Characterization of a Microchannel Plate Photomultiplier Tube with High Sensitivity GaAs Photocathode

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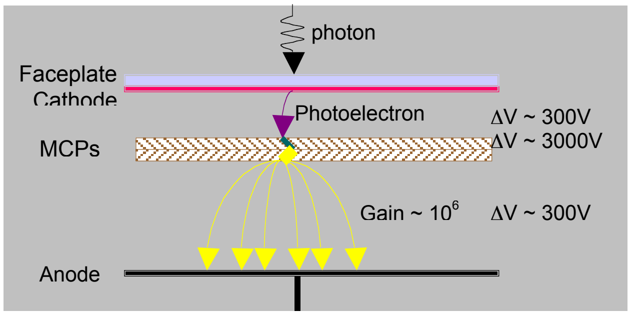
Abstract ***- The characteristics of an 18mm photomultiplier tube (PMT) having a high sensitivity GaAs photocathode have been studied. This PMT, the BURLE 85104, uses a dual microchannel plate (MCP) electron multiplier. We report measurements that include standard DC response, single electron sensitivity and resolution, time response, pulse and count rate linearity, and dark counts as a function of temperature. Data is also presented for a gated version of the PMT that has a high-speed anode. The properties of these MCP-PMTs make them well suited for applications such as LIDAR, fluorescence microscopy and chemiluminescence.***

I. Introduction:

A new family of Microchannel Plate Photomultipliers (MCP PMT) broadens our existing choice of PMTs. The 85104 tube type offers exceptional spectral response, uniformity and speed that is attractive for a number of applications, including . LIDAR, fluorescence microscopy and chemiluminescence The compact design with integrated VDN and optional gating capability makes the 85104 a powerful plug-and-play solution. The 85104 features a GaAs photocathode with greater than 1250 uA/lm luminous sensitivity with excellent red sensitivity having greater than 20% quantum efficiency at 850nm. With Single Photoelectron Resolution better than 150%,

and Peak:Valley Ratios of greater than 2:1, the 85104 is an effective low noise photon counting tool.

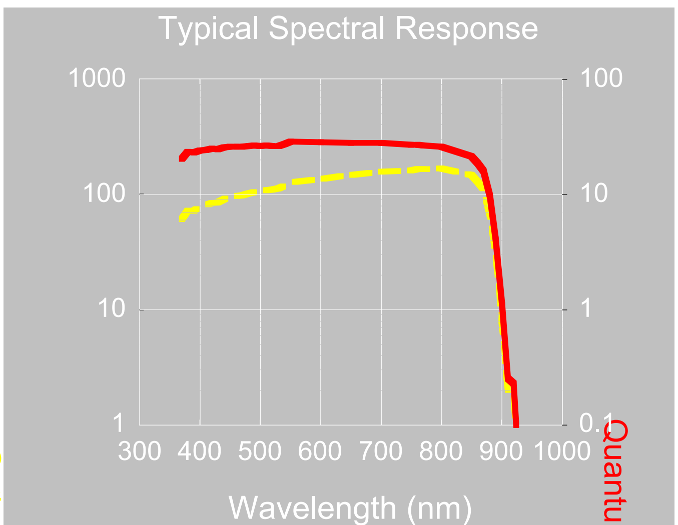
Figure 1 illustrates the basic operation of an MCP PMT. Photons pass through the faceplate of the PMT and initiate the release of photoelectron(s) from the photocathode surface on the interior side of the faceplate. The photoelectron is accelerated toward the front surface of the 1st MCP due to the 300V bias between the cathode and MCP_{in}.. The photoelectron collides with the interior edge of a single pore, creating more electrons, which are consequently accelerated through the pore structure of the MPC due to the 3000V bias on the double stack of MCPs. Continued collisions with channel walls and electron acceleration yield a charge cloud that is emitted from the back side of the MCP stack and accelerated toward the anode collection area which remains at ground potential.



-Figure 1-

II. Cathode Sensitivity:

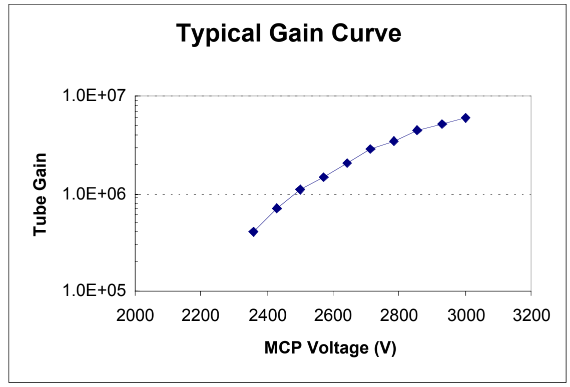
The GaAs transmission mode cathode has a wide spectral range with high Quantum Efficiency from 400-900nm (see figure 1).



-Figure 2-

III. PMT Gain:

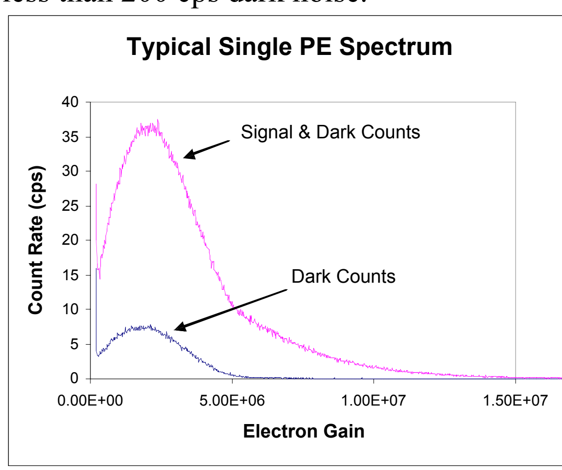
The electron multiplier in the 85104 is a double stack of 5um pore MCPs with L/D Ratio of 60:1. The MCPs are aligned in a chevron configuration to eliminate the possibility of ion feedback to the sensitive photocathode surface. The duel MCP design provides high, uniform electron multiplication well in excess of 1M gain (see figure 3).



-Figure 3-

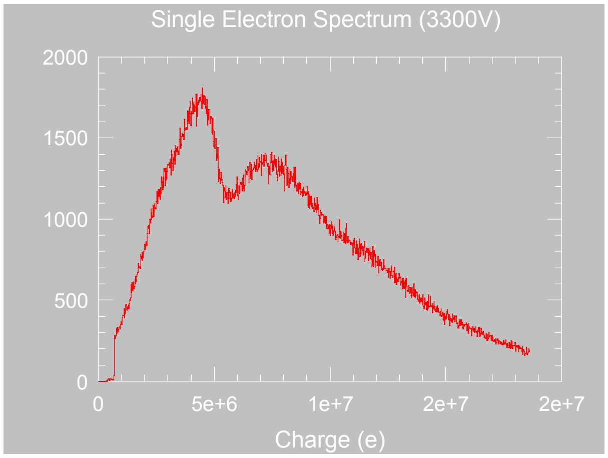
IV. Single Photoelectron Resolution:

The combination of the simple design and choice of high quality MCPs, the 85104 is a low noise device that offers good single photoelectron resolution. Figure 4 illustrates a typical pulse height spectrum for the 85104. The plot shows data for the tube run under dark conditions as well as a subsequent run with low level single photon light levels. The typical Peak:Valley Ratio is in excess of 2:1, with a Pulse Height Resolution (Peak/FWHM) for the Single PE Peak of less than 150%. This particular tube has a SPE Resolution of 134%. Under cooled conditions (-30°C), the 85104 has less than 200 cps dark noise.



-Figure 4-

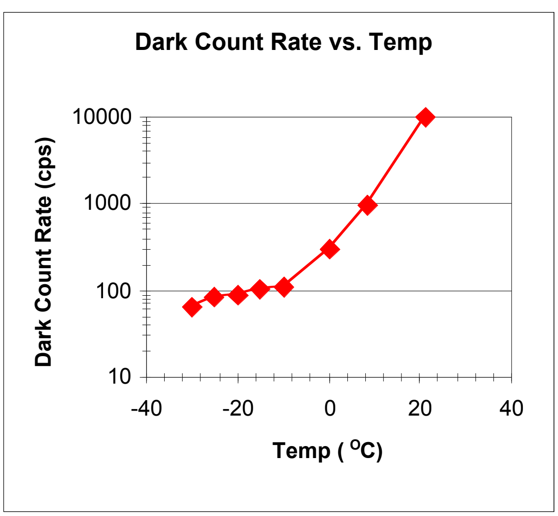
When the PMT is run at higher voltages and exposed to slightly higher light levels (statistically implying the presence of 1, 2, 3PE's), the 85104 is able to qualitatively distinguish 1PE, 2PE and 3PE peaks (see figure 5).



-Figure 5-

V. Dark Noise Measurements:

The semiconductor III V nature of the GaAs cathode demands cooling to reduce thermionic emission of free electrons from the surface of the cathode. At room temperature (22°C) the typical dark count rate of the 85104 is 10,000-20,000 CPS. Under cooled conditions, the dark noise dramatically drops to less than 200 CPS at -30°C. Figure 6 illustrates the decrease dark count rate as a function of temperature. Though the standard dark count rates test is performed at -30°C, figure 5 reveals that there is little advantage gained by cooling below -10°C.

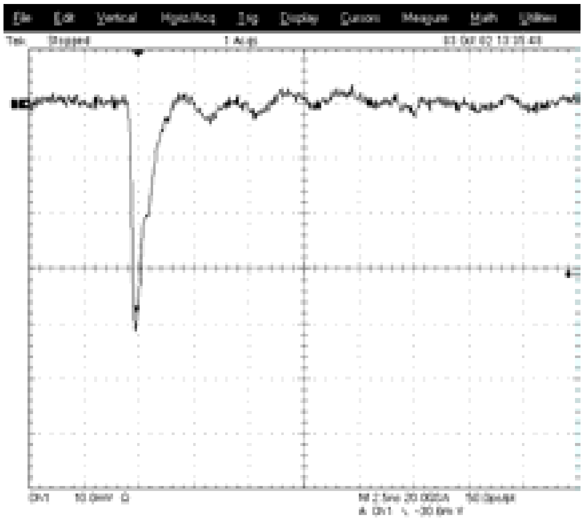


-Figure 6-

(**__Note__**: The *dark count rate* is determined by recording the total number of dark counts between 1/3 photoelectrons and 3 photoelectrons divided by the time of acquisition (typically 100s).)

VI. Timing Characteristics:

The speed of the Microchannel Plate multiplication, short electron path lengths and high speed anode design provide for a very fast, clean signal from the 85104. Transit times of less than 1ns. Single photoelectron pulses have rise times of less than 200ps, and fall times of less than 1ns. The 50-Ohm impedance output of the high speed anode makes the 85104 compatible with a variety of high speed processing electronics. Figure 7 illustrates a single PE pulse. An ongoing effort is being made at Burle to further improve the anode design to reduce the FWHM and make the fall time of the pulse comparable to the rise time. The goal is to have Rise Time = Fall Time = 200ps. When the PMT is pulsed with a 28ps wide pulsed laser pulse with effective light levels on the order of several hundred photoelectrons, the rise time of the resulting output pulse increases to ~350ps. This indicates that the Transit Time Spread (TTS) for multi-photon events is on the order of 200ps. This is essentially due to the structure of the GaAs cathode. To date, a comprehensive test of TTS has not yet been performed.

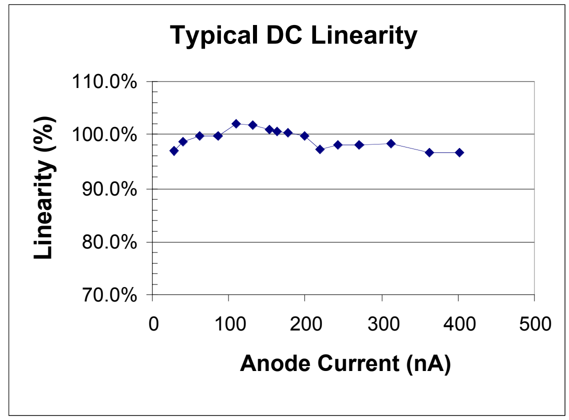


-Figure 7-

Rise Time = 150.6ps
Fall Time = 951.9ps
FWHM = 1.128ns.

VII. Pulsed and DC Linearity:

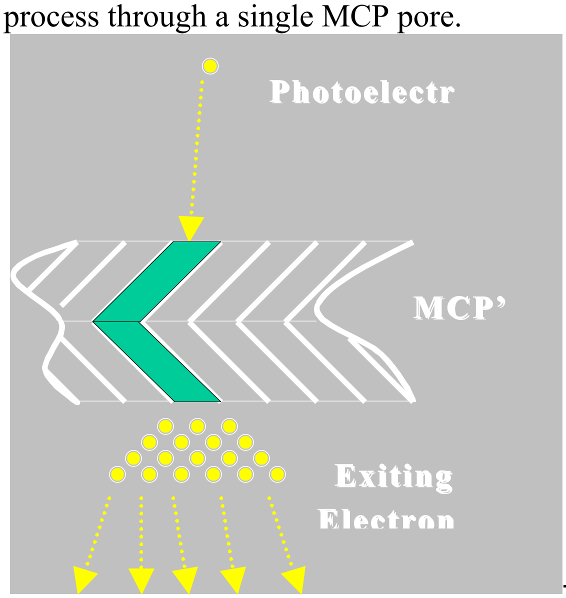
MCP based PMTs are not as robust as their metal channel dynode counterparts so special attention needs to be given to protect the PMT from over exposure to light. The maximum DC output level recommended for the 85104 is 300nA, though life tests have been performed for sustained periods in excess of 0.9uA. Pulsing the 85104 with a high speed laser at a low duty cycle (I_{output} <300nA) provides 95% pulsed linearity at 400mA peak pulse output. Figure 8 is a representative DC linearity curve for the 85104. Linearity for MCP PMTs are governed by a combination of the strip current of the MCPs and the pre size of the channels in the MCPs. Smaller pore sizes provided a greater number of effective multiplier paths pre unit area, while higher strip currents enable spent channels to be recharged more quickly. Advances in MCP technology at Burle in both of the above will result in MCP PMTs with higher pulse, DC and count rate linearity.



-Figure 8-

VIII. Count Rate Linearity:

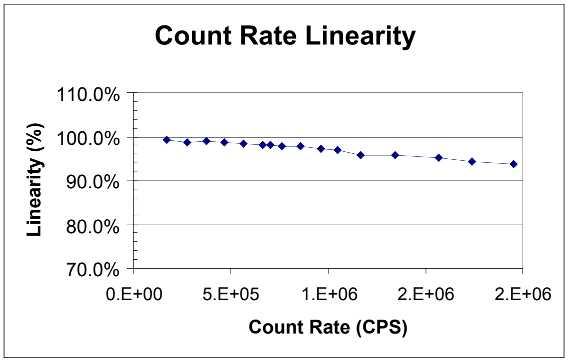
Any single channel pore in an MCP PMT can remain 'dead' after a pulse for as long as several milli-seconds as charge is slowly restored. However, the 18mm diameter of the MCPs effectively provides millions of discrete multipliers in the PMT. Therefore if illumination is spread across a wide area of the cathode, it is unlikely that any one pore will be required to multiply charge during this recharge period. Hence, the 85104 has very good count rate linearity. Figure 9 illustrates the multiplication process through a single MCP pore.



-Figure 9-

Figure 10 illustrates the typical count rate linearity for single PE events when the PMT

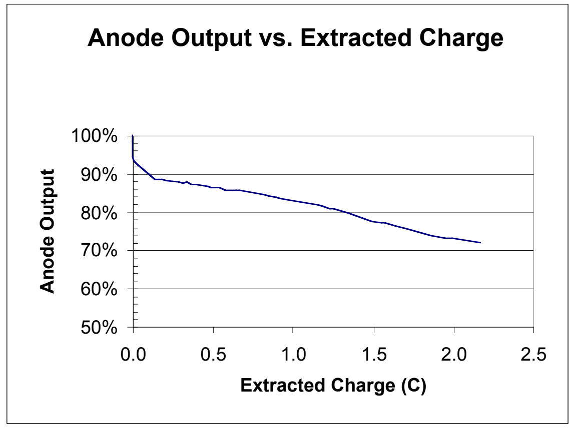
is operated at $0.5x10^6$ gain. In summary, the 85104 remains 93% linear at count rates of $2x10^6$ CPS.
(Note: the count rate is determined by the total number of counts above 1/3 photoelectrons over the time of acquisition.)



-Figure 10-

IX. Lifetime Data:

A classic concern of MCP PMTs has focused on the area of lifetime, namely Ion Contamination of the photocathode. In standard metal channel dynode PMTs there is a chance of residual gas ionization in the back end of the PMT where the electron density is the greatest. When a neutrally charged gas atom gets ionized, the ion is accelerated back in the direction of the photocathode. If the ion eventually reaches the cathode, the transfer of energy in the collision yields a mass release of electrons, giving rise to a large anode pulse as well as a resulting decay of the photocathode sensitivity. In an MCP PMT, ionization can occur in the latter portion of the 2nd MCP, causing positively charged ions to accelerate through a given pore toward the cathode. However, the chevron bias angle of the MCPs causes the ion to collide with the back side of the 1st MCP. Typically a released electron will neutralize the ion and reduce the incidence of ion feedback through the first plate and back to the photocathode. Consequently, ion feedback is greatly reduced and cathode lifetime is extended.



-Figure 10-

Figure 10 shows a typical life test run on the 85104 where the PMT was run at $1x10^6$ gain under constant light exposure yielding an initial DC output of 300nA. The output was tracked for nearly 2200hrs of continuous operation. The overall anode output dropped 28% with a total extracted charge of 2.2C. Following the data trend, one would expect about 5-7C of extracted charge before the tube realizes a 50% decrease in anode output signal.

To better illustrate the effective lifetime of the 85104 the following exercise is provided to determine the anticipated life of the device expressed in total DC operation time of the PMT

Assuming a charge life of…

Total Ext. Charge = 6C
$9.6x10^{19}$ electrons

Tube operating parameters…

Tube Gain = $1x10^6$
Typ. Count Rate = $1x10^5$

Expected Duration of PMT…

$9.6e10^8$s
$2.7x10^5$hrs.
30.4 years of DC operation!!!

X. Gated Operation:

The 85104 is available in a gated version, where the photocathode can be selectively gated ON/OFF. When the PMT is gated off, the MCPs remain biased while the photiocathode itself is actively gated. This allows for fast turn on and off of the PMT. The practice of synchronized gating both reduces system noise and extends PMT life. Currently the 85104 is gated with an external high voltage pulser (supplied with package) which is triggered with a TTL level trigger pulse. Better than 10ns ON/OFF times are possible with better than 10^7 reduction of cathode sensitivity when the PMT is gated OFF. The PMT can be gated on from 100ns to 10us. Alternatively an internal source of HV is under design that will enable the 85104 to be gated without the external pulser, requiring only a TTL level trigger pulse. The addition of the gating capability makes the 85104 an excellent choice for a variety of precision laser ranging applications.

XI. Supporting Equipment:

At Burle Industries, it is our commitment to design and manufacture the highest quality detection devices to satisfy the needs for a host of scientific applications. In order to better serve our customers, we also offer a host of supporting equipment for plug-and-play solutions.

Precision High Voltage Power Supply

- PF1056
- Low Noise (~15mV ripple).
- Neg. 0-5kV.
- 667uA output current.
- Analog programmable.
- Inherent short circuit protection.

Thermoelectric Cooler

High Voltage Gating Module

Cabling