Microchannel plate life tests

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We have investigated the manner in which the gain of a microchannel plate (MCP) changes as the plate is operated at moderate output currents. We find that the total charge per unit area Q (C-cm^{-2}) extracted from the MCP is the relevant quantity for evaluating the performance of the MCP. The shape of the gain vs Q curve may contain important information on the gain decay process. The MCP's showed no long periods of stable gain similar to those frequently exhibited by channeltrons.

Introduction

The uv spectrometer for the Mariner Jupiter/Saturn Mission utilizes microchannel plates (MCP's) in a chevron configuration as a uv detector. Since this mission is of several years' duration, we have tried to determine how the characteristics of a microchannel plate, particularly the gain, change as the plate delivers moderate levels of current for long periods of time.

Test Procedure

The microchannel plates tested were the standard size, 25-mm diam. They had channel center-to-center separations in the 12–20-μm range. Two were manufactured by Varian LSE Division (plate A, VUW 8921A, S/N 975-629-15, and plate B, VUW 8921A, S/N 975-629-68) and two by Galileo Electro-Optics Corporation [plate C, S/N M2026(238-25)-009, and plate D, S/N 521-20-018]. The plates were mounted between a semitransparent aluminum photocathode and an anode, both of which were larger than the active area of the MCP's. The input to the MCP was a uniform flood of electrons derived from the photocathode stimulated by uv radiation from a mercury lamp. The current to the photocathode was monitored and held approximately constant during these tests. For some tests, an aperture was placed immediately in front of the MCP to limit the electron input to about 6% of the active area of the plate. The aperture was moved to allow different regions of the same plate to be evaluated separately and the results compared. The output current from the plate was collected on the anode and measured by an electrometer. An ion-pumped vacuum system provided pressures in the 2–10 $\times$ 10^{-8}-Torr range for these tests.

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The microchannel plates were received from the manufacturers having been operated only for acceptance testing. A standard handling procedure was established to assure that all the tested plates received as nearly as possible the same treatment. Immediately after the receiving inspection, the plates were placed in a clean storage box purged with filtered dry nitrogen. They remained in the storage box until their installation into the vacuum chamber and were returned to the storage box after test. Initial outgassing and stabilization of the plates under vacuum was assisted by electron scrubbing in which the plates were operated at an output current of 1 $\times$ 10^{-8} A-cm^{-2} for about 40 h. The gain stability tests were begun with a gain of approximately 500 and an output current density of 1 $\times$ 10^{-7} A-cm^{-2}. The output current was monitored continuously, and periodic gain vs voltage measurements were made. The input current density and plate voltage were held constant for several hundred hours until decreases in output resulted in the rate of gain decrease becoming inconveniently small. The plate voltage was then increased to maintain reasonably high output currents. Gains in the 6–1000 range were used.

The full active areas of plates A and D were tested. On plate B three separate regions defined by the movable aperture were tested sequentially. One small area of plate C was tested. The accumulated time on all plates totaled 2300 h.

Results

The data show that there was a degradation of gain of the microchannel plates due to their operation at moderate levels of output current. This degradation was examined with relation to the total charge per unit of plate area extracted from the plate, Q C-cm^{-2}. We were able to show that the rate of gain decay with increasing Q was not appreciably affected by the output current density over the range in which we operated, 1 $\times$ 10^{-6} to 2 $\times$ 10^{-8} A-cm^{-2}. Figure 1 shows the gain vs

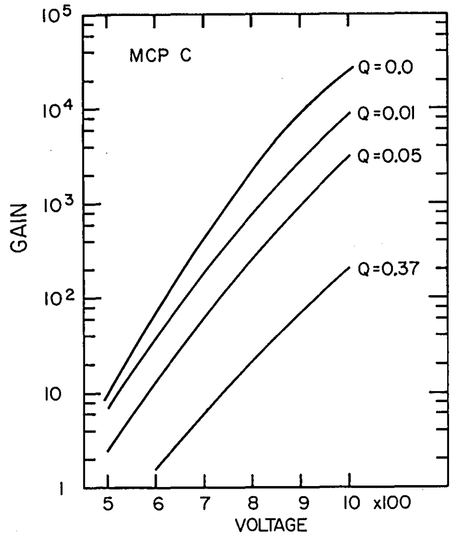

Fig. 1. Gain vs voltage for a representative MCP at four values of Q.

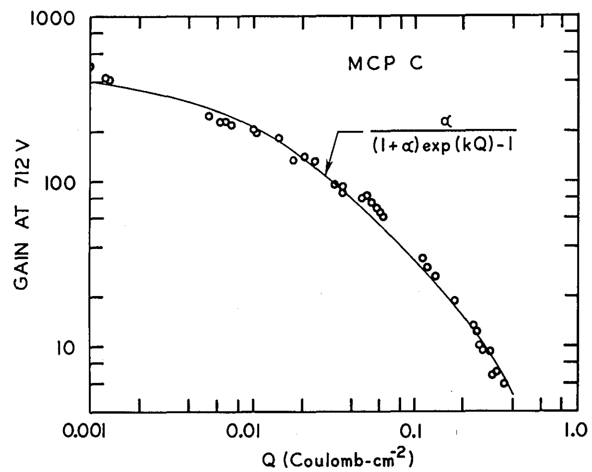

Fig. 2. Gain at a constant voltage as a function of Q for the MCP in Fig. 1. The solid line shows a model fit to the data.

Table I. Ratios

Test	G_0	α	k	$k' = k/\alpha G_0$	k/k'
A	730	1.29	231	0.246	940
B-1	550	0.041	4.70	0.209	23
B-2	550	0.072	5.56	0.140	40
B-3	550	0.030	4.48	0.272	17
C	500	0.029	2.64	0.228	12
D	700	0.26	9.07	0.050	180

plate voltage at several values of Q for plate C. The gain as a function of Q at a constant plate voltage is shown in Fig. 2. All four plates exhibited qualitatively similar decreases in gain although significant quantitative differences were apparent.

The gain at a constant voltage is well described by an equation of the form

$$G = G_0\alpha[(1 + \alpha) \exp(kQ) - 1]^{-1}. \quad (1)$$

The experimental values of G_0, α, and k are shown in Table I for each of the six tests. The curves described by these parameters and the above equation fit all the data points to better than 30%. The tabulated parameters show generally similar performance in all tests except plate A, whose gain decreased at an anomalously high rate. This rapid gain decay can be most readily attributed to a real difference in the plate manufacturing process. The differences found in the three regions of plate B are real; we are confident in the stability of the test procedure and must conclude that the effect was in the nature of the plate.

Another effect common to all tests was noted. There was a small decrease in the slope of the gain vs voltage curve with increased Q. This effect, which is apparent in Fig. 1, is small, but the tendency may be significant as a design consideration.

No significant change in the ratio of the dark current to the gain, sometimes referred to as the equivalent noise input, was found in these tests.

Discussion

The form of Eq. (1) describing the gain decay may contain important clues on the nature of the gain degradation process. The simplest model providing the observed gain degradation characteristics involves a single physical mechanism in which the surface ionization process results in removal of the electron source through reaction with a finite resident population of poisoning species. The rate of loss of the source population $[n_1(Q)]$ with respect to total charge production (Q) is then proportional to the product $n_1(Q)n_2(Q)$, where $n_2(Q)$ is the reactive species population. Thus we have

$$[dn_1(Q)]/dQ = -k'n_1(Q)n_2(Q), \quad (2)$$

where k' is a reaction rate constant. Equating the total loss of the source population to the total loss of the poisoning population yields

$$n_2(Q) = n_2(0) - n_1(0) + n_1(Q). \quad (3)$$

Substituting Eq. (3) into Eq. (2), we find

$$(dn_1)/dQ = -k'n_1^2 - kn_1, \quad (4)$$

where

$$k = k'[n_2(0) - n_1(0)]. \quad (5)$$

This differential equation has the solution

$$\frac{n_1}{n_1(0)} = \frac{\alpha}{(1+\alpha)\exp(kQ) - 1}, \quad (6)$$

where

$$\alpha = k/[n_1(0)k'].$$

Under the assumption that the gain is proportional to n_1, Eq. (6) is the same as Eq. (1), which does adequately describe the data.

A self-consistent interpretation of the rate constants may be made. The rate constant k' which describes the basic process of combination of the secondary emitters and poisoners given by

$$k' = \frac{k}{n_1(0)\alpha} \propto \frac{k}{G_0\alpha}$$

is tabulated in Table I. In spite of widely differing values of the less fundamental constants α and k, the quantity k' is approximately the same for all tests. This is a strong indication that k', the combination rate constant, has a real physical significance, which in turn supports the above described model of the gain degradation process. The implication is that the same basic gain decay mechanism dominated in all six tests. Furthermore, the ratio k/k' defined by Eq. (5) contains information on the relative abundances of the poisoners and secondary centers. These ratios for each of the six tests are listed in Table I. Plate A showed by far the highest ratio k/k'; its more rapid gain decay would be attributed in the context of this model to a larger initial abundance of the poisoners. The results from plate D also show a k/k' significantly higher than the remaining samples. However, the larger k/k' is balanced by the somewhat reduced rate constant k', and the gain degradation for this plate is similar to plates B and C.

Although this model seems to lead to a self-consistent and reasonable interpretation of the data, it may be nonunique. Other models involving more than one physical reaction would fit the data equally well. Various gain decay mechanisms may be operating simultaneously with the process described by this model.

Our results indicate a much more rapid gain decay than does the work of Ruggieri[1] in which two plates were operated for 7000 h. The work of Ruggieri[1] suggested that a well known property of channeltrons, a long period of stable gain in operation, was shared by microchannel plates. However, such a period of stable gain was conspicuously absent in the testing reported here. The gain in both his plates was essentially stable at 3000 with 1-kV potential for the last 6000 h of test. Since the output current was about 9×10^{-9} A-cm^{-2}, the extracted charge was about 0.19 C-cm^{-2}. We can make a comparison to our work. Figure 1 shows that plate C had a gain of 3000 at 1 kV when Q was 0.05 C-cm^{-2}. Figure 2 shows that the extraction of a charge of 0.19 C-cm^{-2} from the reference point of 0.05 C-cm^{-2} was accompanied by a decrease in gain by a factor of ~6. This difference is significant but cannot be accounted for by a difference in test procedure. Although Ruggieri's plates were operated at a lower output current, we were not able to detect a significant change in the gain decay rate as a function of Q within the current range from 2×10^{-8} to 1×10^{-6} A-cm^{-2}, and we feel that a significant difference would not occur going to 9×10^{-9} A-cm^{-2}. We must conclude that there were some differences in the manufacture of Ruggieri's plates and those tested in this program.

Our tests do not exclude the possibility that the gain of the MCP may change after long periods in space nonoperating or operating at trivially small currents. Such data will come from flight experience.

Our application utilizes a chevron configuration, two plates in series, to accommodate a photoelectron counting data system. Virtually all the gain decay occurs in the rear plate. With a pulse gain of 1×10^6 through the two plates and a pulse rate of 10^5 cm^{-2} sec^{-1}, an accumulated charge of ~0.05 C-cm^{-2} would be delivered by the back plate in 850 h. Since the rate of gain decay with increasing Q depends inversely on the accumulated charge delivered, the amount of gain degradation depends on the history of operation. A gain degradation of about a factor of 2 would be experienced for the second 0.05 C-cm^{-2} extracted from a plate, whereas we predict an order of magnitude decrease for the first 0.05-C-cm^{-2} increment.

We suggest that the quality of the MCP and the rate of gain decay can be established early in the plate's operation and that the gain degradation can be minimized by controlled adjustment of Q. It should also be noted that if the MCP is operated for long periods of time with a high contrast image impressed on it, such as a line spectrum, the gain over the image could become nonuniform.

We have not attempted to operate the chevron at its maximum gain to obtain the type of pulse height distribution characteristic of channeltron applications. However, Kellogg[2] and his group have run high current tests and find the same type of gain decay as we report here. It is clear that the gain required to operate a chevron in a pulse saturated mode, $\sim 1 \times 10^7$, could not be sustained for long if the pulse rate were high.

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References

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