AN EVALUATION OF MICROCHANNEL PLATE PHOTOMULTIPLIERS FOR LIQUID SCINTILLATION COUNTING

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ABSTRACT

Recent advances in microchannel plate (MCP) photomultiplier technology has prompted a study to evaluate the use of this photon detector for liquid scintillation counting. The advantages offered by an MCP photomultiplier over a conventional photomultiplier are: better time resolution, low background noise and small physical size resulting in reduced shielding requirements. A comparison between the MCP and conventional photomultipliers is made when measuring ^{3}H (18.6 keV βmax) and ^{14}C (156 keV βmax) in a coincidence liquid scintillation mode of counting.

INTRODUCTION

The use of a microchannel plate (MCP) for electron multiplication was first conceived by Fainsworth in 1930[1] but was not actually applied until the 1960's[2]. The device is similar in operation to a dynode string of a conventional photomultiplier tube (PMT) except that each channel acts like an independent multiplier. Construction of an MCP consists of fusing closely-packed, high resistivity glass capillary tubes and coating the inner walls with a low-work function secondary electron emitting material. An applied voltage across the ends of the channel sets up an electrical field to propel the electron the length of the channel. Electron multiplication occurs when the electron impinges on the surface tube of the wall and is repeated in a cascade interaction the full length of the channel.

Present day commercial MCP devices can readily be fabricated with a diameter of 25 to 50 millimeters and channel pore sizes ranging from 12 to 15 micrometers[3]. At these pore sizes a packing density approaching half a million channels per square centimeter is achievable. MCPs are usually less than one millimeter thick with a preferred channel length to pore size ratio of 45-50. In this configuration, a single stage MCP can achieve an electron multiplication of 10^4 when operating at near saturation voltage.

Positive ion feedback, which occurs in a reverse flow to the electron cascade, is the main reason for the limited 10^4 electron multiplication of these devices. These charged particles originate from ionization of gas molecules within the device and at the output ends of the channels and from ejected atoms from the channel walls. In order to reduce this effect several different MCP configurations have been developed. One is the so called chevron design[4] which utilizes two aligned MCPs but tilted 6° to 8° with respect to each other. A second is the bent channel design[5] and the third, three MCPs in a "Z" configuration[6]. These modified MCP configurations gratly reduce the positive ion effect and are capable of 10^6 electron multiplication.

Photon counting of ultra violet, visible and near infrared wavelengths can be achieved by incorporating a photocathode with an MCP to produce a microchannel plate photomultiplier (MCP-PMT). Because of the short electron transit times, these devices show exceptional qualities for single photon counting, sub-nanosec risetime, low dark current noise, and small physical size. Any one of the above state qualities could be used to advantage in liquid scintillation counting. It was, therefore, the purpose of this study to evaluate the present level of performance of MCP-PMT devices and report our findings for present and future uses with LSC.

EXPERIMENTAL

Two chevron type MCP-PMT's (R1294U) were obtained on loan from the Hamamatsu TV Company Ltd. In order to accomplish coincidence counting both devices were mounted onto a plexiglass frame and aligned to face each other in a 180° orientation, see Figure 1. The detectors and frame were placed in a light-tight, copper box to eliminate extraneous photon interference and cosmic-ray generated Pb x-rays, see Figure 2. Four inches of lead were used to completely surround the copper box for shielding from low energy terrestial radiation.

The sample vial shown in Figure 3 was constructed from a standard

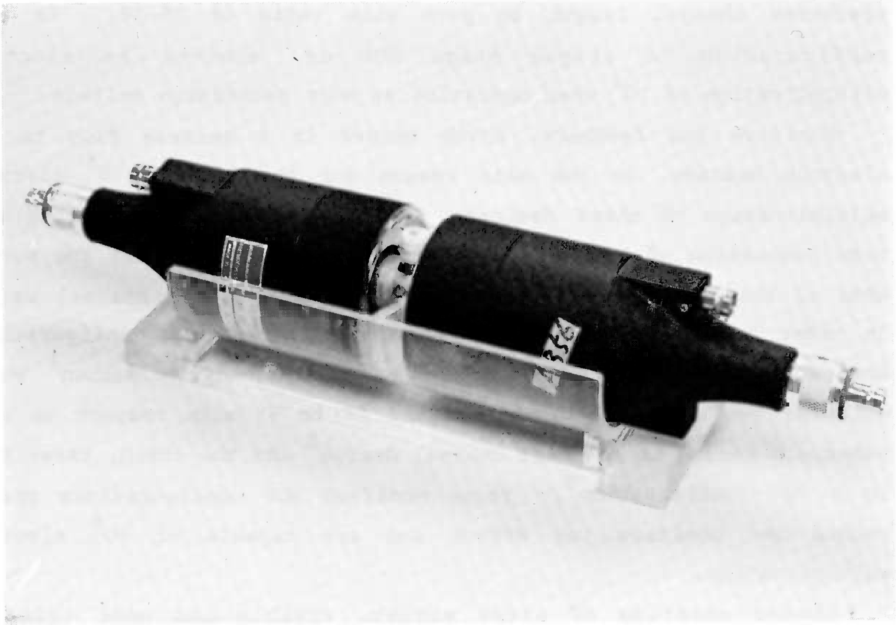


Figure 1. Microchannel plate detectors and LS vial

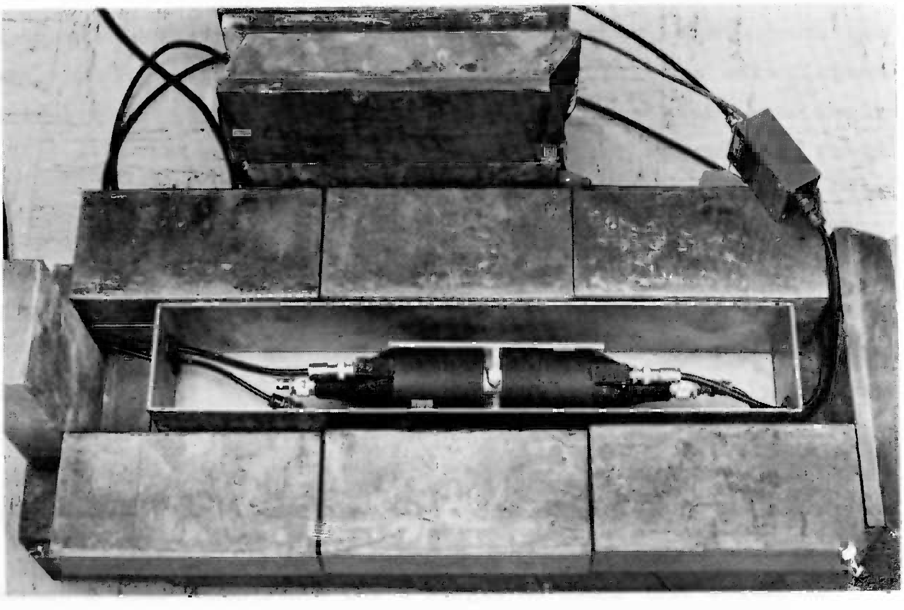


Figure 2. Copper and lead shield for detector assembly.

22 mm diameter by 20 mm long quartz absorption cell onto which two 6.3 mm thick plexiglass light pipes were attached at each end. The primary purpose in the use of the light pipes was not for photon transmission but to extend the vial dimension so as to permit contact with the 11 mm recessed windows of the two R1294U detectors while allowing vial stopper clearance.

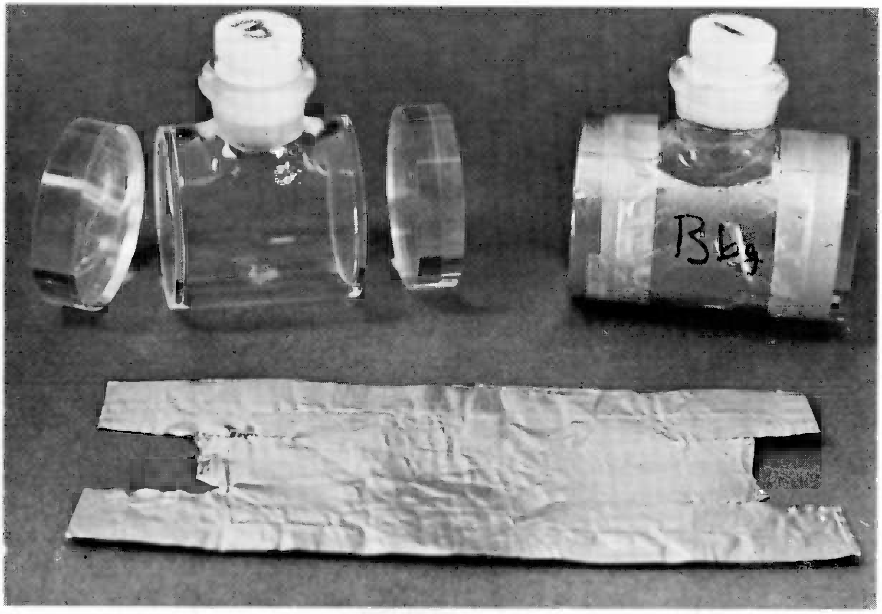


Figure 3. LS sample vial assembly.

The experimental configuration of the electronics employed in testing the MCP-PMT performance is shown in Figure 4. The signal from each detector was first fed to an Ortec 9301 fast preamplifier (gain x 10) and next to an Ortec 574 timing amplifier (gain x 20). This amount of gain was required as the MCP-PMTs only have a gain of approximately 2×10^6 when operated at -2700 V, see Figure 5. The amplified pulses were next routed to an Ortec 584 constant fraction discriminator which generates a fast logic output pulse based either on leading-edge or constant-time derivation technique. All measurements on the R1294U detectors were made in the leading edge mode of operation. The fast logic pulses generated by the 584s were fed to the start and stop input of the Ortec 437 time-to-amplitude

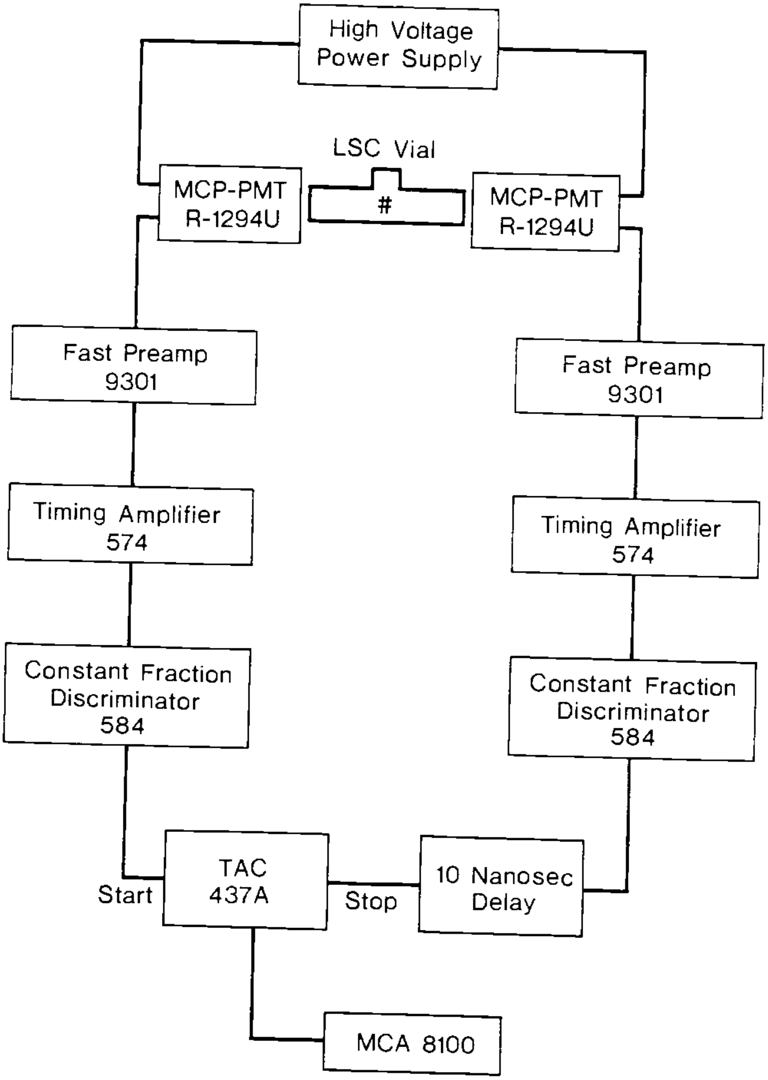


Figure 4. Block diagram of electronics used for microchannel plate testing.

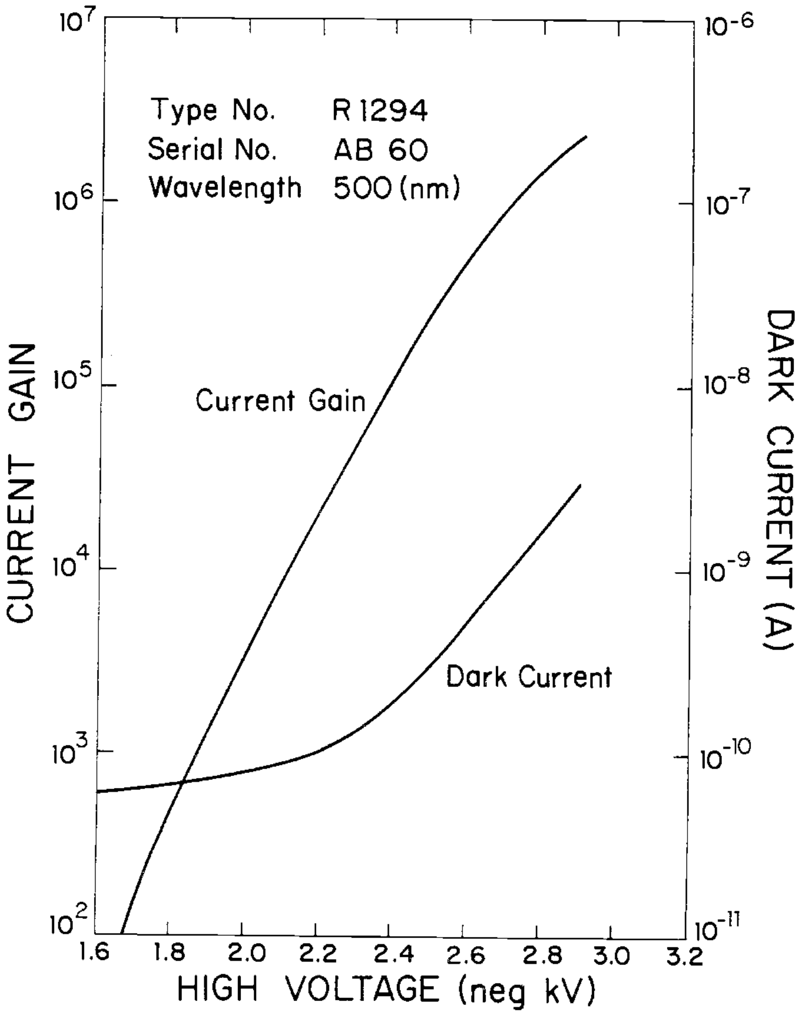


Figure 5. Microchannel plate gain and dark current characteristics

converter (TAC) whose output is proportional to the difference in the time of the start and stop signals. The output of the TAC was routed to the ADC input of a Canberra 8100 multichannel analyzer (MCA) which recorded the timing spectra. The time axis of the analyzer was calibrated by inserting known delays into the stop leg of the TAC.

This system was used to acquire timing spectra for C-14 and H-3 in a toluene-PPO/POPOP cocktail. From the timing spectra, full width half maximum (FWHM), full width tenth maximum (FWTM) and counting efficiency (CE) in the FWTM window were determined. It should be noted that there were no upper level discriminators in the system; hence, in essence, the data collected was in the lower to infinity counting mode.

The sample vials were also counted in a large volume, low background system which uses RCA 4501/V4 PMTs[7]. The FWHM, FWTM and CE were determined from their timing spectra and the results exhibited for comparison with R1294U MCP-PMT data.

RESULTS

Carbon-14 timing spectra for the R1294U and 4501/V4 are shown in Figure 6. The FWHM for the MCP-PMT is larger than was expected when

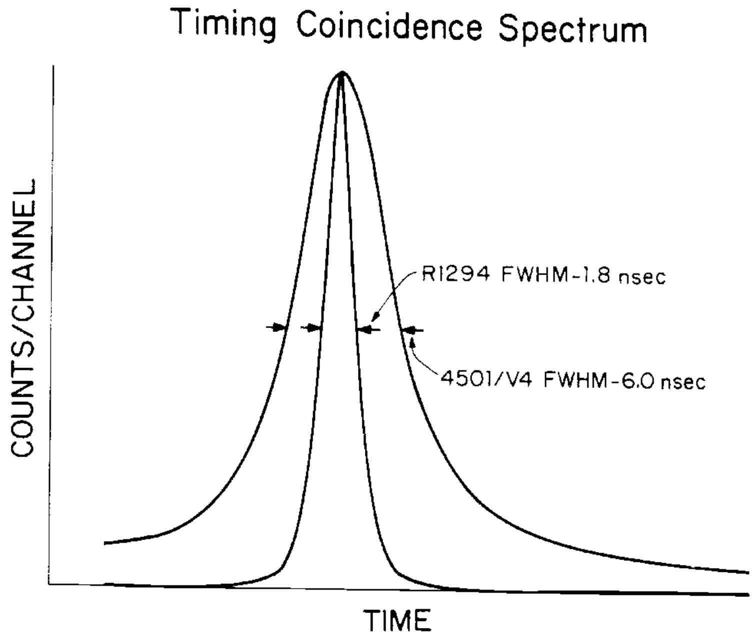
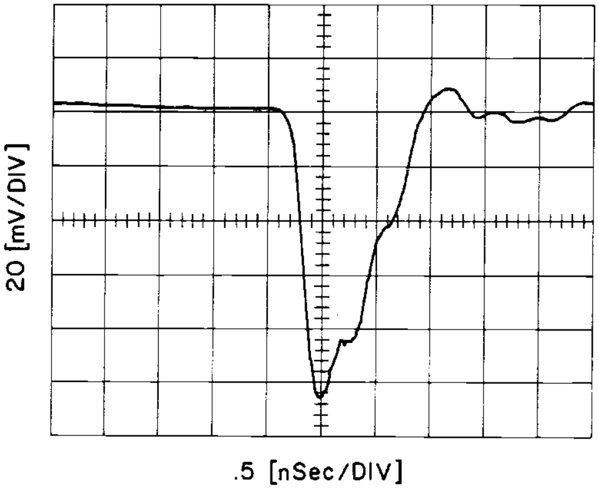


Figure 6. Microchannel plate timing spectra

one considers the risetime of 250 psec for the R1294U tubes as exhibited in Figure 7. Apparently this broadening is due to the risetime of the preamplifier (1.5 nsec) and amplifier (1.2 nsec).



Serial Number : AB 60
Supply Voltage = -2600 [V]
Rise Time = .2341 [nSec]
Fall Time = .783 [nSec]

Figure 7. Microchannel plate output pulse

The FWHM, FWTM and CE at FWTH for both ^{14}C and ^{3}H are compared for the R1294U and 4501/V4 in Table 1.

The low CE for both ^{14}C and ^{3}H were the result of several factors. First, the discriminator threshold was set at approximately 2 keV which was necessary in order to reject the preamplifier noise. Second, the vial used with their plexiglass light pipes and aluminum foil wrap undoubtedly did not possess optimum photon transmittancy, hence reducing the CE.

Table 1. Results for MCP-PMT and Conventional PMT

	FWHM (nsec)		FWTM (nsec)		CE(%)	
	C-14	H-3	C-14	H-3	C-14	H-3
R1294U	1.8	3.1	4.3	10.0	84	18
4501/V4	6.0	10.0	19.0	18.6	59	18

The background for the R1294U was 43 cpm as compared to 12 cpm for the 4501V4 and is significantly higher than one would expect. The time spectra for the background showed that the background counts were not due to chance coincidence but the pulses in each tube were highly correlated in time. In order to determine the origin of this high background the background vial was replaced with an emptyvial which reduced the count rate to 28 cpm. Removing this empty vial did not change the count rate. This strongly suggests that crosstalk was the major contributor to the background. Another possible contributor to the background could have been gamma contamination as care was not taken to select low background (high purity) materials for the construction of the sample holder and light-tight box. Also, the tubes themselves contributed to the background as they had small but measurable amounts of ^{40}K and ^{226}Ra with its daughters ^{214}Pb and ^{214}Bi when measured on a gamma spectrometer.

Finally, the tubes were blocked so they could not see each other which resulted in the count rate being reduced to less than 2.2 cpm. Although the MCP-PMT dark pulse count

$$\left[\sum_{1/8\ \mathrm{pe}}^{16\ \mathrm{pe}} \right]$$

may be on the order of 1800 cps[6] as compared to 180 cps[8] for RCA8850. This higher singles rate did not contribute significantly to the background.

CONCLUSION

Microchannel plate detectors were evaluated for their use in coincidence liquid scintillation counting of ^{14}C and ^{3}H beta activity. Three parameters of the detectors were measured: fast timing, beta counting efficiencyand background.

The timing characteristics were certainly better than conventional photomultiplier tubes but not as good as was expected. With additional MCP-PMT gain (x100) the FWHM of the timing spectra would possibly be less than 1 nsec.

The low counting efficiency observed could have been improved with changes in sample vial and MCP-PMT housing to give optimum optical coupling. Also, increased MCP-PMT gain would improve counting efficiency.

The high background observed appeared to be primarily due to crosstalk with a smaller component due to natural radionuclides in the materials used to fabricate the MCP-PMT detector.

At the present state of development of microchannel plates two other factors should be considered. First, their relatively high cost as compared to conventional photomultiplier tubes used for LS counting and secondly, improvements are needed in their gain stability and lifetime.

The performance of microchannel plates have improved significantly in the past several years as manufacturers have gained experience in the construction of these devices.

It is hoped that the results of this paper will lend assistance in the improvement of these devices for low level counting. Further studies to determine the origin and reduction of detector crosstalk would appear to be in order.

The recommendation we would make for the improvement of MCP-PMT for LS counting are as follows:

1. increased gain
2. reduction in physical size of MCP housing
3. use of low background materials in the fabrication of these devices
4. reduction of detector crosstalk

ACKNOWLEDGEMENTS

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