NPL Polarized Source Group
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Procedures for Making GaAs Cathodes

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In this document we have gathered the various procedures that have been developed for cathode fabrication in the Illinois/CEBAF polarized electron source. They have been revised somewhat from those in the original technical note, #90-5, to include some details specific to construction "quirks" of the original source. As in the earlier version of this note, procedures are listed separately for both conventional ("bulk") GaAs samples and antimony-"capped" samples such as the thin samples used in the polarization vs thickness measurements. The procedure for capped samples will probably also be appropriate for the GaAs on Si samples we plan to try later. Finally, the electrical connections used for the current measurement during cathode preparation are documented in an appendix to this report. The "bulk" GaAs procedure was developed at SLAC by Charlie Sinclair; the "capped" procedure was developed at SLAC and Illinois with his advice.

Cathode Fabrication on "Bulk" GaAs Samples

1. Begin by connecting the nitrogen line to the stalk and establishing a steady flow with the nitrogen pressure at about 3-4 psi as measured by the magnehelic gauge (this will correspond to a nitrogen flow of about 15 slpm; the set points on the flow meter are at 10 and 20 slpm).

2. Connect the stalk heater and thermocouple wiring, and withdraw the stalk to the retracted position, securing it there with the spacer clip.

3. Check that the power leads to the heater have not been shorted and the heater is not burned out. The heater is a Watlow E3A51, which is rated as 300 W at 240 VAC; its resistance should be about 192 Ω.

4. For traditional, non-capped "bulk" GaAs samples, the heat cleaning cycle proceeds as outlined in the following list. While shorter cleaning cycles and lower temperatures are capable of producing usable cathodes, this cycle has been found to yield the highest quantum efficiency cathodes consistently.

   (a) Begin by ramping the temperature of the sample over a 2 hour period from room temperature to 550 C;

   (b) The sample is then held at 550 C for 20 hours.

   (c) Next, the temperature is ramped over a 15 minute period from 550 C to between 580 C and 590 C and held for 4 hours[1].

   (d) At the end of the 4 hour high temperature portion of the cycle, cool the sample as quickly as feasible to minimize contamination of the freshly- cleaned surface.

[1]Occasionally it has been necessary to raise the temperature above 590 C for the best results, but this is not ususlly the case

This is best done by first[2] programming the controller to ramp to 20 C over a period of one hour[3]. Watch the temperature readout, and as soon as the temperature has fallen to 550 C, switch off all heater power. When the temperature has dropped to 450 C, increase the pressure on the nitrogen flow to 20 psi (this will "peg" the magnehelic gauge), and maintain it at that pressure until the sample temperature has dropped to room temperature. It is usually desirable to maintian the flow after room temperature has been reached as there is a lot of thermal energy remaining in the system. The total time for the cool-down from 580 C to room temperature should be about 15 minutes.

5. At least 3 hours before the end of the GaAs heat treatment, begin heating the cesiator so that it has stabilized before you begin the remaining steps. The precise settings of the nitrogen flow and the heater power will be determined by experience.[4]

6. After the stalk reaches room temperature, remove the nitrogen line and stalk thermocouple connector, and lower the stalk to its normal operating position.

7. Make sure that the cesiator is hot.[5] The valve body should be at 250 C, the elbow at 98-102 C, and the tube at 230 C. If the temperatures are not correct, you might want to check the resistance of the nitrogen heater (it should be about 72 Ω), verify that the setting of the variac powering the heater is correct, and/or adjust the fiberfrax wrapping on the cesiator.

8. Attach the battery box and the Keithley picoammeter to the gun, and connect the output from the Keithley to the Houston Instruments chart recorder. (The circuit is described in Appendix A of this note.) For the cathode fabrication procedure the battery box voltage is typically[6] set to 67.5 or 90 Volts.

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[2]When the newest stalk design is used (see 2860-series drawings), it will probably be adequate to cool down by simply turning off the heater power and then raising the nitrogen flow; for this stalk the braze joint does not provide a vacuum seal

[3]This ensures that the temperature doesn't fall *too* rapidly in the initial phase of the cooldown

[4]For the very first cesiator (which is still in use on the original gun) there is a restriction in the nitrogen flow loop around the cesiator. For that cesiator it is necessary to have about 300 psi of nitrogen pressure at the inlet in order to get adequate flow. For newer cesiators that have unrestricted flow the pressure required is between 20 and 30 psi. In either case typical flows range between between 1.2 and 1.7 scfm. The variac on the nitrogen heater is typically set for about 90% of line voltage; the precise value will depend on the nitrogen flow and the length of the line, and should be adjusted to produce the nominal temperatures on the cesiator parts, as outlined in step 7. Once determined for a given setup, it will remain quite constant.

[5]Note that for the *initial* operation of the cesiator you will have to "coat" the inside of the cesiator tube before you can make a cathode. This is done by first heating the cesiator as for normal operation. After the temperatures have stabilized, open the cesiator valve with the cesiator in the retracted position (so that "junk" is not deposited on the cathode). There will be a noticeable rise in the ion pump pressure for the gun, indicating that the valve is open. Periodically insert the cesiator and check for a rise in the photocurrent as it is inserted; this is an indication that cesium is finally escaping into the chamber. Typically 45 minutes to an hour will be required before cesium escapes from the cesiator.

[6]You can raise the voltage if necessary for increased sensitivity, but it should be kept below 100 Volts to avoid emission from the gun surfaces unless the beam is transported to a well-isolated, differentially pumped region (which will not be the case for the source). A better alternative (particularly if the problem is that you are space- charge limited) is likely to be lowering the power of the illuminating lamp.

9. Shine the white light from the microscope illuminator through the side port of the chamber onto the GaAs, and start monitoring the photocurrent. Make sure to zero the chart recorder with the picoammeter, and note all scale changes on the chart paper.

10. With the cesiator in the extracted position, open the VG valve on the cesiator all the way, and let it sit for about one minute. Push the cesiator in and wait for the photocurrent to rise. When the current has reached a maximum, pull back the cesiator and slowly open the NF_3 valve until it registers 1-5 μA on the ion pump power supply[7]. (The NF_3 is left on at this level throughout the remainder of the activation process.) The photocurrent will increase again and when a maximum is reached, insert the cesiator.

11. The current will initially increase (for a few seconds) and then decrease rapidly. Pull back the cesiator when the current has fallen to less than 1/3 of the previous maximum. Continue this cycle until the maximum photocurrent from one cycle to next increases by less than 15%. Now, turn off the cesium, and slowly turn off the NF_3 as the photocurrent levels off. A typical chart recorder output of this process is included in Appendix B of this report.

12. Check the red light/white light ratio by placing the 715 nm cutoff filter in front of the microscope illuminator. A typical number is $R/W = 1/3$.

13. Replace the microscope illuminator by a HeNe laser with a HeNe laser line filter[8] (to block bore light), and measure the quantum efficiency. The quantum efficiency is given by:

$$Q.E.(\%) = \frac{124 \cdot I(\mu A)}{P(mW)\lambda(nm)} \cdot \frac{1}{R}$$

where I = the measured beam current
P = the laser power
λ = the laser wavelength, and
R = the reflectivity of the stainless steel mirror.

For a HeNe laser this equation implies a photocurrent of 5.1 mA per Watt of power incident on the photocathode for a 1% QE photocathode. For our present system the reflectivity of the mirror is 0.61, so 1 Watt of laser power incident on the mirror will produce a photocurrent of 3.11 mA for a 1% QE photocathode. Typical quantum efficiencies are 2-5% for thick($\gtrsim 1\mu m$) samples fabricated using this procedure in a very clean system. While measuring the quantum efficiency, restrict the laser power

[7]This current is dependent on the details of the gun geometry. The value of 1- 5 μA has been found to work best on the Illinois/CEBAF source. Too much pressure or too little pressure will result in incorrect behavior of the photocurrent when the cesiator is retracted (ie., the current will not increase slightly and then decrease. Adjust the pressure as necessary to achieve the behavior shown on the typical chart recorder output included in Appendix B of this report.

[8]The filter will not be needed if the HeNe laser being used doesn't have much bore light.

to $\lesssim$ 1 mW using neutral density filters to avoid space charge effects that can be large at these very low accelerating voltages, and to avoid vacuum problems that may result from electron bombardment of the anode. To check for space charge effects, verify that the current increases linearly with laser power by making measurments of the photocurrent vs. laser power by inserting a series of neutral density filters into the laser beam; in the presence of space charge the current will saturate and not increase with laser power.

14. Begin experiments as desired.

Cathode Fabrication on Antimony-Capped GaAs Samples

1. Begin by connecting the nitrogen line to the stalk and establishing a steady flow with the nitrogen pressure at about 3-4 psi as measured by the magnehelic gauge (this will correspond to a nitrogen flow of about 15 slpm; the set points on the flow meter are at 10 and 20 slpm).

2. Connect the stalk heater and thermocouple wiring, and withdraw the stalk to the retracted position, securing it there with the spacer clip.

3. Check that the power leads to the heater have not been shorted and the heater is not burned out. The heater is a Watlow E3A51, which is rated as 300 W at 240 VAC; its resistance should be about 192 Ω.

4. For antimony-capped GaAs the heat cleaning procedure is simplified; we proceed as follows:

   (a) First we must remove the antimony cap. Ramp the temperature of the sample over a 1 hour period to 350 C, as measured using the stalk thermocouple, then hold it at this temperature for 1 hour.

   (b) At the end of the high temperature portion of the cycle, cool the sample as quickly as feasible to minimize contamination of the freshly- cleaned surface. Since the temperature of the cleaning cycle is lower, it is adequate in this case to simply turn off the heater power and then raise the nitrogen flow by increasing the pressure to about 20 psi (this will "peg" the magnehelic gauge), and maintain it at that pressure until the sample temperature has dropped to room temperature. It is usually desirable to maintian the flow after room temperature has been reached as there is a lot of thermal energy remaining in the system. The total time for the cool-down to room temperature should be less than 15 minutes.

   For subsequent cleaning, the surface is heated to temperatures between 500 C and 550 C for 1 to several hours, following a procedure similar to that for bulk samples

5. At least 3 hours before the end of the GaAs heat treatment (which, for capped samples will typically mean beginning an hour *prior* to the heat treatment) begin heating the cesiator so that it has stabilized before you begin the remaining steps.

6. After the stalk reaches room temperature, remove the nitrogen line and stalk thermocouple connector, and lower the stalk to its normal operating position.

7. Make sure that the cesiator is hot (see footnote in "bulk" sample procedure above). The valve body should be at 250 C, the elbow at 98- 102 C, and the tube at 230 C. If the temperatures are not correct, you might want to check the resistance of the nitrogen heater (it should be about 72 Ω), verify that the setting of the variac powering the heater is correct, and/or adjust the fiberfrax wrapping on the cesiator.

8. Attach the battery box and the Keithley picoammeter to the gun, and connect the output from the Keithley to the Houston Instruments chart recorder. (The circuit is described in Appendix A of this note.) For the cathode fabrication procedure the battery box voltage is typically set to 67.5 or 90 Volts. (see footnote in "bulk" sample procedure above).

9. Shine the white light from the microscope illuminator through the side port of the chamber onto the GaAs, and start monitoring the photocurrent. Make sure to zero the chart recorder with the picoammeter, and note all scale changes on the chart paper.

10. With the cesiator in the extracted position, open the VG valve on the cesiator all the way, and let it sit for 2-3 minutes. Push the cesiator in and wait for the photocurrent to rise. When the current has reached a maximum, pull back the cesiator and slowly open the NF_3 valve until it registers 1-5 μA on the ion pump power supply (see footnote in "bulk" procedure above). (The NF_3 is left on at this level throughout the remainder of the activation process.) The photocurrent will increase again and when a maximum is reached, insert the cesiator.

11. The current will initially increase (for a few seconds) and then decrease rapidly. Pull back the cesiator when the current has fallen to less than 1/3 of the previous maximum. Continue this cycle until the maximum photocurrent from one cycle to next increases by less than 15%. Now, turn off the cesium, and slowly turn off the NF_3 as the photocurrent levels off. The chart recorder output for this process will look similar to the one attached for the bulk GaAs sample.

12. Check the red light/white light ratio by placing the 715 nm cutoff filter in front of the microscope illuminator. A typical number is $R/W = 1/3$.

13. Replace the microscope illuminator by a HeNe laser with a HeNe laser line filter, and measure the quantum efficiency. The quantum efficiency is given by:

$$Q.E.(\%) = \frac{124 \cdot I(\mu A)}{P(mW)\lambda(nm)} \cdot \frac{1}{R}$$

where I = the measured beam current
P = the laser power
λ = the laser wavelength, and
R = the reflectivity of the stainless steel mirror.

For a HeNe laser this equation implies a photocurrent of 5.1 mA per Watt of power incident on the photocathode for a 1% QE photocathode. For our present system the reflectivity of the mirror is 0.61, so 1 Watt of laser power incident on the mirror will produce a photocurrent of 3.11 mA for a 1% QE photocathode. Typical quantum efficiencies are 2-5% for thick ($\gtrsim 1\mu m$) samples fabricated using this procedure in a very clean system. While measuring the quantum efficiency, restrict the laser power to $\lesssim$ 1 mW using neutral density filters to avoid space charge effects that can be

large at these very low accelerating voltages, and to avoid vacuum problems that may result from electron bombardment of the anode. To check for space charge effects, verify that the current increases linearly with laser power by making measurments of the photocurrent vs. laser power by inserting a series of neutral density filters into the laser beam; in the presence of space charge the current will saturate and not increase with laser power.

14. Begin experiments as desired.

Appendix A: Current Measurement During Cathode Preparation

During photocathode fabrication, the cathode current is monitored with a picoammeter. The equivalent circuit diagram for the method we use to measure the cathode current is shown in Figure 1. This appendix details the steps we have taken to match the actual measuring apparatus to the "ideal" circuit diagram in the presence of noise.

In order to realize the circuit shown in Figure 1, it was necessary to build a junction box. This box (2.75″ × 2″ × 1.625″) attaches via a standard BNC connector directly to the electrometer. Another standard BNC connector allows the junction box to supply voltage to the gun via an RG-58 coaxial cable. Finally, a twin-ax connector facilitates the attachment of the junction box to the battery box via a shielded, twisted pair cable. It should be noted that the electrometer's grounding strap is attached to the gun's ground, thereby grounding the outer casings of the junction box and the connectors, the shield of the twisted pair cable, and the outer conductor of the coaxial cable. Figure 2 presents a schematic diagram of the actual measuring apparatus.

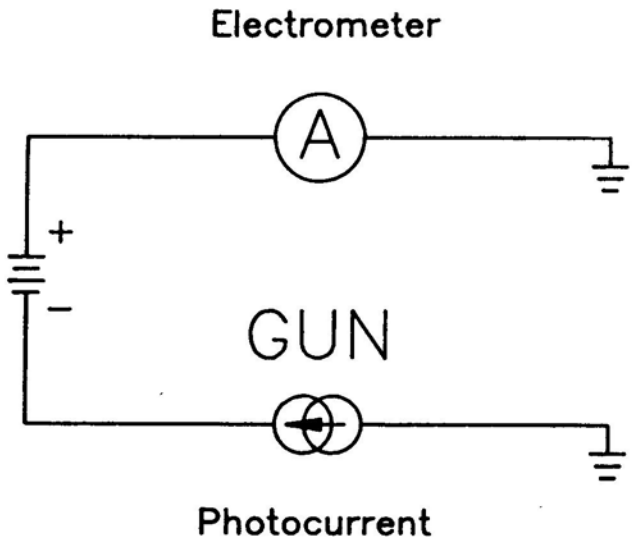

Figure 1: Equivalent Circuit Diagram

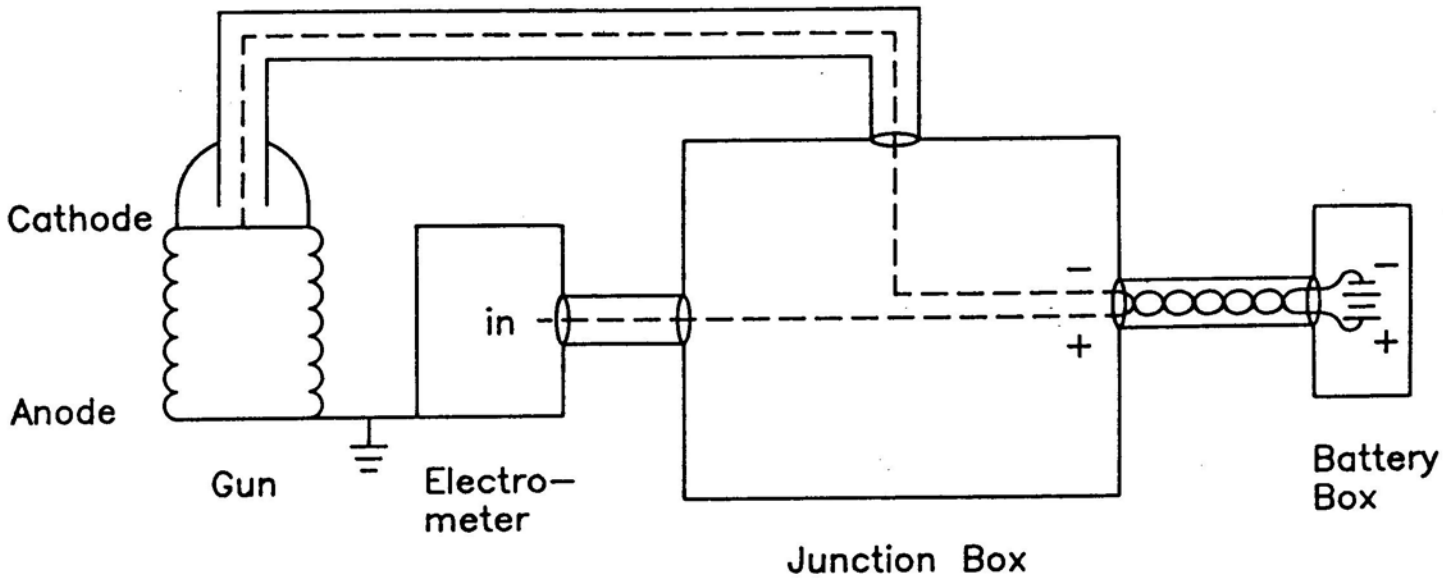

Figure 2: Schematic Diagram of the Electrical Connections

Appendix B: Documentation for the Preparation of a Typical Bulk GaAs Photocathode

In this appendix we provide documentation for the results of typical bulk GaAs photocathode fabrication. Figure 3 shows the chart recorder output for the cesiation process, while Figure 4 shows the quantum efficiency vs wavelength that results for a cathode prepared in a well-baked, clean system. Figure 5 shows the quantum efficiency vs wavelength that has been more typical of recent cathode fabrications in which the bakeout temperature has been limited to 200 C by the (temporary) installation of a viton-sealed valve just below the first solenoid.

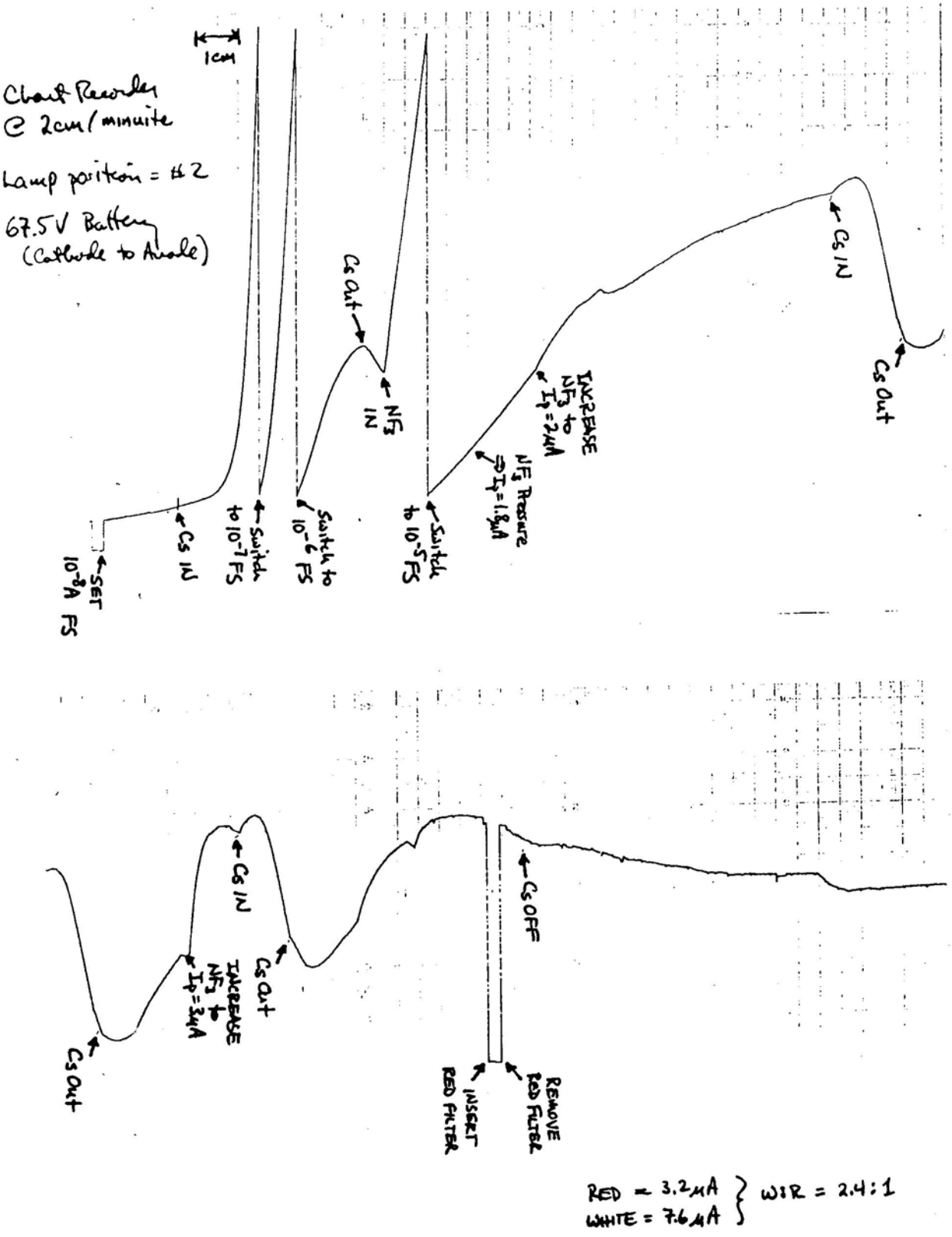

Figure 3: Typical chart recorder output during the cesiation process.

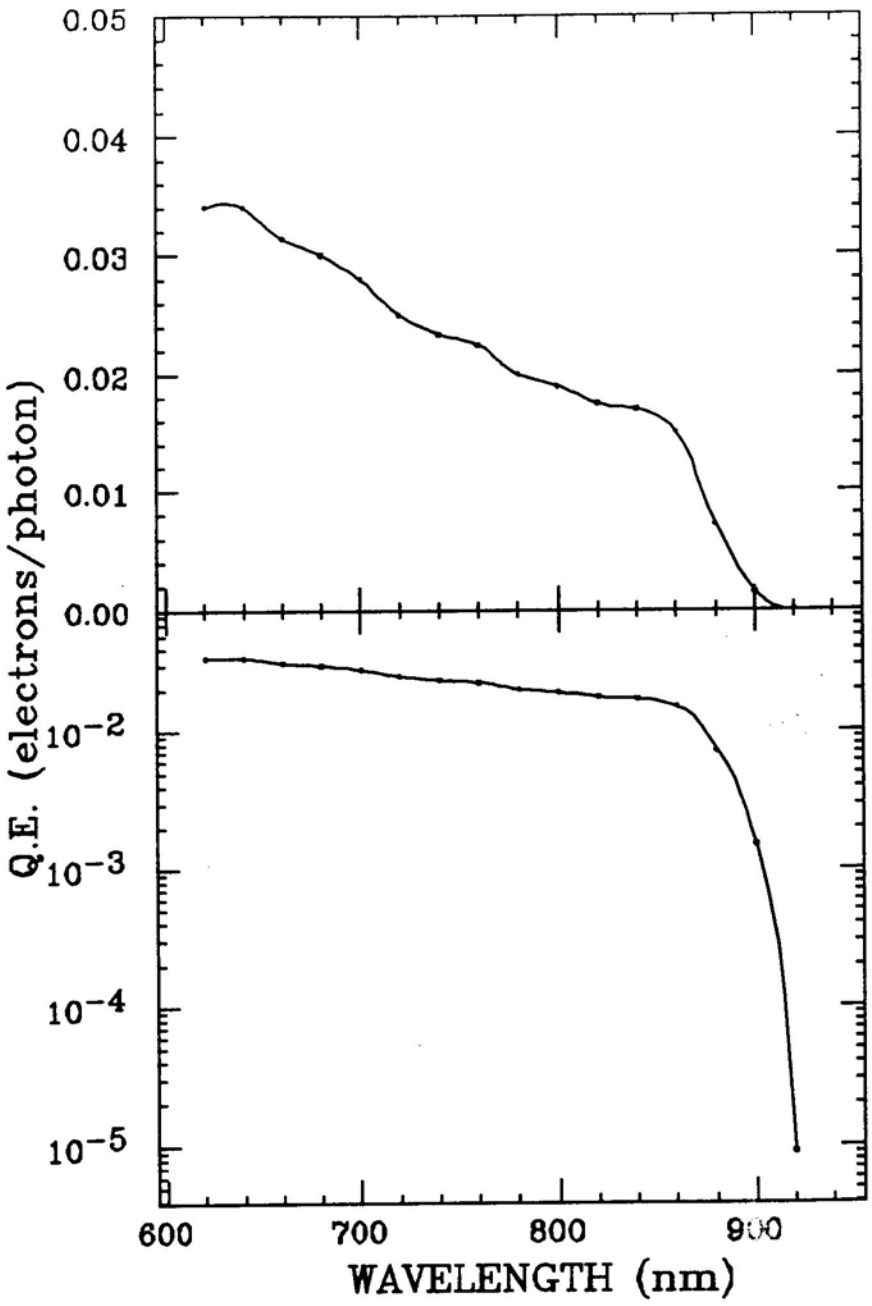

Figure 4: The quantum efficiency vs wavelength for a bulk GaAs photocathode prepared in a clean gun. The same data are shown on both linear and log scales.

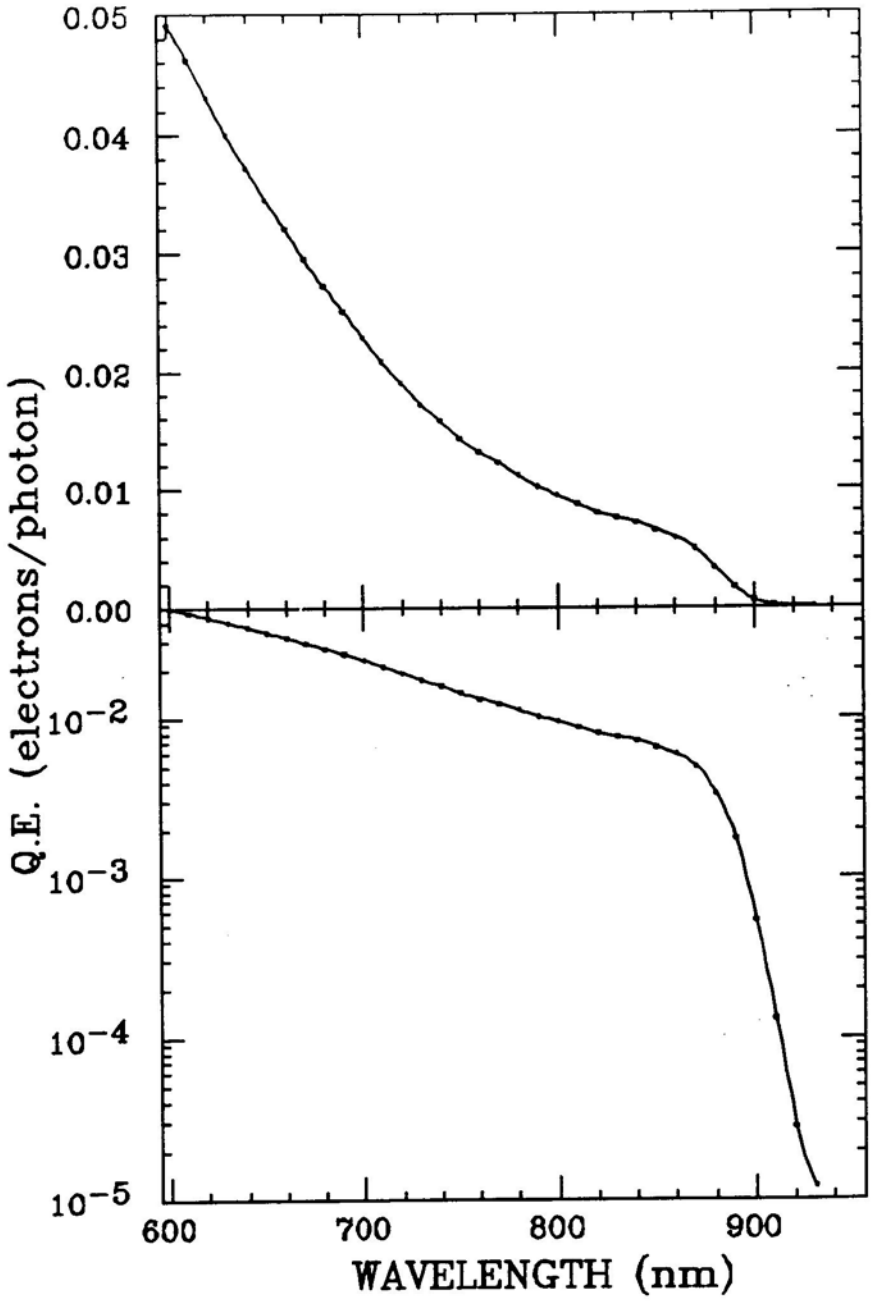

Figure 5: The quantum efficiency vs wavelength for a bulk GaAs photocathode prepared in a reasonably clean gun (in this case, baked only to 200 C). The same data are shown on both linear and log scales.