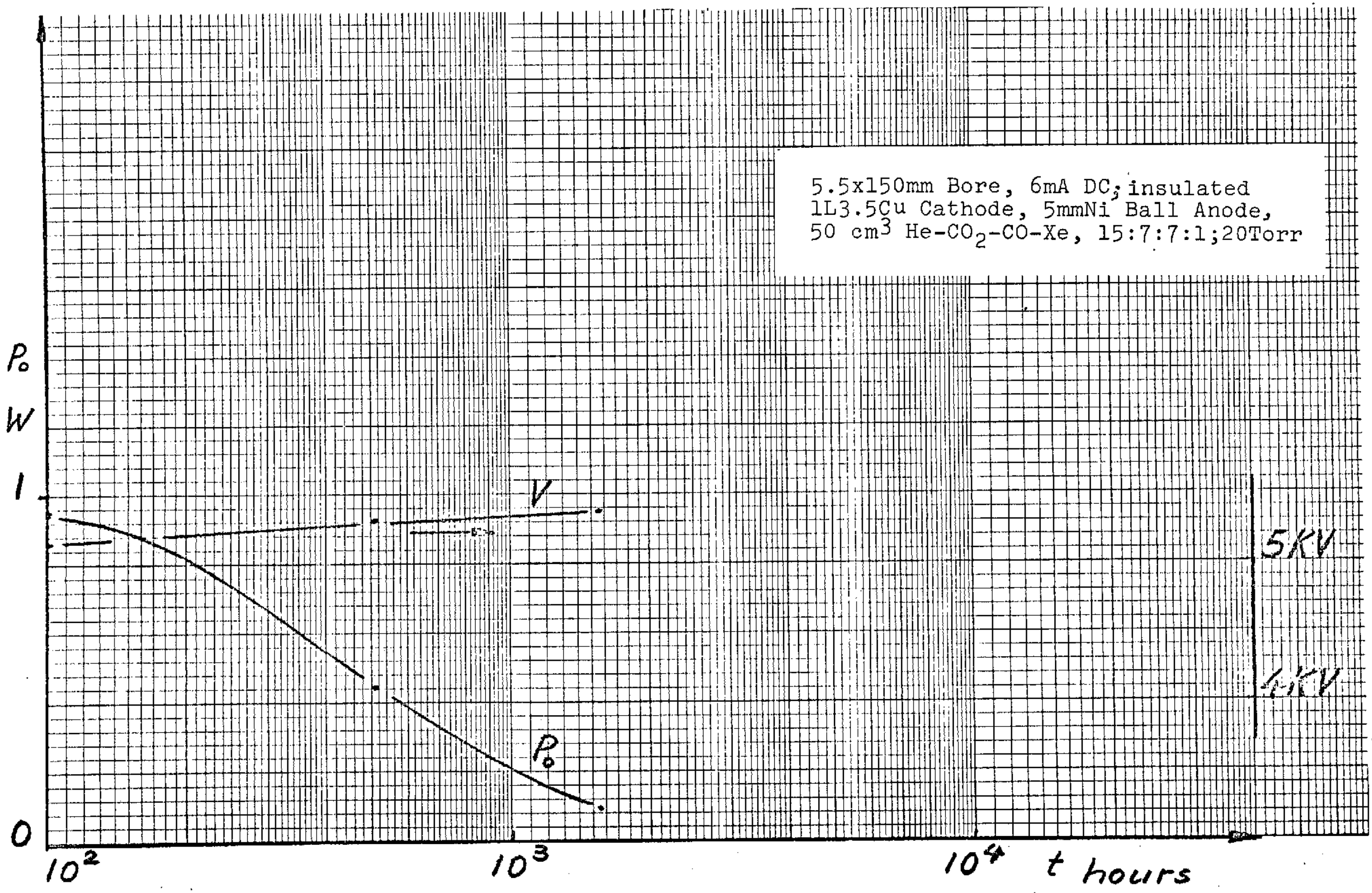


Figure 5. LASER #3, Power output and voltage versus time

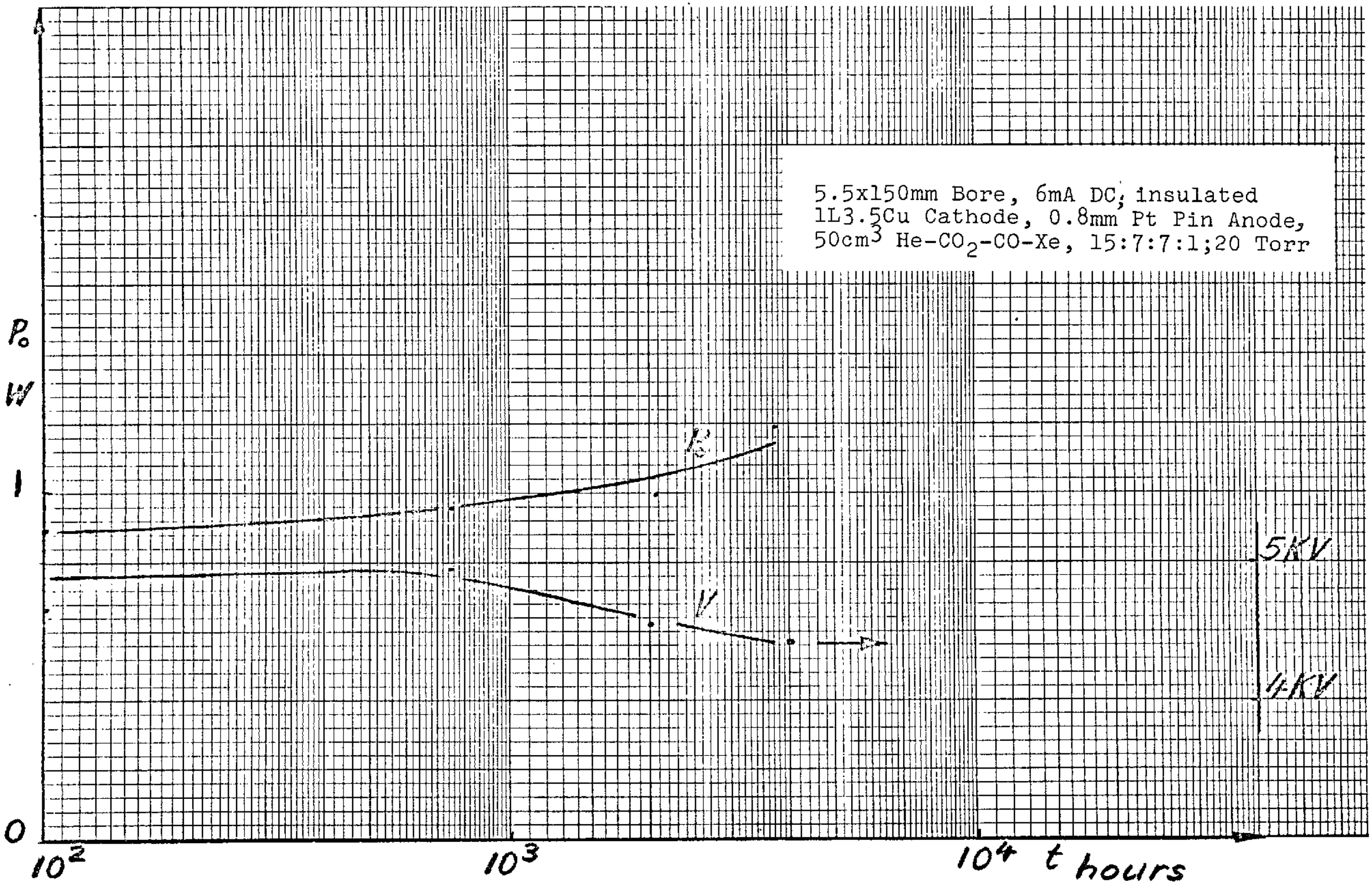


Figure 6. LASER #3a, Power output and voltage versus time

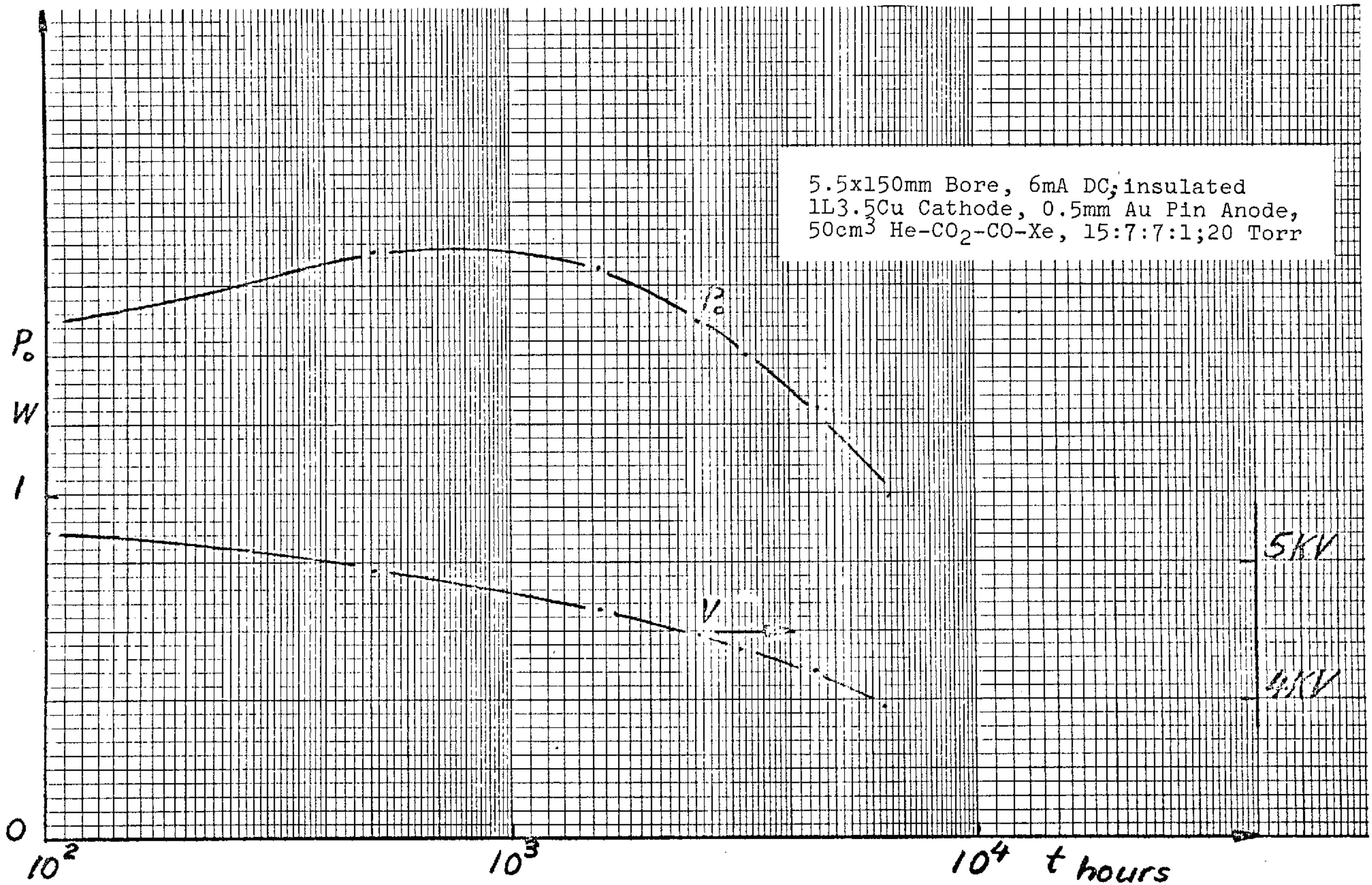


Figure 7. LASER #4, Power output and voltage versus time

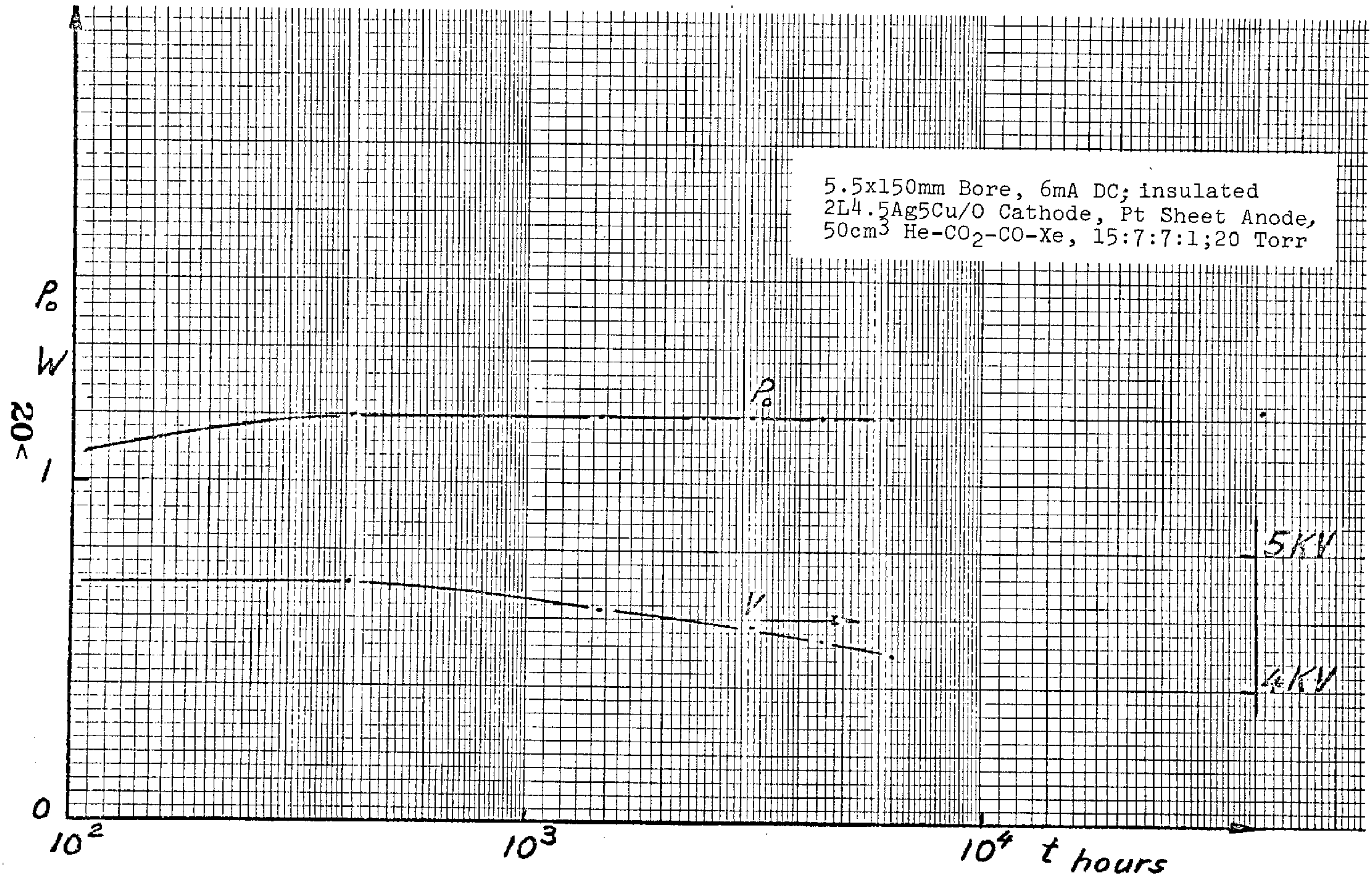


Figure 8. LASER #5, Power output and voltage versus time

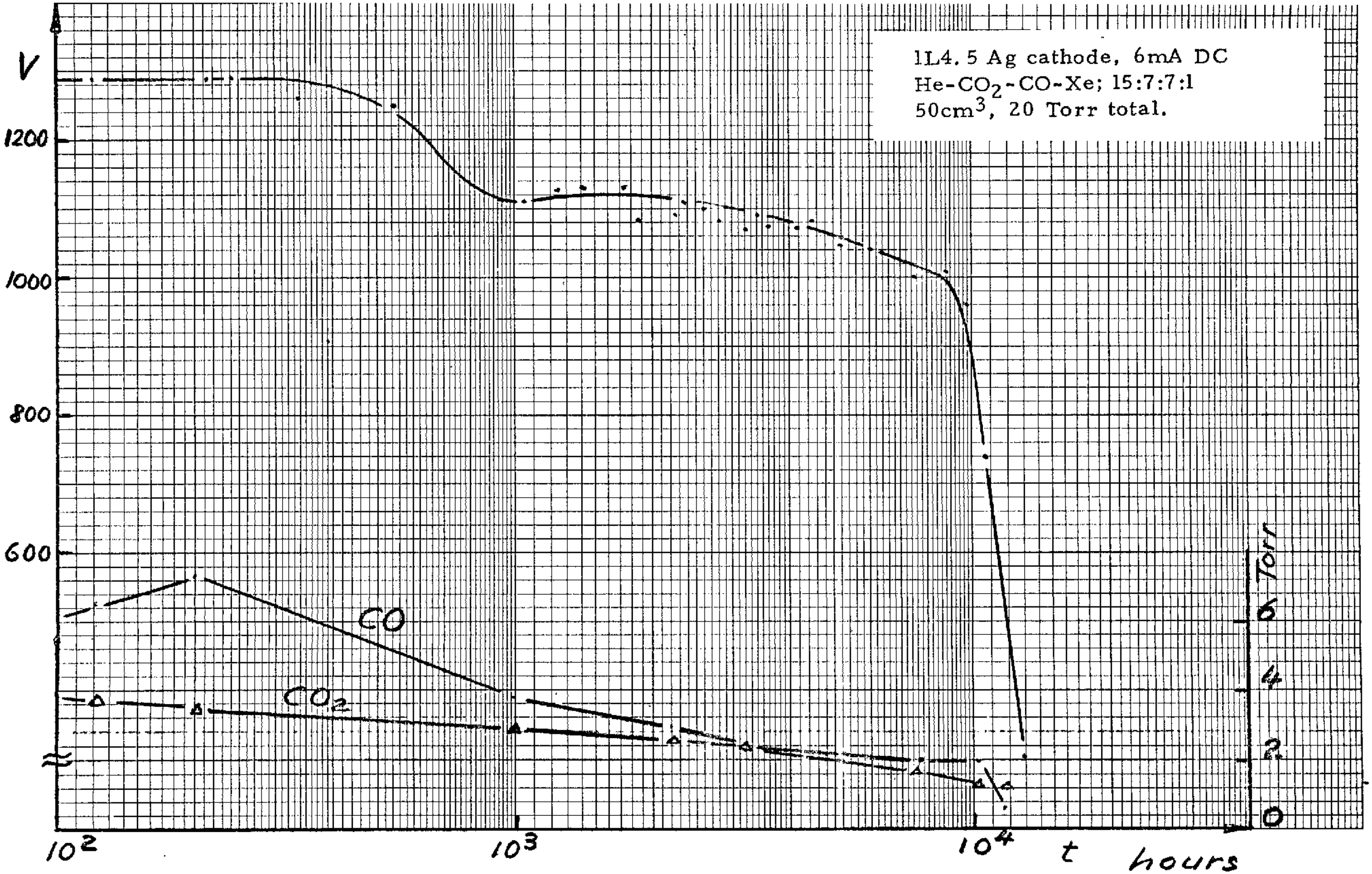


Figure 9. Discharge tube with insulated Ag cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

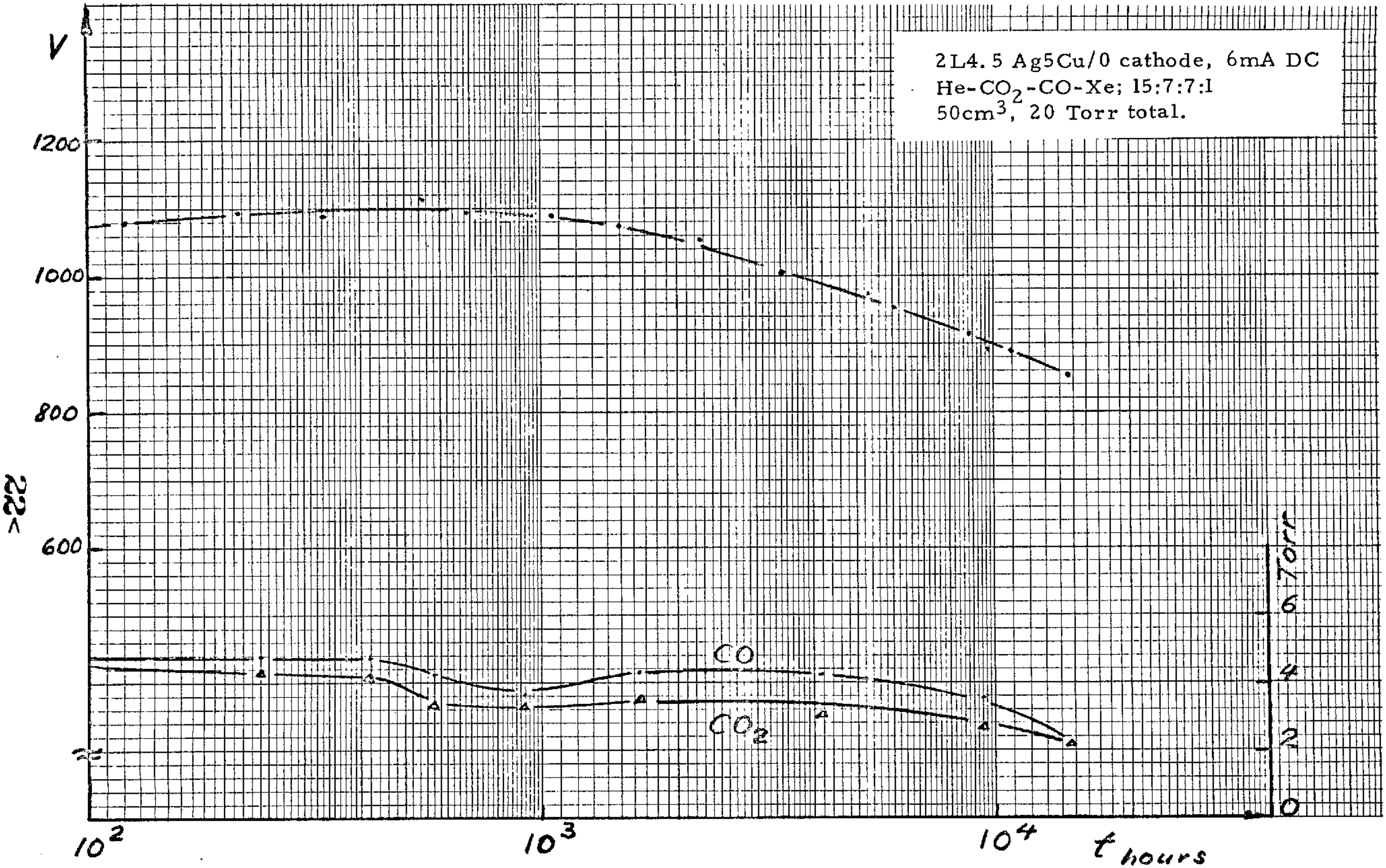


Figure 10. Discharge tube with insulated, internally oxidized Ag 5% Cu cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

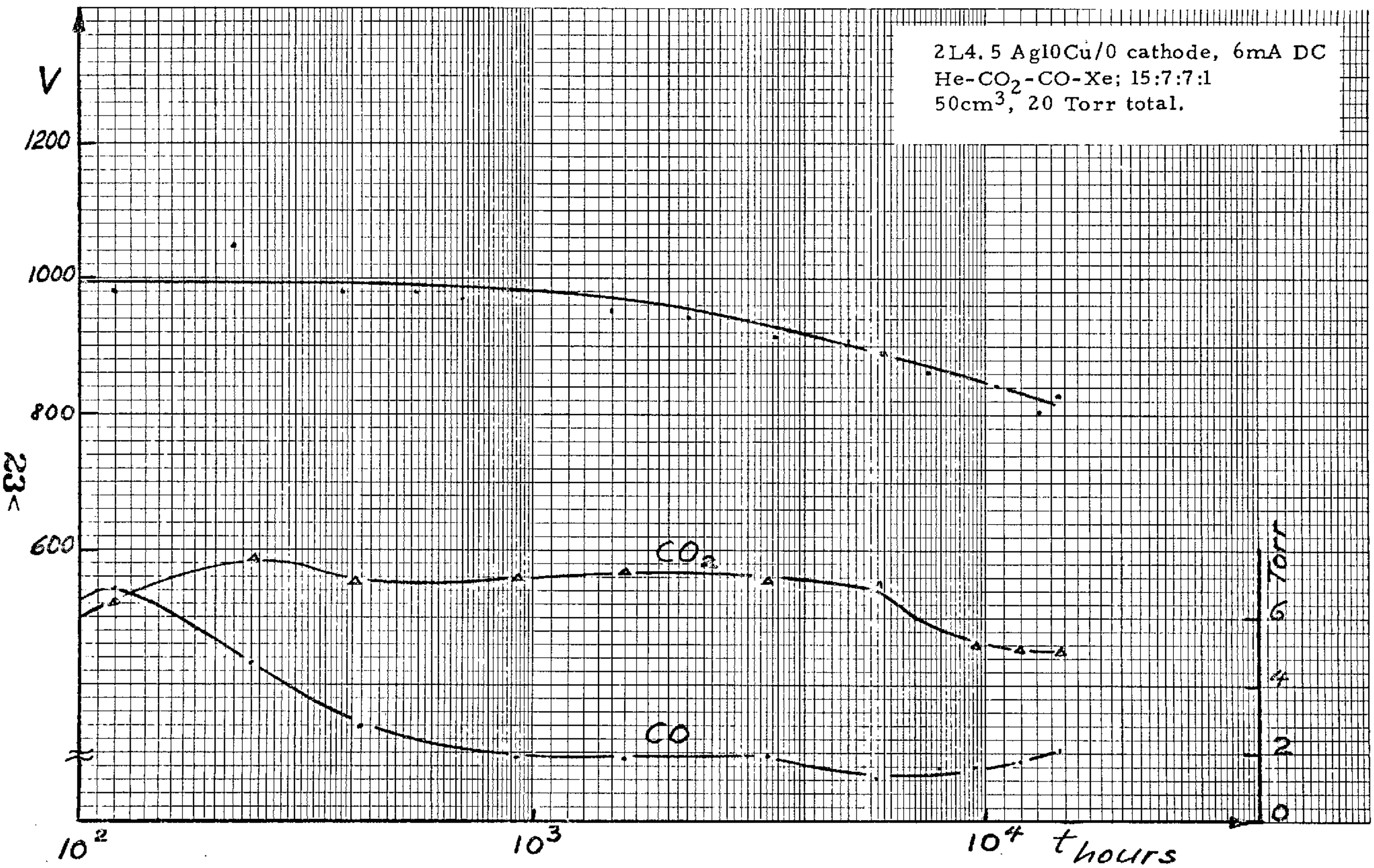


Figure 11. Discharge tube with insulated, internally oxidized Ag 10% Cu cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

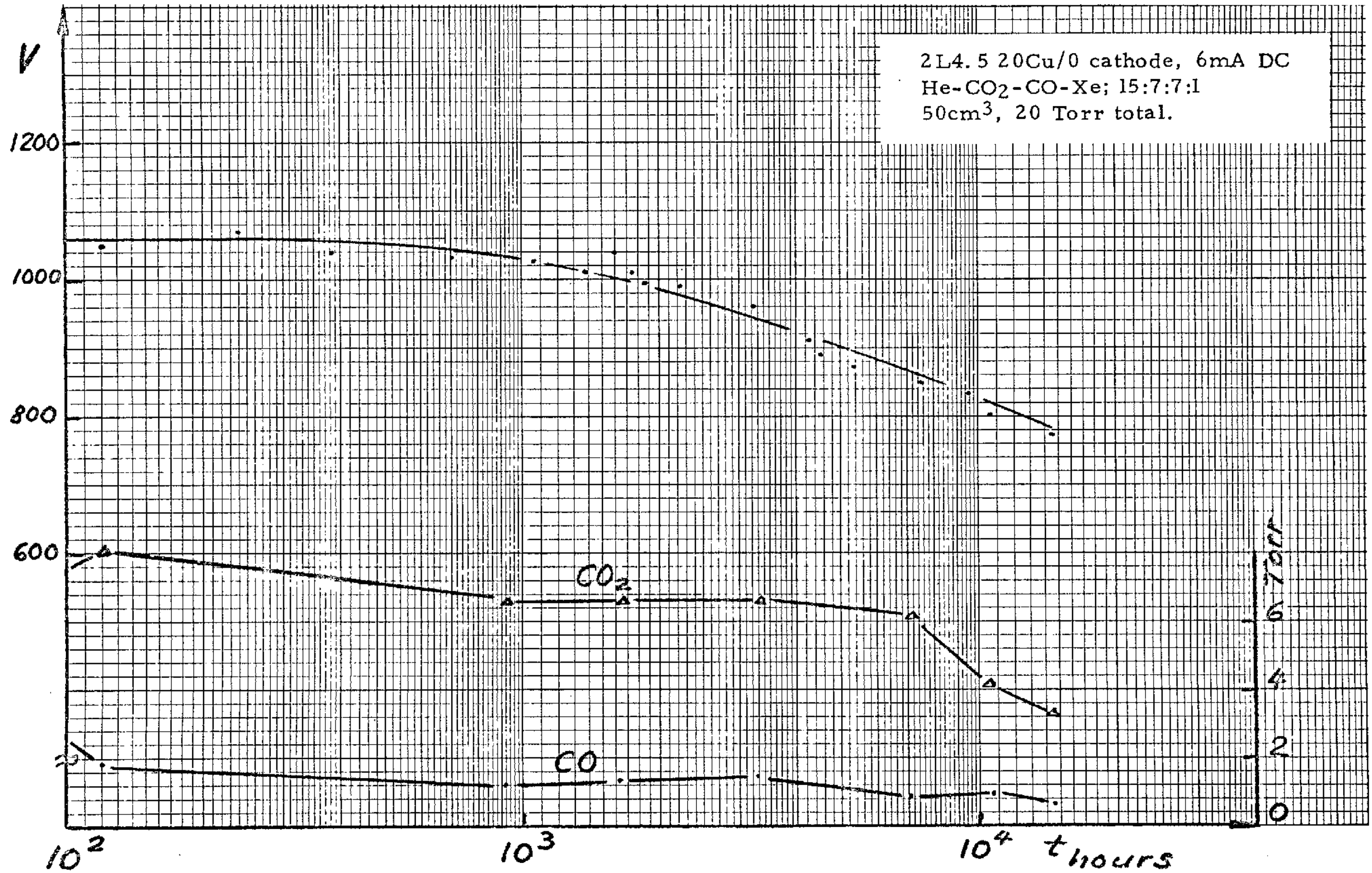


Figure 12. Discharge tube with insulated, internally oxidized Ag 20% Cu cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

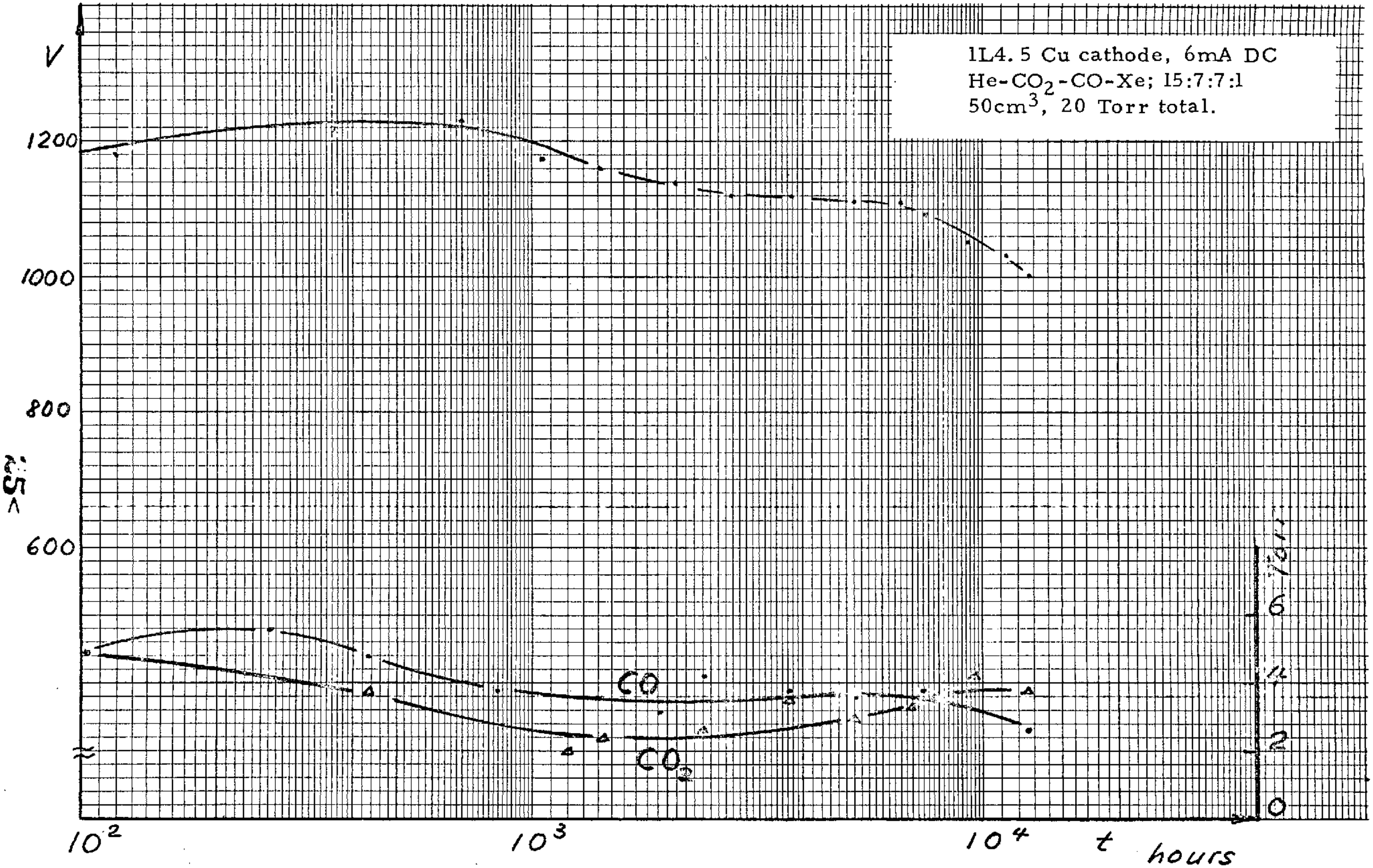


Figure 13. Discharge tube with insulated Cu cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

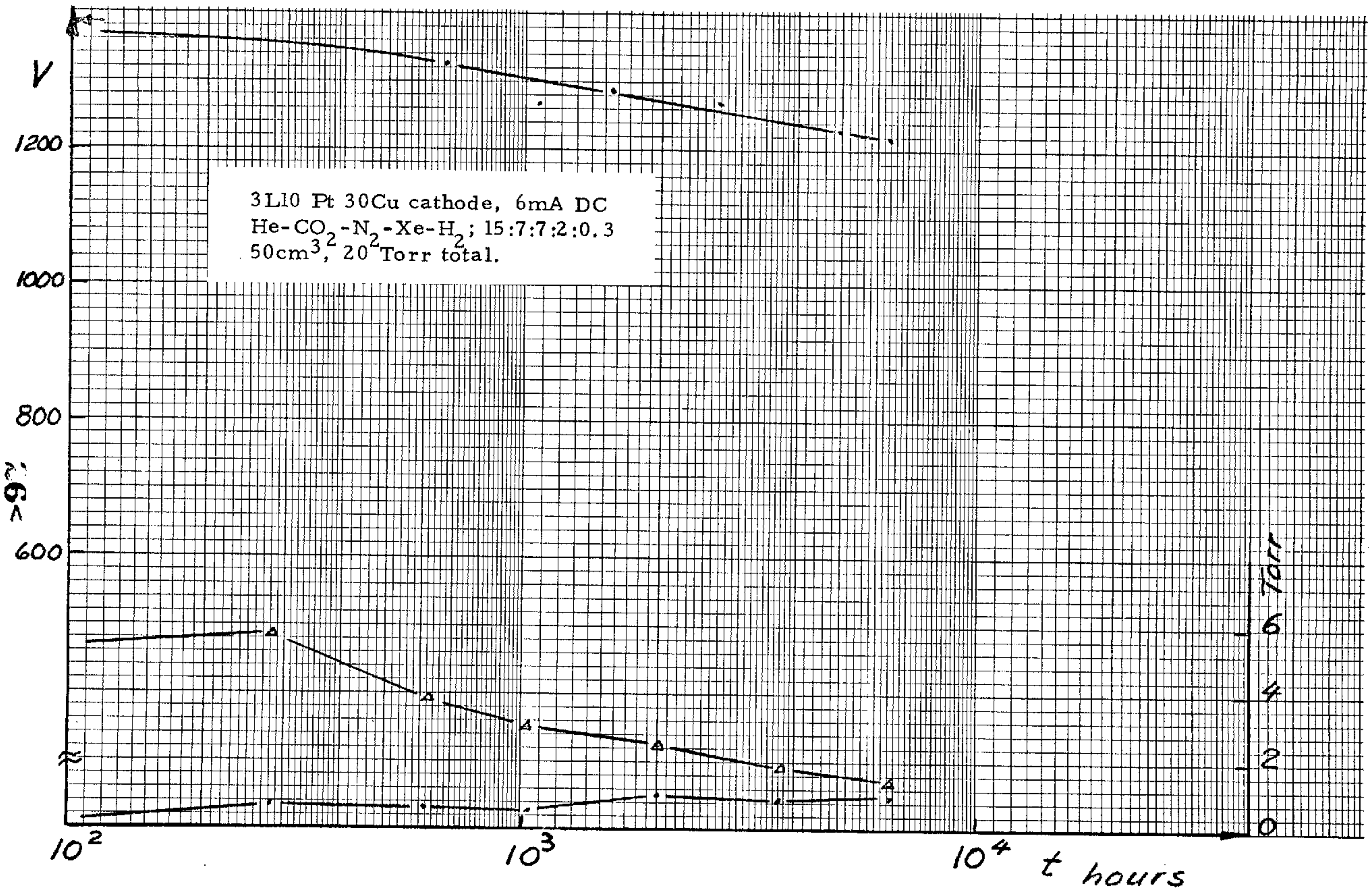


Figure 14. Discharge tube with Pt 30% Cu Cathode:
Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

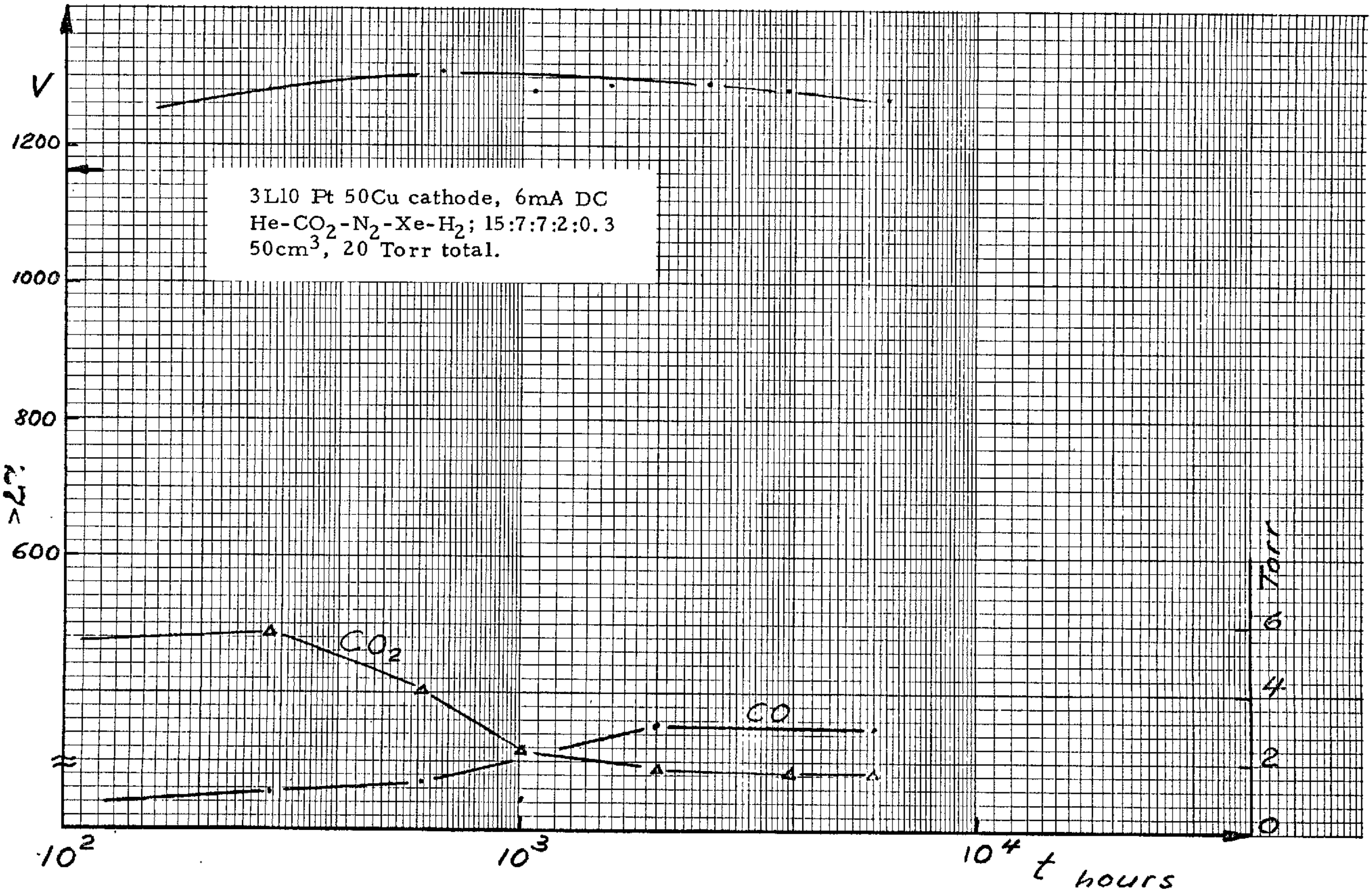


Figure 15. Discharge tube with Pt 50% Cu Cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

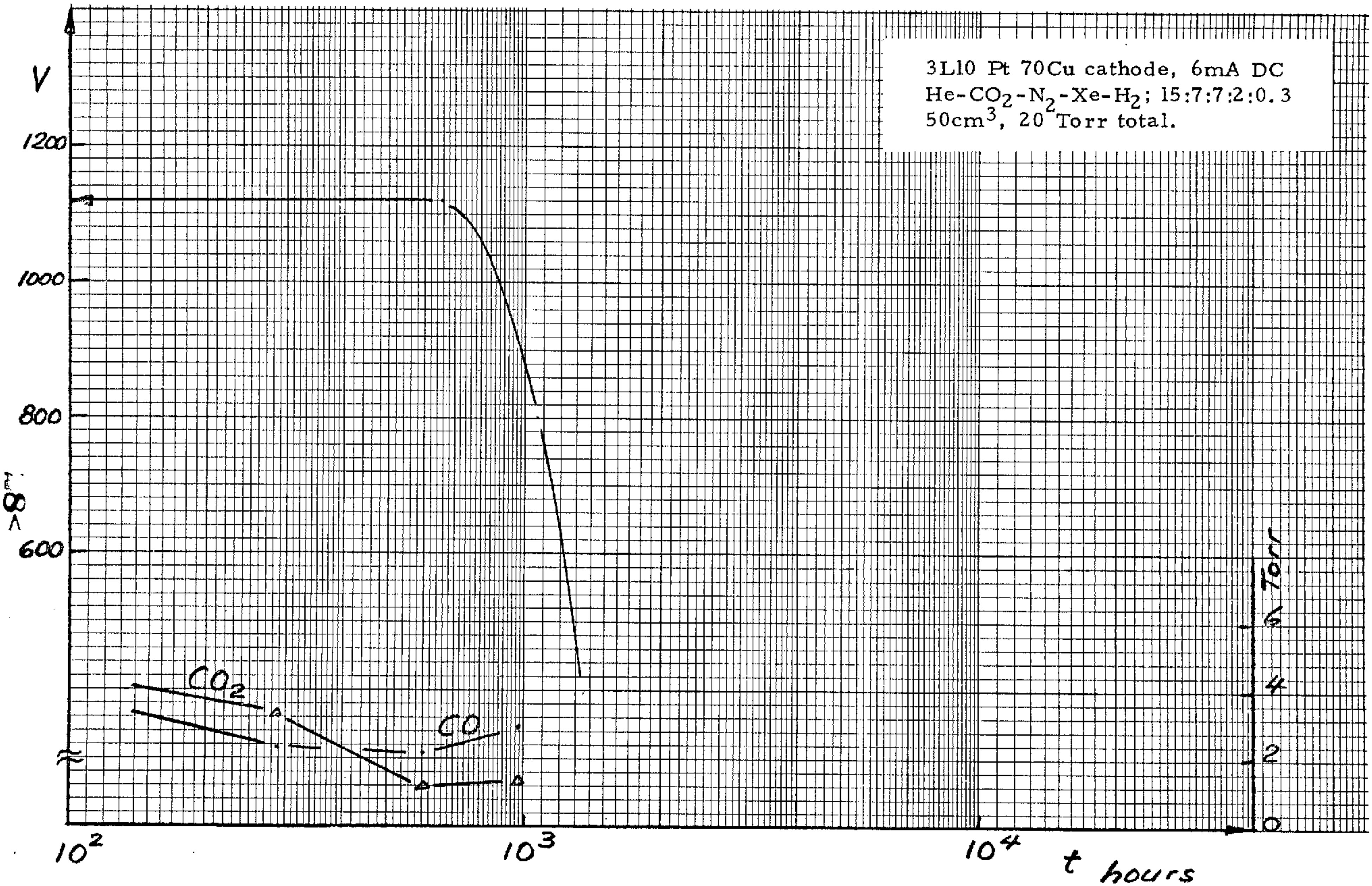


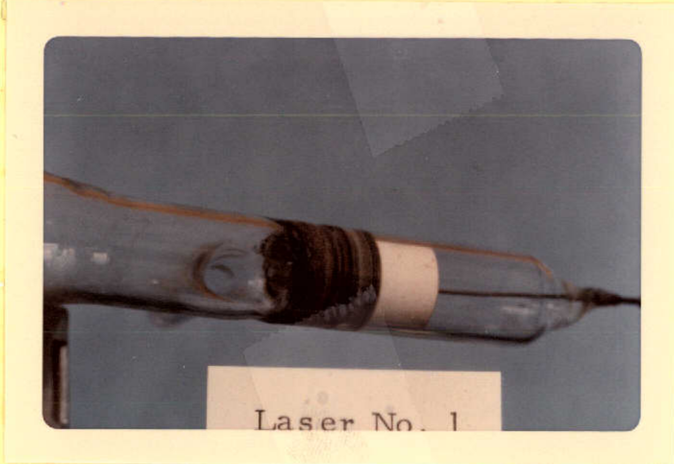
Figure 16. Discharge tube with Pt 70% Cu cathode: Voltage versus operating time (upper curve) and CO_2 and CO partial pressures versus operating time (lower curve).

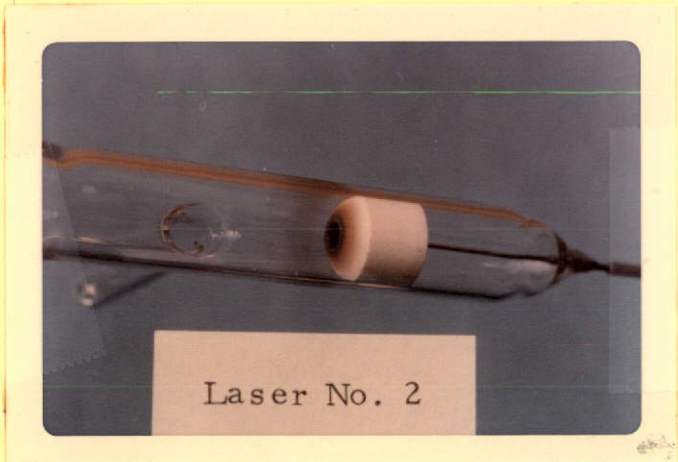
Pictures of

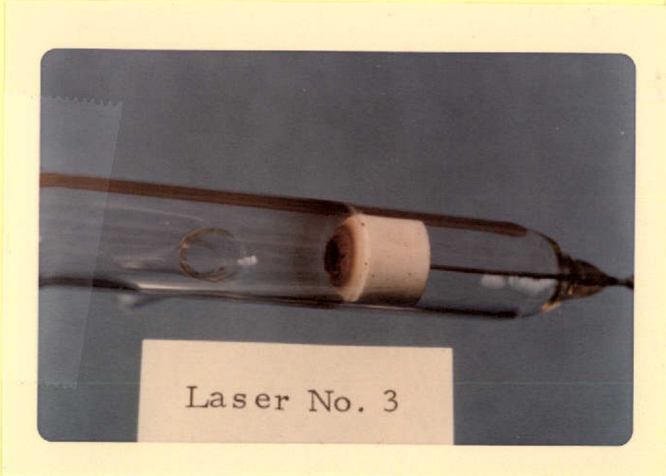
Sputtering Deposits

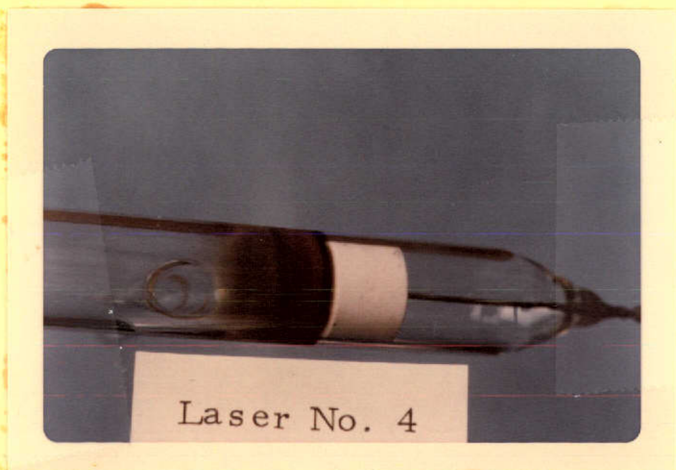
from

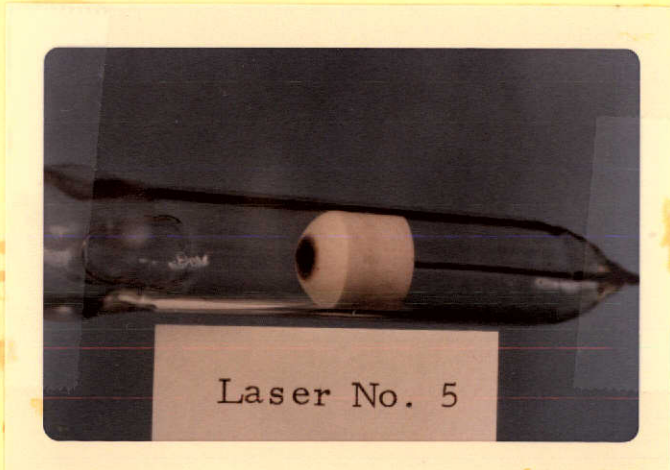
Laser and Discharge Tube Electrodes

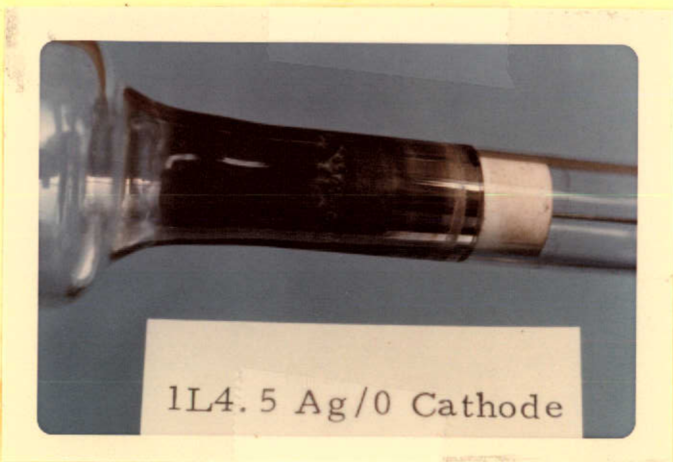

Laser No. 1

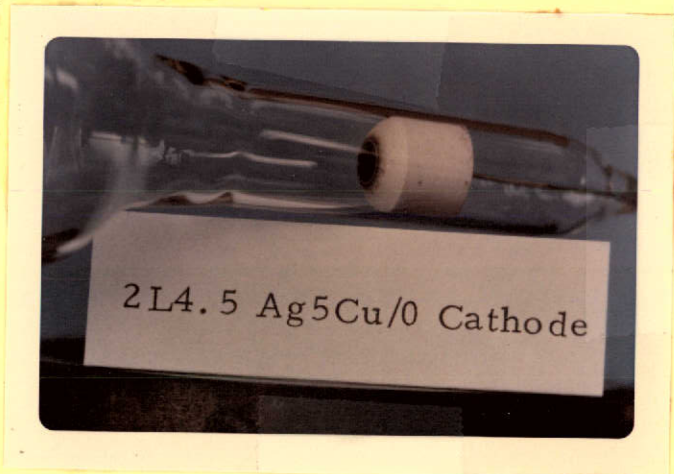

Laser No. 2


Laser No. 3

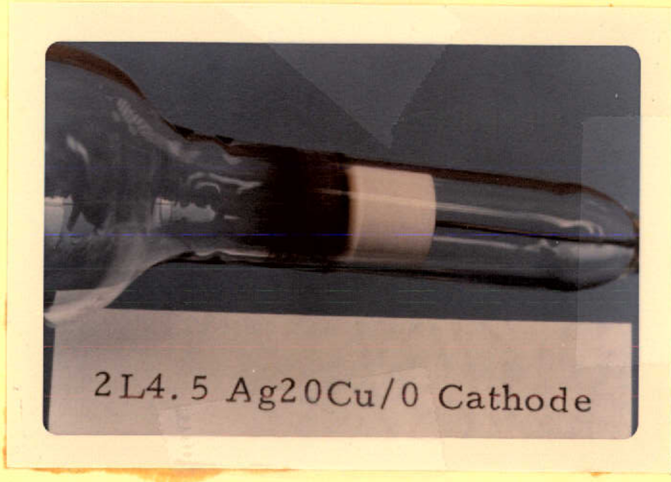

Laser No. 4


Laser No. 5


1L4.5 Ag/0 Cathode


2L4.5 Ag5Cu/0 Cathode


2L4.5 Ag10Cu/0 Cathode


2L4.5 Ag20Cu/0 Cathode