

Photocathode transfer and storage techniques using alkali vapor feedback control

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Photocathodes of quantum efficiency (QE) above 1% at the doubled YAG frequency of 532 nm are very sensitive to the local vacuum environment. These cathodes must have a band gap of less than 2.3 eV, and a work function that is also on the order of ~ 2 V or less. As such, these surfaces are very reactive because they provide many surface states for the residual gases that have positive electron affinities such as oxygen and water. In addition to this problem it is found that the optimal operating point for some of these cesium based cathodes is unstable. Three of the cesium series were tried, the Cs–Ag–Bi–O, the Cs₃Sb and the K₂CsSb. The most stable material found is the K₂CsSb. The required vacuum conditions can be met by a variety of pumping schemes such as using sputter ion diode pumps and baking at 250°C or less for whatever time is required to reduce the pump currents to below 1 μ A at room temperature. To obtain the required partial pressure of cesium, a simple, very sensitive, diagnostic gauge has been developed that can discriminate between free alkali atoms and other gases. This Pressure Alkali Monitor (PAM) can be used with cesium sources to provide a low partial pressure using standard feedback techniques. Photocathodes of arbitrary composition have been transferred to a separate vacuum system and preserved for over 10 days with less than a 25% loss to the QE at 543.5 nm.

1. Introduction

Photocathodes used in photoinjectors can produce very high current densities, i.e. > 1000 A/cm². These cathodes can be made from a variety of materials. However, if a CW injector is to be fabricated, it is found that the limiting technology is the power of mode-locked laser light in the 2.3 eV range and above. At this point in time, obtaining a mode-locked, crystal doubled, CW laser at 30 watts is a major development effort. In order to obtain ~ 8 – 10 nC/micropulse a cathode of about 3% quantum efficiency (QE) at 2.3 eV is required. The cathodes in this class are of the multi-alkali antimonide [1] or gallium arsenide [2] type. Aside from the difficulty in cathode fabrication, the cathode lifetime in the injector is a problem. The chief difficulty is contamination from residual gases. The major effort to improve the vacuum has been to remove the residual water from the system. A number of experiments have been carried out to verify that cathode transfer and storage can be accomplished. The goal for the hardware is to produce a $1/e$ storage lifetime of 240 h (10 d). With these results, it becomes feasible to produce a cassette of cathodes for use on photoinjectors. This development then provides improved operating conditions because the fabrication of photocathodes can be separated from the accelerator, and the cathodes can be stockpiled for later use.

A ten-day storage time meeting these requirements has been demonstrated on two separate pieces of hardware. Both were brought on line *new*, which means that the vacuum components had not been previously

used in ultrahigh vacuum. We found that the cathodes could be preserved if the vacuum system was baked 2 to 3 times at a temperature not exceeding 250°C for 24 h each bake. The criteria for a successful bake was the establishment of a stable, low Cs alkali pressure, i.e. low to mid 10^{-10} Torr region, and a residual ion pump current less than 1 μ A when room temperature was reached ($P_{\text{est}} = 2$ – 3×10^{-9} Torr). An alkali monitor was used, and temperature cycling on the cesium source was observed to determine that the partial pressure of cesium in the unit had reached an equilibrium value. The estimate of the partial pressure of cesium in the chamber, based on a calculation for the detector sensitivity, is a few times 10^{-10} Torr.

2. Experiment

Experiments have been carried out using the equipment schematically shown in fig. 1. One of the 20 l/s pumps has been modified into a pump pipe, and the other simply bolted onto the storage cube. An alkali monitor/feedback system has been added to the top of the cube. Fig. 2 shows the schematic arrangement of this device. The detector probe, similar to a Bayard–Alpert gauge tube, is mounted on one end and a typical cesium source is mounted on the other end of the vacuum tee. The detector works by heating the grid wire to incandescence using a transformer. A standard ion gauge controller was used in the degas mode.

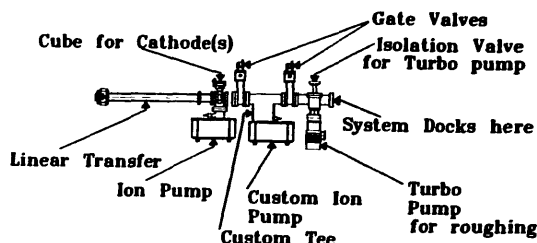


Fig. 1. This is a schematic layout of the transfer system. The photocathodes are made in a system (not shown) that docks adjacent to the turbo pump, used for roughing. The two ion pumps are used to provide a "guard vacuum" against accidental gas leakage across the valve seats. The PAM (not shown) is normally located on the top of the cube. Once the cathodes are moved into the cube, they are illuminated with laser light through a glass viewport, and the emission current is collected and measured from a biased copper ring.

When the wire is hot, and has a work function that exceeds the ionization potential of the alkali, the atoms that strike the wire will leave ionized. The ionization probability is nearly unity, according to the Saha-Langmuir equation [3]. The ions are then collected on the collector wire of the tube. The biases used in the tube are the same as for a normal ionization gauge. The sensitivity is then calculated using the thermodynamic equation for the number of molecules/cm² s, the area of the collector wire, and the relationship between the current on the ion gauge controller and the pressure read. For the systems used, the conversion

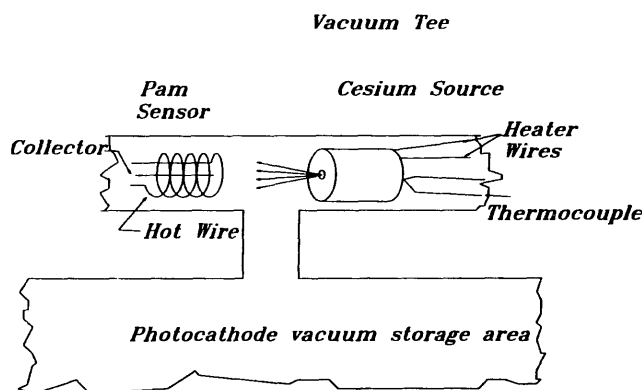


Fig. 2. The Pressure Alkali Monitor (PAM) is placed in a vacuum tee that is mounted on the top of the cube. The cesium source is temperature controlled and alkali pressure controlled through an "or" circuit. If the pressure of the alkali is too low, the source may be heated until a maximum temperature is reached, to prevent an alkali spill. When the desired pressure is reached, the temperature is lowered to just maintain this pressure. If there is any significant water present, the cesium will be react with it at the walls of the chamber, thus lowering the partial pressure of cesium, and causing the circuit to call for more cesium. No more cesium is used than is necessary to maintain a partial pressure at the detector.

factor was ~ 570 (see Appendix A for details). Thus, for a pressure read at 4×10^{-7} Torr, the partial pressure of cesium was about 7×10^{-10} Torr. This is the pressure at the detector, but the actual pressure at the cathode surface is unknown. It is suspected to be much lower. This is because the only volume that needs to become saturated is in the tee itself. Further investigation is needed to determine if it is a true reflection of the partial pressure of cesium over the cathode face. However, the literature suggests that the partial pressure of alkali metals exists in photocathode tubes [4,5]. The presence of a slight excess alkali might enhance cathode lifetime, or represent the partial pressure over the cathode surface. If there is benefit from an excess alkali, it may be due to three effects: (1) the partial pressure of cesium compensates for the evaporation at the cathode surface; (2) the partial pressure of cesium is consumed by the excess water vapor present in the vacuum system, thus acting as a getter pump; (3) both mechanisms are at work. Until further measurements are made, this and other measurements concerning the over pressure of cesium with the multialkali cathodes could simply reflect a slight excess of cesium from final processing, and the complete lack of water to react and bind it to the walls.

3. Results and discussion

The methodology of the experiment was to find the minimum requirements and processing necessary to move and preserve a photocathode. The very first transfer attempts were done with the minimal treatment to the storage cube. The base pressure was just what was obtained without a bakeout of the pumps and system. According to the pump controllers, the base pressure was in the mid 10^{-7} Torr range. The first cathodes had only tens of minutes to an hour for lifetimes.

After the first attempt, an alkali monitor feedback system was adopted. The system was again pumped, but no bakeout effected. The cesium generator feedback system was allowed to equilibrate by coming to a temperature and cycling. The equilibrium of temperature cycling occurs when the temperature to produce a given value at the monitor is well below the previous reaction temperatures on source start up. The cesium sources were often operated at temperatures as high as 595°C to begin to obtain a partial pressure in the 10^{-10} Torr range. Once this pressure was obtained, the temperature of the source would drop with time. In a well baked system, this temperature can be as low as 200°C, or oscillate about 400°C with 30 s to 1 min. periods. Fig. 3 shows the cathode lifetime using only the feedback system and no bake. Again, the cathode lifetime is improved, but is unsatisfactory.

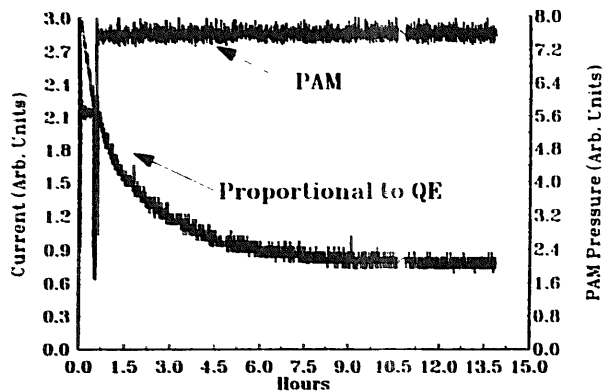


Fig. 3. Cathode lifetime, system 1, 4-5-'91. System was allowed to pump and benefit from the PAM. The lifetime had improved over the system with no bakeout, but the lifetime is still too short.

After several bakeouts on the vacuum system, a lifetime and cesium profile was found as in fig. 4. The cathode after fabrication had a QE only slightly greater than 3%, but it rose to nearly 5%. The QE then began a gradual decline through the first 100 h. At this time, the cesium partial pressure was increased by about 20%. The QE then rose to nearly 5% again, and then began a gradual decline. At about 250 h, the heater on the cesium source was turned off, and just the cesium pressure monitored. As can be seen, the cathode QE rose again slightly, and then began to drop until the experiment was terminated at 330 h or nearly 14 d.

A final test for system 1 was carried out by monitoring the cathode life, while beginning the test on system 2. Fig. 5 shows how the QE varied for 130 hours for the last test run on system 1. There is no significant drop in the QE.

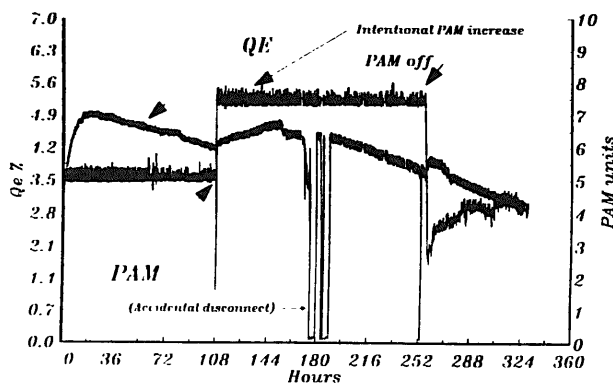


Fig. 4. Proof-of-principle transfer chamber lifetime test with PAM on (7-5-'91). This was the first successful extended storage. A trace amount of water present probably accounts for the initial increase in the QE. However, the continued absorption of water would cause the lifetime to decrease. The effect of changing the partial pressure of cesium in the tee was very small during this run.

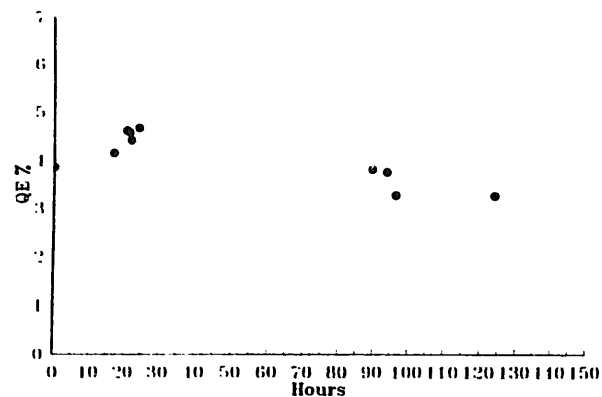


Fig. 5. The next test on this system (5-17-'91) indicates that the cathode lifetime is getting better with time. The specific reasons for this improvement are still under investigation, but likely involve the absence of water and low partial pressure of cesium.

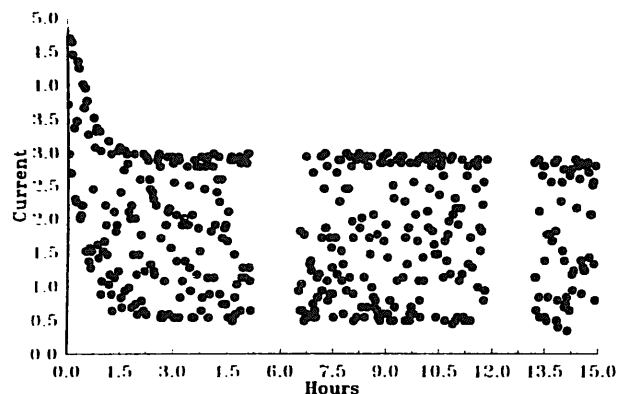


Fig. 6. The first test in the second system (5-29-'91) shows a lifetime of about 3 hours. The scatter in the data was due to a noisy laser near the end of its life. In spite of the scatter, it is clear that there is still too much water present in this system.

System 2 begins with a large scatter plot as shown in fig. 6. The laser seems to have had a lot of noise in it during this test. From the view of the "envelope" of the data, it is clear that the cathode life was very poor

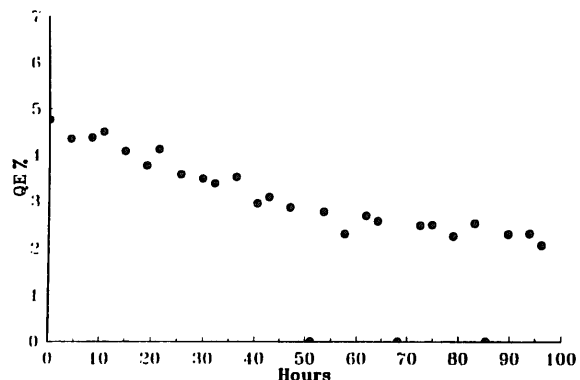


Fig. 7. Test on 6-13-'91: the lifetime has improved after a second bakeout. The $1/e$ time is about 130 h.

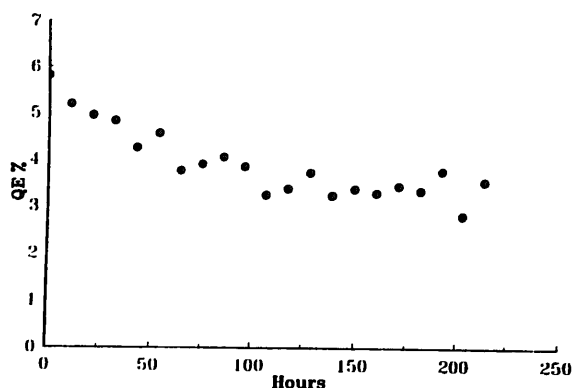


Fig. 8. Test on 6-17-91: further bakeout of the system has improved the cathode life to a level comparable with the first vacuum system. The $1/e$ time is in excess of 800 h.

and tended to decay over about 3 h. Fig. 7 shows about another bakeout and attempt at the storage lifetime. We have improved the cathode life by about an order of magnitude, but have still not done as well as the first system. Fig. 8 shows another test where the data appears to be as good as system 1. Fig. 9 shows one last run obtained on system 2. The data had significant fluctuation due to the changing power of the test laser.

Fig. 10 shows a calculated lifetime [6] for photocathodes based on the change in work function versus exposure to H_2O . It was assumed that the change in work function increased the height of the surface barrier to the vacuum, and thus reduced the surface escape probability. This chart is likely to be accurate to a factor of 2 or 3. The curve represents the working time to $1/e$ change in QE. This calculation was used to estimate the base water pressure in the system.

A summary of the data is shown in table 1. The system number, test start date, estimate $1/e$ times, and

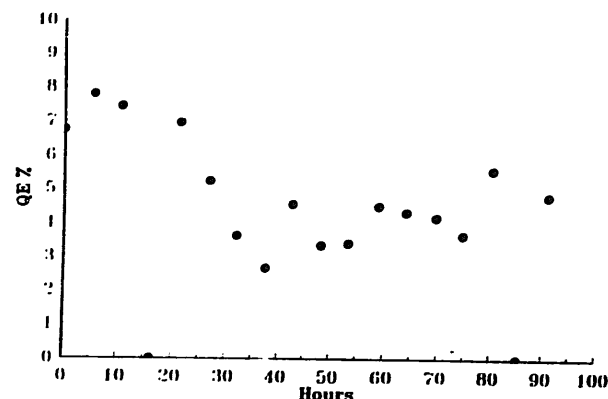


Fig. 9. The last test (6-27-91) on this system provided a lifetime ~ 800 h.

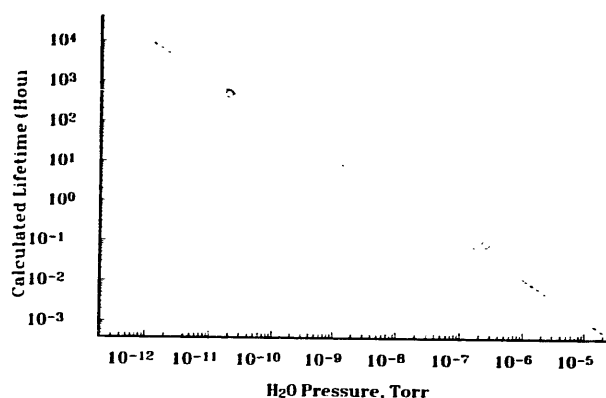


Fig. 10. Lifetime vs partial pressure of H_2O . The cathode lifetime has been calculated by knowing the change in the work function versus water exposure. With this measurement, a surface escape probability can be computed, and a time to $1/e$ determined. This graph was used to estimate the water partial pressure. Two points indicate the scant data obtained to date. Further detailed measurements are the subject of future work.

Table 1
Estimated H_2O pressure

System	Date of test	Estimated hours to $1/e$	Estimated H_2O pressure from fig. 10 in Torr
1	4/5/91	3.4	2×10^{-9}
1	4/19/91	547	8×10^{-12}
1	5/1/91	392×800	$2 \times 10^{-11} - 7 \times 10^{-12}$
2	5/20/91	3.3	2×10^{-9}
2	6/13/91	130	4×10^{-11}
2	6/17/91	865	7×10^{-12}
2	6/27/91	312×1000	$2 \times 10^{-11} - 6 \times 10^{-12}$

Table 2
Conditions for cathode transfer and storage

Pump size	Vaclon, 20 l/s
Pump current	$I < 1 \mu A$
Estimated pressure	$P < 10^{-9}$ Torr
Estimated PAM pressure	$P \sim 7 \times 10^{-10}$ Torr
PAM control temperature cycling period	> 60 s

estimated partial pressure of water obtained from figure 10 are given.

4. Conclusions

The preliminary conditions, shown in table 2, for the cathode transfer and storage have been established. The vacuum pressure in the two pumps on the storage system must be reading less than 1 μ A of current. On our experiment, the current was in excess of 20 μ A due to internal leakage. While we were able to succeed in making this system work, there was always the nagging doubt that the currents may have been across a ceramic insulator, thus providing a constant source of oxygen which would shorten the photocathode life. We have not yet produced and moved multiple cathodes. We do not know the composition of the cathodes produced. Both of these questions will be the subject of the next phase of our investigation.

Appendix

The Pressure of Alkali Monitor (PAM) sensitivity was calculated as follows. The equation for the length of the wire of the ionizer is shown in eq. (1).

$$l = n1 \pi \sqrt{r^2 + a^2} \text{ cm.} \quad (1)$$

Eq. (2) represents the flux of molecules per $\text{cm}^2 \text{ s}$ as derived from thermodynamics.

$$f = 3.5 \times 10^{22} \frac{P}{\sqrt{mT}} \text{ molecules/cm}^2 \text{ s.} \quad (2)$$

If the particles are charged, the current then becomes the area of the wire (eq. 4) times the electron

charge times the flux shown in eq. (3).

$$I = feA \text{ or current in amperes,} \quad (3)$$

$$A = l \pi D \text{ cm}^2 \text{ (area of wire).} \quad (4)$$

The ion gauge sensitivity is 0.1. A/Torr; thus, the conversion between the partial pressure of the cesium and the ion gauge can be readily determined as in eq. 5,

$$\text{Torr}_{\text{Cs}} = \frac{\text{Torr}_m}{10} \left(\frac{\sqrt{mT}}{3.5 \times 10^{22} eA} \right) \frac{\text{Torr}_m}{572}, \quad (5)$$

where the variables are defined as follows: e = electron charge, A = area of wire, f = molecular flux, I = current, Torr_m = measured pressure from ion gauge controller, Torr_{Cs} = actual partial pressure of cesium, m = atomic mass, T = temperature in K, D = wire diameter, 0.0254 cm, l = wire length, n = number of turns, a = pitch per 2π change in Azimuth, r = radius of coil.

Thus, the maximum sensitivity of this device as configured is about $1.75 \times 10^{-12} \text{ Torr}_{\text{Cs}}$, which corresponds to $1 \times 10^{-9} \text{ Torr}_m$ on the ion gauge controller.

References

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